Antennas and Arrays for 60 GHz High Data Rate Wireless Applications

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Cite as: P. Kumar, Antennas and Arrays for 60 GHz High Data Rate Wireless Applications, *International Journal on Communications Antenna and Propagation (IRECAP)*, vol. 9, no. 4, pp. 255-262, 2019.
doi: https://doi.org/10.15866/irecap.v9i4.14473

Abstract – The 60 GHz band has approximately 7 GHz bandwidth with the frequency range 57 − 64 GHz worldwide. This band is an unlicensed band and the research for this band is going on very rapidly since last few years. This paper presents the technical review of high data rate 60 GHz technology and the development of antennas and arrays for 60 GHz applications. The paper covers the introduction to 60 GHz bands for various regions. The advantages, disadvantages and potential applications of 60 GHz technology are discussed. The detailed propagation characteristics of 60 GHz band are presented and analyzed. Based upon analysis of propagation characteristics of 60 GHz band, the requirements for antenna design is discussed. The antennas and arrays design along with the challenges in antenna and array design for 60 GHz technology is presented. The detailed review of various types of 60 GHz antennas and arrays such as high gain antennas, 60 GHz antenna arrays, switched beam array systems, phased array systems etc are discussed and analyzed. Performance comparison of various antennas and arrays is also presented in this communication. The presented 60 GHz technology introduction, propagation characteristics analysis, antenna design types, parameters analysis, challenges etc are helpful in the antennas and arrays design for 60 GHz high data rate wireless systems.

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Keywords: *60 GHz technology, 60 GHz band, antenna and array design*.

I. Introduction

There is always the demand of high data rate and wide bandwidth in wireless communication systems. The 60 GHz band ranging from 57 GHz to 64 GHz is allotted by the Federal Communication Commission (FCC) as unlicensed band. The 60 GHz band provides the wide bandwidth of 7 GHz. In last few years, the researchers has given attention for designing various antennas and arrays for the 60 GHz technology as it provides the advantage of wide bandwidth. The use of 60 GHz frequency band supports the high data rate and the compact size of the wireless systems and antennas. The attenuation due to atmospheric oxygen is for 60 GHz waves is high as compared to the other frequency range, so this band is suitable for short distance communication applications, however for satellite to satellite communication this band can be easily used. So, 60 GHz band attracts the short distance wireless communication applications [1-8]. Due to many advantages of 60 GHz band in modern wireless communications for computers, portable devices in short ranges and high speed data transfer this technology has become a recent topic of research.

This paper presents the technical review to antennas and array design for 60 GHz wireless communication applications. The introduction, advantages, limitation and applications of 60 GHz are presented and discussed. The antennas and arrays for 60 GHz band are discussed in detail. Rest of the paper is organized as follows. Section II discusses the introduction to 60 GHz technology. The propagation characteristics of 60 GHz frequency band are presented in section III. The applications of 60 GHz frequency band have been explored in section IV. The section V discusses the design issues of antennas and arrays for 60 GHz band and conclusion is given in section VI.

II. 60 GHz technology

Using high frequency bands, the goal of high data rate in wireless communication can be achieved. In 2001, Federal Communication Commission allotted around 7 GHz band around 60 GHz worldwide as license free spectrum. The summary of 60 GHz band in different regions is shown in Table I. In Canada, United State of America (USA) and Korea the 60 GHz band is from 57 GHz to 64 GHz, in Europe it is 9 GHz band from 57 GHz to 66 GHz, and in Australia and Japan 60 GHz band is from 59.4 GHz to 62.9 GHz, and from 59 GHz to 66 GHz respectively [4, 8].

TABLE I FREQUENCY BAND OF 60 GHZ FOR VARIOUS REGIONS

S. No.	Region	Frequency range of 60 GHz	Bandwidth
1	Canada and USA	$57-64$ GHz	7 GHz
2	Europe	$57-66$ GHz	9 GHz
3	Japan	$59-66$ GHz	7 GHz
4	Australia	$59.4-62.9$ GHz	3.5 GHz
5	Korea	$57-64$ GHz	7 GHz

III. Propagation characteristics of 60 GHz band

The free space losses are high in 60 GHz band due to its high frequency as compared to the low frequency bands such as ultra-wideband unlicensed band. A comparison of 60 GHz transmission with 2.5 GHz wireless communication is carried out in [9]. In a drywall of thickness 2.5 cm the transmission loss at 60 GHz is 6 dB and at 2.5 GHz the transmission loss is 5.4 dB. The transmission loss of 60 GHz is very high in the office whiteboard of thickness 1.9 cm and it is 9.6 dB, while at 2.5 GHz the transmission loss is 0.5 dB only. The performance of 60 GHz band in terms of transmission loss is better than 2.5 GHz in transparent glass. The transmission loss in transparent glass of thickness 0.3 cm is 3.6 dB and 6.4 dB at 60 GHz and 2.5 GHz, respectively. In mesh glass of thickness 0.3 cm, the transmission loss is 10.2 dB at 60 GHz and 7.7 dB at 2.5 GHz. The transmission loss in clutter is 1.2 dB at 60 GHz and 2.5 dB at 2.5 GHz [9].

IV. Applications of 60 GHz technology

Due to major advantages of large bandwidth, the unlicensed 60 GHz frequency spectrum is suitable for many wireless applications. However, the propagation losses at the 60 GHz band is high, so this frequency band does not attract the long distance wireless applications and suitable for short distance wireless communication only. 60 GHz wireless standards attract this band for short range high speed wireless personal area networks (WPAN) applications and wireless local area networks (WLAN) applications [3]. Due to the favorable characteristics of 60 GHz band, it has the potential for future WiFi applications. The 60 GHz unlicensed frequency band is suitable for many other high speed short distance wireless communication applications [3].

V. Antenna and array design for 60 GHz technology

Antenna is the key component of a wireless communication system, so researchers are continuously working for designing antennas and arrays for 60 GHz applications. As discussed above that the 60 GHz waves are highly attenuated in the atmosphere, so the major challenge in antenna and array design is to achieve high gain, so that the wireless system can be used for long distance application too. Probable solution for achieving high gain in antenna systems are by designing high gain antenna using various techniques, by designing antenna arrays, by designing phased antenna arrays, or by designing switch beam antenna arrays [3].

High gain antennas

Microstrip antennas are suitable for compact wireless applications as these antennas are low profile antennas [10-13]. There is a need of incresing the gain of conventional mocrostrip antenna in order to use for 60 GHz band as low gain is a major limitation of these antennas. Reserachers have proposed many techniques for increseing the gain of these antennas. A 60 GHz Yagi antenna with a 0.18 μm CMOS process was presented in [14]. In this paper, using coplanar waveguide technology, the feeding network is designed and using 0.18 μm CMOS process, the antenna on-chip is fabricated. The voltage standing wave ratio of the antenna is shown in Fig. 2. From Fig. 2, it is observed that the measured and simulated voltage standing wave ratio is less than 2 for the entire 60 GHz frequency band, hence the operating bandwidth is from 55 GHz to 65 GHz. In [15], a high gain microstrip patch antenna is designed for 60 GHz applications. The geometry and the reflection coefficint of the antenna are shown in Fig. 3 and Fig. 4, respectively. By stacking the cavity a maximum gain of 7.6 dBi is achieved. From simulated reflection coefficint of the antenna, it can be observed that the bandwidth of the antenna is approximately from 59.7 GHz to 63 GHz of 60 GHz frequency band. In [16], a high gain fractal microstrip antenna has been designed for 60 GHz frequency band. The antenna structure is shown in Fig. 5. The Minkowski fractal along with superstrate is used and the gain of 14.1 dBi at 60 GHz frequency has been achieved. A wideband microstrip patch antenna is designed for 60 GHz high speed communications in [17]. A U type slot is inserted in the rectangular patch and the antenna is fed by the coaxial probe feeding technique. The structure of the antenna and reflection cofficient of the antenna are depicted in Fig. 6 and in Fig. 7, respectively. A gain of 9.52 dB at 60 GHz with bandwidth of

52.2 GHz – 67.7 GHz is achieved [17]. In [18], a rectangular microstrip antenna is designed and the gain of 7.49 dB is achieved. The antenna structure and reflection coefficinct of the antenna is shown in Fig. 8 and in Fig. 9, respectively. From Fig. 9, it can be observed that the center frequency is 59.968 GHz and bandwidth is approximately from 59.7 GHz to 60.3 GHz. In [19], using photonic band gap crystal the microstrip antenna is designed for 60 GHz wireless communication applications. The geometry and reflection coefficint of the antenna are shown in Fig. 10 and Fig. 11, respectively. The bandwidth of the antenna is approximately from 52 GHz to 64 GHz. The comparative studies of high gain antennas is shown in Table II. It can be observed that the fractal antenna with superstrate technology provides the highest gain for 60 GHz applications and U slot loaded patch antenna provide the large bandwidth.

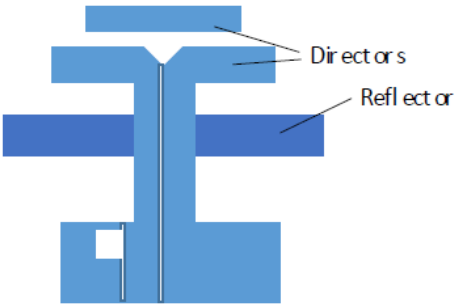


Fig. 1 Yagi antenna structure proposed in [14].

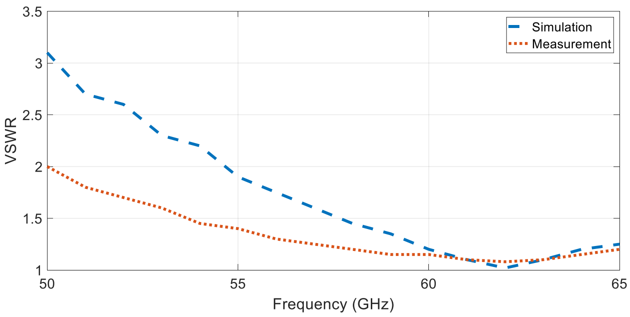
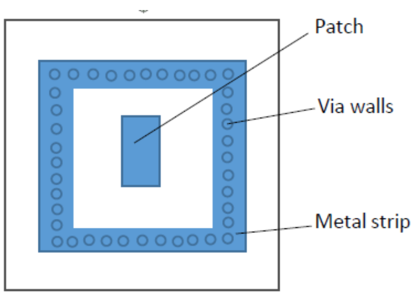


Fig. 2 Simulated and measured VSWR of Yagi antenna [14].



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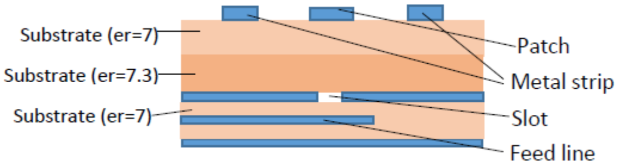

(b)

Fig. 3 The geometry of the patch antenna (a) top view, (b) side view [15].

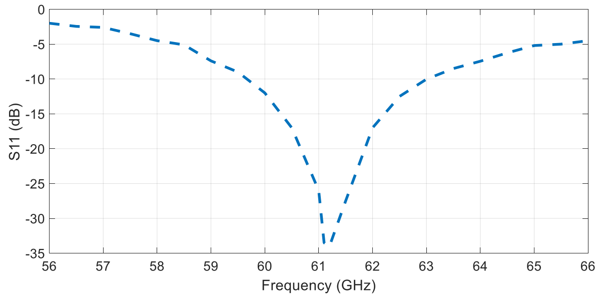

Fig. 4 Simulared refelection coefficient of the antenna [15].

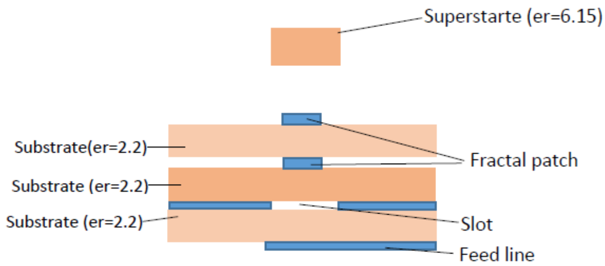

Fig. 5 Structure of the antenna with superstarte [16].

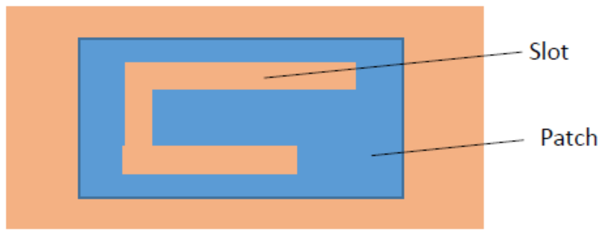

Fig. 6 Geometrical configuration of the antenna [17].

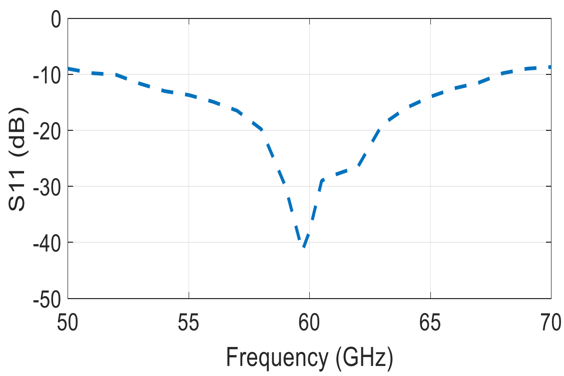

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Fig. 7 Reflection coefficient of the antenna [17].

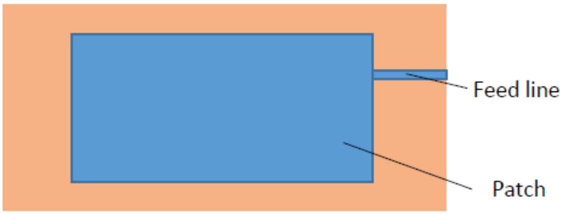


Fig. 8 Rectangular microstrip antenna [18].

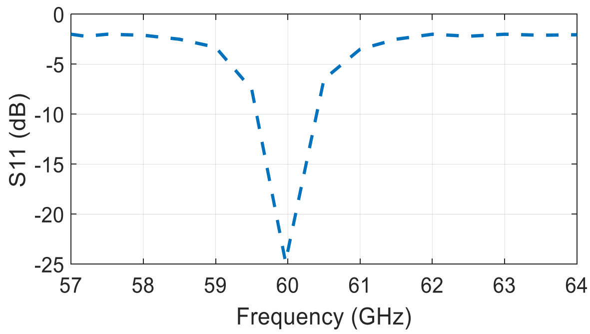


Fig. 9 Reflection coefficient of rectangualr microstrip antenna [18].

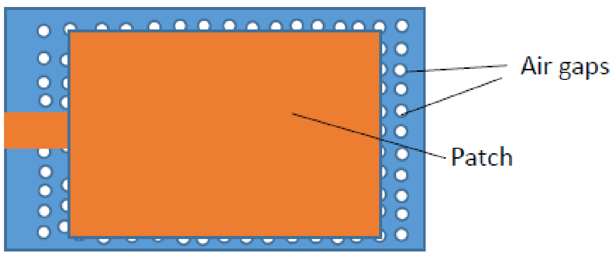


Fig. 10 Microstrip antenna using photonic band gap crystal [19].

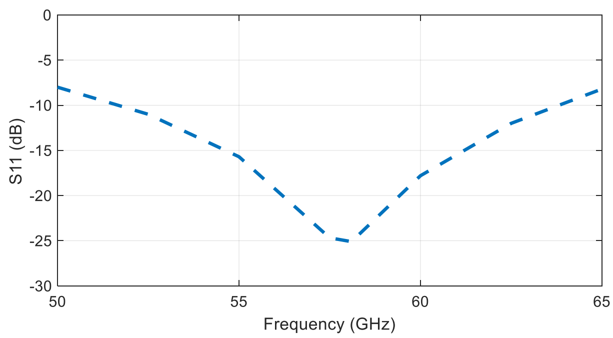


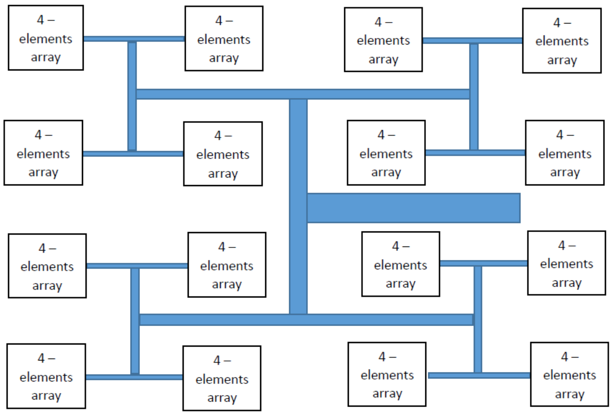
Fig. 11 Reflection coefficient of photonic band crystal band based antenna [19].

TABLE II COMPARATIVE STUDY OF HIGH GAIN ANTENNAS.

Ref.	Patch size	Center freq-uency	Band-width	Gain/ directivity, eff.
[14]	$1.1 \times 0.95\ mm^2$	$60\ GHz$	$55-65\ GHz$ (16.67%)	$-8\ dBi$ (max. sim. Power gain), 10% (sim. rad. eff.)
[15]	$0.54 \times 0.88\ mm^2$	61.5 GHz	$59.8-63.1\ GHz$ (5.37%)	$7.6\ dBi$ (gain)
[16]	$30 \times 30\ mm^2$ (antenna size with superstrate)	$59.25\ GHz$	$56.4-62.1\ GHz$ (9.62%)	$14.1\ dBi$ (gain)
[17]	$2 \times 1.5\ mm^2$	$60\ GHz$	$52.2-67.7\ GHz$ (25.69%)	$9.52\ dB$ (gain)
[18]	$1.59 \times 1.91\ mm^2$	$60\ GHz$	$59.7-60.3\ GHz$ (1%)	$7.491\ dB$ (gain), 97.97% (rad. eff.)
[19]	$2 \times 0.8\ mm^2$	$57.79\ GHz$	$51.83-63.69\ GHz$ (20.53%)	$9.143\ dBi$ (dir.), 76.74 % (rad. eff.)

Antenna arrays

In [20], the planar arrays are designed for $60\ GHz$ applications. The 2×2, 4×4 and 8×8 microstrip arrays were proposed and a maximum gain of $18.48\ dBi$ was achieved. The structure of the array and reflection coefficient are shown in Fig. 12 and Fig. 13, respectively. The achieved bandwidth is approximately $0.6\ GHz$ ranging approximately from $59.7\ GHz$ to $60.3\ GHz$. A 16 elements slotted array on substrate integrated waveguide, was designed and fabricated for $60\ GHz$ applications in [21]. The structure of the array and measured reflection coefficient of the array are shown in Fig. 14 and Fig. 15, respectively. From Fig. 15, it can be seen that the antenna is a triple band antenna. A maximum simulated gain of $17.5\ dB$ was achieved. In [22], a 2×8 elements planar array is designed for $60\ GHz$ band. The structure of the array and measured reflection coefficient of the array are shown in Fig. 16 and in Fig. 17, respectively. The antenna is fed by a feeding network and the maximum gain of 18 dB is achieved. In [23], the microstrip antenna arrays with frequency selective substrate has been designed. The arrays of 2×1 and 4×1 with maximum gain of $14.9\ dB$ and $17.2\ dB$, respectively have been presented. The structure of the 4×1 array and measured reflection coefficient of the array are shown in Fig. 18 and in Fig. 19, respectively. The comparative study of various $60\ GHz$ arrays is done in Table III. It can be seen that the planar arrays provides the highest gain, however this array utilized more number of elements. The large bandwidth is achieved by the planar array.



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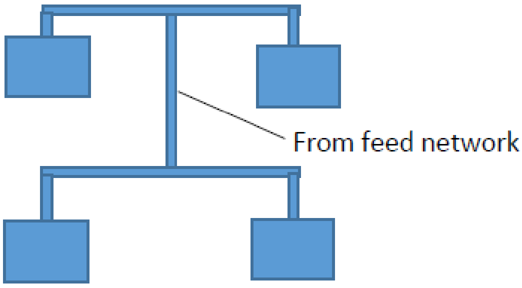


(b)

Fig. 12 Planar arrays, (a) feeding network, (b) 4-elements array [20].

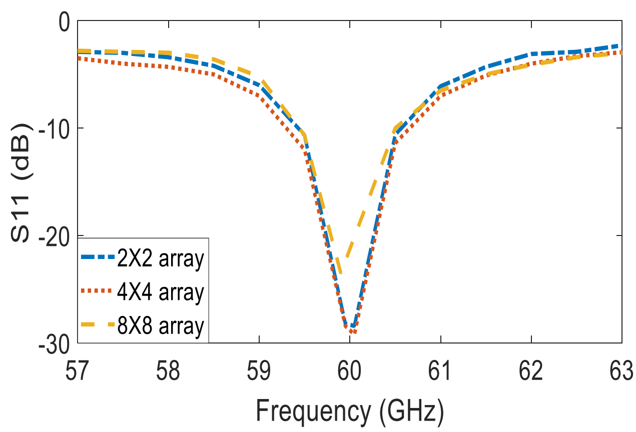


Fig. 13 Reflection coefficient of planar arrays [20].

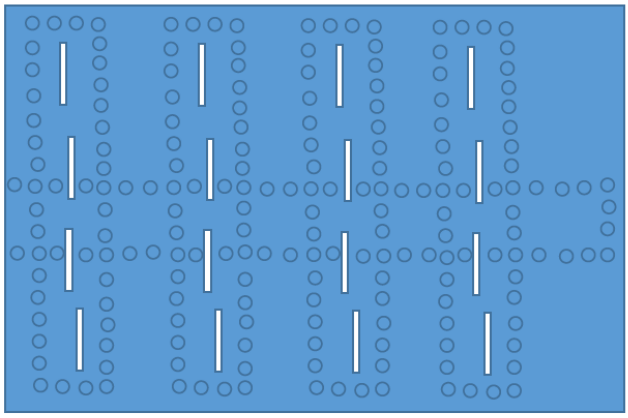


Fig. 14 Slotted array (top view) [21].

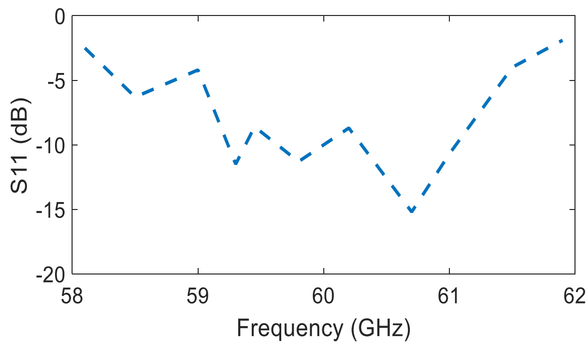
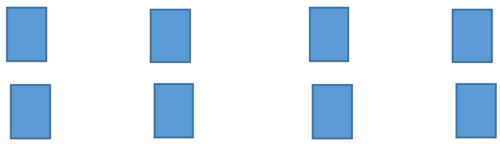
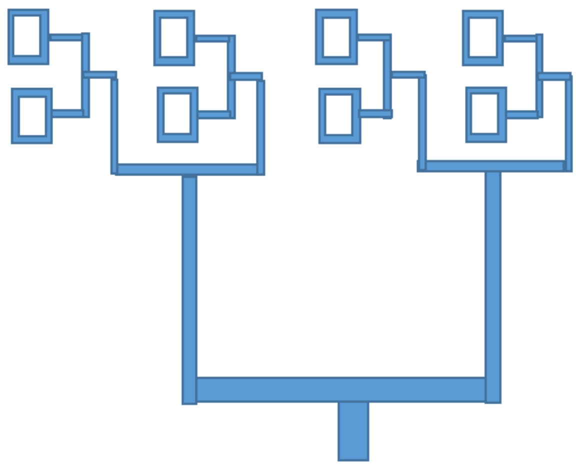


Fig. 15 Reflection coefficient of slotted arrays [21].



(a)



(b)

Fig. 16 Structure of the arrays (a) patch layers, (b) feed network with slot rings [22].

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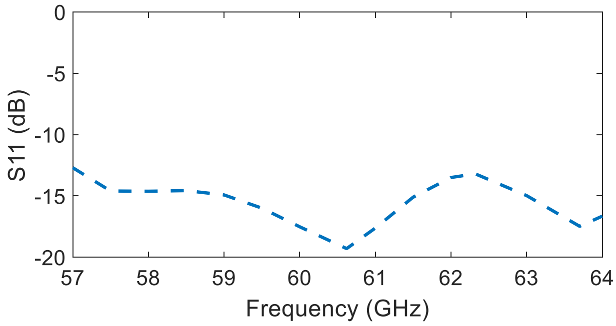

Fig. 17 Reflection coefficient for 2×8 arrays [22].

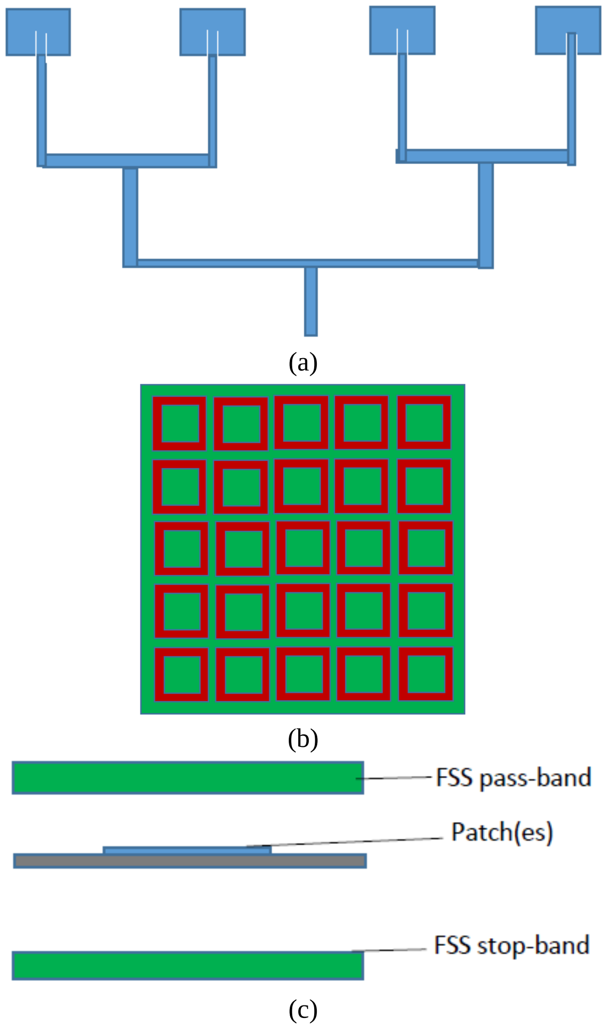

Fig. 18 Structure of the arrays with frequency selective surface (a) array (top view) (b) frequency selective surface (c) side view [23].

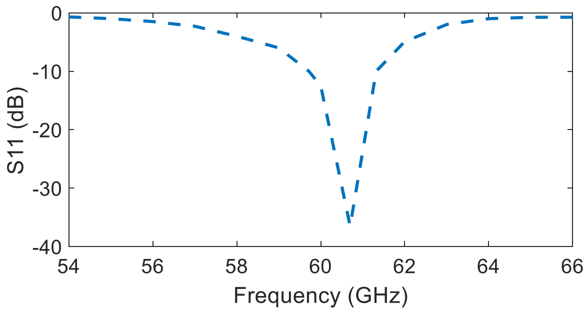

Fig. 19 Reflection coefficient of the 4×1 arrays with frequency selective surface [23].

TABLE III COMPARATIVE STUDY OF 60 GHZ ARRAYS.

Ref.	Patch size, no. of elements	Center frequency	Bandwidth	Gain/ directivity
[20]	1.01×1.52 mm^2, 64	60 GHz	59.7 GHz – 60.3 GHz (1%)	18.43 dBi (gain), 22..44 dBi (dir.)
[21]	16 (no. of elements)	60 GHz	Triple band	17.5 dB (gain)
[22]	16 (no. of elements)	60.7 GHz	Entire 60 GHz band (11.67%)	18 dB (gain)
[23]	4 (no. of elements)	60.5 GHz	59.7- 61.3 GHz (2.64%)	17.2 dB (gain)

Switched beam and phased arrays system

A typical switched beam array system is shown in Fig. 20. In switched beam antenna array system, there are fixed beams in different direction as shown in Fig. 20. One of the beam which is selected by the beam selection is active and rest are inactive. A phased antenna array system is depicted in Fig. 21. In phased array, the beam of the arrays moves upon changing the phase difference between the elements. Phased arrays allow a continuous sweep of the array beam and are more powerful, flexible, and expensive than switched beam arrays, in which the main beam selects one of a set of predefined orientations. In [24], a switched beam microstrip antenna arrays with a 4×4 Butler matrix network is designed and fabricated for 60 GHz band. The array geometry is shown in Fig. 22. Butler matrix is acting as a beamforming network and providing the signals at four different phases. The reflection coefficient of the array is shown in Fig. 23. From Fig. 23, the bandwidth of the array can be observed as approximately from 59.5 GHz to 61.5 GHz. A switched beam antenna on organic liquid crystal polymer platform with 4×4 Butler matrix beamforming network is designed in [25] for 60 GHz applications. The geometrical configuration of the switched beam array based on organic liquid crystal polymer platform is presented in Fig. 24. The bandwidth of the designed array is from 56.7 GHz to 63.7 GHz. In [26], a CPW fed microstrip antenna is designed for 60 GHz switched beam antenna array applications. The antenna is of a compact size of 700 $\mu m \times 720\ \mu m$. The structure and simulated reflection coefficient of the array is shown in Fig. 25 and in Fig. 26, respectively. From Fig. 26, the bandwidth can be observed and is from 58 GHz to 62 GHz. Recently, a 1×4 element cavity backed aperture coupled 60 GHz switched beam antenna array is designed in [27]. Substrate integrated waveguide technology is utilized for designing the feeding network. The structure of the array is shown in Fig. 27. The bandwidth of the designed array is from 56.6 GHz to 64.2 GHz for port 1 & port 4, and from 56.8 GHz to 63.8 GHz for port 2 & port 3. A maximum gain of 13.2 dB is achieved. In [28], a 5×1 linear antenna array with phase shifters is designed for 60 GHz beam steering applications. A membrane process is utilized in order to enhance the radiation characteristics of the antenna array. The structure of the array is shown in Fig. 28. The bandwidth of the array is from 55 GHz to 66 GHz. The radiation efficiency and maximum gain of the designed antenna array are 87% and 9 dBi, respectively. The comparative study of the switched beam/phased array is presented in Table IV. It can be observed that the maximum gain of the array can be achieved by using cavity backed aperture coupled array. The large bandwidth is achieved by the linear array with phase shifters.

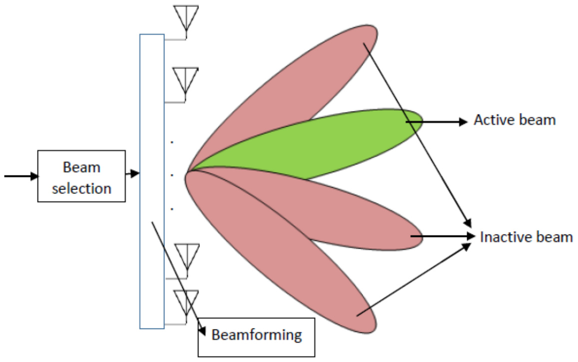

Fig. 20 Switched beam antenna arrays system.

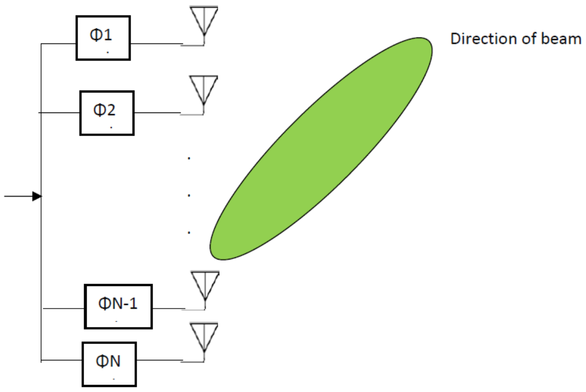

Fig. 21 Phased antenna arrays system.

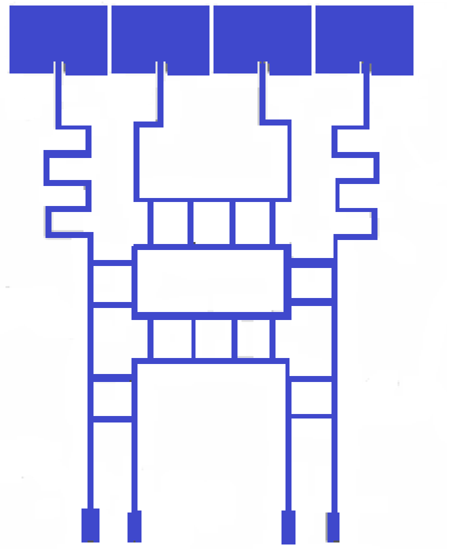
Fig. 22 Switched beam microstrip array (top view) [24].

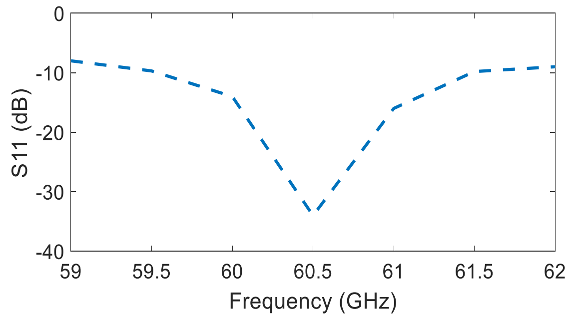

Fig. 23 Reflection coefficient of Switched beam microstrip array [24].

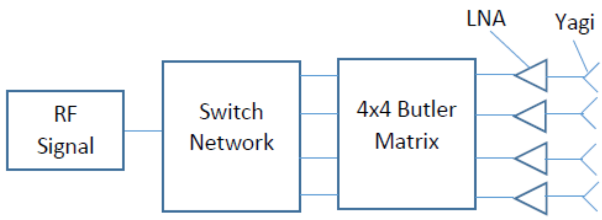

Fig. 24 Geometry of switched beam array [25].

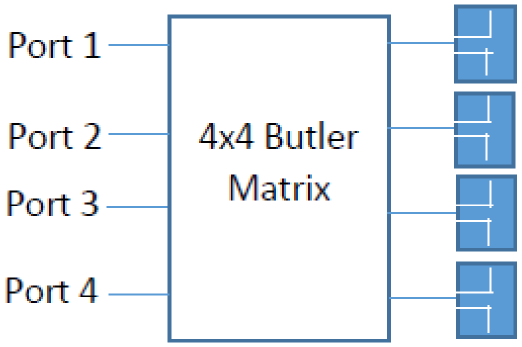

Fig. 25 Structure of CPW fed microstrip antenna is designed for 60 GHz switched beam antenna array applications [26].

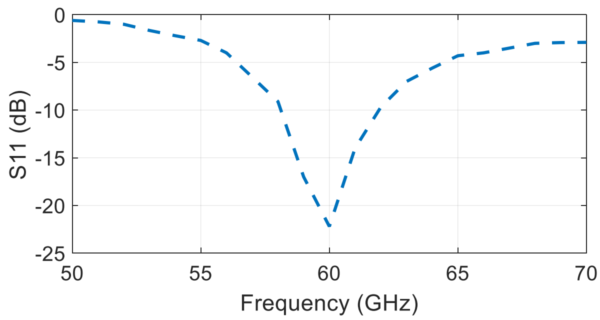

Fig. 26 Reflection coefficient of CPW fed microstrip antenna [26].

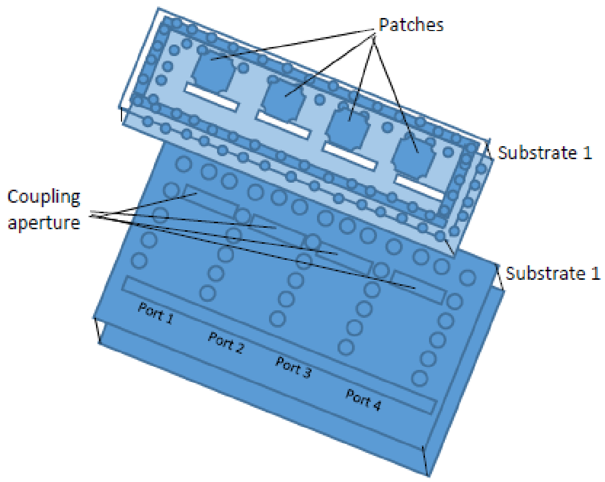

Fig. 27 Structure of cavity backed aperture coupled array [27].

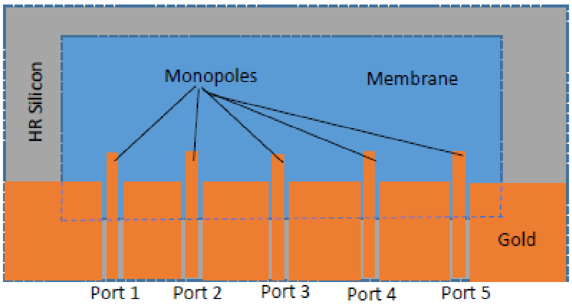

Fig. 28 Structure of 5 × 1 array [28].

TABLE IV COMPARATIVE STUDY OF 60 GHZ SWITCHED BEAM/PHASED ARRAYS.

Ref.	No. of elem-ents	Center frequency	Band-width	Gain/ directivity, eff.
[24]	4	60.5 GHz	59.5 – 61.5 GHz (3.3%)	9.6 dB (gain)
[25]	4	60.2 GHz	56.7 – 63.7 GHz (11.6%)	9.2 dBi (dir.)
[26]	4	60 GHz	58 – 62 GHz	--
[27]	4	60.4 GHz (port 1 and port 4), 60.3 GHz (port 2 and port 3)	56.6 – 64.2 GHz (12.58%) (port 1 and port 4); 56.8 – 63.8 GHz (port 2 and 3) (11.6%)	13.2 dBi (gain)
[28]	5	60.5 GHz	55 – 66 GHz (18.18%)	9 dBi (gain), 87% (rad. eff.)

VI. Conclusion

A detailed review of the 60 GHz technology has been presented. The current status of antennas and arrays design and challenges for the 60 GHz band have been discussed. The detailed studies of various high gain antennas for 60 GHz applications is presented. The arrays and switched beam/ phased array systems for 60 GHz applications are discussed in detail. The advantages, disadvantages, propagation characteristics and potential applications of 60 GHz have been described. From the analysis of advantages, disadvantages and propagation characteristics of 60 GHz frequency band, it can be concluded that the 60 GHz band is suitable for very high data rate short range wireless communication applications and for satellite to satellite applications. To make 60 GHz band suitable for long distance communication, the design of antennas and arrays with high gain are required.

Acknowledgements

Author is sincerely thankful to the reviewers for their comments and suggestions to improve the quality of manuscript.

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