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Research Article

Multiband Patch Antenna for Femtocell Application

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A microstrip patch antenna for multiple LTE (long term evaluation) frequency bands for femtocell application is proposed in this paper. Distributed antenna solution (DAS) has been introduced in cellular network to achieve homogenous indoor coverage. Femtocell is the latest extension to these solutions. It is a smart solution to both coverage and capacity scales. Femtocell operation in LTE band is occupied by higher frequency bands. For multiband femtocell application, miniature antenna design is quite essential. The antenna proposed here is composed of basic monopole structure with two parasitic elements at both sides of the active element. A rectangular slot is introduced at the ground plane of the proposed antenna. The antenna is designed using ElnoS HK light CCL substrate material of relative permittivity of 9.4, dielectric loss-tangent of 0.003 and thickness of 3 mm. The S_{11} response of the antenna is shown to have a bandwidth of 1.01 GHz starting from 1.79 GHz to 2.8 GHz. The characteristics of the antenna are analysed using Ansoft HFSS software.

1. Introduction

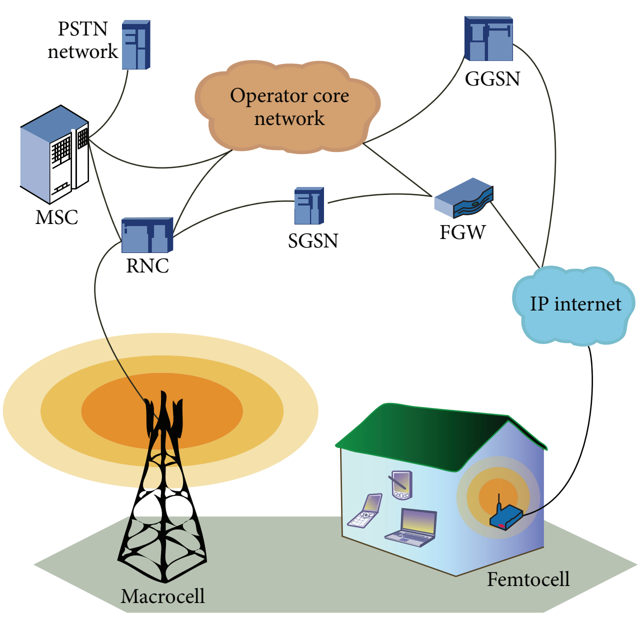
Distributed antenna solution (DAS) boosts the mobile coverage to improve reliability in deep indoor areas and enhance network capacity, easing the pressure on networks at busy hours. Femtocell, which is a new addition to this DAS, is the latest explored field in the development of networking system with huge prospect. It has the potential to outrun the capacity and coverage problems. Femtocell is an extension of existing outdoor micro- and macrocell for indoor coverage. It is similar to a wireless internet router, except it operates in licensed spectrum owned by the network operators. It is a mini-indoor base station for personal use. It provides quality coverage in absence of macrocell and fills up the coverage whole of the network. It is connected to the core network through a backhaul internet connection, like cable or digital subscriber line (DSL) [1, 2]. It communicates with the end user through the same signalling protocols that outdoor-cell uses. It diverts the traffic load from the macrocell through the wire connection. The received signal in femtocell is sent via wired connection to femtogateway. Voice services are provided by the same "mobile switching center" and data services by the same "GPRS support node" that are used in the existing outdoor network [3].

The connection diagram of the femtocell with the existing network is illustrated in Figure 1.

The new multimedia devices and applications are responsible for vast voice and data traffic. Moreover, huge portions of this demand are in indoor environment. For the existing outdoor cell, it is not possible to give high quality of service, especially in urban and suburban areas. Femtocell possess the huge potential to turn out network capacity and attain more economical development plan with less risk and liability as user shares a substantial amount of the initial cost. It also ensures proper utilization of valuable spectra. Cellular operators nowadays prefer cochannel deployment in femtocell level for better spectral efficiency [4, 5]. With high quality access to existing services, femtocells are targeted initially for better coverage in home environments. However, operator has drawn the expansion to the office and public places.

Table 1: LTE frequency bands and corresponding regions.

LTE bands	Uplink (MHz)	Downlink (MHz)	Duplex spacing (MHz)	BW (MHz)	Duplex mode	Deployment in the world
Band 1	1920–1980	2110–2170	190	60	FDD	China, Japan, EU, Asia, Australia
Band 2	1850–1910	1930–1990	80	60	FDD	North/South America
Band 7	2500–2570	2620–2690	120	70	FDD	North/South America, Australia, Asia, Africa
Band 33	1900–1920		N/A	20	TDD	—
Band 34	2010–2025		N/A	15	TDD	China
Band 35	1850–1910		N/A	60	TDD	—
Band 36	1930–1990		N/A	60	TDD	—
Band 37	1910–1930		N/A	20	TDD	—
Band 38	2570–2620		N/A	50	TDD	EU
Band 39	1880–1920		N/A	40	TDD	China
Band 40	2300–2400		N/A	100	TDD	China, Asia
Band 41	2496–2690		N/A	194	TDD	—



RNC: radio network controller
MSC: mobile switching center
PSTN: public switched telephone network
GGSN: gateway GPRS support node
SGSN: serving GPRS support node
FGW: femtocell gate-way

Figure 1: Femtocell connection to an operator's network.

Therefore, antenna design for femtocell application will be subjected to its radiation pattern and coverage tactics. Due to the small size of the device, antenna specification has to be precise and flexible [6, 7]. Enterprise user has been influenced with the better indoor coverage of femtocell and considering it as a part of their IT infrastructure. Operators also consider the rural places where internet backhaul connection is not available; the connection will be provided via satellite, HAP, or fixed terrestrial networks like GSM technology [8, 9]. Also in the busy outdoor environment, femtocell will be deployed in street furniture, building walls, or lamppost with wired or wireless backhaul connection [10]. Femtocell deployment will reach locations like trains, aeroplanes, and ships with proper-wired connection.

In this paper, a microstrip patch antenna is designed for multiband frequency coverage for femtocell application. The proposed antenna covers 12 frequency bands of LTE network with a quality coverage and moderate gain. The rest of the paper is arranged as follows: multiband antenna for femtocell is discussed in Section 2, antenna design is in Section 3, parametric studies are shown in Section 4, results and discussion are in Section 5, and conclusion is in Section 6.

2. Multiband Antenna for Femtocell

Femtocell provides wireless voice and data services to subscribers in both home and office environments. It uses standard wireless protocols over the air to communicate with standard mobile devices and a wide range of other mobile-enabled devices. The latest standard protocol LTE allows femtocells to provide high quality voice and data service to millions of mobile subscribers. In 3GPP standard, both FDD and TDD are envisaged [11]. As most of the wifi devices are operated in the frequency band 2.4 GHz with only three overlapping channels, interference avoidance schemes are quite restricted under those bands. However, femtocell operates in the operators' licensed spectrum giving enough options for quality of service even in dense heterogeneous network. It can also adjust the transmit power to cope up with the mobile environment, reducing the interference and increasing user battery life. In LTE standard, there are 43 frequency bands assigned for commercial use. Among them, 32 bands are for FDD and 11 bands are for TDD duplex mode. For indoor coverage application like femtocell, higher bands are preferred. In this paper, a multiband microstrip patch antenna is designed for LTE standard. The antenna covers 3 FDD frequency bands and 9 TDD frequency bands. Table 1 shows the range of the bands and its deployment region [12, 13].

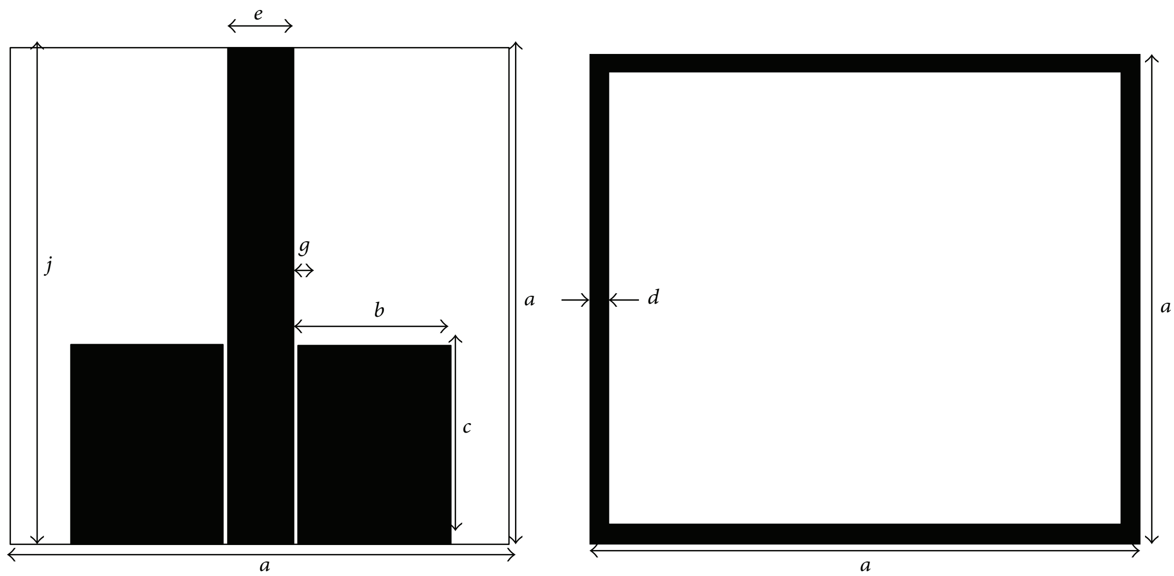


Figure 2: Proposed dimension of the antenna (a) patch and (b) ground plane.

Because of the miniature size of the femtocell, antenna design for femtocell is complicated. Most of the commercially available femtocells are equipped with omnidirectional single antenna. However, femtocell has a low coverage area and the relative position of femtocell is not always in the centre of the coverage zone. Multielement directional antenna can change the coverage region according to the users and femtocells position. For such a purpose, microstrip patch antenna is suitable for femtocell application. It is also small and easy to fabricate for commercial use [14–17]. Small size, lightweight, low profile, and low assembly cost allows using it in a wide range of wireless appliances [18, 19]. However, it has a narrow beamwidth, which is a challenge for multiband coverage [20–22]. The side lobe and the back lobe of the antenna might also cause effect on the other elements. To optimize these effects, electromagnetic absorption techniques and characteristics are analysed previously [23, 24]. However, microscript patch antenna mounting is subjected to harmful radiation in its surroundings [25]. The microstrip patch antenna proposed in this paper is to cover multiple frequency bands in LTE network.

3. Antenna Design

The proposed patch antenna is designed using ElnoS HK light CCL substrate material with a relative permittivity of $\varepsilon_r = 9.4$ and a dielectric loss tangent of 0.003. The thickness of the substrate $h = 3$ mm. The design was done in commercially available Ansoft HFSS version 15. Figure 2 shows the proposed antenna structure. The dimensions are tabulated in Table 2. Basic backbone of the antenna comes from a microstrip monopole antenna with a height of 50 mm. Two rectangles are introduced at both sides of the monopole to establish coupling. Both of them are passively coupled with the monopole antenna. A gap of 0.75 mm is introduced between the coupling elements. The even and odd mode coupling characteristics of the microstrip lines can be found using the equations given in [26]:

Table 2: Design parameters of the proposed antenna.

Dimension	Value (mm)
Antenna dimension, a	50
Passive rectangle width, b	15
Passive rectangle length, c	20
Gap between active and passive component, g	0.75
Ground plane microstrip line width, d	3
Substrate thickness, h	3
Active rectangle width, e	6
Active rectangle length, j	50

$$\left(Z_{oe}\right)_{n-1,n} = \frac{1}{Y_0}\left[1 + \frac{J_{n-1,n}}{Y_0} + \left(\frac{J_{n-1,n}}{Y_0}\right)^2\right],$$
$$\left(Z_{oo}\right)_{n-1,n} = \frac{1}{Y_0}\left[1 - \frac{J_{n-1,n}}{Y_0} + \left(\frac{J_{n-1,n}}{Y_0}\right)^2\right]. \quad (1)$$

Although the relative permittivity is given by $\varepsilon_r = 9.4$, the effective permittivity of the used substrate can be found using the equations given below:

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\left(\sqrt{(12h/X) + 1}\right)}. \quad (2)$$

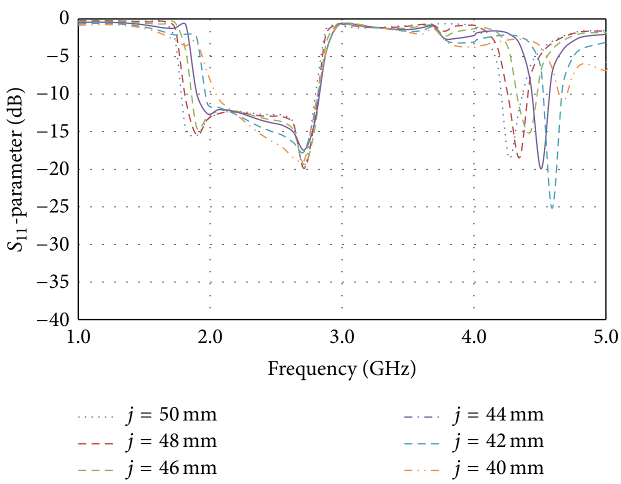


FIGURE 3: Return loss response for change in the value of "j."

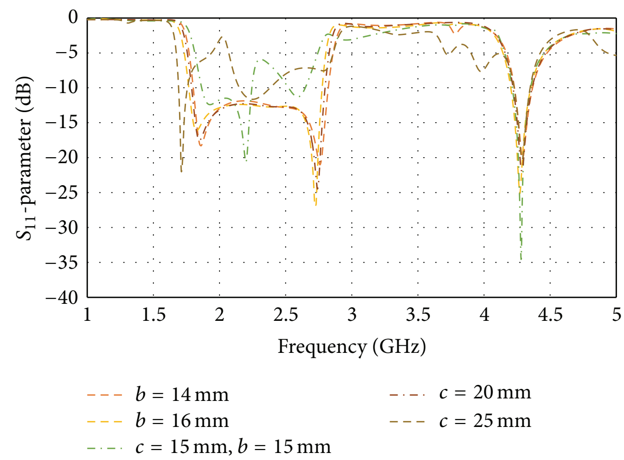


FIGURE 4: Return loss response for change in the value of "b" and "c."

The ground plane of the antenna is rectangle with a rectangular slot in the middle. From Babinet's principle, the radiation for the complimentary of the ground plane is comparable with the radiation pattern of the original structure. The principle is supported by the equations below [27]:

$$
\begin{aligned}
E_{\theta s} &= H_{\theta c} \qquad E_{\varphi s} = H_{\varphi c}, \\
H_{\theta c} &= -\frac{E_{\theta s}}{\eta_0^2} \qquad H_{\varphi c} = -\frac{E_{\varphi s}}{\eta_0^2}.
\end{aligned}
\tag{3}
$$

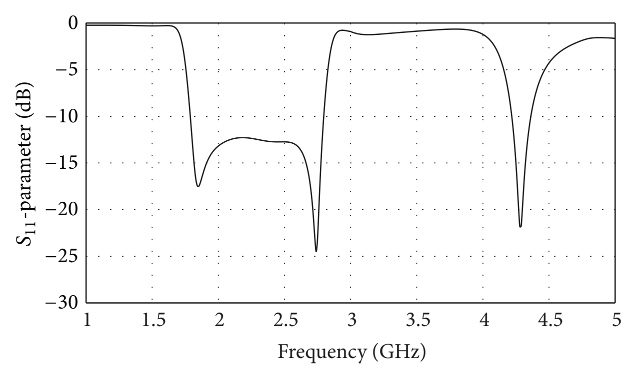


FIGURE 5: Return loss (S_{11}) response of the proposed antenna.

4. Parametric Studies

In this section, we have shown some parametric studies by changing the finite values of the antenna dimension. Considering the feasibility of the antenna, the parametric studies are chosen to be related to each other. The main purpose of the parametric studies was to check the stability of the reflection coefficient response with the change in the antenna parameters. Figure 3 shows the reflection coefficients for changing the values of "j" (referring to Table 2). As it can be seen from the graph, the change in the value of "j" parameter changes the lower portion of the LTE band. With the decrement of "j" value, the lower band starts to degrade almost missing the frequencies lower than 2 GHz, whereas the upper portion of the achieved LTE band remains constant. Figure 4 shows the parametric studies by changing the value of "b" and "c." For $c = 25$ mm almost the entire LTE band is lost which is crucial for the design. For $c = 15$, a substantial amount of the LTE band is achieved but most of the bands are lost considering the margin of the reflection coefficient is −10 dB. For $c = 20$ mm, we get the desired wideband for the LTE application. Again for $b = 14$ mm, the S_{11} at the pass-band lifts up at a very small amount. The same result happens for $b = 16$ mm. We have chosen the optimized value to be $b = 15$ mm, where the S_{11} response is at its best.

5. Results and Discussion

The aperture type patch antenna dimensions are validated and evaluated using finite element method (FEM) built in the HFSS software. Figure 5 shows the reflection coefficient response of the proposed antenna. From the graph, we can see that at a −10 dB scale, the pass-band frequency of the antenna starts at 1.79 GHz and it lasts up to 2.8 GHz with 12 selective frequency bands for the LTE application. Therefore the proposed antenna can easily be used for femtocell coverage.

Figure 6 shows the radiation pattern of the antenna at frequencies 1.85 GHz, 2.27 GHz, and 2.69 GHz. From the graphs of the figure, we can see that the cross-polarization of the antenna at the selected frequencies is minimized, whereas the copolarization of the antenna shows a directional pattern. At 1.85 GHz, one of the nulls at almost 90° line is visible; however, the second null cannot be found. This can happen due to finite number of solution points which were chosen while validating the radiation pattern of the antenna. Same pattern can be seen at the radiation pattern for the frequency 2.27 GHz. However, for 2.69 GHz frequency, the radiation pattern of copolarization shows two nulls at 90°

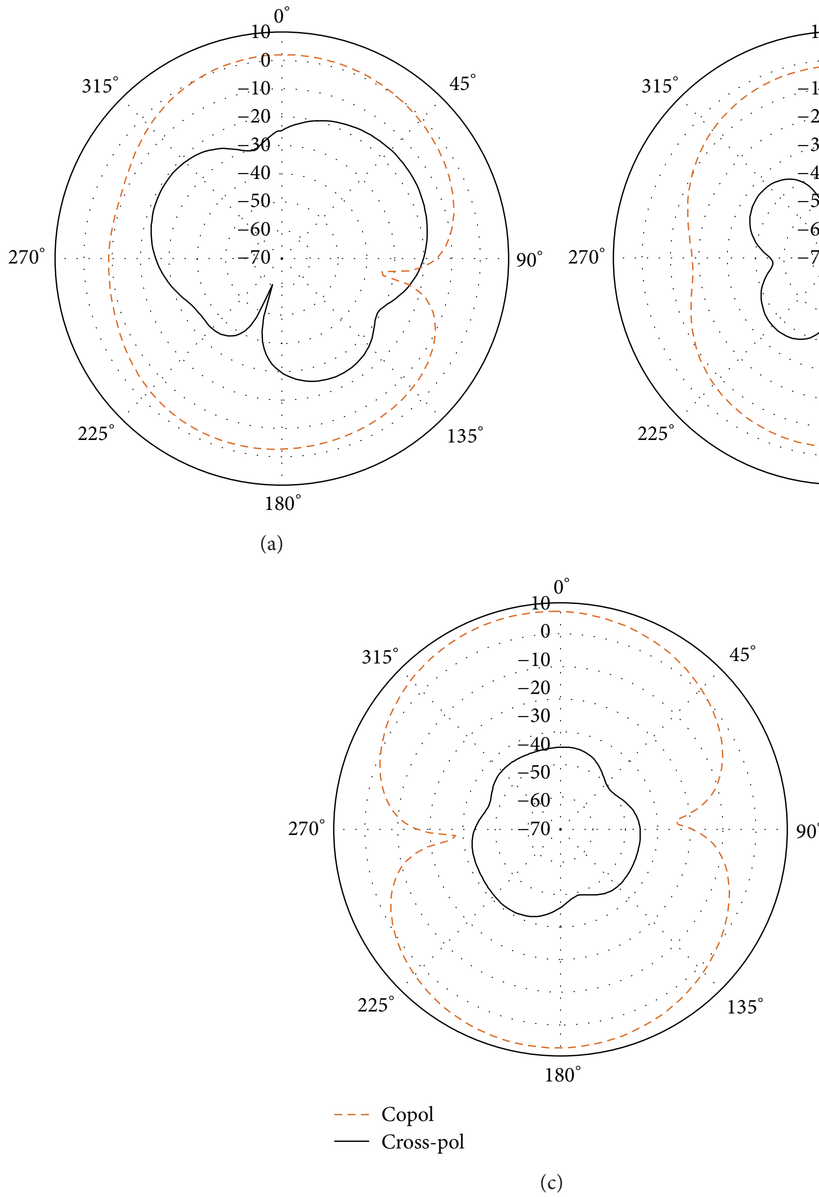


Figure 6: Radiation pattern of the antenna at E-plane for the frequencies (a) 1.85 GHz, (b) 2.27 GHz, and (c) 2.69 GHz.

and at 270°. All the radiation patterns shown are for the E-plane of the antenna. Figure 7 shows the peak-realized gain of the antenna. At the pass-band, the gain is above 2.5 dBi at an average, which is more than enough for LTE application.

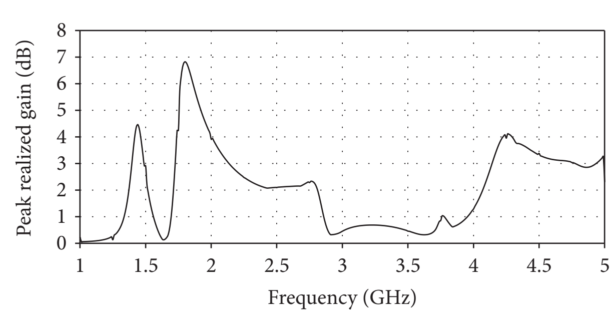


Figure 7: Peak realized gain of the proposed antenna.

6. Conclusion

The absence of quality coverage in indoor environment has created the substantial need of femtocells. Especially the increase of multimedia applications has created the higher data demand. In LTE/LTE-A and the future protocols that will follow, will surely emphasis on Gigabyte data speed that only can be possible with distributed cells like femtocells. For indoor purpose, higher bands are preferable for higher data speed target. The proposed antenna in this paper covers multi-LTE frequency bands that are used in both FDD and TDD in different regions of the world. The design of a microstrip patch antenna is also suitable for multielement antenna configuration for femtocell. Interfacing with the digital attenuator to each antenna element, the proposed antenna can be used to optimize the coverage area. Such operation reduces the cotier and cross-tier interference in dense femtocell network. However, the successful development femtocells require the coordination of digital and analogue hardware and modem, protocol, and software. These have to be brought together to deliver standards compliant devices in an attractive cost.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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