A Novel Dual-Band 28/38 GHz AFSL MIMO Antenna for 5G Smartphone Applications

H M Marzouk¹, a, M I Ahmed², b, and A A Shaalan¹, 3, c

¹ Department of Electronics and Communications, Faculty of Engineering, Zagazig University, Zagazig, Egypt,
² Department of Microstrip, Electronics Research Institute, Giza, Egypt
³ Faculty of Engineering, Delta University for Science & Technology, Egypt

E-mail: a hala.marzouk90@gmail.com, b miahmed@eri.sci.eg,
c shaalan_zag2010@yahoo.com

Abstract. This manuscript introduces the design and analysis of dual-band air-filled-slotted-loop MIMO antenna which operates at 28 and 38 GHz frequencies for coming fifth-generation 5G for mobile communications. The antenna designed using low-cost FR-4 substrate material that achieving good performance of means of gain and efficiency. The dual-band operation acquired by presenting an air-filled-slotted loop AFSL structures in the radiators. The antenna model contains radiating patch at the upper edge with three AFSLs for 28 GHz and radiating patch at the lower edge with three AFSLs for 38 GHz. The attained results demonstrate that the reflection coefficients for the upper and lower antennas below -10 dB in the frequency bands (27.7 - 28.7) GHz and (37.3 - 38.6) GHz with impedance bandwidths 3.5% for 28 GHz and 7% for 38 GHz which has the quality of covering the 5G band. The introduced antenna is designed and simulated by industry-standard CST 2017 MWS and HFSS programs with substrate size of 55 x 110 mm² with h = 1.6 mm and εr = 4.3.

1. Introduction
The request to a higher bandwidth for future technologies is greater than ever earlier. Today, the band as of dc to microwave (30 GHz) is just about used up. So, Millimeter waves wireless communication technology propositions the higher bandwidth for next-generation [1]. There will be the main requirement especially on the consumer equipment and base station infrastructures by way of 5G is established and applied [2]. For a highly practical design of mm-wave antennas, we need to use low-cost materials and robust mechanical and electrical properties that can be easily used in printed circuit boards (PCB) technologies that allow a moderate spacing between MIMO antenna elements [3]. The mm-wave multiple-input-multiple-output MIMO system is a technique to multiply the radio link capacity using multiple transmission and receiving antennas to utilize multipath propagation [4]. The 5G MIMO antenna was introduced by Ojaroudiparchin [5] and it has verified the design of a single band AFSL phased antenna array on a standard FR-4 PCB technology which consists of ten slot-loops located at the mobile higher verge region. Detailed reviews on in the mm-wave MIMO antenna
technology can be realized in review papers by several authors [6]-[7]-[8]-[9]-[10]-[11]-[12]. Following from that, this manuscript presents a new proposal of dual-band air-filled-slotted-loop MIMO antenna, built on an approach similar to [6], for 5G smartphone applications as all previous work operate at the single band or not fitted to the practice of the smartphone dimensions. Moreover, because the wavelength becomes increasingly smaller at the upper frequencies, the efficient matches in designing an antenna vary from reducing size and minimization to rise the gain and the efficiency. The introduced antenna design consists of three slotted loop elements for 28 GHz band which are positioned on the top verge region of the mobile handset board and three slotted loop elements for 38 GHz band which are positioned on the bottom verge region of the mobile handset board.

2. MIMO antenna geometry
The recommended antenna array resonates in 28 & 38 GHz band which is mandatory for 5G mobile communication. Appropriate design and realization of the 28 GHz & 38 GHz antenna array within a cellular handset is one of the most important features converts to the real design [7]. Our goal is to introduce an air-filled-slotted-loop MIMO antenna conception and to debate real design methods that explain the mutual coupling that occurs between the radiating elements in the non-ideality of mm-Wave antenna arrays conditions [13]. The construction of the MIMO antenna with suitable chosen dimensions is associated with the antenna performance as in figure 1. So, the choice of antenna dimensions is very critical to give the optimal results at both frequencies that assigned for 5G smartphone applications. The high effect of approximately crucial parameters on the antenna performance is done in [13]. The antenna is designed based on an FR-4 substrate with thickness h = 1.6 mm, permittivity εr = 4.4, and loss tangent tan δ = 0.025. The upper antenna contains a radiating patch with three air-filled-slotted-loops for 28 GHz and the lower antenna contains a radiating patch with three air-filled-slotted loops for 38 GHz. The antenna has a total dimension of W x L x h which is fit for application in the usual handset equipment. The amplitude of the reflection coefficient is set by adjusting the feeder point along the y-axis to be Lf1 from the upper verge for the 28 GHz antenna, and Lf2 from the lower verge for the 38 GHz antenna. This arrangement of the dual-band antenna suppresses the undesired backward radiation. The impedance matching and return loss are improved to be superior to 10 dB over the two bands, the lengths of the upper and lower patch radiators were further optimized to be Lp28 and Lp38, respectively.
Figure 1. (a) 6–Element 28/38 GHz AFSL MIMO Antenna, (b) 28 GHz Single Element, (c) 38 GHz Single Element, (d) 3-Elements 28 GHz, and (e) 3-Elements 38 GHz.

Table 1. Dimensions of the Introduced 5G AFSL MIMO Antenna

| Parameter | Value (mm) | Parameter | Value (mm) |
|-----------|------------|-----------|------------|
| W         | 55         | W₁        | 1.2        |
| L         | 110        | W₂        | 1          |
| L₁        | 5.4        | t₁        | 0.3        |
| L₂        | 4          | h         | 1.6        |
| L₃₂₈      | 4.8        | d₁        | 3.1        |
| L₋₄₃₈     | 4.7        | L₋₄₂      | 3.4        |

The two arrays are considered to have a thickness of $t = 0.035$ mm on the top and bottom areas of the substrate and thickness of $h = 1.6$ mm through the substrate (substrate is pierced and copper is positioned), ground plane and the top and bottom patches with air-filled slotted loop structure. Slotted loops of $t₁ \times L₁$ and $t₂ \times L₂$ from the upper and lower radiators were introduced through both the substrate and the ground. As soon as the aimed performance of a particular element placed at the centres of the top and bottom radiating patches was grasped, two same reproductions of the AFSL radiators were regularly positioned at a distance $d₁$ which is corresponding to $0.29 \lambda₀$ (where $\lambda₀$ is the
free space wavelength) from the two upper and lower corners of the substrate. The final adjusted 
parameters are itemized in Table 1. Low return losses and high antenna efficiencies are realized by the 
filling with air that has permittivity \( \varepsilon_r \) of 1 and loss tangent \( \tan \delta \) of 0.

3. Results and discussion
The performance of the offered antenna is analyzed and optimized using full-wave EM simulator CST 
MWS and ANSYS HFSS. The dimensions of the patch lengths feeding point locations and air gaps are 
adjusted to make them resonant at the looked-for frequencies.

3.1 Return Loss and Isolation
As can be perceived in the \( |S_{11}| \) plot of figure 2, by varying the feeding point \( L_{f1} \) from 4 to 4.7 mm with 
increment of 0.2 mm, the lower cut-off frequency could be varied from 29.934 to 28.212 GHz and the 
value of \( |S_{11}| \) was varied from -4.38 to -21.09 dB whereas the upper cut-off frequency could be varied 
from 34.844 to 37.942 GHz and the value of \( |S_{44}| \) was varied from -4.01 to -21.1 dB. This is because 
the change in the feed point location varies the excitation mode which produces different resonance 
frequencies.

![Figure 2](image-url)

**Figure 2.** Simulated \( |S_{11}| \) with different \( L_{f1} \) at 28 GHz and (b) Simulated \( |S_{22}| \) with different \( L_{f2} \) at 28 
GHz.

The intended antenna’s return losses and insertion losses \( |S_{ij}| \) coefficients plotted vs. the frequency are 
demonstrates in figure 3. The values of reflection coefficients covered in the assigned frequency bands 
(−10 dB reference level) were -13.79 dB at 28.17 GHz and -30.36 dB at 37.9 GHz with a respectable 
agreement between the two simulators used. The results illustrated in figure 3 are based on the results 
obtained in figure 2. It was found that by moving the feeding point location, the resonance frequencies 
were changed and the impedance matching for return losses to superior to -10 dB over the two bands 
was improved.
Figure 3. S-Parameters of the Introduced AFSL MIMO Antenna. (a) Return losses, (b) Insertion losses.

3.2 Envelope Correlation Coefficient
A significant factor for MIMO antenna characterization is the correlation coefficient (ρ). It is a measure of the isolation between numerous MIMO antenna channels and the correlation between signals received at similar sides of a wireless link. ECC or ρ should be smaller than 0.5 for decent MIMO process rendering to equation (1). For the offered 6-element AFSL MIMO antenna system, ρ was premeditated at the two frequencies 28 and 38 GHz, and the corresponding obtained value is $5.69 \times 10^{-5}$ and $8.65 \times 10^{-6}$ as presented in figure 4.

$$
ECC (\rho) = \frac{|S_{11} \cdot S_{12} + S_{21} \cdot S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)}
$$

Figure 4. Envelope Correlation Coefficient for the 6-elements AFSL MIMO Antenna for (a) 28 GHz and (b) 38 GHz.

3.3 Radiated Far-field Patterns
The far-field radiation patterns of the introduced Air-Slotted-Loop antenna are illustrated in figure 5. The three-dimensional view is revealed with a directivity, gain and efficiency of 5.535 dBi, 5.126 dBi and 91.02 % at 28 GHz and 4.932 dBi, 4.607 dBi and 92.81 % at 38 GHz. As seen from the results, the antenna has a respectable radiation performance and the obtainable results display that the radiation patterns are reliable in the dual bands. Those are, to some extent, good values for the 5G and millimeter waves where the propagation losses and attenuation are high at the higher frequencies.
3.4 Current Distribution

It was appreciated in Figure 6 that, there were strong induced currents flowing around the slotted-loop resonators. This could be recognized to the existence of the coupling current. On the other hand, when the AFSL configuration was presented through the ground, it was discovered that the surface current was surrounded about the configuration and the induced current in the other antenna ports was reduced. The currents on the other port radiators are inclined to be decoupled. Therefore the isolation between the antenna ports was improved.

This explains the good performance, radiation features, gain, and efficiency of the introduced AFSL MIMO antenna and this antenna is appropriate and satisfactory based on the results in figure 3, figure 4, figure 5 and figure 6.
4. Conclusion
This manuscript presents a novel air-filled-slotted-loop dual-band MIMO antenna at the upper and lower regions which are appropriate for the marketable smartphones. It introduced extensive frequency bands from (27.7 – 28.7) GHz and (37.3 - 38.6) GHz with impedance bandwidths 3.5 % and 7 % for 28 GHz and 38 GHz, respectively. The separation among the antenna elements is very good. -28 dB mutual coupling is obtained without the necessity of supplementary isolation constructions. Return loss superior to -10 dB across the nominated bands was realized. Radiation features, gain, and efficiency is appropriate and satisfactory which has the quality of covering 5G bands.

REFERENCES
[1] P. Adhikari, "Understanding millimeter-wave wireless communication," Loea Corporation, 2008.
[2] T. S. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, et al., "Millimeter-wave mobile communications for 5G cellular: It will work!," IEEE Access, vol. 1, pp. 335-349, 2013.
[3] R. Wang, "Integrated Planar Antenna Designs and Technologies for Millimeter-wave Applications," Universitätbibliothek, 2014.
[4] A. Agarwal, G. Misra, and K. Agarwal, "The 5th generation mobile wireless networks-key concepts, network architecture and challenges," American Journal of Electrical and Electronic Engineering, vol. 3, 2015, pp. 22-28.
[5] N. S. Ojaroudiparchin, Ming Pedersen, Gert Frolund, "A 28 GHz FR-4 compatible phased array antenna for 5G mobile phone applications," in Antennas and Propagation (ISAP), 2015 International Symposium, 2015, pp. 1-4.
[6] M. Ur-Rehman, M. Adekanye, and H. T. Chattha, "Tri-band millimeter-wave antenna for body-centric networks," Nano communication networks, vol. 18, 2018, pp. 72-81.
[7] Y. A. Hashem, O. M. Haraz, and E.-D. M. El-Sayed, "6-Element 28/38 GHz dual-band MIMO PIFA for future 5G cellular systems," in 2016 IEEE International Symposium on Antennas and Propagation (APSURSI), 2016, pp. 393-394.
[8] D. Imran, M. Farooqi, M. Khattak, Z. Ullah, M. Khan, M. Khattak, et al., "Millimeter-wave microstrip patch antenna for 5G mobile communication," in 2018 International Conference on Engineering and Emerging Technologies (ICEET), 2018, pp. 1-6.
[9] I. da Costa, S. A. Cerqueira, and D. Spadoti, "Dual-band slotted waveguide antenna array for adaptive mm-wave 5G networks," in Antennas and Propagation (EUCAP), 2017 11th European Conference on, 2017, pp. 1322-1325.
[10] R. Hussain, A. T. Alreshaid, S. K. Podilchak, and M. S. Sharawi, "Compact 4G MIMO antenna integrated with a 5G array for current and future mobile handsets," IET Microwaves, Antennas & Propagation, vol. 11, 2017, pp. 271-279.
[11] M. M. M. Ali and A.-R. Sebak, "Design of compact millimeter-wave massive MIMO dual-band (28/38 GHz) antenna array for future 5G communication systems," in 2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM), 2016, pp. 1-2.
[12] V. Raghavan, A. Partyka, A. Sampath, S. Subramanian, O. H. Koymen, K. Ravid, et al., "Millimeter-wave MIMO prototype: Measurements and experimental results," IEEE Communications Magazine, vol. 56, 2018, pp. 202-209.
[13] D. Liu, U. Pfeiffer, J. Grzyb, and B. Gaucher, Advanced millimeter-wave technologies: antennas, packaging, and circuits: John Wiley & Sons, 2009.