Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2016, Article ID 8536058, 7 pages
http://dx.doi.org/10.1155/2016/8536058

Research Article

A Multiband Proximity-Coupled-Fed Flexible Microstrip Antenna for Wireless Systems

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Received 4 August 2016; Accepted 18 September 2016

Academic Editor: Renato Cicchetti

A multiband printed microstrip antenna for wireless communications is presented. The antenna is fed by a proximity-coupled microstrip line, and it is printed on a flexible substrate. The antenna has been designed using a general-purpose 3D computer-aided design software (CAD), CST Microwave Studio, and then realized. The comparison between simulated and measured results shows that the proposed antenna can be used for wireless communications for WLAN systems, covering both the WLAN S-band (2.45 GHz) and C-band (5.2 GHz), and the Wi-Max 3.5 GHz band, with satisfactory input matching and broadside radiation pattern. Moreover, it has a compact size, is very easy to realize, and presents a discrete out-of-band rejection, without requiring the use of stop-band filters. The proposed structure can be used also as a conformal antenna, and its frequency response and radiated field are satisfactory for curvatures up to 65°.

1. Introduction

In modern wireless systems, different bands of the frequency spectrum are used to fulfil the high data rate required in the communications, and the antennas of these communication systems must operate in different frequency bands (multiband antennas).

Microstrip patch antennas have found many applications in wireless communication systems, because of their light weight, low profile, low cost, high performance, and compact size, besides an easy design, fabrication, and integration into frontend circuits [1–4]. As a matter of fact, planar antennas are a very common choice for Universal Mobile Telephone Systems (UMTS), Synthetic Aperture Radars (SAR), and Radio-Frequency Identification (RFID) systems [5–7].

The use of multiband antennas is the best choice, because it reduces the numbers of antennas to be mounted in the communication system and can allow satisfying the requirements of different wireless communication systems, which can share the same multiband antenna, such as Wireless Local Area Network (WLAN) and IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX), with a substantial saving of space, cost, and complexity realization of the wireless system itself. Therefore, several different multiband WLAN planar antennas have been proposed in recent years [8–12], showing either a multiband or a tuneable behavior. In particular, a dipole printed on a thin, low-permittivity dielectric substrate and having high operational bandwidth and low radiated signal distortion has been proposed in [9]. It is particularly suitable for multiprotocol WLAN, WiMAX, and UWB wireless communications, and, thanks to a reduced parasitic coupling with the radio frequency circuitry, also in communication systems and radio base stations and, in general, for all the emerging applications of the wireless technology.

In the last years, flexible technologies are becoming very popular in a number of wireless applications such as health monitoring systems and flexible displays and sensors [13], because of the many advantages offered by the antennas fabricated on these flexible substrates. As a matter of fact, if compared with traditional planar antennas fabricated on rigid materials, they offer light weight, small thickness, low

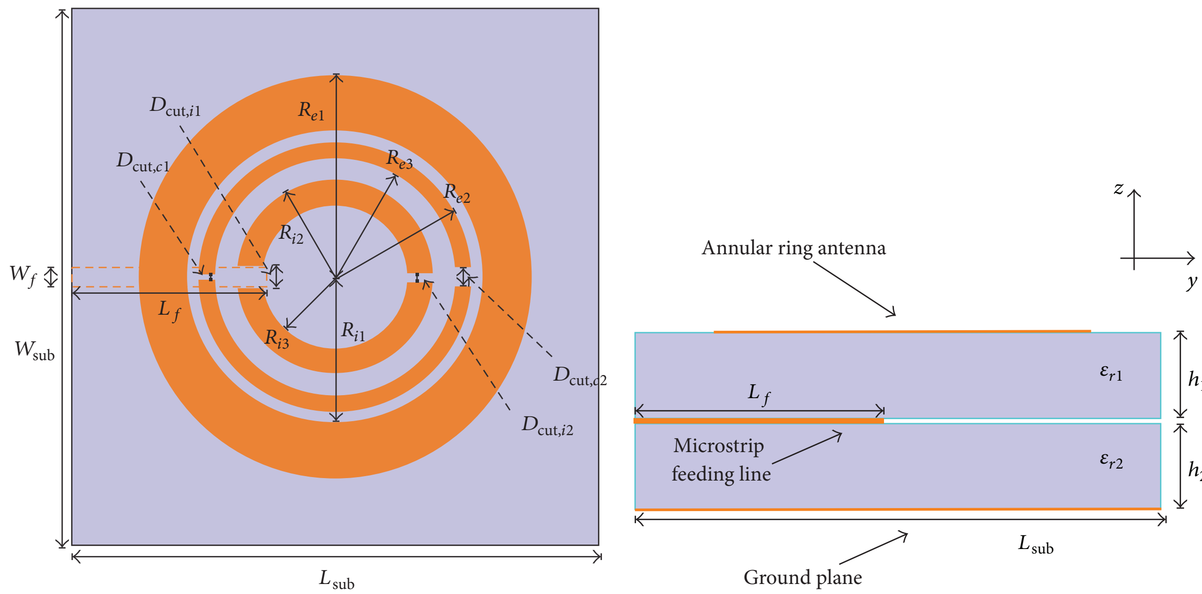


Figure 1: Antenna layout. (a) Top view; (b) side view. $L_{sub} = W_{sub} = 40$ mm, $W_f = 1.41$ mm, $L_f = 14.75$ mm, $h_1 = h_2 = 0.5$ mm, $R_{e1} = 15.22$ mm, $R_{i1} = 11.22$ mm, $R_{e2} = 10.27$ mm, $R_{i2} = 9.24$ mm, $R_{e3} = 7.41$ mm, $R_{i3} = 5.675$ mm, $D_{cut,c1} = 0.25$ mm, $D_{cut,c2} = 1.25$ mm, $D_{cut,i1} = 1.5$ mm, and $D_{cut,i2} = 0.5$ mm.

profile [13], and an easy mounting over conformal surfaces. Flexible antennas can be designed on textile substrates [14], paper [15], PET [16], Kapton, adhesive-layer substrates, and so on [17]. However, on the other hand, these substrates can be severely affected by the environmental conditions. For example, paper and textile substrates are likely subjected to discontinuities and fluids absorption, PET and paper have relatively high losses, and paper is very sensitive to humidity and is not robust to bending and rolling.

In this work, we present a multiband printed antenna, working both in the S and in the C frequency bands (2.45 GHz, 3.5 GHz, and 5.2 GHz), which meets the requirements of different wireless communication standards, such as IEEE 802.11, HiperLan, and Bluetooth [18]. We decide to use a flexible but robust dielectric substrate (ARLON AD250 with 0.5 mm thickness), in order to limit the effect of the environment over the antenna performance. The use of different and cheaper dielectric substrates such as paper, or PET, is possible, of course, but it probably will lead to a nonnegligible decrease of the robustness of the final antenna.

In the design of planar antennas, the most common feeding techniques are the microstrip-fed [8, 9] and the coplanar waveguide- (CPW-) fed [10–12]. The most serious disadvantage of microstrip antennas is certainly their very small bandwidth, and a large number of attempts have been made to increase the bandwidth of printed antennas beyond the typical values of a few percent [19]. The most straightforward way of doing this is to use a thicker substrate, but it is difficult to achieve more than about 4-5% bandwidth in this manner, before the imaginary part of the input impedance becomes too large, causing matching problems [20, 21]. As an alternative, parasitic elements can be inserted to obtain a double resonance response, or an appropriate matching network can be designed to improve the bandwidth of a patch on a thick dielectric substrate [22].

Since we need a flexible structure, the antenna substrate must be thin and flexible, and therefore, in this work, we choose an alternative method to enhance the bandwidth of a microstrip antenna, which consists of a microstrip feed line proximity-coupled to a patch antenna printed on a dielectric substrate, which lies above the feeding line [23, 24]. This proximity-coupled feeding technique is also referred to in the literature as “electromagnetically coupling.”

The geometry of the proximity-coupled annular ring antenna proposed in this paper is shown in Figure 1. The microstrip feed line is printed on the bottom substrate, while the annular concentric rings are printed on the upper substrate, bonded to the feed substrate. The feed line is centered with respect to the rings, and its length, measured from the edge of the dielectric substrate, is equal to L_f. In general, the two substrates may be of different thickness and permittivity, but in our case both substrates are equal (ARLON AD250 with 0.5 mm thickness).

Differently from [23], in order to match each annular ring to the coupled microstrip feeding line, we did not use any shunt tuning stub, but we add two symmetrical cuts on each ring (see Figure 1), as described in the following section. The working frequency band of the antenna is determined by both the impedance bandwidth (the bandwidth over which the antenna remains matched to the feed-line to some specified level, which is typically determined by the frequency range in which the S11 has a module less than −10 dB) and the radiated field bandwidth (the bandwidth over which the far field pattern remains satisfactory). In our case, the far field pattern bandwidth is larger than the input impedance bandwidth, which is the most critical point. Although the antenna bandwidth is not very large (about 1.5–2%, due to the thin substrate used to obtain a flexible antenna), due to the chosen dielectric substrate (which is thin and flexible), the proposed structure can be used also as a conformal antenna and is very robust with respect to flexibility, since it has been bended with different curvatures, and the simulations show a very stable frequency response, and a satisfactory radiated field, for curvatures up to 65°.

The designed antenna, due to its bandwidth characteristics, can be suitable for applications related to the Vehicle-to-Vehicle (V2V) Communication Systems, employed to provide safety warnings and traffic information, such as the Wireless Access in Vehicular Environments (WAVE)/Dedicated Short Range Communication (DSRC) based Intelligent Transportation System (ITS) [25, 26] and also for short range communications devices employed in V2V and in vehicle-to-roadside (V2R) communications units [27]. As a matter of fact, the operating bandwidth required for these systems is very limited (from 20 to 80 MHz around the operating frequency of 5.8 GHz) [25, 26].

The proposed structure is very compact, flexible, and easy to realize and has a very cheap production cost. Moreover, it radiates a broadside pattern, is characterized by a good matching within the WLAN frequencies (both S-Band and C-Band), and Wi-Max frequency, and presents a satisfactory out-of-band rejection, which allows avoiding undesired interferences, making it particularly suitable for modern wireless systems. The antenna has been designed using a general-purpose 3D computer-aided design software (CAD), CST Microwave Studio, and then realized and characterized, with a good agreement between measured and simulated data.

2. Design of Multiband Annular Ring Patch Antenna

The antenna geometry consists of three concentric annular rings printed on a top dielectric layer, fed by a proximity-coupled microstrip line, printed on the bottom dielectric substrate, which is attached to a metallic ground plane, as shown in Figure 1. The substrate used is a flexible Arlon AR250, with a thickness of $h = 0.5$ mm, relative permittivity $\varepsilon_r = 2.5$, and $\tan\delta = 0.0018$. The antenna size is 40 mm × 40 mm, and it is very compact.

The width W_f of the microstrip line has been chosen equal to 1.41 mm, which corresponds to an input impedance of 50 Ohm. The length of the feeding line has been optimised to get a satisfactory input matching of the complete antenna.

For each of the three working frequencies (2.45 GHz, 3.5 GHz, and 5.2 GHz), an annular ring has been designed, fed by a coupled microstrip line. The internal radius of the ring mostly influences the ring's resonant frequency, whereas the outer radius mainly influences the ring's input impedance, with a little effect also on the resonant frequency. In order to match the annular ring with the microstrip line, we inserted two symmetrical cuts in correspondence with the feeding microstrip line. The depth of these cuts can be used to modulate the input resistance of the antenna, with only a little effect on the imaginary part of the input impedance. In our case, the cuts have been inserted only in the two internal rings, whereas the external ring has no need to be cut.

We started designing the external annular ring, which must resonate at 2.45 GHz, obtaining an internal radius equal to $R_{i1} = 11.22$ mm and an external radius $R_{e1} = 15.22$ mm, with a length of the microstrip feeding line of $L_f = 14.75$ mm.

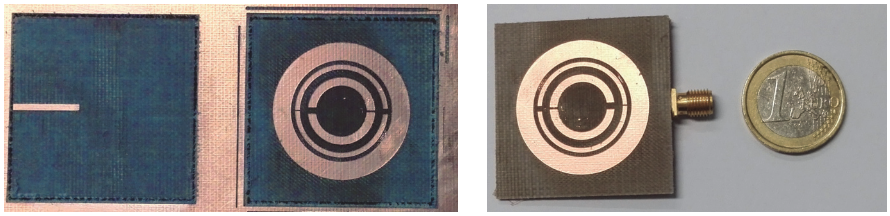
Then, taking the microstrip line length fixed at the value of $L_f = 14.75$ mm, we separately designed the central annular ring, resonating at 3.5 GHz, obtaining an internal radius equal to $R_{i2} = 9.24$ mm. The external radius has been chosen small enough to keep a distance of about 1 mm between the external and central ring, obtaining $R_{e2} = 10.27$ mm, so as to limit the coupling between these two rings. The matching between the feeding line and this central ring has been obtained by cutting the two sides of the ring symmetrically with respect to the feeding line and with a depth of $D_{\text{cut},c1} = 0.25$ mm and $D_{\text{cut},c2} = 1.25$ mm (see Figure 1).

The same procedure has been used to design the internal annular ring: taking the microstrip line length fixed at the value of $L_f = 14.75$ mm, we separately designed the internal annular ring, resonating at 5.2 GHz, obtaining an internal radius equal to $R_{i3} = 5.675$ mm and an external radius of $R_{e3} = 7.41$ mm. In this case, the resonant frequencies of the internal and central ring being far enough, we had no difficulties in the choice of the external radius. Also in this case, to improve the matching between the feeding line and the internal ring, we inserted two cuts in the two sides of the ring, symmetrically with respect to the feeding line, and with a depth of $D_{\text{cut},i1} = 1.5$ mm and $D_{\text{cut},i2} = 0.5$ mm (see Figure 1). Finally, we merged the three designed annular rings, obtaining the whole multiband antenna depicted in Figure 1. Thanks to the carried out design choice, as described above, the three rings are decoupled enough, and the frequency response of the whole antenna maintains the resonances and the bandwidth of each single ring, allowing obtaining a satisfactory multiband antenna, as we will show in the next section.

3. Results

The annular ring antenna designed in Section 2 has been manufactured (see Figure 2) and characterized. In Figure 3, the comparison between the simulated and experimental reflection coefficient is shown, and the input matching is satisfactory, having three resonances in the required portions of S- and C-band for WLAN and Wi-Max applications (2.45 GHz, 3.5 GHz, and 5.2 GHz). The simulated and measured data are in good agreement, and the out-of-band rejection is satisfactory, especially considering that no stop-band filters have been used in the antenna design. This behavior is mainly due to the relatively narrow frequency band of each annular ring which is part of the multiband antenna.

Figure 4 reports the frequency behavior of the realized gain G_R for the antenna shown in Figure 1 (evaluated by CST). The antenna gain has a peak value equal to 4.6 dB in the S-band and equal to 5.8 dB in the C-band. On the other hand, it



(a) (b)

Figure 2: Photo of the designed antenna shown in Figure 1: (a) top and bottom layers; (b) assembled antenna.

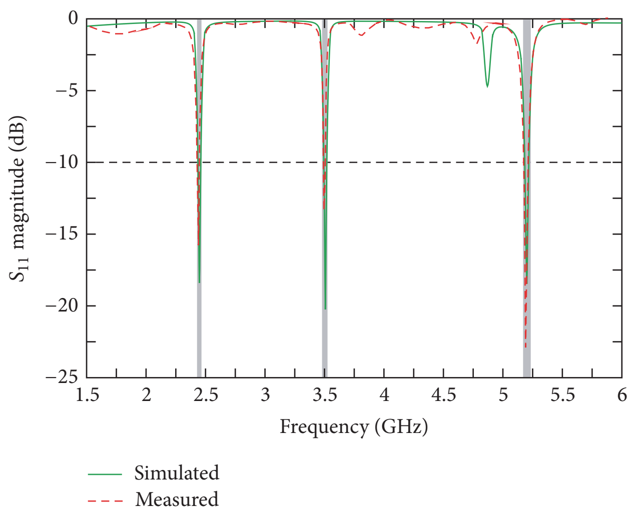


Figure 3: Frequency response of the designed antenna shown in Figure 1.

rapidly drops to less than 3 dB out of the working frequency band, confirming the very good out-of-band rejection of the proposed antenna, due to the small bandwidth of each annular ring, which works only for frequencies close to its resonant frequency.

In Figure 5, the simulated E- and H-Plane antenna radiation patterns are shown. The radiation pattern shows a broadside behavior within the design frequency bands (2.45 GHz, 3.5 GHz, and 5.2 GHz), with an F/B ratio greater than 10 dB, while it deteriorates very rapidly out of band, with both a bad SLL and front-to-back ratio. Therefore, the proposed structure can be successfully used as a multiband antenna for wireless communications.

In order to test the robustness of the proposed structure with respect to flexibility, in Figure 6 the frequency response of the antenna is shown for different values of the curvatures (from 18° to 65°). The frequency response is very stable for all the tested bendings, with a maximum difference of ±10 MHz with respect to the planar case reported in Figure 3, and the far field pattern remains broadside for all the working frequencies, with only a slight deterioration due to the bending of the radiating structure. The results in Figure 3 correspond to a bending towards the y-direction (see Figure 1(b)). Thanks to the structure symmetry, similar results, and therefore a similar robustness, can be obtained if the

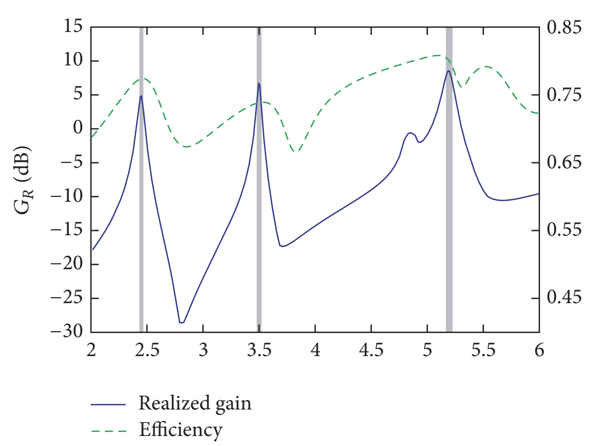


Figure 4: Realized gain and radiation efficiency of the designed antenna shown in Figure 1.

bendings are performed along the x-direction. These results confirm very good robustness of the proposed antenna, which can be successfully used also as a conformal antenna, with no modification on the geometry of the nonconformal (i.e., planar) structure, whose dimensions are reported in Figure 1.

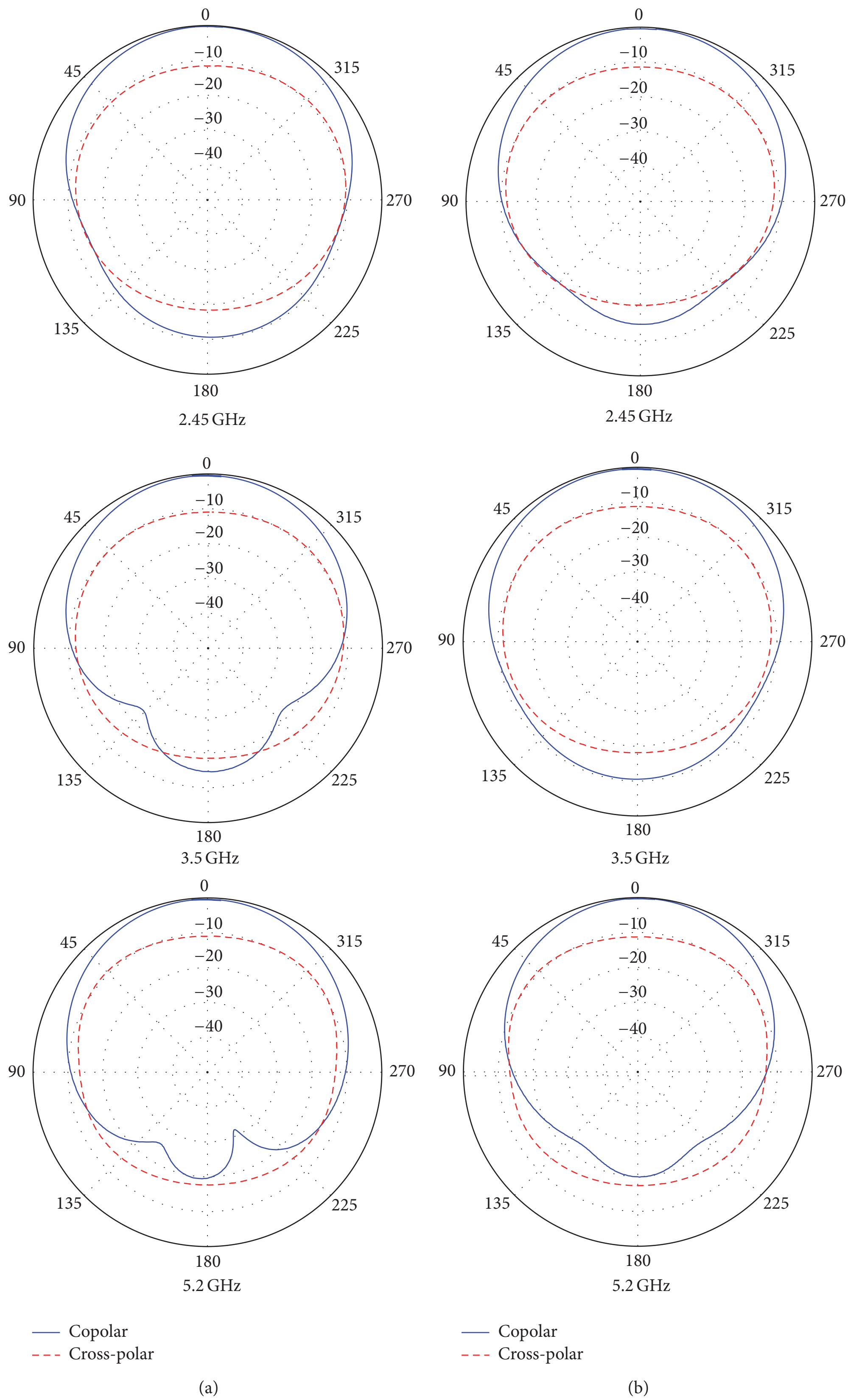


Figure 5: (a) E-Plane and (b) H-Plane radiation pattern of the designed antenna shown in Figure 1.

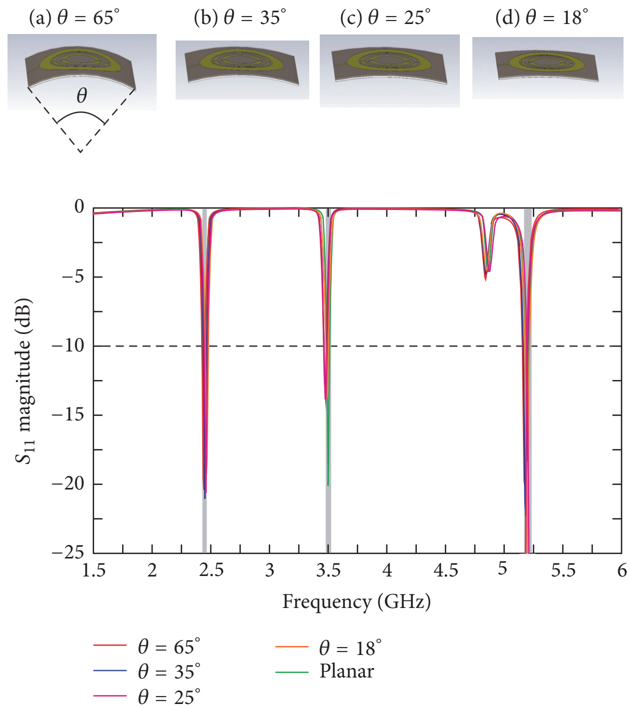


FIGURE 6: Frequency response of the designed antenna shown in Figure 1 for different curvature angles.

4. Conclusion

In this work we present a multiband printed microstrip antenna for wireless communications, fed by a proximity-coupled microstrip line and printed on a flexible substrate, which covers both the WLAN frequencies (both S-Band at 2.45 GHz and C-Band at 5.2 GHz) and Wi-Max frequency at 3.5 GHz. The simulated and measured results are in very good agreement, showing a very good input matching, a broadside radiation pattern, and an excellent rejection out of its operating frequency band, without the use of stop-band filters, avoiding undesired interference. The antenna realized gain is above 4.6 dB within the working band and rapidly decreases in the out-of-band range. The proposed structure can be used also as a conformal antenna, and its frequency response and radiated field are satisfactory for curvatures up to 65°.

Competing Interests

The authors declare that there is no conflict of interests.

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