Chapter 4

Evolution and Move toward Fifth-Generation Antenna

Kioumars Pedram, Mohsen Karamirad and
Negin Pouyanfar

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.74554

Abstract

With the introduction of various antennas in the field of antenna technology, most of the constraints related to the transmission and receiving of the signals at different intervals have been resolved. By the rapid growth in industry and consequently high demands in the communication arena, the conventional antennas are unable to respond to these extended requirements. However, those initial antennas were suitably used in the field of technology. In the recent decades, by introducing new antenna technologies such as metamaterial structures, substrate integrated waveguide (SIW) structures and microstrip antennas with various feeding networks could meet the demands of the current systems. As stated before, in the frequency ranges of below 30 GHz, antenna size and bandwidth are of the important issues, so that novel antennas can be created in low frequencies, which are able to achieve reliable radiation properties when combined with new multi-band antennas. Generally, transmission lines are practical in low frequencies and short distances, while higher frequencies are mainly used due to bandwidth goals. This chapter is organized into three subsections related to the 5G wireless communication systems: antennas below 15 GHz or accordingly antennas with wavelength less than 1/20; antennas operating between 15 and 30 GHz; higher frequency antennas or millimeter-wave antennas, which are desired for above 40 GHz.

Keywords: multiband antenna, 5G application, mm-wave, substrate integrated waveguide (SIW), MIMO, array antenna

1. Introduction

From the beginning of human civilization, communications had basic importance for human society in recent years' human used electromagnetic spectrum beyond of visible area for telematics communication through radio waves radio antenna is a basic part of a radio system. A radio antenna is a tool that provides the possibility of radiation or receiving radio waves. As we know, one of the biggest human sources is electromagnetic spectrum and antennas played a basic role in using this natural source. Despite several antennas in techs many of limitations have been solved in sending and receiving in some areas. The first practical cellular network which used analog systems arose in 1982 as a first generation in 1991 the analog system had been improved to the digital one or internet-based generation named as second generation this technology also added cellular data in format of General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution (EDGE). Approximately 10 years later, the third generation had been introduced to improve data rate further. After a decade, the current LTE networks had emerged which commonly named fourth generation. A new generation of network tech has been used the fifth generation of network or 5G like previous generation mutation will improve in cases like a speed velocity fifth generation. Some believe that new generation of mobile networks received new frequencies bands braid band received wide spectrum in each frequencies channel. Some believe that the new mobile generations usually provide new and wider frequency bands compared to the first, second, third and fourth generations, which provide up to 30 kHz, 200 kHz, 5 MHz and 20 MHz, respectively. The higher frequency band may interfere with K band which is specified for satellite communications. From user's perspectives, the former mobile generation (4G) provides a significant peak rate bit up to 1Gbps. Therefore, for the 5G to be different, it should support more data rate speed, so that makes it possible to connect different devices, simultaneously along with higher spectrum efficiency (more data rate per unit), low battery usage, lower delay, and disconnection. Moreover, lower cost for establishment of infrastructures, flexibility, higher scalability, and reliability should be taken into consideration. The existing problem is that higher radio frequencies cannot perform well in long distances or cross the walls between them and mobile devices. Thus to solve the aforementioned problems, service providers must focus on the new communication antenna technologies. Antennas with high input and output capacities will be able to transmit parallel radio waves which accordingly define a signal beam and eventually the radio signal energy directs toward a specific path, which the user is situated. Since antennas are key elements of wireless communication systems, an expert design can meet the demands of systems and consequently improve system performance. Antenna role in the communication systems is similar to the eyes and glasses for a human. Antennas scope of activities is extensive and dynamic so that during the past six decades, antenna technology has had an undeniable evolution in the communication arena. Most of the important improvements in this field are currently used by public users. However, today we face more challenges since the system efficiencies have been noticed. Most of these improvements in antenna technology have been evolved since 1970.

2. Antenna in 5G application

The initial research in the field of fifth generation has been started since 2012. With the standardization procedure of this generation of the mobile telecommunication networks,

http://dx.doi.org/10.5772/intechopen.74554

beginning since 2015, it is anticipated that first experimental samples will be set up in 2018. Based on the most forecasts, commercialization of these networks will be postponed to the next 2 or 3 years. Many investigations have been done in this field in the past few years so that some researchers have worked on antennas to improve their impedance bandwidth. In some cases, unidirectional pattern concentration with high gain or pattern rotating has been tried. Recently due to the tremendous increase in the number of devices connected to the wireless communication systems and accordingly a significant increase in demands for new and high-quality applications, antennas with wider impedance bandwidth, high gain and rotatable radiation pattern especially in higher frequencies are required.

2.1. Antennas below 15 GHz or accordingly antennas with a wavelength less than 1/20

Radio frequency has a set of physical properties. One of those is the wavelength of the signal. At 2.4 GHz this is approximately 12.5 cm (4.92 inches) and 5–6 cm (2–2.3 inches) at 5 GHz as well as 2.5–3 cm (1–1.15 inches) at 10 GHz. The difference and approximation are due to the fact that the wavelength is the result of the direct correlation of the exact frequency (2.400–2.483.5 GHz in the 2.4 GHz range and 5.250–5.725 GHz in the 5 GHz range). To optimize sending and receiving the signal, the antenna is designed around those physical properties. The elements inside the antennas will vary in size to match the wavelength (or more commonly 1/4 or 1/8 or 1/16th the size of the wavelength). So first and the foremost difference in between is the size of the antennas. The 2.4 GHz antennas are bigger than the 5 GHz antennas. Mind that the same size antenna enclosure may be used for various reasons, two biggest ones being the cost of development and production and also overall esthetics. There are many antenna types available: dipole omni antennas, patch, and Yagi antennas, just to name a few. There are many subtypes, too many to name all of them here. Different antenna type will provide different radiation pattern. Starting with Dipole-Omni antenna that will provide 360° coverage in vertical setup (point of the antenna facing straight up or down) to focus, narrow beamwidth antennas used for Point to Point communication and everything in between. The RF focus will result in the higher gain of the antenna as it directs all the available energy into a certain direction [1–3].

2.1.1. Antenna based on SIW structure for 5G application

A Substrate Integrated Magneto-Electric Dipole antenna has been introduced for 5G Wi-Fi applications in [1]. A new technique is used to reduce the height of the ME dipole antenna by utilizing the tapered H-shape ground plane. As the conventional approach of folding parallel walls is hard to fabricate and also challenging, a pair of open slots has been cut on the ground plane. Hence surface current path is folded along the x-axis. The proposed configuration consists of four layers as shown in **Figure 1**. The antenna is fed by a Γ-shaped probe located between the two arms of the Bowtie dipole. The simulated and measured results shown in **Figure 2** reveal that the proposed structure provides an impedance bandwidth of 18.74% between 4.98 and 6.01 GHz and gains of about 6.8 and 7.2 dBi, respectively.

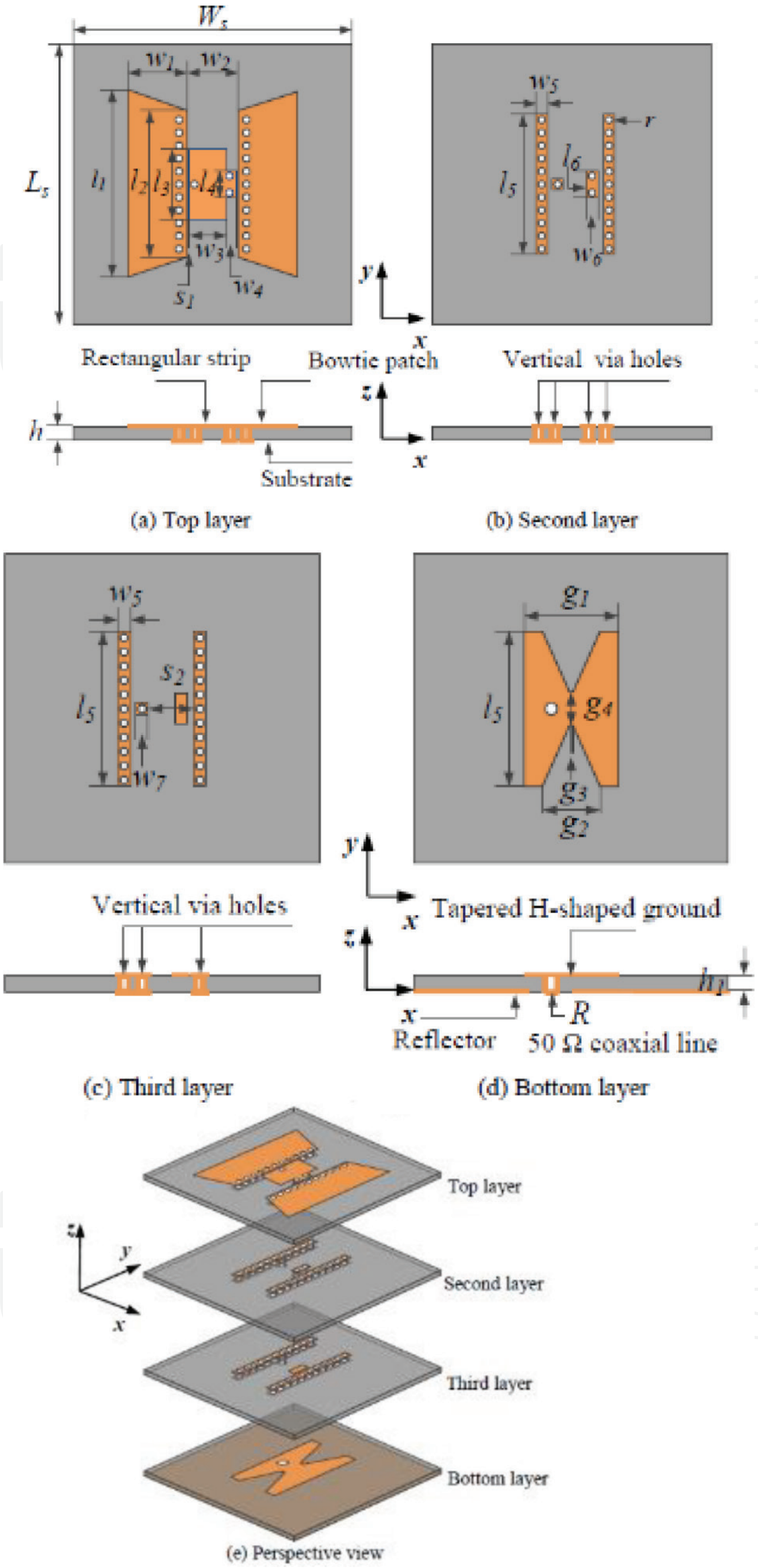


Figure 1. Geometry of the substrate integrated ME-dipole [1].

With the outstanding features with respect to the conventional ones, including wide impedance bandwidth, symmetric patterns, low back radiation and at the same time more than 80% efficiency, the proposed multilayer configuration with a novel technique to reduce the height of the ME dipole antenna is a suitable candidate for 5G Wi-Fi application.

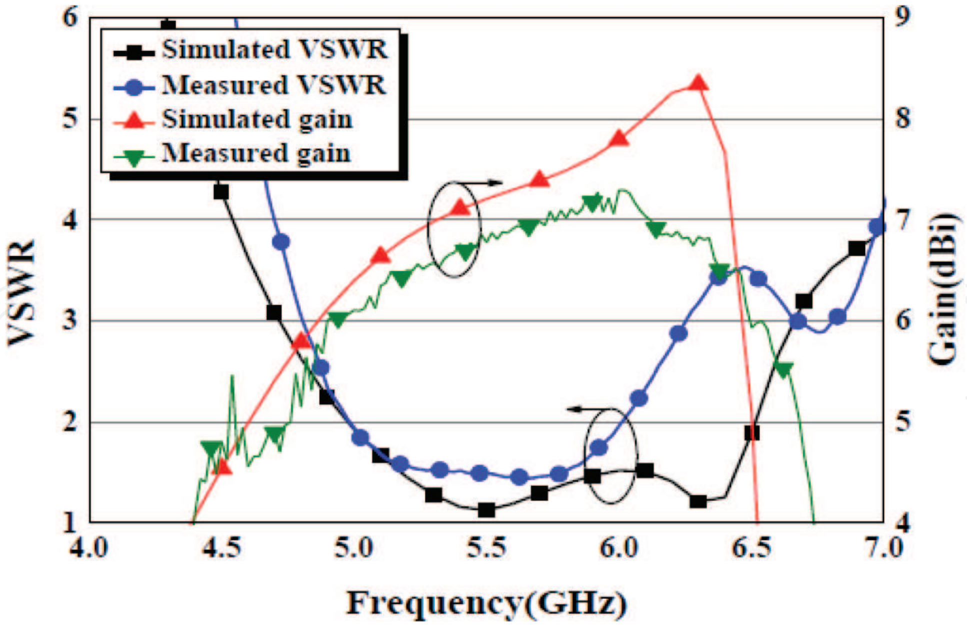


Figure 2. Simulated and measured VSWR and gains versus frequency [1].

A new configuration based on substrate integrated waveguide concept has been investigated for 10 GHz frequency band in [2]. In order to enhance the antenna gain, different structures with two and four grooves have been proposed. The aperture-coupled antenna consists of a rectangular patch in which the power is coupled through the cavity and hence into free space. The cavity dimensions are optimized so that they can determine resonance frequency and radiation pattern of the antenna. The geometry of the designed configurations with two and four grooves and their corresponding simulated results are shown in **Figure 3**. Via based cavity structure has a remarkable impact on cavity performance in SIW patterns and it is demanding to adjust its resonance frequency due to abrupt changes of current distributions near walls. Therefore, the rectangular cavity's edges are created by drilling out the two L-shapes in the middle substrate. Despite of drilling out the shapes, the corners have been left to keep the substrate inside the cavity in place. Thereafter, the walls of the cavity are metallized as a PCB manufacturing process.

The simulated reflection coefficient reveals that adding the grooves have approximately no effect on the S11 if the distance between patch and grooves are accurately determined. Moreover, this distance changes the directionality of the antenna, as depicted in **Figure 4**.

2.2. Antenna in mid-frequency (15 and 30 GHz) for 5G application

Due to the steep increase in the number of electronic devices and accordingly high data traffic, wireless communication technology is required to use higher frequency bands to overcome the shortcomings existed in the existing networks. Fifth generation (5G) mobile networks have been extremely noted to overcome the existing networks problems such as bandwidth shortage caused as a result of the exponentially growth in the number of electronic devices and users connected to wireless systems, since it can provide a peak data rate of at least 100 Mb/s in urban areas, 10 Gbps for static users and 1 Gbps for mobile users. Two of the important bands specified for testing 5G cellular communication systems are 28 and 39 GHz in the US and Europe, respectively. These frequency ranges extend from 24.5 to 29.5 GHz

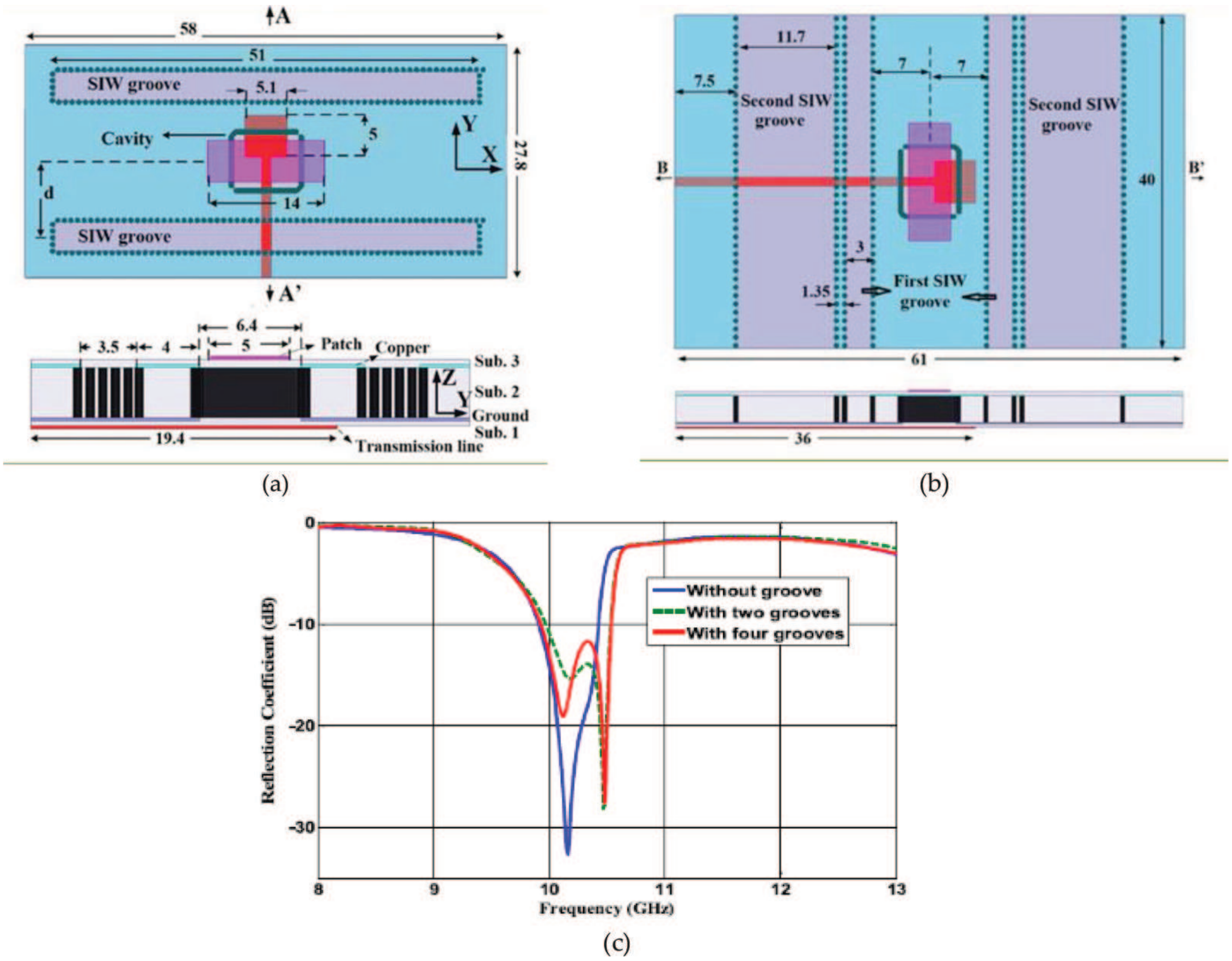


Figure 3. Configuration of proposed aperture antenna (a) with two grooves, (b) with four grooves, (c) reflection coefficient of the proposed antenna without/with grooves [2].

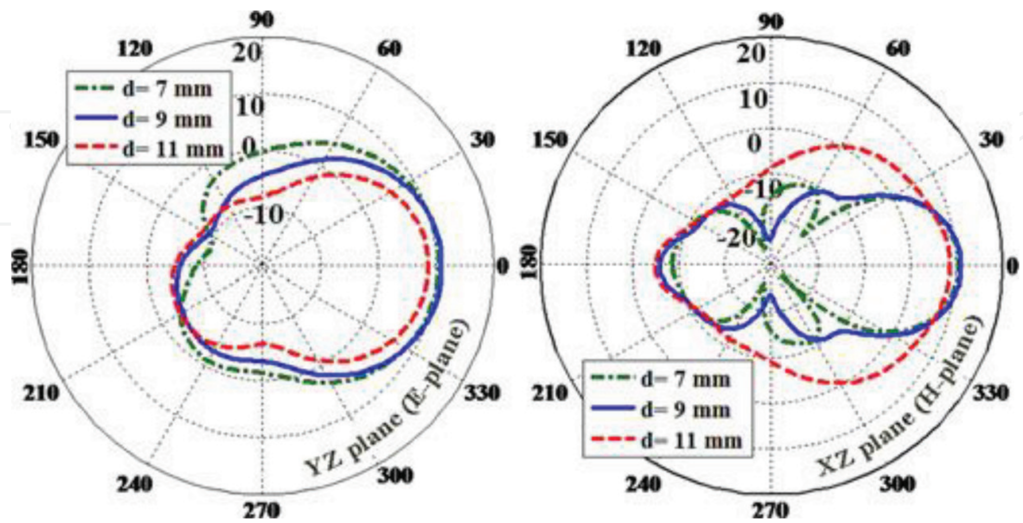


Figure 4. Radiation pattern of the proposed antenna with two grooves for different distance between patch and grooves for center frequency [2].

and 37.0 to 43.5 GHz with center frequencies of 28 and 39 GHz, respectively. Improved data rates of up to 2.5 Gbps with multiple connections are among important characteristics of 5G cellular communications [4]. The US Federal Communications Commission (FCC) has recommended frequency bands of 28 and 37–39 GHz for the ongoing wireless networks (5G), as well as 33 GHz, which was specified for satellite and navigation applications. The Ka-band (at 28/38GHz) can be suitable for frequency division multiplexing (FDD), in which single antennas providing dual-band performance is preferred. The significantly increased path loss at very high-frequencies has to be compensated by higher antenna gains, which is made possible by increasing the number of antennas at the base station [5]. Compared to the current 1–2 GHz cellular bands, the spectrum at 28 GHz has less free space path loss. In fact, oxygen loss (due to oxygen molecule absorption in atmosphere) and rain attenuation will have less impact on the 28 GHz spectrum, hence providing better propagation conditions when compared to the existing cellular networks. It should be noted that the 28/38 GHz signals will not be going to penetrate a car's windows or roof. Therefore, these kinds of devices will be important for these frequency bands in direct communication with a user device. For future 5G applications, it has been indicated in [6] that, a high gain antenna (>12 dB) is required, which has the capability to be directed in certain directions. One introduced technology to overcome the existing deficiencies and to meet the aforementioned goals is the massive MIMO, which means extending MIMO concept to hundreds of antennas at the base station as a promising solution to increase data rate and network capacity by allowing beamformed data [7]. Another introduced technology to obtain an efficient beam steering characteristic is to use phased array antennas, which are one of the key parts in 5G wireless systems, since smaller antennas can be employed as arrays to improve performance [8]. It should be noted that the capability of beam steering in antennas is not compatible with most of the previous generations (2G, 3G and 4G), since they usually broadcast signals in wide beams, hence dissipating energy in unwanted directions. The importance of utilizing phased array antennas is that they can direct and accordingly focus the signal beams to a desired direction toward the receiving antenna. As an example, the IBM and Ericsson has designed a phased array, which supports beam steering of less than 1.4° for focusing the beam toward users. There have been some techniques to design multiband antennas, among which is the slotted-SIW structures. The slotted SIW is a good option for designing the directional multi-band antennas. By utilizing different slot configurations in these antennas more directional radiation patterns can be obtained. This can be explained such that in the SIW structures usually one of the layers contains the ground and the other has the radiating apertures. The surface current is disturbed by the engraved slots to accurately radiate electromagnetic waves. This method can also be used for the incoming wireless network. As the modern wireless systems require low profile and easy to integrate devices providing high gain and efficiency, microstrip patch antennas are highly recommended. Therefore, small antennas with dual-band or multiband properties are preferred for applications operating in Ka-band for the futuristic 5G technology.

A microstrip array antenna designed in [9] provides an impedance bandwidth ($S_{11} < -10$ dB) of about 7 GHz from 23.9 to 31 GHz and 12.5 dB gain at 29 GHz, but poor radiation efficiency due to the lossy FR-4 substrate has been observed. Since the scanning angle of more than 45° is required for mobile antennas, a planar array with beam switching capability is proposed in [10], which provides 1 GHz impedance bandwidth relative to the center frequency of 28.05 GHz and an average of 10 dBi gain. Another 28 GHz multilayer FR-4 PCB antenna array is presented in [11]. The structure consists of 16-element shows a fan-beam like radiation pattern. Results indicate that nearly 11 dB gain and more than 3 GHz impedance bandwidth has been obtained. The presented array is a complicated and expensive structure due to the multilayer technology. Some recently published configuration to achieve the acceptable performance for these important frequencies will be discussed in detail. Three different oriented microstrip inset fed patches are designed in [12]. In the first design, two patches are placed side by side while in the other two configurations opposite feeding structures are used. The geometry of all structures and their corresponding reflection coefficients are presented in **Figures 5** and **6**, respectively. It can be seen in all three configurations, S_{11} is the same and about 1.5 GHz, which is due to the symmetrical structures of the antennas. The simulated and measure mutual coupling for structure 3 is shown in **Figure 6**. As it is obvious because of the small size of the antenna S12 < −20 dB at 28 GHz has been obtained.

A compact, broadband printed-dipole antenna, and its' corresponding 8-element array antenna have been investigated in [10] to work at 28/38 GHz, which are the key frequency band for ongoing 5G. The single element design consists of microstrip feed line on the top layer of the substrate and the dipole along with the ground plane on the other layer. An integrated balun including a 45° folded microstrip and a rectangular slot has been employed and optimally adjusted to improve impedance matching. The bandwidth of about 36% in the frequency range of 26.5–38 GHz and 4.5–5.8 dBi gain has been obtained. The simulated and measured results for the single element proposed antenna are shown in **Figure 7**.

2.3. Higher frequency antennas or millimeter-wave antennas which are desired for 60 GHz

With recent ongoing advances in new generations of telecommunications, the research on 60 GHz antenna design has become progressive, since their ability to provide high data rate services for fifth-generation (5G) applications. As a matter of fact, the implantation of 5G networks requires wide bandwidth which satisfies the demand to have real-time video streaming, machine to machine communications and IOT. For the sake of aforesaid, providing broadband infrastructure is a noticeable challenge in 60 GHz technology as it is an alternative of fiber optics. Thereby, the design of antenna with a low profile, high gain, and high radiation efficiency is necessary. Hitherto, some efforts have been conducted to alleviate these requirements [13].

2.3.1. Wideband linearly polarized transmitarray antenna for 60 GHz

In this section, a transmitarray antenna for backhauling at V-band is discussed. Such high capacity is of interest for operators to have multihop in the ranges of hundreds of meters to 1 km. for this purpose, three different frequency bands (28 GHz, V-band, and E-band) are dedicated to millimeter wave backhauling. According to the substrate integrated waveguide-based planar array have been undertaken. Contrary to microstrip based arrays in which high insertion loss hampers the performance, the employment of spatial feeding illumination in

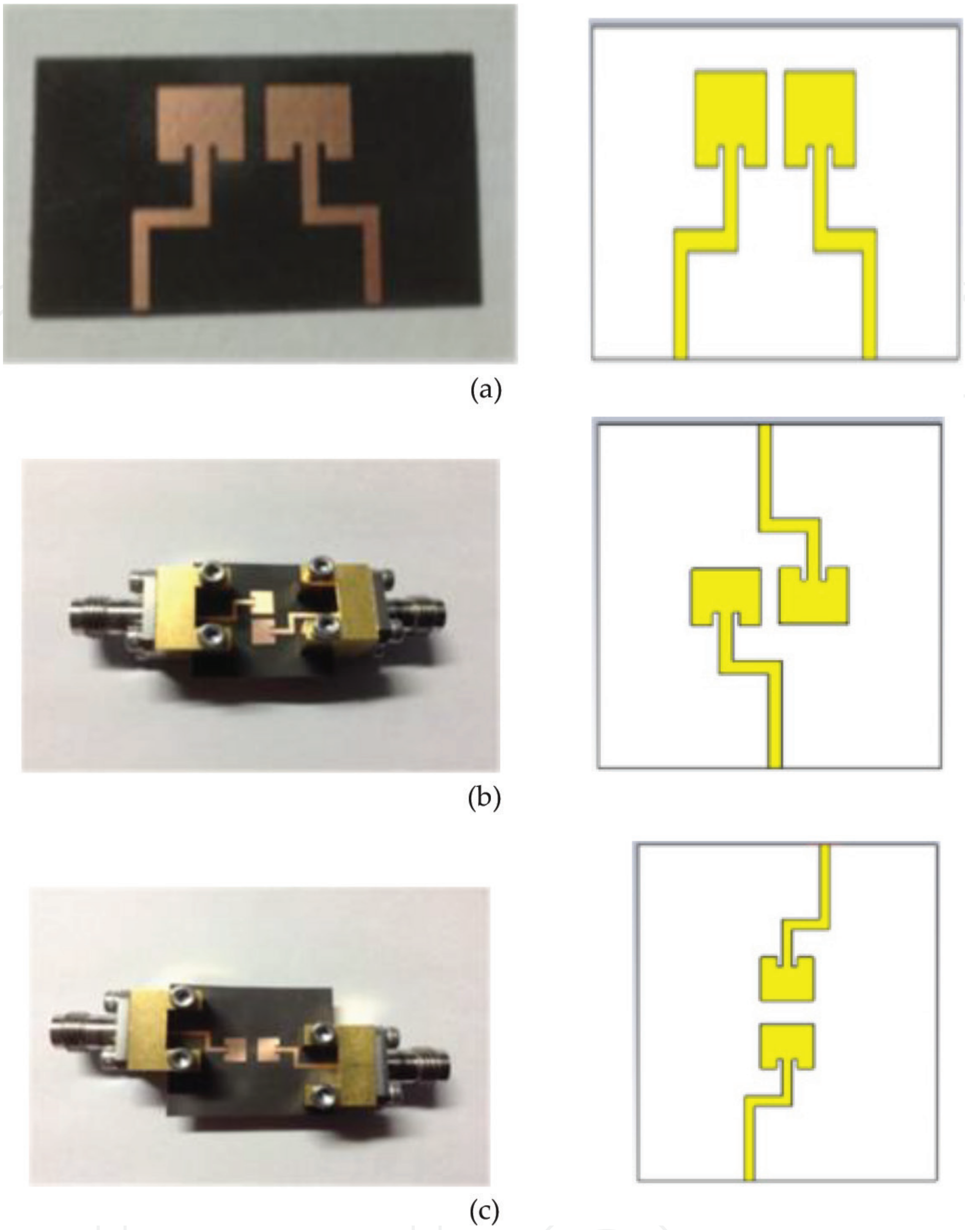


Figure 5. Three different configurations of patch array antennas designed. (a) Antenna 1; (b) antenna 2; (c) antenna 3 [9].

transmitarray antenna has drawn considerable research interest. While one or more focal sources illuminate, each unit cell of the transmitarray as a concept have been made of Rx antenna coupled to Tx antenna. Realizing the transmission phase shifting can be obtained by connecting two antennas through a phase shifter. Several studies have been conducted on the transmitarray antenna in last decades, typically with the focus on implementing such patterns in the structures. Recent years, such topological patterns have been demonstrated. One of these is illustrated in **Figure 8** [14].

The proposed structure uses 3-b phase optimization including 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° over the whole 57–66 GHz. The arrangement of this 3-b is according to two different patterns. The first one is composed of the simple patch which is described in [15]. The

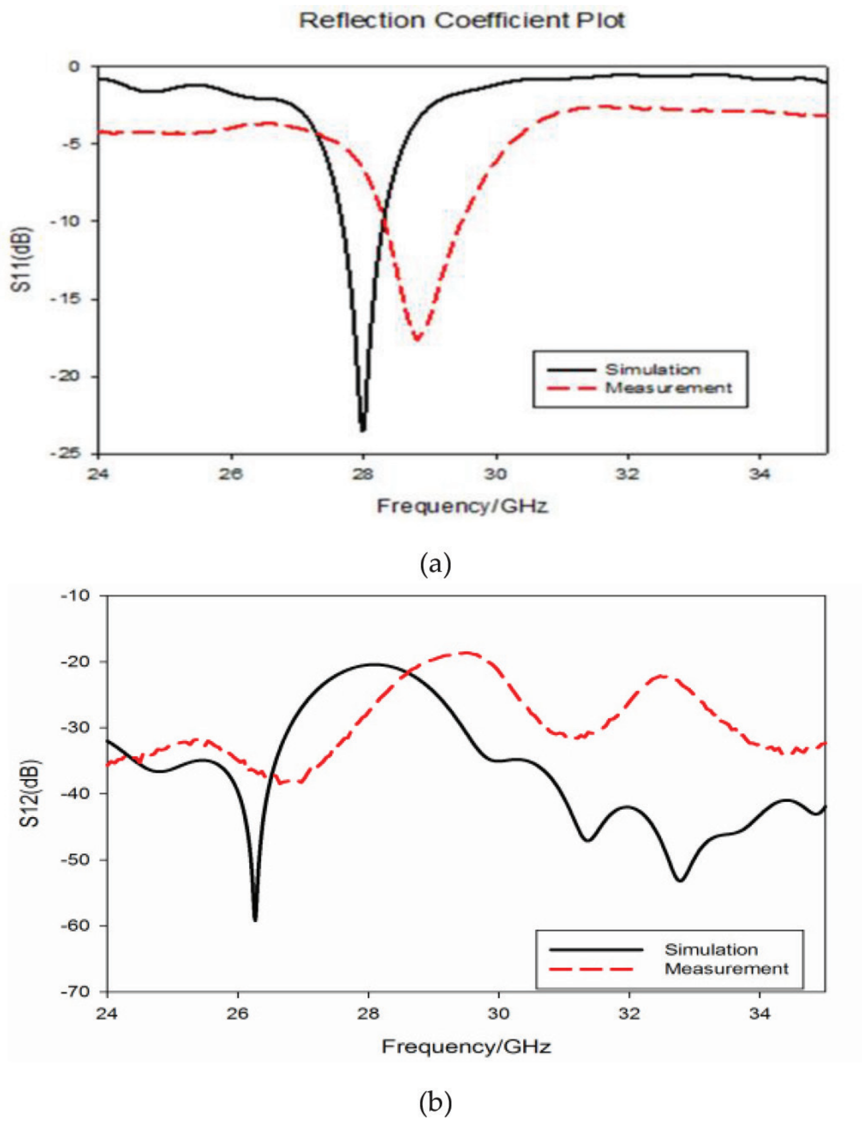


Figure 6. Measured and simulated: (a) return loss for designed antennas 1–3 and (b) mutual coupling for the proposed antenna [9].

second one utilized a capacitive fed patch in the structure. From **Figure 9**, it can be seen that the profiled skirt protecting the antenna from its surrounding, is roughly more complex than standard pyramidal horn structures. Thereupon, a radome is included to protect the array from the environment. The optimization of the unit cell's phase distribution is outperformed using in-house software [16] to gain the radiation pattern [17].

2.3.1.1. Unit-cell design and frequency response

As shown in **Figure 9**, the two types (1 and 2) are demonstrated for the pattern in order to obtain a 3-b phase resolution. Thereafter, using eight unit cell configuration architectures have offered a 45° relative phase shift between each phase state. The unit cell size is optimized to $0.51\lambda_0 \times 0.51\lambda_0$ at 61.5 GHz. The structure is composed of two patch antenna separated with a 508 μm thick dielectric substrate with $\varepsilon_r = 2.5$ and $tan\delta = 0.0017$. The via hole has been utilized

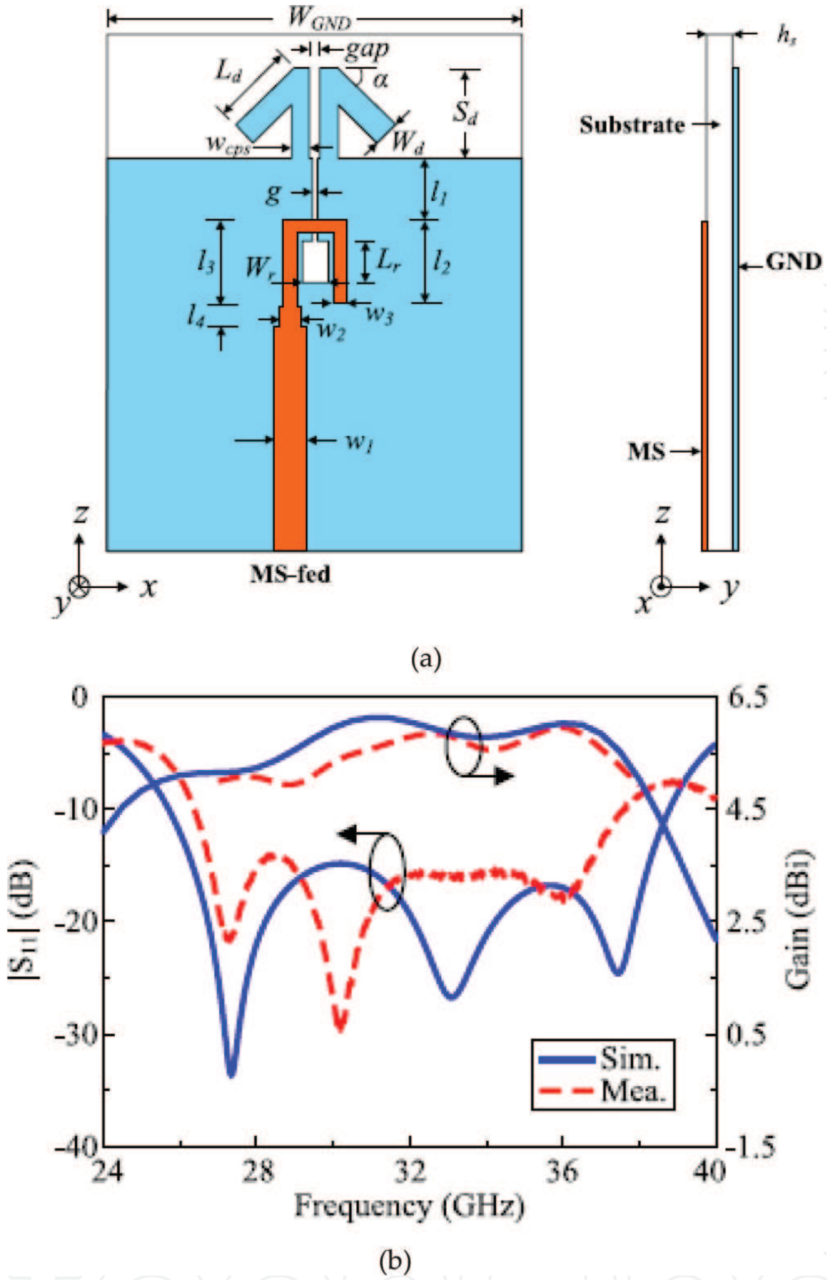


Figure 7. (a) Geometry of the printed-dipole antenna, (b) the simulation and measurement gain and S_{11} of the single element [10].

to ensures the coupling between patches. The configuration of the design is as follows. The unit cell type 1 is designed to reveal the phase state 0° and 45°. It should be noted that the 45° phase shift is derived by resizing the 0° phase state unit cell [18]. In the same way, the unit cell type 2 is used to generate 90° and 135° phase shift.

Figure 10 indicates that the coefficients are lower −9.65 dB over the whole 58–66 GHz. Hence, the ripple inside the presented tapered focal source could be reduced through minimizing the losses of the transmitarray reflection coefficient. Furthermore, the simulated transmission coefficient in **Figure 10(b)** remains approximately better than −1 dB for each unit cell.

Figure 8. Perspective view of the complete transmitarray antenna [14].

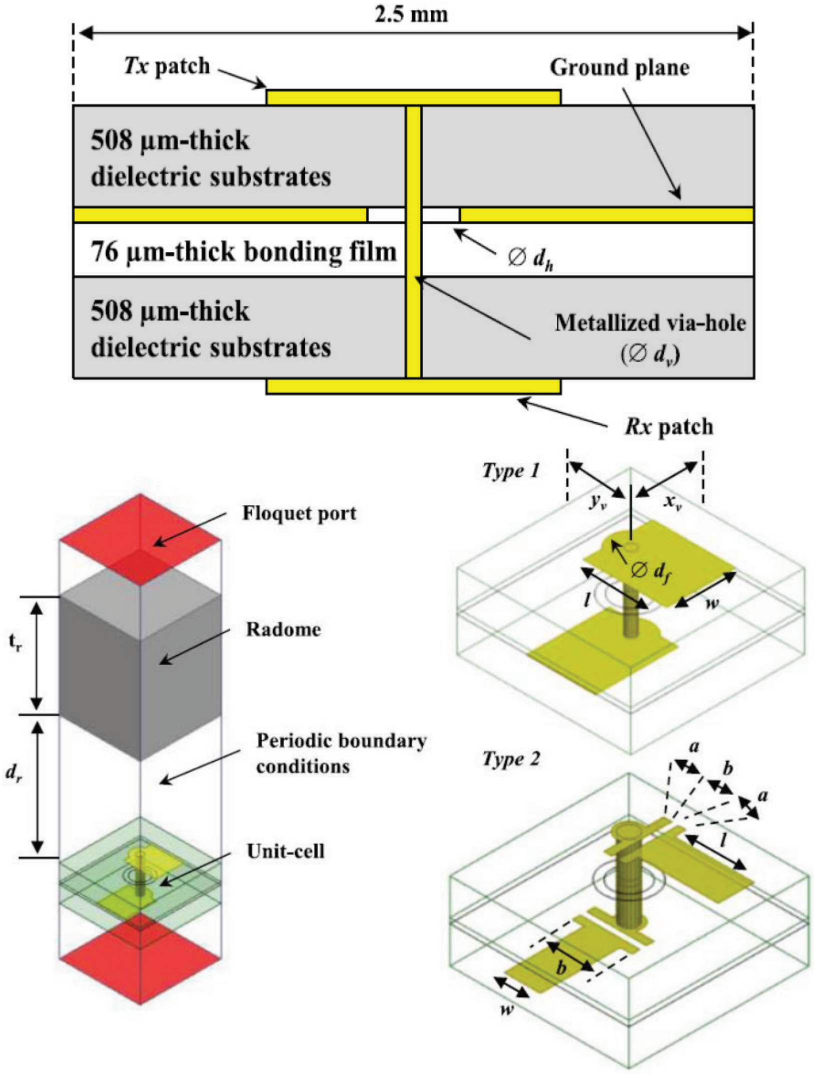


Figure 9. Unit cell cross sectional, detailed pattern and electromagnetic simulation setup with random [14].

At last, the transmission phase is presented in **Figure 10(c)** which illustrates the phase shift of 45° between each unit cell phase resulting in a 3-b phase quantization. As a matter of fact, the transmission coefficient and phases are roughly stabled up to 40° under oblique incident wave as well as investigation in [18, 19].

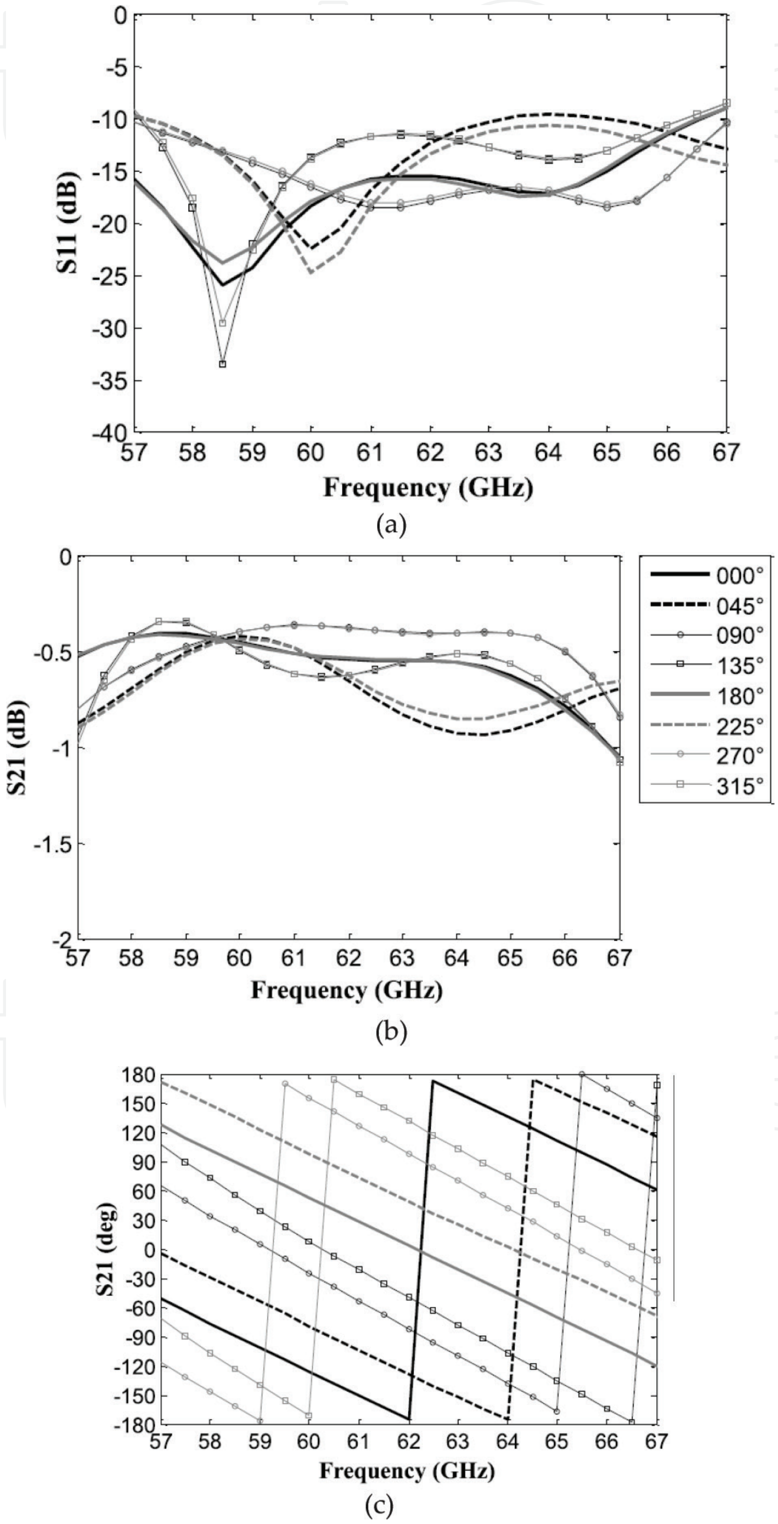


Figure 10. Amplitude of the (a) reflection, (b) transmission coefficient and (c) transmission phase of the unit cell [14].

2.3.1.2. Design and characterization

The simulated frequency response of the transmitarray structure is shown in **Figure 11** for three different array diameters (D). Obviously, it can be found that by reducing the diameter, the maximum gain is reduced, as well. In addition, the transmitarray frequency response is

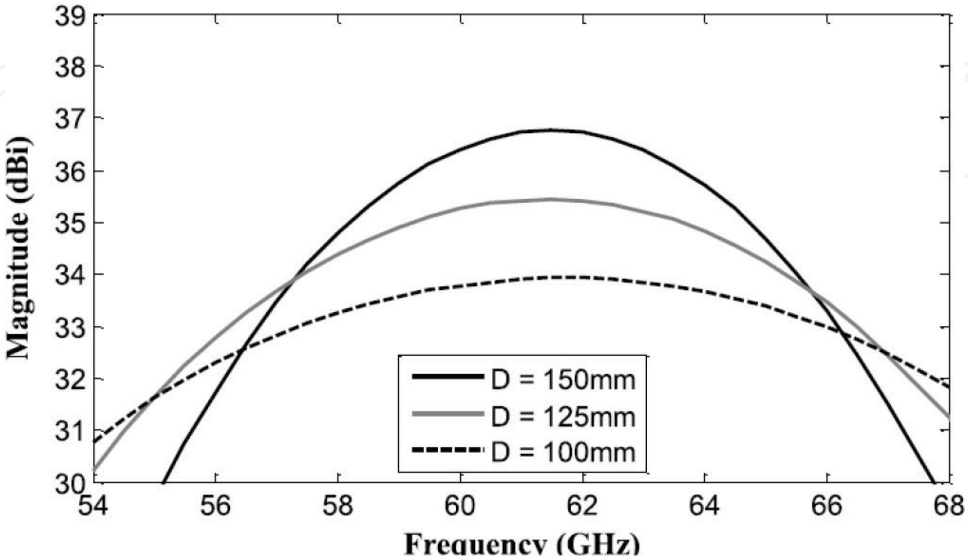
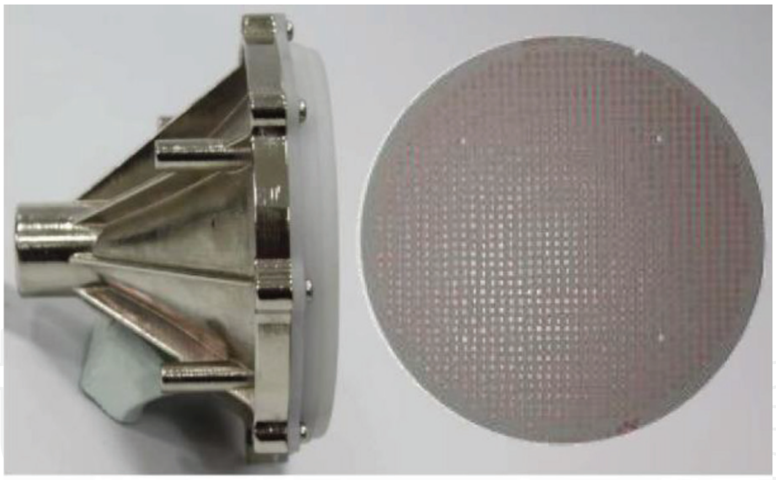
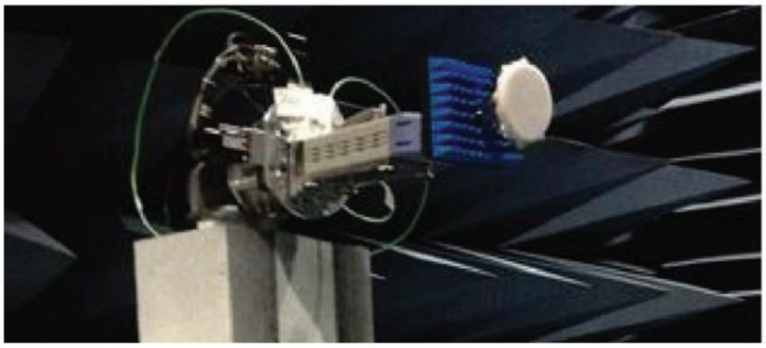


Figure 11. Transmitarray frequency response as a function of the array diameter using the method described in [19].



(a)



(b)

Figure 12. (a) Fabricated antenna and (b) the transmit array antenna in chamber room during measurement process [14].

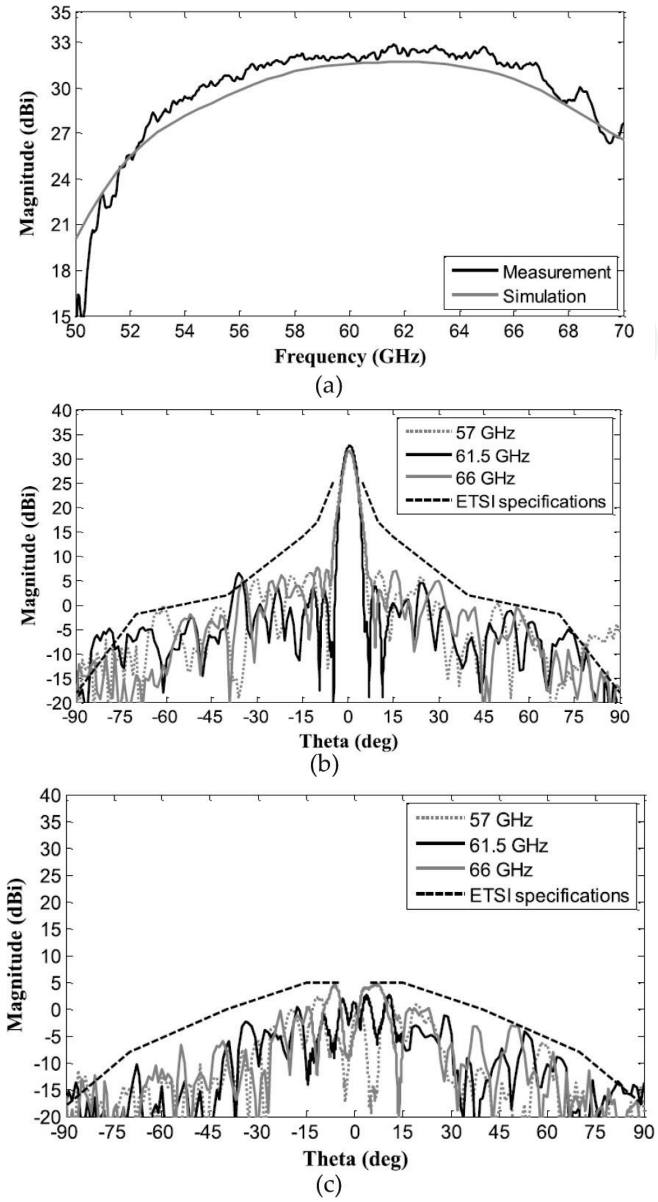


Figure 13. (a) Measured and simulated broadside gain; measured radiation pattern of the linearly polarized transmitarray in (b) co-polar and (c) cross-polar situations [17].

approximately flattened across a stabled gain over the bandwidth of 57–66 GHz. The stabled frequency response can be justified through discussing the phase shift behavior of the unit cell and calculated phase compensation at central frequency 61.5 GHz. In fact, the phase error which is defined as the difference between the calculated phase compensation at a central frequency and at a frequency different from the optimization one increases and a reduction in gain is generated. According to the gain reduction, the true-time-delay technique can be performed which is demonstrated in [20].

2.3.1.3. Fabricated transmit array and experimental results

Figure 12 presents the fabricated 100 mm diameter linearly polarized transmitarray antenna. In order to verify the simulation procedure, **Figure 13(a)** shows the maximum gain in the broadside direction. It can be found that a maximum gain of 32.5 dBi has been obtained with a bandwidth of 15.4% (57–66.5 GHz) through an aperture efficiency of 42.7%. The results of the simulation and measurement are roughly the same, but there are some differences, which have been undertaken. The first one is considering an infinite array of identical elements in simulation procedure. The second is about the non-constant distance between the radome and the planar array, which confirms the mechanical constraints. The measured gain radiation pattern (H-plane) for co- and cross-polar is presented in **Figure 13(b)** and **(c)**. It can be seen that cross polarization discrimination higher than 31 dB has been obtained at three different frequencies (57, 61.5 and 66 GHz).

Although the designed linearly polarized transmit array antenna has been characterized in V-band, a tradeoff between aperture efficiency and array sized is done to guarantee the bandwidth. For this purpose, the designed structure presents a broadside gain of 32.5 dBi at 61.5 GHz with an aperture efficiency of 42.7%. Moreover, the fractional bandwidth of 15.4% from 57 to 66.5 GHz has been obtained across the proposed gain.

3. Conclusion

Many technologies have been introduced and developed for the fifth-generation networks. They are either the evolved shapes of the previous generations technologies or sometimes new. In this chapter we first explained different performance, application and types of antennas used in various frequency bands of fifth generation cellular networks and some works have been discussed in each section. Antennas in frequency bands of less than 15 GHz, which equal to less than 1/20 wavelength, uses new structures to improve bandwidth, beam rotation and energy concentration as well. But for antennas in frequency range of 15–30 GHz and upper than 40 GHz or millimeter-wave antennas, the main issue is the appropriate size of antenna while achieving a good radiation performance. Therefore, in these frequencies horn antennas, MIMO antennas, dielectric resonator antennas and phased array antennas are widely used, so that a reasonable bandwidth can be obtained by beam rotating characteristic of the mentioned antennas. Moreover, by making changes on these antennas or by combining different types, it would be possible to enhance antenna characteristics such as production cost, design and production complexity, physical size, etc. multiband performance of the antenna can be argued from different aspects; such that this antenna can eliminate the need to several antennas hence less space will be occupied. Based on the different frequency band of the fifth generation which were explained separately in this chapter, it can be inferred that in the lower band good performance is also required in addition to a small size antenna, while in the upper bands, antenna is small but has a low quantitative and qualitative efficiency, therefore, it requires the use of larger antennas such as horn antennas. Also it should be noted that in these three cases (three frequency bands) MIMO, array and SIW structures are widely used.

Author details

Kioumars Pedram*, Mohsen Karamirad and Negin Pouyanfar

*Address all correspondence to: pedram.qmars@gmail.com

Department of Electrical Engineering, Urmia University, Urmia, Iran

References

[1] Lai HW, Wong H. Substrate integrated magneto-electric dipole antenna for 5G Wi-fi. IEEE Transactions on Antennas and Propagation. 2015;**63**:870-874

[2] Honari MM, Mirzavand R, Melzer J, Mousavi P. A new aperture antenna using substrate integrated waveguide corrugated structures for 5G applications. IEEE Antennas and Wireless Propagation Letters. 2017;**16**:254-257

[3] Ban Y-L, Li C, Wu G, Wong K-L. 4G/5G multiple antennas for future multi-mode smartphone applications. IEEE Access. 2016;**4**:2981-2988

[4] Ali M. Advanced 5G Substrates with Integrated Antennas [thesis]. Atlanta, Georgia: Georgia Institute of Technology; 2017

[5] Saada MHA. Design of Efficient Millimeter Wave Planar Antennas for 5G Communication Systems. Gaza: The Islamic University; 2017

[6] Ojaroudiparchin N, Shen M, Fr G. Multi-layer 5G mobile phone antenna for multi-user MIMO communications. In: 2015 23rd Telecommunications Forum Telfor (TELFOR); 2015. pp. 559-562

[7] Chen Z, Zhang YP. FR4 PCB grid array antenna for millimeter-wave 5G mobile communications. In: 2013 IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-BIO); 2013. pp. 1-3

[8] Alreshaid T, Hammi O, Sharawi MS, Sarabandi K. A millimeter wave switched beam planar antenna array. In: 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting; 2015. pp. 2117-2118

[9] Yu LC, Kamarudin MR. Investigation of patch phase array antenna orientation at 28GHz for 5G applications. Procedia Computer Science. 2016;**86**:47-50

[10] Ta SX, Choo H, Park I. Broadband printed-dipole antenna and its arrays for 5G applications. IEEE Antennas and Wireless Propagation Letters. 2017;**16**:2183-2186

[11] Asaadi M, Sebak A. High-gain low-profile circularly polarized slotted SIW cavity antenna for MMW applications. IEEE Antennas and Wireless Propagation Letters. 2017; **16**:752-755

[12] Ashraf N, Haraz O, Ashraf MA, Alshebeili S. 28/38-GHz dual-band millimeter wave SIW array antenna with EBG structures for 5G applications. In: 2015 International Conference on Information and Communication Technology Research (ICTRC); 2015. pp. 5-8

[13] Pedram K, Karamirad M, Ranjbaran SMH. A novel circular polarization MIMO antenna in 60 GHz technology. In: 2017 IEEE 4th International Conference on Knowledge-Based Engineering and Innovation (KBEI); 2017. pp. 0335-0338

[14] Jouanlanne C, Clemente A, Huchard M, Keignart J, Barbier C, Le Nadan T, et al. Wideband linearly polarized transmitarray antenna for 60 GHz backhauling. IEEE Transactions on Antennas and Propagation. 2017;**65**:1440-1445

[15] Kaouach H, Dussopt L, Lanteri J, Koleck T, Sauleau R. Wideband low-loss linear and circular polarization transmit-arrays in V-band. IEEE Transactions on Antennas and Propagation. 2011;**59**(7):2513-2523

[16] Di Palma L, Clemente A, Dussopt L, Sauleau R, Potier P, Pouliguen P. Circularly polarized transmitarray with sequential rotation in Ka-band. IEEE Transactions on Antennas and Propagation. 2015;**63**(11):5118-5124

[17] Fixed Radio Systems; Characteristics and Requirements for Point-to-Point Equipment and Antennas; Part 4-2: Antennas; Harmonized EN Covering the Essential Requirements of Article 3.2 of the R&TTE Directive, document EN 302 217-4-2 V1.5.1. ETSI; 2010

[18] An W, Xu S, Yang F. A two-layer transmitarray antenna. In: Proceedings of the IEEE Antennas and Propagation Society International Symposium (APSURSI); Memphis, TN, USA. July 2014. pp. 864-865

[19] Clemente L, Dussopt R, Sauleau PP, Pouliguen P. Wideband 400-element electronically reconfigurable transmitarray in X band. IEEE Transactions on Antennas and Propagation. 2013;**61**(10):5017-5027

[20] Clemente L, Dussopt R, Sauleau PP, Pouliguen P. Focal distance reduction of transmit-array antennas using multiple feeds. IEEE Antennas and Wireless Propagation Letters. Nov. 2012;**11**(11):1311-1314