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# SHAPING THE FUTURE OF WIRELESS COMMUNICATION: AN ANALYSIS OF REFLECTARRAY ANTENNAS FOR 5G/6G

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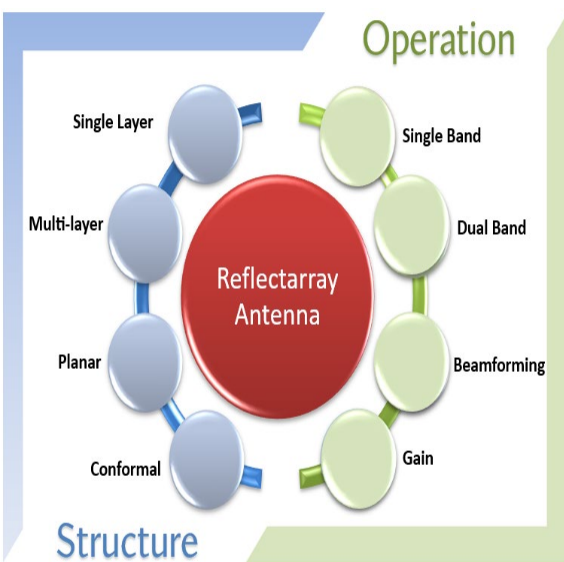
**Graphical abstract**




**Abstract**

The rapid development of intelligent emerging applications and technologies requires a huge data rate along with reliable and efficient connectivity. Each new generation is better than the last one in several ways. Fifth Generation (5G) communication represented various features as compared to 4th generation communication. However, 5G specifications severely limit on demands of innovative emerging technologies. Which include a high data rate, more capacity, low latency, reliability, resource sharing, and energy per bit. While testing phase for 5G is ongoing in most countries, the 6G technology has become the focus of modern research. In this paper, we discuss the implementation of 6G projects worldwide, requirements, and 6G emerging technologies applications such as Multi-Sensory XR, Robotics and Autonomation, Smart and Remote Healthcare, Internet of Everything (IoE), Wireless power transfer and Wireless Brain Computer Intercommunication. Reflectarray antenna (RAs) are a potential antenna for 5G and 6G systems because they have many advantages including high gain, beam modelling, beam scanning, reconfigurability, and multiple beams. This study represents a comprehensive review of the design of single and dual band reflectarray antenna in some specific research areas. The development of several design operations for improving the reflection phase, gain, and efficiency are covered in detail. Several methods of enhancing the unit cell reflectarray featured properties to make them 5G-compatible.

*Keywords*: Reflect array antenna, 5G/6G communication system, Single Band, Dual Band



## 1.0 INTRODUCTION

Demands for increased wireless system capacity, throughput, reliability, and latency have led to improvements in wireless communication since first-generation (1G) towards to fourth generation (4G) technology systems. These requirements determine the primary technologies necessary for developing each new generation of wireless communication systems, the most recent of which are 5G and 6G. In addition, the rapid growth in various smart technologies, for example artificial intelligence (AI), virtual reality (VR), 3-dimensional media, and the Internet of Everything (IoE), has caused a significant increase in traffic [1]. International Telecommunication Union (ITU) has presented the estimated mobile data traffic analysis in 2015 [2].

The estimation of Worldwide mobile data traffic was 7.462 EB/month during 2010 and hopefully will be expected to increase by 5016 EB/month by 2030 as shown in Figure 1. The increasing global mobile traffic number shows how important it is to make communication systems better.

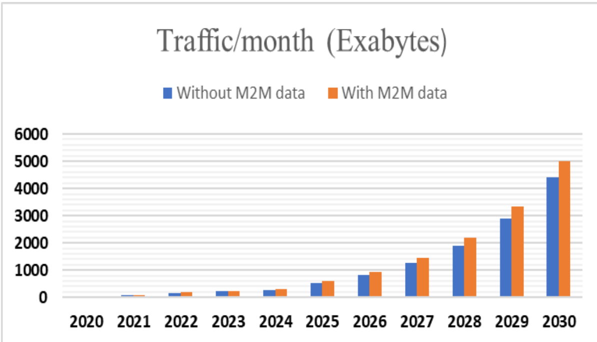



**Figure 1.** Estimation of Global Mobile Data Traffic Analysis

In the recent past, most countries have made some intention to advance the 6G infrastructure. The United Kingdom (UK) and Germany are investing in 6G-related emerging technologies, including quantum technology, whereas the United States (US) started working in the terahertz range for 6G mobile networks in 2020 [3]. The Ministry of Industry and Information Technology Republic of China has declared the authoritative announcement that the country is concentrating on the development of 6G.

Here are some of the most significant ongoing projects:

1. In Finland, a 6G concept at the University of Oulu for 2030. The department of the university has joined into a partnership contract with Japan's Beyond 5G Promotion Consortium to supervise the task on 6G technology for the complete 6G Flagship research project. Japan was one of the first countries to start developing 6G networks, even though 5G was just getting started.
2. The Terahertz frequency range for 6G is the focus of study at the Electronics and Telecommunications Research Institute of South Korea, which is among the top countries in the implementation of 5G.
3. In addition to launching test satellites, the Chinese Ministry of Industry and Information Technology provides financial support and manages the country's 6G research and development.
4. A European group of academics and business representatives called Hexa-X is advancing and promoting the study of 6G standards in an EU country. The Finnish communications company Nokia is leading this endeavour.

In this study, we discussed several emerging technologies, requirements, and applications of the 5G/6G communication system as summarized in section II. In section III, it is all about Antenna for 5G/6G. Reflectarray antenna operation and structure are presented in section IV. Several research activities on the design of reflectarray antenna for 5G communication systems in section V. Finally, in section VI we conclude this article with the main points. Figure 2 represents the overall organization of this paper.

## 2.0 REQUIREMENT AND APPLICATIONS OF 6G TECHNOLOGY

There are several trade-offs that relate to the implementation of 5G technologies. These include system capacity, delay, energy efficiency, implementation cost, dependability, and hardware complication. Additionally, future 6G systems will have to provide peak data rates of more than 1Tbps, which is ten times faster than 5G [4],[5]. The minimal communication plane delay should be 25, and consumer mobility of approximately nearly 1000km/h, must be considered a condition of airborne terminals. After 2030, it is probably expected that 5G won't be able to satisfy consumer demand. In that case, the next generation i-e 6G is expected to meet the future needs of consumers and fill the gap where 5G is limited [6]. Based upon recent developments and estimates of upcoming requirements, the major purpose for 6G communication systems and devices provide tremendously high data rates, (ii) the lowest latency, (iii) worldwide connection, (iv) reduced energy usage Internet of Things (IoT) plans, (v) a huge number of connected devices, (vi) high dependable connectivity, and so on [3]. The comparison between 4G, 5G, and 6G communication systems is summarized in Table 1.

**Table 1** Summary of Comparison between 4G, 5G, and 6G Communication Systems

| Issue | 4G | 5G | 6G |
|---|---|---|---|
| **Data Rate** | 1 G-bps | 10 G-bps | 1 T-bps |
| **Haptic Communication** | Not at all | Partially | Completely |
| **Planning** | MIMO | Support Massive MIMO | Intelligent Surface |
| **Latency** | 100 ms | 10 ms | < 1 ms |
| **Satellite Integration** | Not at all | No | Completely |
| **Mobility Platform** | Up to 350 km/hr | Up to 500 km/hr | Up to 1000 km/hr |
| **Spectral Efficiency** | 15 bps/Hz | 30 bps/Hz | 100 bps/Hz |
| **Artificial Intelligence** | Not at all | Partially | Completely |
| **Autonomous Support** | Not at all | Partially | Completely |
| **XR Incorporation** | Not at all | Partially | Completely |

Every technology presents its new and upgraded version of services. Comprehensive Artificial intelligence would be deployed towards the inside of 6G [4]. In this part, some potential and emerging applications for 6G are discussed that are also picturized in Figure 2.

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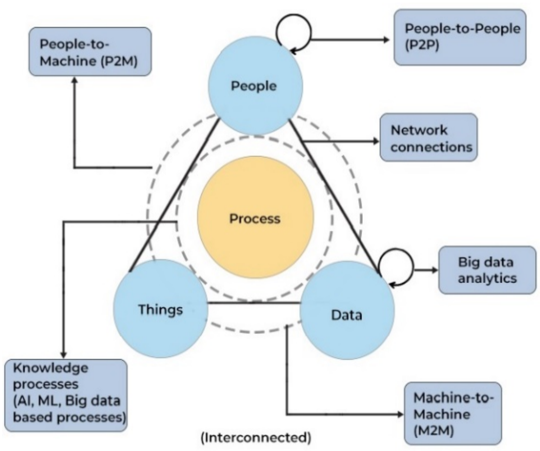



**Figure 2** Elements of Internet of Everything [2]

## 2.1 Multi-Sensory XR Application

The high bandwidth and low latency for the 5G users have enhanced the Virtual/Augmented Reality experience. However, several problems already encountered will need to be fixed in a 6G network. The next generation of 6G systems and networks will improve the experience of virtual reality and augmented reality. Data from multiple sensors with huge amounts of data can be processed. Therefore, these AR or VR will be composed of enhanced mobile broadband (eMBB) and ultra-reliable low latency communication (URLLC) in a 6G network [3],[5]. This technology has many uses, such as remote surgery and diagnosis, high-resolution sensing for remote exploration, and more.

## 2.2 Robotics And Autonomation System

At present, many researchers in automotive technology are focusing their attention on the study of automated and connected vehicles. 6G will enable full automation using AI. Future generation systems should be multi-layered, and they should have the capability to integrate with AI throughout the network [5], [6]. This will enable the internal components to be controlled automatically. Strianti et al. [7] have proposed implementing network-based resource control, self-handling, and caching. 6G technology will enable efficient reliable, secure, and smooth communication channels for operating real-time robotic operating underwater for certain applications such as security, imaging, and rescue [8]. Ultra-high-definition live streaming such as 8k, and 16k videos is possible due to the low latency and high-speed data transmission of 6G.

## 2.3 Smart and Remote Healthcare

The excellence of remote healthcare solutions is mainly determined by the quality and availability of connectivity [9]. Regarding this point, we would like to point out that 6G will bring the best wireless communication quality by using THz band communications and network automation solutions. 6G will focus on very high throughput with ultra-low latency. The future 6G will facilitate reliable remote monitoring systems and enable reliable remote surgery with the help of a high data rate and very low latency, 6G enables the propagation of massive medical data making the treatment and quality of care easy. In the future, it will be able to offer medical devices that can do specific medical tasks [10]. This will make it much less likely that medical staff will encounter viruses.

## 2.4 Internet of Everything (IoE)

Everything today can connect to everything else, resulting in the creation of a new distributed ecosystem that goes beyond the well-known IoT (Internet of Things) concept [11]. The IoE concept is based on all-around connectivity, intelligence, and cognitive processing. The Internet of Everything (IoE) is a network that connects people, things, processes, and data and provides enhanced intelligence and cognition throughout the networked world [1][9]. IoE provides network intelligence to enable more smart decisions and simple data exchange. So, the connection can be between machine to machine (M2M), people to people(P2P), P2M people to machine (P2M), and vice versa are summarized in Figure 3

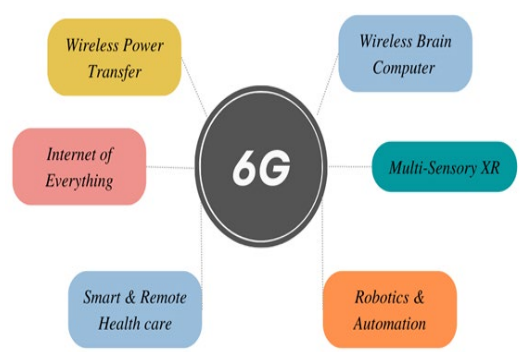



**Figure 3** 6G applications and technologies

## 2.5 Wireless Power Transfer

No doubt, the next generation 6G technology has the potential to provide reliable and efficient linking between mobile devices. However, wireless energy transfer is one of the potentials of 6G technology, which can specify suitable power to the batteries of devices like sensors, nodes, and. 6G is expected to utilize novel power control procedures and systems such as wireless charging and advanced wireless power transfer (WPT) [12]. Future communication networks will make it possible to use energy harvesting and optimization techniques to make things work well in harsh environments, like under the sea and remote areas.

## 2.6 Brain-Computer Wireless Intercommunication

Brain-computer interface (BCI) is a system for controlling everyday appliances, gadgets, particularly residential appliances, and medical devices. Smart headsets, intelligent embedded devices, and body sensors are part of the BCI applications. The human brain and outside electronic gadgets can communicate with one another directly [8][11]. The brain signals are captured by the BCI and are transmitted to a digital device wirelessly, that further analyses it, and then sends commands or initiates activities. BCI is limited as these devices require more data rate, wide bandwidth, and low latency [13]. 6G technology has the capability to support more applications as it tends to support high data, more devices, and low latency, such as transferring and storing of the information of human basic five senses and helps in human interaction with the environment and different applications [14].

## 3.0 ANTENNA FOR 5G/6G

In any communication system, an antenna has a major role as the design of an air interface depends entirely on the antenna design. As a result of the significant wireless growth from 1G to 6G, technologies and network capacity are also changing to meet the rapidly expanding consumer needs [15],[16]. Along with these rapidly growing requirements, the antenna design community has made significant technological improvements [17],[18]. Designing and selecting the proper antenna can overcome the mm wave-associated propagation challenges. Array antennas are recognized as a suitable option for compensating for path loss challenges in short-range communications [19]. Several different types of antennas are described in the literature for planned 5G operations. Reflectarrays might be a good substitute for 5G/6G systems. An innovative antenna design created by the combination of a phase array antenna and a reflector, bearing the advantages of both antenna categories [23]. RA offer better gain, the capacity to shape beams, change radiation patterns, scanning, and multi-beam potentials [24]. Various works are proposed in the literature for improving each parameter needed for a 5G/6G compatible reflectarray. The author [25] carried out the computational study and proposed an LC-based binary phase reconfigurable reflectarray meta surface comprising 20 x 20 elements that have 108 GHz operating frequency. The phase difference of 177° was kept between the ON and OFF states at their center frequency, and reflection amplitudes of 0.88 were achieved in both states. In Author [26] has also proposed a 400 GHz quartz-based RA with polarization diversity for high-speed 6G communications within highly dense base stations.

As listed in Table 2, Reflecarrays antennas have been evaluated with respect to many perspectives using various strategies and approaches for designing RAs for 5G communication systems.

**Table 2** Some Existing Studies on Reflectarrays for 5G/6G

| Reference | Year | RA research directions |
|---|---|---|
| R. Shamsaee et al [53] | 2015 | Designing and Realization of Dual Band Single Layer Reflectarray Antenna for X and K Bands |
| Iman Derafshi et al [54] | 2016 | Dual-band Reflectarray Antenna design for X/Ku Band by using a Novel FSS-Backed unit cell with Quasi Spiral Phase Delay Line |
| M.Hashim et al.[29] | 2017 | Review Study on the High Efficiency and High Gain Reflectarrays for 5G Communications Systems |
| M.Hashim et al.[30] | 2017 | Literature Review Study on Wide-band Reflectarray Antennas for the 5G Communication Systems |
| M.Hashim et al.[31] | 2018 | A Review on the Adaptive Beamsteering and Polarization Diversity in Reflectarray Antennas for 5G Reflectarrays |
| M.Inam Abbasi et al. [55] | 2019 | Designing and characterization of efficient millimeter wave (mm-wave) planar reflectarray antenna for 5G communication systems |
| S Costanzo et al [57] | 2019 | A Dual-band Single Layer reflectarray cell for 5G communication technology |
| M.Hashim et al. [58] | 2020 | An Innovative design of Asymmetric Patch Reflectarray Antenna having Ring Slots in the Ground for 5G Communication Systems |
| S Costanzo et al [59] | 2020 | Dual polarization and Dual-band reflectarray antenna for mmWaves/5G applications |
| Tahir Bashir et al [60] | 2021 | Designing and Analysis of Reflectarray Compound Unit Cell for 5G Communication Systems |
| Abdul Azeem et al [61] | 2021 | A High Bandwidth and High Gain Reflectarray Antenna for 5G Communication technology |
| Panagiotis Ioannis et al [56] | 2022 | A detailed survey on the Wideband Reflectarrays for future 5G/6G communication systems. |
| E. Hadian et al [62] | 2023 | Design of a Wideband Flower-like Shape Metamaterial Reflectarray Antenna |
| Manzoor Elahi et al [63] | 2023 | A Wide-band and Low Cross-polarization Reflectarray Antenna for Satellite Application |
| This paper | 2023 | Shaping the Future of Wireless Communication: An Analysis of Reflectarray Antennas for 5G/6G |

## 4.0 REFLECTARRAY ANTENNA OPERATION AND STRUCTURE

Recently, the reflectarray antenna presented various advantages and capabilities that have promoted continuous development and exciting applications. Berry, Malech, and Kennedy gave the concept of the reflectarray antenna in 1963s [27]. A reflectarray antenna is comprised of an array of radiating patch elements on a flat substrate or surface that redirects the incident signal coming from an appropriate feed at a distance. A plane reflectarray antenna is lightweight and can reflect incident signals similar to a parabolic reflector but with the attractive property of beam scanning.

The reflectarray antenna design is flexible, making it appropriate for high gain and wideband applications [28]. The thin reflecting surface of a reflectarray can give a wide phase range, but it comes with a high path loss and a complicated design. The basic part of a reflectarray is a resonant unit cell, and its performance can be measured by its return loss, beam width, and reflection phase [29]. Fundamentally reflectarray antenna design comprised of rectangular patch elements. Each element can be modelled as a unit cell that can be analysed using the full-wave methods [30] as shown in Figure 4. A single or unit cell can be viewed as either a single element alone free from the impacts of mutual coupling or it can be considered as an array element set up in a periodic array environment with the potential for mutual coupling with nearby elements [31].

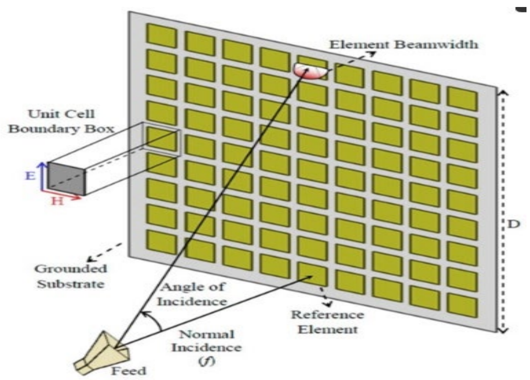



**Figure 4** Basic building model of a microstrip reflectarray antenna with an offset feed [30]

The beamwidth of the individual unit cell elements defines the gain of a reflectarray. The gain will be higher if the beamwidth is narrow. As a result, the total gain of the entire reflectarray model will depend on the cumulative impact of the beamwidths of each of the patch elements of the unit cell [32]. To achieve the high gain performing in the required direction, every single element on the reflectarray antenna is required to be designed with a suitable progressive reflection phase [33]. In the reflectarray, the phase of reflection can be manipulated by elements attached to unit cell elements having different sizes, rotation angles, or stub lengths. The incidence angle of an element's feed is determined by the distance (f) it comes from the reflectarray. In reflectarray antennas, the feed distance is typically expressed as a ratio of f/D, where D is the reflectarray longest dimension and f is the operating frequency [34],[35].

### 4.1 Analysis of Reflectarray Elements in Periodic Array Design

Reflectarray antennas are generally comprised of planar arrays of printed radiating elements that employ phase shifters to radiate the beam in a specific direction. The reflectarray elements are typically fabricated from a conductive material, such as copper or aluminium, and can be designed with a variety of shapes, sizes, and orientations. Reflectarray elements can be analysed systematically with the help of the powerful periodic array design approach [36]. To enhance the performance of the reflectarray, the design method considers the periodicity of the array, the size and orientation of the elements, and other factors. The first limiting factor of differential spatial phase delay can be shown in Fig. 6 representing an axially fed reflectarray with a focus distance F.

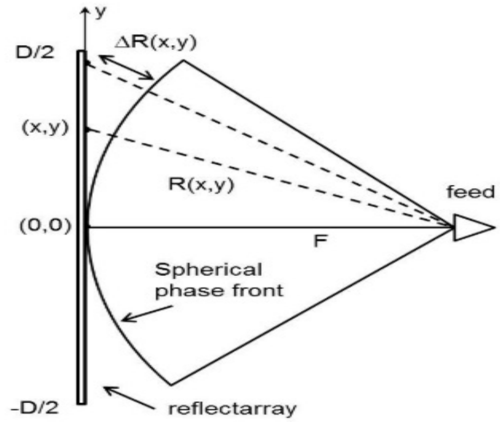



**Figure 5**. Reflectarray Antenna with differential spatial phase delay [23]

The feed generates a spherical wave that collides with the aperture of the reflectarray [23] [24]. When the paths difference $R\ (x,y)$ between the focal distance F and each ray emerging from the feed up to the generic $(x,y)$-element is considered, a differential phase delay is formed at each array position.

$$\varphi_{inc}(x,y,f) = \frac{2\pi}{Co}\, f\, \Delta R\ (x,y) = -\frac{2\pi}{Co}\, f\left(\sqrt{F^2+x^2+y^2}-F\right) \tag{1}$$

where $f$ is the operating frequency and Co denotes the speed of light in a vacuum. Every element of the RA antenna needs to be formed with consideration for the phase delaying, steering the major beam in the direction that is intended, or producing the antenna radiation pattern accurately, at a particular center frequency. In the case of considering the broadside pencil beam, the phase of each element array $f_0$ must be.

$$\varphi_{refl}(x,y,f_0) = \frac{2\pi}{Co}\, f_0\left(\sqrt{F^2+x^2+y^2}-F\right) \tag{2}$$

$$\varphi_{inc}(x,y,f) = \frac{2\pi}{Co}(f_0,f)\left(\sqrt{F^2+x^2+y^2}-F\right) \tag{3}$$

### 4.2 Beam Scanning Reflectarray Approach

They are commonly classified into two approaches mechanical approach and electronic phase tuning approach as shown in Figure 7. The basis of both techniques is on the concept of adjusting the properties of the embedded resonators thus controlling the phase response of unit cells.

In the form of mechanical approach has been proposed in [37] analysis and development of a beam steering RA that resonates at 26 GHz by mechanically rotating array. This is possible by using a single stepper motor that easily controls the angle at which the array is positioned. By adjusting the tilt angle between +30° and -30°, the beam steering more than 60° obtained. The maximum gain of 26.47 dB was reached by a 20x20 element array at 0° and at 61.9° in the elevation plane, it decreased to 19.8 dB. In addition, measurements showed that the fabricated RA antenna had a maximum bandwidth of 13.1% and a least side lobe level of 25.9 dB. To minimize the complications related to the offset feed horn, the proposed RA was angled in the XZ plane at the tilt angle ‘T’ of 20°, as illustrated in Figure 6.

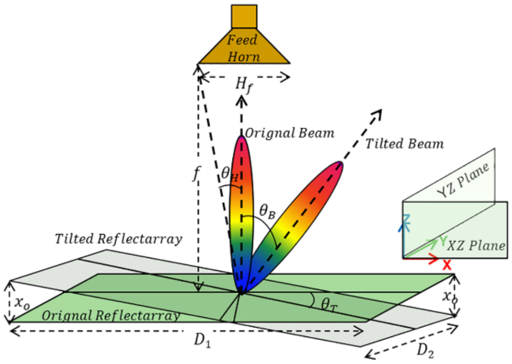



**Figure 6**. Schematic Diagram of beam-steering reflectarray antenna by mechanically rotating the array [37]

By changing the reflectarray antenna, the direction of the phase of surface current is varied, as illustrated in Figure. 8. Phase direction of the surface current is shown with the red solid arrow for the RA with fixed beam, whereas direction with specific tilt angles is shown by the black dotted arrow.

Lastly, a potential way to design reflectarrays in the terahertz (THz) and millimeter range is the deployment of emerging tunable dielectric substrates, such as graphene, Barium-Strontium-Titanate (BST) thick-film ceramic, and metamaterials. Here [39] proposed a work for analysing and designing an LC-based configuration RA antenna having a slot-embedded patch element configuration in the X band frequency range. Rectangular slots with different widths were designed on the patch elements, and it was found that resonant frequency shifts from 10.46 GHz to 8.78 GHz by varying the width of a slot from 0.2 W to 0.6 W. In a K-15 Nematic LC-based design for a frequency-tunable reflectarray antenna [40], the highest surface current on the patch elements occurs in the center of the patch length, as can be seen in Figures 7 (a) and (b). Figures (c) and (d) show that a circular and rectangular slot is integrated into the center of the patch element.

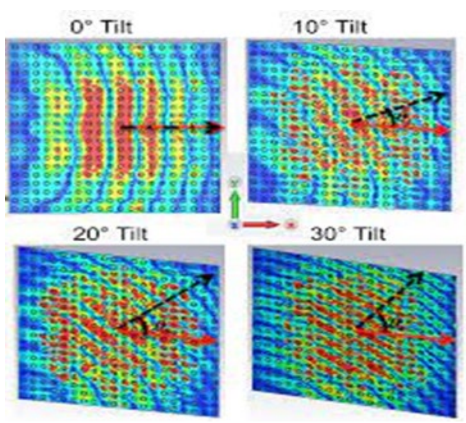



**Figure 7** Different tilt angle effects on the phase of the surface current distribution [37]

Recently, various other reflectarray antenna designs have been suggested by different researchers. They use the electronic component to tune or reconfigure the microstrip elements that are combined with electronic devices like PIN diodes, MEMs, and varactor diodes. In [38], an aperture-coupled reflectarray element for pattern reconfigurability applications has been proposed that provides a full phase adjustment range with a single varactor diode as shown in figure 8 (a) & (b).

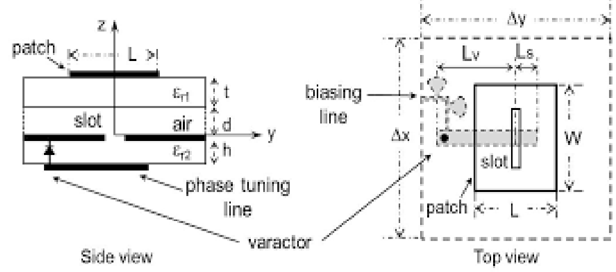



**Figure 8**. Reflectarray element [38] (a) Side view (b) Top view

### 4.3 Dual Polarization Of Reflectarray Antenna

Dual polarization is a crucial feature in modern reflectarray antenna systems that enables them to transmit and receive signals simultaneously in two orthogonal polarizations. This technology offers significant advantages, such as increased capacity and improved spectral efficiency in wireless communication systems [41][42].

There are various ways to improve each reflection parameter mentioned in the literature [43][44][45]. For microwaves and the millimetre range, some related work has been thoroughly studied for various reflectarray design specifications [46]. A study in detail analysis has been provided based on various dual linear polarized designs and dual circular polarized designs [47]. One key benefit of dual polarization in reflectarray antennas is the ability to minimize interference between signals. With separate feed networks for each polarization, these antennas can transmit and receive signals in a more controlled manner, reducing cross-polarization interference and enhancing the overall signal quality [48][49].

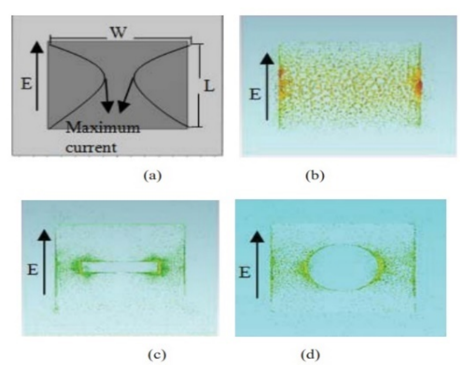



**Figure 9** Proposed Reflectarray Design [39] (a) a unit cell showing E-field with maximum surface current (b) Surface current without slot (c) Surface current with rectangular slot (d) Surface current with circular slot.

For the future 5G communication wireless coverage at the frequency range of 27.7 GHz, a dual-polarized shaped beam passive reflectarray antenna has been suggested [50]. Dual polarisation operation is also recommended in [51] at the frequency range of 13.285 GHz to use the standard square and rectangular patch elements as shown in Figure 9. In addition to this, [52] proposed that a DRA reflectarray be used for dual-polarization operation in the frequency range of X-band using a windmill slot element.

## 5.0 SINGLE-BAND AND DUAL-BAND REFLECTARRAY ANTENNA FOR 5G COMMUNICATION SYSTEMS

In [53], Malfajani discussed the single-layer, dual-band microstrip patch RA antenna design, and its fabrication are analysed. They suggested reflectarray design that supports K and X frequency bands. Every component within the reflectarray antenna contains a circular patch that comprises two-phase delay lines connected to the patch and slots as shown in Figure 10. The suggested element design offers an impressive linear phase range, exceeding 500 degrees in the X frequency band and 800 degrees in the K-band. The outcome measured indicates that at the frequency of 10.2 GHz, it achieves 26.2 dB maximum gain along with 16% of a 1-dB gain bandwidth. Meanwhile, at 22 GHz, a 29.7 dB gain is achieved with a 1-dB gain bandwidth of 9.1%. proper arrangement of the array elements effectively reduced the cross-polarization.

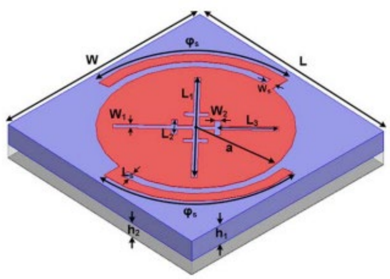



**Figure 10** Proposed Unit Cell Element in [53]

Another novel approach has been utilized to achieve a dual-band X/Ku Reflectarray Antenna (RA) by utilizing the FSS-Backed RA unit cell [54]. In this innovative method, an RA designed for the Ku band is developed using FSS-Backed cell element and placed on top of a typical X-band RA. For both bands, phase manipulation is carried out employing a wide-band cell element equipped with an associated quasi-spiral phase delay line. The basic unit element used in this study was shaped as a ring containing four quasi-spiral delay lines with FSS top and bottom elements as can be seen in Figure 11 (a), (b), (c), and (d). The efficiency of the reflectarray antenna designed for the band is measured at 40%, whereas for the Ku band, it stands at 36%. In the case of the Ku band, the 1-dB gain bandwidth for the X band is approximately 13% and for the Ku band, it is approximately 11%.

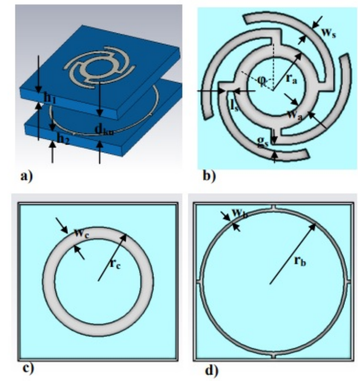



**Figure 11** Dual band Ku/X band RA antenna [54] (a) Proposed unit (b) Phasing Element (c) Bottom FSS element (d) Top FSS element.

In 2019, for 26 GHz which is one of the potential bands for the future 5G communication networks, Muhammad Inam et al [55] proposed research on designing and characterizing the millimeter wave RA antenna that is based on unit cells. Various design arrangements have been examined in this work for characterizing the RA proposed for 26 GHz operating frequency [56]. Various basic square patches, rectangular patch elements, rectangular patches with rectangular and circular slots, circular rings, and rectangular rings are analysed and investigated, as shown in Figure 12. Author found that patch rectangular patch element achieved a bandwidth of a maximum of 560 MHz with the lowest reflection loss of 1.02 dB. However, the phase error of 80° was obtained for the rectangular patch element which is significantly greater than the 13° for circular and 10° for the rectangular ring structural elements. A reflectarray antenna designed with circular rings of a maximum gain of 26.7 dB. Additionally, in comparison to the circular ring element reflected with circular ring elements, which exhibited 13.1% bandwidth, the RA with rectangular patch element array had a better 1 dB gain drop bandwidth of 13.6%.

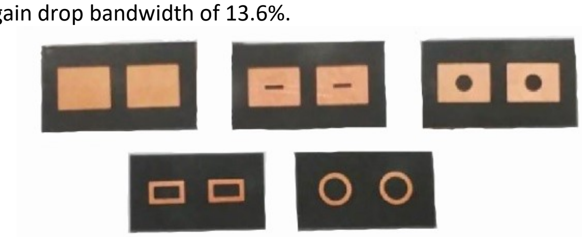


**Figure 12** Fabricated of Different Unit Cells [55]

Another proposed work in 2019 [57] for the single layer with dual-band facility reflectarray cell for 5G communication networks and systems. A reflectarray unit cell design is suggested that operates in the Ka-band (at 28/38 GHz) as shown in Figure 13 (a) and (b). To achieve minimal losses of about 0.7 dB and nearly entire phase ranges of about 320° at the two operational frequencies, two pairs of miniaturized fixed-length fractal patches have been fabricated. After a detailed examination of the unit cell, it was found that the two pairs of resonant elements have minimal impact on each other, indicating that there is no significant mutual coupling effect. The proposed compact cell successfully demonstrated reflectarray ability to produce a fixed scanned beam under dual-band operation.

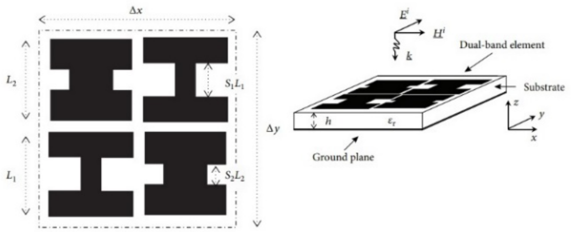


**Figure 13**. Proposed Cell Design [57] (a) Top View (b) 3D-View

The design of an element of a unit cell reflectarray significantly impacts performance enhancement. Low gain and narrow bandwidth properties of a reflectarray can be better by increasing the complexity of design, and it is not a favourable mark at high-frequency operation. This research [58] presents a dual resonance asymmetric patch reflectarray antenna with a single layer for 5G communications at 26 GHz as shown in Figure 14. By integrating a circular ring slot technique at the ground level, a phase range of 650° is obtained from the suggested element for gain enhancement. When measuring cross-polarization in reflectarray antennas for both linear polarizations, the maximum value obtained was approximately 20 dB. Reflectarray antenna with a circular aperture develops 332 asymmetrical patch components and can attain a gain of 24.4 dB with a bandwidth of 3 GHz at 26 GHz, which constitutes an 11.5% bandwidth.

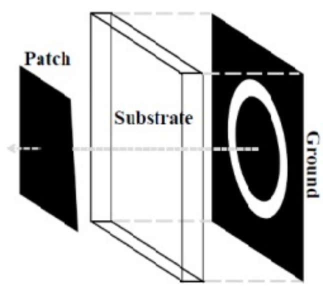


**Figure 14**. Asymmetric patch alignment with the ground ring [58]

Moreover, A novel dual-band and dual linear polarization RA antenna was proposed by O.costanzo specially optimized for mmWaves and 5G applications. A suggested single-layer unit cell operates at two distinct frequencies, specifically 27 and 32 GHz, within the Ka-band, employing a dual-polarization mode. The unit cell design incorporates miniaturized fractal patches in two pairs [59]. Each pair operates at two discrete frequency ranges within, the proposed Ka-band as can be envisioned in Figure 15 (a) and (b). To achieve double polarization operating at both frequencies, the pair that consists of two linearly polarized patches are rotated at 90° with respect to each other.

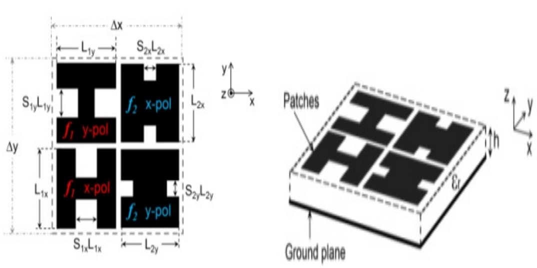


**Figure 15.** Schematic representation of a Unit cell with dual-polarized/dual-band RA antenna [59]

In 2020, Tahir Bashir et al. [60], proposed a single-layer unit element for a frequency range of 26.5-29.5GHz (Ka-band) with a 28GHz center frequency. The suggested unit element has a unique structure constructed with the combination of two simple patches with different shapes, namely cross dipole, and square patches, as presented in Figure 16 (a) and (b). By using this approach, a complete phase range of 360° is obtained at 28 GHz and this achievement may be the possibility of accomplishment to design a multi-beam RA for 5G communication systems. According to the simulation results and analysis, these compound elements perform well relating to the maximal reflection phase range of 348.589° with the lowest reduction in incident field strength, current density of 112 A/m, and fabrication tolerance of 0.2.

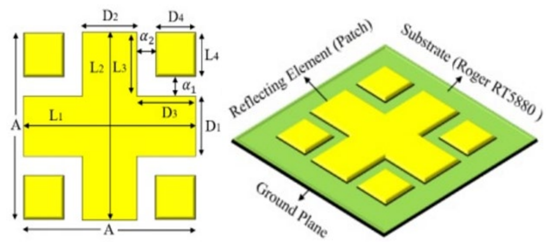


**Figure 16** Geometry of proposed compound unit element [60]

In recent times, when designing single layer dual band reflectarry with benzocyclobutene (BCB) approach was demonstrated by Abdul Azeem in 2021 [61] as shown in figure 17 (a) and (b). In this research, the design of a reflectarray with high gain and bandwidth is presented for deployment in 5G networks that operate in millimeter wave (mm-Wave) at 28GHz and 38GHz.

The unit cell is optimized to accomplish full phase reflection of 334° across the operating band in order to improve the gain of the proposed design, a reflectarray comprising a 15×15 element configuration was developed using the optimized unit cell as a basis. The reflectarray is excited using a horn feed with a gain of 15dB and 165mm of feeding distance. So, a gain of 23dB was found at a lower operating frequency (28GHz) but also 25dB at an upper operating frequency (38GHz).

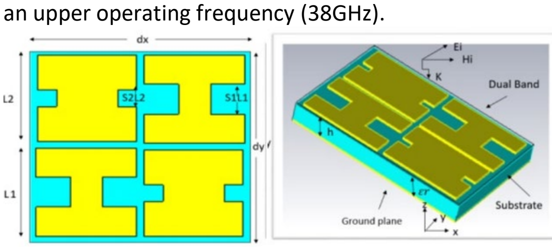


**Figure 17** Proposed Cell Design in [61]

The author in [62] analysed a novel reflectarray antenna design that features novel metamaterial unit cells. This structure revolves around the utilization of two distinct types of unit elements, both having flower-like shapes (FLS) and resonating at the frequency of 12.5 GHz. Specifically, each unit cell is modelled by joining an elliptical and a triangular shape as shown in Figure 18 (a), (b), and (c). To feed the entire structure of the antenna, a Ku band horn antenna is recommended. This design approach is particularly suited for reflectarray antennas targeting gains within the range of 20 to 30 dBi, coupled with satisfactory radiation efficiency.

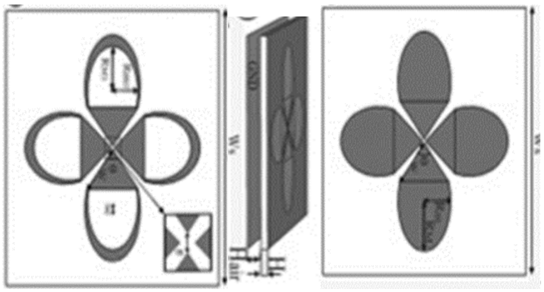
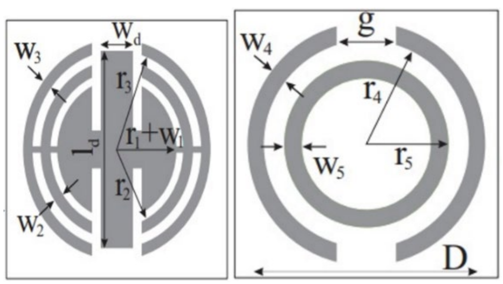


**Figure 18** Configuration flower-like shapes (FLS) metamaterial unit cells [62] (a) the first type (b) side view (c) the second type

For the wideband reflectarray approach, according to reference [63], a distinctive double-layer element design has been introduced. On the top layer, this element comprises a spider-shaped structure and a pair of concave arms showing a circular ring on the medium layer, as illustrated in Figure 19 (a) and (b). Phase ranges up to 8000 are available linearly in the unit cell. For the implementation of this concept, an offset-fed reflectarray with an octagonal aperture, incorporating the proposed cell design, has been constructed to operate at 11.725 GHz.The operating frequency range of reflectarray is 10 GHz to 13.85 GHz, and it provides a 3 dB gain bandwidth of 32.3% and a 1 dB gain bandwidth of 25%. This impressive efficiency of aperture of about 42% is attained along with the maximum gain is 31.2 dBi.




(a) Top Layer (b) Middle Layer

**Figure 19** Geometry of the proposed unit cell [63

## 5.1 Reflectarray Antenna Performance Evaluation

A compare performance analysis of some selected reviews of single band and dual band reflectarray antennae is shown in Table 3. Single band reflectarrays are designed to operate in a single frequency band. They are simpler to design and manufacture as compared to dual band reflectarrays. Single band reflectarrays are less expensive and offer better performance within their frequency range. They offer high efficiency, low cross-polarization, and good radiation patterns. However, their bandwidth is limited, and they cannot operate in multiple frequency bands simultaneously. Dual band reflectarrays are designed to operate in two frequency bands simultaneously as shown in table 3. They have two independent reflectarray surfaces, each optimized for a specific frequency band. Dual-band reflectarrays offer wider bandwidth as compared to single-band reflectarrays. They can also support multiple applications by operating in different frequency bands. However, designing and manufacturing dual-band reflectarrays is more complex and expensive as compared to single-band reflectarrays. The additional reflectarray surface also leads to increased losses and reduced efficiency. Ultimately, the choice of reflectarray antenna depends on several factors, including the operating frequency, radiation pattern requirements, size and weight constraints, and cost considerations. A detailed analysis of these factors can help determine the most suitable reflectarray antenna for a given application.

**Table 3** Performances Analysis of single and dual band reflectarray antenna

| Techniques | Frequency GHz | Phase Span | Gain dB | Aperture Efficiency | 1dB Gian BW | Complexity |
|---|---|---|---|---|---|---|
| Dual Band [53] | 10.2/22 | 500/800 º | 26/29 | 47/25% | ----- | Low |
| Dual Band [54] | 17/8.5 | 360 º | 23/24 | 40/36% | 15% | Moderate |
| Single Band [55] | 26 | 238º | 26.7 | ---- | 13.6% | Moderate |
| Dual Band [57] | 28/38 | 320/320º | 21/25 | ----- | 3.4/3.9% | Moderate |
| Asymmetric Patch [58] | 26 | 650º | 24.4 | 28% | 6.1% | Low |
| Dual Band [59] | 27/32 | 340/325º | 22.9/25.7 | 29/38% | 2.4/2.4% | Moderate |
| Single Band [60] | 28 | 349º | ---- | 22% | ---- | Low |
| Dual Band [61] | 28/38 | 334 º | 23/25 | ----- | ----- | Moderate |
| Single Band [62] | 12.5 | 700 º | 25 | 53% | 16.4% | Moderate |
| Single Band [63] | 11.7 | 360 º | ----- | 41% | 25.2% | Moderate |

## 6.0 CONCLUSION

In this paper, we have discussed the current and future generations of wireless communication systems. It has been concluded that 6G will no doubt bring a revolution in technology, integrate various technologies, improve network performance, and increase Quilty of services (QoS), resulting in smart cities and societies having everything connected to the network. We provided an overview of research projects being conducted in several nations to develop a 6G vision.

As from the discussion, it can be assumed that different design and architectural features can be used to improve reflectarrays, which is possible for advanced future systems. In summary, the choice between dual-band and single-band reflectarray antennas depends on the specific design requirements and application needs. Single band reflectarray are simpler and more cost-effective, with better performance within their frequency range. Dual band reflectarray offer wider bandwidth and multiple frequency band operation, but their design and manufacturing complexity come at a higher cost and reduced efficiency. The design of a reflectarray unit cell is the first thing to be considered when analysing any expected changes in the conventional parameters. In this paper, we discussed some selected unit cell elements for single and dual bands with different materials. However, a single-layer compound unit element and asymmetric patch present better performance characteristics such as maximum reflection phase range with minimum reduction in the magnitude of the incident field, surface current density, and fabrication tolerance. The performance characteristics of a reflectarray antenna based on various frequency ranges discussed in this study are suitable for 5G communication systems. Furthermore, reflectarray antenna are increasingly being viewed as an enabling technology for 5G/6G systems, it is essential for research to concentrate on mm-wave reflectarray, where strict fabrication tolerances and more prominent phase errors require extensive investigation. Future studies could be made more challenging by the inclusion of factors like material properties, cost expense, and power consumption associated with extremely high frequencies.

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## Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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