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Two-Port SIW Array Antenna with Circular Polarization for 5G Base Station

Mehdi Shirichian
Department of Electrical Engineering
Amirkabir University of Technology (Tehran Polytechnic)
Tehran, Iran
m.shirichian@aut.ac.ir

Gholamreza Moradi*
Department of Electrical Engineering
Amirkabir University of Technology (Tehran Polytechnic)
Tehran, Iran
ghmoradi@aut.ac.ir

Reza Sarraf Shirazi
Department of Electrical Engineering
Amirkabir University of Technology (Tehran Polytechnic)
Tehran, Iran
sarraf@aut.ac.ir

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Abstract— **The demand for mobile communication systems with high data rate has drawn attention to the millimeter-wave frequencies to increases the channel capacity compared to current 4G cellular networks. So, the fifth generation (5G) mobile communications is presented which is to work in mm-wave frequency band to improve data rate, capacity and latency. One of the challenges of 5G application is the base station and mobile antennas which should be robust against fading. Therefore, in this paper, a two port substrate integrated waveguide (SIW) slot base station antenna for 5G application at 28 GHz is presented. The realized gain of the two-port antenna with a high isolation (20 dB) and circular polarization is 6.35 dBi. The 5-element array of the two-port antenna with the same excitation can increase the gain 8 dB, but it has some nulls. With phase shift for excitation ports, the nulls are cancelled.**

Keywords- Fifth generation; millimeter-wave; base station; circular polarization and array antenna.

I. Introduction

High data rate wireless communications is one of the consequential demands of cellphone users in recent years. The number of mobile devices in 2021 is predicted to be around 11.6 billion devices, which can increase the global mobile data traffic to 49 Exabytes/month [1,2]. The current 4G cellular networks cannot support this amount of capacity, so the next generation (5G) is presented to solve this main problem [3]. Also, latency is decreasing in 5G to lower than 1 ms. In addition, the peak data rate jumps to 20 Gbit/s, which is 20 times more than that of 4G [3]. Allocating mm-wave band as an operating frequency for 5G mobile communication systems helps reach the 20

*Corresponding Author

Gbit/s peak data and latency lower than 1 ms [4].

According to the 3rd Generation Partnership Project (3GPP), uplink and downlink range for Asia and Americas is 26.5GHz to 29.5GHz [5]. Based on this frequency band, the design and implementation of 5G antennas face with various challenges. The major challenge is the high gain of antennas to deal with the path loss [6], which leads reduced signal strength. In order to overcome this problem, array [4] and phased array antennas [7] are recommended. Other challenges of designing antennas can be divided into two parts a) mobile devices b) Base Station (BS). Low back lobe, size reduction, fan beam pattern and *etc* are the most difficulties for cell phones. On the other hand, circular polarization and high gain antennas are some features of base station antennas which the first feature is related to be robust against fading and movable devices and the other feature is necessary to overcome losses. For base stations, some antennas are recommended which are based on leaky-wave structures [8,9]. Leaky-wave antennas are so useful because they do not need feed network and the pattern will change with frequency due to its structure. Unfortunately, most leaky wave antennas have Linear Polarization (LP) which might increase fading, if transmitter and receiver antennas be LP. Moreover, beam shaping in 3 GHz band width for covering all of the space is somewhat inconceivable.

As mentioned in the previous paragraph, having a circular polarization with high gain antenna is so critical for BSs. In this paper a two port circularly polarized (CP) SIW antenna is designed. Compared with [8,9], the proposed CP antenna is more robust against mismatch polarization and fading. Moreover, compared with [10], the proposed CP antenna has a better isolation and higher gain. In comparison with [11] which can connect to different devices in various frequency, the proposed antenna in this article can link with two devices in the same frequency.

In addition, with the presented array antenna, the gain increases and unlike the array antennas which produces narrow beam at least at one plane, the proposed array antenna in this article has a wide power beam width (gain higher than 0 dBi according to link budget) in each plane, so it can cover massive area. The array antenna which contains 5 elements does not occupy a huge place because the dimension of the proposed array antenna is less than $10 \times 5 \times 1\ \mathrm{cm}^3$.

The reminder of this article is structured as follows: section II defines base station topology, and in section III the two-port antenna is designed. Next, the array antenna is presented and the simulation results will be discussed in section IV. Finally, section V concludes the article.

II. Base Station Model and Link Budget

As mentioned before, free space path loss is the consequential challenge of 5G systems. Due to high operating frequency and high free space path loss, using base stations in indoor for 5G is recommended [9]. Covering all parts of indoor and having multi input are so critical.

It is assumed that there is a space with the height of 5 meter (m), width of 12 m and the length of 17 m (conference hall) as shown in Fig. 1.

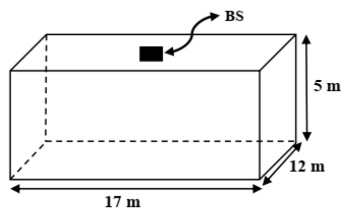

Figure 1. Indoor BS Model

The free space path loss (FSPL) is obtained from Eq. (1).

$$\text{free space path loss (dB)} = 20\log R + 20\log f + 32.45 \quad (1)$$

where R is distance in m and f is operating frequency in GHz. As shown in Fig. 1, the distance between farthest points from BS is almost 11.6 m. According to Eq. (1), the free space path loss for this distance at 28.5 GHz is 82.8 dB. It should be noticed that the sensitivity of the mobile phone is around -90 dBm. According to [5], the EIRP of the transmitter should be less than 47 dBm, so based on

$$P_r = EIRP(dBm) - FSPL(dB) + G_r(dBi) \quad (2)$$

the power density around receiver is almost -36 dBm when EIRP=47 dBm. Therefore, in this article, the minimum transmitter antennas gain is considered 0 dBi and the transmitter power is chosen 27 dBm, then the receiver antenna gain is supposed -10 dBi. Therefore, there is an almost 30 dB margin to detect signals at the receiver. It means that there is not any blind spots in the represented area.

So the beam width of the antenna whose realized gain should be more than 0 dBi to cover all parts of Fig.1 at Phi = 0°, Phi = 90° and Phi = 54° are phi = 50° phi = 60° and phi = 64° respectively. Therefore, the two port SIW antenna should cover these conditions.

III. Two-Port Antenna

As it is presented in the previous section, a CP antenna with aforementioned conditions is needed. Therefore in SIW structures, a cross over slot is needed to propagate circularly polarization [12].

A. The Proposed Two-Port Antenna

Based on [10], a two-port antenna is designed. The schematic of this antenna is illustrated in Fig. 2.

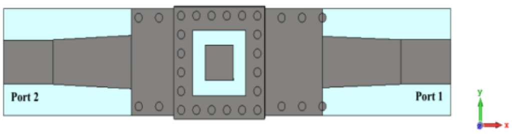

Figure 2. Two-port antenna with cavity [10].

The isolation and the realized gain of this antenna, are shown in Figs. 3 and 4, respectively.

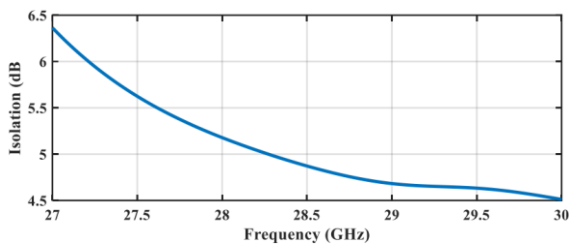

Figure 3. The isolation of the antenna shown in Fig. 2.

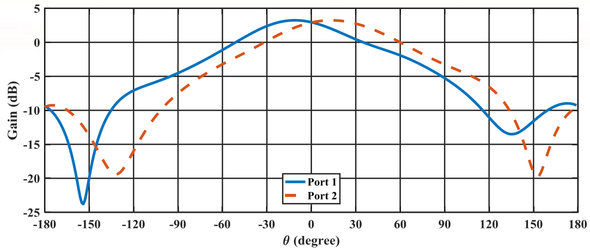

Figure 4. The realized gain of the antenna shown in Fig. 2.

As shown in Figs. 3 and 4, not only is the isolation low, but also the realized gain of the antenna is lower than that of the one port antenna [10]. The isolation is one of the important parameters in N-port systems, also increasing the realized gain helps to cover huge areas. So, the goal of this article is increasing the value of isolation and realized gain simultaneously.

Therefore, based on [13] and similar to [10], a two port SIW antenna with crossover slot is designed. The substrate RT5880 with $\varepsilon_r = 2.2$ and tanδ=0.0009 is chosen. The height of substrate is 0.787 mm. The vias diameter (0.5 mm) and space between the centers of two adjacent vias (1.42 mm) are chosen to propagate the first propagation mode (TE_{10}). The width of slot is 0.61 mm. All dimensions are presented in Table I. The width w_S provides 50 Ohm microstrip line. The cross over slot antenna in SIW structure is shown in Fig. 5.

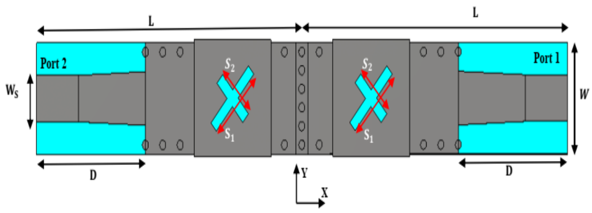

Figure 5. The presented two-port SIW crossover slot antenna.

Table I. Dimensions of the antenna shown in Fig. 2. All units are in mm.

L	W	D	S_1	S_2	W_s
22.2	5.98	8.912	4.314	1.793	2.5

Unlike [9] which has a slot to propagate, the presented antenna in this article has two crossover slots and each slot is isolated with some vias. These vias are located $\lambda/4$ far from the center of slot at the center frequency

(28.5 GHz). So each port is isolated unlike [10] and each slot can propagate.

The designed antenna cannot satisfy the requirements, so like [9] a cavity is designed for the top of each cross over slot which helps to have a better gain, better Axial Ratio (AR) and intended pattern. The first dimensions of cavity for the first resonant mode at 28 GHz (TE10) is obtained from Eq. (3).

$$f_r = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m\pi}{a}\right)^2+\left(\frac{n\pi}{b}\right)^2+\left(\frac{k\pi}{d}\right)^2} \quad (3)$$

where c is speed of light, ε_r is dielectric permittivity constant ($\varepsilon_r = 2.2$), a is the width (here is 5.98 mm), b is the height (here is not considered because of first mode) and d is the length of cavity which is obtained from the resonance frequency (28.5 GHz). So d is equal to 4.5 mm which is optimized to giant better performance.

Fig. 6, shows the proposed two port antenna.

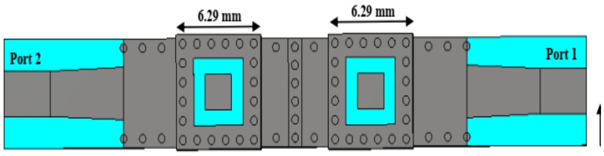

Figure 6. The proposed two-port antenna.

B. The Results of Two-Port Antenna

One of the challenges of N-port structures is isolation. The presented two port antenna vias which separates two ports has a good isolation. The S_{11} and S_{12} of the antenna are illustrated in Figs. 7 and 8, respectively.

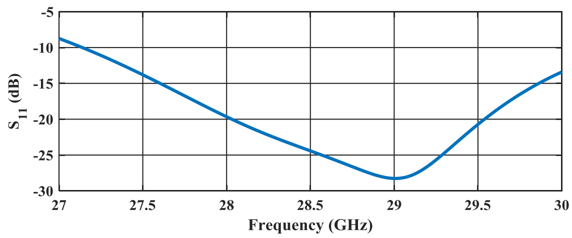

Figure 7. The S_{11} of the proposed antenna versus frequency.

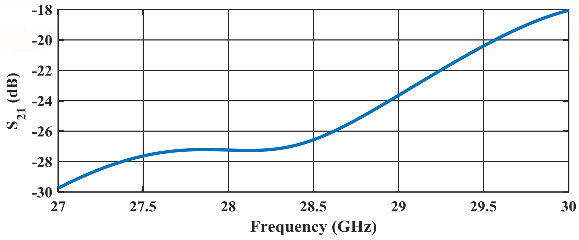

Figure 8. The S_{21} (isolation) of the antenna over frequency.

As shown in Fig. 7, the two ports of the antenna are matched over operating frequency. Also, the isolation of the two ports is excellent and it is higher than 20 dB over the operating frequency band (Fig. 8).

The Axial Ratio (AR) of the antenna over frequency is illustrated in Fig. 9.

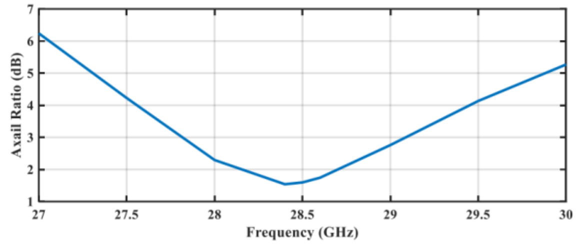

Figure 9. Axial ratio of the antenna versus frequency.

As shown in Fig. 9, the antenna has a circular polarization at 33% of the frequency band (26.5-29.5 GHz).

As mentioned in section 2, the radiation pattern on the presented antenna at three different planes at center frequency when port 1 is excited is illustrated in Fig. 10.

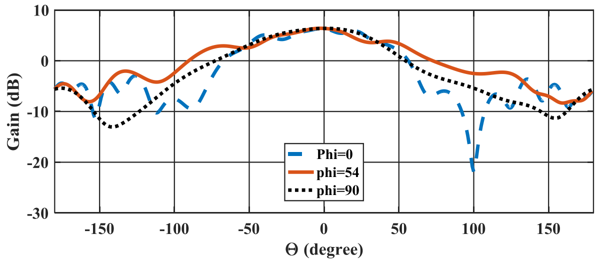

Figure 10. The radiation pattern at the different planes when port 1 is excited.

As shown in Fig. 10, the maximum realized gain is 6.35 dBi. Also, the required beam width which is explained in section 2, is satisfied.

The radiation pattern on the presented antenna at three different planes at center frequency when port 2 is excited is illustrated in Fig. 11.

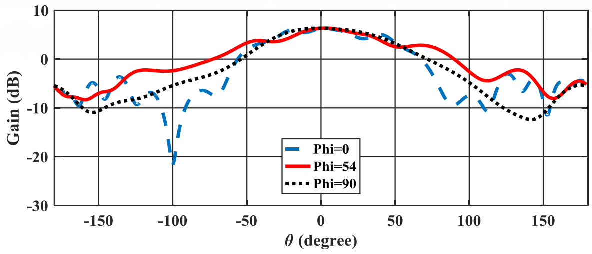

Figure 11. The radiation pattern at the different planes when port 2 is excited.

Because of symmetry of the presented antenna, the realized gain is 6.35 dBi. The presented two-port antenna covers the area with a gain higher than 0 dBi. The proposed two-port antenna has 3 dB higher gain [9] and higher isolation.

IV. The Array Two-Port Antenna

In order to increase the gain of the antenna, 5 elements of the two port antennas (planar array) with the distance of 10.5 mm ($\frac{\lambda}{2}$) are combined and simulated (Fig. 12).

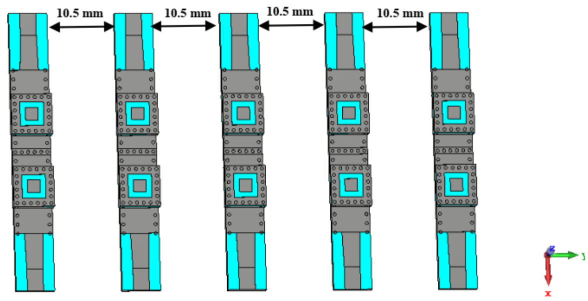

Figure 12. The array antenna.

When the amplitude of excitation are the same, the total pattern at Phi = 54° and Phi = 90° are changed and the grating lobe happens. Although the gain increases (13.1 dBi), some sharp nulls happen at the covering area, so it is not suitable for covering the area. Fig. 13 shows the radiation pattern of array antenna at three different planes.

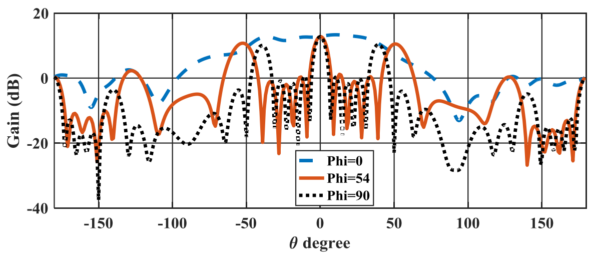

Figure 13. The radiation pattern of array antenna at three different planes with the same excitation.

In order to cancel the sharp nulls at two planes, the phase of excitation should be difference for each element. The phase of center element is zero, the two elements which are close to the central element should be excited with -90° phase shift. Finally, the two adjacent elements should be excited with -180° phase shift. The result is shown in Fig. 14.

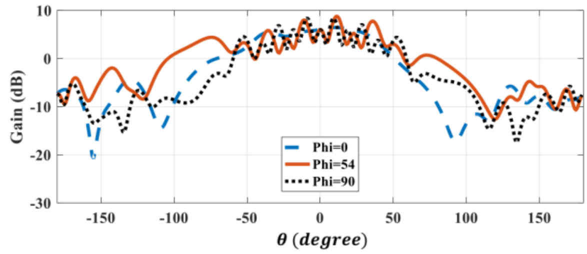

Figure 14. The radiation pattern of array antenna at three different planes with different phase shifts.

As illustrated in Fig. 14, the realized gain is reduced to 8.3 dBi. Although the radiation pattern has some fluctuation. It does not have any nulls at the covering area.

Although the proposed array antenna with different phase shift has lower gain compared to the same phase, it does not have any nulls and according to link budget for the presented scenario, there is a high margin. Therefore, canceling the nulls is so consequential rather than lower gain.

V. Conclusion

In this paper, a high isolation two ports cross over slot SIW antenna for 5G base station has been presented which has. The realized gain of antenna for each port excitation is 6.35 dBi. The presented antenna can cover the area with the dimensions of $17 \times 12 \times 5\ mm^3$. To increase the gain, 5 elements of two ports antenna with $\frac{\lambda}{2}$ distance is considered with the same excitation amplitude and phase. Although the gain boosts almost 7 dBi, some nulls happen. In order to cancel the nulls, some phase shift applied and final realized gain is 8.3 dBi.

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Mehdi Shirichian was born in Tehran, Iran in 1992. He obtained his B.Sc. degree in Electrical Engineering from K. N. Toosi University of Technology, Tehran, Iran in 2014, and the M.Sc. degree from K. N. Toosi University of Technology, Tehran, Iran in 2017. He is currently working toward the Ph.D. degree in Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran. His research interests are in the areas of 5G Antennas, Phased Array Antenna, Rectenna, and SWIPT systems.

Gholamrreza Moradi was born in Shahriar, Iran in 1966. He received the Ph.D. degree in Electrical Engineering from Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran in 2002. His main research interests are Numerical Electromagnetics, Antennas, Active Microwave and MM-Wave Circuits and systems. He is conducting some collaborative projects on 5G antenna together with university of Alberta and University of Dresden. Dr. Moradi is currently an Associate Professor with the Electrical Engineering Department, Amirkabir University of Technology. He has published more than one hundred papers in the refereed journals and international conferences.

Reza Sarraf Shirazi was born in Yazd, Iran in 1958. He received the PhD degrees in electrical engineering from Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran in 2006. His main research interests are Numerical Electromagnetics and Radio Wave Propagation. He is currently an Assistant Professor with the Electrical Engineering Department, Amirkabir University of Technology. He has published several papers in the refereed journals and international conferences.