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Modeling a Square Slotted Antenna for 5G Applications using an Equivalent Circuit Approach

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The emergence of 5G technology is expected to significantly impact high-bandwidth wireless applications, making efficient antenna designs essential. This research paper presents an equivalent circuit for a square-slotted patch antenna design for 5G cellular applications. Indeed, the equivalent circuit for an antenna can be represented by a simple circuit model, such as a resonant LC circuit or a transmission line model. These models can be used to determine the resonance frequency, bandwidth, and radiation pattern of the antenna. Matching networks can also be designed using the equivalent circuit to match the antenna and receiver impedances. This analysis of the antenna can offer valuable insights into its behavior, serving as a foundation for a more extensive investigation. The antenna has been designed and simulated on an FR4 substrate featuring a relative permittivity ε_r of 4.3, and it is sized at $4.5 \times 5.2 \times 0.3$ mm^3. In the proposed design, a 50Ω microstrip line feeds a square-slotted radiating patch, and power dividers join the two elements. As part of 5G technology, it is crucial to achieve high bandwidth with reduced losses and improved gains. This study employs AWR and HFSS to simulate and design the square-slotted microstrip patch antenna, and in terms of gain and S_{11}, the results are compared. The proposed design has the potential to contribute to the development of high-performance 5G antenna systems.

Keywords: 5G applications, Equivalent Circuit, Gain, Bandwidth.

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1. INTRODUCTION

Wireless communication's growing relevance has fueled the study and development of microstrip patch antenna (MPA) topologies, ranging from miniaturized circuits to antenna arrays. Over the past few years, the field of wireless communication has seen several generations of technological advancements, from the first-generation (1G) analogue voice-only mobile system to the more recent from 1G to 5G [1]. As previously described, each of these generations use techniques such as cellular frequency reuse, packet switching, modulation, and so on. [2-3].

The microstrip patch antenna is widely recognized type of microstrip antenna, favored for its low cost, small size, lightweight, and ease of fabrication. However, the traditional microstrip patch antenna has very limited bandwidth and low gain, leading to a growing demand for small-sized antennas for various mobile and other applications. As a result, numerous bandwidth enhancement or broadband techniques for microstrip antennas have been recently reported [4, 5]. Researchers have also contributed to the design of 5G antennas, as described in previous works [6-8]. This study focuses on designing a microstrip antenna array that single or multiple feed lines can support. The proposed antenna can be implemented using low-cost FR4 substrate while maintaining acceptable and good performance in terms of gain and efficiency.

This paper's significant aim is to provide a similar circuit design for a 5G antenna. To achieve this goal, we designed the antenna using HFSS and simulated the proposed technique using AWR. In low-frequency circuits, resonant circuits are commonly used to provide a selective frequency, and the resonant frequency depends on the values of the impedances in the circuit. Similarly, this work uses resonant circuits based on microstrip lines to generate a high frequency that meets the requirements for 5G applications. These circuits consist of passive components and are equivalent to an oscillating circuit. The proposed antenna is designed and simulated using AWR and HFSS, and the results obtained from both software tools are compared in terms of S11.

2. ANNTENNA CONFIGURATION

2.1 The Proposed Model

The rectangular monopole antenna is considered the most exact geometrical shape for a printed radiating element, which can be modelled as an artificial magnetic conductor (AMC) [9]. In order to simplify the lens model curve without compromising antenna performance and lowering the profile, a proposed antenna based on microstrip technology is presented in [10]. The antenna is built on a small FR4 substrate with a low relative permittivity (ε_r) of 4.3, a thickness of 0.3 mm, having dimensions $4.6 \times 5.2 \times 0.3$ mm^3 and a tangent loss of 0.0025. A 50 Ohm proximity-feed microstrip line is utilized for powering the patch [4]. The equation that determines the patch's length and width [11] is utilized as the design method.

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$$L = W = \frac{c}{2f_r\sqrt{\left(\frac{\varepsilon_r+1}{2}\right)}}, \quad (1)$$

Equation (1) can be used to calculate the length (L) and width (W) of the slotted patch antenna, where c represents the speed of light and denotes the resonant frequency. Fig. 1 illustrates the suggested antenna geometry for 5G wireless mobile communications. The top view modifications are presented in Fig. 2, while Table 1 delineates the specifications of the dimensions pertaining to the slotted patch antenna.

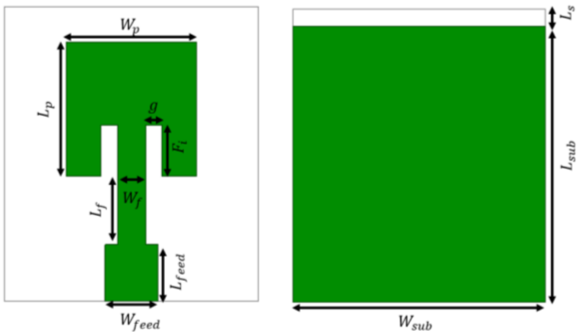
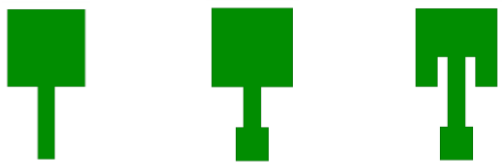


Fig. 1 – The 5G antenna geometry



(a) (b) (c)

Fig. 2 – Variations of Top view for antenna geometry: (a) First design (step 1), (b) Second design (step 2), (c) Final design (step 3).

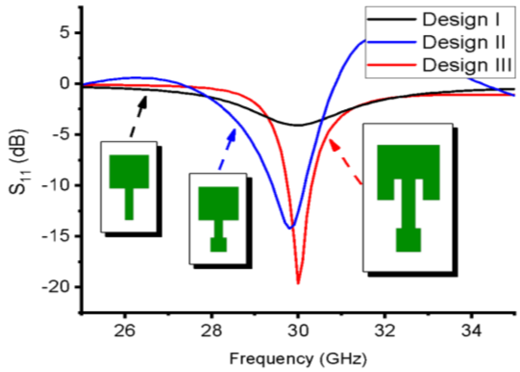
Table 1 – Parameters of the antenna (in mm)

Parameters	Values
W_p	2.362
L_p	2.362
W_f	0.51
L_f	1.21
W_{sub}	4.6
L_{sub}	5.2
L_s	0.3
L_{feed}	1
W_{feed}	0.955
F_i	0.8
g	0.3

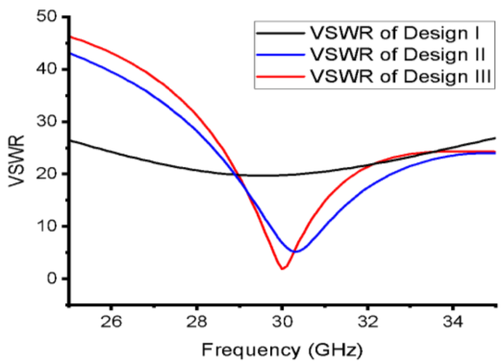
To optimize the antenna's performance, a 50 Ω microstrip feed line is used with a width of W_{feed} = 0.955 mm and a length of L_{feed} = 1 mm. The dimensions $F_i \times$ g = 0.8 × 0.3 mm², with F_i and g being 0.8 mm and 0.3 mm respectively, were chosen to achieve the most favorable resonant frequency and return loss level.

2.2 Equivalent Circuit

The suggested antenna is made up of two identically sized single components. An analogous lumped-element circuit model may be used to characterize the antenna impedances. Each antenna component, such as resistors, inductors, and capacitances, may be represented as a group of lumped elements. As a result, equivalent circuit models with similar schematics, components, and values can be created. Fig. 4 depicts the proposed first 5G antenna corresponding lumped-element circuit model.



(a)



(b)

Fig. 3 – S_{11} for the design I, II and final design antenna (a); VSWR for the design I, II and final design antenna (b)

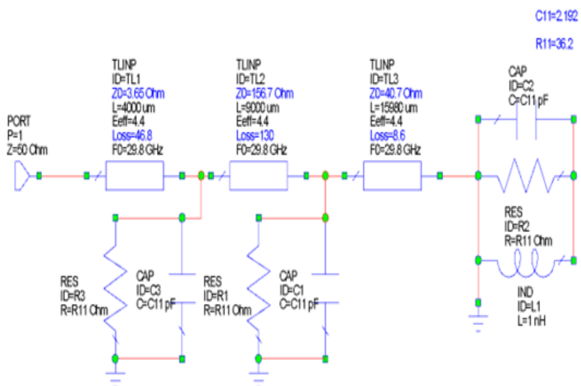


Fig. 4 – Equivalent circuit for the proposed antenna

The initial stage in constructing the first antenna's schematic is to represent only one single element with lumped components. The feed line of a single-element antenna is divided into two sections of varying widths. Each part can be represented by a parallel arrangement of resistor R_1 describe the radiation resistance and a capacitor C_1 show the coupling effect of both parts, as illustrated in Fig. 1. There is a slot in the microstrip patch close up to the microstrip feed line, which is shown by TL_2 in the schematic and added the patch's coupling effect with the ground plane. R_2, L_1, C_2 and TL_3 represent the resistance and inductance of the patch's capacitor and transmission line. And Table 2 displays the optimized value for the first antenna.

Table 2 – The values of the antenna that have been optimized are shown below.

Parameters	**Values**
$TL_1(Z_0)$	3.65 Ω
R_1	36.2 Ω
R_2	36.2 Ω
R_3	36.2 Ω
$TL_3(Z_0)$	40.7 Ω
$TL_2(Z_0)$	156.7 Ω
C_1	2.192 pF
C_2	2.192 pF
C_3	2.192 pF
L_1	1 nH

3. RESULTS AND DISCUSSION

Simulation is an essential part of the design and optimization of 5G antennas. Infact, simulating a 5G antenna involves defining the antenna geometry, choosing a simulation software, creating a simulation model, defining simulation parameters, running the simulation, optimizing the design, and verifying the simulation. This section examines the impact on performance of a monopole antenna through an assessment of the design procedures. The optimal values for these instances' characteristics are critical for impedance matching and monopole antenna behavior. The following figures illustrate the VSWR, return loss and 3D polar plot, E-plane and H-plane, obtained using HFSS and using lumped port configuration.

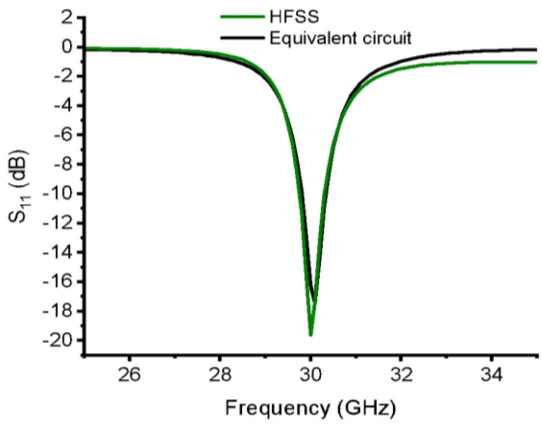


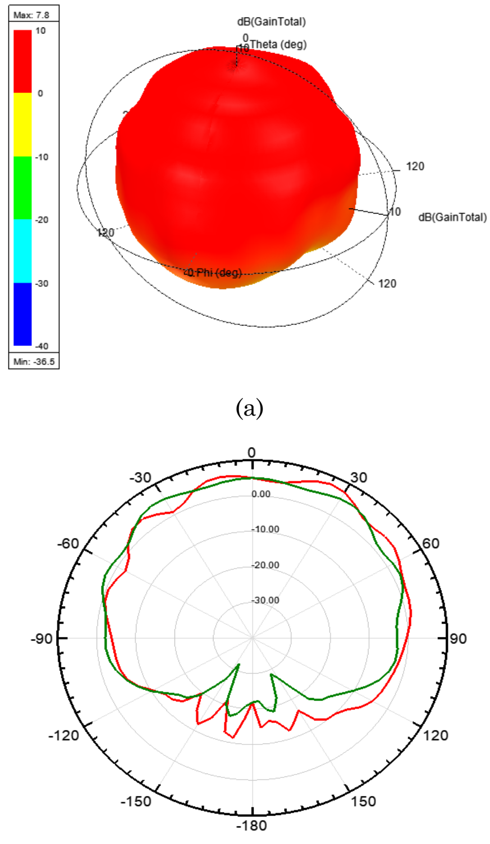
Fig. 5 – The simulated S_{11} response of the suggested antenna, along with its schematic, is presented below.

The simulated S_{11} of the model is shown in Figure 5. A comparison between the S_{11} values obtained from AWR and HFSS indicate that the S_{11} values below – 10 dB are achieved. This result suggests that the AWR findings correspond well with those obtained from the full-wave analysis. It is important to note that due to the symmetry of the antenna and model, the S_{11} values obtained from HFSS and AWR are identical within the operating frequency range.

The S_{11} values are acquired as the antenna's return loss, with a value of – 10 dB regarded as excellent for mobile communication. Fig. 3 (a) illustrates the simulated reflection coefficient S_{11} for the top view variations in the first microstrip patch antenna.

To achieve an optimal match for different via designs, slight adjustments are made to the slot positions. As depicted in Fig. 5 (a), the simulated 10 dB return loss bandwidth ranges from (29.52-30.60 GHz) to (29.75-30.30 GHz) when transitioning from case I to the final case. The VSWR plot of the first design patch antenna is illustrated in Fig. 3. For most wireless applications, the acceptable level of VSWR should not exceed 2.5 dB, and ideally, it should be 1 dB. Fig. 3 (b) demonstrates that the VSWR value attained at the resonant frequency of 29.8 GHz for the first design patch antenna is 0.98 dB.

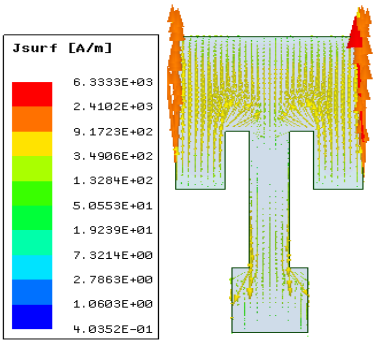
Fig. 6 (a) displays the patch antenna's radiation pattern and gain, which are approximately 7.8 dBi, are quite similar. Fig. 6 (b) illustrates the simulated radiation patterns at the operational frequency for the proposed antenna. At a 30 ° angle in the E plane, the highest radiation is detected, whereas the primary beam in the H plane is oriented towards – 30 °.Overall, the proposed antenna performs well in both simulations.



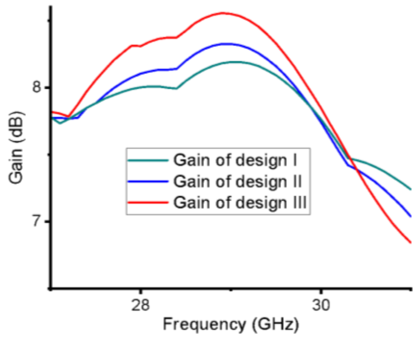
(a)

(b)

Fig. 6 – Gain 3D for the first design antenna (a), E-plane (red curve) & H-plane (green curve) of the antenna input impedance (b)



(a)



(b)

Fig. 7 – Current distribution at 29.5GHz (a), Gain for the step-1, step-2 and final design antenna (b)

Fig. 7 (a) illustrates the surface current distribution plots of the proposed antenna at 29.5 GHz. The current intensity is found to be higher in the side region than in other parts of the patch.

The simulated gain of the variations bottom view for the monopole antenna is shown in Fig. 7 (b). The gain for the first desgin I antenna is around 7.5 dB, the second desgin II is around 7.6 dB, and the desgin III is around 7.8 dB. It has stable gain for the ka-band of 5G technology.

4. CONCLUSION

In summary, the suggested antenna configuration consists of a slotted microstrip patch connected to a ground plane and fed by a 50 Ohm microstrip feed line utilizing lumped port excitation, has been effectively validated through simulation using two software platforms, namely HFSS and AWR. The results demonstrate a high level of simulated bandwidth, rendering the antenna design suitable for deployment in the next generation of wireless communication systems. These findings are significant as they contribute to the ongoing development and advancement of wireless communication technology, especially in the emerging 5G standard. Further research and experimentation may be required to fully explore the potential of this antenna design and its applications in future wireless communication systems.

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Моделювання квадратної щілинної антени для додатків 5G за допомогою підходу еквівалентної схеми

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У статті представлено еквівалентну схему для конструкції патч-антени з квадратними щілинами для мобільних додатків 5G. Еквівалентна схема для антени може бути виконана у вигляді резонансного LC-ланцюга або моделі лінії передачі. Ці моделі можна використовувати для визначення резонансної частоти, смуги пропускання та діаграми спрямованості антени. Мережі узгодження також можуть бути розроблені за допомогою еквівалентної схеми для узгодження імпедансів антени та приймача. Цей аналіз антени може запропонувати цінну інформацію про її поведінку, служачи основою для більш ретельного дослідження. Антена була розроблена та змодельована на підкладці FR4, що має відносну діелектричну проникність ε_r 4,3, і має розмір 4,5 × 5,2 × 0,3 мм^3. У запропонованій конструкції мікросмужкова лінія 50Ω живить випромінювальну ділянку з квадратними щілинами, а дільники потужності з'єднують два елементи. У рамках технології 5G вкрай важливо досягти високої пропускної здатності зі зменшеними втратами та покращеними приростами. У цьому дослідженні використовуються AWR і HFSS для моделювання та проектування мікросмужкової антени з квадратними щілинами, а результати порівнюються з точки зору посилення та S11. Запропонована конструкція може допомогти в розробці високоефективних антенних систем 5G.

Ключові слова: Застосунки 5G, Еквівалентна схема, Підсилення, Пропускна здатність.