Design and Simulation of a PIFA Antenna for the Use in 4G Mobile Telecommunications Networks

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ABSTRACT

This paper describes the design and simulation by HFSS simulator of a probe-fed and multi-band Planar Inverted-F Antenna (PIFA) for the 4G mobile networks. The antenna works in 8 bands. Five bands are auctioned by FCC for 4G (LTE and WiMax) such 710 MHz, 1900 MHz (PCS), 2.3 GHz (WCS band), 3.65 GHz (rural 4G) and 5.8 GHz (FCC unlicensed band). The antenna allows working around 910 MHz ISM band. The GPS signal can be received in GPS L2 band around the frequency 1575 MHz. The antenna offers also a wideband around 8.62 GHz. The simulation allowed the characterization of the designed antenna and the computing of different antenna parameters like S11 parameters, resonant frequency, bandwidth, radiation efficiency, gain and diagram pattern. The results are very interesting and respect mostly the requirements.

Keywords: PIFA; HFSS; 4G; ISM; GPS

1. Introduction

In telecommunications, 4G is the fourth generation of mobile communication technology standards. It is a successor of the third generation (3G) standards. A 4G system provides mobile ultra-broadband Internet access, conceivable applications include amended mobile web access, IP telephony, gaming services, high-definition mobile TV, video conferencing, 3D television and Cloud Computing.

Two 4G candidate systems are commercially deployed: the advanced Mobile WiMAX standard and LTE (Long Term Evolution) advanced. The In the US, Sprint Nextel has deployed Mobile WiMAX networks since 2008, and MetroPCS was the first operator to offer LTE service in 2011 [1]. Also, modern mobile communication devices tend to integrate multiple communication systems into a portable handset. From the voice, the high speed internet, the 4G connectivity, Bluetooth, Wi-Fi and GPS. Since each communication protocol may operate in a distinctive frequency band, instead of using several antennas, it is highly desirable to have one broadband or multi-band antenna to meet the antenna needs of multiple applications. Knowing also that 4G equipment made for different continents are not always compatibles, because of different frequency bands. The objective is to design antennas supporting 4G in bands allowed by FCC.

There are actually precedent works to design multi-band antennas for 4G [2-11], the problem is that antennas support some bands which are not allocated by the spectrum regulator with other bands allowed. For example, the 2.3, 3.65, 5.8 GHz bands auctioned for 4G by FCC are not allowed in Europe for 4G. For this, the designed antenna will then work in the following 4G FCC licensed bands like 710 MHz, 1900 MHz, 2.3 GHz, 3.65 GHz and FCC unlicensed band of 5.8 GHz. Also, the antenna will work in the following FCC bands of 910 MHz, 1575 MHz, and 8.62 GHz. The designed antenna is a miniaturized PIFA. The PIFA consists in general of a ground plane, a top plate element, a feed wire attached between the ground plane and the top plate, and a shorting wire or strip that is connected between the ground plane and the top plate.

The antenna is fed at the base of the feed wire at the point where the wire connects to the ground plane. The PIFA is an attractive antenna for wireless systems where the space volume of the antenna for wireless systems where the space volume of the antenna is quite limited. It requires simple manufacturing, since the radiator must only be printed. The addition of a shorting strip allows a good impedance match to be achieved with a top plate that is typically less than \( \lambda/4 \) long. The resulting PIFA is
more compact than a conventional half-wavelength probe-fed patch antenna [12].

To obtain multiple bands, the author used slots in the patch. Also, parasitic elements are used to increase bandwidth of some bands and finally the author used bent and meandered shapes of patch to respect the miniaturization requirement.

The design and simulation was done by HFSS simulator (using the finite element model) and the results respect the requirements for mostly bands.

In the next section, the author describes the designed antenna. After, he will expose the results of simulation in different bands. In the last part, the results will be discussed and compared before making conclusions.

2. The Designed Antenna

2.1. Description of the Antenna

As shown in Figures 1-3, the designed antenna has a rectangular radiating patch with two parts, one is planar (horizontal) and the other is bent vertically. The first part has a length \( L_p = 29.9 \) mm and a width \( W_p = 50 \) mm. The bent part has a deep of \( 10 \) mm and the same width \( W_p \). The patch is placed at a height \( h \) equal to \( 11 \) mm from the ground plan. The ground plan has a length \( L_g \) equal to \( 90 \) mm and a width \( W_g \) equal to \( 70 \) mm. The patch is matched to the ground plan via a rectangular shorting plate which the width \( W_s \) is equal to \( 3 \) mm the length \( h \).

The feeding point is situated at a distance \( p \) equal to \( 3 \) mm from the rear edge of the patch. The patch is fed by a \( 50 \) \( \Omega \) wire, a semi-rigid coax with centre conductor that extends beyond the end of the outer conductor is used to form the PIFA feed wire. The outer conductor of the coax is soldered to the edge of a small hole drilled in the ground plane at the feed point. The volume between the radiating plate and the ground plan is filled by air except a thin region \( 0.8 \) mm under the radiating patch who is composed of FR4 epoxy (\( \varepsilon_r = 4.4 \)).

Seven slots are etched on the patch. Five slots \( S_3 \) to \( S_7 \) (towards the feeding point) with V shape and which dimensions are shown by Figure 4 and given by Table 1. The dimensions and position of the slot \( S_8 \) witch thickness is equal to \( 1 \) mm is given by Figure 5 and Table 2. The slot \( S_2 \) witch thickness is equal to \( 1 \) mm is etched along the patch perimeter (except the rear side) at a distance \( 0.5 \) mm from the patch sides.

2.2. Description of Required Bands

The required bands are grouped and presented in Table 3 with frequency bands, theoretical resonant frequency, required bandwidth and the use for what each band was allocated by FCC.
3. The Reflection Coefficient \( S_{11} \)

As shown in Figure 6, the designed antenna presents (along the spectrum band from 0 to 10 GHz) 8 peaks around the bands B\(_1\). The Figures 7-14 present the \( S_{11} \) parameter variation for every band for more precision.

The figures curves show interesting \( S_{11} \) values around different required bands. The found resonant frequency of each band, the \(-10\) dB bandwidth and also the \( S_{11} \) max for the whole band are grouped in Table 4.

4. Antenna Parameters

The Table 5 summarizes the mean antenna parameters for different bands. The chosen parameters peak gain and radiation efficiency.

5. Antenna Radiation Pattern

The Figures 15-22 present the 2D radiation pattern (for the maximum fields) around different bands.

As the pattern shape is concerned. The antenna has no privileged antenna directivity in the bands B\(_1\), B\(_2\), B\(_3\) and B\(_6\). The antenna is more directive in other bands. The field maximum intensity becomes greater when the frequency increases. The intensity varies from 4 for the 710 MHz band to 28 V/m in the band of 8.62 GHz.

6. Simulation Results and Discussion

The peak of each band B\(_i\) is created by the slot S\(_i\). The band B\(_1\) is due to the whole patch perimeter. Except for the band B\(_4\), the designed antenna presents very interesting parameters and performance. For most bands (B\(_2\), B\(_3\), B\(_5\) and B\(_8\)) the \( S_{11} \) parameter values respect the requirement of \(-10\) dB for almost the whole frequency band. In the band B1, the \( S_{11} \) is under \(-7\) dB. The antenna has a gain from 0.26 to 12.61 and a radiation efficiency from 67% to 100%. The radiation pattern is omnidirectional for bands B\(_1\) to B\(_3\) and more directive.
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Figure 6. $S_{11}$ (frequency) in $[0 - 10 \text{ GHz}]$.

Figure 7. $S_{11}$ (frequency) in $B_1$ band.

Figure 8. $S_{11}$ (frequency) in $B_2$ band.

Figure 9. $S_{11}$ (frequency) in $B_3$ band.

ment is necessary (without influencing the other bands). To improve the bandwidth, a parasitic element with a height of 3 mm and a bent part of 1 mm as shown by Figure 23 was introduced close by 0.5 mm to extreme left of the antenna (where there is not the short plate). The Figure 24 shows the $S_{11}$ variation in the PCS band, we can notify that the maximum value is $-3 \text{ dB}$ (that value was $-2 \text{ dB}$ without parasitic element) and a $-10 \text{ dB}$ bandwidth equal to 45 MHz (instead of 32 MHz) that means 32% of the whole band (instead of 23%). A bandwidth improvement was then carried out.

7. Conclusion

In comparison with recent works [2-11] consisting on designing PIFA antennas for the 4G mobile networks (LTE and WiMax) and especially for the antennas that covers this number of bands (8) allowed by the same spectrum regulator (FCC here), the designed antenna presents a succeeded trade-off for the major requirements: large bandwidth, high gain, high radiation efficiency, regular radiation pattern and miniaturization criteria. The
Figure 10. $S_{11}$ (frequency) in B4 band.

Figure 11. $S_{11}$ (frequency) in B3 band.

Figure 12. $S_{11}$ (frequency) in B6 band.
Figure 13. $S_{11}$ (frequency) in $B_7$ band.

Figure 14. $S_{11}$ (frequency) in $B_8$ band.

Figure 15. 2D radiation pattern in $B_1$ band.

Figure 16. 2D radiation pattern in $B_2$ band.

Figure 17. 2D radiation pattern in $B_3$ band.
Figure 18. 2D radiation pattern in B4 band.

Figure 19. 2D radiation pattern in B5 band.

Figure 20. 2D radiation pattern in B6 band.

Figure 21. 2D radiation pattern in B7 band.

Figure 22. 2D radiation pattern in B8 band.

Figure 23. The parasitic element (in red).
Figure 24. The PCS bandwidth enhancement result.

development of antennas for the 4G and eventually the next generation (5G) will continue. The design of such antennas will depend also on the reached goal to use for 4G the same licensed frequency bands around the world.

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