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Different Structures of mmWave MIMO Array Antennas for 5G Applications: A Review

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Abstract

This review of literature outlines advances in antenna design based on 5G millimeter-wave (mm-wave) technology and establishes that it has the potential to meet previously unrealized data rates, very low latency, and spectral efficiency, and meet the growing needs of the current wireless network. The current condition of the mm-wave technology and the antenna array development, and what they can do in the 5G applications, have been mentioned in the review. It also presents the ideas of more advanced antenna design, including dielectric resonator antennas, with multiple inputs and multiple outputs, and a single-layer MIMO antenna, which can operate over a great variety of frequencies. Microstrip array antennas in this regard are important, especially at 28 and 38 GHz, since they have the ability to achieve high gain and provide high precision in beamforming to reduce serious propagation losses at mm-wave frequencies. Moreover, they are very small, inexpensive, and can be combined with printed circuit technologies, and thus they suit well in real-life 5G applications. These antenna arrays maximize spectral efficiency and system capacity as they are able to support advanced MIMO techniques and therefore can maximize communication performance and reliability in congested cities.

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1. INTRODUCTION

Many technical wireless application areas have been focusing on the millimeter wave spectrum due to its extensive bandwidth and reduced latency. However, the following benefits come with the cost of the greater path loss, limited propagation, and atmospheric attenuation. Understanding channel properties is crucial to addressing these problems [1]. A variety of channel models, including The first and second winners models, the floating-intercept at a single frequency (FI) theory, the reference spacing for single-frequency close-in (CI) free space theory, Alpha, Beta, and Gamma (ABG) theory, the CI with several frequencies theory, and others, are developed for research on circumstances for the atmosphere and loss of paths in an urban and suburban region [2]. In order to deal with the problem of millimeter wave propagation with severe path loss, all of these designs highlight the necessity of higher-gain, directional, or beamforming antennas. Due to their many benefits over one-element or omnidirectional antennas, such as better gain, focused radiation, scanning with wide-angle beams, Broad bandwidth, numerous beams, and adaptive beamforming, array antennas may solve the aforementioned problems [3]. Despite each of these benefits, there are two main issues with an array antenna: grating lobes resulting from incorrect element spacing and a higher side-lobe level. Numerous studies have been carried out on a variety of array-form antennas. The previously microstrip array's gain and directivity antennas with 16- 64-256- and 1024 elements have been empirically evaluated and demonstrated to be enhanced throughout the 10–35 GHz frequency band by Ely Levine. However, it is also clear that while surface wave losses stay fixed, loss of Ohmic and dielectric, and radiation losses all rise with a number of radiating element[4]. Structures for co-planar waveguides (CPW) enable the control of radiation loss. By minimizing leaking waves as well as directing those within an appropriate Substrate-integrated waveguide (SIW) technology reduces the surface waves in the direction. These low-loss, extremely effective antennas could function having higher TE levels and solve the surface wave & loss of electromagnetic radiation that microstrip antennas experience. During designing at mm Wave, SIW necessitates a high level of precision machining since the via's dimensions as well as distance decrease [5]. The design is small and simple to build thanks to the SIW antenna and microstrip feed line. The low-profile configuration for the Vivaldi/tapered antenna to a notable increase in mutual coupling plus a low side-lobe level (SLL). Among these combinations is the magneto-electric microstrip patch element of SIW in a dipole. The need for excellent gain and wide bandwidths led researchers to investigate several combinations of architectures [6]. The feeding network for these antennas must be small, simple to feed, and have minimal radiation losses. This allows the network of feeds to be generally divided into series, parallel, and hybrid (series plus parallel mixing). With an extra switching RF circuit, an array antenna's frequency, radiation, and polarization can be altered to create programmable arrays. The array frequency could be adjusted by Band-pass filters using RF diodes and radiating elements oriented orthogonally. The beam might be guided in the desired direction by applying power of the same magnitude in relation to different phases for the collection of components generated by using phase-control elements like layers of graphene, active RF diodes, Butler matrices, or phase shifters. Because of its flexibility, resistance, and high conductivity, graphene is becoming more and more popular in the antenna industry. By superimposing the two distinct polarizations using different feeds, the polarization's orientation may be changed [7]. An overview of each cellular generation's characteristics and development is given in Table 1.

Table 1. The evolution of cellular generation and its features [2]

Evolution of Cellular Generation	2G	3G	4G	5G
Frequency Bands	900–1800 MHz	2100 MHz	700–2600 MHz	Between 1 GHz and mmWave (>6 GHz)
The bandwidth of the channel	About 200 KHz	5 MHz	20–100 MHz	Sub-6 GHz: over 100 MHz, mm Wave: over 400 MHz
Modulation technique of Waveform	GMSK	OFDM	QPSK, 16/64 QAM, OFDM	QPSK–256 QAM

Access Methods	The TDMA	The WCDMA	SC-FDMA (UL) and OFDMA (DL)	SC-FDMA (UL) and OFDMA (DL)
Peak Data Rates	DL: 100–120 kbps, UL: 10–30 kbps	DL: 15–25 Mbps, UL: 4–6 Mbps	DL: 500 Mbps–1 Gbps, UL: 200–500 Mbps	DL: 10–20 Gbps, UL: 5–10 Gbps
Spectral Efficiency	Very low	<1 bps/Hz	2 to 4 (bps/Hz)	More than 30 bps/H
Use Cases	Both texting and making voice calls	Video calls, internet browsing, moderate-speed	High-speed internet, HD video streaming, online gaming	mMTC, URLLC, IoT, ultra-low latency applications,eMBB

2. 5G COMMUNICATION TECHNOLOGY

In order to serve severely populated areas, 5G terrestrial wireless communications networks are anticipated to be rapidly deployed globally through the next ten years. The fifth-generation (5G) wireless communications are expected to become the forefront as the demand for higher speeds of data increases daily [8]. The main goals for 5G communication networks are excellent reliability and minimal latency (1 ms), improved mobile communication between devices, greater flexibility, and higher data rates (up to 20 Gbit/s). Those networks employ sub-6 GHz macro-cells overlapping with millimeter wave. As a result, there are several issues using the antenna design technologies at access points, mobile terminals, or only the front-haul/backhaul phases[9].antennas with phased arrays, massive-MIMO, and multiple/ input multiple/ output (MIMO) techniques are becoming used to deal with these issues.

2.1 ACTIVE BANDS FOR 5G

The main 5G new radio (NR) techniques consist of phased array antennas, huge MIMO, and MIMO. A new frequency nomenclature was introduced by the 5G NR, which operates in the mmWave range (FR2) and either as sub-7 GHz (FR1) or sub-6 GHz. The special features, functions, and difficulties of these two frequency bands-FR1 and FR2-should be understood by the antenna manufacturers. In these operating frequency ranges, it is more difficult to place the antenna component in the MIMO network closely compared to the FR2 band, where the antenna size is smaller and more easily positioned. Nonetheless, feedline coupling is strong at the mm-wave band [10]. Propagation properties for the mm Wave and sub-6 GHz spectrum differ. The first type has a low data rate and offers wider coverage via non-line-of-sight (NLOS) networking. However, the latter supports high rates of data and a restricted range in line of line-of-sight (LOS) scenarios [11]. The primary cause of the disparity in coverage of areas between the two scenarios is losses in the atmosphere, namely, lower with sub-6 GHz spectrum compared to the mm wave bands. An excellent choice to short distance Communication from LOS is the mm Wave frequency band. This facilitated the development of massive MIMO antennas, which use Thousands or even hundreds of separate or antennas that are co-located primarily while at the base station in order to fight cross-cell interference and rapid fading[12]. The mm Wave range considerably enhances its spectral efficiency via beamforming and beam steering. But at mm Wave, they are significant loss of signal in the link that supplies the antenna with the communication circuit's output; in order to mitigate these losses, a novel antenna-on-chip (AoC) concept has gained popularity recently. The antenna and radio transceiver circuitry are combined onto a single chip in AoC (Antenna-on-Chip) utilizing Rearwards ends of the line (BEOL) technique. However, the silicon substrate has a low resistivity and high permittivity, which is a critical problem affecting the radiation efficiency, because much of the energy is lost in the form of heat or surface waves. To alleviate these thermal and integration challenges, special methods like micromachining to etch the substrate under the antenna or proton implantation to enhance the resistivity and hence lessen the losses and improve the overall performance[13]. A five-generation antenna categories in the present research can be separated into two categories that facilitate smartphone antennas, base stations, and huge MIMO approaches in order to examine the many application types [14]. Applications and strategies of sub-6 GHz 5G networks with massive MIMO are detailed in Figure 1.

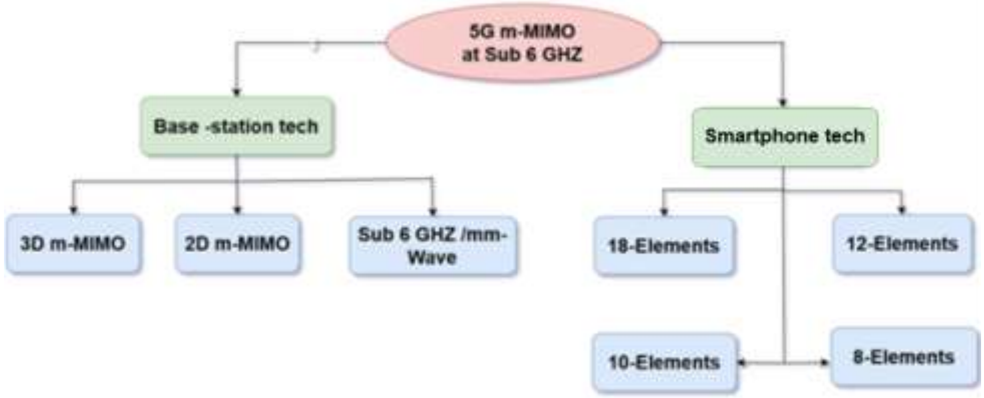

Fig. 1. Usage with 5G MIMO techniques around sub-6 GHz [4]

2.2 FIFTH GENERATION (5G) MIMO AT SUB-6 GHZ

The fifth generation of smartphone networks (5G) is expected to provide excellent latency and data speeds, in addition to increase the bandwidth and power efficiency of wireless networks. Numerous technologies have been researched to be applied in 5G networks. One of the key technologies that is expected to direct the development of 5G is the MIMO technology. Several antennas, which offer greater spectrum & power efficiency, enable communicating with many individuals at once, utilizing Similar resources. Spatial multiplexing will allow communication using the terminal device, User Equipment (UE), using the identical frequency and Period of time when a base station has several antennas in operation [15]. Additionally, by adding more antennas to the base station's upgraded devices, the improvement in beamforming methodology created about using MIMO designs about using MIMO designs could be leveraged to lower the amount of transmitting energy necessary[16]. In 5G networks operating at frequencies lower than 6 GHz, MIMO is a cutting-edge antenna technique that enhances coverage, capacity of the network, spectral efficiency, and practical data rates. MIMO supports several users at once by utilizing multiple antenna elements. Frequency spectrum, gain, isolation, radiation pattern, polarization, and beam width are all important aspects of MIMO antennas. Extending the bandwidth is one potential method to boost throughput as well as data transmission speeds in later versions of wireless and mobile phones, since a larger bandwidth yields a greater data rate. In big arrays with limited area, reducing the impacts of mutual coupling between antenna components necessitates several strategies appropriate for such a dense capacity of antenna components without expanding the distance between antennas[17]. The system will benefit from strong isolation and low correlations due to minimal mutual coupling without experiencing any efficiency limitations[18]. An additional coupling channel can be added by using metal supports between the antenna's components, or a spatial band-stop filter can be created by adding an external metamaterial wall or a spatial polarization-rotated wall.

2.3 MILLIMETER-WAVE (MM WAVE)

One of the most important technologies for next-generation (5G) wireless communication involves millimeter-wave (mmWave). It makes use of NR FR-I (410 MHz to 7.125 MHz) and FR-II (24 GHz to 52 GHz) frequency ranges, that encompasses mm Wave bands[19]. Greater capacity, decreased latency, and increased speeds of data transfer are made possible via these higher frequencies. Deploying mm Wave technology presents a hurdle because those wavelengths are shorter at larger frequencies, making additional signals susceptible to fading by things and being obstructed by plants and structures. 5G networks that employ mm Wave technology usually need additional points of access and base stations, that serve placed near each other, to get around this problem[20]. An additional problem is that mm Wave, other wireless transmissions have the potential to interfere with communications more often, and environmental factors like fog and rain. To address these problems, 5G networks that employ mm Wave technology focus the signals in particular directions using beamforming & sophisticated signal processing methods, which enhances signal quality and lowers interference [21]. Notwithstanding these difficulties, mm Wave technology provides 5G networks with a number of advantages, such as more capacity, lower latency, and faster rates of data transfer. These advantages are especially significant to applications like augmented reality (AR), & HD video streaming that need a lot of capacity.

2.3.1 TYPICAL PARAMETERS FOR MM WAVE ARRAY ANTENNAS

To satisfy the demands of mm Wave usage and 5G, the Gain, bandwidth, radiation, SLL, grating lobes, beam steering, beam forming, and multiple beams are among the performance characteristics of an array antenna that have been standardized by academics and via the third-generation partner project (3GPP)[22]. The following requirements should be fulfilled by the set of antennas that are developed: To solve the route loss factor in propagation, it has to have an effective gain of more than 20 dBi. It should have a small beam half-power beam width (HPBW) of less than 10◦ and function in the Q, U, E, and W bands. The SLL should have no grating lobes and be less than 20 dB. For connecting several users at once, the highest beam steering capability is (+ 180°,- 180°)with continuous, discrete scanning or scanning with the capability for multiple beams[23].

2.3.2 USES FOR MILLIMETER-WAVE ANTENNAS

In addition to communication services, mm-wave antennas are utilized in the following industries: medical, defence, and vehicle technology.

1. Fifth and sixth generation networks: mm Modern technology enables wireless communication at higher speeds, delivering quicker data transfer, decreased latency, and improved performance.
2. Body-centric and wearing antennas: mm-wave antennas are small and flexible, supporting developments in smart fabrics, wearable electronics, and health monitoring equipment.
3. The connection between autonomous cars and UAVs: mm Wave antennas are essential for vehicle-to-everything (V2X) communications, enabling data in real time sharing for collision prevention and navigation.
4. Remote sensing and Radar: mm Wave radar systems can be employed in industrial, weather, and defence applications, offering accurate detection of objects and environmental sensing.

5. MIMO ANTENNA

With fourth and fifth generation and later versions of 5G (B5G) transmission over wireless network technologies, the key enabling technology is the multiple input multiple output (MIMO) antenna [24].

MIMO allows for typical mobile rates of download for consumers in 4G connectivity. Conversely, 5G promises to increase fast data rates for access to improved mobile broadband (eMBB) and allow a variety of services, such as the internet of things (IoT) and vital machine-to-machine connections[25]. Increases in frequency range, therefore/or the ratio of signals to noise (SNR) can be used to improve the data rate, but the cellular network sets these parameters, & an antenna manufacturer has no control over them. As a result, alternatives for increasing the data rates to a few Gbps include spatial multiplication and additional antennas at the transmitter and receiver[26]. There is ample room at the BS to accommodate an increase in the number of antennas. Antenna developers have to offer a creative and small design solution because of the UE side's space limitations. Apart from achieving high data rates, MIMO enhances connection dependability and takes advantage of the multipath settings in several wireless networking situations, including indoors and outdoors [27]. improves connection dependability and communication possibilities. The design of MIMO antennas necessitates a variety of techniques to improve the diversity of antennas, such as polarization, pattern, and space; these involve the patterns of electromagnetic radiation, radiated efficiency, and bandwidth impedance, which have been the metrics mostly employed to describe those antennas [28]. In addition, parameters such as mutual coupling (Sij)/isolation, the multiplexing of efficiency, envelope correlation coefficient (ECC), total active reflection coefficient (TARC), diversity gain (DG), mean effective gain (MEG), and channel capacity (CC) are critically evaluated to assess their performances. A conclusion was that the benefits and characteristics of MIMO are met by the 5G specifications, as seen in Figure 2.

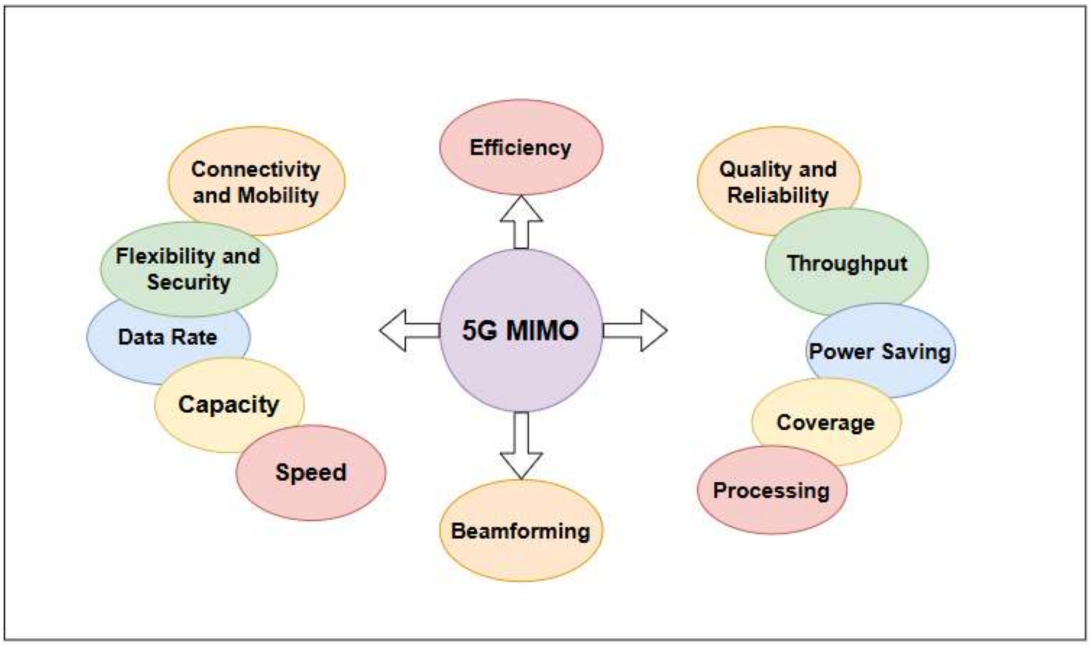

Fig. 2. 5G requirements and benefits of MIMO [4]

6. LITERATURE SURVEY

The survey considered the main discussion for the features of 5G to get the configurability in mm-wave regions. Therefore, this survey presents the mm-wave frequencies that have high speeds in 5G regions using compact and simple antenna designs.

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In 2020, PARVEEZ SHARIFF B. G.1, et al presented the eight-element linear antenna array plus a MIMO array with circular polarization (CP) at particular angles, a wide bandwidth, high gain, and narrow beam characteristics have been developed. To increase capacity for channels and lower RF chains complexity, the design is expanded to a two-port MIMO array, which may be scaled to an N-port arrangement. IMO antenna performs similarly over 37.5–39 GHz, with narrow beamwidths, sidelobe levels between -7 and -16 dB, and isolation more than 30.5 dB. The linear array exhibits excellent coupling through 20.7 and 42.4 GHz with CP around 37.5–40.5 GHz. Beam-steering radar and FMCW are used to verify MIMO performance, and the findings are satisfactory [29].

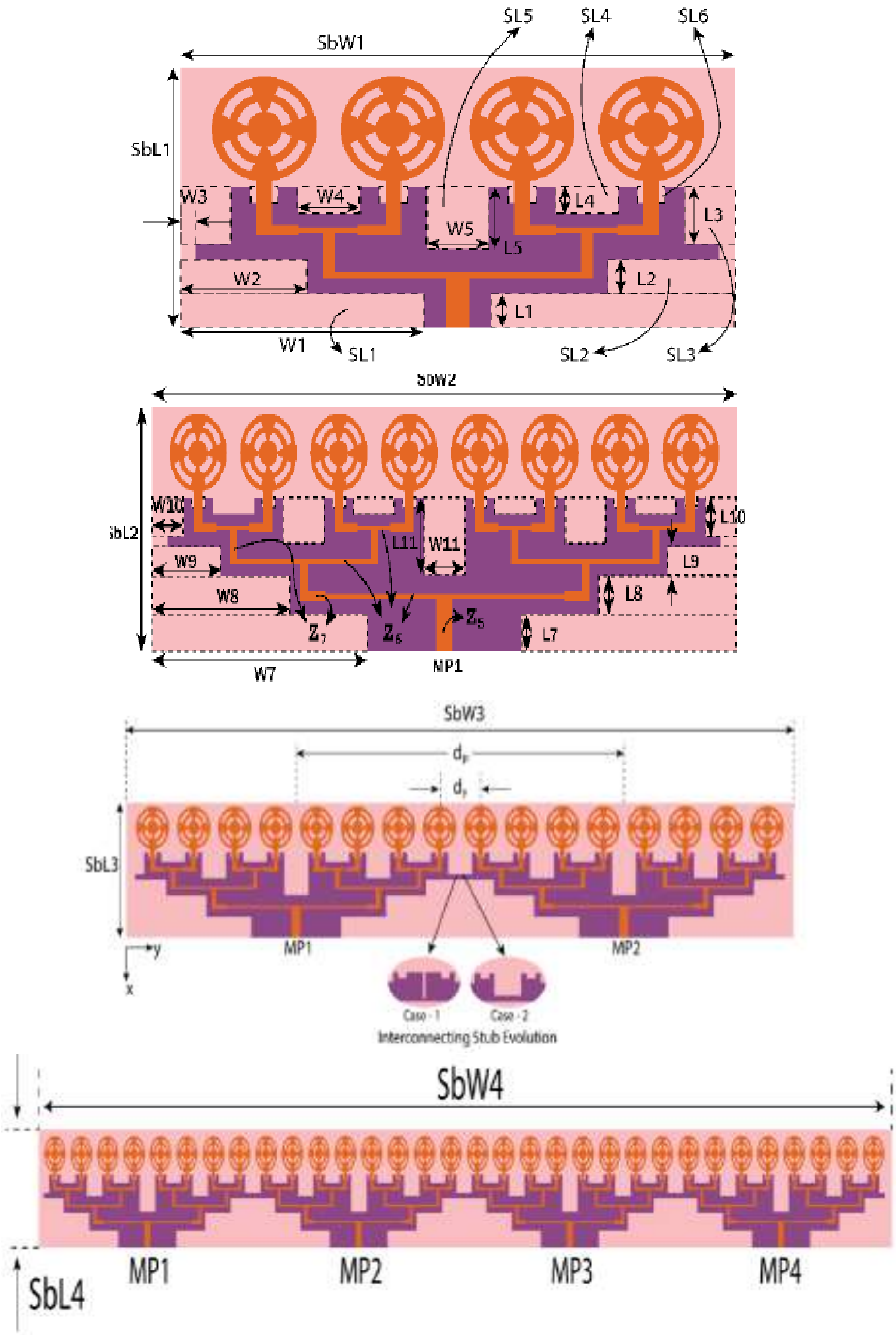

Fig. 3. The proposed antennas of [29]

Geun-Sik Kim and Dong-You Choi, Member, KIICE in 2020, suggested a four-element microstrip patch array antenna for 5G applications that combines corporate and series feeding approaches. Two insets are included in each patch to provide a broad bandwidth reaching 23.13–30.21 GHz. Yagi elements, which consist of a single reflector at each open end and three directors on the topmost patches, improve gain and radiation efficiency, reaching a maximum gain of 8.7 dB. The antenna has remarkable radiation efficiency exceeding 80% throughout the operational band, and it is built on a cheap FR4 substrate. The suggested antenna's bandwidth is larger and has a smaller size (22 × 28 mm2) than earlier designs that used corporate feeds or series, which makes it appropriate for IoT and 5G applications [30].

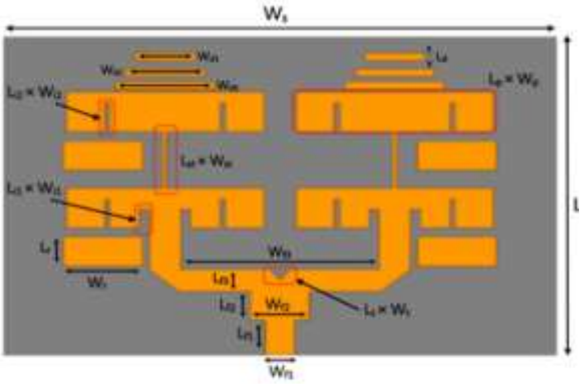

Fig. 4. The proposed antenna of [30]

Mahnoor Khalid et al. (2020) suggested a 4-port MIMO antenna. A design implemented on a Rogers RO4350B substrate using measurements of 30 × 35 × 0.76 mm, beginning with a single element working at 2.8 GHz and expanding to a dual-element array before arriving at a four-port MIMO arrangement. Excellent MIMO performance was demonstrated by the antenna's coverage of the 25.5–29.6 GHz frequency band, a peak gain of 8.3 dBi, and an efficiency of roughly 82%. The above antenna could be used for 5G mm Wave, smart devices, and portable Wi-Fi connections. It also suggested that slot design and defective ground structures be further optimized to improve isolation and boost gain with upcoming millimeter-wave technologies [31] .

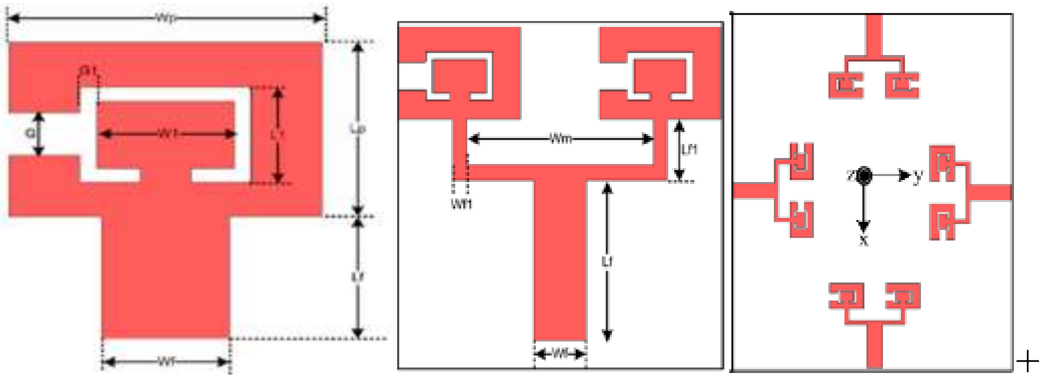

Fig. 5. The proposed antenna of [31]

Rusmono, Efri Sandi et al, in 2020, presented an article to overcome the issue of single-band antennas not being able to span multiple different bands. The study suggests a patch and slot modification involving the addition of patches and slots on Rogers RT5880 (εr = 2.2, h = 0.787 mm), starting with a 28 GHz patch, adding another patch for 38 GHz, and a slot for 24 GHz, then expanding to a 4×1 array and 2T2R MIMO. Minor variations between simulation and measurement occur, but the design proved functional and is suggested as a platform for additional multiband MIMO antenna research [32].

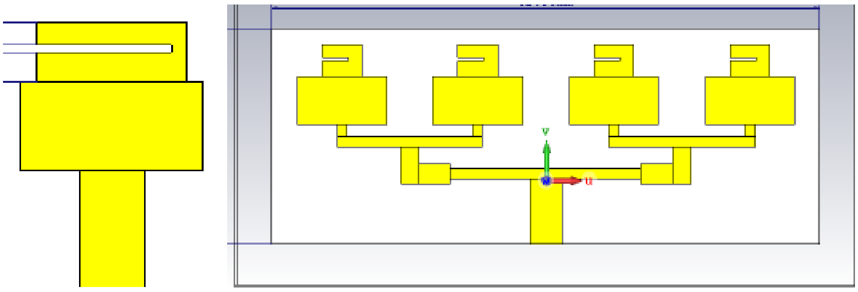

Fig. 6. The proposed antenna of [32]

NIAMAT HUSSAIN1 et al, in 2020, presented this study**.** Within the paper, a meta-surface-based small-profile circularly polarized (CP) antenna is presented. The antenna's compact single-layer design ($1.0\lambda_0 \times 1.0\lambda_0 \times 0.04\lambda_0$) covers the 5G spectrum (25–29.5 GHz). It's a single component with a Metasurface that provides a broad gain of 11 dBi, a very high radiation efficiency (>95%), and an impedance bandwidth of 23.4% (24.5–31 GHz) and a 3-dB AR bandwidth of 16.8% (25–29.6 GHz). To improve performance, A 2x2 MIMO with a 4-port configuration is constructed, demonstrating high isolation (>30 dB). Both simulated and measured results agree well, confirming stable radiation, low cost, and scalability, making the antenna a strong contender for 5G applications [33].

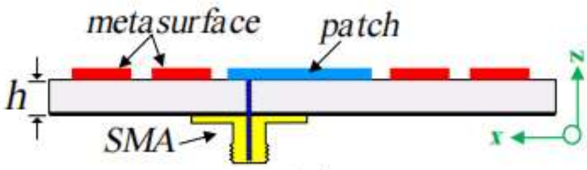

Fig. 7. show the proposed antennas [33]

Hafiz Usman Tahseen1, Lixia Yang2, and Wang Hongjin in 2021 suggested that an antenna system contains two 1x16 arrays on the same edges of the substrate. Initially, only one patch antenna component with a bandwidth of impedance of 36.16–39.27 GHz is built and simulated on a Rogers-5880 substrate at a center frequency of 38 GHz. This bandwidth is increased to 31.30–39 GHz by adding a half-moon slot. Following that, a 12.91 dB simulation gain is obtained by simulating a 1×4 antenna array for array demonstration and end-fire coverage. According to the research, this dual-array antenna system offers a promising option for phased array cellular systems and a strong contender for 5G mm-wave multi-wireless applications [34].

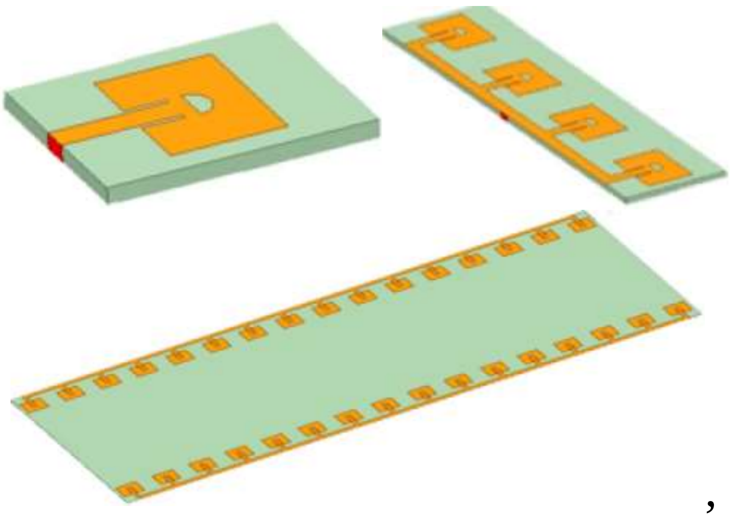

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Fig. 8. show the proposed antennas [34]

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Jalal Khan 1, Sadiq Ullah 1, et al, in 2022, presented the design for a MIMO antenna with 5G communication on 37 GHz. First, a single element was designed on Rogers RT5880 (thickness = 0.254 mm, εr = 2.2), which produced a reflecting coefficient at (–10 dB), an output gain at 6.84 dB, and a bandwidth of approximately 780 MHz. After that, a 2*1,1*4 array was created, which increased the gain with a reflection coefficient. 1*4 having a bandwidth of almost 677 MHz, gain of 12.8 dB, a bandwidth of 677 MHz, and a reflection coefficient of –33.23 dB. Last but not least, a MIMO setup was suggested, which consists of two (4x1) arrays positioned at a 90° angle to offer great isolation and pattern variety. Isolation was over 40 dB, radiation efficiency was 85%, ECC was below 0.00014, and diversity gain was about 10 dB. It is advised that the design be improved for dual-band operations within a future version by utilizing overlapping apertures as well as double-layer gridded patches [35].

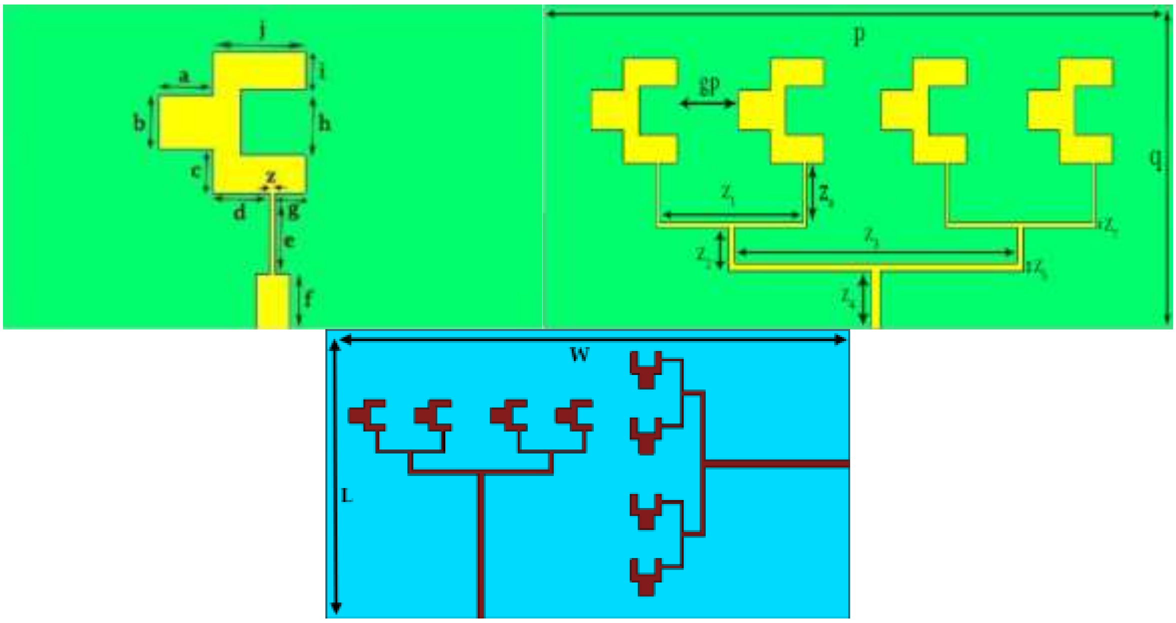


Fig. 9. shows the proposed antennas [35]

Daniyal Ali Sehrai1 et al in 2023 suggested. The design of a high-gain antenna array using millimeter-wave five-generation base stations is presented in this work. A single fork-shaped microstrip element, which performed satisfactorily after that, an 8x8 array was created, which increased gain but still had significant side lobes. When the concept was extended to an 8x16 array, it demonstrated more steady performance and improved impedance matching. Last but not least, the 8×32 array met the requirements for 5G applications by achieving high gain, narrow beamwidth, and acceptable side lobe levels. For increased base station efficiency, the authors suggest making additional adjustments to minimize side lobes and use dual polarization [36].

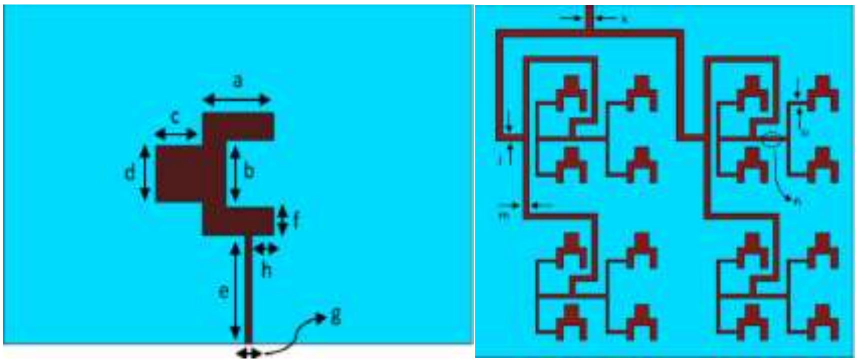


Fig. 10. shows the proposed antennas (single and array) [36]

H.R. Barua, I.A. Chowdhury, in 2024, offering the study for development and simulation of a highly efficient 5G mm-Wave MIMO antenna array designed to operate handheld devices and tablets. The design comprises single-element, 1×2 array, 1×4 array antennas. The overall efficient performance and the radiation effective efficiency are in excess of 70%, which makes them ideal for mobile millimeter-wave applications. The method of design approach includes creating a single component first, then extending to arrays. The simulation analysis demonstrates that the antennas achieve excellent isolation and reflection characteristics. This design is restricted to a frequency range of 37 GHz [37].

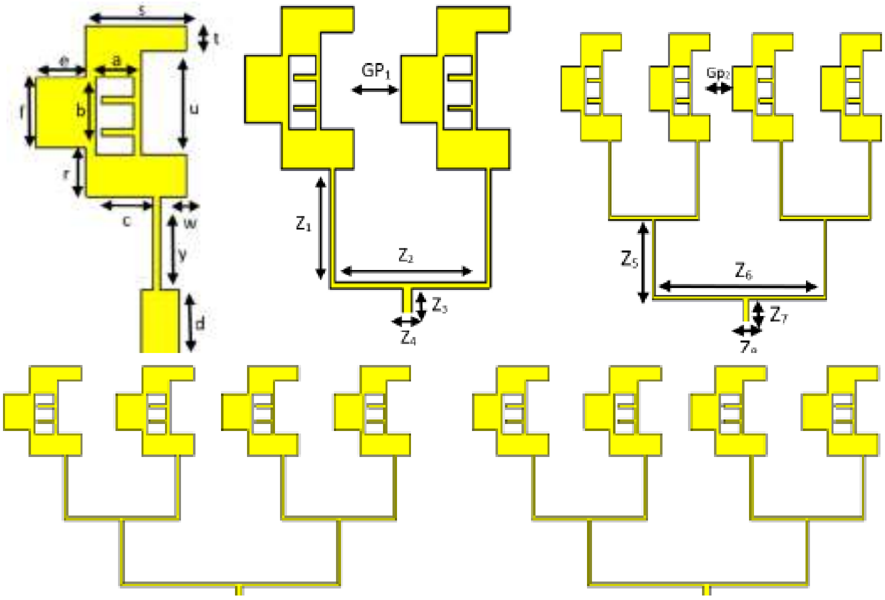


Fig. 11. shows the proposed antennas [37]

Masuod Ghasemi in 2025, suggested a neural network using 670 CST simulation samples as training data was used to optimize a beginning antenna component that was 10 × 6 mm² in order to maximize gain, bandwidth, and impedance match while reducing antenna size .Compact dimensions of 4.21 × 7 mm², bandwidth of 0.9 GHz (36.9–37.8 GHz), return loss fewer than -30 dB, gain of 7.8 dB, and radiation performance surpassing 83% for a single antenna. The maximum gain increased to 13.2 dB using a 1×4 array design using the element that has been optimized. Compact size, high gain, increased efficiency, and shorter design time than manual tuning is among the benefits .Future research could expand this ML-driven strategy to more frequency bands, different antenna designs using dual-polarized or just circular arrays, and sophisticated models like CNNs or hybrid ML-EM approaches [38].

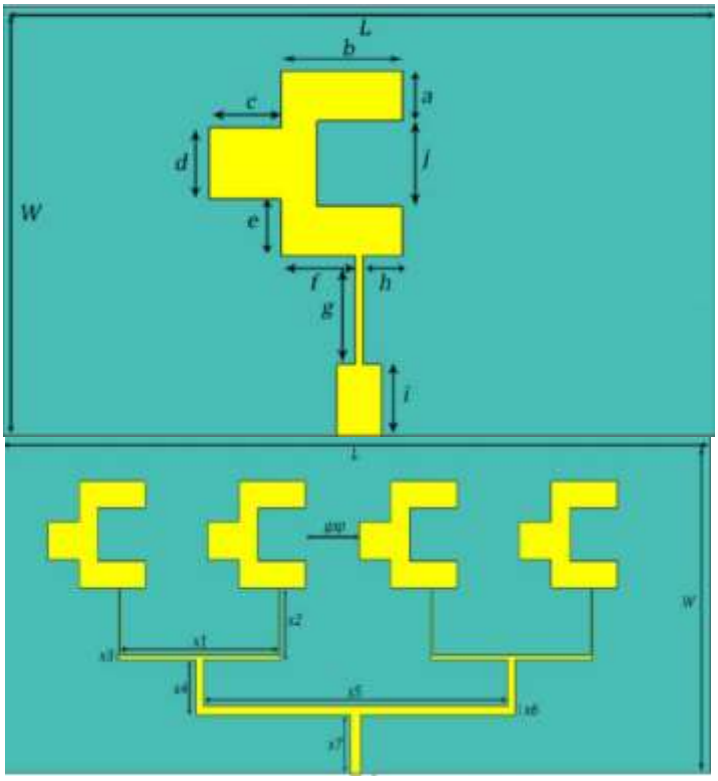
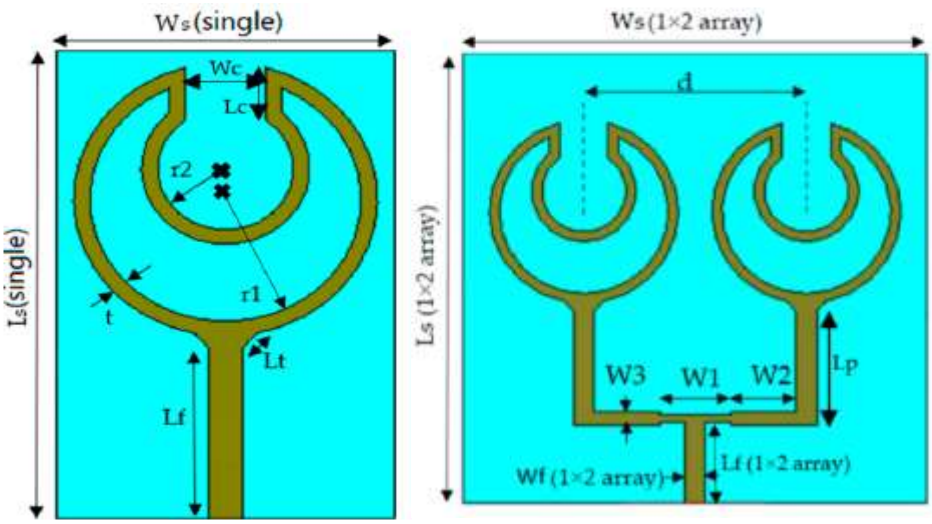


Fig. 12. shows the proposed antennas [38]

Heba Ahmed et al in 2025 suggested the configuration of a circular stub patch antenna that is empty with a rectangular flaw in a crescent form. It is fixed to a cheap FR-4 substrate (1.6 mm thick, ε_r = 4.4, loss angle = 0.02). The one-element model was followed by 1×2 and 1×4 arrays, and finally a two-port MIMO array measuring 140 × 135 × 1.6 mm³. With gains of 7.66 and 7.84 dBi and an efficiency rating of 71.5%, this antenna had a bandwidth of 3.01–6.5 GHz. CCL ≈ 0.2-bit/s/Hz, ECC = 0.02, MEG <-6 dB, and TARC <-10 dB [39].



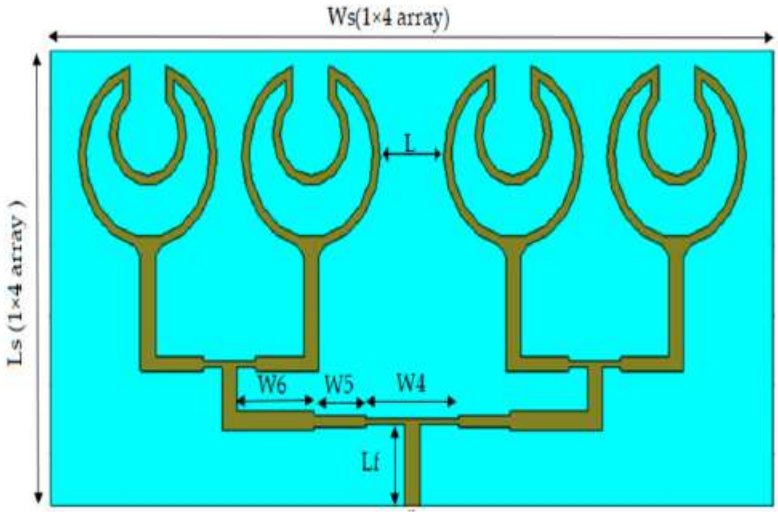


Fig. 13. shows the proposed antennas [39]

B. G. PARVEEZ SHARIFF et al in 2025 presented. This study addresses for mm Wave issues such as high path loss, shadowing, and Doppler effects by proposing a dual-band MIMO array antenna to applications using 5G at 28 and 38 GHz. A single-element antenna (Ant1) expanding to a 1x4 array (Ant2) increased efficiency beyond 90%, and gain from 7.4 dBi to 12 dBi. Elliptical LHCP emerged at 38 GHz, whilst circular polarization (RHCP) was detected at 28 GHz. results of further development into two-port (Ant3) and four-port (Ant4) MIMO arrays. These findings demonstrate this suggested antenna is being appropriate to wireless applications in 5G since it provides high gain, superior isolation, and dependable channel efficiency [40].

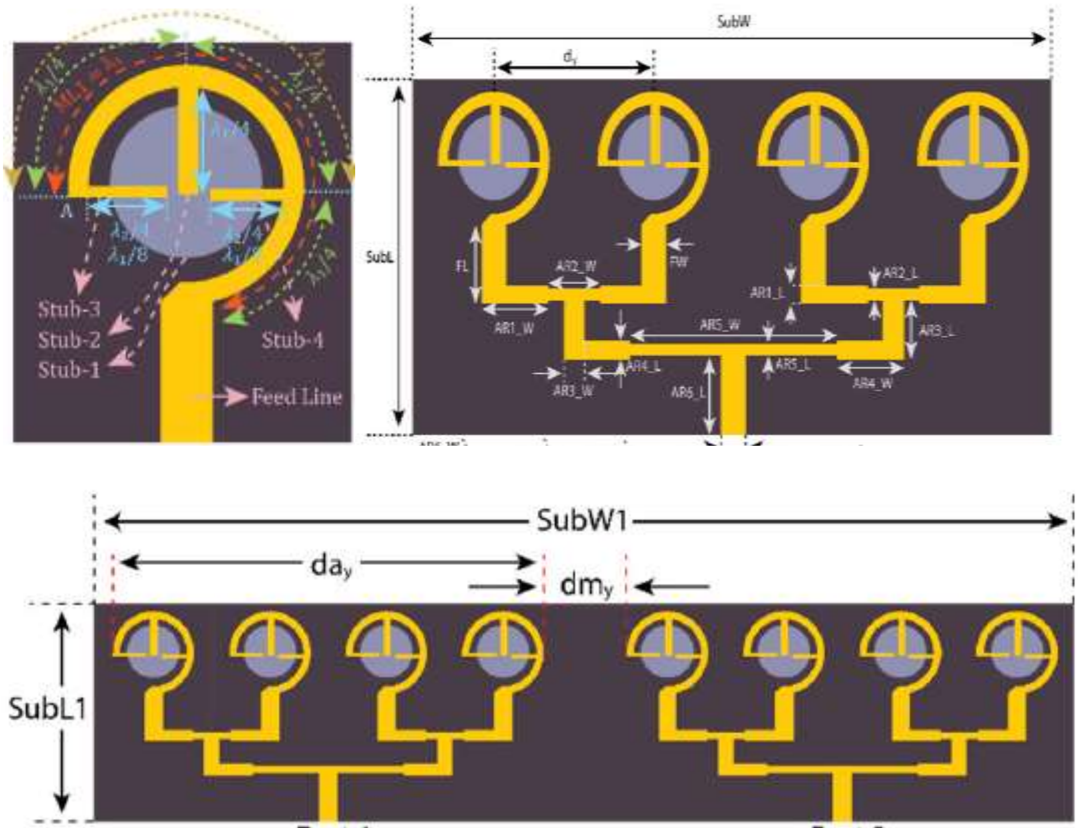


Fig.14. show the proposed antennas [40]

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Karima Benkhadda1, et al in 2025, presents this paper, a 1x2 microstrip patch antenna array for applications utilizing 5G during(24 and 26.9) GHz, using Rogers RT5880 (ε_r = 2.2, loss tangent 0.0009) is designed and simulated. Higher gain, better S-parameters, reduced VSWR, enhanced directivity, and a broader bandwidth are the desired outcomes. A two-element array on the same substrate was used to simulate CST after a single rectangular patch was first created at 24 GHz. array demonstrated a significant improvement: S11 = –68.70 dB, gain = 10.52 dB, directivity = 11 dBi, and efficiency = 95.63%. Further research on beamforming, bandwidth enhancement, compact design, and integration with new technologies is required. The advantages include increased bandwidth, better gain, and the elimination of secondary lobes. The drawback is performance susceptibility for design changes [41].

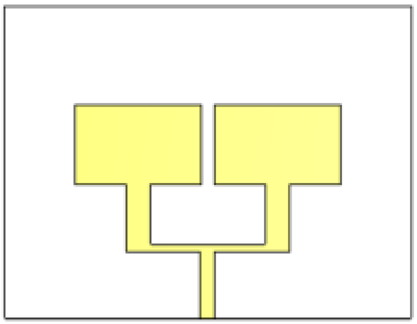

Fig. 15. shows the proposed antennas [41]

Mohammed Mahaboob Basha in 2025 suggested this study shows a small dual(band/ port)and quad-port MIMO antenna array with 5G millimeter waves application working at 28/38 GHz i. The goal is to get beyond single-element antenna drawbacks such as excessive coupling, limited gain, and inadequate bandwidth in small devices. Using a Rogers RT/ Duroid 5880 substrate (εr = 2.2, th = 0.79 mm), the suggested design makes use of a corporate-feed two-element array with a strip at the patch edge and a circular slot in the ground plane. This antenna operates in doul bands, from 27.1 to 28.71 GHz and from 36.2 to 42 GHz. With a small dimension of 25 × 20 × 0.79 mm³, this four-port MIMO architecture offers high realized gains of about (10.4 and 10.1) dBi, and exceptional isolation (<−27 dB during 28 GHz) , (<−20 dB during 38 GHz). Results from measurements and simulations concur well. Compactness, high gain, high efficiency, and robust isolation are among the benefits. Limitations include the difficulty of fabricating thin substrates and the need to reduce bandwidth for multiport feeding. To improve 5G efficiency, the report suggests expanding the design towards two-band integration in mobile and Internet of Things technologies [42].

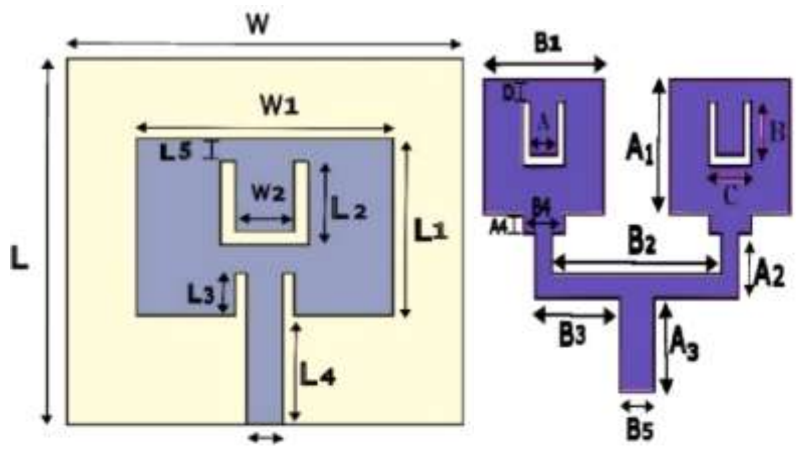

Fig.16. shows the proposed antennas [42]

Table 2. The comparison between the recent works presented in this review

Refs.	Size mm^3	No. of elements	Frequency bands GHz	Best S11 dB	Isolation dB	Gain dBi	Efficiency %
[38]	10x6x0.254	Single element	36.9-37.7	-22	-	5.8	83%
	7X4.21X0.254	optimized using a neural network trained	36.9-37.7	-27	-	7.8	83%
	18.6X7.1X0.254	1x4 Array antenna	36.9-37.7	>-10	-	13.2	83%
[39]	46x30x1.6	Single element	2.84-6.33	-22	-	4.9	4.9%
	66 × 66 × 1.6	1X2 Array antenna	2.83 -6.36		-	8.1	8.1%
	140 × 66 × 1.6	1X4 Array antenna	3.01 - 6.5	-35	-	9.259	9.9%
	140 x135 x 1.6	MIMO array	3.5 - 5.8	-32	-59	7.84	71.5%
[40]	stub=0.47λ2 h=0.254	Single element	27-28.68 and 36.25-41.31	-16 and -20.5	-	7.5 and 7	-
	12.1x25x 0.254	1x4 Array antenna	26.5-29-5 and 36.31-39.68	-26 and -25	-	12 and 11.5	90% for two bands
	12.1x55x 0.254	MIMO array	26.37 - 31.06 and 37.56 - 41.46	-36.76 and - 41.45	-39 and - 32	12 and 12.5	90%
	115x12.1x0.254	N-Port	26.5 – 30.75 and 37.50 – 41.35	-22 and -48	- 40 and - 42	12 for two bands	90%
[41]	14 x 20 x 1.575	Single antenna	24-27	-31.54	-	8.093	99.58%

	14 x 20 x 1.575	1x2 Array antenna	24-27	-68.70	-	10.52	95.63%
[42]	5.4 x 5.7 x 0.79	Single antenna	26.5-28.1 And 37.25-41.9	-23 and -13	-	7.5 and 6.3	-
	7.6 x 10.8 x0.79	1x2 Array antenna	27.1 - 28.72 and 36.2-42	− 17. and -27	-	10.1 and 10.2	-
	10.8 x15.2x0.79	MIMO 2- ports	27.1 - 28.72 and 36.2-42	− 18 and -32	-23 and -18.5	10.5 and 11	-
	25 × 20 × 0.79	MIMO 4-ports	27.2–28.72 and 36.2–42	−17 and -27	−27 and −20	11 and 10.5	high
[37]	6 x 10 x 0.254	Single antenna	37	-23.477	-	6.44	86%
	6X10 x 0.254	1x2 array antenna	37	-48.771	-	7.89	81%
	7.7X19 x 0.254	1x4 array antenna	37	-55.658	-	10.88	78%
	7.7x32x0.254	MIMO 2-port	37	-58	>-25	11	78%
[36]	10x6x0.254	Single antenna	37.2	-30	-	7.6	-
	25.5x27.5x0.254	8x8 antenna array	39	-20	-	13	-
	27.5x55x0.254	8x16 antenna array	39.1	-47	-	15.3	-

	30x110x0.254	8x32 antenna array	37.2	-45	-	21.2	-
[35]	10x6x0.254	Single antenna	780MHZ	-22	-	6.84	-
	hs=0.254	1x2 antenna array	653MHZ	-36.24	-	12	-
	20 x 8 x 0.254	1x4 antenna array	677MHZ	-35.23	-	12.8	-
	20x40 x0.254	MIMO antenna	port1 38.35-38.66 Port2 37.29-38.64	-31 and -28	-40	>12.8	85%
[34]	2.34X3.12x0.5	Single antenna	36.16-39.27	-26	-	7.15	-
	3.43x29.80x0.5	1x4 antenna array	31.30-39	-32.78	-	12.91	-
	29.80x90.49x0.5	1x16 antenna array	31.30-39	-27	-	17	-
[29]	6x6x0.254	a single element	23-42	-22	-	6.2	about70%
	19.8x8.86x0.254	4-element linear	20.5-41.3	-25.8	-	10.5	90%
	11.16x 38.2 x0.254	8-element linear	20.5-42.2	-30	-	13	89.7%
	11.16x 75x0.254	Two-Port MIMO Antenna	20.7-42.4	-32	-60	13.5	89.5%
	148.6 x 11.16 x0.254	Four-Port MIMO Antenna	20.5-41.3	-50	-80	>13.5	90%
[30]	22x28x1.6	single element	23.13-30.21	-	-	-	>80%

Al-Furat Journal of Innovations in Electronics and Computer Engineering (FJIECE)
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	22 × 28 × 1.6	4-element linear	23.13-30.21	-20	-	8.7	>80%
[31]	2x3x0.76	Single element	26.8-29.6	-41	-	5.2	90%
	D element=11	2-element linear	26.2-29.7	-22	-	>5.2	-
	30x35x0.76	4-port MIMO	25.5-29.78	-23	-17	8.45	85%
[32]	11.92x11.96 x0.787 with 24 GHZ 7.92x7.96 x0.787 with 28 GHZ 8.92x8.96x0.787 with 38 GHZ	Single element	24,28,38	>-10	-	-	-
	42.90X14.89	1 port-MIMO Antenna	24,28,38	-20.65 and -20.30 and -19.19	-	improving	improving
[33]	12x12x0.5	Single element	24.5-316.	-23.4	-	11	90%
	Distance =(2xp) +y	4-port MIMO	25-29.5	-28	-35	11.3	95%

7. CONCLUSION

The studied literature emphasizes how antenna design for 5G mm-wave communication has advanced significantly, especially in the 28 GHz frequency range. These developments, which offer previously unheard-of data speeds, ultra-low latency, and improved spectral efficiency, have enormous potential to satisfy the growing needs of wireless networks. Investigating mm Wave technology and antenna array developments offers important information about how they can affect mobile broadband applications, such as 5G networks. There is still much space for development and more study to address issues related to millimeter wave antenna arrays, even if the reviewed works highlight novel designs, including MIMO antennas with a single layer and Dielectric resonator antennas with multiple inputs and multiple outputs. Future wireless network technologies and the development of 5G communication are expected to be facilitated by sustained efforts in this space.

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