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Dual-Band Silo-Slotted Antenna with Equivalent Circuit Model for 5G mm-wave Applications

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This article explores the development and fine-tuning of *a mm*-wave MPA (microstrip patch antenna) featuring silo slots. The starting design parameters are computed using established formulas relevant to patch antenna construction. The antenna is simulated on a substrate with specific material properties, utilizing Rogers 5058 substrate material characterized by a (ε_r) of 2.2 and a tangent-loss of 0.0009. A comparative analysis is conducted to showcase the simulated performance of the presented silo-antenna using HFSS with its equivalent circuit model implemented in AWR. This involves meticulous adjustment of components to achieve the desired characteristics. The article traces the evolutionary phases of the antenna's design, highlighting geometric modifications and alterations to the ground plane. Further, it elaborates on the resonant frequencies of the antenna and offers a comparative assessment of the S_{11} parameter between AWR and HFSS simulations, revealing strong agreement. The proposed antenna maintains an attractive size of 14 mm × 12 mm and it operates at dual operating bands resonating at 28.1 GHz and 37.9 GHz. Variations in gain for different design iterations are scrutinized and finally the peak gains of 5.2 dBi and 6.5 dBi are attained for the suggested antenna at the operating frequencies of 28 and 37.9 GHz, respectively along with desired radiation patterns in E and H planes at distinct frequencies. The suggested antenna is suitable for 5G applications supporting 28/38 GHz bands in mm-wave spectrum.

Keywords: Antenna, Dual-band, Equivalent Circuit, Gain, mm-wave, 5G.

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1. INTRODUCTION

Presently, an escalating demand exists for novel microwave and millimeter-wave systems to tackle the burgeoning communication challenges related to scalability, bandwidth, and amplification. Consequently, antennas play a pivotal role in catering to the requirements of satellite communication, spanning various frequency bands for diverse satellite communication applications [1]. 5G communication standards are swiftly becoming pervasive and gaining ever more significance in our everyday routines. This importance is set to further escalate as an increasing number of devices and applications necessitate the high-quality signal transmission capabilities offered by this network. Additionally, human endeavors have spurred the proliferation of the IoE and IoT across domains like education and entertainment [2]. Researchers are continually striving to enhance antenna gain. In the past few years, development of technology has become extremely popular in both developed and developing countries [3]. In the last few decades, we've witnessed the communication standards, including 1G, 2G, 3G, 4G, and the latest, 5G. The 5G of cellular technology, known as 5G, delivers data transfer speeds in the gigabit per second (Gbit/s) range, effectively erasing the limitations of earlier technologies. Additionally, 5G also enables rapidly growing low-power IoT applications, serving as primary frequency ranges for 5G deployment, are anticipated to offer a favorable balance between coverage and capacity, particularly within the N257 and N258 bands. The initial operating band of the 5G network is partitioned on sub bands FR1 and FR2. The initial one comprises of several allocated frequencies from 450 MHz to 6 GHz. The second encompasses assigned frequencies from 24.25 to 52.6 GHz [4-7]. Particular attention is paid to applications around 28 GHz, as wider bandwidth is available in this frequency range [8]. Various techniques and methods have been described in the literature to overcome these limitations while improving antenna performance. Radiating element slots [9, 10]. Additionally, DGS technology is used to increase gain, especially in high-frequency applications, suppress cross-polarization; expand frequency bandwidth [11].

This paper introduces the design, fine-tuning, and performance evaluation of a dual-band silo slot microstrip patch antenna specifically crafted for use in 5G wireless communication applications. This research aims to leverage established antenna design principles and simulation tools to provide an antenna solution that not only meets the stringent requirements of 5G networks, but also offers the benefits of dual-band operation. Additionally, the equivalent circuit model is used to fine-tune antenna characteristics to best match simulated and actual performance.

2. MATERIALS AND METHODS

The silo-slotted MPA (microstrip patch antenna) is presented in this section. The initial patch size and width are computed using the well-known and exten-

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sively used fundamental formulae for patch antenna construction, as described in [12]. In [13] for example, small semi-circular protrusions are used to change the geometry of an antenna's microstrip patch in order to achieve the highest feasible gain. Figure 1 depicts the final geometry with underlined dimensions from Table 1. The antenna structure is built using circular and rectangular slots. The silo-antenna proposed is constructed on Roger 5058 substrate with a 0.38 mm thickness, with (ε_r) of 2.2 and 0.0009 tangent loss.

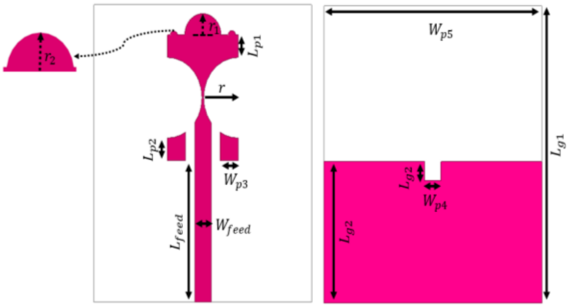


Fig. 1 – Configuration of proposed 5G Silo-antenna

In regards to the silo-slotted microstrip patch antenna, the top view configuration with three silos – two with radius equal to r_2 and the last one equal to r_2 – are added in the patch antenna upstairs along with the circular slots on the right and left in the center and a rectangular slot close feed line as shown in Fig 1(a). Additionally, Fig 1(b) shows the bottom view of a silo microstrip-based antenna with a rectangular slit above the ground plane.

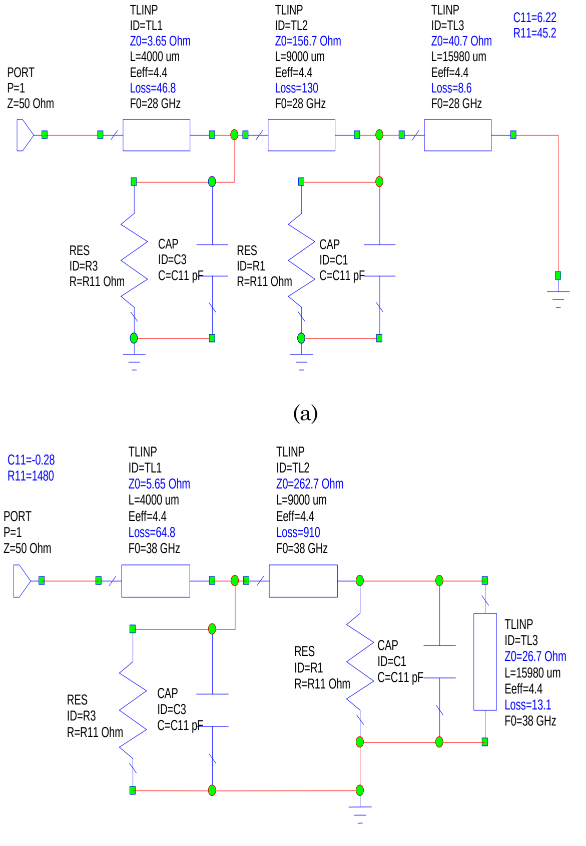
Table 1 – Antenna dimensions

Parameters	Dimensions (mm)
L_{p1}	1.06
L_{p2}	1.06
r_1	1
r_2	0.2
L_{g1}	14
W_{p5}	12
L_{g3}	8.35
r	1.9
W_{p3}	0.99
W_{feed}	0.9
L_{feed}	8.35
W_{p4}	0.9
L_{g2}	0.9

The suggested antenna has an overall dimension of 14×12 mm^2 and a 50 Ohm microstrip supplied line of 6.66×0.9 mm^2 that is well-matched for impedance. To match the needed initial responses, the starting values are optimized using the ANSYS HFSS program.

3. EQUIVALENT CITCUIT MODEL FOR THE ANTENNA

In this section, we conduct a comparative analysis between the simulated performance of the proposed antenna using HFSS and the simulation of its equivalent circuit model using AWR. The components have been fine-tuned to achieve the desired S11 characteristics, as illustrated in Fig. 2.



(a)

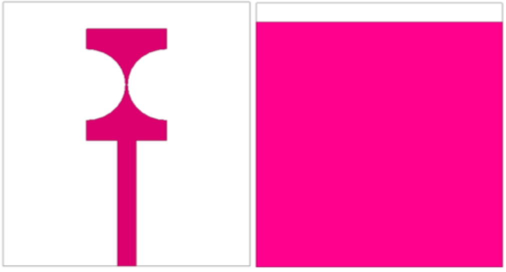
(b)

Fig. 2 – The equivalent circuit for proposed antenna at 28GHz (a); the equivalent circuit for proposed antenna at 38GHz (b)

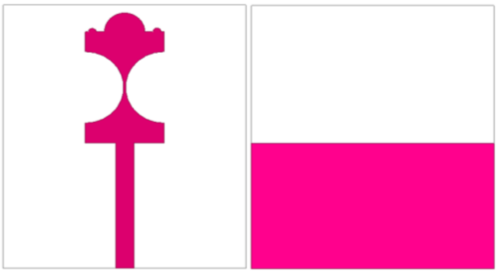
4. RESULTS AND DISCUSSION

Fig. 3 depicts the suggested antenna's evolutionary stages. Fig. 4 displays the reflection coefficients obtained at different design cases. Fig. 5 compares the S11 parameters attained by HFSS and equivalent circuit model by AWR design tools. Fig. 6 presents the variations in gain for the prescribed antenna. As shown in Fig. 3(a), the initial design included a straight forward microstrip patch as well as a feed line. In the initial design step (First Design), the antenna resonates at 29.1 GHz and 37.9 GHz, as illustrated in Fig. 3 (initial design). In second design stage, antenna resonates at 29.1 GHz and 37.7 GHz due to inclusion of semi-circular slots at both sides of the patch. The ground plane is slotted with a rectangular on top, as demonstrated in Fig. 3 (second design). In third design, a rectangular slot having larger area than previous stage is perturbed into the ground plane and a stub is added to the upper edge of the silos. There is an improvement in impedance matching at the higher band due to suggested changes. changes to the right while the lower band is shifted to 28.7 GHz. In Final design of the process, the antenna undergoes additional modifications where small stubs are added to both the right and left sides of the rectangular slot as shown in Fig. 3.

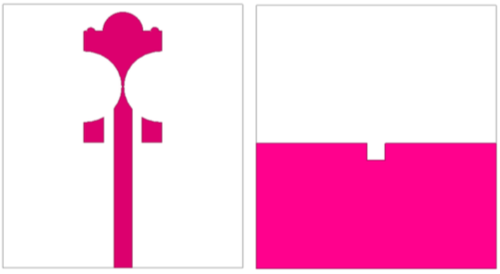
(a) First design



(b) Second design



(c) Third design



(d) Final design

Fig. 3 – Variations of Top & Bottom views in the designed the third 5G antenna; (a) – first design, (b) – second design, (c) – third design and (d) – Final design

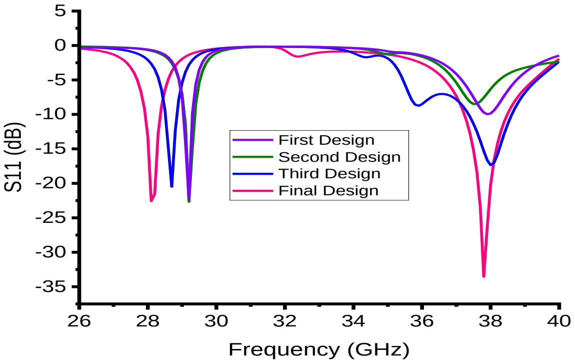


Fig. 4 – S11 for the Variations in design geometry

This alteration is made to achieve the specific frequency bands of interest, as illustrated in Fig. 4. Finally, the parameters r_1, r_2, r are fine-tuned to obtain the desired resonating bands as illustrate in Fig. 4.

The S11 parameters obtained from simulation and Equivalent circuit model (ECM) analysis for the suggested antenna is demonstrated in Fig. 5. The Equivalent circuit model result and Full wave simulation results are in well agreement as displayed in Fig. 5. In the higher operating band, the – 10 dB bandwidth by HFSS is slightly higher as compared to AWR results. The proposed antenna shows dual operating bands covering the bands 27.9 to 28.4 GHz and 37.2 to 38.5 GHz. The simulated gain plot of the proposed antenna is presented in Fig. 6. It can be observed that the maximum gains equaling 5.2 dBi and 6.5 dBi are obtained at 28 and 38 GHz. Within operating bands.

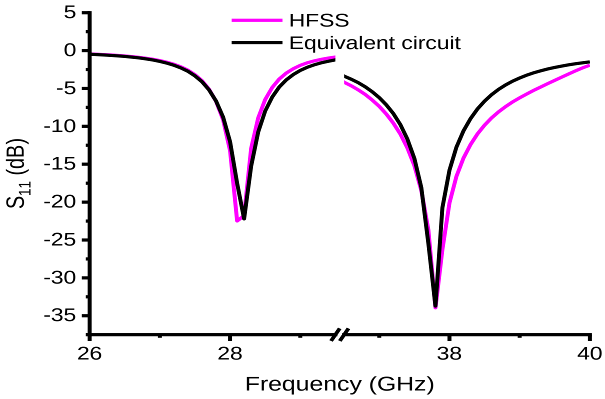


Fig. 5 – S11 parameter of the antenna from HFSS and ECM

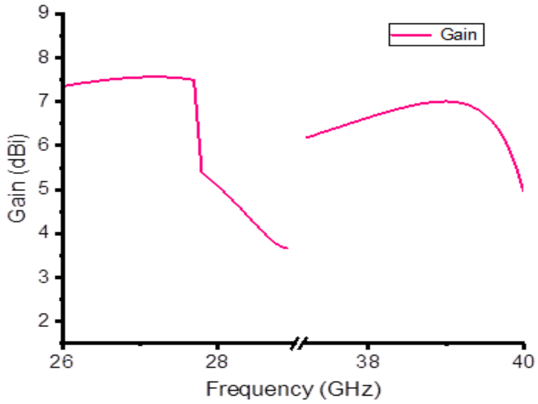
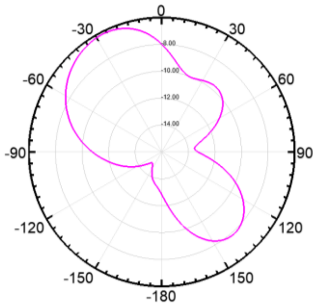
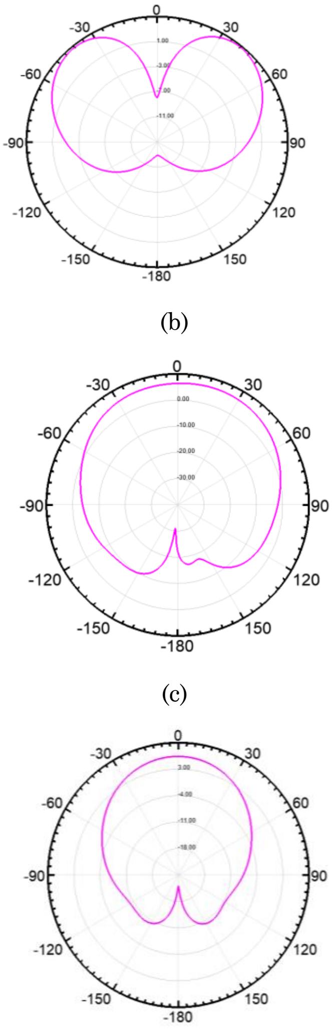


Fig. 6 – Gain of the designed antenna



(a)



(b)

(c)

(d)

Fig. 7 – Radiation patterns (a) *H*-plane at 28.1 GHz (b) *E*-plane at 28.1 GHz (c) *H*-plane at 37.9 GHz (d) *E*-plane at 37.9 GHz

Fig. 7 shows the radiation patterns for the proposed antenna operating at both 28.1 GHz and 37.9 GHz in both the (E & H) plane. Notably, at 28.1 GHz, the radiation patterns in both the H&E planes exhibit bidirectional characteristics. In contrast, at 37.9 GHz, both the H & E plane patterns are unidirectional. The depicted impedance and radiation pattern results confirm the suitability of the suggested antenna at 28/38 GHz mm-wave 5G applications.

1. CONCLUSION

The conclusion of the article emphasizes the successful design and optimization of the silo-slotted microstrip patch antenna. Several key points can be summarized; it demonstrates the effective use of established formulas and simulation tools like HFSS and AWR for designing and fine-tuning the antenna. The antenna design successfully achieves the desired frequency bands, with resonances at 28.1 GHz (27.9 to 28.4 GHz) and 37.9 GHz (37.2 to 38.5 GHz). The comparative analysis between the simulated S_{11} values in AWR and HFSS shows a close match, confirming the precision of the model in the operating frequency range. The proposed structure highlights significant improvements in gain for specific frequency bands, ultimately resulting in a high gain of 5.2 dBi and 6.5 dBi at 28/38 GHz for the final design. The antenna is also analyzed, showing bidirectional patterns at 28.1 GHz and unidirectional patterns at 37.9 GHz in *H*-plane and *E*-plane. The study's findings are significant for applications requiring high-performance antennas in the specified mm wave 5G frequency ranges.

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Дводіапазонна силосно-щілинна антена з моделлю еквівалентної схеми для додатків 5G мм-хвиль

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У статті розглядається розробка та тонке налаштування MPA (мікросмужкової патч-антени) α - мм-хвиль, що має силосні щілини. Початкові параметри конструкції обчислюються за допомогою встановлених формул, що стосуються конструкції патч-антени. Антена моделюється на підкладці зі специфічними властивостями матеріалу, використовуючи матеріал підкладки Rogers 5058, який характеризується (ε_r) 2,2 і дотичними втратами 0,0009. Проведено порівняльний аналіз, щоб продемонструвати змодельовану продуктивність представленої силосної антени з використанням HFSS з моделлю її еквівалентної схеми, реалізованою в AWR. Це передбачає ретельне налаштування компонентів для досягнення бажаних характеристик. У статті простежуються еволюційні фази конструкції антени, підкреслюються геометричні модифікації та зміни площини заземлення. Крім того, у ньому докладно розглядаються резонансні частоти антени та пропонується порівняльна оцінка параметра S11 між симуляціями AWR та HFSS, виявляючи сильне узгодження. Запропонована антена має привабливий розмір 14 мм × 12 мм і працює в подвійних робочих діапазонах, що резонують на частотах 28,1 та 37,9 ГГц. Варіації підсилення для різних проектних ітерацій ретельно вивчаються, і, нарешті, досягаються пікові підсилення 5,2 та 6,5 дБі для запропонованої антени на робочих частотах 28 та 37,9 ГГц відповідно разом із діаграмами спрямованості в площинах *E* та *H* на різних частотах. Антена підходить для додатків 5G, що підтримують діапазони 28/38 ГГц у міліметровому спектрі.

Ключові слова: Антена, Дводіапазонна, Еквівалентна схема, Підсилення, Міліметровий діапазон, 5G.