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Reconfigurable Microstrip Printed Patch Antenna for Future Cognitive Radio Applications

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Abstract

A family of compact microstrip antennas are presented targeting applications such as Long-Term Evolution (LTE), Wireless Local Area Networks (WLAN), Universal Mobile Telecommunications system (UMTS), Global System Mobile (GSM) and global positioning system (GPS). These antennas consist of a rectangular shaped structure printed over FR4 substrate. The antenna occupies a small volume of 70x54x1.6mm^3. A 50-Ohm strip line was used to feed the proposed antennas. For miniaturization purposes, an I- shaped slot was inserted in the appropriate location on the radiator resulting in the second version (antenna with I-shaped slot). The integration of the slot helped towards shifting the resonant frequency downwards, which potentially created an additional resonant frequency to cover the WLAN2400MHz, but this resonant frequency is still static in nature. Thus, tuning mechanisms were introduced to tune the resonant frequency over a wide continuous frequency range. A lumped capacitor was firstly used as the tuning approach, in which its capacitance was varied from 0.5pF to 3pF , covering the frequency range from 2300MHz to 1500MHz. Secondly, the varactor diode was exploited to verify this; by changing the bias voltage across the varactor from 0.21V to 12.9V, the antenna operates over the targeted range from 1500MHz to 2300MHz. Both the simulated and measured results show a stable performance. The proposed antenna may be suitable for future cognitive radio system.

Keywords: varactor, microstrip antenna; cognitive radio; embedded slot ;GPS ;GSM UMTS; WLAN; LTE.

1. Introduction

We are entering a digital society, where the user in increasingly requiring access to the internet at the touch of a button, at any place and anywhere. This scenario is re-engineering future emerging devices, so that they are more technically flexible and able to deliver high quality content. Where portable devices were only connected to a single service provider, new advances in network virtualization and system coexistence are allowing devices to be connected to several wireless networks in order to provide cost-effective service delivery to the end-user. This scenario is placing stringent design requirements on the antenna design in terms of miniaturization and the ability to work over various carrier frequencies. In particular, portable wireless devices such as smart phones, tablet computers and laptops , which operate over various systems, i.e. WLAN and GSM/UMTS/LTE WWAN are gradually becoming very popular and required to be lightweight, small size and low cost. To cover all the above-mentioned wireless communication systems within a single device, this requires antennas for different systems and standards, or ideally one "super" flexible antenna able to support connectivity with heterogeneous systems. In other words, an antenna that is miniature in size and able to be tuned to support a wideband of wireless applications.

A candidate technology to support this heterogeneous requirement is microstrip antenna technology [1]. Microstrip patch antennas have attracted a huge area of interest and have been widely used in several applications such as mobile handsets, satellite communications, aerospace, radars. A microstrip patch antenna is one that is lightweight, mechanically robust, compact size, and offers a frequency agility that can be tuned to support a range of wireless channels. This has given the microstrip antenna several advantages over its conventional counterpart antennas [2-4]. Microstrip antenna with different techniques have been proposed for use in various applications [5-10]. For example, works in [5-7] proposed microstrip patch antennas that are capable of covering the lower band of WLAN2400MHz. While on other hand, authors in [8-10] have come up with microstrip antenna structures to operate over the 3G-UMTS2100MHz. Analysing the works in [5-10], one can

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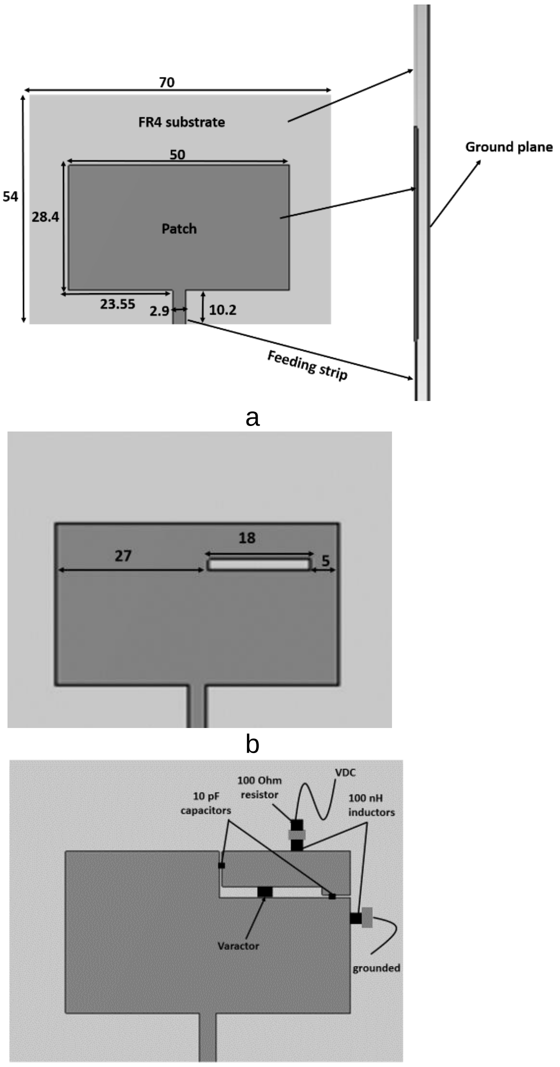
obviously understand that these microstrip patch designs, either cover the WLAN standard as in [5-7], or operate over the 3G service of UMTS as in [8-10]. To meet the requirement of the newly launched LTE service, the microstrip antenna design has to be revisited. Several microstrip patch antennas which are capable of operating over the LTE bands have been reported [11-15]. Although each of these designs are optimal for specific technologies, it is clear that a single flexible antenna structure that can operate over LTE and legacy WLAN and 3G is required. However, this requires us to reinterpret the way we perceive the antenna device; we should not see this is as a static or hardwired solution, but one that is virtual. Borrowing terminology from the networking world, the antenna should be virtualised and software defined in order to respond to the available networks in the near vicinity. This is often referred to as cognitive radio.

Cognitive radio (CR) is a technology that became prominent with market drivers towards the use of licensed spectrum by secondary users. In CR technology, the secondary users aim to exploit pockets of unused spectrum by detecting available opportunities, and transmitting on these within predefined power levels without harming the incumbent users [16]. CR requires a software defined radio that is able to reconfigure the transmitter in real-time in order to communicate with the intended wireless network. Therefore, we export this idea to the 4G world and beyond, by assuming a CR terminal that is able to communicate with legacy and future emerging technologies to ensure seamless connectivity for sustaining the quality of service, rather than for exclusive use of CR applications. Therefore, we investigate the notion of a reconfigurable antenna.

Microstrip patch antenna can be implemented for both sensing and communication [17]. Several tunable printed antennas have been reported [18-23]. These antennas were tuned by using two different technologies either by varactor as in [18-21] or/and PIN diode switching as in [22-23]. By attaching the tuning technology over a proper location of the patch, and varying its DC voltage over a certain values of the varactor or changing the ON/OFF state of the PIN, the resonant frequencies can be tuned over a wide frequency range, without the need for altering the antenna dimensions once fabricated. However, some of these antennas have come up with a large volume and low gain, which may not be suitable for integration in today's smart phone due to the space limitation. Thus, a family of unloaded and loaded compact microstrip patch antennas were proposed, that cover the GPS,GSM,UMTS and LTE services. The proposed unloaded antennas (with and without slot) have demonstrated several advantages over previous works in [5-15], for example it has a smaller size compared to work in [5,6,8,9,10], and also shows a better gain in contrast to previous work in [5,7,9,10,15]. On the other hand, the proposed tunable design (third version), achieves a wider continuous tuned frequency range compared to works [18-23]; in addition, this version provides a degree of miniaturization compared to works in [18,19,20,22]. In all, there is a clear need for a cost-effective and reconfigurable antenna design based on mircrostip technology that is able to communicate with legacy (GPS, GSM, UMTS, LTE) and shows promising adaptability towards 5G (sub 6GHz), enabled by CR technology.

2. Antenna Design and Concept

The full configurations of the three proposed microstrip multi-band patch antennas are displayed in Figure 1. The layout of the proposed design is based on printed patch radiator. The patch has a compact volume of 50x28.4mm^2 printed over an RF4 substrate with size of 70x54x1.6mm^3. This type of antenna usually derives its name from its shape/structure. Figure 1 shows a patch antenna, which has a rectangular top layer and thus names appropriately. This patch antenna consists of two metal planes, the bottom layer being the ground plane (70x54mm^2) and the top layer is the radiating patch and a dielectric material between them.



c

Figure 1. the geometry of proposed antenna , (a) without slot, (b) with one slot, (c) with tuning circuit .Unit in mm

A 50-Ohm microstrip line is used to feed the proposed structure. This feed was chosen due to ease of fabrication and matching. Several simulation optimisations were carried out to select the optimal location of the feedline. However, there was no a significant effect on the antenna return loss, when the feedline set at both edges or in the middle. Thus, the feeding strip was connected at the edge of the middle part of the patch as shown in Figure 1. An I-shape slot is embedded over the surface of the patch as shown in Figure 1(b). The main objectives of this etched slot are to shift the resonant frequencies downwards, as well as reducing the antenna size. The slot has uniform width of 2mm. The full dimensions of the top patch is stated in Figure 1.

3. The Contribution of Embedded Slots

To prove the contribution of the embedded slots over the patch surface, the calculated and measured S11 of the present antenna with and without slot is studied and presented in Figure 2. One can note that the simulated model of the antenna without the inclusion of the uniform slot operates at the LTE2600MHz.

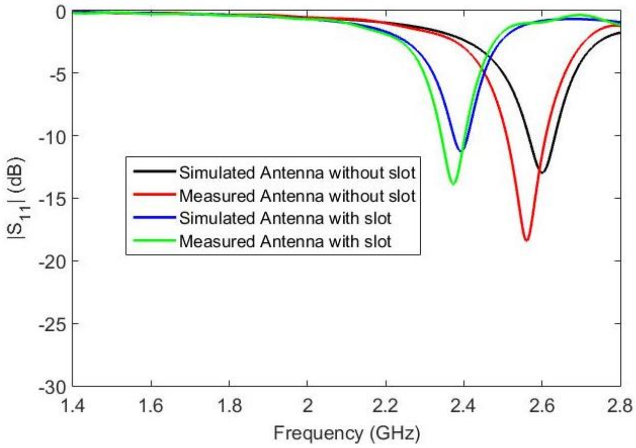
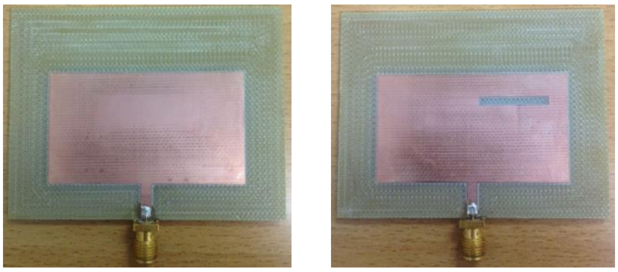


Figure 2. The S11 of the unloaded proposed antennas

However, as previously mentioned, the main target of the embedded slots is to shift the resonant frequencies downwards in order to cover the spectrum of other standards. Therefore, by carefully optimizing the shape and locations of the embedded slot, other services such as WLAN was easily accomplished within the same antenna structure. This also resulted in reducing the antenna size.

For proof-of-concept, the antennas with and without I-shaped slot were fabricated as depicted in Figure 3. The measured S11 of both versions is presented in Figure2. It is obvious that, a perfect impedance matching were achieved covering the two services of LTE2600MHz and WLAN2400MHz, in which the measured outcomes are in good agreement with the computed data. From this finding, the proposed antenna may be considered as an attractive candidate to operate over 3G and 4G systems. In addition, a huge size reduction was achieved due to the implementation of an embedded slot approach.



a b

Figure 3. The prototypes of the proposed antennas , (a) without slot, (b) with I-shaped slot

4. The Effect of the Patch Size

Due to the limited space within todays' smart phones and other portable wireless devices, the radiators are required to be slimmer and thinner, while at the same time cover the existing bands of the 3G system along with the newly released bands of 4G. This added more pressure on the antenna designers to identify the best and optimal geometry of the radiator before the antenna could be manufactured and tested experimentally. Thus, the geometry of the radiator was carefully studied and investigated. Four different sizes of the radiator i.e. 40 x 18.4 mm^2, 45 x 23.4 mm^2, 50 x 28.4 mm^2 and 55 x 32.4 mm^2, are used. The corresponding outcomes are depicted in Figure 3. One can note that, when the patch size was set at 40 x 18.4 mm^2 and 45 x 23.4 mm^2 the antenna does not satisfy the first resonant frequency of LTE200MHz. In other work, there is an impedance matching at both sizes. However, when the size of 50 x 28.4 mm^2 was analysed, the proposed antenna shows a perfect impedance matching over the operational band of LTE2600MHz with -22 dB return loss. It is also observed, that the LTE2600MHz band was more or less accomplished, when the radiator is set at 55 x 32.4 mm^{2,} , but is coupled with limitations as some power is reflected bank, as well as being to larger size for todays' smart devices.

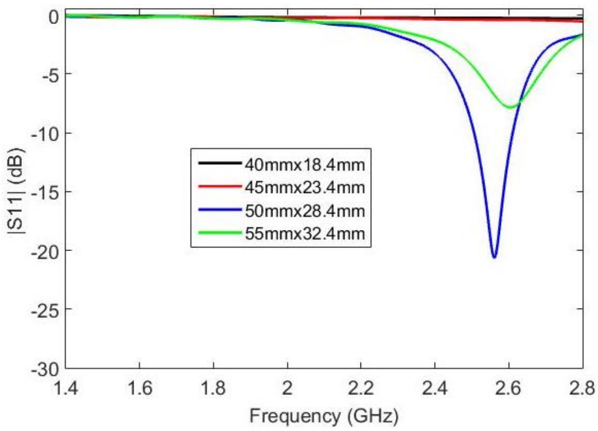


Figure 4. Simulated S11 variation of proposed antenna with different sizes of the patch

Therefore, the size of 50 x 28.4 mm^2 was selected to be the best size of the proposed radiator. This analysis is carried out with the help of CST microwave studio [24].

5. Results and Discussions

5.1 Refection Coefficient of the Antenna

Although, the above-mentioned antennas (with and without slot) have achieved some advantages such as size miniaturization and covering two important frequency bands of LTE and WLAN, however, these two resonant frequencies are fixed and cannot be altered/tuned once the antenna is fabricated, and this may not be considered attractive for cognitive radio system. Thus, in the first instance , a lumped capacitor is attached over the proper position of the I-shaped slot of the second antenna as shown in Figure 1 (d). By varying the capacitance of the used capacitor from 0.5pF to 3pF, the resonant frequency is widely shifted downwards from 2300MHz to 1500MHz, covering several wireless standards such as GPS, GSM and UMTS as indicated in Figure 5.

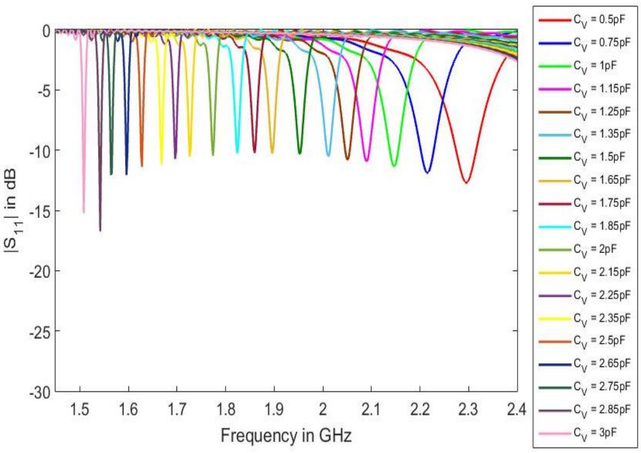
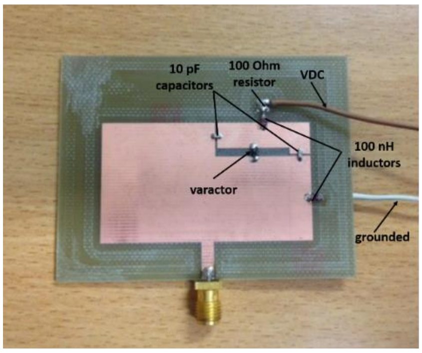
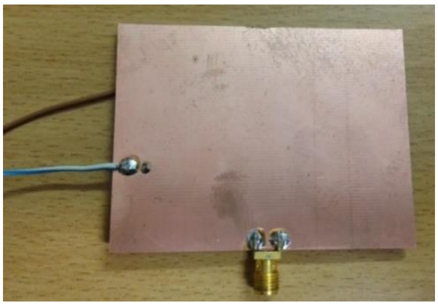


Figure 5. Simulated S11 of the capacitor -loaded antenna

For validation purposes, the I-shaped slot antenna along with a varactor diode and a suitable DC bias circuit were further explored as shown in Figure 6. The exploited BBY52-02W varactor diode has come up with a tuning reverse bias voltage range from 0–15 V. The two RF chokes value of 100 nH were used for DC passing, and a 100 ohm resistor to control the current flowing to the varactor. Two capacitors with value of 10 pF were attached to both ends of the slot for DC blocking and an isolation of the short-circuited.



a



b

Figure 6. The antenna prototype with DC bias circuit, (a) top view (b) bottom view.

Figure 7 indicates that by inserting the varactor over an accurate location of the slot, the proposed design achieved the target frequency range from 1500MHz to 2300MHz, when the DC voltage of the varactor was tuned from 0.21V to 12.9V.

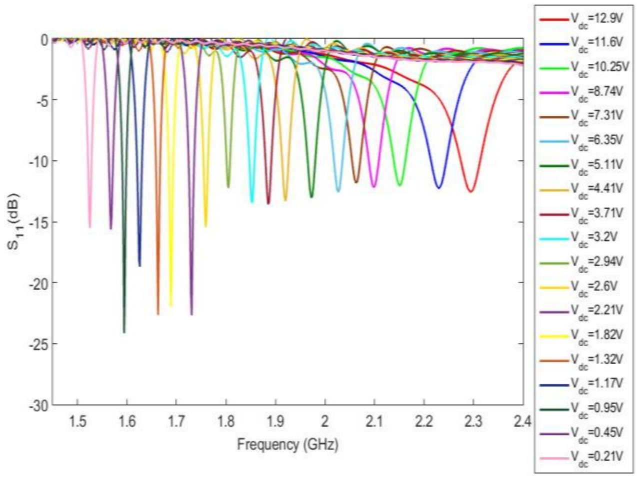


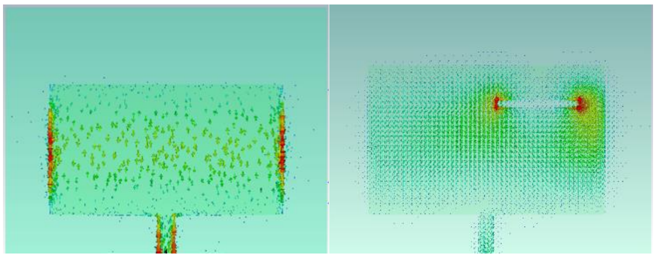
Figure 7. Measured S11 of the varactor -loaded antenna

A satisfactory continuously tunable resonant frequency occurs at all intermediate bias voltages. The S11 obtained from measurements with the biased varactor agrees well with the computed S11 data obtained in Figure 5.

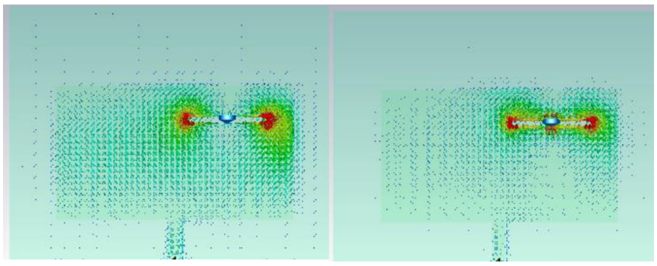
5.2 The Current Surfaces of the Proposed Antennas

To have a deeper insight on the resonant behavior of antenna, the currents surfaces for the unloaded and loaded antenna were examined. Initially, the current surface of the unloaded versions (with and without slot) at the two-targeted bands .i.e. 2600MHz and 2400MHz are illustrated in Figure 8 (a) (b). Broadly speaking, the microstrip patch antenna mainly radiates at the edges, which means most of the currents exist at the edges, with some currents at the microstrip line where the antenna was fed. Looking at Figure 8 (a) , this fact was proved. As can be seen in the case of the antenna without slot (LTE2600MHz), most of the currents concentrate at the right and left edges. Thus, to disturb the currents of the proposed microstrip patch antenna, in which the antenna will be able to operate over various frequency bands, a technique should be added/inserted at both edges. Therefore, an I-shape slot was embedded at both edges, which resulted in creating an additional band of WLAN2400MHz. The current surfaces of the proposed antenna with I-shape slot is displayed in Figure 8 (b) . One can obviously see, that most of the current in the slotted version induce around the slot. This also confirms the objective of the slot techniques in Figure 2, that changes the antenna electrical length, which in turn leads to a huge size reduction and shifting of the resonant frequency downwards.

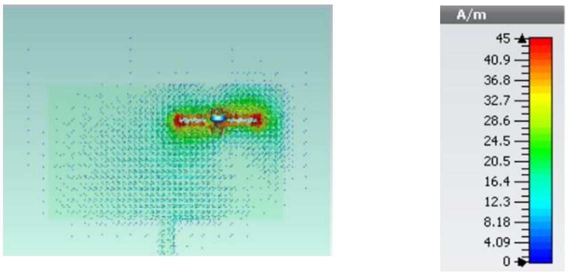
In the case of the tuneable (loaded) antenna, the currents surfaces at the three resonant frequencies, i.e 2200MHz, 1900MHz and I550MHz, when the capacitance of the capacitor was respectively varied over 0.75pf, 1.65pf and 2.85pf were studied and investigated as depicted in Figure 8 (c) (d) and (e) . One can note that most of the currents travel around the slot, as well as on both sides of the attached capacitor at the three-targeted frequencies.



(a) at 2600MHz (b) at 2400MHz



(c) 0.75 pF at 2200MHz (d) 1.65 pF at 1900MHz

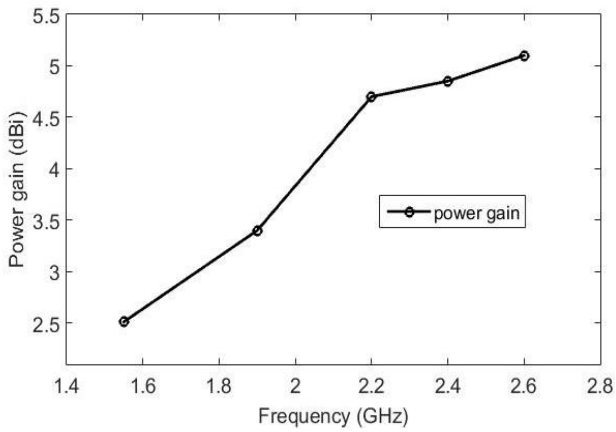


(e) 2.85 pF at 1550MHz

Figure 8. The current surfaces of the three version of the proposed antennas , (a) antenna without slot at 2600MHz, (b) antenna with one slot at 2400MHz, (c) loaded with 0.75pf at 2200MHz ,(d) loaded with 1.65pf at 1900MHz, (e) loaded with 2.85pf at 1550MHz

5.3 Power Gain, Efficiency and Radiation Patterns

Figure 9 shows the power gains and radiation efficiencies of the unloaded and loaded proposed versions. The first version of the antenna (without slot) that operates at LTE2600MHz exhibits power gain of 5.1dBi, while the antenna with I-shaped slot shows a gain of around 4.9dBi. In the case of tunable design, the gain was dropped to 4.75dBi, 3.2dBi and 2.6dBi over the three resonant frequencies of UTMS2200MHz, GSM1900MHz and GPS1550MHz, when the capacitance of the capacitor was varied from 0.75pf, 1.65pf and 2.85pf correspondingly. The power gain of the proposed tunable antenna verifies the statement that the power gain values are significantly affected by the capacitance. It can be seen, that while the capacitance value is larger, a current through the varactor increases so that the loss is increased. This in turn resulted in a low gain at large capacitance (low frequency) as depicted in Figure 9 (a) . In addition, due to the miniaturization of the proposed antenna, this caused a reduction in gain at the low frequency.



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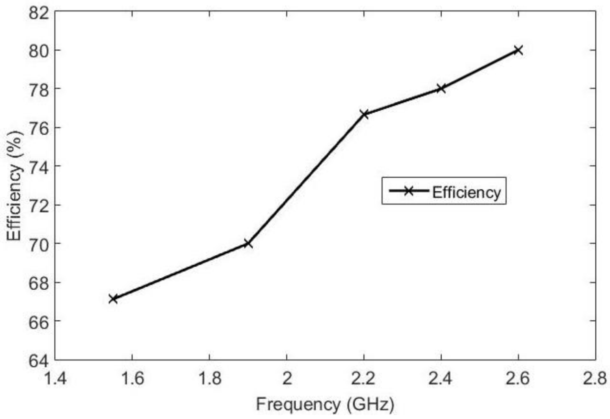
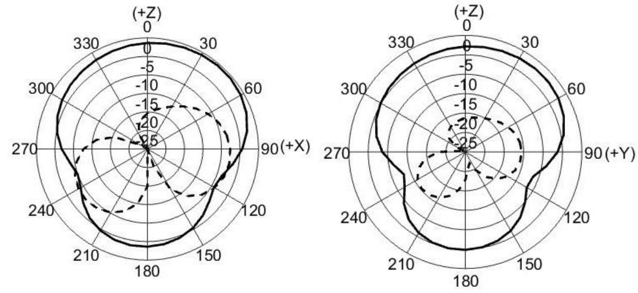


b

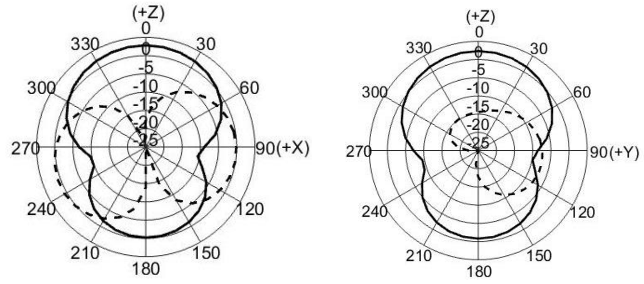
Figure 9. Power gains and radiation efficiencies of the proposed antennas

The antennas efficiencies, also as expected, agreed with the obtained gain. To be more explicit, the proposed un-slotted design exhibited good radiation efficiency value of 80% over the targeted band of LTE2600MHz as shown in Figure 9 (a) , while the antenna with the I-shaped embedded slot shows an efficiency of around 78% at the lower band of WLAN2400MHZ. In addition, the tunable proposed design accomplished efficiencies of 76.6%, 69.3% and 67.4% over the three services of UTMS2200MHz, GSM1900MHz and GPS1550MHz.

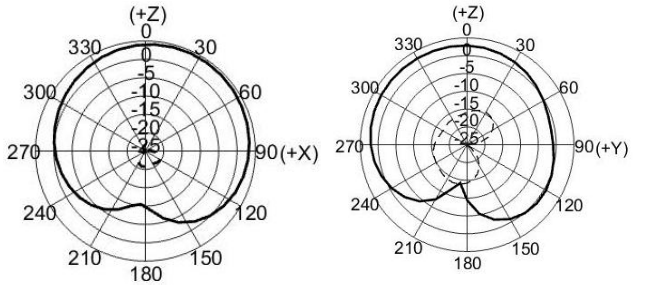
Figure 10 depicts the far-field radiation patterns of the three versions of the proposed antennas. Two planes, i.e., E-plane (xz) and H-plane (yz) were chosen to investigate the radiation patterns of the proposed antennas at the Five-targeted frequencies, namely 2600MHz, 2400MHz, 2200MHz, 1900MHz and 1550MHz. It should be noted, that the proposed antennas indicate a nearly omni-directional radiation pattern over the entire selected bands.



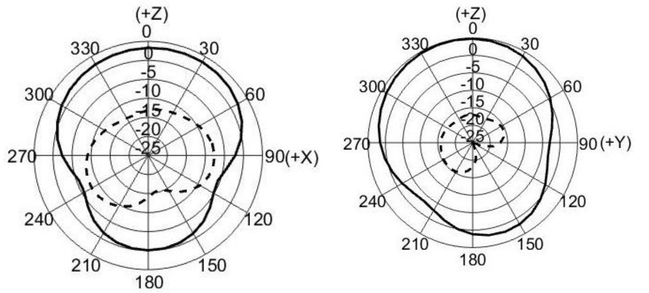
xzplane2600MHz yzplane2600MHz



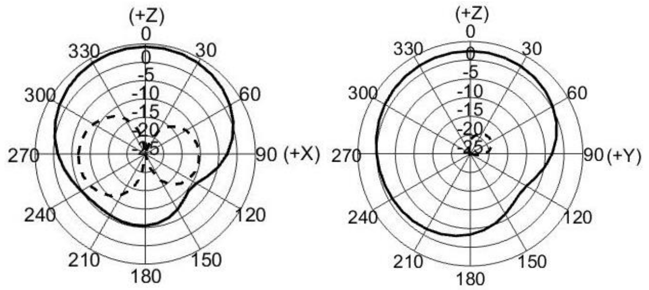
xzplane2400MHz yzplane2400MHz



xzplane2200MHz yzplane2200MHz



xzplane1900MHz yzplane1900MHz



xzplane1550MHz yzplane1550MHz

Figure 10. Normalized antennas radiation patterns for two planes (top: x–z plane, bottom: y–z plane) at 2600MHz, 2400MHz, 2200MHz, 1900MHz, 1550MHz "____" co-polarization; "---------" cross-polarization

6. Conclusion

A family of compact microstrip patch antennas have been presented, fabricated and tested. The initial un-slotted antenna design operated at LTE2600MHz, while the second I-shaped slot antenna was able to cover the WLAN2400MHz. It was clear, that the embedded slot approach offered key benefits in terms of shifting the resonant frequency downwards, as well as achieving a significant antenna size reduction. The proposed antennas along with the inserted slot technique are optimized for best results through simulation. To envisage this type of antenna for cognitive radio application, the slotted antenna was tuned by using a varactor diode. This allowed the antenna to be tuned over a wide frequency range from 1500MHz to 2300MHz. The computed results are in good agreement with the measured results; demonstrating that the proposed antenna can be a good solution for next generation multiband smart phones that are able to connect to legacy wireless networks in cost-effective manner, as part of the 5G paradigm.

Acknowledgments

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