A Comprehensive Review on Millimeter Waves Applications and Antennas

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Abstract. Millimeter wave (mmWave) bands attract large research interest as they can potentially lead to data rate of almost 10Gbits/sec and huge available bandwidth where as the microwave frequencies are limited to 1Gbits/s. This paper presents a comprehensive review of millimeter wave communications, frequency bands proposed by ITU, applications of mmWaves, advantages, limitations, challenges and research directions. Various antennas proposed by researchers for mmWave applications are described in detail. The described models are analyzed and compared with common antenna parameters. Applications like HD gaming, ultra high definition multimedia, security and surveillance demand for high data rates and more bandwidth. These all applications will drive mmWaves technology to develop and offer wide bandwidths with high speed data.

1. Introduction

Millimeter waves open up more spectrums and are more expensive. They occupy frequency spectrum from 30GHz to 300GHz and are in spectrum between microwaves (1-30GHz) and infrared (IR) waves. Wavelength (λ) of millimeter waves is in range of 1-10mm. Due to small wavelength, mmWave devices facilitate large antenna arrays to be packed in miniature physical dimension. Without varying antenna size, it is possible to pack more antenna elements at mmWave frequencies than at microwave frequencies resulting in narrower beam [1]. The neighboring frequencies 10-30GHz have comparable wave propagation as millimetre waves. The mm-wave communication bands are now drawing more attention because of huge bandwidth and data rate communication services and are becoming leading applications like high definition television (HDTV) and ultra-high definition video (UHDTV) [2,3]. Frequency spectrum of mmWaves (30-300GHz) is illustrated in Fig. 1. E-band and V-band are the two key bands in mmWaves. V-band is a continuous spectrum from 57-66GHz and E-band ranges from 71-76GHz and 81-86GHz. Longer transmission distances can be achieved from E-band as it enable Gbps data rates without any oxygen absorption. Table 1 describes the type of antennas that can be used for millimeter wave applications. Their respective advantages and disadvantages are also tabulated.

![Fig. 1. Frequency Spectrum of millimetre waves in GHz](image_url)
2. Emerging applications of mmwave communications

D-band (110-170 GHz) can be used for high data rate wireless communication such as wireless backhaul and chip-to-chip communication [4]. Mm-Wave communications can be used in virtual reality communications, wearable devices, vehicular networks, 5G communication systems, satellite communications, Object imaging and tracking with mmWave technology and Object detection with mmWave technology.

| Antenna Type     | Advantage                                                                 | Disadvantage                                                                 |
|------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Microstrip       | Low profile, low cost, microwave integration, light weight, easy mass production. | Small power capacity, low radiation efficiency, narrow band.                  |
| On-Chip Integrated | High degree of integration, high reliability, compact structure, low cost, mass production. | Low resistivity, small metal conductivity, high dielectric                    |
| Horn             | Wide frequency band, small side lobes, high power capacity, simple structure | Low gain                                                                     |
| Lens             | Wide frequency band, high directivity                                      | High profile                                                                 |
| Reflector        | High gain and efficiency, small size, good radiation directivity           | High cost                                                                    |

Fig. 2. Millimetre waves applications

Emerging and existing applications of millimetre waves are presented in Fig. 2. These applications are: IEEE 802.11ad WiGig technology, satellite communications, automotive applications, radar applications, 5G and smart cell concept, medical applications like mmW therapy, body scanning applications usually at airports, virtual reality headsets and HD video applications.

3. Advantages and limitations of mmwaves
Some hypothetical and lightning round advantages of millimetre waves are large bandwidth, small components sizes, greater resolution, low interference and increased security.

**Large Bandwidth:** The applications of microwave frequencies are limited to 1 gigabit per second data transfer rates. Millimeter waves provide large bandwidth that can translate to better data transfer rates and can attain speeds of about 10 gigabits per second. This higher data transfer rate with high speed can make real time gaming, high quality video streaming and other bandwidth intensive applications.

**Greater Resolution:** Narrow beams can be achieved with millimetre waves and hence greater resolution can be achieved.

**Small components sizes:** Small size is another major advantage of millimeter-wave equipment where high frequency makes very small antennas for necessary and possible applications.

**Low interference and increased security:** As millimetre wave beams are narrow and short range they are less prone to interference and it is much harder to intercept the signal thereby increasing security of signals.

The major limitations of millimetre waves are: limited range and line of sight (LOS).

**Limited Range:** The factors shorter wavelengths ranging from 1mm to 10mm high atmospheric attenuation due to fog, rain and moisture, affect of transmission range of millimetre waves. The transmission range can be increased by using high gain antenna array that boosts-up effective radiated power.

**Line-of-sight (LOS):** Millimetre wave communication required line-of-sight (LOS) communication and the physical obstacles in practical applications will weaken the signals thereby reducing the transmission range.

4. **Related works**

Conformal antenna is a type of antenna that conforms to a prescribed surface and has many advantages compared to the planar counterparts [5-7]. A SIW conformal antenna array with different orientations like axial and circumferential are discussed in this paper. The characteristics of a conformal shape are first discussed on SIW and radiating slot and then an array is mounted on this cylindrical surface. This antenna uses single dielectric substrate on which all the components are fabricated. By using this SIW scheme the difficulty in integration of array elements and feed network are reduced which also avoids parasitic coupling and radiation leakage. The advantage of this integrated conformal antennas are they provide good conformability and avoid unwanted leakage. The simulation is done on Ansoft HFSS for different parameters at 35GHz and compared with designed results.

A conformal antenna array prototyped with a switching network is fabricated and SP3T semiconductor is used as switching element between 3 arrays. Results of both designs are compared and tested at 61GHz, where the reflection coefficient is -20dB and bandwidth is 1.5GHz with a maximum gain of 18.7dB, 18.6dB and 18.8dB for the 3 antenna arrays.

The author Cyril Luxey proposed and designed conformal antenna and studied the performance and radiation patterns by varying radius of a cylindrical supporting structure [7]. To design a wearable antenna the radii of it should be small as they are integrated into wrist watches, rings and bracelets. The proposed antenna consists of linear series fed array operating at 58.8GHz with linear polarization.

The paper [8] presents comparison of various antennas designed for mm-wave applications. Initially we discuss about a Broadband High gain Beam scattering micro-strip array antenna with integrated 3rd order filtering feature for mm-wave applications which was proposed by Mao to achieve low profile with high gain, which also improves bandwidth and frequency selectivity without increasing thickness of antenna [8]. In this antenna two 4x4 sub-arrays of broadside radiation and scanned beam are implemented with four-way power divider to feed sub-arrays. Two substrate materials are used separately for lower and upper substrates to reduce the antenna loss. Different parameters like S parameters, gain are observed at 3 resonant frequencies (24, 27 and 30GHz) using HFSS 15 simulator and compared with design results. Gain of 3 antennas (proposed element and 2 sub-arrays) is 7.5dBi, 10dBi and 12.5dBi. A fractal antenna that is transparent and conformal is proposed for vehicle
communication applications [9]. Ka-band linear array antenna is proposed by the author Kalyan in [10] for beam steering applications. The author has proposed a circularly polarized metamaterial inspired antenna with quad band for satellite communication applications [11].

A printed flexible antenna on PET substrate is proposed at Ka-band (20-40GHz) for 5G applications. This antenna offers high bandwidth and further inkjet printing is a process which controls the magnitude of radiation loss and radiation efficiency of proposed antenna [12]. These type of antennas are mostly used for wearable such as uniform or casual clothing. The antenna is simulated using CST Software and fabricated with Dia-matix Inkjet printing with silver nano-particle conducting link. Results are simulated and measured achieving a maximum gain of 7.44dBi at 39GHz frequency. A hexa-decagon patch antenna is proposed for satellite communications operating at Ka-band [13]. The author has proposed a compact conformal antenna for 5G based cooler communication applications [14]. Zhang proposed a novel 3D-printed mm-wave SPP rod antenna with wideband and low cross polarization level, which is used to achieve high EM field confinement [15]. This works same as dielectric waveguides. This antenna is designed with 6 same SPP unit cells to achieve a smooth TE to TM conversion with tapered groove SPP depth hp increasing linearly by maintaining the dimensions same. If the tapered SPP cell numbers are large than high peak gain and smaller side lobe can be achieved. This antenna is designed to cover frequencies from 50GHz –75GHz with 29.2 radiating length and achieved a peak gain of 14.5dBi. A T-shaped MIMO antenna with CSRR is proposed for vehicular communications and 5G cellular networks [16].

A compact MIMO antenna with DGS and good isolation is proposed for automotive communications [17]. Author Syeda proposed a flexible conformal antenna array antenna for mm-wave applications at ka-band [18]. Antenna is designed with a flexible printed circuit like LCP (Liquid Crystal Polymer) available with a thickness of (25-80) μm which can be used as wearable antennas. The fabrication is done by two advanced methods like LPK F, Inkjet printing while array is using Laser prototyping and simulated using FIT based CST STUDIO SUITE. Initially CPW fed patch is designed with a pair of L-shaped stubs and then extended with 2 element array configurations. Performance of these two antennas is compared in-terms of gain and directivity. Results show that there is an enhancement in gain for conformal array antenna compared to planar antenna. The author has proposed 8-element cooperate fed array antenna that operates from 24.7-40.4GHz for millimetric wave applications [19]. Conformal antenna based on LCP for 5G vehicular communications is proposed in [20]. An enhanced Franklin antenna for future 5G communication applications is proposed [21].

Mm-wave antennas based on Spoof SPP fed by standard waveguide are proposed and fabricated using 3D printing and surface metallization process to produce high gain and low cross-polarization. In this paper, the author Zhang designed and fabricated two antennas: Tapering SPP rod antenna and SPP leaky–wave antenna with wide SPP grooves and also compared these two antennas with narrow grooves. Widened grooves produce high antenna gain than narrow grooves [22]. Dielectric tapering rod antennas produce high gain and stable radiation patterns when compared with single tapering rod antenna and array of multiple tapering rod antennas. Antenna with wider grooves will have increase in ohmic loss and slightly reduced efficiency but gain is 3db larger than narrow grooves where it is 7db larger for leaky-wave with wider grooves than narrow grooves. SPP rod antenna is designed in the operating band of 50-75GHZ with gain of 16.06-19.3dBi, on the other hand SPP Leaky-wave antenna are designed in the operating band of 50-70GHz with 20.1-23.9dBi gain. A Single layer Travelling wave Circularly Polarized antenna with frequency scanning function is proposed which provides low profile, low cost, wide band and easy processing [23]. This antenna is preferred for Commercial applications. In this antenna curved micro-strip transmission lines are used as CP radiation elements and complete array antenna is etched on a single layer substrate. Different types of CP antennas are developed earlier where the antenna assembly is complicated, increase cost and bad product rate. By use of TW mechanism and single layer substrate the previous problems can be reduced. A novel multi-band rectangular DRA for future 5G wireless communication system is proposed in [24]. It consists of slots etched on left and right sides of upper radiator as stacked radiator. Table 2 describes the comparison of various antenna proposed by researchers.
Table 2. Comparison of various antennas proposed for millimeter wave applications

| References | Type of Antenna | Dimensions of Antenna (Length x Width x thickness) | Substrate Material | Dielectric Constant | No. of Elements | Array | Operating Bands (GHz) | Gain (dB) |
|------------|-----------------|--------------------------------------------------|-------------------|-------------------|-----------------|-------|------------------------|----------|
| Cheng [5]  | Conformal slot array antenna | h = 0.254mm Rogers5880 | 2.2 | 8 | √ | 34.25 - 35.75 | 12 |
| Semkin [6] | Conformal antenna array with switching network | (31 x 46.4)mm2 x 127μm RT/DUROID 5880 | 2.2 | 16 | √ | 61 | 18.8 |
| VasiliiS emkin [7] | Conformal antenna array | (25 x 20 x 0.127) mm3 Polytetrafluoroethylene | 2.2 | 4 | √ | 58.8 | 17.2 |
| Chun-Xu Mao [8] | Microstrip Array Antenna | 3.05 x 0.2 x 0.2 mm3 RO4003C RO 5880 | 3.55 | 2.2 | 3 | √ | 22-32 | 12.5 |
| SyedaFi zzah Jilani [12] | PET based Flexible antenna | (16 x 16) mm2 x 135μm PET | 3.2 | 1 | x | 20-40 | 7.44 |
| Qing-Le Zhang [15] | Wideband mm-wave tapered dielectric rod antenna | 10 x 20 x 25 mm3 copper NA | 32 | x | NA | 50-75 | 14.5dB |
| SyedaFi zzah Jilani [18] | Mm-wave Conformal antenna | (11 x 12) mm2 x 100μm Rogers ULTRALAM 3850 | 2.9 | 2 | √ | 26 - 40 | 11.35 |
| Qing-Le Zhang [22] | mm wave tapered antennas based on Spoof SPP | 19.2 x 12.5 x 12.5 mm3 copper NA | N1 = 32 N2 = 24 | x | NA | 50-75 | 16.06 -19.3 | 20.1-23.9 |
| Yu-Hang [23] | Single layer CP wave antenna | h = 0.508mm Rogers 4350B | 3.66 | 7 | √ | 28-34 | 20.3 - 21.9 |

5. Conclusion
A comprehensive survey of millimeter waves, their applications, advantages and limitations is presented in this paper. A detailed review of various antennas proposed by researchers is also described. Some proposed antennas are compared with common antenna parameters. Millimeter waves enable large bandwidth with high speed data rates up to 10Gbps. Large bandwidth, small components sizes, low interference and increased security are the pros of mmWaves. The main limitations of mmWaves are limited range and line-of-sight (LOS). The emerging and existing applications of mmWaves are: IEEE 802.11ad WiGig technology, satellite communications, automotive applications, radar applications, 5G and smart cell concept, medical applications like mmW therapy, body scanning applications usually at
airports, virtual reality headsets and HD video applications. These applications will drive mmWaves to next level and researchers can find appropriate research directions to overcome the present limitations in respective applications.

References

[1] Xiong Wang, Linghe Kong, Fanxin Kong, Fudong Qiu, Mingyu Xia, Shlomi Arnon, Guihai Chen 2018. Millimeter Wave Communication: A Comprehensive Survey, IEEE Communications Surveys & Tutorials, 20, 1616-1653.

[2] Cihat Şeker, Muhammet Tahir Güneş, Turgut Ozturk 2018. A Review of Millimeter Wave Communication for 5G, 2nd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT).

[3] R. Thandaiah Prabu, M. Benisha, Dr. V. Thulasai Bai, V. Yokesh 2016. Millimeter Wave for 5G Mobile Communication Application, 2nd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB).

[4] Aritra Banerjee, Kristof Vaesen, Akshay Visweswaran, Khaled Khalaf, Qixian Shi, Steven Brebels, Davide Guermandi, Cheng-Hsueh Tsai 2019. Millimeter-Wave Transceivers for Wireless Communication, Radar, and Sensing, IEEE Custom Integrated Circuits Conference (CICC).

[5] Yu Jian Cheng, Hang Xu, Da Ma, Jie Wu, Lei Wang and Yong Fan 2013. Millimeter-Wave Shaped-Beam Substrate Integrated Conformal Array Antenna, IEEE Transactions on Antennas and Propagation, 61, 4558 – 4566.

[6] V. Semkin, F. Ferrero, A. Bisognin, J. Ala-Laurinaho, C. Luxey, F. Devillers and A. V. Räisänen 2015. Beam switching conformal antenna array for mm-wave communications IEEE Antennas and Wireless Propagation Letters, 15, 28 - 31.

[7] Vasili Semkin, Aimeric Bisognin, Fabien Ferrero, Cyril Luxey 2017. Conformal Antenna Array for mm-wave communications- performance Analysis, International Journal of Microwave and Wireless Technologies, 9, 241 – 247.

[8] Chun-Xu Mao, Steven Gao, and Yi Wang Broadband High-Gain Beam-Scanning Antenna Array for Millimeter-Wave Applications, IEEE Transactions on Antennas and Propagation, 65, 9, 4864 – 4868, 2017.

[9] Madhav, B. T. P.; Anilkumar, T.; Kotamraju, Sarat K. 2018. Transparent and conformal wheel-shaped fractal antenna for vehicular communication applications, AEU-International Journal of Electronics and Communications, 91, 1-10.

[10] Kalyan, S. S. S.; Kavya, K. Ch Sri; Kotamraju, Sarat K. 2018. Analysis of Synthesized Ka-Band Linear Array Antenna for Beam Steering Applications, Journal of Mechanics of Continua and Mathematical Sciences, 13, 193-206.

[11] Rao, M. Venkateswara, Madhav, B. T. P., Anilkumar, T, Nadh, B. Prudhvi 2018. Metamaterial inspired quad band circularly polarized antenna for WLAN/ISM/Bluetooth/WiMAX and satellite communication applications, AEU-International Journal of Electronics and Communications, 97 229-241.

[12] Syeda Fizzah Jilani, Qammer H. Abbasi, Akram Alomainy 2018. Inkjet-Printed Millimetre-Wave PET-Based Flexible Antenna for 5G Wireless Applications, IEEE MTT-S International Microwave Workshop Series on 5G Hardware and System Technologies (IMWS-5G).

[13] Kumar Naik K., Amala Vijaya Sri P 2018., Design of hexadecagon circular patch antenna with DGS at Ku band for satellite communications, Progress In Electromagnetics Research M, 63, 163-173.

[14] Usha Devi Y., Rukmini M.S.S., Madhav B.T.P 2018. A compact conformal printed dipole antenna for 5G based vehicular communication applications, Progress In Electromagnetics Research C, 85, 191- 208.
[15] Qing-Le Zhang, Bao-Jie Chen, Qian Zhu, Ka Fai Chan, Chi Hou Chan 2019. Wideband Millimeter-Wave Antennas with Low Cross-polarization Based on Spoof Surface Plasmon Polaritons, IEEE Antennas and Wireless Propagation Letters, 18, 1681 - 1685.

[16] Rao, Manikonda Venkateswara; Madhav, Boddapati T. P.; Krishna, Jagupilla; Devi, Yalavarthi Usha; Anilkumar, Tirunagari; Nadh, Badugu Prudhvi 2019. CSRR-loaded T-shaped MIMO antenna for 5G cellular networks and vehicular communications, International Journal of RF and Microwave Computer-Aided Engineering, 29,1-14.

[17] Madhav, Boddapati T. P.; Devi, Yalavarthi Usha; Anilkumar, Tirunagari 2019. Defected ground structured compact MIMO antenna with low mutual coupling for automotive communications, Microwave and Optical Technology Letters, 61, 794-800.

[18] SyedaFizzah Jilani, Max O. Munoz,Qammer H.Abbasiand AkramAlomainy 2019. Millimeter-Wave Liquid Crystal Polymer Based Conformal Antenna Array for 5G Applications IEEE Antennas and Wireless Propagation Letters, 18, 84-88.

[19] T Anil Kumar, Y U Devi, Madhav Boddapati T. P, Kotamraju Sarat K, Rajesh Vullanki 2019. High gain flexible liquid crystal polymer based 8-element printed antenna for millimetric wave applications, International Journal of RF and Microwave Computer-Aided Engineering, 29, 1-11.

[20] Devi Y. Usha, Rukmini M. S. S., Madhav B. T. P. 2019. Liquid crystal polymer based flexible and conformal 5G antenna for vehicular communication, Materials Research Express, 6, 1-12.

[21] Vanaja C., Pavithra N., Sravya N., Manoj M., Dhanade Y.B. 2019. Enhanced franklin antenna for the future 5G communication applications, International Journal of Innovative Technology and Exploring Engineering, 8, 1168-1172.

[22] Qing Le Zhang, Bao Jie Chen, Ka Fai Chan, and Chi Hou Chan 2020. High-Gain Millimeter-Wave Antennas Based on Spoof Surface Plasmon Polaritons, IEEE Transactions on Antennas and Propagation, 68, 4320 - 4331.

[23] Yu-Hang Yang, Bao-Hua Sun, and Jing-Li Guo 2020. A Single-Layer Wideband Circularly Polarized Antenna for Millimeter-Wave Applications, IEEE Transactions on Antennas and Propagation, 68, 4925 - 4929.

[24] Anab M, Irfan Khattak M, Owais MS, Khattak AA, Asif S 2020. Design and Analysis of Millimeter Wave Dielectric Resonator Antenna for 5G Wireless Communication Systems, Progress In Electromagnetics Research C, 98, 239–255.