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BANDWIDTH ENHANCEMENT OF NEW PRINTED ANTENNA STRUCTURE FOR 5G MOBILE NETWORKS APPLICATIONS

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Abstract. *This paper presents a design and the development of a new broadband planar slot antenna for 5G wireless communication applications. The proposed antenna is suitable to operate at 8.5 GHz with a return loss less than −10 dB. To develop this structure we have conducted a design based on the microstrip line combined with a slot technique and a modified geometry antenna in order to enlarge the bandwidth and adapt the impedance thus minimizing distortion in order to avoid high crosstalk and radiation. The proposed antennas have been designed, optimized, miniaturized and simulated by using Momentum software integrated into ADS "Advanced Design System". To validate the ADS results before the antenna achievement, we have conducted another study by using CADFEKO. The prototype of the antenna was achieved, measured and tested.*
Keywords: Microstrip antennas, Rectangular patch, Millimeter wave, Slot antenna, ADS, CADFEKO

1. **Introduction.** The 5G aims to respond to the strong growth of traffic by offering a wide bandwidth and communications in real time as well as supporting a large number of connected devices. Due to the physical limitation of the small antennas, the multi-antenna transmission continues to play a very important role in the 5G. The effective path loss and the effective aperture of the antennas will not be affected by the change of frequency. In order to increase the aperture of the antennas as much as possible the 5G radio will use hundreds of antenna elements. The frequency band likely to be exploited is 3-300 GHz while less than 3 GHz is almost exhausted. The band from 3 to 30 GHz is called Super High Frequency band (SHF) and the band 30 to 300 GHz named the Extremely High Frequency (EHF) or millimeter wave band [1]. These two wavebands are considered by Pi and Khan [2] to be millimetric as long as they have the same characteristic of propagation with a wavelength between 1 and 100 mm. The microstrip antennas are characterized by their compatibility with other microwave integrated circuits radiofrequency in manufacture and weak effect of coupling in installation [3,4] as well as their broadband profile, small size, light weight, low cost and ease of manufacture [5,6]. In order to widen the bandwidth of this type of structure, the insertion of the microstrip line, the variation of the antenna geometry and a variety of slot shapes [7,8] present extremely important solutions [9,10]. Many research studies have come up with techniques to achieve wideband operation for printed antennas [11,12]. In this paper, a new low cost broadband microstrip antenna

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is designed by using microstrip and slot techniques to match the input impedance, large bandwidth, low radiation loss, less dissipation and the ease of being integrated with passive or active components.

Recently, it has been shown in [13] that using patch antenna structure with 8.5 GHz as a resonate frequency, it is clear that our structure has a miniaturized design with very important bandwidth. We have obtained this result with eliminating the parasitic patch and adding rectangular slot instead of hexagonal one. Moreover, the proposed antenna has the wider bandwidth from 7.6 GHz to 9.38 GHz instead of 8.5 GHz to 8.72 GHz for the referenced antenna.

In Section 2 we present the design of rectangular patch antenna based on theoretical equations to obtain the basic structure dimensions. In Section 3 different simulations using ADS and FEKO have been done where slot structure is introduced in the radiating element which leads to generating a required resonant frequency and therefore improving the bandwidth. In Section 4 prototype antennas were fabricated for experimental evaluation where good agreement between simulated and measured results was obtained. Finally, in Section 5 some concluding remarks are given.

2. **Antenna Design.**

The design of rectangular patch antenna is based on the procedure given by Luxey et al. [14]. This can be used for a first sizing. The optimization can then be carried out using an electromagnetic simulator.

We consider a ground plane that is perfect and infinite, and we have the following equations used to find out the width, height, length and power position of the patch antenna.

W is a patch width and it is given by Equation (1).

$$W = \frac{\delta}{2}\sqrt{\frac{2}{1+\varepsilon_r}} \tag{1}$$

with:

$\delta = \frac{c}{f_r}$

c: Speed of light

f_r: Resonant frequency

ε_r: Relative permittivity

L is the physical patch length calculated based on Equations (2)-(6).

$$h \leq \frac{0.3 * c}{2\pi * f_r * \sqrt{\varepsilon_r + 1}} \tag{2}$$

with:

h: Maximum height

$$\Delta L = h * 0.412 * \frac{(\varepsilon_{ref} + 0.3) * \left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{ref} - 0.258) * \left(\frac{W}{h} + 0.8\right)} \tag{3}$$

with:

ΔL: Extending the patch length

$$\varepsilon_{ref} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \left[1 + 12 \cdot \frac{h}{W}\right]^{-\frac{1}{2}} \tag{4}$$

$$L_{eff} = \frac{\delta}{2\sqrt{\varepsilon_{eff}}} = \frac{c}{2 \cdot f_r \cdot \sqrt{\varepsilon_{eff}}} \tag{5}$$

with:

L_{eff}: Effective patch length

ε_{ref}: Reference permittivity

ε_{eff}: Effective permittivity

$$L = L_{eff} - 2\Delta L \tag{6}$$

The length and width of the ground are given by Equation (7).

$$L_g = L + \frac{c}{20 \cdot f_r}, \quad W_g = W + \frac{c}{20 \cdot f_r} \tag{7}$$

with:

L_g: Ground length
W_g: Ground width
The position of the power is given by Equation (8)

$$X_F = \frac{L}{2\sqrt{\varepsilon_{ref}}}, \quad Y_F = \frac{W}{2} \tag{8}$$

The antenna structure designed is based on a microstrip line, with the use of slot techniques, taking the gain and directivity into consideration. The purpose of the slot was to control the radiation pattern in order to obtain an increased bandwidth.

The geometry of the proposed antenna is shown in Figure 1. It is simulated by using FR4 epoxy substrate with relative permittivity $\varepsilon_r = 4.4$, thickness of $h = 1.6$ mm, and total area of 4×26 mm^2. The microstrip antenna is excited with 50 Ω characteristic impedance.

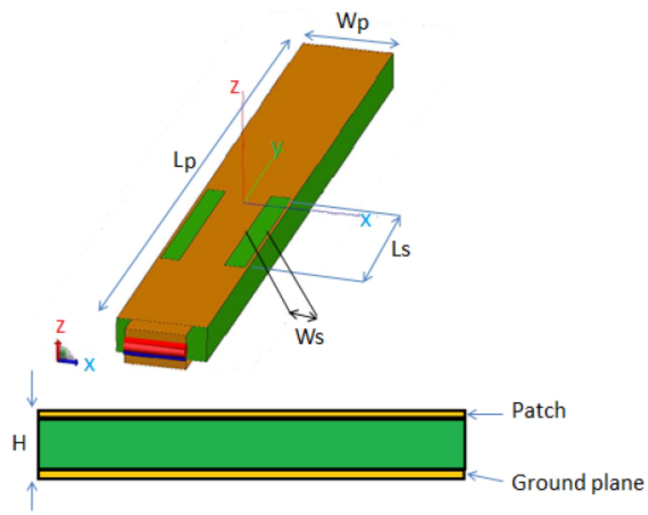


FIGURE 1. The geometry of the proposed antenna

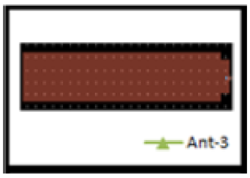
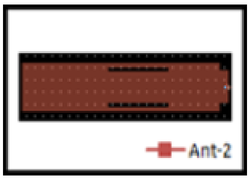
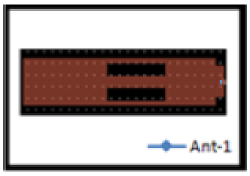
3. **Simulations and Comparison.** The dimensions of the antenna are optimized and miniaturized by using ADS "Advanced Design System" and FEKO. Based on the theoretical parameters and after many optimizations, the dimensions of the final structure are shown in Table 1.

TABLE 1. Antenna dimensions

Variables	Value (mm)
Lp	26
Wp	4
Ws	1
H	10
Ls	7.5

The return loss and bandwidth improvement for successive slots geometry in Table 2 by using the optimization and miniaturization techniques integrated into ADS are presented in Figure 2. The final circuit is operating in a large frequency band between 5.7 GHz and 10.7 GHz.

Table 2. Slots dimensions

Antenna	Slot value “Ws” (mm)
	0
	0.3
	1

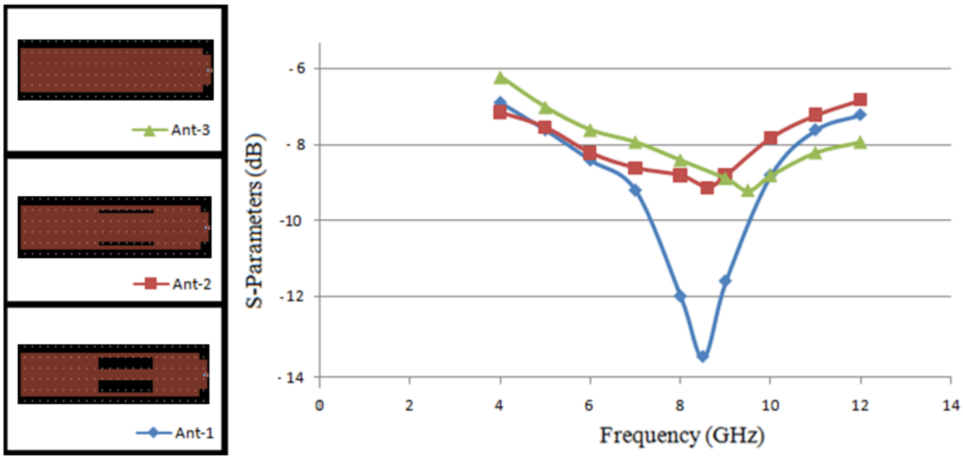


Figure 2. The return loss vs frequency ADS results

As shown in Figure 3 the antenna validated into ADS simulation has a bandwidth from 5.7 GHz to 10.7 GHz and $f_r = 8.5$ GHz. For the comparison of these results we kept the same antenna geometry and we have conducted another simulation by FEKO, and we found that the bandwidth is from 8.85 GHz to 8.98 GHz and $f_r = 8.9$ GHz.

The simulated radiation pattern of the antenna is illustrated in Figure 4.

According to the above representation of the radiation pattern, the angle of opening of this antenna is 126°, which is beneficial for a base station for maximum coverage during the mobility of the subscriber. In our case, we took the rear lobe as a reference which means that the rear/front ratio is 6.14 dB therefore good power transmission. From 3D view it is omnidirectional antenna which radiates radio wave power uniformly in all directions in one plane.

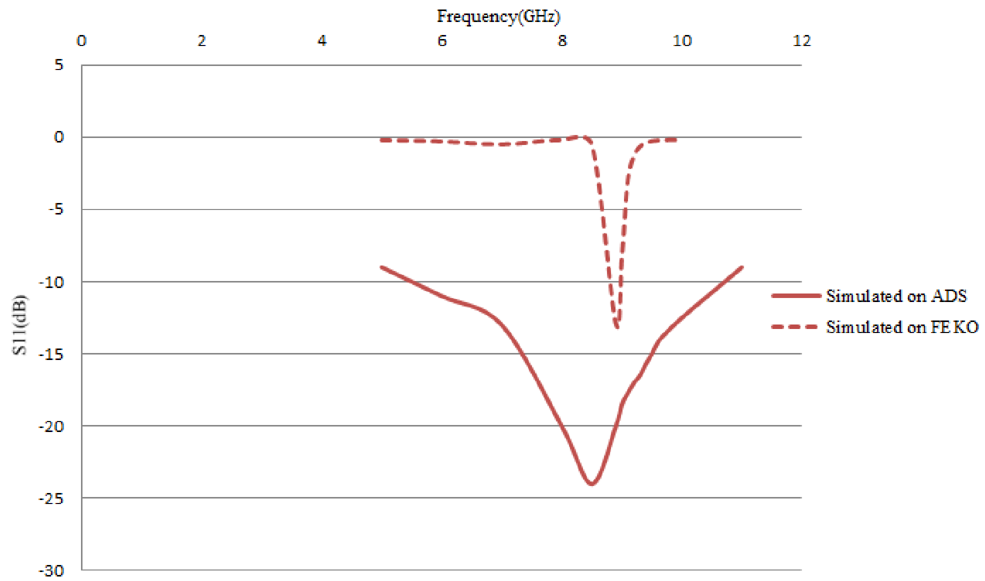
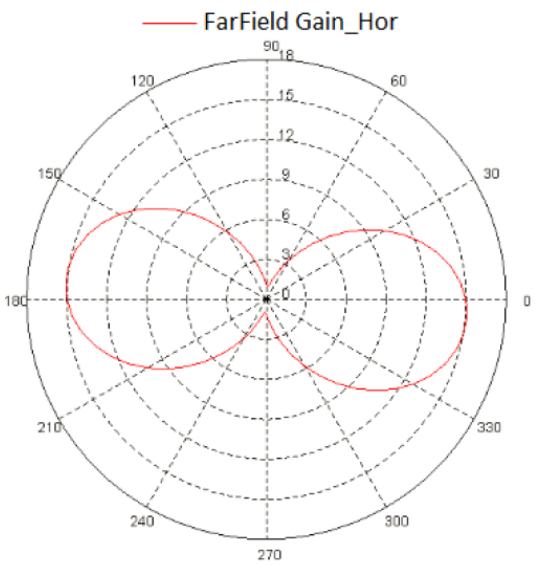
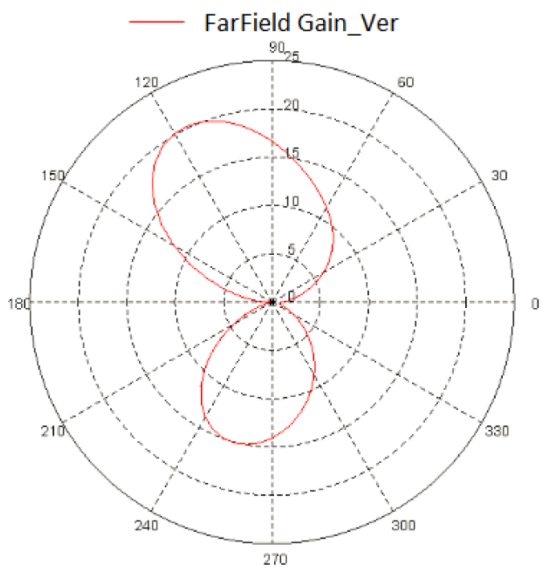


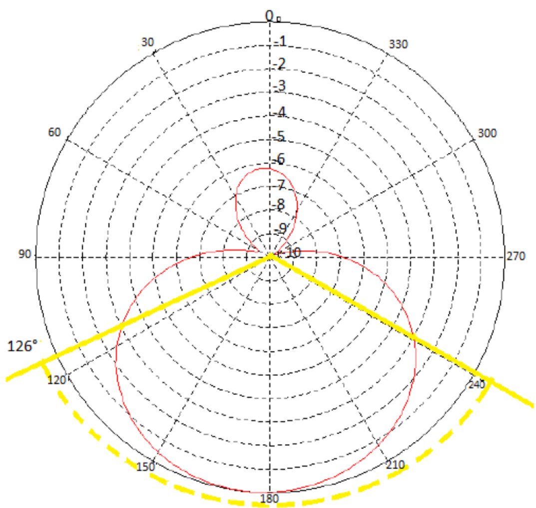
FIGURE 3. The return loss versus frequency



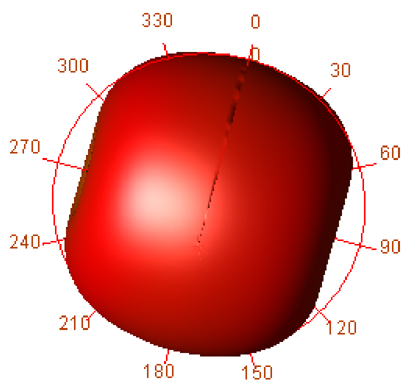
(a) Horizontal radiation pattern



(b) Vertical radiation pattern



(c) 2D radiation pattern



(d) 3D radiation pattern

FIGURE 4. The radiation pattern

Based on the simulations results presented above we conclude that for a same antenna geometry we have nearly the same results as resonate frequency using ADS and FEKO with acceptable and reasonable bandwidth 130 MHz.

4. **Achievement and Measurement.** After the comparison of simulation results on ADS and FEKO, we have achieved the antenna structure on a PCB (Printed Circuit Board). The fabricated antenna is shown in Figure 5.

FIGURE 5. Fabricated prototypes of the proposed antennas

The measured and simulated results for the reflection coefficient of the proposed antennas are shown in Figure 6. The reflection coefficient magnitude was measured using Agilent Technologies 8010A Analyzer.

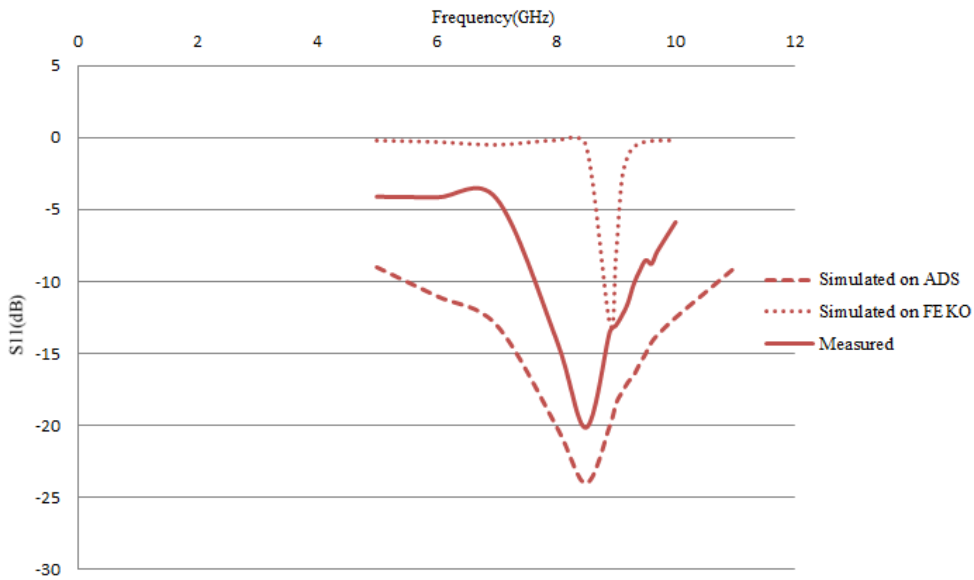


FIGURE 6. The return loss measured and simulated vs frequency

Due to manufacturing imperfections, the measurement results are not exactly similar to the simulated results. We note that the measured bandwidth of the fabricated antennas retained the UWB characteristics. We conclude that after achievement and simulation on ADS of the same antenna structure we have a same resonate frequency with acceptable and reasonable bandwidth for 5G antenna, but the lower and the higher frequencies of the measured S11 parameter are shifted back to higher frequencies compared to the simulated results on FEKO.

5. **Conclusions.** In this study, we have performed the conception and the simulation of a new low cost rectangular planar antenna based on the theoretical equations and by using two high electromagnetic simulators FEKO and ADS to obtain the suitable 5G antenna geometry operating in 8.5 GHz with a return loss less than −10 dB. In other hand after studying several researches, the elaborated design is based on different methods such as a microstrip line combined with a slot technique and a modified geometry antenna in order to enlarge the bandwidth and adapt the impedance. The measured and simulation results are in agreement which validate the antenna structure for 7.6 GHz-9.38 GHz operating in mobile network applications. The proposed design methodology could be used for future researches to develop the new structure operating in different 5G bands with enhanced bandwidth.

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