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Dual-Band Slim Microstrip Patch Antennas

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***Abstract*—This paper presents a planar dual-band slim microstrip patch antennas. The antenna comprises four sections: a patch and shorting, centered, and offset pins with the overall size of 30×50 mm^2. It is shown that the centered and offset pins help to improve antenna matching while providing efficient radiation performance. With the aid of shorting pins, lower band operation at 1900 MHz is achieved. Moreover, the higher frequency band is expanded from 3480 to 3570 MHz. Simulations show that at the lower band frequencies, the antenna gain and efficiency are 1.0 dBi and 28%, respectively. Whereas at the upper-frequency band, the antenna maximum gain is 2.4 dBi, and the efficiency of at least 25% is observed. The numerical simulation shows that the number of resonant frequencies is directly related to the patch width. In order to validate simulation results, a prototype of the proposed antenna is fabricated and measured. Good agreement has been achieved between the simulation and measurement results.**

***Index Terms*—Dual-band antenna, handheld/portable applications, slim antenna, radiation enhancement, shorted-pin microstrip patch antenna**

I. Introduction

THE rapid growth of high mobility necessity and multifunctional wireless communication systems, increase the interest for compact, low-profile, integrated and multiband microstrip antennas in recent years. However, the main difficulties in front of engineers to design compact antennas include narrow bandwidth and low radiation efficiency. In recent years, many techniques have been reported for designing miniaturized microstrip patch antennas. One of the most promising methods is to add a shorting pin. A pin-loaded technique was first introduced in [1]. The problem is theoretically analyzed using transmission-line model [2] and Green's function approaches based on cavity model [3]. This technique is applied to control input impedance [4] and implementing a dual-band [5], polarization-agile [6] and tunable [7] patch antennas. In [8], the authors suggested demonstrating a shorting post in proximity to the feed point to suppress surface wave propagation. Recently, the pin-loaded technique is utilized to present a wide 3-dB axial ratio beamwidth [9], high-gain [10], enhanced gain [11] and enhanced bandwidth [12]–[14] patch antennas. In these papers, the authors try to adjust the location of loading pins in order to modify current distribution and consequently manipulate antenna impedance (tuning the resonant frequency and broadening the antenna bandwidth) and radiation (decreasing the radiation beamwidth and improving polarization characteristics). However, it is notable that these structures generally do not address electrically small antennas. Even though these works have concluded that a shorting post will display resonance frequencies above the fundamental mode of the unloaded patch antenna. On the contrary to these designs, some researchers focused on miniaturizing patch antenna using the pin-loaded method, however, the obtained results suffer from a dramatically low gain [15]-[18].

The main objective of this paper is to present a simple, low-cost, miniaturized, efficient, slim antenna with a moderate gain and half-space radiation. From the practical point of view, the proposed structure could be mounted in several types of portable devices where the antenna has to be slim and hemispherical radiation should be required. In such applications, although the dipole-like antennas may be preferred, however, due to the ground plane existence that commonly implemented to support RF and digital front-end circuits; and their omnidirectional radiation pattern, the wire-type antenna is not applicable. At first, the pin-loaded antenna is studied to determine the possibility of reducing the patch length using pin-loaded technique and simultaneously decreasing the antenna resonant frequency. It is shown that the shorting pin could help to overcome the physical limitations observed in conventional microstrip patch antennas such as low gain and low efficiency, Second, a simple approach based on utilizing additional shorting pins is proposed to defeat low gain and low-efficiency drawbacks. It is shown by applying the proposed method, the radiation and matching of a shorted-pin single patch antenna enhanced simultaneously while it provides a single feed dual-/multiband compact antenna. Due to the shunt inductive effect of these pins, the resonant frequency of the dominant mode can be tuned to cover the desired frequency band. The numerical simulation shows that increasing the width of the proposed antenna causes decreasing resonant frequency while it provides half-space radiation pattern as expected in microstrip patch antennas. The number of resonant frequencies is directly related to the patch width. Moreover, at the lower frequency a greatly enhanced gain, >14 dB, and a low cross-polarization observed when it compared with an equivalent simple pin-loaded patch antenna (a pin-loaded patch antenna with the same resonant frequency). The proposed structure is demonstrated experimentally. The results of simulation and measurement are shown good agreement.

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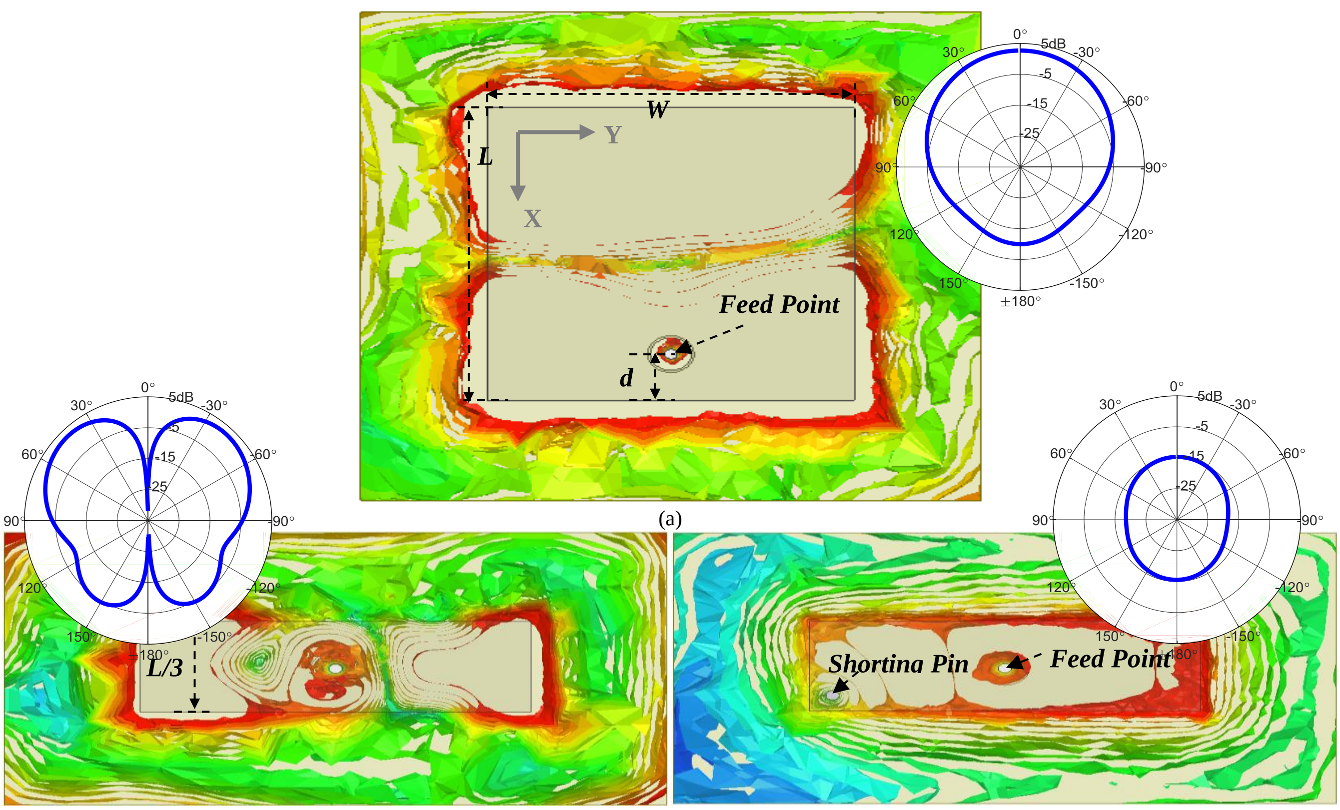
II. Problem Definition

Having a miniaturized patch antenna, one can load a patch with a shorting pin. However, the main drawbacks of this method are the antenna low gain and efficiency. Using a shorting pin, although the electrical length of the patch increases and makes the antenna miniaturized, the radiating edge decreases significantly, which causes antenna gain to drop. In this paper, the main goal is to find and introduce a solution to resolve this radiation reduction. Assume a coaxial feed is utilized to excite the patch from the backside of a ground plane in a distance d away from the edge of the patch. To investigate the antenna behavior, a commercial numerical simulator is used. For a rectangular patch antenna with the size of $L \times W$, $W \approx L$ and without any pins with the dominated TM_{10} mode operation and $f = 2.5$ GHz, the electric field intensity beneath the patch can be intuitively considered varying as a cosine function along the x-axis and be a constant along the y-axis, respectively. Its electric field distribution is numerically simulated and depicted in Fig. 1(a). The resonant frequency of the second-order mode is about $f = 4.5$ GHz. The numerical simulation shows that the antenna gain at $f = 2.5$ GHz is about 3 dBi. Next, it is assumed that the antenna length reduced to $L/3$. Since $W > W/2 > L$ the first order mode of this new structure is TM_{01} and the resonant frequency is about $f = 4.5$ GHz. The electric field distribution is also simulated and depicted in Fig. 1(b). The simulation shows that the antenna gain in the dominant mode is about 2.5 dBi.

Now, we intend to use the aforementioned patch antenna, with a shorting pin along its diagonals and near to the edge to demonstrate miniaturization. Once a shorting pin with a radius of 0.5 mm is introduced, the field distribution is certainly perturbed due to effects caused by this pin. Fig. 1(c) illustrates the field distribution for the dominant mode in this latter case. Simulations show that the resonant frequency of the dominant mode is about $f = 1.2$ GHz, while the second-order mode is TM_{01} and its resonant frequency is about $f = 3$ GHz. The numerical simulation shows that the gain of a pin-loaded microstrip antenna at $f = 1.2$ GHz is lower than -14 dBi which is drastically low to use in practical applications. It should be noted that in this figure, the overall dimensions refer to the dimensions of the substrate. The antenna radiation pattern corresponding to the dominant mode is also provided in this figure.

It is clear that the half-space pattern of a conventional patch antenna, Fig. 1(a), covert to an approximately omnidirectional radiation in a shorted-pin microstrip patch antenna (Fig. 1(c)). According to this figure, reducing the length of a patch causes a change in its dominant resonant frequency, which leads to reducing the radiating edge. Consequently, it makes radiation efficiency and antenna gain decreased. Using a shorting pin, although the electrical length of the patch increases and makes the antenna miniaturized, the radiating edge decreases significantly, which causes antenna gain to drop. In order to keep antenna electrical length small and simultaneously increase the antenna gain and efficiency; two additional pins are suggested as illustrated in Fig. 2. These additional pins help to tune surface current directions and prevent the opposite current



(b) (c)

Fig. 1. The simulation results for the electric field and the radiation pattern at the dominant mode resonant frequency of a rectangular microstrip patch antenna printed on 1.524 mm thick FR4 substrate with a dielectric constant of 4.4 and d=4.75 mm, (a) W=30 mm, L=30 mm, and 50×50 mm^2 overall dimensions, (b) W=30 mm, L/3=10 mm, and 30×50 mm^2 overall dimensions, and (c) antenna of section b which is loaded by a shorting pin.

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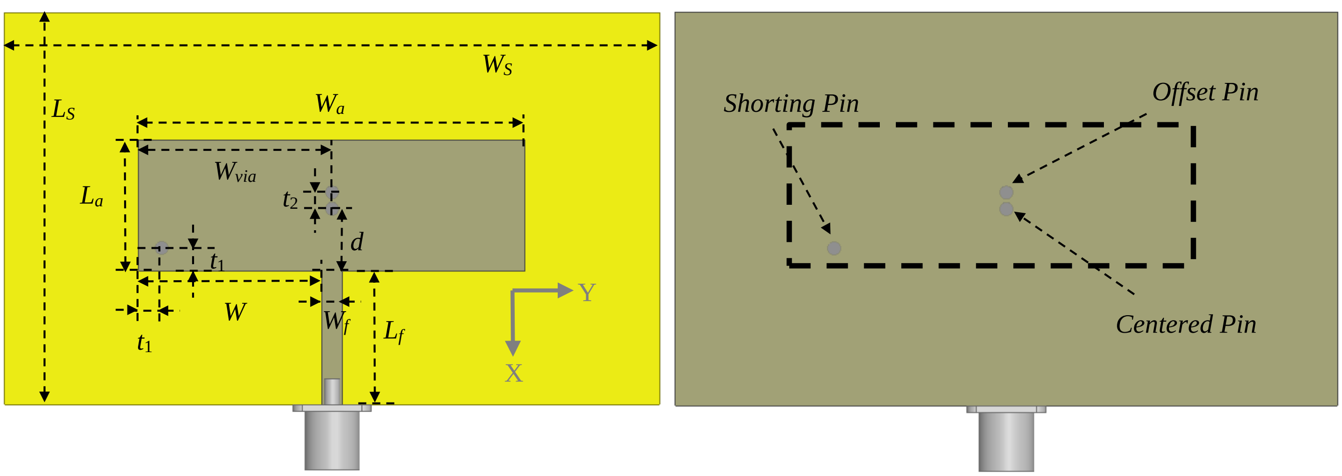
cancellation. In the next section, the effects of these pins on the antenna input impedance and radiation characteristics are investigated. In the next section, a comparison between conventional shorted-pin and proposed structure has been presented.

III. Compact Efficient Microstrip Antenna

To demonstrate the proposed concept, here a microstrip patch antenna has been considered. The schematic of the proposed pin loaded patch antenna and the fabricated prototype are shown in Fig. 2. The antenna is represented as a perspective view, from the front and the back. The antenna is printed on a 30 × 50 mm^2 single layer FR4 substrate with a dielectric constant of 4.4 and a thickness of 1.54 mm and the patch size is 10 × 29.5 mm^2. The shorting pin is located along the antenna diagonals and near to the edge to demonstrate miniaturization. The pin is located at a distance t_1 away from the edges of the patch. A pair of additional shorting pins with a distance of d away from the microstrip feed point is implemented between the patch and a ground plane. Both of them have a radius of $r = 0.5$ mm and the spacing between them is set to t_2. To feed the antenna, a microstrip line connected to an SMA connector is used. The width of the feed line is W_f while its length is L_f. To analyze the proposed design, the HFSS simulator is utilized. The antenna parameters are labeled in the figure caption. The antenna is designed to work in the handheld/portable applications.

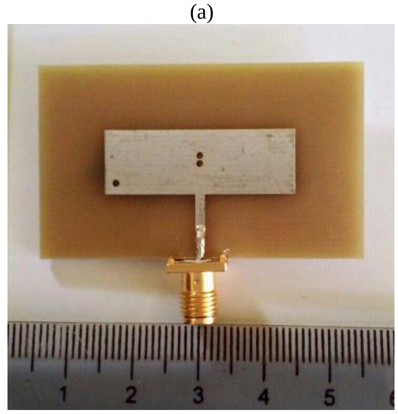
IV. Simulation and Measurement Results

Fig. 3 shows the simulation results of the real part of the antenna input impedance and the effects of each pin on it. A patch antenna can be equal to a lossy shunt resonator when operating in each of its resonant modes. To correctly evaluate its resonant frequency and input impedance at resonance, the reference plane for impedance should be moved to the feeding point, rather at the SMA connector. This is because the feeding line will serve as an impedance transformer, and the calculated impedance at the SMA connector is totally different from the feeding point. To give a better understanding, the results with and without a feeding line de-embedded are shown in this figure. We can see from this figure that adding a shorting pin near the patch edge has a remarkable effect on the antenna input impedance, especially at the lower frequencies. With the aid of a centered pin, although a low-frequency resonance increases up to 2 GHz, as described later, it has a critical role to enhance gain and efficiency. It changes the surface current direction and prevents the opposite current cancellation. The offset pin tunes the low-frequency band to the desired application while it does not change the upper band considerably.



(Top View) (Bottom View)

(a)



(b)

Fig. 2. Geometry of proposed centered and offset pins-loaded patch antenna: L_S=30 mm, W_S=50 mm, L_a=10 mm, W_a=29.5 mm, L_f=10.25 mm, W_f=1.5 mm, W=14 mm, W_{via}=14.75mm, d=4.75 mm, t_1=1.75 mm, t_2=1.25 mm, (a) Schematic view, and (b) Antenna prototype

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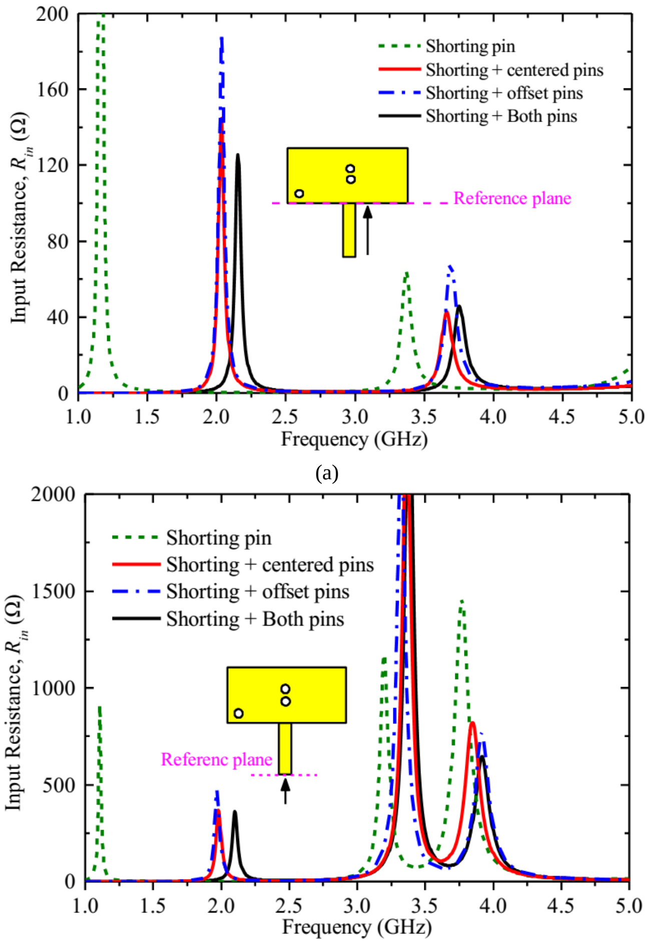

Fig. 3. Simulated real components of input impedance for the shorted-pin patch antenna, antenna loaded with the centered pin, antenna loaded with the offset pin, and the proposed antenna (based on the proposed antenna of Fig. 2) (a) reference plane from feeding point (b) reference plane from SMA connector.

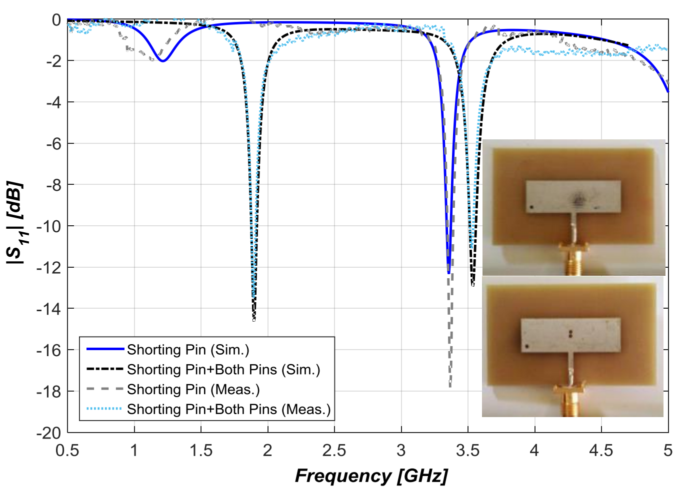

Fig. 4. Antenna prototype and measured and simulated reflection coefficients of the proposed loaded and unloaded patch antennas

Fig. 4 shows the simulated and measured reflection coefficient of the antenna with/without centered and offset pins. Measurements are in good agreement with the simulation results. The antenna has a low-frequency band that can be tuned by the offset pin location. Here, it is adjusted to cover TD-LTE 1900 MHz with the antenna impedance bandwidth ($|S_{11}|<-10$ dB) of 4% from 1850 to 1930 MHz (80 MHz). At the higher frequencies, the antenna operates from 3480 to 3570 MHz and the impedance bandwidth of about 2.2% (90 MHz). For the patch length of 10 mm, an equivalent printed patch antenna resonates at 3.0 GHz (Since $W>L$, the dominant mode is TM_{001}). According to Fig. 4, the numerical simulations show that the proposed structure provides more than 38% size reduction. The dimension of the patch is $0.18\lambda_L \times 0.06\lambda_L \times 0.01\lambda_L$, while the antenna overall dimension is $0.3\lambda_L \times 0.18\lambda_L \times 0.01\lambda_L$ (f_L = 1.9 GHz and λ_L is the free space wavelength corresponding to the lower frequency).

Fig. 5 represents the antenna measured gain and simulated radiation efficiency. In this figure, the results for loaded (solid line) and unloaded (dashed line) antennas are compared. It is evident that the antenna gain and efficiency are dramatically increased when compared with those obtained by a shorted-pin patch antenna. It should be noted that although the shorted-pin patch antenna is totally not matched at all in the lower band, and the low gain and efficiency are mainly caused by reflection at the port, the proposed antenna resolves the matching problem while it provides high gain and efficiency simultaneously.

The radiation efficiency of the antenna at the lower band frequencies is about 28% along with >1 dBi gain, which is appropriate for practical portable applications. These parameters at the higher band are in the range of 25~35% and 1~2.4 dBi, respectively. Adding additional pins, the resonant frequency of the pin-loaded antenna increases from 1.1 GHz to 1.9 GHz. For a fair comparison between the pin-loaded and the proposed antennas, we scaled the pin-loaded antenna to increase its resonant frequency up to 1.9 GHz. At the same resonant frequency which both pin-loaded and proposed antennas operate at their first dominant resonance frequency, the numerical simulations show that the antenna realized gain and efficiency are -14 dBi and 2%, respectively. Thus, in the new structure, the antenna gain has increased at least 15 dB and the radiation efficiency improved by a factor of about 14 times compared to the pin-loaded antenna with the same resonant frequency.

In order to analyze the radiation quality of the proposed antenna, here a comparison with the theoretical limits is presented. As described in [19], the upper band of antenna gain and efficiency could be calculated. For an antenna with the diameter of D = 30 mm at f = 1.9 GHz, the maximum achievable gain is about 2.0 dBi. For this antenna, the efficiency should be greater than 13%. Moreover, at the higher frequencies, the theoretical bands of antenna gain and efficiency are 5.0 dBi and 25% respectively. It is clear that the antenna has good radiation performance.

Fig. 6 shows the distribution of tangential electric field and surface current at f =1.9 GHz. Comparing the electric field distribution of a conventional shorted pin and centered and offset pin-loaded patch antennas, it is evident that a shorted-pin patch antenna has in-phase electric field distribution along the entire perimeter of the patch. Whereas in a centered and offset pins-loaded patch antenna, the radiating electric field is much

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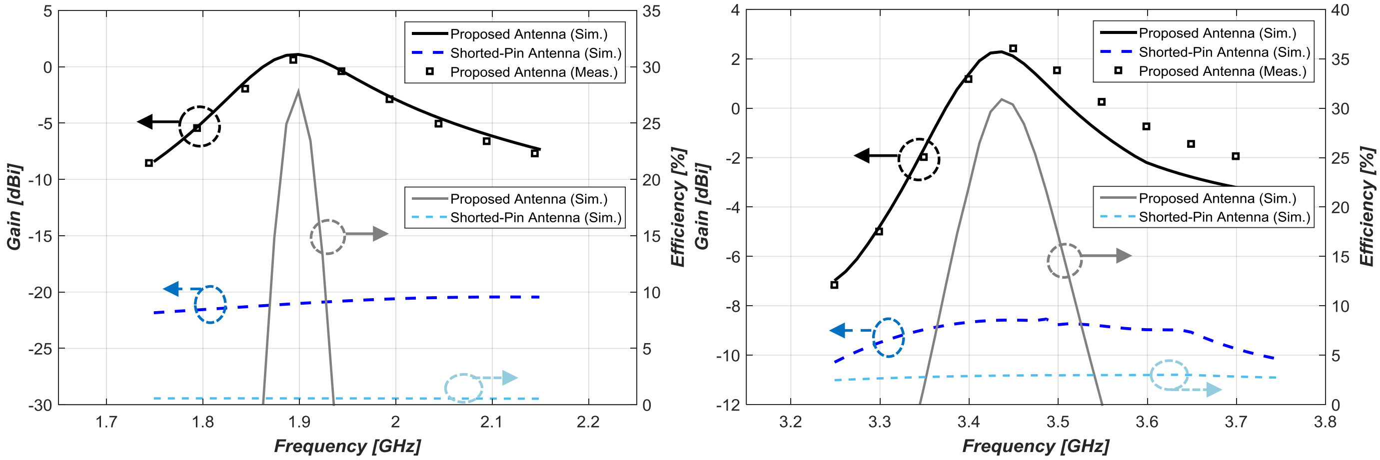
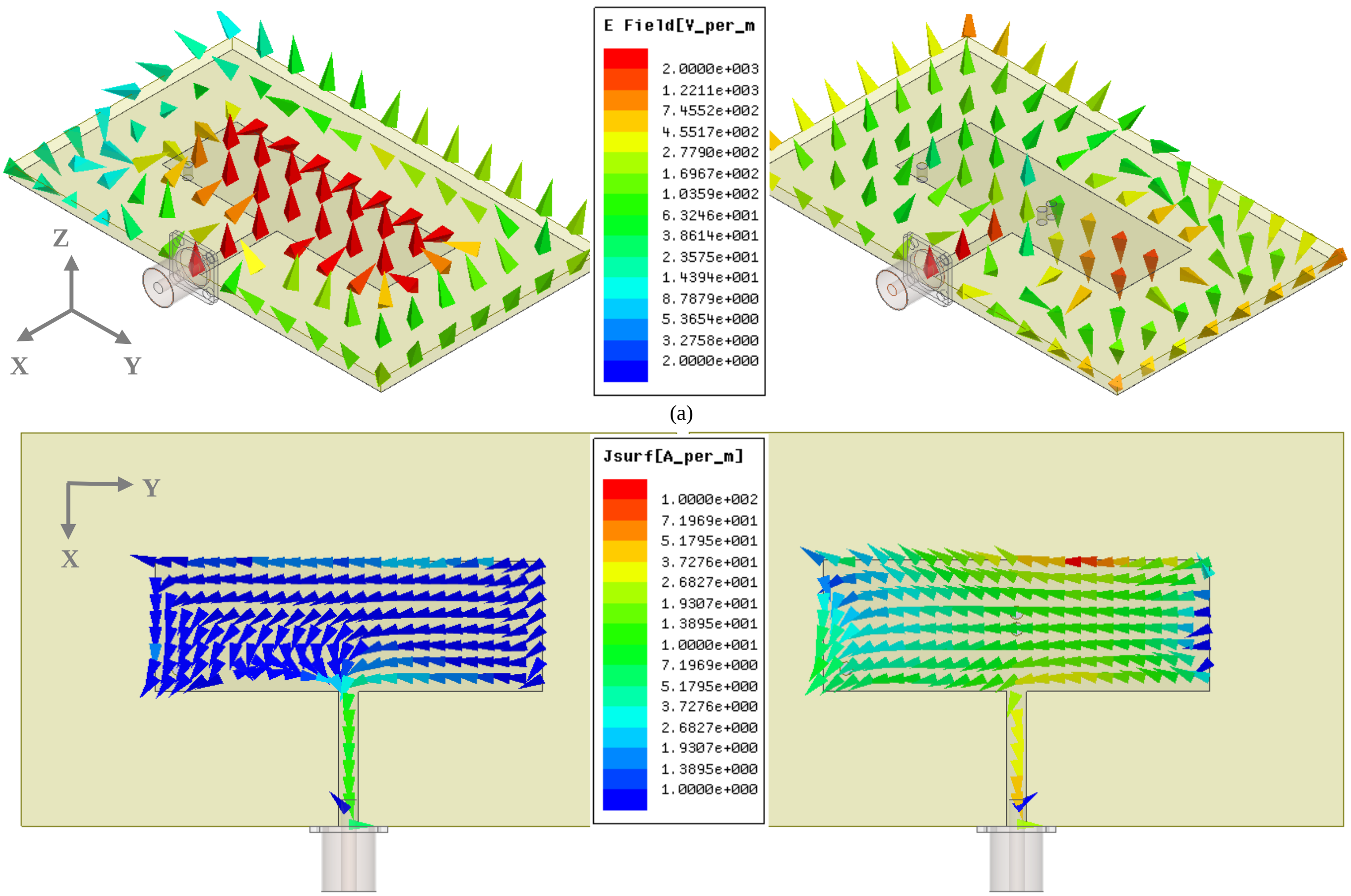


(a) (b)

Fig. 5. Measured peak gain and simulated radiation efficiency of the proposed antenna at (a) lower- and (b) higher-frequency bands.



(a)

(b)

Fig. 6. (a) Electric field, and (b) surface current distributions of shorted pin (left) and proposed (right) patch antennas at f=1.9 GHz.

like the patch excited at its first mode. Since the electric field on each edge is approximately of the same magnitude, but the opposite direction, the radiated field components cancel each other at the pin-loaded antenna while they radiated when adding additional pins.

Simulated surface current distribution illustrated that the centered and offset pins change the surface current directions and prevent the opposite current cancellation on the left side. Moreover, it is clear that using centered and offset pin makes the current vectors be aligned to the y-axis considerably. This feature helps to reduce the x-axis components and the antenna cross-polarization.

The normalized measured far-field radiation of the antenna is depicted in Fig. 7 at f = 1.9 and 3.5 GHz. At the lower band, the antenna had a cross-polarization discrimination of >10 dB, while at the upper band, comparable co- and cross-polarization components are obtained. However, in practical applications the antenna position is non-predictable and the latter feature is accordingly suitable for compact handheld/portable communication systems [20]. Due to the electrical size of the

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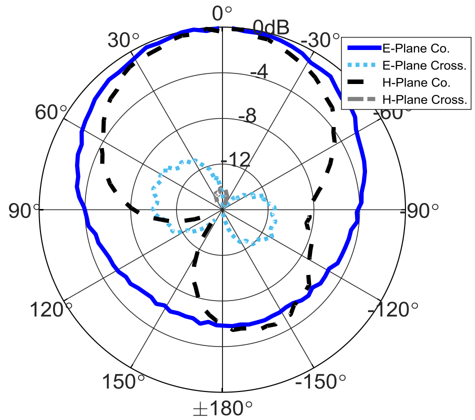
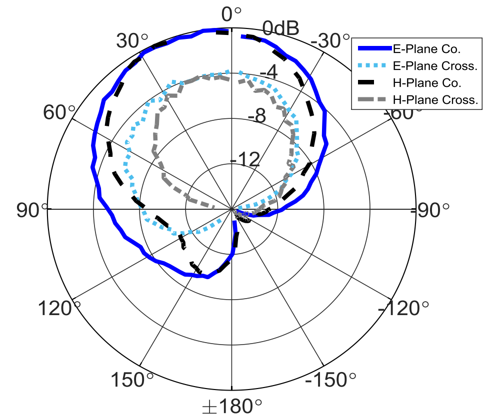


(a)



(b)

Fig. 7. Normalized measured radiation patterns of the proposed centered and offset pin-loaded patch antenna at (a) f = 1.9 GHz, and (b) 3.5 GHz.

TABLE 1 COMPARING THE ANTENNA PERFORMANCE WITH THOSE PROPOSED IN THE LITERATURE

Antennas	f (GHz)	Max Gain (dBi)	Max η (%)	BW ($\|S_{11}\|<-10$ dB) (%)	No. of Layers	Dimension (λ_0)
Ref [22]	1.95/2.45	8.3/7.8	88/91	5/4.5	Three layers	0.32×0.32×0.0975*
Ref [23]	1.23/1.57	4.7/1.5	-	-	Two layers	0.52×0.52×0.05
Ref [24]	1.7/8.2	-	-	0.35/3.2	Single-layer	0.32×0.27×0.01
This Work	1.9/3.5	1/2.4	28/35	4/2.2	Single-layer	0.30×0.18×0.01

* 3D structure includes a reflector

patch, $0.06\lambda_L \times 0.18\lambda_L$, the antenna exhibits similar radiation characteristics to a compact microstrip patch antenna, and a half-space radiation with a large amount of side lobe level and back radiation has been achieved. At the higher frequencies, the dominant mode contributes to the common radiation pattern of a simple microstrip patch antenna (Fig. 7(b)), however, using shorting pins causes a degrading surface current which consequently leads to having asymmetrical radiation pattern. It should be noted that due to the asymmetry of the radiator, it is expected to have an asymmetrical radiation pattern. Besides, some slight asymmetry is attributed to the SMA connector [21].

Table 1 tabulated the antenna performance with those proposed in the literature [22]–[24]. We compared the maximum of radiation efficiency, η, and measured gain in the antennas operating frequency. A dual-band circular patch antenna incorporating a circular slot is introduced in [22]. A circular slot is inserted into the ground plane that radiates by capacitive coupling between the patch and the ground plane. The antenna radiation performance is good, however, this structure has a three-dimensional configuration which is not suitable for low-profile applications. In [23], a dual-band microstrip loop antenna with an electromagnetically coupled feed for frequency-insensitive reactance variations is proposed. The antenna consists of a terminating 50Ω and two microstrip loops printed in two different layers that are coupled to each other. It is fed using a coaxial cable integrated to a hybrid chip coupler that excited radiating elements. This latest structure suffers from the large electrical size. In [24], a miniaturized single-layer, single-feed, the dual-frequency microstrip antenna is proposed. The dual-band behavior is achieved by a shorting pin. Although the antenna radiation performance did not report by the authors, an extremely narrow impedance bandwidth indicated that the antenna gain and efficiency are drastically low at the lower frequency.

Although the tabulated antennas dimensions are comparable with that proposed one in this article, the length of the suggested antenna is about 0.06λ which is considerably small while compared with the other structures. Moreover, the numerical simulations show that we can reduce the patch length more to obtain slim, strip-like patch antennas. Furthermore, increasing the patch width (W_a) helps to reduce the resonant frequency (Fig. 8). In this case, the antenna configuration seems to be similar to a printed dipole antenna with the additional ground plane. However, in contrast to a printed dipole antenna this antenna radiates due to the equivalent magnetic current and consequently, it radiates hemispherical as expected in microstrip patch antennas. The numerical simulations are also shown that increasing the patch width, the antenna resonates at the frequency higher than the original one by more than twice and the number of resonant frequencies is directly related to that. In Fig. 8, the reflection coefficient of the proposed antenna as a function of patch width when W_a = 29.5 mm (W_S = 50 mm and L_S = 30 mm) and 109.5 mm (W_S = 130 mm and L_S = 30 mm) have been compared. The antenna radiation pattern when W_a = 109.5 mm is also demonstrated.

The behavior of a loaded patch antenna as a function of pins location is also investigated, however, the results are not presented here. Simulations show that the variation of the pins location in x-direction has no significant effect on the antenna gain and return loss at the lower frequencies. Although it causes degrading antenna gain and return loss at the higher band. Moreover, the variation of pins in the perpendicular direction has a dramatic effect on the antenna return loss. It causes a change in both resonant frequencies. It has a drastic effect on the antenna gain. Simulations show more than 10 dB reduction

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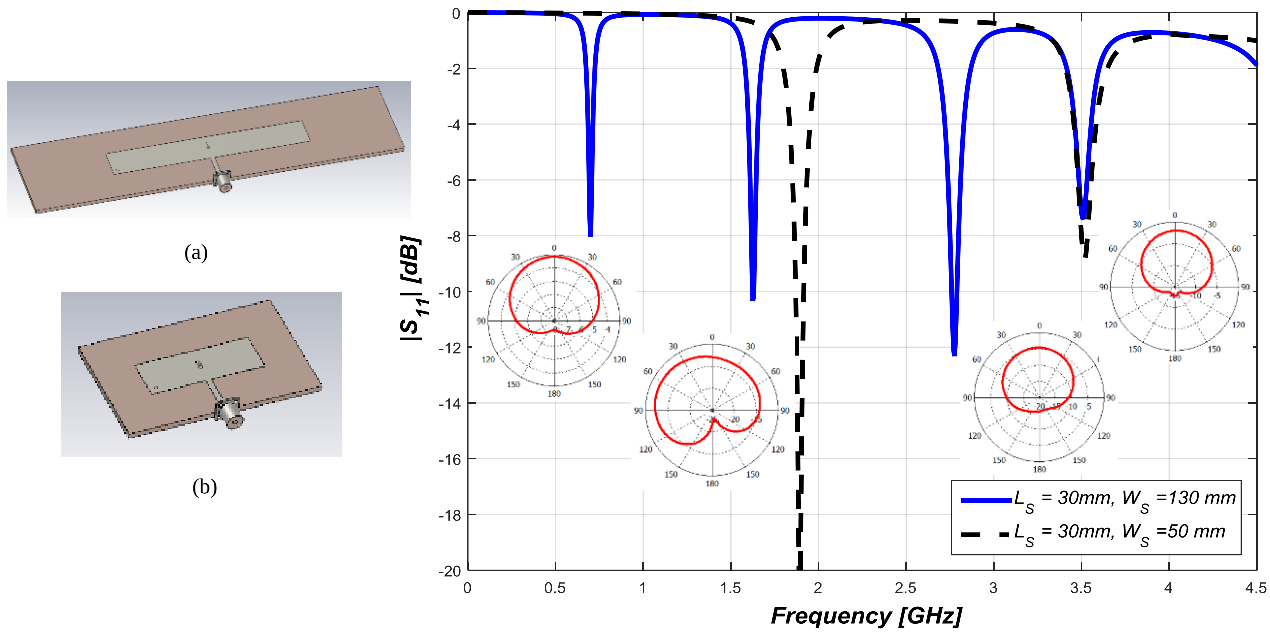

Fig. 8. The proposed antenna: (a) L_S = 30 mm, W_S = 130 mm, L_a = 10 mm, W_a = 109.5 mm, (b) L_S = 30 mm, W_S = 50 mm, L_a = 10 mm, W_a = 29.5 mm, and (c) simulated reflection coefficient and radiation pattern of the proposed loaded as a function of patch width.

at the lower frequency band, which is due to the matching degradation. The numerical simulation shows that although increasing the pins offset regarding the centered causes to decrease resonant frequency, the antenna could not be matched which overall leads to decrease the antenna performance.

V. Conclusion

We proposed a new low-profile dual-band slim antenna with a moderate gain and half-space radiation. It is shown that utilizing centered and offset pins helps to miniaturize a patch antenna with a low cross-polarization level. It simultaneously causes impedance matching and radiation improvement. The numerical simulation shows that the number of resonant frequencies is directly related to the patch width. The antenna is fed by a simple microstrip line. As an example a compact, slim, dual-band patch antenna has been presented, fabricated and tested. The antenna overall dimensions are $0.3\lambda\times0.18\lambda\times0.01\lambda$. The antenna shows a proper gain of at least 1.0 dBi and adequate efficiency of >25% through the entire frequency band.

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