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DESIGN OF POLYGONAL PATCH ANTENNAS FOR PORTABLE DEVICES

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Abstract—In this paper, extending the design technique presented by the authors in a previous work, we propose the study of a new family of polygonal patch antennas for portable devices of communication systems. Such antennas are suitable to be mounted in modern terminals, enabling wideband/multi-frequency operation and new multimedia features. The desired electromagnetic behaviour of the proposed radiators is obtained by adding either shorting posts, properly located between the polygonal patch and the ground plane, or circular slots, drilled at the appropriate position on the patch surface. Circular slots are also useful to easily accommodate a photo-camera in the terminal, in order to enable multimedia services and video calls. Some practical layouts of polygonal patch antennas to be used in: a) modern PDAs and Smart Phones integrating cellular phone operation and wireless functionalities; b) UMTS terminals integrating also GSM functionalities, are, finally, presented. The effectiveness of the proposed designs is confirmed through proper full-wave numerical simulations.

1. INTRODUCTION

Microstrip patch antennas have been widely used in the second generation of mobile telecommunication systems, due mainly to their low weight and low profile, conformability, easy and cheap

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realization [1, 2]. The success of such components in the new generation of wireless mobile systems and beyond is strongly related to the development of new design techniques, capable to provide microstrip antennas with enhanced performances.

For instance, modern portable devices usually need antennas with a multi-frequency operation mode. New cellular and wireless telecommunication systems, in fact, do not need only two different operating carriers for uplink and downlink channels, but also different carriers to handle different services. For instance, Universal Mobile Telecommunication System (UMTS) portable devices, operating in Europe in the frequency band 1900–2200 MHz, usually provide also Global System for Mobile Communications (GSM) services and, thus, have to operate at 900/1800 MHz, as well. In addition, some cellular equipments are designed to handle not only different services, but also the same services in different countries, so that other additional carriers have to be added (for instance, GSM services work at different frequencies in USA and in Europe).

Moreover, the need for staying connected to the Internet and for wireless connections with other portable devices, leads the manufacturers to include also Wi-Fi and Bluetooth capabilities in modern portable devices and mobile phones, such as Portable Device Assistants (PDAs) and Smart Phones. The design of such components is not an easy task from the electronic and electromagnetic point of view, due to several not only technical constraints. Handling different signals through dedicated electronic circuits with Digital Signal Processing (DSP) tools and limiting the electromagnetic interference among the different RF circuits working on different carrier frequencies, are two of the main technical issues in the design of this kind of portable devices. Other relevant constraints come from the design of the external case, whose shape and dimensions should be always more and more attractive for the final users. Since in the final layout the antenna represents the most bulky circuit part, if compared to miniaturized DSP and electronic circuits, antenna designer is usually asked to integrate the operation of all the different services in the same radiator and, sometimes, to accommodate also some other hardware, such as cameras for handling multimedia services and video calls, within the antenna space.

In this frame, thus, there is needs for *broad-band antenna operation*, in order to handle the different high bit-rate multimedia services available for the final user. Eventually, all the aforementioned enhanced performances should be preferably achieved without increasing the size of the antenna.

Different techniques have been suggested in the literature to achieve multi-frequency operation and enhanced impedance bandwidth of microstrip antennas. Some of them are based on the employment of parasitic elements or stacked configurations, which usually do not preserve compactness requirements [3–9]. Some other techniques, based on the employment of reactive loads and reactive slots on the patch, instead, do not degrade the compactness of the component, but suffer of limited flexibility, making the design of high-performing devices with enhanced features rather difficult [10–14]. Finally, other techniques are based on band-notched filters, which allow keeping the antenna size rather small, enable the broadband behaviour, but usually exhibit asymmetric and strongly irregular radiation patterns [15–17].

Polygonal patches have been suggested by the authors as good candidates for telecommunication applications, since they may provide antennas with the required broad-band behaviour and multi-frequency operation, without increasing the space occupancy [18–23].

Irregular patches, such as the polygonal ones, in fact, enable an increased number of antenna resonances, which can be suitably spaced along the frequency axis, simply by choosing properly some geometrical parameters like: patch dimensions, number, length, and slope of the patch shape sides. On the other hand, the authors have already remarked that the main drawback of using irregular patches is the irregular current density distribution on the patch [23]. This undesired effect is the cause of scarce polarization purity and of the potential asymmetry of the radiation pattern on the principal planes, compared to regular rectangular patch radiators. In mobile communication applications, however, polarization purity and radiation pattern symmetry are not crucial issues, and, therefore, these aspects may be easily sacrificed to obtain a wider bandwidth and/or better multi-frequency behaviour.

The authors have already presented in [23] a design technique for polygonal patches in order to provide multi-frequency and/or broadband operation. This technique has been directly applied in [23] to the design of patch antennas for regular† UMTS terminals and dual band Wi-Fi computer cards. In this paper, we present an extension of that design technique, which, making use of properly located shorting posts and circular slots, allows to straightforwardly design polygonal patch antennas for the new generation of PDAs, that integrate different wireless services (UMTS, Wi-Fi, Bluetooth), and UMTS terminals, that regularly integrate a photo-camera to enable modern multimedia communications (Multimedia Messaging Service — MMS, video calls,

† The antennas presented in [23] are intended only for the UMTS service and are not designed to be included in advanced devices capable of handling different wireless services and hosting cameras for multimedia communications.

etc.) Some practical layouts, showing the effectiveness of the extended design technique here proposed are also presented and supported by proper numerical simulations.

The structure of the paper is as follows: in Section 2, the design of polygonal antennas presented in [23] is briefly recalled; in Section 3, the design technique is extended introducing shorting posts to increase the impedance bandwidth of the antennas; in Section 4, we present the design of polygonal antennas with circular slots, in order to accommodate the photo-camera within the antenna of UMTS terminals.

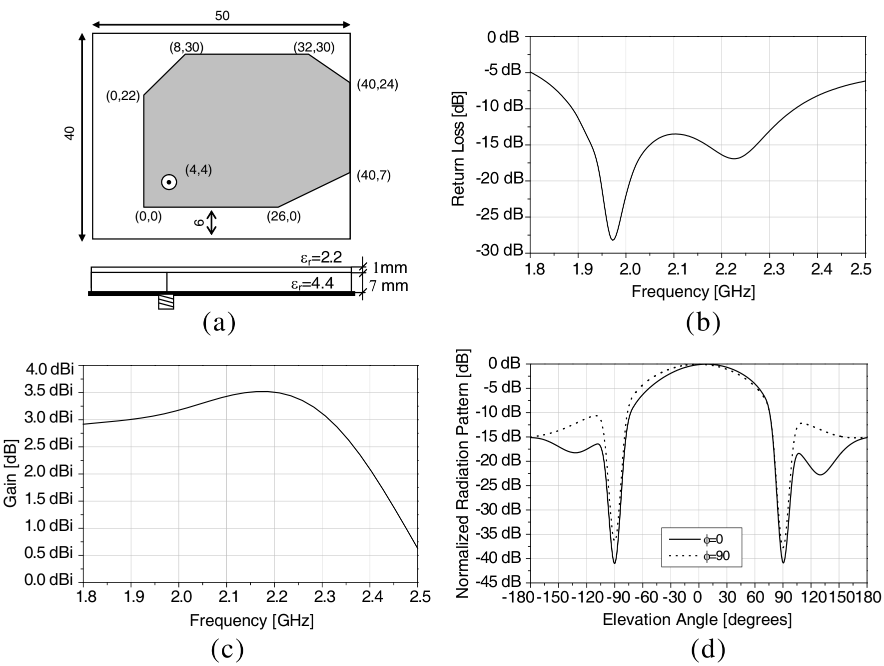


Figure 1. (a) Polygonal patch antenna layout for UMTS terminals, and (b) its impedance, (c) gain and (d) radiating features at the central UMTS frequency of 2050 MHz. The antenna is fed by a $50\,\Omega$ coaxial probe and is covered by a plastic overlay. The geometrical dimensions in Fig. 1(a) are expressed in mm. The results presented in this figure come from [23].

2. PRELIMINARY DESIGN OF A POLYGONAL PATCH SHAPE FOR UMTS TERMINALS

We have already presented in [23] a layout of a polygonal patch for UMTS mobile terminals (see Fig. 1(a)). The matching features of this antenna, reported in Fig. 1(b), show how the operation in the UMTS frequency band has been easily accomplished‡. As already pointed out in [23], the broadband behaviour of the antenna is due to the interaction between a pair of fundamental modes supported by the polygonal patch.

In this design, the oblique sides are responsible for the enhanced interaction between the modes, which is otherwise not possible in conventional rectangular patches. Gain and polar radiation patterns on the principal planes at the central operating frequency are also reported here for completeness§.

In this paper, we consider this design as the starting point for the implementation of the extended design techniques, leading to the synthesis of improved layouts in terms of operating bandwidth and number of handled services.

3. DESIGN OF WIDEBAND POLYGONAL PATCH ANTENNAS WITH SHORTING POSTS

As previously mentioned, the antenna depicted in Fig. 1(a) fits well the UMTS specifications, but cannot be mounted as the solely antenna in modern PDAs, where wireless connections (i.e., Bluetooth and Wi-Fi), operating in the band 2400–2485 MHz, are also needed. Since the antenna is the most bulky part of a portable device, it is not advisable to use different antennas for different services. Looking at Fig. 1(b), it is clear that, in order to enable also Bluetooth and Wi-Fi services, we need to extend the antenna operation to the upper frequency region at least up to 2485 MHz, keeping the return loss less than -10 dB. Since the return loss in Fig. 1(b) exhibits a pronounced negative peak around 1950–2000 MHz, we presume that the design of the antenna depicted in Fig. 1(a) is not extreme yet and that such an antenna, with a proper

‡ The threshold adopted to define the impedance bandwidth is usually set at -10 dB. According to this definition, the antenna depicted in Fig. 1(a), is suitable for operation in the UMTS frequency band (1900–2200 MHz).

§ The antenna sketch reported in Fig. 1(a) and the corresponding simulated radiating and impedance matching results plotted in Figs. 1(b)–1(d), come from [23] and have been reported here only for convenience, since they represent the starting point for the extended designs proposed in the paper. Simulations have been performed through a full-wave numerical code, based on the Method of Moments (MoM) [24].

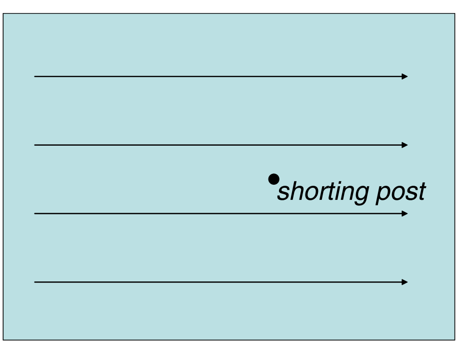
loading technique, may operate with a $-10\,\mathrm{dB}$ specification within a broader frequency range.

In order to increase the upper limit of the frequency operation band, we propose in the following to use shorting posts placed underneath the patch.

The effect of a shorting post, which physically connects the patch to the ground plane, may be easily explained by means of the cavity model [1], as shown in [25]. The shorting post, in fact, behaves like an inductive load L_{sp} that affects the parallel resonant LC circuit, describing the behaviour of the modes of a patch antenna. The effects introduced by the post depend on both the frequency and the post position (x_{sp}, y_{sp}).

Usually, shorting posts are employed to introduce a new resonant mode, whose resonant frequency is below the resonant frequency of the first natural mode of the unloaded patch (let us call it as the "zero" mode). This usually results in a reduction of the patch dimensions for the operation at a given frequency and it is mainly due to the interactions between the post and the static capacitance of the patch. Exploiting this new mode introduced by the shorting post, it is possible to achieve easily a multi-frequency operation with electrically short antennas. However, this is a well established technique and we do not enter into further details here.

Our attention here is not focused on the "zero" mode, but on the effect of L_{sp} on the modes of the unloaded patch. In terms of an equivalent circuit, each mode of the loaded patch can be represented as a parallel LC circuit, with the inductance L_{sp} connected in series, as shown in Fig. 2 in the case of a rectangular patch. This equivalent



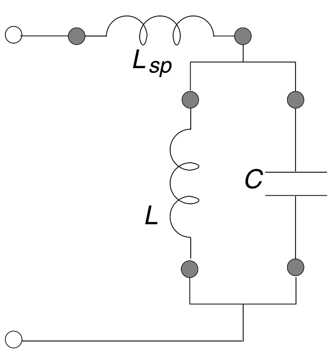


Figure 2. (a) Rectangular patch loaded with a shorting post and (b) the associated equivalent circuit.

circuit representation results in an up-shift of the resonant frequencies of the unloaded patch modes.

Referring to the fundamental modes only, the insertion of a shorting post at the centre of the patch would not affect the resonant frequencies of the modes. As it can be easily verified through the cavity model approach, in fact, the electric field in the centre of the patch would be zero [1] (i.e., the voltage across the shorting post would be zero, as well) and, thus, the equivalent inductance of the shorting post results $L_{sp} = 0$. Moving, instead, from the centre of the patch towards a radiating edge (i.e., along the direction of the current flow of a fundamental mode), the electric field increases (i.e., the voltage across the shorting post increases, as well) and, thus, the equivalent inductance L_{sp} also increases, resulting in an up-shift of the resonant frequency of the corresponding fundamental mode. On the other hand, an orthogonal movement of the post with respect to the current flow of a given mode, does not affect the corresponding resonant frequency.

This means that, the resonant frequencies of two orthogonal modes can be independently tuned by moving the post along the directions of the current flows of the two modes.

In the case of the patch depicted in Fig. 1(a), as already pointed out in [23], the resonant mode responsible for the operation in the upper frequency band is the one characterized by a vertical power flow (i.e., the mode with the electric field directed along the y-axis). This

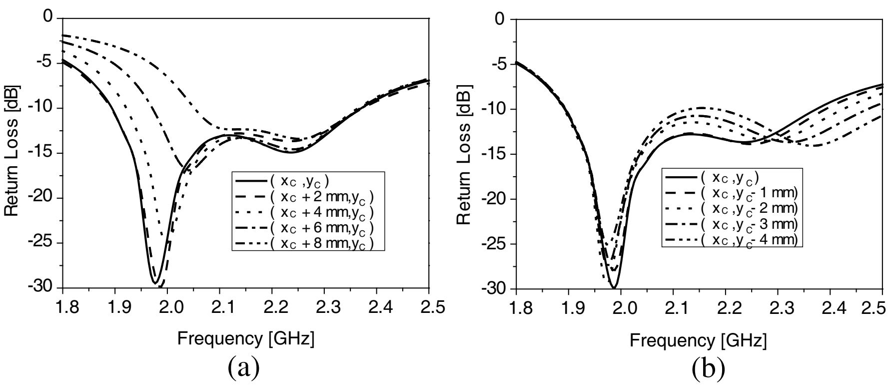


Figure 3. Effects of the insertion of a shorting post on the fundamental modes of the antenna depicted in Fig. 1(a). (a) Simulated return loss as a function of the frequency for different positions of the shorting post along the x-axis. (b) Simulated return loss as a function of the frequency for different positions of the shorting post along the y-axis.

means that, in order to increase the resonant frequency of this mode, the shorting post should be moved from the centre of the patch along the y-axis. On the other hand, moving the shorting post along the x-axis, would increase the resonant frequency of the other fundamental mode, responsible for the antenna operation in the lower frequency band and directed along the x-axis. All these physical intuitions are fully confirmed by the full-wave numerical simulations presented in Fig. 3.

The final antenna layout is reported in Fig. 4(a) and the simulated matching, gain, and radiation patterns on the principal planes are given in Figs. 4(b), 4(c), and 4(d), respectively. We remark here that the antenna layout reported in Fig. 4(a) does not differ from the original one of Fig. 1(a), but for the shorting post. The operation,

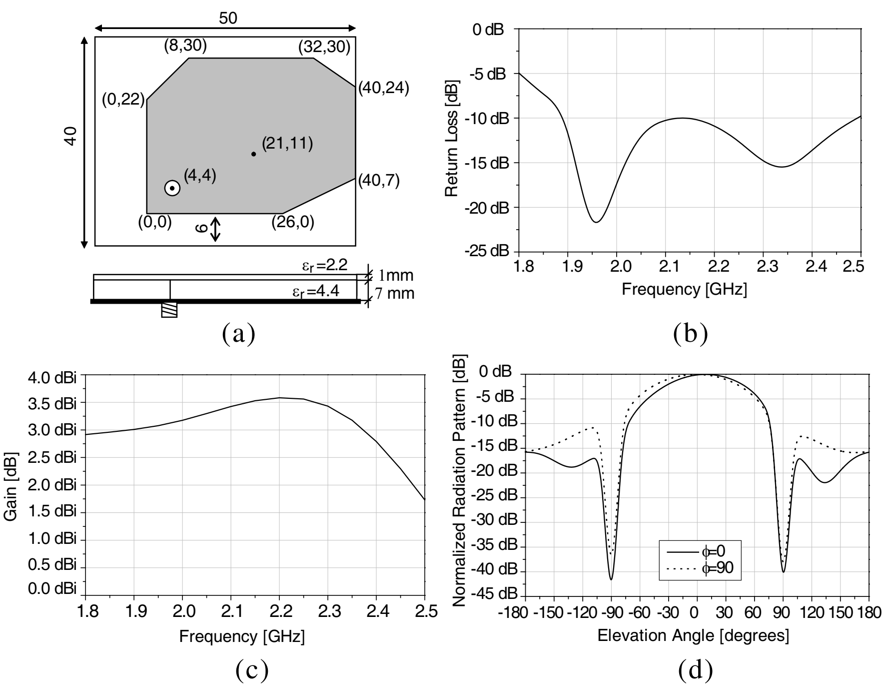


Figure 4. (a) Layout of a polygonal patch antenna with a shorting post for the operation in UMTS, Wi-Fi, and Bluetooth frequency bands. (b) Return loss as a function of frequency. (c) Gain as a function of frequency. (d) Polar radiation patterns at the central frequency of the UMTS service (2050 MHz) on both the principal planes.

however, is extended in frequency, covering also Wi-Fi and Bluetooth services. Moreover, the presence of the shorting post introduces the "zero" mode, resonating at a lower frequency (not shown in Fig. 4), whose operation might be tuned on an additional service (e.g., GSM operating at 900 MHz).

Sometimes, it is not useful to activate all the wireless services together, since it may cause a faster consumption of the battery charge. For this reason, it is wise to provide the antenna itself with switch on — switch off capabilities. This feature may be easily implemented in the layout shown in Fig. 4(a). The shorting post, in fact, may be easily replaced by a PIN diode, which is an electronic controllable switch. When the wireless tools are off and the portable device is used only as a UMTS terminal, the switch is open and the antenna behavior is the one reported in Fig. 1. On the other hand, when also Wi-Fi and/or Bluetooth operation is needed, the switch is closed and the antenna performances are the ones depicted in Fig. 4, when the shorting post electrically connects the patch surface to the ground plane.

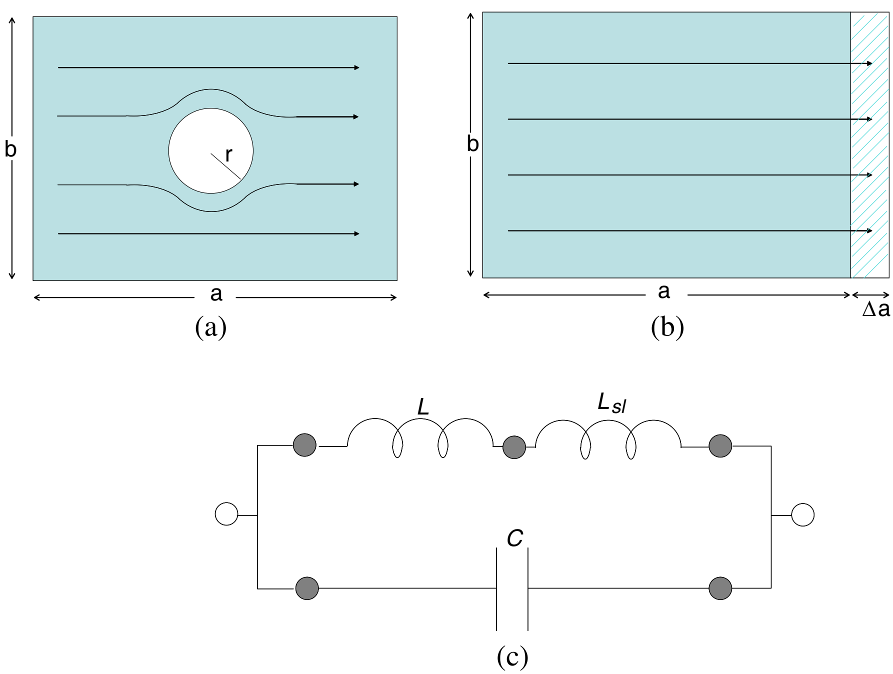


Figure 5. (a) Rectangular patch with a circular slot. (b) Equivalent dimensions of the rectangular patch loaded with a circular slot. (c) Equivalent circuit representation.

4. DESIGN OF WIDEBAND POLYGONAL PATCH ANTENNAS WITH CIRCULAR SLOTS

Another issue previously mentioned is the integration of a photo-camera within the volume of the antenna to enable multimedia services on the portable device. In order to accommodate typical cameras, an 8 mm circular slot may be cut on the patch surface. However, when introducing a circular slot on the patch, the electromagnetic behaviour of the antenna changes. To easily understand the slot influence, let us consider again a rectangular patch with a circular slot in the middle. Referring to a horizontally directed mode, the superficial current density has to flow around the slot, increasing its path, as shown in Fig. 5(a). In terms of the equivalent circuit associated to the resonant mode of the rectangular patch, the inductance L is increased by an equivalent quantity L_{sl}, due to the longer path of the current. Therefore, as shown in Fig. 5(b), the patch dimension along the current flow is virtually lengthened of a quantity Δa, given by $\Delta a = \pi r^2/b$. The equivalent circuit associated to this patch mode affected by the presence of the circular slot, therefore, is the one depicted in Fig. 5(c), where the slot influence is described in terms of the inductance L_{sl} connected in series with the mode inductance L.

Depending on the slot diameter, the resonance of the fundamental mode of the rectangular patch can be brought to a very low frequency, leading, thus, to electrically small antennas. As it happens for the "zero" mode of the patch loaded with a shorting post, the radiator, in fact, operates at a lower frequency, while keeping the space occupancy fixed. In this way, it is again possible to easily enable a multi-frequency antenna operation. For instance, by cutting a circular slot with proper dimension and position on the patch of Fig. 1(a) it is possible to make it working not only in the UMTS band, but also at a lower frequency (e.g., GSM at 900 MHz). However, this is a conventional employment of slots in microstrip antennas and we will not give here further details. On the other hand, apart from introducing a new mode at lower frequencies, the presence of the circular slot affects also the interaction between the fundamental modes of the patch, which is one of the key aspects to achieve a broadband behaviour through polygonal patch shapes [23].

In the layout of Fig. 6(a), for instance, the 8 mm circular slot suitable to host the photo-camera is placed at a proper position on the patch surface. A metallic cylindrical shell is also used to cover the photo-camera and avoid the interaction between the electromagnetic field and the electronic circuits of the camera. In this case, the choice of the circular slot position on the patch has been suggested by the previous design of the polygonal patch loaded with the shorting post (Fig. 4(a)). The metallic shell which electrically connects the patch and the ground plane, in fact, behaves as the shorting post and introduces the same up-shift of the resonant frequency of the vertical mode. On the other hand, the position of the circular slot is also such that the interaction between the two resonating modes is not affected very much. The result is the return loss shown in Fig. 6(b), which is very similar to the one reported in Fig. 4(b). Also antenna gain and radiation patterns do not differ very much from the ones reported in Fig. 4(c)–4(d). This antenna, however, represents a further extension of the one depicted in Fig. 4(a), since it can be used in PDAs and Smart Phones integrating UMTS, Wi-Fi/Bluetooth functionalities, and multimedia services requiring the presence of a camera. In addition, the presence of the slot enables also the operation at a lower frequency (not shown in Fig. 6(b)), which

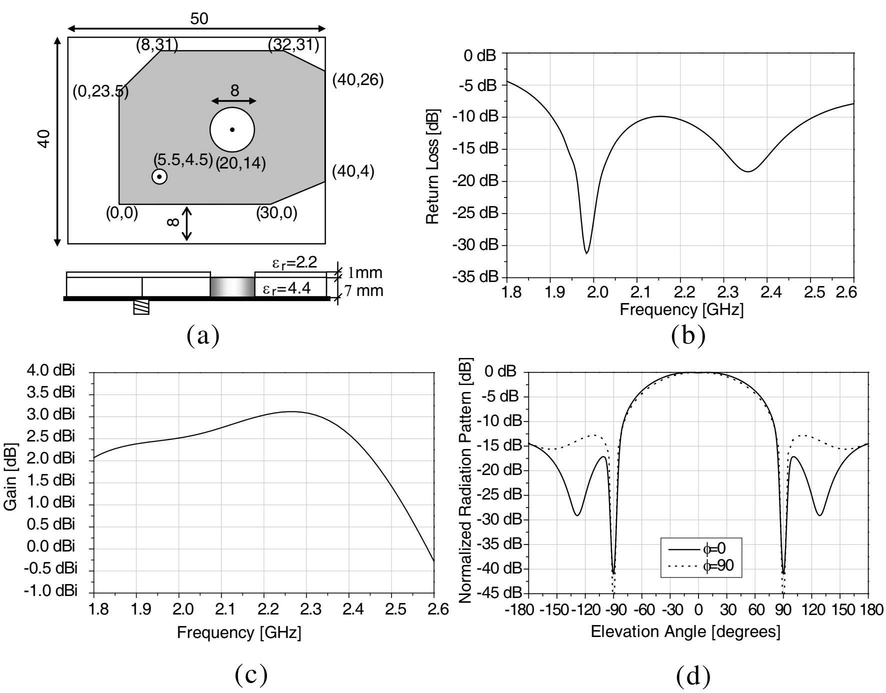


Figure 6. (a) Layout of a polygonal patch antenna with a circular slot for the operation in UMTS, Wi-Fi, and Bluetooth frequency bands. (b) Return loss as a function of frequency. (c) Gain as a function of frequency. (d) Polar radiation patterns at the central frequency of the UMTS service (2050 MHz) on both the principal planes.

can be tuned for GSM services at 900 MHz or for the reception of the Global Positioning System (GPS) signal at 1575 MHz, integrating, thus, satellite navigation tools. In the latter case, however, polygonal patches should be designed in a very symmetric way, since circular polarization purity is a key aspect to design effective radiators to be employed in navigation systems.

The circular slot on the patch surface can be used not only for accommodating the camera within the antenna volume, but also as a new degree of freedom available for the designer. For instance, the new resonance introduced by the slot at a lower frequency can be tuned to be very close to the other fundamental resonances of the polygonal patch to enable a broadband behaviour extending towards the lower limit of the frequency band of operation. The layout proposed in Fig. 7(a) differs from the one of Fig. 6(a), basically because of

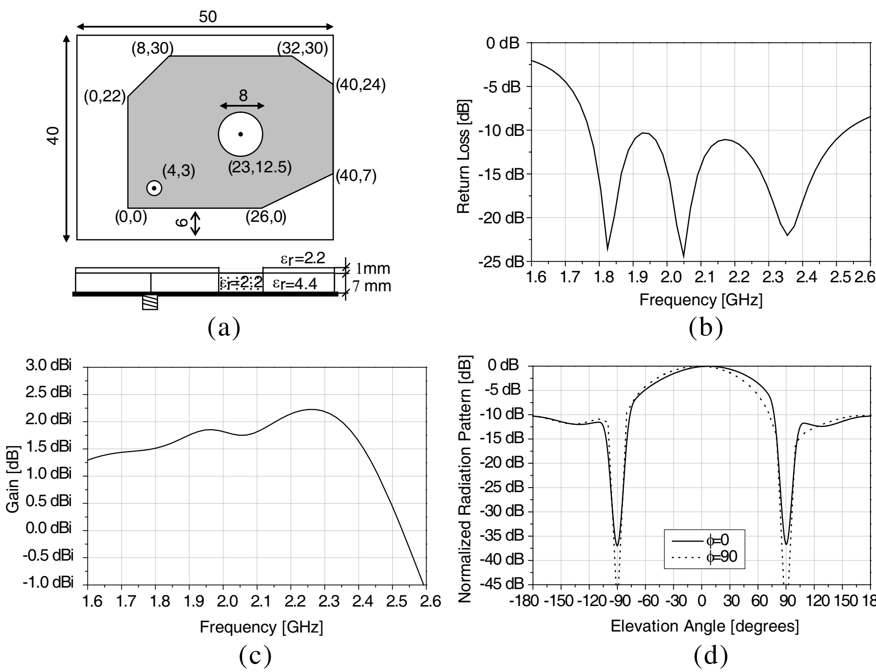


Figure 7. (a) Layout of a polygonal patch antenna with a circular slot for the operation in GSM, PCS, UMTS, Wi-Fi, and Bluetooth frequency bands. (b) Return loss as a function of frequency. (c) Gain as a function of frequency. (d) Polar radiation patterns at the central frequency of the UMTS service (2050 MHz) on both the principal planes.

the absence of the metallic cylindrical shell placed between the patch and the ground plane. The cylindrical volume underneath the slot is this time filled by a plastic material. The position of the slot has been chosen in such a way to affect the interaction between the two modes, while the presence of the plastic cylinder lowers the effective permittivity of the substrate region underneath the slot. The result is that the interaction between the two modes of the polygonal patch now happens at slightly higher frequencies. In summary, the presence of the new mode due to the circular slot extends the lower limit of the frequency band of operation, while the presence of the plastic cylinder extends the upper limit. The final result is shown in Fig. 7(b). The antenna is now able to cover GSM at 1800 MHz, PCS at 1900 MHz, UMTS, Wi-Fi and Bluetooth.

5. CONCLUSION

In this paper, we have presented a technique to design polygonal patch antennas with enhanced bandwidth features for the operation in portable devices of the new generation of multimedia mobile systems. Starting from a basic design of polygonal patches for UMTS terminals and making use of shorting posts and circular slots, it has been shown how it is possible to integrate wireless functionalities (Wi-Fi and Bluetooth), multi-frequency operation, and hardware accommodation of a photo-camera in regular UMTS antennas, without changing the shape and increasing the space occupancy. Several antenna layouts, based on the new concepts proposed in the paper, have been also presented and supported by full-wave simulations performed with a code based on the Method of Moments.

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