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Present to Future Antennas for Wireless Communication

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***Abstract:** Antenna is an essential part of the human life in present world and will be indistinguishable part of the life in coming days. Various generations of antenna designs are required to enhance data rate from 2 kbps to 1 Gbps and higher. Even uplink and downlink delays are dependent on the mobile generations. Modern wireless communication works on the low latency and high data rates for the VOD and BOD services. As, the population of mobile phones demand is growing exponentially, so the higher frequency bands are in demand and compactness of the devices is the prime object along with reliability of the signals/data. Various generations of the antennas are available and have enhancement in applications as well as enhancement in the data rates. Therefore, SISO, MIMO, arrays, MIMO-arrays are available for specific requirements. A thorough literature review has been done to focus the light on the antenna technologies.*

***Keywords:** 4G,5G, MIMO, Array, THz*

I. INTRODUCTION

Modern wireless communication has number of applications for the online services like voice, video, and gaming applications. For such applications bandwidth on demand and reliability of the connection is required. Varieties of antennas are designed for the transmission and reception of the signals. Single input single output (SISO) is one of the techniques, where a single antenna is located at the transmitter and the single antenna at the receiver. SISO has limited signal to noise ratio (SNR), works in line of site communication (LOS), requires at least 250 MHz of the bandwidth to achieve 1Gbps of data rate, has 4-6 bps/Hz spectral efficiency, and works in serial communication only. The capacity of the SISO can be calculated using the Shannon's formula. The capacity of the SISO is the logarithmic function of SNR [1].For the present day scenario most of the wireless applications are dependent on the reliable communication and therefore, multiple antennas at the transmitter and multiple antennas at the receiver are required to create the multiple data streams between the communicating devices/base stations. Multiple input multiple output (MIMO) is one of the best wireless communication techniques to have voice on demand (VOD), bandwidth on demand (BOD), continuous signaling, large coverage, large SNR range, linear increase in capacity (without wastage/extra power), high rata rate (upto 1 Gbps without wasting the bandwidth), higher spectral efficiency, and very low latency [2]. For the present wireless applications and future technologies high data rate (> 1 Gbps) and very very low latency are of prime importance due to toll collection, smart cities, industry 4.0, driverless vehicles, online medical surgery (or robotic surgery), online video streaming etc.

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For such applications MIMO antennas can be combined with the arrays to have very high gain and directional radiation patterns. Mm-waves in the range of 30-300 GHz frequency were suggested to solve the problem of spectrum shortage by international telecommunication union (ITU). The 4G works for the LTE bands under 3.6 GHz frequency range and is specially used for voice, video, data communication etc under the 1Gbps data rate and has 5 MHz to 20 MHz scalable bandwidth. However, for the online gaming, live streaming, fast uploading and fast downloading purpose 5G antenna arrays/MIMO-array antennas with higher frequency bands (i.e. 28 GHz and higher) are required due to compactness of the devices. The ITU has set some standards for the 5G antenna array applications. The 4G was the project of 3G partnership project (3GPP), and the 5G is the project of the 5G private public partnership (5G PPP). 5G bas minimum 100 MHz of bandwidth under 6 GHz spectrum and more than 1 GHz bandwidth for higher frequency bands. Beamforming is one of the techniques in 5G to provide strong coverage of the user/building in an intended location. A sharp and narrow beam is used in case of beamforming. Modern and smart antenna technology requires certain networks like Butler matrix for the coverage in certain specific directions i.e. $\pm 20^0$, $\pm 45^0$, etc [3]-[4]. Another aspect of high data rate is the THz antennas, Terahertz technology provides up to 10 Gbps data rate in unallocated frequency range 0.1 THz 10 THz. Terahertz utilizes low transmission power with non-ionic high frequency range and spatial diversity can be achieved [5]. This paper consists of the review of the different microstrip patch antennas for the 4G, 5G, and THz frequencies with single element, multi-element, arrays, and MIMO designs.

II. ANTENNAS FOR 4G WIRELESS COMMUNICATION

The 4G provides spectrum saving, high data rates upto 1Gbps, low latency, and reliable communication. The frequencies under 700/800/900/1800/1900/2100/2200/ 2300/2400/2500/3500 MHz bands have very low frequency spectrum in the scalable range of 5 - 20 MHz bandwidth only. For the uplink and downlink operation, 4G has 6.7-15.0 bits/s/Hz spectral efficiencies. Different single antennas and MIMO antennas are available for the LTE. The antenna design shown in paper was simulated using the CST-MWS software and most of the designs were fabricated and checked for the validity in anechoic chamber for radiation pattern and gain measurements. The vector network analyzer was used to measure the return loss and isolations. These all the designs are discussed here with their frequency bands and possible requirements as per antenna generations.
An antenna was may be designed for linear polarization, circular polarization, and elliptical polarization. Various diversity techniques help to control the size of the antennas, and improve gain, efficiency, etc.

A 2x2 polarization diversity based planar LTE MIMO antenna with regenerative shape has been designed on the FR-4 dielectric substrate for 2:1 VSWR (89% power is radiated and 10% power is reflected) 1.68-2.24 GHz operating band to cover LTE 1800/1900 frequency bands. The design achieved more than 13 dB isolation, more than 3.0 dBi gain, and ECC level of less than 0.01. The fabricated views are shown in Fig 1, and the simulated and measured S-parameters with more than 10 dB isolation in band are shown in Fig 2 [6].

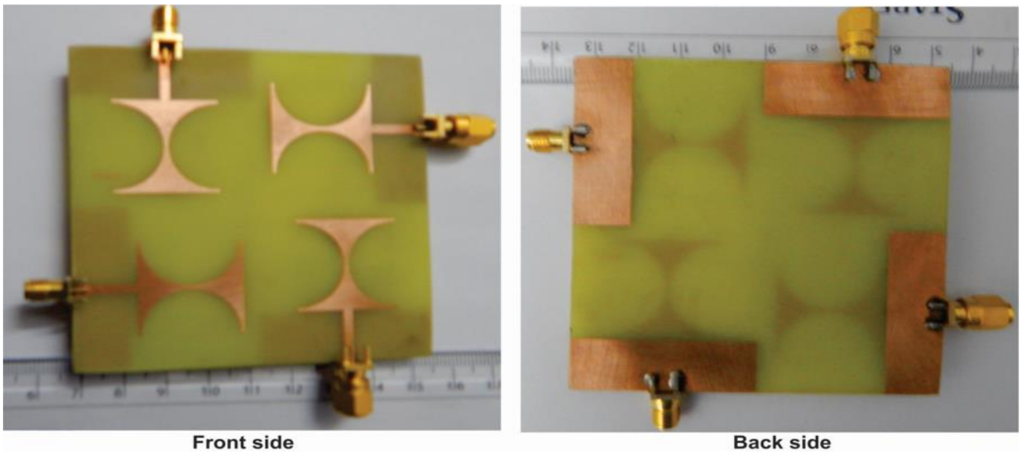

Fig 1. Fabricated views of the LTE MIMO antenna © [6]

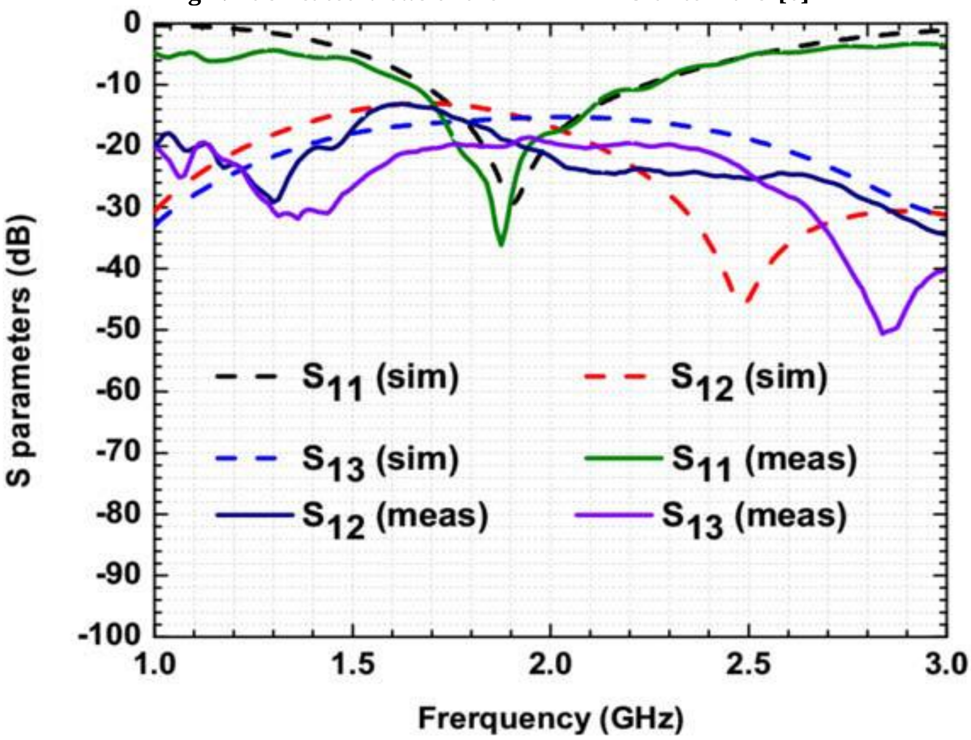

Fig 2. Simulated and measured S-parameters © [6]

In case of moving transmitter and moving receiver, circularly polarized (CP) antennas are preferred. A 2x2 CP MIMO antenna (left hand and right hand) was designed on the FR-4 dielectric substrate for 5.8 GHz (5.48-6.024 GHz) frequency for IEEE 802.11 WLAN band NLOS applications. The design achieved CP mode with less than 2 dB axial ratio, using two 90^0 apart asymmetric slots etched at the center of the rectangular patch. The design used the 50 Ω, 70.7 Ω, and 100 Ω line to form the power divider, and as more than 33 dB of isolation, 5.34 dBi gain at resonant, and very low value of ECC. The simulated views, fabricated views, S-parameters in the CP band with isolation, and radiation patterns (Left hand circular polarization (LHCP) and right hand circular polarization (RHCP)) is shown in Fig 3 [7]. This CP MIMO antenna can be used in all wheather conditions due to dual polarization, also , the problem of polarization mismatch can be controlled using these antennas. The effect of offsetting is used to enhance the bandwidth of antennas. On this concept, a 2x2 wideband MIMO antenna with 2.0-7.31 GHz frequency band was designed on FR-4 dielectric substrate of size 54.82 x 96.09 mm^2. The design covered 2:1 VSWR band for LTE bands, WLAN bands, and WiMAX bands under the operating band. More than 12.6 dB of isolation, more than 2.5 dBi gain, and more than 80% radiation efficiency were achieved in design. The fabricated front and back views of the wide band MIMO antenna are shown in Fig 4, and the simulated and measured S-parameters with 2:1 VSWR impedance band and more than 10 dB isolation between the different radiating elements are shown in Fig 5 [8].

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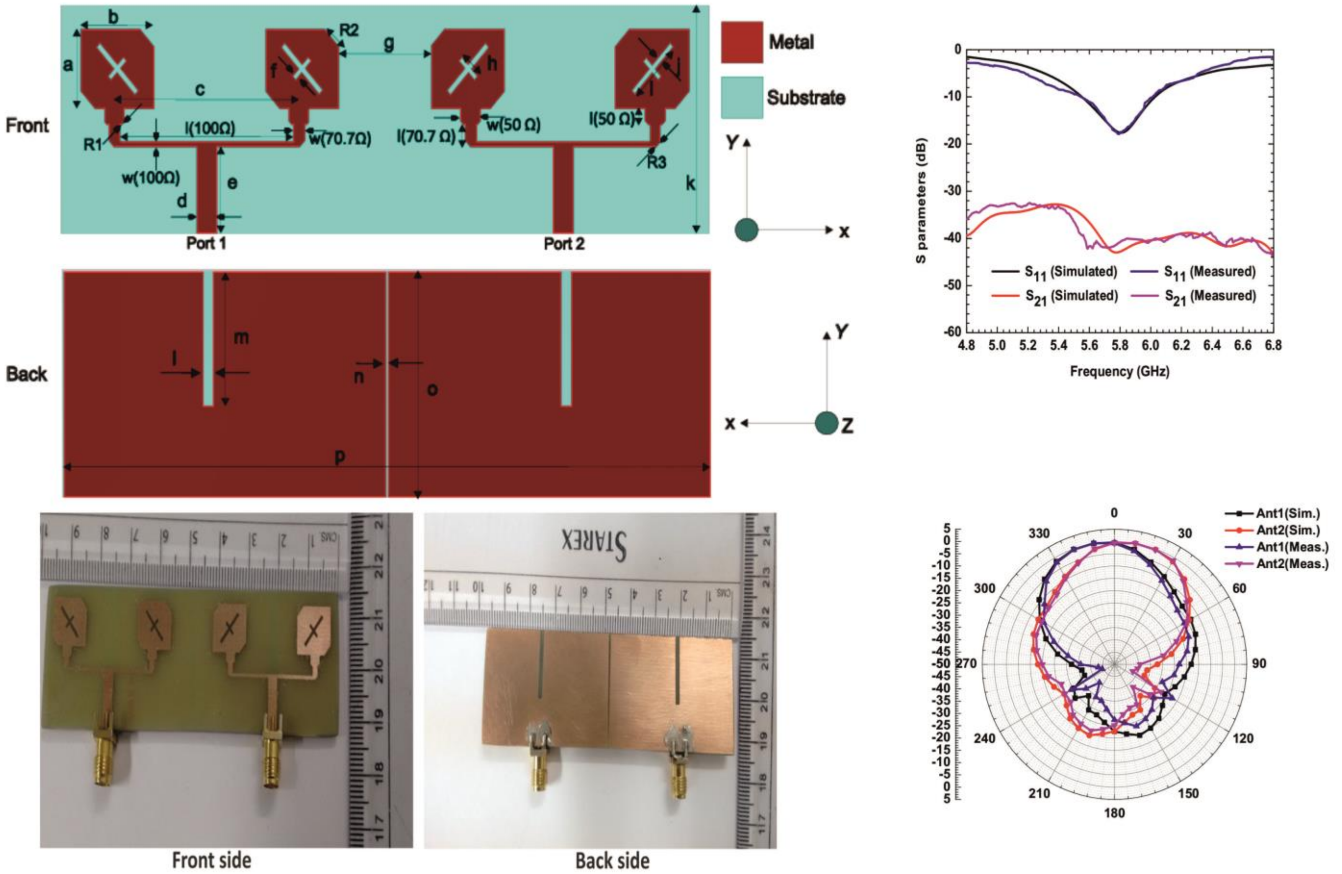

Fig 3. Schematic views, fabricated views, S-parameters, and radiation patterns © [7]

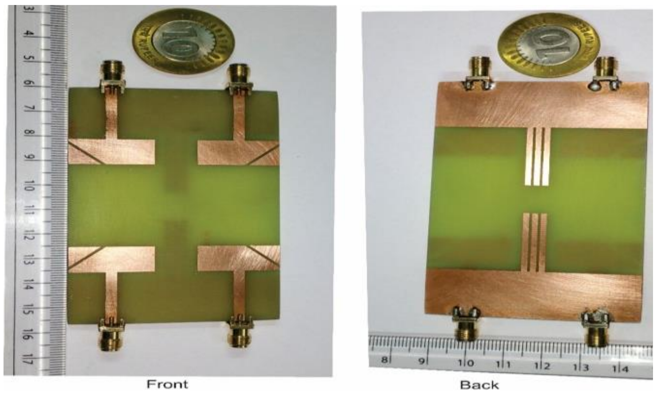

Fig 4. Fabricated views of the wideband MIMO antenna © [8]

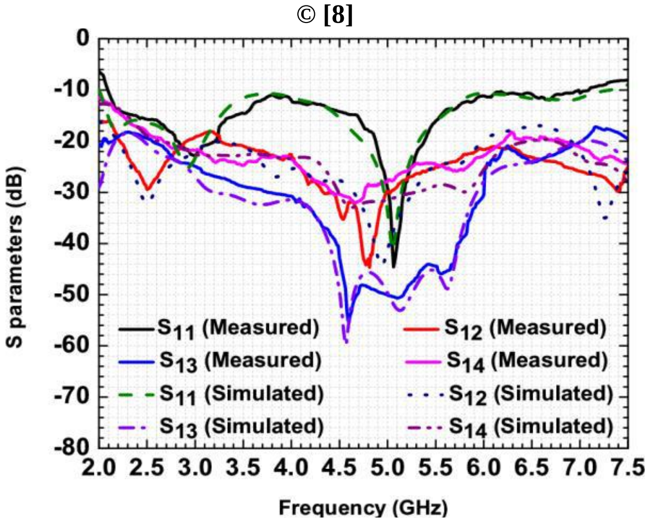

Fig 5. S-parameters of the wideband MIMO antenna © [8]

III. ANTENNAS FOR 5G WIRELESS COMMUNICATION

The lower and higher spectrum of the 5G band covers the frequency ranges designed to follow 6 GHz lower frequency spectrum having 3.30-4.20 GHz, 4.40-4.99 GHz frequencies. The higher frequency band covers 24-28 GHz, and 37-40 GHz respectively. For 5G applications, the antenna arrays are mostly preferred to achieve higher gains and directed radiation patterns. For 2-element antenna array, the equations are given (1) and (2).

$E_t = E_1 + E_2 =$ âθjŋ (1)

$$E_t = \left\{ \frac{e^{-j\left[kr_1 - \left(\frac{\beta}{2}\right)\right]}}{r_1}\cos\theta_1 + \frac{e^{-j\left[kr_2 - \left(\frac{\beta}{2}\right)\right]}}{r_2}\cos\theta_2 \right\}, \quad (2)$$

where, E_1 and E_2 are the electric fields of elements respectively, E_t is the total field radiation and β is the phase difference in input excitations between the two array elements. An array factor is used to multiple with the individual element's field to get total field for an array. The calculation for AF is given in equation (3).

$$AF = 2\cos\left[\frac{1}{2}\, kd\cos\theta + \beta\right] \quad (3)$$

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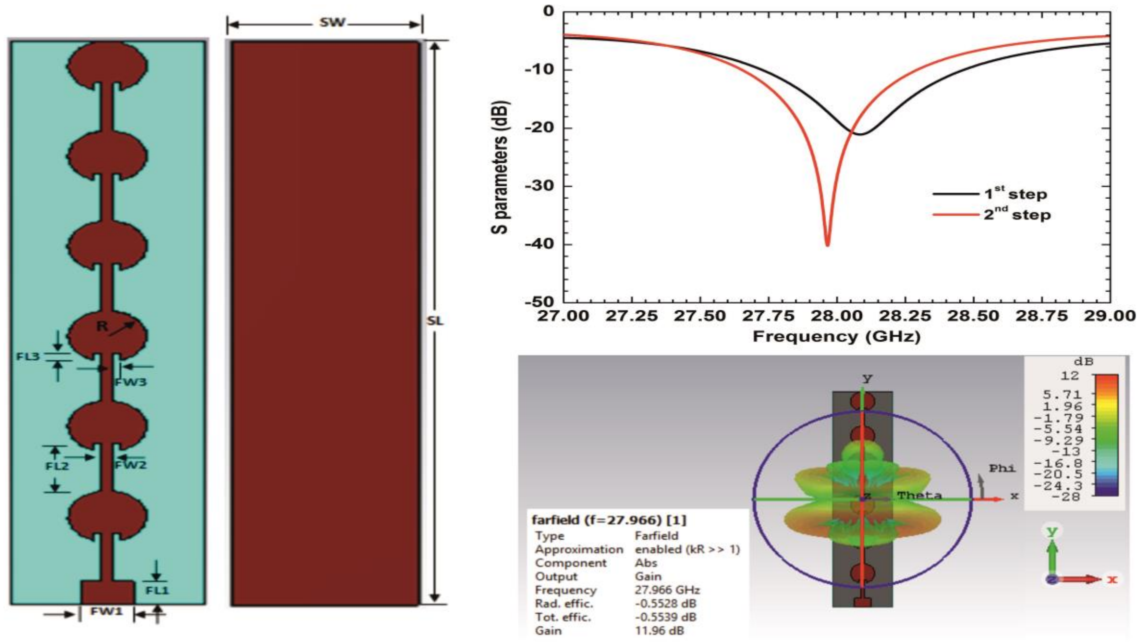

Fig 6. Schematic views, S-parameters, and radiation pattern of circular patch array © [9]

A 5G 1x6 array antenna with 2:1 VSWR band was designed on Rogers RT duroid 5880 on size 37.60 × 8.45 mm^2 for 27.654-28.291 GHz frequency band. The design achieved 12 dBi gain and 88.04% radiation efficiency at 28 GHz resonant frequency using inset fed circular patch antenna array. The schematic front and back views, S-parameters in 2:1 VSWR band, and radiation pattern are shown in Fig 6 [9]. The combination of array with MIMO results in high gain, high capacity, high spectral efficiency, and high data rate. A design with this concept was carried out on Rogers Duroid 5880 substrate of size 23.83 x 53.52 x 0.79 mm^3. A 2x8 MIMO-array antenna achieved 10.67 dBi gain and 88.2% efficiency at 28 GHz frequency. The design steps, final MIMO-array design, and corresponding S-parameters with steps and MIMO-array are shown in Fig 7 [10].

For the 5G 1x16 element tapered antenna with series fed and parallel arrangement power divider arms was designed for more than 1 Gbps data rate application with 2:1 VSWR 27.5-28.5 GHz operating band (28 GHz resonant frequency) on Rogers RT duroid 5880 with 35 x 28 mm^2. The gain in the design at the resonant was 17.9 dBi. The band and bandwidth enhanced array antenna design steps and corresponding S-parameter results, and radiation pattern are shown in Fig 8 [11]. A 5G array antenna with 2:1 VSWR impedance band for 27.70 - 28.38 GHz frequency was designed on the Rogers RT duroid 5880 substrate of size 30 x 26 x 0.79 mm^3. The tapered patch arrangements were used to enhance the bandwidth without compromising with the gain. The 17.7 dBi of gain was obtained in the design. The design is shown in Fig 9 along with S-parameters and radiation patterns [12].

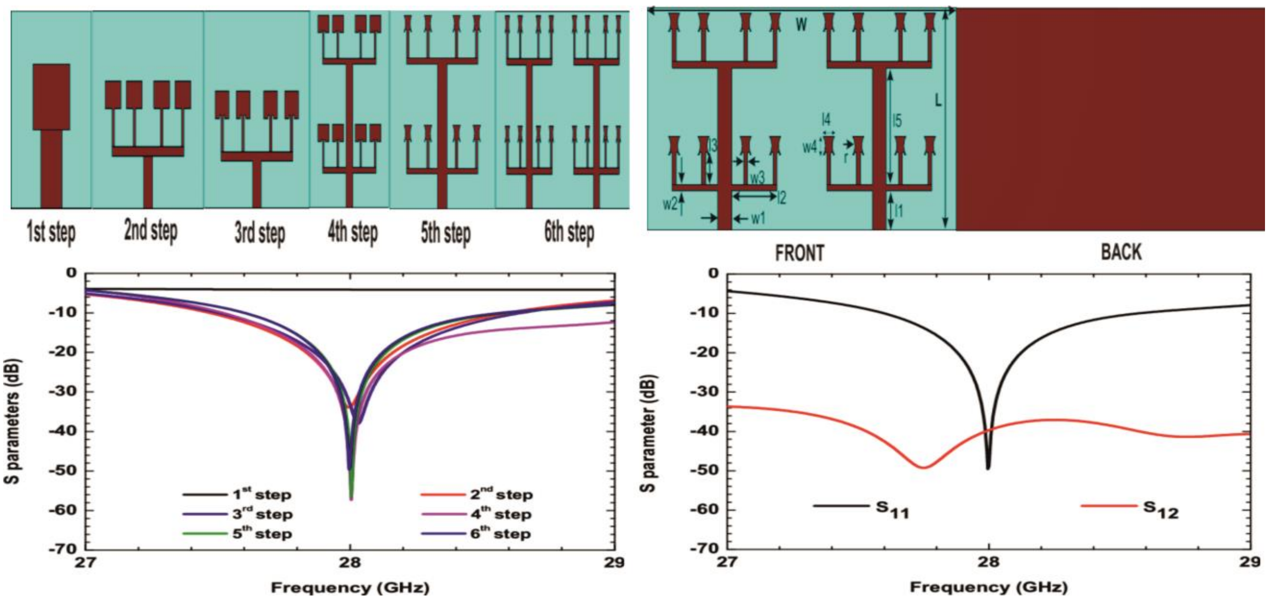

Fig 7. Schematic views and S-parameters of generating patch MIMO-array © [10]

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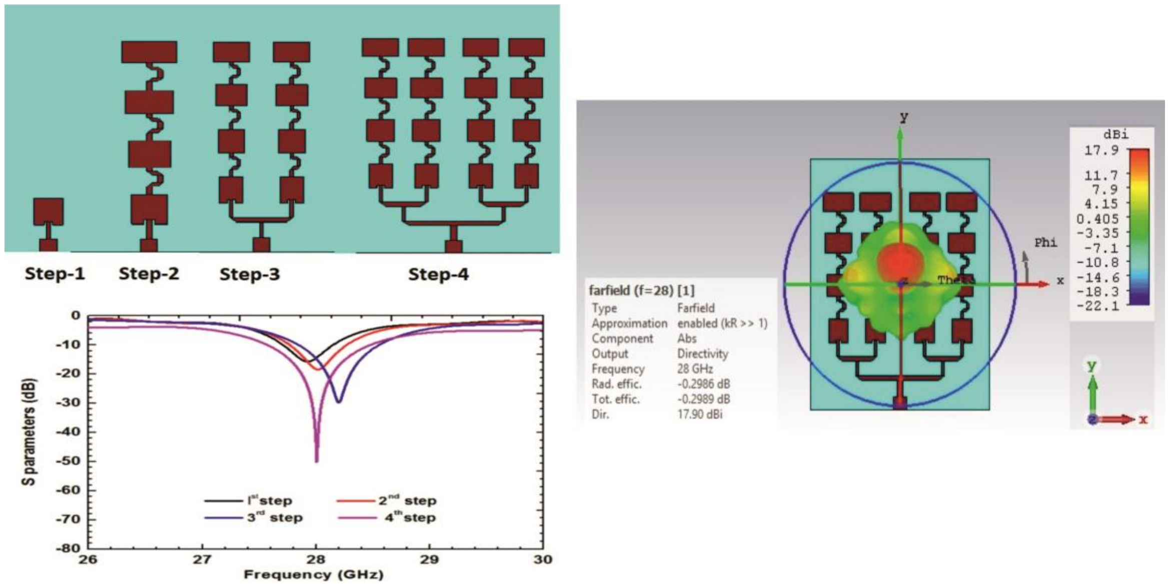

Fig 8. Gain and bandwidth enhancement tapered antenna array with delay lines: Design step S-parameters, and radiation patterns© [11]

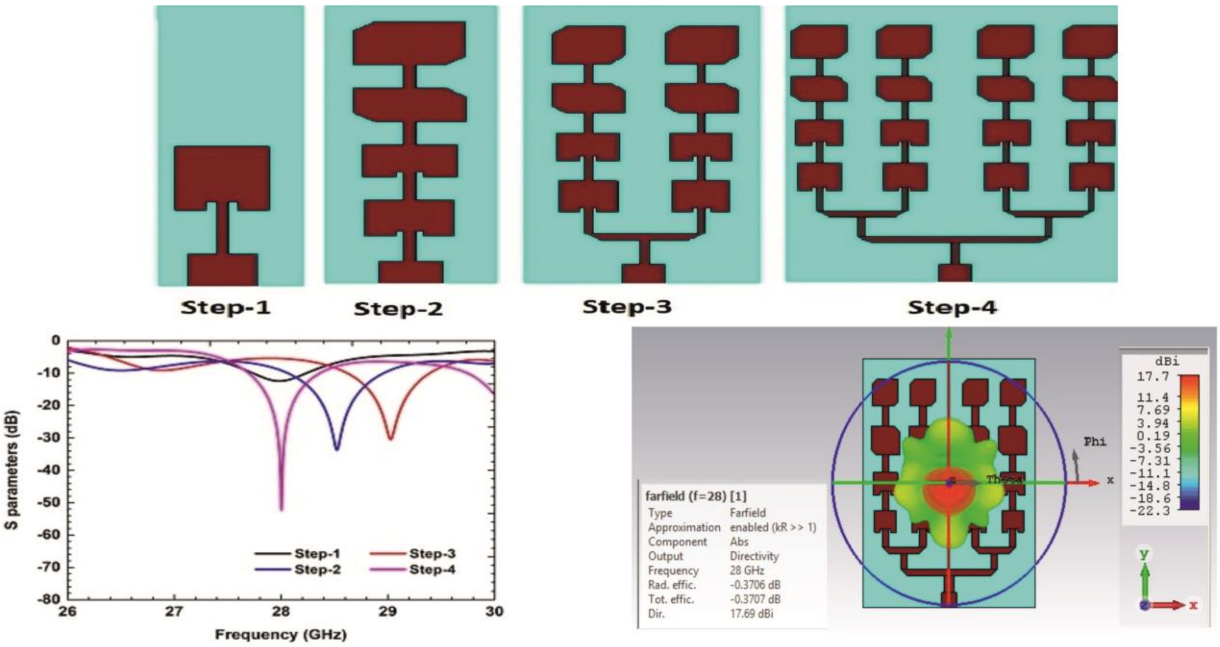

Fig 9. Series-parallel fed high gain array antenna and results © [12]

Similarly, the massive MIMO is the part of 5G technology and is the multi-user environment. As the number of radiating elements are restricted up to 8 antennas in LTE transmission, but for fifth generation networks, eight elements per point are not sufficient. Massive MIMO is the strong solution of such limitations, and have capabilities to support more than eight elements per transmission point in multi-user MIMO (MU-MIMO) environment. Multiple data streams are transmitted to a single user MIMO (SU-MIMO), while involving spatial multiplexing in multipath propagation. To reduce the cross talk and to gain the benefit of multiple beams in MU-MIMO, best beam is selected for the coverage of each user (it controls the side-lobe-level also). Massive MIMO has hundreds and thousands of base stations that serves 10 and hundreds of the user end equipment. Out of the different duplexing channels, time division duplex (TDD) is preferred in Massive MIMO to control the overheads to acquire channel state information (CSI) [3].

IV. ANTENNAS FOR THz WIRELESS COMMUNICATION

All the above discussed single port, MIMO, arrays, MIMO-array antennas are the requirements of the present generations of the wireless and mobile devices. In future most of the frequency bands will move in higher bands like 1000 GHz (1 THz). These THz antennas will have very large bandwidths like 30-40 GHz for the large data transmission and reception, and very large capacity. Therefore, the future applications will require such high gain and very wideband antennas.

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An antenna based on the polymide (ε = 3.5 and tanδ =0.0027) of size 800 x 600 x 191.29 μm^3 substrate with photonic band gap (PBG) structure was designed for the hidden object detection like explosives and for the different substrates, metals and their properties in the frequency range of 0.6125 - 0.6514 THz. The design consists of a rectangular patch with holes in the polyimide substrate to control the adverse effects of the surface wave propagation. A generalized shape of the patch is used in the design to move the whole frequency band to any operating band. The design resonant frequency was 0.6308 THz, radius of curvature was 75 μm, cylindrical PBG radius was 11.95 μm, antenna gain was 7.934 dBi, and the radiation efficiency was 85.71% in the design. The size of the PBG antenna with the defected ground structure was designed using the following width and length equations (4) and (5). The PBG with generating shape based patch antenna for THz application is shown in Fig 10, and the return loss with 2:1 VSWR band (-10 dB) is shown in Fig 11 (a comparison between PBG and conventional substrate [5].

$$W = \frac{2m+1}{\sqrt{\varepsilon_r}} \times \frac{\lambda_0}{2} \quad (4)$$

$$L = \frac{2n+1}{\sqrt{\varepsilon_{reff}}} \times \frac{\lambda}{2} - 2\,\Delta L \quad (5)$$

where, m and n are used for the mode of the antenna, and ʎ is the wavelength.

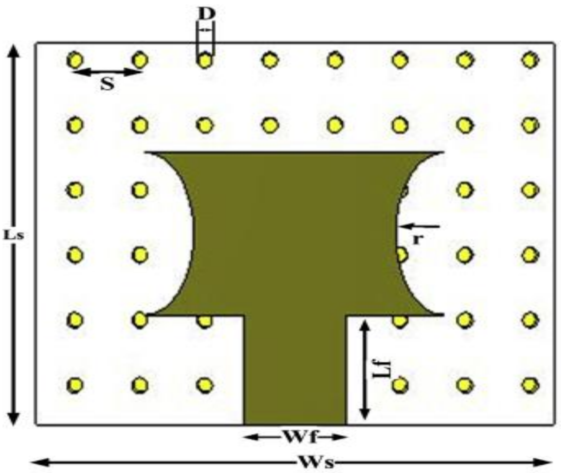

Fig 10. Schematic view of the PBG antenna at THz application © [5]

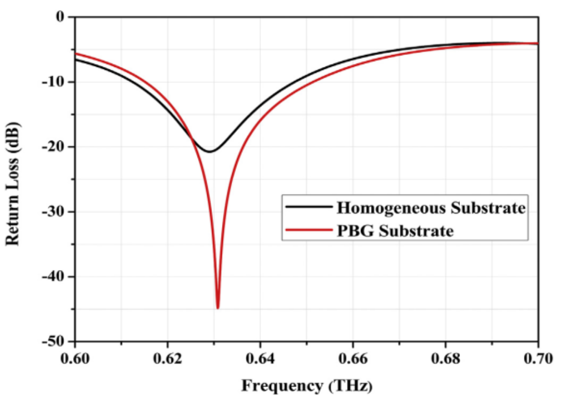

Fig 11. Return loss of PBG antenna at THz application © [5]

V. CONCLUSION

Antennas are used for the transmit and receive operations of the voice, video, and data, etc. Varieties of antennas are available for the different generations of services from multimedia to real time applications [13]. These works for high speed, high capacity, and bandwidths as per requirements. All the above discussed array, MIMO, MIMO-array, and THz designs have their pros and cons like size, inter-element coupling, port to port coupling, etc. On the other hand these designs are used for beamforming, high capacity, large coverage, high isolation, high gain, high directivity, and high efficiency. Based on the above literature review, researchers, academicians can design their own antennas for the present and future needs of the wireless applications in compact and portable devices.

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