Design of 5G-oriented patch antennas, a comprehensive survey

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Abstract

With the advent of 5G, higher speeds, more connected users and lower latency are required. To accomplish such goals, new antennas compatible with 5G technology are necessary. Patch antennas, being made of resistant and cheap materials, easy to mass-produce and low profile, represent a solid candidate for deployment in a 5G scenario. This paper aims to serve as a comprehensive guide for designing an antenna using microstrip technology, oriented to provide 5G services. This paper proposes a top-down approach, explaining first the general concepts and orienting the study towards more specific subjects. The topics discussed are the underlying technologies of 5G, patch antennas, circular polarization and array theory. Each topic provides an explanation of its fundamental principles, with an approach intended to be comprehensive instead of technical, and focusing towards giving practical design considerations for a 5G-oriented antenna.

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1. Introduction

Nowadays, there is a growing demand by the end user for higher speeds in cell phone networks, as well as a need for a greater capacity to support more connected devices, and a lower latency or delay time to communicate data. To address those demands, the fifth generation of cellular networks, also known as 5G, is born.

Compared to the 4G networks, 5G offers the following significant advantages:

(i) Much faster speed: 5G download speed is estimated to be 100 to 1000 times higher than 4G. With 5G, a speed of 10 Gbps would be achieved against the 20 Mbps that 4G presents on average.

(ii) Lower latency: in 4G networks, the average latency is about 50ms, and it is expected that with 5G it will be reduced to 10ms (in the theoretical case, it could be achieved up to 1ms).

(iii) More devices connected simultaneously

(iv) Less interference and more efficient use of the spectrum

To provide service, the 5G standard requires new technologies, at the software and hardware level. Among the hardware level needs, a fundamental element is the antenna for communicating the receiver device with the base station.

The deployment and massification of 5G networks will benefit multiple existing services, such as high-quality video streaming with low latency, web surfing or file downloading. Also, this new standard is a fundamental step for developing new and exciting technologies, such as smart cities, internet of things (IoT), autonomous vehicles, data processing in the cloud, telemedicine, virtual reality (VR) or augmented reality (AR), among others.

Patch antennas are antennas made of robust and cheap materials and easy to mass produce. Those characteristics makes them very promising for deployment on 5G base stations.

This paper presents an overview of the main topics associated to a 5G patch antenna. The aim of this work is to serve as a starting point for anyone that wants to design a proper 5G antenna using microstrip technology. For that matter, the focus will be on the practical design considerations, aiming to also provide a comprehensive guide of the underlying operating principles. Also, references to other related works will be provided along the document, to better illustrate the concepts discussed.

The paper is structured as follows. Section I presents the underlying technologies of 5G that make possible the promised improvements over 4G networks. In Section II, the basics of patch antennas are discussed, a special focus is done in the radiating element's shape and in feeding techniques, because those are the main design variables. Circular polarization is explained in Section 3, and common methods to achieve it in patch antennas are presented. Finally, in Section IV, array theory is presented.

2. 5G enabling technologies

In order to achieve the proposed goals regarding speed, latency and capacity, the fifth generation standards rely in five major technologies [1]: full duplex communications, Sub6-mmWave, small cells, Massive MIMO and beamforming.

2.1. Full-duplex communication

This communication mode enables the transmission and reception of information simultaneously on the same frequency by the same antenna. This is achieved by using silicon transistors that break the reciprocity of the antenna and enables it to transmit and receive information simultaneously on the same frequency without colliding.

If an antenna is transmitting and receiving simultaneously, the transmitted wave is picked by the transmitting antenna as an echo, and added to the received signal carrying information. This echo has more power than the wave that the antenna receives and carries information. For the system to work properly, the echo must be suppressed, so an echo-cancelling technology is implemented. This technology stores the transmitted signal and then subtracts it from the received one, so that only the received information is left.

In previous generations of cellular technologies, the communication was commonly achieved by two means. The first was using the antenna as a transmitter or receiver, taking turns between these two states in a half-duplex mode. The second most common mean was full duplex but using two different frequencies, one for transmission and other for reception.

The full duplex method utilized in 5G has the advantage that a single carrier frequency is needed, so it uses half the spectral resources that traditional full-duplex schemes. Also, the resources are utilized all of the time, in contrast to the half-duplex mode, resulting in a better performing system.

2.2. Sub6 – mmWave

The Sub6 and mmWave designations correspond to the range of frequencies below 6Ghz and between 24 and 300 GHz, respectively.

Most wireless technologies use the Sub6 frequency band, resulting in colliding signals in the crammed spectrum, which causes poor performance of the systems that rely on the use of the frequency resources, as seen in [2-4], where Wi-Fi and LTE signals coexist on the same frequency range. In order to deal with the situation, the 5G standard proposes using the mmWave spectrum, which is used mainly for satellite communications and radar systems and is not as overloaded as the Sub6 bands.

For 5G communications, both Sub6 and mmWave frequencies are proposed. For example, for Sub6 communications, the 3.4-3.6 GHz is proposed in some countries, and for mmWave the bands 24.25-27.5 GHz and 27.5-29.5 GHz are also possible candidates for providing 5G services.

2.3. Small Cells

The use of mmWaves instead of Sub6 frequencies deals with the problem of the crowded spectrum, but also introduces new ones. With higher frequencies, the transmitted signal is subject to higher propagation loss, resulting in a smaller coverage area. Also, at this frequency range, waves can be absorbed by tree's leaves, rain and buildings. In order to solve this problems, it is necessary to have more base stations to give the same coverage area, located in strategic points as to ensure line of sight with the user's device, avoiding the absorptions by surrounding objects. These base stations with lower coverage area are called small cells. A user on the move will switch between small cells, connecting with the closer one in order to have a better service

Small cells transmit less power compared to 4G and previous generations base stations, and being located closer to the user's client device, this last one also needs less power to communicate with the base station, resulting in less battery consumption and radiated energy.

Having a smaller coverage area, adjacent small cells can use the same frequency to give service to different users, resulting in higher spectral efficiency than previous generations.

Last but not least, the use of an interconnected network of base stations with the previously stated frequency reusing capabilities, results in a capability to handle more connected devices.

2.4. Massive MIMO

MIMO stands for Multiple Input – Multiple Output, a MIMO system consists of an array of at least two antennas for reception and two for transmission, or more. A base station with MIMO capabilities can receive information from multiple sources and transmit it to multiple users.

Massive MIMO is an extension of the MIMO system, where the number of antennas in the array is greater than 64. Such a system has the advantage of being capable to service more clients at the same time. In 4G base stations, 12 antennas are normally used: 8 for transmission and 4 for reception.

2.5. Beamforming

As the number of clients being serviced at the same time increases, so does the interference between them. If the antennas broadcast the signal in all directions simultaneously, besides interfering with each other, much power and spectral resources are wasted in unnecessary directions. To address both problems, beamforming techniques are utilized. Beamforming consists of focusing the power of the radiated wave in a narrow beam, targeted to reach the user's location, instead of transmitting omnidirectionally.

By focalizing the radiation in a narrow beam, the energy necessary to reach the user is reduced, and the spectral efficiency increases, because in a single base station, the same frequency can be reutilized in different directions. Also, beamforming contributes to extend the distance that the wave can travel, which is a problem at higher frequencies, as previously stated.

Without Massive MIMO arrays, beamforming would not be possible. In an array of multiple antennas, each one has its own radiation characteristics, independent of the others. If multiple transmitting antennas are excited simultaneously with the same wave, but with different amplitudes or phases, the radiation of each antenna will interfere with the others. If the interference is constructive in a direction, the radiated waves from each antenna are in phase, and the radiation will be stronger in that particular direction. The beam of focused energy achieved by beamforming technology is done by adding multiple radiating sources in phase in the direction of the beam.

Beamforming not only focuses the radiated energy in a narrow beam, but it is also capable of electronically steering the direction of that beam. This is accomplished by feeding each antenna with different phase shifts, so that the constructive interference is done in another direction. This is a major advantage, because the steering is electronic and not mechanical, so no moving parts are required. If the array has each individually fed antenna in a grid pattern, the beam can be aimed in the vertical and horizontal directions. If the array has each element disposed in a horizontal or vertical line, the beam can then be steered only in horizontal or vertical directions, respectively.

In a beamforming-enabled base station, when receiving signal from a device, each antenna in the array receives the signal with a slightly different time, because of being located in a different position. From this delay between receiving times in different antennas, the direction of the received beam can be estimated, so in transmission the beam is steered in that particular direction.

3. PATCH ANTENNAS

A microstrip transmission line is a type of electrical transmission line for microwave frequencies that can be fabricated with PCB materials. It is made of three stacked layers: the bottom one consists of a ground plane made of conductive material, the middle layer acts as a substrate made of dielectric material and finally, the top layer is a conductive band.

Microstrip technology can be used to build transmission lines or antennas, according to the configuration of the top conducting band. There are certain geometries that can radiate electromagnetic waves from fringing fields around their edges, and then act as an antenna. Such type of radiating elements made from microstrip technology are called "patch" antennas [5]. In [6-12], most of the aspects of patch antennas are analyzed in great detail. An example of this type of antenna can be seen in Figure 1.
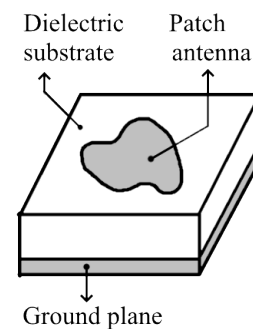

Figure 1. Patch antenna

Patch antennas have associated a set of advantages and disadvantages. Regarding the advantages, being made with PCB materials, they are cheap to manufacture, easy to mass-produce, compact in size and made of resistant materials. In a 5G deployment scenario, considering that a high number of base stations is needed, and that line of sight is necessary, so the antennas will be located outdoors, exposed to different weather conditions, all of the mentioned advantages are crucial.

On the other hand, because of the structure of patch antennas, the main disadvantages are that they are low power in relation to other antennas, they have a narrower bandwidth, low efficiency, considerable losses, low gain

and are affected by temperature. Most of those disadvantages are not crucial for 5G purposes. For example, the low power handling that they provide is sufficient for the power that a base station needs to transmit, as with the bandwidth. Other disadvantages can be compensated with the use of certain techniques. In that regard, a high gain antenna necessary for 5G communication can be obtained with the use of arrays, and the return losses can be decreased by locating the antenna's feeding point in another position.

3.1. Materials

In a patch antenna, different layers configurations can be used, and each layer can be made of a conductive or a dielectric material. For example, a three-layered antenna can be made with a conductive layer as a ground plane, a dielectric layer above, and a conducting layer on top for the radiating element.

Usually, the conductive band of the patch antenna is made of a thin layer of copper, about 0,035 mm thick in most cases, although other thickness can be used, depending on the manufacturer.

Regarding the dielectric layer, the most common materials are FR-4 and Teflon (PTFE). When choosing a dielectric material for an antenna, the following characteristics must be taken into consideration:

- Relative dielectric constant (ε_r or Dk)
- Thickness
- Temperature coefficient of dielectric constant (TcDk)
- Dissipation factor (Df)

3.2. Radiating element's shape

The radiating element can be of any shape, but simpler geometries are preferred because they are simpler to analyze. Most common shapes are rectangular and circular, plenty of research was done and design equations were obtained for those two geometries [13]. The design equations should be treated as an approximation, and further parameter tuning is necessary to obtain optimal results. For this purpose, specialized software utilization is recommended.

3.3. Feeding methods

There are many ways to feed the antenna. The four most commonly used are microstrip line, coaxial probe, aperture coupling and proximity coupling.

Microstrip line
In this feeding technique, a microstrip transmission line connects directly to the radiating element from the source. Impedance matching can be achieved by using a quarter lambda transformer, in order to reduce the return losses.

There are three microstrip line feeding methods: edge feed, offset-edge feed and inset feed, as illustrated in Figure 2.
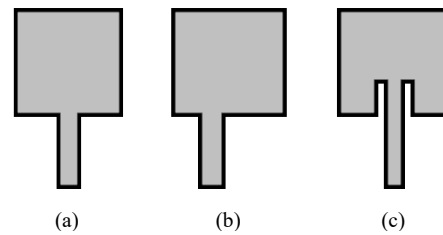

Figure 2. Microstrip feeding techniques. (a) Edge feed. (b) Offset-edge feed. (c) Inset feed.

Coaxial probe
Also called pin-fed method, the inner conductor of a coaxial line goes through the ground plane and the substrate, connecting to the radiating element in a specific point of its geometry, as seen in Figure 3. The location of the feeding point determines the return losses of the antenna. The outer conductor of the coaxial line connects to the ground plane.
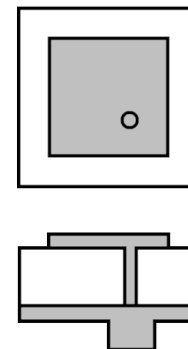

Figure 3. Coaxial probe feed.

Aperture coupling
In this method, there is no direct contact between the antenna and the source, and electromagnetic field coupling is utilized to excite the radiating element. For this feeding technique, a five-layered configuration is utilized. The top layer contains the radiating element, made of a metallic plate, this layer is located over a substrate made of dielectric material. Below the substrate, a ground plane with a slot can be found. This slot couples the radiating patch with the transmission line, located in the bottom layer, below a second substrate made of dielectric. The layer configuration for this feeding method can be seen in Figure 4.
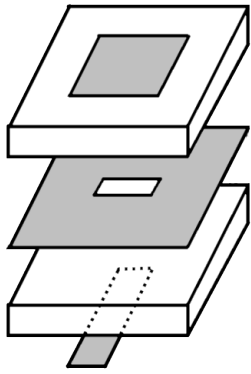
Figure 4. Aperture coupling feed

Proximity coupling

As in aperture coupling, proximity coupling is a non-contacting method with a five-layer configuration, schematized in Figure 5. In this case, the bottom layer is a ground plane made of conductive material located below a dielectric substrate. Over this layer, a microstrip feed line is located, made of conductive material. Above the microstrip line, another dielectric layer can be found, which serves as a substrate for the top layer, made of conductive material and containing the radiating element.
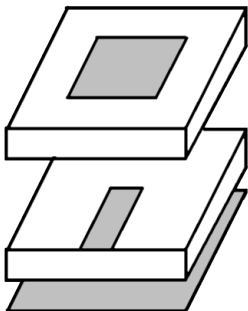

Figure 5. Proximity coupling feed

4. Circular polarization

When an electromagnetic wave is traveling through space in a certain direction, its associated electric field vector draws a shape in the plane perpendicular to the propagation direction, known as the polarization figure. The aforementioned shape, because of the periodical behavior of the traveling wave, is an ellipse. If that ellipse, from the observer's point of view, is drawn clockwise, the wave is Right Hand polarized, otherwise is Left Hand polarized.

An ellipse is defined by three parameters: the length of the major axis, the length of the minor axis and the angle between the major axis and the x axis, as seen in Figure 6. Varying this parameters, three different polarizations can be achieved.
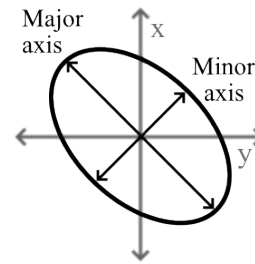

Figure 6. Ellipse parameters

If the length of the minor axis is zero, then linear polarization is obtained, also if this is true, and the angle between the x axis and the major axis of the ellipse is 90° the polarization is also vertical, and if that angle is 0°, then horizontal polarization is achieved. When the length of both ellipse's axis is equal, the wave has a circular polarization. In a final scenario, when the polarization is not circular nor linear, then it's elliptical. The polarization figures related to the aforementioned polarization types are presented in Figure 7, for an electromagnetic wave that propagates in the z direction, perpendicular to both x and y axis.
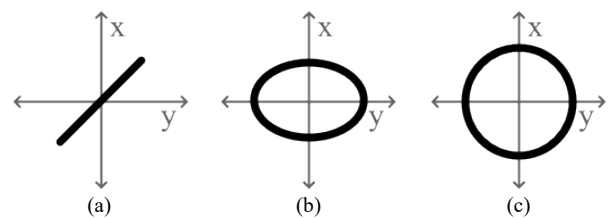

Figure 7. Polarization figures. (a) Linear. (b) Elliptical. (c) Circular.

A parameter for identifying the type of polarization of a wave is the Axial Ratio. This is the ratio between the major and minor axis. If the ratio is infinite, then the polarization is linear, if it is equal to one the wave has circular polarization, and for a ratio value between one and infinite, the polarization is elliptical [14, 15].

In a simple 5G communication between the base station and a mobile device, if the base station's antenna has linear vertical polarization, then the antenna in the user's device needs to be oriented in the same way, otherwise the wave won't be properly received and the communication won't be possible, or will deteriorate. For the communication to be possible independently of the device's orientation, circular or almost-circular polarization is required. Circular polarization has the added benefit of reducing propagation losses, because wave reflections only change the direction of the polarization, without adding or subtracting the reflected waves.

In practical situations, perfect circular polarization is sometimes hard to achieve, and an axial ratio of two (3 dB) is considered acceptable, corresponding to an elliptical polarization.

4.1. Circularly polarized patch antennas

Rectangular and circular patch antennas both have linear polarization. As presented in [16], there are multiple methods for achieving circular polarization from linearly-polarized patch antennas. The most common ones are the single and dual point fed antenna.

The single-point fed antenna method consists on feeding the radiating element in a single spot, usually located in the patch's diagonal or in a symmetry axis, and introducing slight perturbations to the shape of the radiating element, such as notches, slots or truncated corners. With the correct choice for the location of the feeding point, and by adding adequate perturbations, it is possible that two orthogonal modes exist at the same frequency, each of which will have the same magnitude and a phase shift of 90°, allowing circular polarization. Multiple circularly-polarized single-fed antenna designs can be seen in [17-25], some examples are shown in Figure 8.
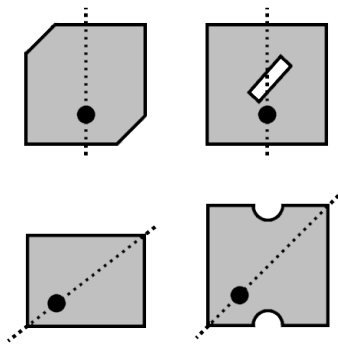

Figure 8. Single-point fed antennas examples

The second most common method consists of feeding the radiating element in two spots, located in orthogonal axis and at the same distance from the center of the antenna. By applying to these spots the same signal but with a 90° phase shift, two orthogonal modes are excited, and circular polarization is achieved. In [26], a dual fed circularly-polarized circular antenna is modified in order to achieve circular polarization with a single feeding point. In Figure 9, two examples of antennas fed with dual-point method are shown.
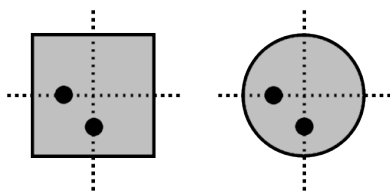

Figure 9. Dual-point fed antennas examples

The circular polarization by dual-point feeding method is easier to achieve than the single-point technique, because in the later, much trial and error is required for getting the right perturbations. Despite this, dual-fed method by itself requires two different ports to feed the antenna, and a RF source that can generate a 90° phase shift. In order to use a single feeding point and keep the simpler design of a dual-fed antenna, a power divider such as a T-junction, Wilkinson, quadrature hybrid [27, 28] or ring hybrid can be used, as seen in Figure 10.
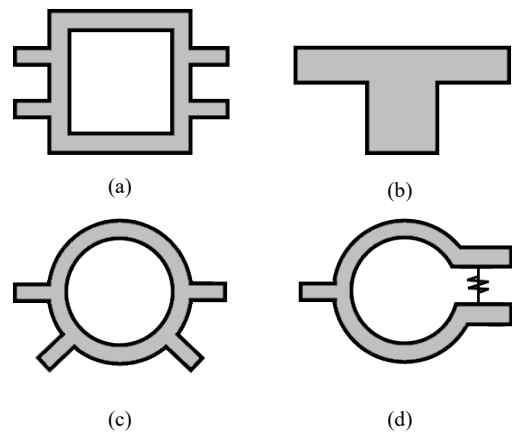

Figure 10. Power dividers. (a) Quadrature hybrid. (b) T-junction. (c) Ring hybrid. (d) Wilkinson

There is a third method for achieving circular polarization from linearly-polarized patch antennas. This is done by designing an array with antennas in determined positions and orientations, so that the sum of the waves radiated from each antenna has circular polarization. This technique has the disadvantage that the array requires more space than a single antenna. A design using this method is presented in [29].

5. Antenna Arrays

A single patch antenna has low gain, so if a base station pretends to give service using only a single antenna, its coverage area will be reduced. To address this problem, an array of antennas can be used [30].

An array is a set of multiple antennas with the same characteristics. Each antenna radiates or receives simultaneously.

With the use of an array, a greater gain and better signal to noise ratio than a single antenna can be accomplished. This is possible because of the constructive interference of the radiated waves by each individual antenna.

The antennas in an array can be placed to shape a linear, planar or volumetric array, usually at a fixed distance from each other. In linear arrays, each antenna is located in a line, whereas in planar arrays, each element can be found in the same plane, usually in the form of a

grid. Finally, in volumetric arrays, each antenna is located in a 3D space. Volumetric arrays can be obtained by stacking planar arrays. An example of a linear and a planar array is shown in Figure 11.
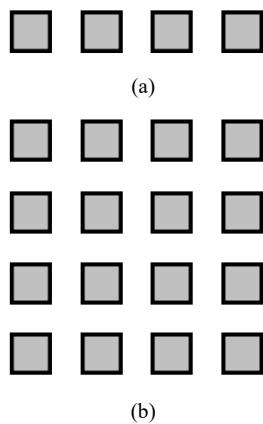

(a)

(b)

Figure 11. Antenna arrays. (a) 4-element linear array. (b) 4x4 planar array

The phased antenna array is a combination of multiple antennas whose feeding signal's relative phases are intentionally altered in a way that the array's radiation diagram is modified and the direction of the maximum directivity changes. This allows an electronic steering of the radiated energy, and is the basic principle of beamforming.

If the array is linear, varying the relative phase between elements would result in directional steering of the radiated beam in a linear axis, along the line formed by the antennas. If the array is planar instead, the beamforming could be achieved along two orthogonal axes, for example, in a vertical and horizontal direction simultaneously. For 5G applications, depending on the area of service, a planar array will be required or a linear array could be sufficient. Different designs of planar, phased, microstrip arrays can be seen in [31-35].

It is worth noting that for an array to be beamforming-capable, each of its elements need to be individually fed with a phase varying signal. If the elements are connected by a fixed feeding network, then greater gain than a single antenna will be accomplished, but electronic steering of the radiated beam won't be possible. This type of array can be seen in [36-38]. The array presented in [39] is capable of beamforming only in the vertical direction, because all its horizontal elements are connected by a fixed feeding network.

When building an array of multiple antennas, two variables need to be taken in consideration: the number of antennas and the distance between them. Regarding the amount of antennas, more radiating elements imply greater gain at the expense of needing a better RF source with more outputs. As additional antennas are added, a limit can be reached, if that's the case, an extra antenna

won't contribute significantly to the total gain of the array.

The distance between the antennas in an array is usually fixed in a determined direction. That means, if a planar array is being made, the horizontal distance between consecutive antennas is always the same, and so is the vertical distance among consecutive antennas in a vertical axis. The horizontal and vertical distances are not necessarily equal.

When choosing a fixed distance between antennas in any axis for a planar array, two considerations must be done. First, if the distance is too small, the antennas are too close and they interfere with each other in a phenomenon called mutual coupling. In order to minimize the coupling between antennas, they should be separated by a distance of at least half the wavelength of the radiated wave. This means, the distance should be at least $\lambda/2$. On the other hand, if the antennas are too far apart, unwanted diffraction lobes appear, these lobes use a high amount of the available power to radiate in unwanted directions, meaning that the main beam has less power to transmit. The distance at which diffraction lobes appear depends on the current distribution used to excite the array, if each antenna element is excited with a wave with the same amplitude and a varying phase, then the distribution is uniform, and a maximum distance of λ is recommended to avoid the apparition of unwanted diffraction lobes. Having in consideration the mutual coupling and the diffraction lobes, a distance between consecutive antennas between $\lambda/2$ and λ is recommended. An analysis on mutual coupling is performed in [40,41].

6. Conclusion

By the end of the paper, the reader should have a general understanding of the underlying 5G technologies, and of the requirements and alternatives available when designing a novel 5G-oriented patch antenna.

Regarding the microstrip antenna design considerations, the fundamental topics were presented and considerations to the specific 5G-deployment scenario were made. The analysis of this type of antenna included different layers layouts, basic materials, feeding methods, radiating element's shape, array configuration and different techniques to obtain circular polarization.

In a 5G deployment scenario, research and design of new and better antennas is fundamental, so the authors hope that this work will serve as a starting point for new advances in the field.

References

[1] Nordrum and K. Clark , "Everything You Need to Know About 5G," IEEE Spectrum: Technology, Engineering, and Science News, 27-Jan-2017. [Online]. Available: https://spectrum.ieee.org/video/telecom/wireless/everything-you-need-to-know-about-5g.

[2] V. Sathya, M. I. Rochman, and M. Ghosh, "Measurement-Based Coexistence Studies of LAA & Wi-Fi Deployments in Chicago," IEEE Wireless Communications, pp. 1–8, 2020.

[3] V. Sathya, M. Mehrnoush, M. Ghosh, and S. Roy, "Wi-Fi/LTE-U Coexistence: Real-Time Issues and Solutions," IEEE Access, vol. 8, pp. 9221–9234, 2020.

[4] V. Sathya, S. M. Kala, M. I. Rochman, M. Ghosh, and S. Roy, "Standardization Advances for Cellular and Wi-Fi Coexistence in the Unlicensed 5 and 6 GHz Bands," GetMobile: Mobile Computing and Communications, vol. 24, no. 1, pp. 5–15, 2020.

[5] D. Orban and G. Moernaut, "The Basics Of Patch Antennas, Updated," www.rfglobalnet.com, Sep-2005. [Online]. Available: https://www.rfglobalnet.com/doc/the-basics-of-patch-antennas-updated-0001.

[6] Aznar Ángel Cardama, Antenas. Barcelona: Universidad Politécnica de Cataluña, 2009.

[7] R. Bancroft, Microstrip and printed antenna design. SciTech, 2009.

[8] D. G. Fang, Antenna Theory and Microstrip Antennas. CRC Press, 2009.

[9] R. Garg, P. Bhartia, I. J. Bahl, and A. Ittipiboon, Microstrip antenna design handbook. Boston: Artech House, 2001.

[10] J. R. James, P. S. Hall, and C. Wood, Microstrip antenna: theory and design. London: Peregrinus on behalf of the Institution of Electrical Engineers, 2015.

[11] Pandey, Practical microstrip and printed antenna design. Norwood, MA: Artech House, 2019.

[12] D. M. Pozar and D. H. Schaubert, Microstrip antennas: the analysis and design of microstrip antennas and arrays. New York, NY: IEEE, 1995.

[13] C. Balanis, Antenna theory: analysis and design. Hoboken, NJ: Wiley-Interscience, 2016.

[14] Goyal, A. Gupta, and L. Agarwal, "A Review Paper on Circularly Polarized Microstrip Patch Antenna," International Journal of New Technology and Research (IJNTR), vol. 2, no. 3, pp. 138–142, Mar. 2016.

[15] L. Sun, G. Ou, Y. Lu, and S. T, "Axial Ratio Bandwidth of a Circularly Polarized Microstrip Antenna," Advancement in Microstrip Antennas with Recent Applications, Jun. 2013.

[16] M. Jain and M. Tyagi, "Circular Polarization techniques in Microstrip Antennas," Vidya Journal of Engineering & Technology, vol. 3, no. 1, pp. 127–144, 2017.

[17] W.-S. Chen, C.-K. Wu, and K.-L. Wong, "Novel compact circularly polarized square microstrip antenna," IEEE Transactions on Antennas and Propagation, vol. 49, no. 3, pp. 340–342, 2001.

[18] Deshmukh, S. A. Shaikh, A. A. Desai, K. A. Lele, and S. Nagarbowdi, "Design of Notch Cut Circularly Polarized Circular Microstrip Antenna," 2015 Fifth International Conference on Advances in Computing and Communications (ICACC), 2015.

[19] N. Hasan and S. C. Gupta, "A dual band Microstrip Patch antenna with circular polarization," Conference on Advances in Communication and Control Systems 2013, 2013.

[20] S. K. Lee, A. Sambell, E. Korolkiewicz, S. F. Ooi, and Y. Qin, "Design of a circular polarized nearly square microstrip patch antenna," Microwave Journal, Jan. 2005.

[21] P. Ranjan and S. Mishra, "Design of Circularly Polarized Rectangular Patch Antenna with single cut," Conference on Advances in Communication and Control Systems 2013 (CAC2S 2013), 2013.

[22] P. Sharma and K. Gupta, "Analysis and optimized design of single feed circularly polarized microstrip antennas," IEEE Transactions on Antennas and Propagation, vol. 31, no. 6, pp. 949–955, 1983.

[23] E. N. Tziris, P. I. Lazaridis, K. K. Mistry, Z. D. Zaharis, J. P. Cosmas, B. Liu, and I. A. Glover, "1.62GHz Circularly Polarized Pin-Fed Notched Circular Patch Antenna," 2018 2nd URSI Atlantic Radio Science Meeting (AT-RASC), 2018.

[24] F. Xu, X.-S. Ren, Y.-Z. Yin, and S.-T. Fan, "Broadband Single-Fed Single-Patch Circularly Polarized Microstrip Antenna," Progress In Electromagnetics Research C, vol. 34, pp. 203–213, 2013.

[25] S. S. Yang, K.-F. Lee, A. A. Kishk, and K.-M. Luk, "Design And Study Of Wideband Single Feed Circularly Polarized Microstrip Antennas," Progress In Electromagnetics Research, vol. 80, pp. 45–61, 2008.

[26] T. Kingsuwannaphong and V. Sittakul, "Compact circularly polarized inset-fed circular microstrip antenna for 5 GHz band," Computers & Electrical Engineering, vol. 65, pp. 554–563, 2018.

[27] S. S. Bharathwaj and K. Prakash, "Circular polarization Dual-Feed Microstrip Patch antenna with 3dB hybrid coupler for WLAN," International Journal of Engineering Science Invention, vol. 2, no. 9, pp. 39–44, Sep. 2013.

[28] T. Jayachitra, V. K. Pandey, and A. Singh, "Circularly Polarized Microstrip Patch Antenna with FR4 substrate in dual-feed for WLAN applications," International Journal of Advanced Research in Computer Science and Electronics Engineering (IJARCSEE), vol. 2, no. 12, Dec. 2013.

[29] M. A. Rahman, Q. D. Hossain, and M. A. Hossain, "Design of a circular polarization array antenna using linear polarization patches," 2014 International Conference on Electrical Engineering and Information & Communication Technology, 2014.

[30] J. Zhang, X. Ge, Q. Li, M. Guizani, and Y. Zhang, "5G Millimeter-Wave Antenna Array: Design and Challenges," IEEE Wireless Communications, vol. 24, no. 2, pp. 106–112, 2017.

[31] P. Gupta, L. Malviya, and S. V. Charhate, "5G multi-element/port antenna design for wireless applications:a review," International Journal of Microwave and Wireless Technologies, vol. 11, no. 9, pp. 918–938, 2019.

[32] M. M. M. Ali and A.-R. Sebak, "Design of compact millimeter wave massive MIMO dual-band (28/38 GHz) antenna array for future 5G communication systems," 2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM), 2016.

[33] Y. Gao, R. Ma, Y. Wang, Q. Zhang, and C. Parini, "Stacked Patch Antenna With Dual-Polarization and Low Mutual Coupling for Massive MIMO," IEEE Transactions on Antennas and Propagation, vol. 64, no. 10, pp. 4544–4549, 2016.

[34] V. H. R. Keerthi, H. Khan, and P. Srinivasulu, "Design of 9x9 Microstrip patch antenna with Dual-Feed for C-Band radar application using ADS," International Journal of Scientific & Engineering Research, vol. 4, no. 7, Jul. 2013.

[35] C.-X. Mao, S. Gao, and Y. Wang, "Broadband High-Gain Beam-Scanning Antenna Array for Millimeter-Wave Applications," IEEE Transactions on Antennas and Propagation, vol. 65, no. 9, pp. 4864–4868, 2017.

[36] S. Alam, E. Wijanto, B. Harsono, F. Samandatu, M. Upa, and I. Surjati, "Design Of Array and Circular Polarization Microstrip Antenna For LTE Communication," MATEC Web of Conferences, vol. 218, p. 03006, 2018.

[37] Z. Muludi and B. Aswoyo, "Truncated microstrip square patch array antenna 2 × 2 elements with circular polarization for S-band microwave frequency," 2017 International Electronics Symposium on Engineering Technology and Applications (IES-ETA), 2017.

[38] D. Imran, M. M. Farooqi, M. I. Khattak, Z. Ullah, M. I. Khan, M. A. Khattak, and H. Dar, "Millimeter wave microstrip patch antenna for 5G mobile communication," 2018 International Conference on Engineering and Emerging Technologies (ICEET), 2018.

[39] M. K. Ishfaq, T. A. Rahman, Y. Yamada, and K. Sakakibara, "8×8 Phased series fed patch antenna array at 28 GHz for 5G mobile base station antennas," 2017 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), 2017.

[40] P. Xingdong, H. Wei, Y. Tianyang, and L. Linsheng, "Design and implementation of an active multibeam antenna system with 64 RF channels and 256 antenna elements for massive MIMO application in 5G wireless communications," China Communications, vol. 11, no. 11, pp. 16–23, 2014.

[41] R. Jedlicka, M. Poe, and K. Carver, "Measured mutual coupling between microstrip antennas," IEEE Transactions on Antennas and Propagation, vol. 29, no. 1, pp. 147–149, 1981.