Wasit Journal of Engineering Sciences

Journal homepage: https://ejuow.uowasit.edu.iq

A Review of mm-wave Antenna Design at 60 GHz for 5G Applications System

Nada N. Tawfeeq[1] | Atheed H. Sallomi[2] |

Affiliations
[1,2] Electrical department,

Mustansiriyah University, Baghdad,

Iraq

Correspondence
Nada N. Tawfeeq,
Mustansiriyah University, Baghdad,
Iraq
Email:
nada.nasih@uomustansiriyah.edu.iq

Accepted
5-January-2024
Doi: 10.31185/ejuow.Vol12.Iss1.538

Abstract
The rapid advancement of mobile technology is closely tied to developments in electronic circuit designs and computer science. As a result, it is important to monitor the progress of antenna systems, which form the foundation of wireless technology. Microstrip patch antennas have emerged as a leading design in modern communication methods due to their small size, low cost, and ease of manufacturing. Over the past 40 years, numerous studies have been conducted on antenna systems, and this review article provides a comprehensive overview of the earlier and more recent achievements in microstrip patch antennas in the 60 GHz band, which is a crucial frequency range for fifth-generation (5G) technologies. This article discusses mm-wave antennas operating at 60 GHz and provides brief descriptions of their properties, construction techniques, and some related difficulties.

Keywords: mm wave, microstrip patch antenna (MPA) design, fifth-generation applications.

الخلاصة

تقدم التكنولوجيا المتقدمة للهواتف المحمولة مرتبطة ارتباطًا وثيقًا بتطورات تصميم الدوائر الإلكترونية وعلوم الحاسوب. ونتيجة لذلك، فمن المهم مراقبة تقدم أنظمة الهوائيات، التي تشكل أساس التكنولوجيا اللاسلكية. ظهرت هوائيات الرقاقة الميكروستريب كتصميم رائد في أساليب الاتصال الحديثة بسبب حجمها الصغير وتكلفتها المنخفضة وسهولة تصنيعها. على مدى الأربعين عامًا الماضية، أجريت العديد من الدراسات على أنظمة الهوائيات، ويقدم هذا المقال النظرة الشاملة للإنجازات السابقة والحديثة في هوائيات الرقاقة الميكروستريب في نطاق ٦٠ جيجاهرتز، وهو نطاق تردد حاسم لتقنيات الجيل الخامس. يناقش هذا المقال هوائيات الموجات المليمترية تعمل عند ٦٠ جيجاهرتز ويقدم وصفًا موجزًا لخصائصها وتقنيات البناء وبعض الصعوبات المرتبطة بها.

الكلمات المفتاحية: الموجة المليمترية، تصميم هوائي الرقاقة الميكروستريب (MPA)، تطبيقات الجيل الخامس.

1. INTRODUCTION

Among the most researched fields in today's communication systems is the wireless standard. The development of millimeter wave frequency for 5G applications has been driven by the need to address the challenges, including path losses, the use of superstrates over the mm-wave antennas, the need for conformality to the phone's shapes, the shared volumes with non-mm-wave antennas, and the high screen-to-body ratios [1]. The essential goal about 5G technology is providing higher coverage with minimal power usage and cheap cost by using a band of high-frequency along with large bandwidth for enhancing data transfer data rate [2]. In 2015, the World Radio Communications Conference listed several available for 5G wireless cellular network of (24 – 86) GHz band and considerable bandwidth of 10 GHz using millimeter waves [3]. Microstrip patch antennas (MPA), which are lightweight, small, and incorporated in circuits, are crucial for supporting wireless communication systems' mobile terminals. The creation of an antenna with broad properties, high gain, and the ability to work in high frequencies is being driven by recent trends. As a result, for potential implementation of microstrip antennas, size reduction and capacity improvement have emerged as key layout concerns [4-5]. This paper's goal is to present 60 GHz performance characteristics and design versatility for microstrip patch antennas. In order to provide the viewers a feel of the variety given via an MPA and the possible advantages when set side by side with conventional small-gain designs. The survey examines the most recent advancements about MPAs technology providing advancements in various methodologies. This article addresses the variety of MPA models that are now feasible, very small, compact, wide-band; multi bands MPAs with increased gain to meet the major requirements on mm wave antennas to overcome the challenges that comes with the utilization of 60 GHz band.

2. MICROSTRIP PATCH ANTENNA AT 60 GHZ

As the next-generation wireless technology seeks to cover more customers and even service through a significant increase of mobile implementations, 5G is going to introduce flexibility to mm-wave communications. The advent of 5G grid necessitates antennas with hitherto unknown characteristics on a mobile station, including beamforming capabilities of the radiating pattern to accomplish spatial scans [6-7]. Such necessity introduces a number of design difficulties to get an acceptable balance between theoretical design problems and practical requirements profile or low-cost production processes. Broadband antennas are necessary for many current and future communication systems, in addition to numerous radar implementations, work over many frequencies. Depending upon the wanted gain and bandwidth improvement techniques already reviewed, several academics started on working on overcoming the innate drawback of the impedance's limited bandwidth, and they achieved some remarkable findings.

2.1.Compact and Low-Profile Models

This section discusses MPA's made for 60 GHz that are either small in size or low profile and emphasizes the bandwidth performance that may be obtained. These designs are compatible with printed circuit board (PCB) technology and are deemed suitable for use in mobile devices like smart-phones and tablets.

2.1.1.Low–Profile Model

MPAs with lower dielectric constants can be developed for purposes that necessitate low antenna layouts. Figure 1 shows the endfire antenna design which consists of metal cap and substrate [8]. The substrate includes microstrip line (MSL), a post-wall waveguide (PWW) and a MSL-PWW adaptation for the antenna feeder. Within the PWW, a matching post is used to cancel reflection. As can be seen, the antenna is made up of a junction in the shape of letter T and two slots to increase the gain and have equal beamwidth in E and H planes. This construction is resistant to manufacturing tolerance and has small dimensions of 8.0×4.5×2.5 mm3 and high gain compared to several reported lower profile MPA designs at high frequencies shown in Table ١.

2.1.2.Compact MPA'S

Wireless technology has advanced significantly, and several cellular gadgets are getting increasingly compact. Size reduction necessitates the use of small antennas. The form of the radiating patch, feed strategy, substrate material, and configuration of parasitic element are recognized to be the key variables influencing the bandwidth of an MPA. A variety of broadband approaches have been developed for the construction of small and broadband patch antennas. Figure 2 depicts a compact design using approaches such as the design structure of substrate-integrated waveguide (SIW) feeder [9]. The feeding structure makes production relatively easy and inexpensive and more suitable for frequency up-conversion due to the demand for accuracy in the manufacturing process employed. In [10] a gridded patch is made up of nine equal rectangular sections spaced by a length substantially less than the wavelength in free-space at a given center frequency. A bonding film has been deployed and a PTFE (polytetrafluoroethylene) substrate to form a structure of compact three-layers observed in figure 3. For the antenna layout, a beam shifting mechanism has been also suggested by joining neighboring outer sections in the gridded patch.

2.2. Wideband MPA's Models

Broadband antennas are important since many wireless applications, both new and old, operate on broadbands. This section presents the MPAs' attainable bandwidth for various bandwidth-enhancing approaches. Because the MPAs' bandwidth is proportional inversely to their dielectric constant, MPAs with small ε_r values provide the optimum wideband efficiency. Various designs on broadband, multiband antennas , different-slot shapes, directional, array design are shown next.

2.2.1.Microstrip patch antenna arrays

A group of two or more antennas is called to by the term antenna array (sometimes known as a phased array. The efficiency of a single antenna is increased by combining or processing the antenna signals. The antenna array might be utilized to: improve overall gain; offer variety reception; and ascertain the orientation of received signal [11] [12]. Linear arrays are employed in situations where fan-shaped radiation patterns are required.

Figure 4 shows a 2×2 sub-array fed a Groove Gap Waveguide (GGW) E-plane corporate feed network. It has the potential of feeding high-gain of 32 dB single-sheet slot array. The distinguishing characteristic of the design is the ability of switching from linear to circular polarization using nails of same bed and wide bandwidth of 9 GHz. As for figure 5, in addition to the use of 8x1 patches that covers a wide bandwidth of 45GHz, a single frequency selective surface FSS is introduced. The spacing between frequency selective surfaces and antennas was shown to have a major influence on providing the optimum performance in terms of gain while maintaining the wide bandwidth.

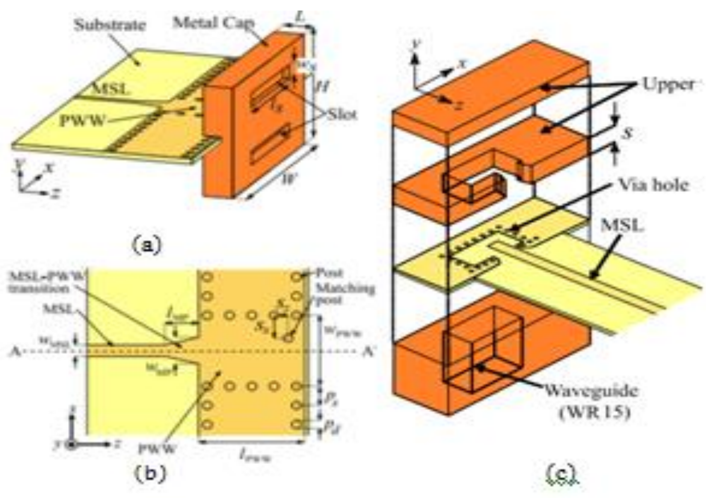
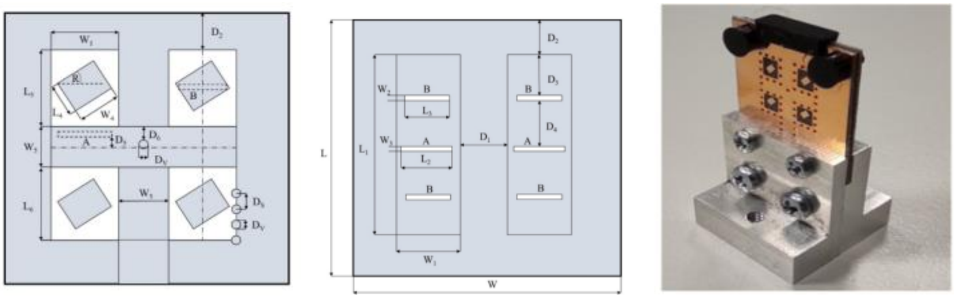
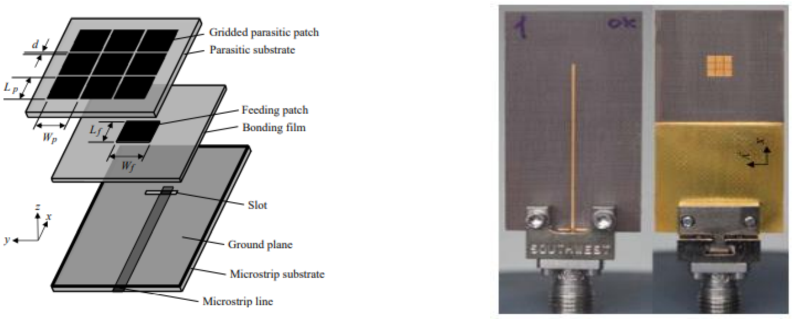


Figure 1 An example of a PCB- integratable metal cap slot antenna: a. antenna in 3-D b. upper view of the substrate c. waveguide microstrip line transition, fc=60 GHz, gain= 7.8 dB, BW=17.8 GHz from [8].



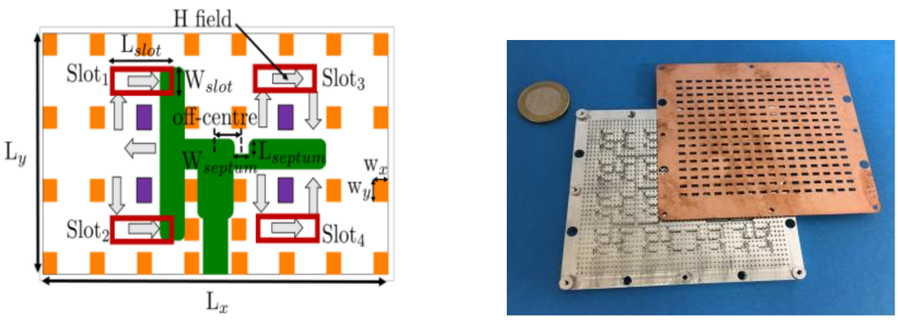
(a) (b) (c)

Figure 2 Antenna design from [9]: (a) top layer (b) bottom layer (c) manufactured array with large SIW via: fc=60 GHz, BW=5.1 GHz.



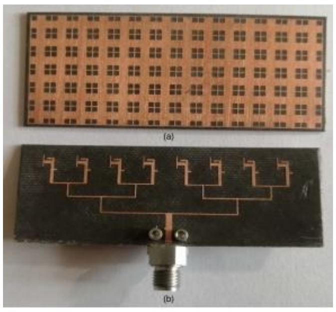
(a) (b)

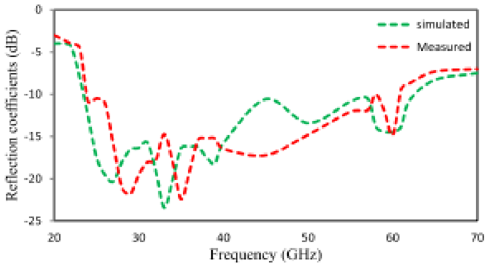
Figure 3 An example of the aperture coupled stacked MSA from [10]: (a) gridded parasitic patch (b) top and bottom views of the fabricated antenna. Fc=60 GHz, Gain= 8 dB, BW=6 GHz.



(a) (b)

Figure 4 Slot-array single-layer antenna from [11]: a. Basic cell of a 2×2 array supplied by GGW. The feeder (green), shortened-nails (purple), aperture (red) and the H-field (arrows) b. Manufactured antenna: fc =55/56 GHz, Gain=32 dBi, BW=9 GHz.





(a) (b)

Figure 5 An example of an array antenna with single layer frequency selective surface (FSS) [12]: a. The 8-elements are fed by one port and the FSS consists of 14 × 6 unit cells b. Comparison of simulated and measured reflection coefficients over very wide bandwidth from 20 GHz to 65 GHz, covering millimeter wave 5G bands (including 28 GHz, 38 GHz and 60 GHz)., fc=60 GHz, gain=15 dB, BW=45 GHz.

2.2.2.Electromagnetic Bandgap (EBG) structures

A group of two or more antennas is called to by the term antenna array (sometimes known as a phased array. The efficiency of a single antenna is increased by combining or processing the antenna signals. The antenna array might be utilized to: improve overall gain; offer variety reception; and ascertain the orientation of received signal [11-12]. Linear arrays are employed in situations where fan-shaped radiation patterns are required as can be depict in figure 6..

2.2.3.MPA's different Slot shape designs

2.2.3.1.Slot resonators MPA’s

The Introduction of slots on the radiating patch not only improves performance and minimize antenna layout but also increases bandwidth. Various mm wave antenna and method designs, reconfigurable, tunable, and array antennas for various purposes are associated with the slot concept. Figures 7 and 8 show antennas with Q and L-square slots in the radiator with microstrip feeder. Further details of the effect of the different shapes of slots on the antenna’s behavior are shown in table 2.

2.2.3.2.Slots in Ground Structure

The main idea of introducing a slot within the ground plane of the MPA, it behaves like some load. It may be utilized to move the input impedance value closer to the characteristic impedance. This optimizes the input impedance match and the return loss (RL). Figure 9 displays a four-element regular patch antenna with Z-shaped slots on the ground plane. A standard patch antenna with four elements and ground plane Z-slots. As shown in Figure 9(b), the addition of a slot in the shape of a Z has increased the resonance frequency and bandwidth of the MPA from 60.7 GHz with a restricted band when the ground plane is full into 60 GHz and a bandwidth of 5.9 GHz.

2.2.4.Reconfigurable designs with beam-steering ability

The capacity to modify the radiation pattern direction has several applications in various systems which need scanning or interfering signal reduction. Beam patterns are adjusted via moving the MPA physically or electronically controlling certain antenna properties. Fig. 10 depicts an example of beam steering capability. The antenna layout starts with a standard circle-shape antenna with an annular slot. Two electronic switches have been used to produce triple distinct beam configurations. Using either switch separately leads to a 70° change in the central radiation pattern path within similar band properties.

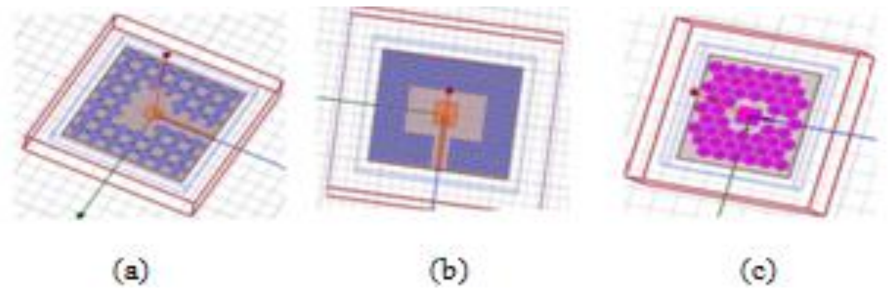


Figure 6 An example of 60 GHz mm-wave MSA with three types of electromagnetic bandgap surface as a ground plane[15]: a. mushroom EBG b. cross EBG c. hexagonal EBG: fc = 60 GHz, Gain=8.3 dB, BW=11 GHz.

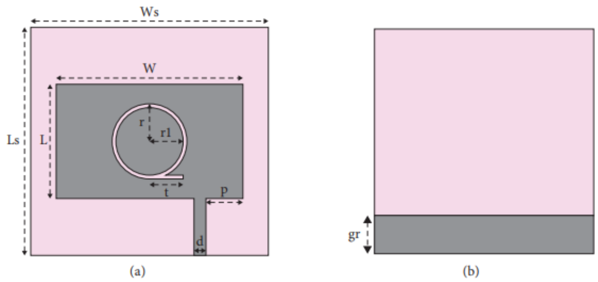


Figure 7 An example of a Q slot mm-wave antenna for body centric communication from [16]: a. top view b. bottom view. Fc=60.06 GHz, Gain=8.62 dB, BW=12.11 GHz.

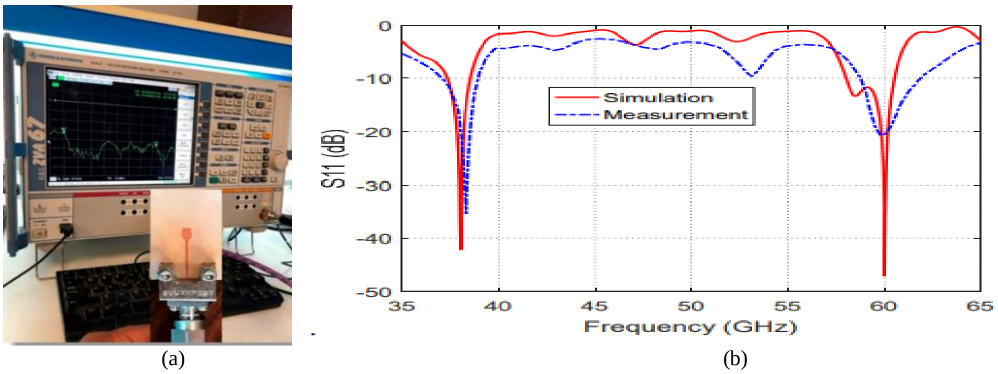


Figure 8 A model of dual-band patch antenna with L and square slots [17]: a. experimental setup b. frequency response S11. f_c = 38,60, Gain = 6.5,5.5 dB BW =2,3.2 GHz.

In [19] a new millimeter wave band with reconfigurable orientation antennas is presented. A multilayered pyramidal Dielectric Resonator Antenna DRA excitation origin is topped with a superstrate of frequency selective surface to form a hybrid antenna. An easy 45° mechanical rotation of the pyramidal DRA allows that device to change from circular to linear polarization as seen in Figure 11.

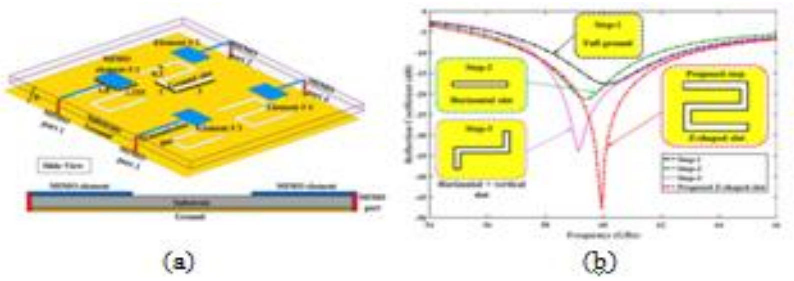
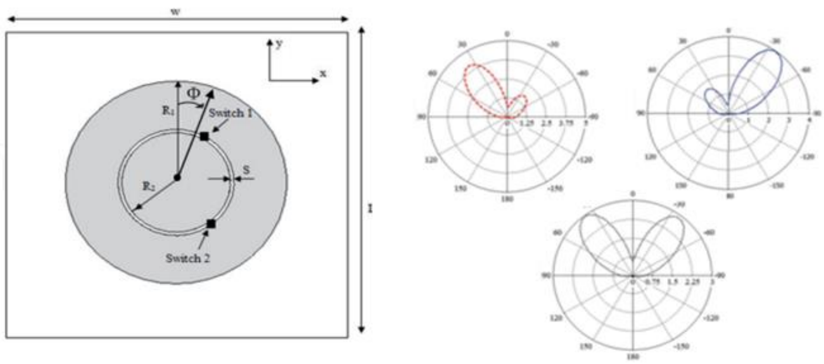


Figure 9 An example of MIMO antenna of four-elements and Z slots on the ground plane: a. 3 D view b. effect of slot the ground plane on the S11.[18] Fc=60 GHz, Gain=14.8, BW=6 GHz.



(a) (b)

Figure 10 An example of a reconfigurable circle patch MSA [19]: a. the structure of the antenna. b. Radiation patterns in yz-plane in 3 various states. Fc=60 GHz, Gain= 4.8 dB, BW= 2 GHz.

2.2.5.Periodic/fractal designs

Regarding the antennas created at mm-wave bands, there are many issues through the fabrication process such as: micromachining, complexity, cost, and vulnerability. Many design approaches, including the numerous strategies discussed above, are employed simply to enhance the bandwidth of a microstrip antenna. Another approach is by using repetitive shapes.

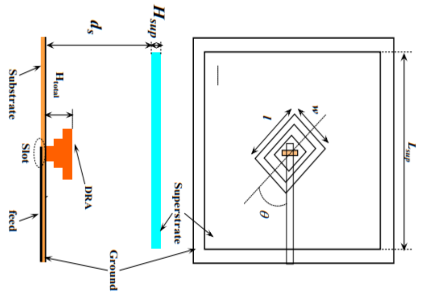


Figure 11 An example of a reconfigurable polarization DRA antenna [20]. Fc=60 GHz, Gain = 18 dB , BW=8 GHz.

In [21], the log-periodic structure where the Yagi-Uda antenna concept influenced antenna geometry. A log-periodic dipole is often constructed from a sequence of dipoles arranged in lateral way to the design axis. The components' various sizes resulted in distinct resonance frequencies, allowing for a broadband functioning. Such addition resulted in a succession of shorter dipoles pointing to the "large side" of the proposed antenna as shown in figure 12. Figure 13 shows a modified antenna design with a typical circular-shaped patch with second fractal circular-shaped patch along with triple elliptical patches to increase the operating range of the antenna. A round slit is carved on the radiating patch to optimize the antenna's radiating pattern.

2.2.6.Multi band microstrip patch antenna

When 5G mobile communication is used, wireless channel capacity may be expanded without the need for extra spectrum or power in scattering-rich situations. This can be accomplished by increasing the number of antennas at the wireless link's transmitter and/or receiver. Because many antennas are needed in a compact system such as a mobile device, the single antenna must be compact and operate at multiple operational frequencies as needed [23-24]. In [25], a patch antenna in the shape of an umbrella has been seen. The design resonates throughout three frequency bands 28, 38, and 55 GHz. A circular patch antenna resonating at a higher frequency of 44 GHz was created. The circular radiator is then etched with two identical rectangular slots, resulting in the construction of a semi-circular-shaped radiator and another band at 30 GHz. A rectangular shaped stub is inserted and two triangular shaped protrusions are incorporated to get the required bands as shown in Figure 14.

Comparatives analysis of different antenna designs for millimeter waves applications are listed in Table 1. The references are sorted in accordance to the array factor. The majority of the 60 GHz antenna models reviewed in the literature utilizes a substrate with a dielectric constant of 2.2. As the number of antenna elements increases, the gain is improved but at the cost of larger dimensions [26-34].

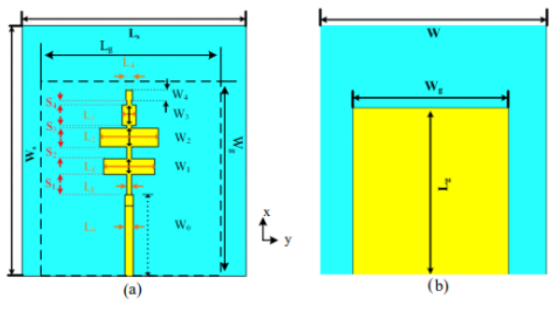


Figure 12 Example of periodic shape antenna [21] (a) top view, and (b) bottom view. Fc= 60 GHz, Gain 11.8 dB, BW=12.4 GHz.

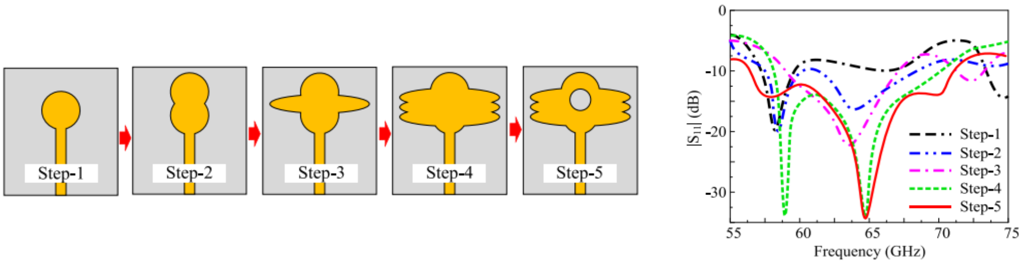


Figure 13 An example of fractal design [22] a. five steps to obtain the antenna's optimum layout b. Return loss comparison of the different design steps. Fc=64.5 GHz , Gain= 10.3 dB, BW=16.1 GHz.

According to [35], the gain and area performance of single element designs are better than those presented in [36-37], but this comes at the expense of bandwidth. Table 2 shows that most of the slot resonators have a single operating frequency and a bandwidth above 2 GHz. However, when combined with an array of elements, the bandwidth of the slot resonators can be widened. In one study [44], using two F-shaped slots resulted in a very low profile antenna with an area of less than 1 mm^2 and high gain compared to other designs.

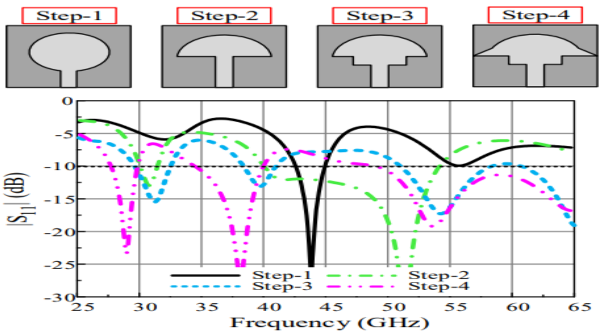


Figure 14 An example of design stages of tri band antenna with return losses. [25] fc=28 GHz, 38 GHz, and 55 GHz, Gain=6.6, 7.0, 7.35, BW=2.3, 5.2, 15.

3. SUMMARY AND CONCLUSION

The antenna field has had a very prosperous time in engineering over the last many years. Technology innovations in some new antennas, such as mm-wave antennas, the wideband, dual-band, multi-band or reconfigurable structures, low profile, compact, impedance bandwidth, high gain or linear/circular polarization implementations, and so on, have contributed to its success. The focus of this article is on antennas that operate in the millimeter wave (mm-wave) frequency band at 60 GHz. The article provides an overview of the properties of these antennas, as well as various construction techniques that are used to make them. Additionally, the article discusses some of the challenges and issues that are associated with mm-wave antennas operating at this frequency.

Table 1 Comparative analysis of different antenna designs for millimetre wave applications

Antenna configuration	F_c (GHz)	ε_r	Area (mm2)	BW (GHz)	Gain (dB)	AF	RL (dB)	Ref
Substrate-integrated waveguide-based	60	-	35 x 56.4	11.5	22.8	8 x 8	-25	[26]
two-layer Liquid Crystal Polymer substrate	55-65	2.9	40.64 x 25.4	10	17.1	8 x 8	<-13	[7]
Circular Contour Feeding Line	60.1	2.2	-	0.3	11	4 x 3	-20.2	[28]
Gridded Parasitic Patch Stacked	60	2.2	20 x 20	15.6	8.6	3 x 3	-35	[29]
Pattern Reconfigurable Wideband Stacked	60	2.2	20 X 40	10	8.5	3 x 3	-35	[30]
double feeding proximity coupling structure	45, 57, 66	3	10 × 5	3, 5, 3	5.6	3 x 3	-38	[31]
transparent patch antenna array	60	3.75	25 x 25	-	15.6	4 x 2	-30	[32]
MPAA with FSSs	60	2.2	-	1.65	17.2	4 x 1	-36	[33]
Monopole Antenna	60	3.55	12 × 9.6	6.6	11.6	1 x 2	-25	[34]
I-shaped MPA	60	2.2	5.576 x4.3	3.03	10.1	N/A	-40	[35]
End-Fire Tapered Slot	60	3.66	15 x 15	13	10.54	N/A	-30	[36]
extended aperture - inspired circular patch	60	2.2	13 x 12	16.1	10.3	N/A	-30	[37]
X-band rectangular MPA	60	2.98	6.23 x 6.7	11.57	6.92	N/A	-32	[38]
Pharaonic Ankh-key Broadband Antenna	60- 72	2.2	7.5 x 7.5	12	8.4	N/A	-20.2	[39]

Table 2 Comparative analysis of various slot shapes at 60 GHz

Slot shape	MPA configuration	F_c (GHz)	ε_r	Gain (dB)	Area (mm^2)	BW (GHz)	Ref.
asymmetrical U- slot	single-layer	5.5-5.9 /55-95	2.2	9/9	50 x 40	4/40	[40]
circular slot	E-shaped patch 2x2 array	60	3.27	11.42	6.4 x 6.4	15	[41]
Q slot	Rectangular MPA	60	4.3	8.62	12.9 × 14	12.11	[15]
Printed U- slot	Dielectric Resonator Antenna	60	2.2	8.2	9.75 x 7.5	9	[42]

π slot	**SIW Cavity-Backed Antenna**	**60**	**N/A**	**17.92**	**13 x 10.7**	**8**	**[43]**
Double F-slot	**Rectangular MPA**	**59.93**	**11.9**	**5.4**	**0.98 x 0.62**	**4.028**	**[44]**
H and E slots	**Rectangular MPA**	**60**	**2.2**	**5.48**	**8 x 8**	**4**	**[45]**
Square and L slots	**Two rectangular**	**38,60**	**3**	**6.5,5.5**	**15 x 25**	**2,3.2**	**[16]**
Ring slot	**Circular disk patch**	**60**	**2.3**	**4.8**	**5.4 x 5.4**	**2**	**[18]**

REFERENCES

[1] H. Huang, "Evolution of millimeter-wave antenna solutions and designs to Ccellular Phones," *IEEE Access.*, vol. 8, pp. 187615-187622, 2020, doi: 10.1109/ACCESS.2020.3027424.

[2] A. Benjebbour, K. Saito, Y. Saito, and Y. Kishiyama, "5G radio access technology, " *NTT Docomo Technical Journal*, vol. 17, pp. 16-28, 2016.

[3] N. Cardona, L.M. Correia, and D. Calabuig, "Key enabling technologies for 5G: millimeter-wave and massive MIMO," *International Journal of Wireless Information Networks,* vol. 24, pp. 201–203, 2017, doi:10.1007/s10776-017-0366-z.

[4] W. An, X. Zhang, X. Luo, Y. Wang, J. and L. Xiong, "60-GHz Double-layer transmitarray antenna using complementary structure," *Frontiers in Physics*, vol. 10, p. 883686, 2022, doi:10.3389/fphy.2022.883686

[5] A. Mohammed, S. Kamal, M. Bin Ain, F. Najmi, Z. Ahmad, Z. Zahar, R. Hussin, I. Zubir, and M. Rahman, M. "Improving the gain performance of air substrate patch antenna array using the effect of conductive material thickness study for 5G applications," *Journal of Physics: Conference Series*, vol. 1529, p. 052020, 2020, doi: 10.1088/1742-6596/1529/5/052020.

[6] S.R. Thummaluru, R. Kumar, and R.K. Chaudhary, "Isolation and frequency reconfigurable compact MIMO antenna for wireless local area network applications," *IET Microw; Antennas and Propagation*, vol. 13, pp. 519–525, 2019, doi: 10.1049/iet-map.2018.5895.

[7] M. Abirami, "A review of patch antenna design for 5G," *In Proceedings of the 2017 IEEE International Conference on Electrical, Instrumentation and Communication Engineering (ICEICE),* pp. 1–3, 2017, doi: 10.1109/ICEICE.2017.8191842.

[8] T. Tomura, T. Hirayama, and H. Hirokawa, "A PCB-Integratable metal cap slot antenna for 60-GHz band mobile terminals," *IEICE Transactions on Communications,* vol. 102, No. 2, pp. 317-323, 2018, doi: 10.1587/transcom.2018EBP3070.

[9] J. Spurek, and Z. Raida, "SIW-based circularly polarized antenna array for 60 GHz 5G band: feasibility

study," *Sensors*, vol. 22, No. 8, p. 2945, 2022, doi: 10.3390/s22082945

[10] A. Bondarik, and D. Sjoberg , "Gridded Parasitic Patch Stacked Microstrip Antenna with Beam Shift Capability for 60 GHz Band," *Progress In Electromagnetics Research B*, Vol. 62, pp. 319-331, 2015.

[11] W. E. McKinzie, D. M. Nair, B. A. Thrasher, M. A. Smith, E. D. Hughes and J. M. Parisi, "60-GHz 2 x 2 LTCC patch antenna array with an integrated EBG structure for gain enhancement," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1522-1525, 2016, doi: 10.1109/LAWP.2016.2517141.

[12] R. Ullah et al., "Wideband and high gain array antenna for 5G smart phone applications using frequency selective surface," *in IEEE Access*, vol. 10, pp. 86117-86126, 2022, doi: 10.1109/ACCESS.2022.3196687

[13] M. J. Al-Hasan, T. A. Denidni and A. R. Sebak, "A new UC-EBG based-dielectric resonator antenna for millimeter-wave applications," IEEE International Symposium on Antennas and Propagation, vol. 2011, pp. 1274-1276, 2011, doi: 10.1109/APS.2011.5996520.

[14] G. K. Palikaras, A. P. Feresidis, and C. G. Parini, "Advances in conformal metamaterial antennas using high impedance (HIS) and electromagnetic bandgap (EBG) surfaces," *Antennas and Propagation (EUCAP) Proceedings of the 5th European Conference,* pp. 3466 – 3469, 2011.

[15] U. Sana, U. Sadiq & K. Shahbaz, "Design and analysis of a 60 GHZ millimeter wave antenna," *Jurnal Teknologi*, vol. 78, pp. 63-68, 2016.

[16] M. Khan, K. Islam, N. Shovon, M. Baz, and M. Masud, "Design of a novel 60 GHz millimeter wave Q-slot antenna for body-centric communications," *International Journal of Antennas and Propagation, vol. 2021*, pp. 1-12, 2021, doi: 10.1155/2021/9795959.

[17] M. H. Sharaf, A.I. Zaki, R. K. Hamad, and M. M. Omar, "A novel dual-band (38/60 GHz) patch antenna for 5G mobile handsets.," *Sensors,* vol. 20, pp. 1-19, 2020.

[18] S. Ullah, WH. Yeo, H. Kim, et al. "Development of 60-GHz millimeter wave, electromagnetic bandgap ground planes for multiple-input multiple-output antenna applications," Sci Rep 10, 8541, 2020, doi: 10.3390/s20092541.

[19] Y. I. Al-Yasir, H. A. Al-Behadili, B. A. Sawadi, N. O. Parchin, A. M. Abdulkhaleq, A. S. , Abdullah, and R. A. Abd-Alhameed, "New radiation pattern-reconfigurable 60-GHz antenna for 5G communications," *Chapter New Radiation Pattern-Reconfigurable 60-GHz Antenna for 5G Communications.* 2019.

[20] T. Elkarkraoui, G. Y. Delisle, and N. Hakem, "60 GHz polarization reconfigurable DRA antenna," *Open Journal of Antennas and Propagation,* vol. 4, pp. 176-189, 2016, doi: 10.4236/ojapr.2016.44014.

[21] K. Issa H. Fathallah, MA. Ashraf, H. Vettikalladi, S. Alshebeili, "Broadband high-gain antenna for millimetre-wave 60-GHz band," *Electronics,* vol. 8, p. 1246, 2019, doi: 10.3390/electronics8111246.

[22] M. Hussain, S. M. Rizvi, A. Abbas, A. Nadeem, I. Alam and A. Iftikhar, "A wideband antenna for V-

band applications in 5G communications," *2021 International Bhurban Conference on Applied Sciences and Technologies (IBCAST),* pp. 1017-1019, 2021, doi: 10.1109/IBCAST51254.2021.9393018.

[23] S.R Thummaluru, R. Kumar, RK Chaudhary, "Isolation and frequency reconfigurable compact MIMO antenna for wireless local area network applications," *IET Microwaves, Antennas Propagation,*vol. 13, pp. 519–525, 2019, doi: 10.1049/iet-map.2018.5895.

[24] M. Abirami, "A review of patch antenna design for 5G," *In Proceedings of the 2017 IEEE International Conference on Electrical, Instrumentation and Communication Engineering (ICEICE),* pp. 1–3, 2017.

[25] M. Hussain, S. Jarchavi, S. Naqvi U. Gulzar S. Khan, M. Alibakhshikenari and I. Huynen, "Design and fabrication of a printed tri-band antenna for 5G applications operating across Ka-, and V-band spectrums," *Electronics,* 10, pp 1-10, 2021, doi.org/10.3390/electronics10212674.

[26] S. Liao, P. Chen, P. Wu, K. M. Shum, and Q. Xue, "Substrate-integrated waveguide-based 60-GHz resonant slotted waveguide arrays with wide impedance bandwidth and high gain," *IEEE Transactions on Antennas and Propagation,* vol. 63,pp. 2922-2931, 2015, doi: 10.1109/TAP.2015.2423696.

[27] G. Zhang, S. Pu, X. Xu, Y. Liu, and C. Wang, "Design of 60-GHz microstrip antenna array composed through circular contour feeding line," *2016 Asia-Pacific International Symposium on Electromagnetic Compatibility (APEMC),* vol. 01, pp. 1010-1013, 2016, 10.1109/APEMC.2016.7522931.

[28] I. Fitri, and T. A. Akbar, "A new gridded parasitic patch stacked microstrip antenna for enhanced wide bandwidth in 60 GHz band," 2017 International Conference on Broadband Communication, Wireless Sensors and Powering (BCWSP), pp. 1-4. 2017, doi: 10.1109/BCWSP.2017.8272571.

[29] A. Bondarik, and D. Sjöberg, "Pattern reconfigurable wideband stacked microstrip patch antenna for 60 GHz band," *International Journal of Antennas and Propagation,* vol. 2016, pp. 1-11, 2016, https://doi.org/10.1155/2016/5961309.

[30] A. Firdausi, G. Hakim, and M. Alaydrus, "Designing a tri-band microstrip antenna for targetting 5G broadband communications. *MATEC Web of Conference EDP Sci 218,* pp. 03015, 2018, doi: 10.1051/matecconf/201821803015.

[31] A. Martin, O. Lafond, M. Himdi, and X. Castel, " Improvement of 60 GHz transparent patch antenna array performance through specific double-sided micrometric Mesh Metal Technology," *IEEE Access,* vol. 7, pp 2256-2262, 2019.10.1109/ACCESS.2018.2886478.

[32] E. Hussein, and N. Qasem, "Design and optimization of rectangular microstrip patch array antenna using frequency selective surfaces for 60 GHz," *International Journal of Applied Engineering Research.* Vol. 11. pp. 4679-4687, 2016.

[33] T. S. Mneesy, R. K. Hamad, A. I. Zaki, and W. A. E. Ali, "A novel high gain monopole antenna array for 60 GHz millimeter-wave communications. Applied Science, vol. 10, p. 4546. 2020, doi: 10.3390/app10134546.

[34] M. Saeed, “Design and simulation of rectangular microstrip patch antennas (45 GHz and 60 GHz) for V-band applications,” *Passer Journal,* vol. 4, pp. 100-104, 2022, doi: 10.24271/psr.2022.333252.1124.

[35] N. Wang, and G. Peng , "A 60 GHz End-fire high-gain tapered slot antenna with side-lobe suppression," *Progress In Electromagnetics Research Letters,* vol. 55, pp. 145-151, 2015, doi: 10.2528/PIERL15070702.

[36] M. Hussain, S. Naqvi, W. Awan, W. Ali, E. Ali, S. Khan, and M. Alibakhshikenari, (2021). “Simple Wideband Extended Aperture Antenna-Inspired Circular Patch for V-band Communication Systems,” *AEU - International Journal of Electronics and Communications,* vol. 144, p. 154061, 2022, doi: 10.1016/j.aeue.2021.154061.

[37] M. Rabbani, and H. Ghafouri-Shiraz, “Improvement of microstrip patch antenna and bandwidth at 60GHz and X bands for wireless applications,” *IET Microwaves, Antennas and Propagation,* vol. 10, no. 11, pp. 1167-1173, 2016, doi: 10.1049/iet-map.2015.0672.

[38] M. Noha, M. Rashad, W. Swelam, M. H. Abd El Azeem, “Pharaonic Ankh-Key millimeter wave broadband antenna design and fabrication for 5G applications,” IEEE Transaction on Antenna and Propagation, vol. 8, pp. 341-452, 2017, doi: 10.1109/APUSNCURSINRSM.2017.8073336.

[39] J. Saini, and S. K. Agarwal “Design a single band microstrip patch antenna at 60 GHz mllimeter wave for 5G application”, *International Conference on Computer, Communications and Electronics (Comptelix),* pp. 227-230, 2017, doi: 10.1109/COMPTELIX.2017.8003969.

[40] T. Jang and C. S. Park, "60-GHz Wideband L-Probe Circular Slotted E-Shaped Patch Antenna Array," *in IEEE Access,* vol. 10, pp. 79939-79947, 2022, doi: 10.1109/ACCESS.2022.3194708.

[41] T. Elkarkraoui, G. Y. Delisle, and N. Hakem, “60 GHz polarization reconfigurable DRA antenna,” *Open Journal of Antennas and Propagation,* vol. 4, pp. 176-189, 2016, doi: 10.4236/ojapr.2016.44014.

[42] N. Mungaru, and T. Shanmuganantham, “Back to Back Pi-Shaped Slot with SIW Cavity-Backed Antenna for 60 GHz Applications,” *International Journal of Microwave and Optical Technology,* vol. 14, pp. 402-408, 2019.

[43] F. Ahmad, and B. Tlili, “Design and analysis of millimeter wave double F slot patch antenna for future 5G wireless communication,” *International Conference on Electrical and Computing Technologies and Applications (ICECTA),* pp. 1-4, 2017, doi: 10.1109/ICECTA.2017.8252049.

[44] J. Saini and S. K. Agarwal, "Design a single band microstrip patch antenna at 60 GHz millimeter wave for 5G application," *International Conference on Computer, Communications and Electronics,* vol. 2017, pp. 227-230, 2017, doi: 10.1109/COMPTELIX.2017.8003969