JOURNAL OF NANO- AND ELECTRONIC PHYSICS *ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ*
Vol. **15** No 1, 01025(5pp) (2023) Том **15** № 1, 01025(5cc) (2023)

A Low-profile Wideband Two Ports MIMO Antenna Working at 38 GHz for mm-wave 5G Applications

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(Received 10 November 2022; revised manuscript received 14 February 2023; published online 24 February 2023)

Designed for increased speed and capacity, 5G has the potential to significantly expand the way the data will be processed and transported, and will allow a wide range of new use cases, which go far beyond the smartphone, already targeted by the 3G and 4G technologies. The present paper focused on the development of new antenna technologies for millimeter waves 5G communications. In this direction, a new two-ports Multiple Input Multiple Output (MIMO) antenna functioning in the mm-wave band is proposed in this paper to support 5G communications at 38 GHz. The proposed MIMO configuration has a size of 43 × 25 mm² is printed on FR4 substrate material with a 0.8 mm thickness, a dielectric loss tangent of 0.02 and a relative permittivity of 4.4. By incorporating combinations of rectangular and triangular shaped slots into the patch elements and a partial ground plane with a rectangular slot, the desired band operation is achieved with enhanced gain and bandwidth. The considered antenna in this paper has a bandwidth of 3.38 GHz (36.8 GHz-40.18 GHz) in the desired band of 5G applications with isolation less than – 24 dB and peak gains of 4.85 dBi at 38.5 GHz. The proposed MIMO antenna covers many countries band like UK (37-40), USA (37-37.6), Canada (37.6-40.0) and Australia (39 GHz).

Keywords: MIMO antenna, 5G communication, 38 GHz, mm-wave.

DOI: 10.21272/jnep.15(1).01025 PACS number: 84.40.Ba

1. INTRODUCTION

The spectrum of 5G services not only covers the bands below 6 GHz, including the bands currently used for 4G networks, but also extends to bands of frequencies in the millimeter wave spectrum, which was not previously envisaged for mobile communications [1-3]. The frequency bands in the range from 24 GHz to 300 GHz have been targeted as having the potential to support large bandwidths and high data rates. The Ku-band (26-40 GHz) is well established as an attractive and cost-effective high-capacity solution for point-to-point applications, capable of supporting radio links up to 20 Gbit/s over short distances of 2 to 3 km. The needs to have data rates of the order of 100 Gbit/s (ie bandwidth needs between 10 and 15 GHz, for a spectral efficiency of 5G devices of the order of 8 to 10 bit/Hz) then results in the exploitation of the spectrum of requirements to W-band and D-band systems, where from large amounts of additional bandwidth then become available [4]. The design of antenna solutions within the framework of the present thesis has thus focused on one of the envisaged frequency bands, the D band. Indeed, in 2018, the Committee European Electronic Communications (ECC) of the CEPT has published recommendation 18(01) identifying sub-bands, totaling 31.8 GHz of bandwidth, on a total block of about 45 GHz (from 130 to 174.8 GHz). Although the purpose of 5G is not only to meet the insufficiencies linked to the increase or bandwidth, but to reduce energy consumption with a service omnipresent quality and obtain an ultra-short latency time. Faced with these requirements, the fifth generation will have to combine several technologies in order to have a mobile network that will be able to meet expectations. In this direction, we can mention: the use of Ku band by exploiting frequencies above 24 GHz which becomes more than never essential for 5G and will facilitate the integration of hundreds of radiant elements at the level of the base station thanks to their low wavelengths. Thus, the technology of the Massive MIMO is nothing more than a densification of the traditional MIMO (Multiple Input Multiple Output) used in previous generations [5-7]. This technique is an approach to increase the capacity of the channel and to provide high multiplexing and diversity in the uplink and downlink directions. These performances will depend heavily on the number of antennas in the base station compared to the numbers of users. Thus, antenna always occupies the largest volume in the communication chain, this explains the huge amount of research on antenna for 5G applications. In fact, many antenna has been reported in literature [8-15]. In [7], authors proposed a 4 × 4 MIMO antenna for 5G application. The projected antenna in [8] shows a maximum gain of 13.7 dB at 37.3 GHz along with a bandwidth ranging from 36.8 GHz to 38.8 GHz. Syah et al. in Ref. [9] used an Array antenna for 5G Communication. The projected antenna offers a gain of 9.24 dB. Authors of Ref. [10] suggested a fed open-ended circular-ring 2 × 2 MIMO antenna. Authors of Ref. [11] suggested a high isolation MIMO antenna which is planned for smartwatch applications. In [12], authors proposed an array antenna functioning at 28 GHz. The

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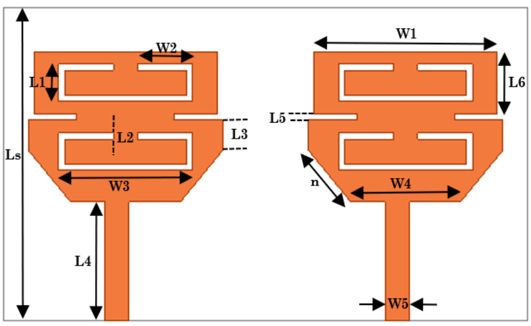
suggested antenna offers high bandwidth with reasonable gain. Authors of Ref. [13] presented a new feeding method for antenna for 5G application. end-launch connector model is used to feed the suggested antenna. The antenna has a peak gain of 18 dB at 28.5 dB. In [14], a Quad-Port MIMO Antenna working at 29/39 GHz for 5G Applications. A peak gain of 8.11 dB is obtained at 39 GHz. To draw a big picture about antennas used for 5G application one can refers to [15-18].

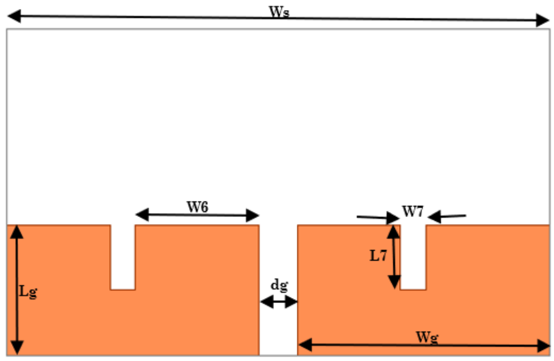
This article presents a MIMO antenna for 5G millimeter wave bands at 38 GHz. A High frequency structure simulator (HFSS) software is used to build and analyze the proposed antenna design. The two-element MIMO antenna has a size of 43 × 25 × 0.8 mm^3. MIMO antennas consist of two identical single antenna elements with each antenna element being a combination of rectangular patches and rectangular and triangular slots on the top plane and partial ground planes with rectangular slots on the back plane. The MIMO antenna is designed on an FR4 substrate with a relative dielectric constant of 4.4, and a loss tangent of 0.02. The effect of inter-element distance is discussed in this article to determine which distance will work with the suggested antenna design. As result, the MIMO antenna with the inter-element distance of $d = \lambda + 0.25$ mm has better performance regarding bandwidth, return loss, isolation, and gain in the operational bandwidth. With this distance, the suggested antenna has an isolation of less than – 24 dB with a bandwidth of 3.38 GHz (36.8 GHz-40.18 GHz) and peak gains of 4.85 dBi at 38.5 GHz. The two-element MIMO antenna covers many countries such as UK (37-40), USA (37-37.6), Canada (37.6-40.0) and Australia (39 GHz).

2. ANTENNA GEOMETRY

In this paragraph, we have focused on antenna design steps. The planned antenna geometry is illustrated in Fig. 1. The top plane of the MIMO antenna made up of a combination of rectangular patches and rectangular and triangular slots shown in Fig. 1(a). To increase the performance of the projected antenna, the back plane is made up of a partial ground plane with a rectangular shaped slot shown in Fig. 1(b). The design is realized on a rectangular substrate FR4 with a relative dielectric constant of 4.4, and a loss tangent of 0.02 and dimensions of 43 × 25 × 0.8 mm^3. The suggested MIMO antenna was designed and simulated using the ANSYS High-Frequency Structure Simulator (HFSS) software.



(a)



(b)

Fig. 1 – The geometry of the proposed two ports MIMO antenna (a) Top view (b) Bottom view

Table 1 – Dimensions of the proposed MIMO Antenna

Parameters	Dimension (mm)
W1	16
W2	4.5
W3	11
W4	4.96
W5	2
W6	9
W7	2
Ws	43
Wg	20
dg	3
n	5.52
L1	3
L2	0.5
L3	2
L4	9.5
L5	0.5
L6	5.5
L7	5
Ls	25
Lg	10

Table 1 shows the dimensions of the proposed MIMO Antenna. These parameters are used to build the final antenna configuration. Based on a single antenna we have prepared a two-port MIMO antenna by using same parameter that we have considered to design the patch in single element antenna.

3. RESULTS AND DISCUSSION

Fig. 2 illustrates the reflection coefficient variation curve versus frequency for the single antenna and the proposed MIMO antenna. Conferring to the simulated results, the two-element MIMO antenna compared to a single element provides improvements in the reflection coefficient. The single antenna resonates at the frequency of 38.53 GHz with a bandwidth of 2.53 GHz (37.37 GHz-39.9 GHz) and a return loss equal to – 18.8 dB. The MIMO antenna functioning at 38.6 GHz with a bandwidth of 2.66 GHz (37.2 GHz-39.86 GHz) and a return loss equal to – 28.95 dB. So, MIMO antenna outperforms single element antenna regarding bandwidth and return loss. Another critical parameter which will be carried out in this work is the antenna gain.

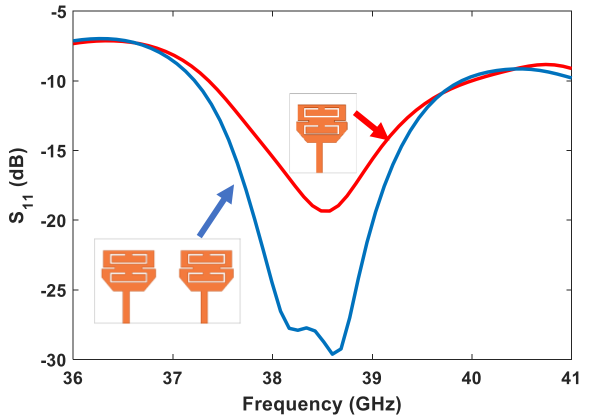


Fig. 2 – Performance of Single antenna versus MIMO antenna regarding the S11 parameters

Fig. 3 illustrates the gain comparison between single and a MIMO antenna with two elements, the MIMO antenna provides a higher gain than the single antenna, with a peak gain of 4.25 dBi at 38.5 GHz. MIMO antenna gain is practically superior to 3 dB at the operating band.

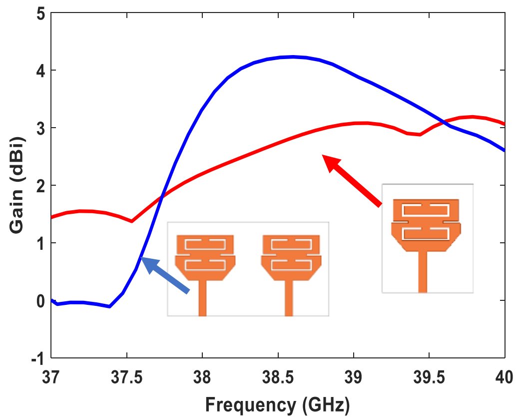


Fig. 3 – Performance of Single versus MIMO antenna in reference to gain

Table 2 summarizes the antennas performance regarding bandwidth, resonance frequency and gain. It shows that the two-ports MIMO antenna gives the best performance related the above mentioned parameters.

Table 2. Comparison between single and MIMO antenna performance

Antenna Design	Resonant Freq. (GHz)	– 10 dB operating Bandwidth (GHz)	Maximum Peak Gain (dBi) in the operating band
Single element	38.53	37.37-39.9	3
Two-element MIMO	38.6	37.2-39.86	4.25

The distance between the two elements of MIMO antenna is a critical parameter to achieving good impedance matching and better isolation.

Figure 4 illustrates how the reflection coefficient varies with frequency for different spacing between elements. As seen in Figure 4, $d = \lambda + 0.5$ mm has the greatest bandwidth in the desired band with a bandwidth of 3.38 GHz (36.8 GHz-40.18 GHz).

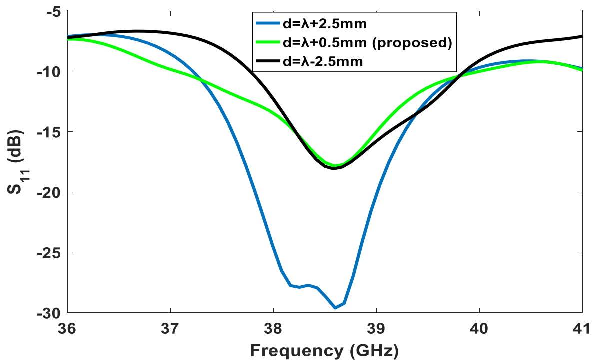


Fig. 4 – Impact of inter-element spacing on (S11) of two-element MIMO antenna

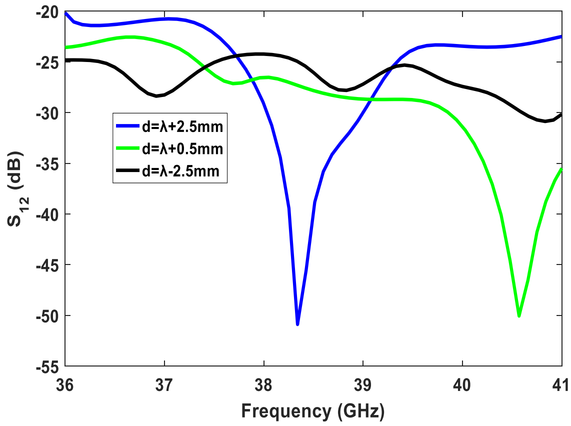


Fig. 5 – Impact of inter-element spacing on isolation

Fig. 5 shows the S12 parameter, which represents the isolation between individual components of the two-element MIMO antenna. Less isolation equals lower coupling, which is one of the difficulties in designing an antenna with more than one antenna element. It is noticeable that the MIMO antenna with $d = \lambda + 0.5$ mm and $d = \lambda + 2.5$ mm have isolation of less than – 24 dB over the full desired frequency band and have a maximum isolation of – 51 db and – 49 dB respectively. Because the two distance give comparable results we choose $d = \lambda + 0.5$ mm as optimal parameter in order to have a compact antenna. Another parameter which play an important role in antenna conception is gain. In the following the performance of the projected antenna will be studied regarding gain.

As shown in Fig. 6, a two element MIMO antenna with $d = \lambda + 0.5$ mm has a much higher gain than a two element MIMO antenna with $d = \lambda + 0.25$ mm and $d = \lambda - 0.25$ mm in the operational band. In fact, the maximum peak gain of two element MIMO antenna is 4.85 dBi with $d = \lambda + 0.5$ mm while for the two element antenna with $d = \lambda + 0.25$ mm and $d = \lambda - 0.25$ mm, the maximum peak gain is 4.2 dBi and 3 dBi, respectively in the desired band.

The results presented in Table 3 show that when the d is fixed to λ + 0.5 mm, the antenna provides better performance in reference to bandwidth, return loss, isolation, and gain in the operational bandwidth.

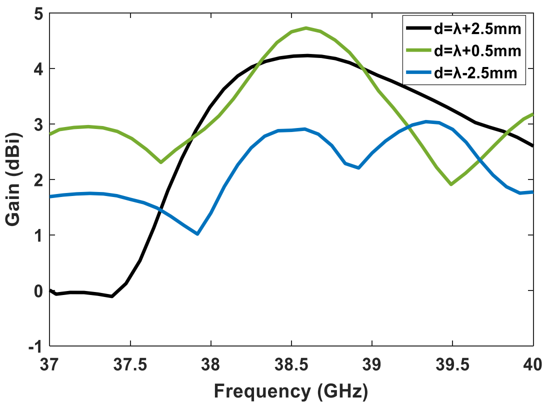
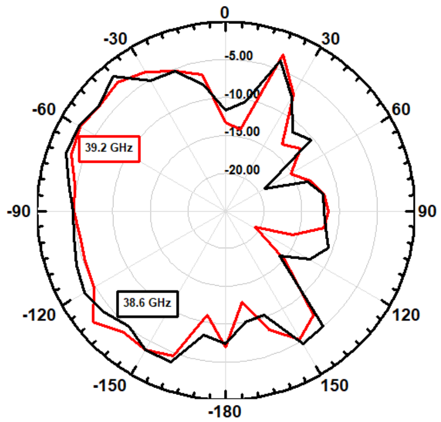
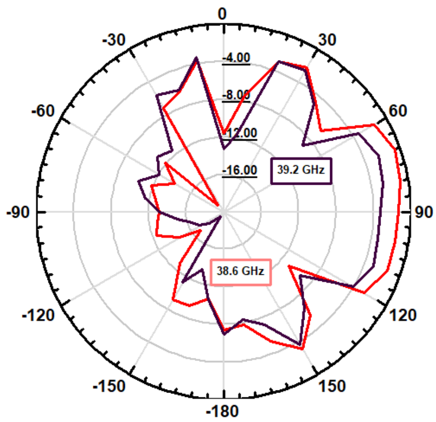


Fig. 6 – Impact of inter-element spacing on gain



(a)



(b)

Fig. 7 – Simulated 2D radiation pattern of the proposed MIMO antenna at 38.6 and 39.2 GHz, (a) *E*-plane (b) *H*-plane

The radiation patterns in the *E* and *H* planes of the proposed MIMO antenna which are simulated at 38.6 and 39.2 GHz are shown in Fig. 7. As depicted in Fig. 7, the results for radiation patterns at 38.6 and 39.2 GHz are closely matched in both *E*-plane and *H*-plane, and the antenna exhibit widespread radiation in the two planes (*E*-plane and *H*-plane), indicating high gain. A directional radiation pattern is observed in MIMO antennas that is necessary for 5G application. Table 3 summarize the antenna performance in reference to the inter-elements spacing.

Table 3 – Impact of inter-element spacing on antenna performance

Ref. Year of Publication	Bandwidth (GHz)	Gain (dBi)	Isolation(dB)
19 (2020)	1.11	3.28	– 35
20 (2019)	2.10	1.83	– 20
21 (2020)	1.3	4.0	–
22 (2020)	1.3	4.604	< – 28
23 (2017)	1.39	5	–
24 (2021)	2.2	9	< – 19
This work	3.38	4.85	< – 24

4. SUGGESTED ANTENNA COMPARED WITH OTHER WOKS

The proposed MIMO antenna is compared to several other antennas of the fifth generation of wireless technology shown in Table 4.

Table 4 – Performance assessment with other stated works

Inter-element spacing d	Res. Freq. (GHz)	−10 dB Bandwidth (GHz)	Peak Gain (dBi) in bandwidth
$d = \lambda + 2.5$ mm	38.6	37-40.1	4.2
$d = \lambda + 0.5$ mm (proposed)	38.5	36.8-40.18	4.85
$d = \lambda$ 2.5 mm	38.5	37.2-39.86	3

5. CONCLUSION

In this paper, a MIMO antenna for 5G millimeter wave bands at 38 GHz is presented. The two-element MIMO antenna has a size of 43 × 25 × 0.8 mm^3 designed on FR4 substrate with a relative dielectric constant of 4.4, and a loss tangent of 0.02. To design and analyze this antenna a High frequency structure simulator (HFSS) software is used. To determine which inter-elements distance will work with the suggested antenna design, this article discusses the effect of inter-element distance. Accordingly, MIMO antenna with a distance between elements of λ + 0.25 mm has better performance regarding bandwidth, return loss, isolation, and gain. Using this distance, the suggested antenna has an isolation of less than – 24 dB with a bandwidth of 3.38 GHz (36.8 GHz-40.18 GHz) and peak gains of 4.85 dBi at 38.5 GHz. This antenna is regarded as an appropriate mm-wave antenna for 5G NR frequency band n260 (37-40 GHz).

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Низькопрофільна широкосмугова антена з двома портами MIMO, що працює на частоті 38 ГГц для додатків 5G мм-хвиль

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Розроблений для збільшення швидкості та ємності, 5G має потенціал для значного розширення способів обробки та транспортування даних, а також забезпечить широкий спектр нових галузей використання, які виходять далеко за рамки смартфонів, на які вже націлені технології 3G і 4G. Ця стаття присвячена розробці нових антенних технологій для зв'язку 5G міліметрового діапазону. У цьому напрямку пропонується нова двопортова антена з кількома входами і багатьма виходами (MIMO), що працює в мм-діапазоні для підтримки зв'язку 5G на частоті 38 ГГц. Запропонована конфігурація MIMO має розмір 43 × 25 мм² і надрукована на матеріалі підкладки FR4 товщиною 0,8 мм, тангенсом діелектричних втрат 0,02 і відносною діелектричною проникністю 4,4. Використовуючи комбінації слотів прямокутної та трикутної форми в елементи накладки та часткову площину заземлення з прямокутним слотом, бажана робота діапазону досягається з розширеним посиленням і пропускною здатністю. Запропонована нами антена має смугу пропускання 3,38 ГГц (36,8 ГГц-40,18 ГГц) у бажаному діапазоні додатків 5G з ізоляцією менше ніж – 24 дБ і підсиленням 4,85 дБі на 38,5 ГГц. Пропонована антена MIMO за своїми параметрами може охопити діапазон багатьох країн, наприклад Великобританію (37-40), США (37-37,6), Канаду (37,6-40,0) та Австралію (39 ГГц).

Ключові слова: MIMO антена, Зв'язок 5G, 38 ГГц, Хвилі міліметрового діапазону.