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INSPECTION ON SUPERWIDE BAND 5G ANTENNAS FOR COMMUNICATION APPLICATIONS

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Abstract

The 5th Generation (5G) technology requires a higher data rate, superior bandwidth, improved efficiency, and compact antennas for smartphones to facilitate with different types of super wideband antennas are inspected with design methodology, gain, bandwidth, and other performance parameters are analyzed to find applications in 5G technology. The different types of array antenna provide higher gain but fed with a single port demonstrate similar capabilities as a single antenna. The multiple-input multiple-output (MIMO) antenna having the capability of multipath propagation, higher data rate, enhanced capability, and link reliability, which provides the solution to 5G technology. The substrate integrated waveguide (SIW) antennas explore the advantage of classical metallic waveguides such as low radiation loss, high power, high gain, and high selectivity, and also planar antenna consists of low profile, low cost, lightweight, and ease of integration with microwave circuits. The combined capability of SIW with MIMO structure is the potential candidate for 5G smartphones. The simple SIW antenna simulated using high-frequency structured simulation (HFSS) software tool, which provides the multiple band's resonances from 21 GHz to 50 GHz operating band and reflection coefficient |S_{11}| at 28.66 GHz is -58.577 dB as standard value is less than -10dB.

Keywords:

Approximate Computation, Wallace Multiplier, 3:2 Compressor, Low Power, PDP

1. INTRODUCTION

The new generation of cellular networks, ever-rising insistence on higher data rates has persuaded the utilization of millimeter-wave (mm-Wave) frequency band for 5G technology [1]. The superwide band and multi-band antennas are essential for serving the different applications over the bands as cover the 0.9 -100 GHz with the acceptable gain [2]-[3]. To cater to the needs of 5G communication, an array antenna plays a vital role to achieve a high data rate, bandwidth, and improved efficiency. The major researchers focused on 28 GHz, 37 GHz,39 GHz,60 GHz, and the E-band for 5G communication [4]-[6]. The T-slot mobile antenna with 8 elements provides a gain of 10dB and good isolation [1]. The grid array antenna offers a better gain of 16.5dBi and the 4x4 array antenna provides 18.5 dBi at 5G frequencies [6]. The array antenna demonstrates the similar capability of the single antenna as fed with a single port. The MIMO antenna exhibits multipath propagation, enhanced capability, high data rate, and link reliability [7].

More number of MIMO antennas for 5G applications recorded [5] [7]-[13]. In 1994 Shigeki first time recorded the substrate integrated waveguides to enhance the integration and lower the cost of production [14]. The planar processing technologies like printed circuit board (PCB) and low-temperature co-fired ceramic (LTCC) are blended with the transformation of a non-planar structure into a planar structure (SIW). The advancement in SIW technology is capable of handling high power, low radiation loss, high-quality factor, mechanical and electrical shielding as a conventional rectangular waveguide with ease of integration and fabrication [15]. The linear polarised SIW with slot provides the gain of 7.8 dBi [16]. In other literature designed different SIW single element antennas [14] [17]-[19]. SIW multibeam slot array 4×4 offers a gain of 12.1 dBi at 30 GHz and wide beam coverage of 140 degrees [20]. The other literature work on the SIW array is considered for higher gain [21]-[26]. The SIW advantages combined with the MIMO technique for 5G antennas were reported [5] [27]-[29].

In this work, inspecting different superwide band antennas covering 5G communication applications. The design of a single microstrip antenna, different array antenna, advanced MIMO, and SIW antenna deliberated considering the gain, bandwidth, and compactness of the antenna. The Simple SIW multiband antenna was simulated using High-Frequency Structured Simulation (HFSS) simulation software tool.

The article is organized as in section 2, Inspection on existing literature deliberated. The proposed simple SIW antenna design and analysis are considered in section 3. The simulation results of the proposed antenna. In section 4 and the conclusion and future scope are detailed in section 5.

2. INSPECTION ON EXISTING LITERATURE

Manohar et. al. [2] designed a band-notched monopole super wideband (SWB) antenna having a triangular tapered feedline of 50 Ω and radiating patch covers 0.9-100 GHz frequency spectrum with a chamfered ground plane. The impedance matching, except in the notched band of 4.7-6.0 GHz for IEEE 802.11a and HIPERLAN/2 band with a reflection coefficient of |S_{11}| < -10 dB. The C-shape material of parasitic is in place to comprehend band notch characteristics as shown in Fig.1.

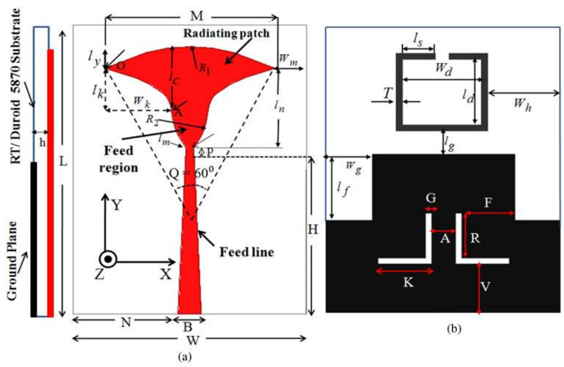


Fig.1. Band-notched SWB antenna; (a) front view and (b) back view [2]

An antenna of T-slot is proposed by Zhao et. al. [4]. The 8×1 T-slot-based array is placed at the upper layer of the mobile phone as shown in Fig.3. The antenna resonates at 28 GHz and 16 dB is the isolation between the antenna elements. In this literature [30] designed a 4×4 high gain antenna with a corporate feeding technique that distributes power evenly to all elements in the array as shown in Fig.4. The array antenna resonates at 28 GHz frequency with a reflection coefficient of $|S_{11}| < -10$ dB, high gain of 17 dB, and bandwidth more than 300 MHz

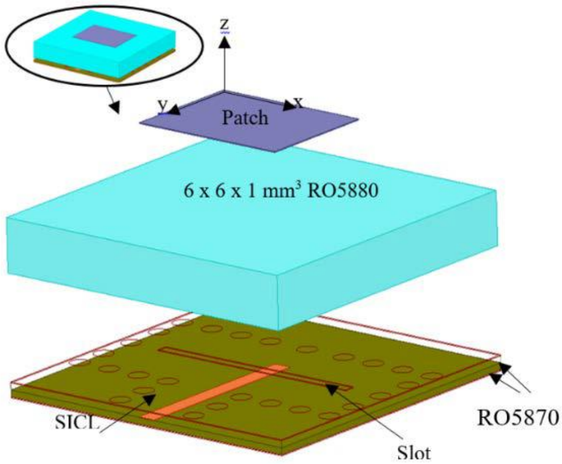


Fig.2. Single-feed Dual-band Aperture-coupled Antenna [3]

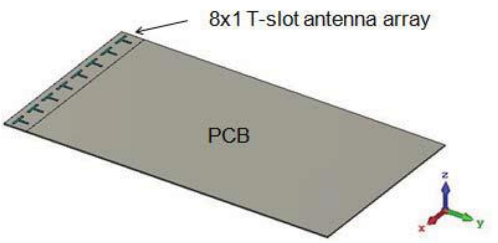


Fig.3. 8×1 antenna array of T-slot [4]

Yan et al. [31] presented a compact dual-band 8 element planar MIMO antenna with a total efficiency of about 60-85%.The antenna resonates at 3.3-3.6 and 4.8-5.0 GHz with transmission coefficients (S_{21}, S_{32}, S_{43}) are less than -10 dB and reflection coefficient of (S_{11}, S_{22}, S_{33}, S_{44}) < -10 dB.The envelope correlation coefficient shows good isolation between elements is extremely low as 0.15 in the operating frequency bands.

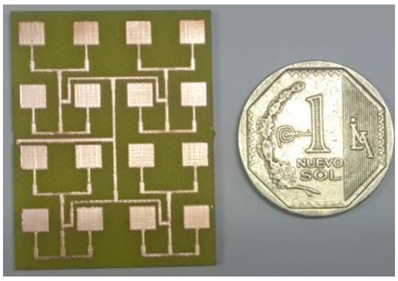


Fig.4. 4×4 high gain antenna array based on corporate feed [30]

Amrutha and Sudha [9] presented a doughnut slot MIMO antenna resonates at 28 and 45.54 GHz. The single doughnut slot antenna resonates at two frequencies 28.08 and 45.54 GHz with a bandwidth of 1.14 and 1.41 GHz respectively. The return loss at 28.08 GHz is -52.53 dB, at 45.54 GHz is -16.51 dB, and the gain of the antenna is 5.94 dB, 4.89 dB respectively. The 2×2 antenna array having a gain of 5.94 dB,4.89 dB, and has a return loss of -45.22, -15.32 dB at 28.26 and 45.61 GHz respectively. The envelope correlation coefficient (ECC) is much less than 0.5. The doughnut slot MIMO antenna is shown in Fig.5.

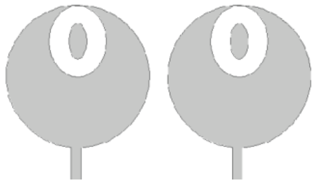


Fig.5. Doughnut slot MIMO dual-band antenna [9]

Hussain et al. [10] designed a metasurface circularly polarized MIMO antenna. The compact single element having a dimension of $1.0\lambda_0 \times 1.0\lambda_0 \times 0.041\,\lambda_0$ with working bandwidth from 25 to 31 GHz for $|S_{11}| < -10$ dB and axial ratio bandwidth 16.8% (4.6 GHz). The antenna offers substantial radiation patterns and high efficiency of (>95%) and a peak gain of 11 dBi. The single element is portrayed to 2×2 MIMO, rendered each element perpendicular to each other with isolation between antenna elements is < -30 dB shown in Fig.6. The MIMO antenna provides a diversity gain of 9.91dB, channel capacity losses 0.19 bits/s/Hz, and a minimal envelope correlation coefficient (0.015).

Hu et. al. [11] presented a dual-polarized subarray antenna. The single element is designed with dual off center-fed dipoles, resonates with the bandwidth of 27.6–30.8 GHz,35.4–38.9 GHz, and gain of 6.9 dBi, 5.3 dBi at 28 GHz and 38 GHz respectively. The 2×2 subarray having 4 horizontal and 4 vertical feeding ports with a design area is 34.0×36.0 mm^2. The subarray provides high gain (13.1 dBi, 13.2 dBi at 28 GHz and 38 GHz respectively) and bandwidth ranging from 3 and 4.6 GHz respectively. In addition to the 4x4 array antenna having scanning ranges ±45° for the dual bands with a peak gain of 19.6 dBi, 17.8 dBi at 28 and 38 GHz accordingly as shown in Fig.7.

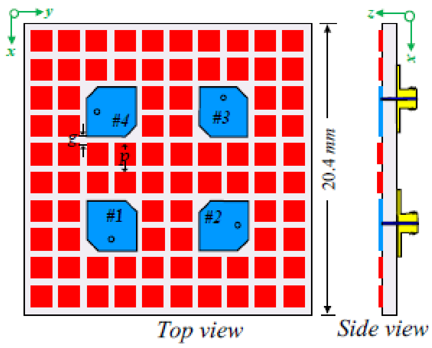


Fig.6. Meta-surface circularly polarized MIMO antenna [10]

Ahmed et al. [6] presented an array resonating at 28GHz for 5G communication. The 20cell grid array in rhombic structure is fabricated with Rogers 5880 substrate and dimension of 40×40×0.25 mm^3 as shown in Fig.8. The array resonates with the reflection coefficient of $|S_{11}|$<-10dB, gain of 16.5 dBi, and bandwidth of 5.41% at 28GHz.The array of 4x4 consists of 16 elements with the spacing of 0.75 λ and is connected to quarter-wave transformers of a matching network with 100Ω line interconnect the patches. The patch array having a peak gain of 18.41dBi at 27.80 GHz and a fractional bandwidth of 2.38%.

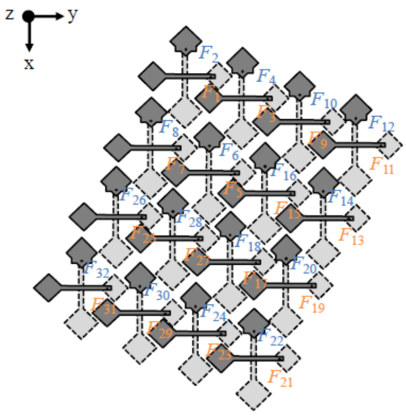


Fig.7. Large scale dual-band 2x2 subarray [11]

Klionovski et al. [32] designed a wideband array with a feed network of butler matrix operates in the frequency of 27-33.7 GHz. Also provides two orthogonal polarization and beam steering capability with wide-angle. The butler network consists of 3-dB directional couplers, delay lines, and two crossovers. The beam steering capability achieved at -42º, -13º, 13º,42o as shown in Fig.9.

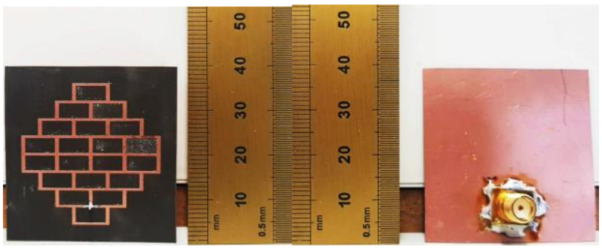


Fig.8. Grid array front and back view [6]

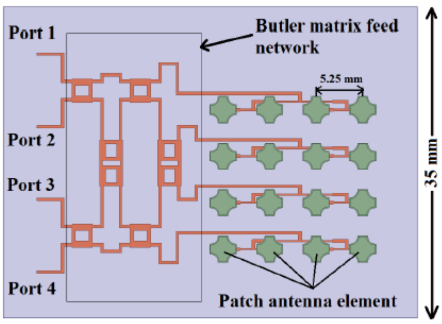


Fig.9. Proposed Array antenna with a butler matrix feed [32]

Khalid et al. [12] presented a 4-Port defected ground MIMO antenna offers the bandwidth of 25.5-29.6 GHz and gain 8.3 dBi at resonating frequency of 28 GHz as shown in Fig.10. The Rogers RO4350B substrate material is used for the antenna design, radiating structure is on the top layer with each port excited separately and Defected Ground Structure (DGS) at bottom layer with a rectangular, zigzag, and circular shape to boost the antenna performance. Elfergani et al. [13] designed MIMO antenna having a dimension of 12.5 mm × 12.5 mm × 0.8 mm3 with FR4 as a substrate as shown in Fig.11. The antenna resonates at 35 GHz with a 6 dBi peak gain and efficiency of 87%. The antenna having a good diversity gain of 10 dB and impedance matching of 25 dB.

Kapil and Sharma [7] designed superwide band hexagonal slot MIMO, with dual notch band compact antenna having a dimension of 20×35×0.787 mm3 as shown in Fig.12. The hexagonal slot is introduced on a radiating patch, the inverted T stub eliminates the WLAN (5.150 -5.825 GHz) band and Downlink Satellite System (DSS) band (7.25-7.75 GHz) detached by C pattern parasitic material. The two-port MIMO antenna provides a gain of 5.95 dBi and a diversity gain of 9.95 dB. The MIMO antenna efficiency is around 91% with TARC is -<40 dB.

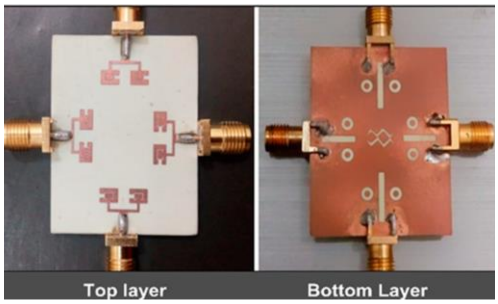


Fig.10. 4port MIMO with DGS [12]

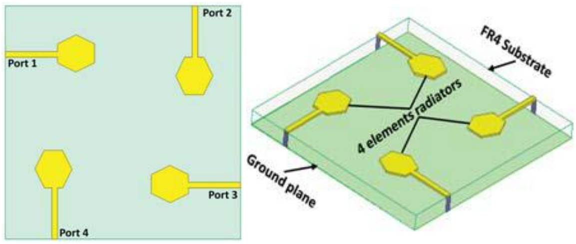


Fig.11. Proposed 4port MIMO [13]

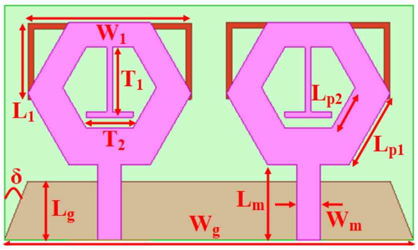


Fig.12. Proposed 2 port hexagonal MIMO antenna [7]

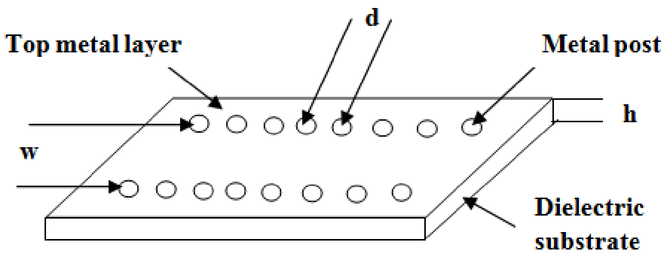


Fig.13.Geometry of simple SIW antenna [15]

Debnath and Chatterjee [15] presented a literature on Substrate Integrated Waveguide (SIW) antenna and arrays. The SIW is similar to classical metallic rectangular waveguide provides the advantages of handling high power, high-quality factor, and properties of mechanical and electrical shielding. The SIW is the technology transforming the non-planar structure into a planar structure which offers the fabrication process of nonplanar arrangements. The most pleasing part of the SIW technique provides space to fabricate including active, passive components along with antenna as well on the similar substrate. The design of SIW consists of top and bottom plates, as dielectric substrate material in-between connects the top and bottom plates through parallel vias as shown in Fig.13.

The different types of passive antennas like slot, leaky-wave, horn, log periodic and dipole antennas were investigated as shown in Fig.14. The cavity-backed active and special type of dielectric resonator antenna were analyzed.

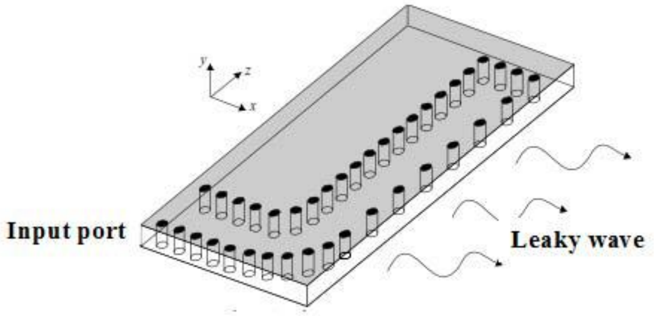


Fig.14. Leaky wave SIW antenna [15]

Priya et al. [16] designed a Substrate Integrated Waveguide (SIW) with a linear polarized Structure that resonates at 54 GHz with a peak gain of 7.8 dBi. The SIW cavity antenna was modified (shown in Fig.15) by applying slots, resonating frequency shifted from 45.1 to 54.6 GHz with operational bandwidth ranges from 0.2 to 0.92 GHz.

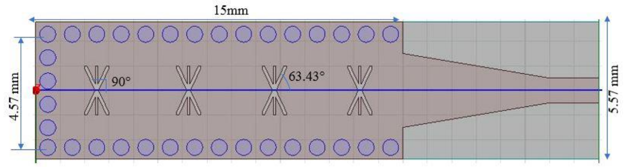


Fig.15. SIW antenna with Linear Polarization [16]

Sharma et al. [5] designed a 4 port MIMO SIW fed antenna with cylindrical dielectric resonator antenna (DRA) as shown in Fig.16. The antenna resonates at 27.7 GHz with a bandwidth of 6.92% (26.64-28.55 GHz). The antenna offers a gain of 5.07-5.70 dBi with ECC <0.0005 and CCL under the nominal value of 0.6 bits/sec/Hz at the operating band.

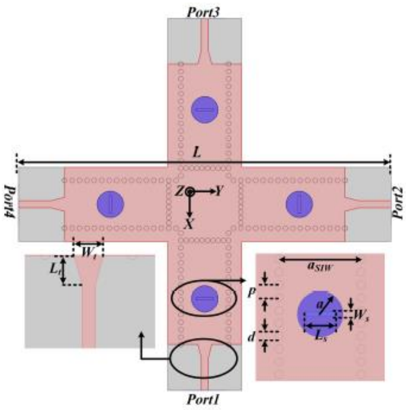


Fig.16. 4 port MIMO DRA with SIW fed 5G antenna [5]

Paola et al. [22] This research work presented a multibeam SIW monopole antenna array that resonates at 30GHz with a peak gain of 12.3dBi and covers 180o angle. The antenna design is compromises of 8 monopoles engraved on a RO4003 substrate. Specially four monopole elements are placed over the PCB to scan the required backside area and the bottom four elements to flash through the front space. The good dielectric material is used to reduce the impact of surface current placed below the antenna elements to attain the desired beam steering.

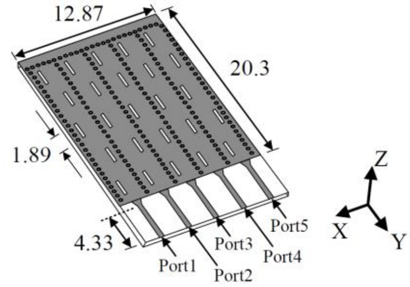


Fig.17. Five port SIW slot array antenna [24]

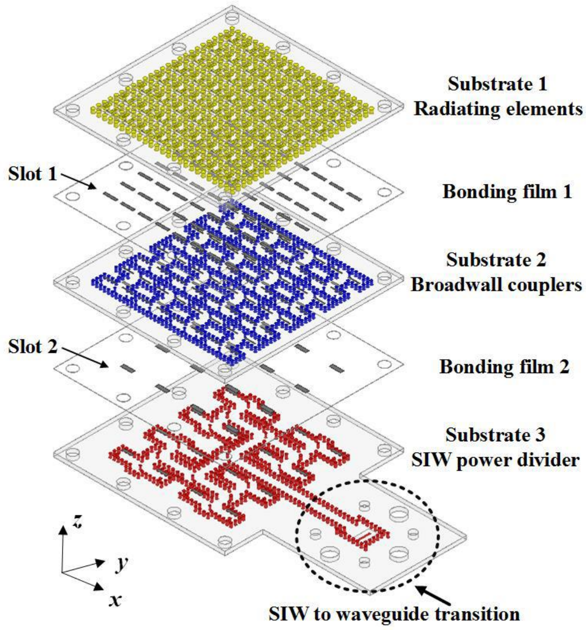


Fig.18. 8×8 SIW antenna array [25]

Choudhuri et al. [24] presented a beam steerable SIW slotted array antenna resonates at 75GHz with impedance bandwidth of 8% (74.5GHz–80.34GHz) shown in Fig.17. The antenna achieves a steerable beam angle of ± 15º and boresight gain 18.56dBi. The array consists of 5 elements separately excited SIW section with slots. The wideband capabilities are achieved by a particular dimension of slots.

Zhu et al. [25] designed a SIW array antenna with a wideband ranging from 57-71GHz.The different array antennas are considered with 8×8 is the highest array antenna scans the bandwidth of 22.9% (56.1 to 70.6 GHz), around 80% radiation efficiency, and 26.7 dBi peak gain. The 8×8 array antenna was designed by combining a 2×2 sub-array as shown in Fig.18. The comparative study of literature is shown in Table.1.

Table.1. Comparative study of different literature

Ref	Design Technique	Number of elements used	Dimension	Substrate	Gain	Performance
[2]	Band-notched monopole super wideband (SWB) antenna	Single	30 mm×40 mm ×0.787 mm	RT/Duroid	7 dBi at 25 GHz	Frequency bandwidth 0.9–100 GHz
[3]	Dual-band aperture antenna	Single	6×6×1.27 mm^3	Rogers 5880	6.25 dBi 8.5 dBi	Frequency: 28 GHz and 38 GHz. Cross-polarization < 48 dB and Bandwidth-2GHz
[4]	T-slot antenna array	8×1	50mm×100mm	FR4	10dB	Frequency: 28GHz Return loss: -25dB (Appx) Isolation b/w Antenna :16dB
[5]	SIW fed MIMO DRA (Dielectric resonator antenna)	4×4		RT/Duroid 6010	5.07-5.70 dBi	Frequency at 27.7 GHz. Bandwidth (26.64-28.55 GHz). Port isolation is 27 dB and (ECC) is well below 0.0005.
[6]	Grid Array Antenna	Grid	40mm×40mm	RT/Duroid 5880	16.5 dBi	Bandwidth: 26.79 to 27.10 GHz and 28.44 to 29.23 GHz
[6]	Microstrip patch Array	4×4	40mm×40mm	RT/Duroid 5880	18.45dBi	Bandwidth:27.42 to 28.08 GHz
[8]	Dual-band MIMO antenna	4	130mm×4mm ×0.8 mm	FR4		Frequency:3300-3600 MHz and 4800-5000 MHz and efficiencies are above 50%
[9]	Doughnut slot MIMO antenna	2×2	6mm×6mm	Rogers RT-5880	5.94dB, 4.89dB	Frequencies 28.08 and 45.54 GHz. Return loss -52.53 and -16.51 dB Bandwidth of 1.14GHz
[16]	linearly polarized (SIW) antenna	Single	23mm×6.385mm	RT/Duroid 3003	7.8 dBi.	Frequency 45.1 GHz to 54.6 GHz Bandwidth 0.72 GHz.
[20]	SIW butler matrix multibeam slot array	4×4	72mm×27.4mm ×0.508 mm	Rogers 5880	12.1 dBi	Frequency:30 GHz, Wide beam coverage of approximately 140 degree
[21]	Slotted SIW Array Antenna	4×1		Rogers RT5880	5 dB	Frequency:26.9 to 29.8 GHz. HPBW of 144.9° and Efficiency 98.8 %.
[22]	A phased array of (SIW) monopoles	8×1	130 mm×70 mm ×1.524 mm	RO4003	12.3 dBi	Scan area 180 degrees and 12.3 dBi peak gain at 30 GHz.
[23]	Wideband 5G beamforming printed array	4×4	70mm×40 mm ×0.254 mm	RT Durroid-5880	9 dBi	2.4GHz for LTE-A. 28 GHz with the ability of beam steering over a 70°-angular space
[31]	Dual-band (MIMO)	8	145mm×75mm ×0.8mm	FR4		Frequency: 3.3-3.6 GHz and 4.8-5 GHz Return loss: -22 dB and -29dB (Appx) efficiencies are about 60-85%.
[32]	Patch antenna with Butler matrix network	4×4	35mm×47mm	Rogers RO3003		Frequencies 27-33.7 GHz. Port Isolation -15 dB

3. ANTENNA DESIGN

The simple SIW antenna designed on a substrate of RT Duroid (5880) having a dielectric constant (ε_r) 2.2 and loss tangent (δ) 0.0009 at operating frequency 28 GHz (covers wideband) as shown in figure 19 and designed parameters are mentioned in table 2. The design of the SIW antenna leans on classical metallic waveguide width a and cutoff frequency (f_c) for the fundamental mode. The propagation of TE10 wave as given by Eq.(1) and Eq.(2).

$$f_c = \frac{c}{2\pi}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \quad (1)$$

$$f_c = c/2a \quad (2)$$

where c is the velocity of light in m/sec, b is the length of the waveguide, and m and n represent the integers for the propagation mode. The non-planar waveguide transformed into planar by parallel vias at a distance of w acts as a wall for planar structure [14][17][33] determined from Eq.(3) - Eq.(5).

$$w = a_d + \frac{d^2}{0.98p} \quad (3)$$

$$a_d = \frac{a}{\sqrt{\varepsilon_r}} \quad (4)$$

where a_d is the dielectric-filled waveguide width, d is

the diameter of the via, p is the pitch length and ε_r is the permittivity of the substrate. The Eq.(3) specified in does not consist of the diameter to width (d/a) ratio. The diameter advances, it provides an error, so a valid Eq.(5) is mentioned in [33].

$$w = a_d + 1.08\frac{d^2}{p} + 0.1\frac{d^2}{a_d} \quad (5)$$

The vias are placed such that there won't be any radiation leakage through the vias. It has to satisfy the two crucial conditions: [14].

$$\lambda_g/5 < d \quad (6)$$

$$p \le 2d \quad (7)$$

where λ_g is the guiding wavelength determined by the following Eq.(8).

$$\lambda_g = \frac{2\pi}{\sqrt{\frac{(2\pi f)^2 \varepsilon_r}{c^2}\left(\frac{\pi}{a}\right)^2}} \quad (8)$$

The wave is propagating through the ports of the SIW in TE10 as it satisfies the propagation modes mentioned in the Eq.(9)-Eq.(10) of classical rectangular waveguide [34] and

resonating at multiple bands to achieve the required operation as an antenna.

$$\gamma_g = \sqrt{\left(\omega^2\mu\varepsilon - k_0^2\right)} \quad (9)$$

The propagation of the wave through the guide if $\omega^2\mu\varepsilon > k_0^2$ and

$$\gamma_g = \pm j\beta = j\omega\sqrt{\mu\varepsilon}\sqrt{\left(1-\frac{f_c}{f}\right)^2} \quad (10)$$

where k_0 represents cutoff wavenumber, γ_g is the propagation constant, β is the phase constant, and f is the operating frequency of the waveguide.

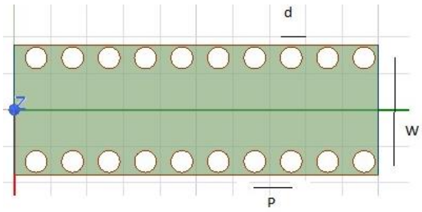


Fig.19. SIW antenna

Table.2. SIW antenna design parameters

Parameters	Values(mm)
Width of the Waveguide (a)	7.112
Length of the SIW (b)	20
Substrate Height (h)	0.508
Width between Parallel vias (w)	5.67
Pitch Length (p)	2
The diameter of vias (d)	1.2
The thickness of Metal (th)	0.01

4. SIMULATION RESULTS

The antenna is designed to resonate above 21 GHz with multiple bands resonance as reflection coefficient shown in Fig.20.The reflection coefficient $|S_{11}|$ at 28.66 GHz is -58.577 dB as the standard value is less than -10 dB. The multiple bands resonate well below the standard value -10 dB and also voltage standing wave ratio (VSWR) is below 1.5 for multiple resonances as shown in Fig.21.

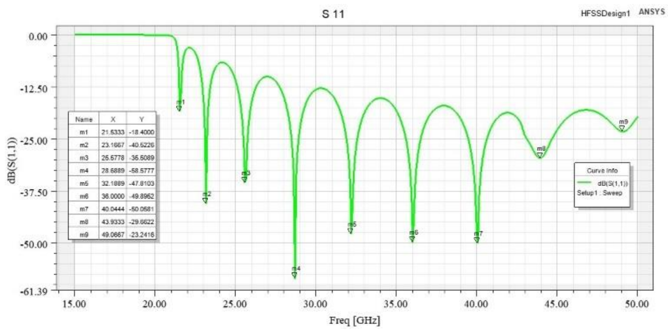


Fig.20. S_{11} (Reflection coefficient) resonates at multiple bands

The wave propagation is considered in three modes with cutoff mode1 below 15 GHz, mode2 at 28.53 GHz and mode3 at 42.8 GHz shown in Fig.22(a).

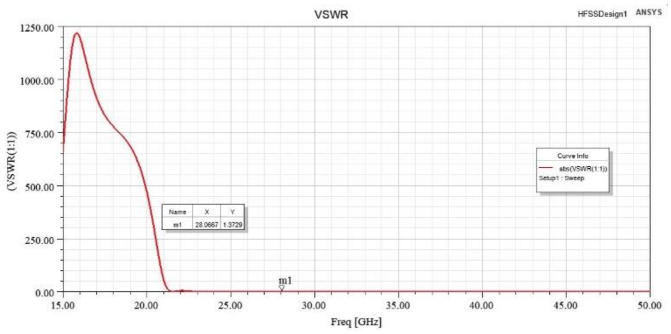
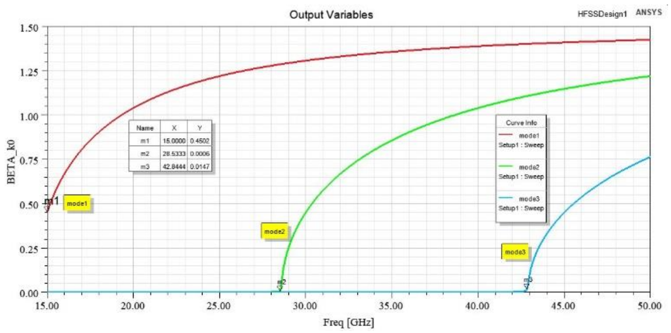
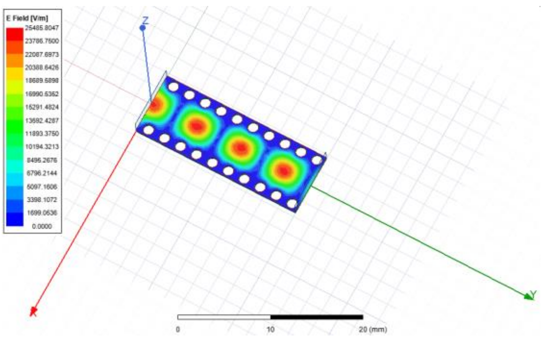


Fig.21. VSWR at multiple frequencies

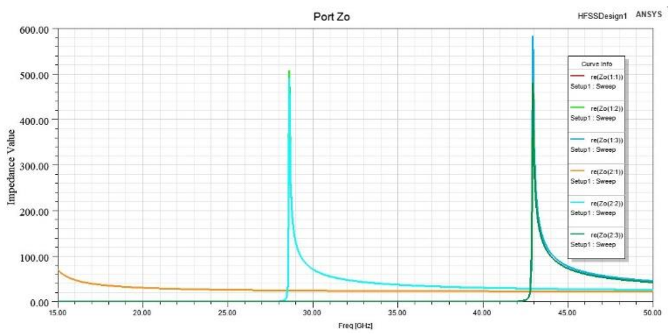
The electric field (E-field) distribution is accommodated within SIW as there is no radiation loss outside the vias as shown in Fig.22(b) and the impedance plot shown in Fig.22(c).



(a)



(b)



(c)

Fig.22. (a) Cut-off modes (b) E-field distribution (c) Impedance plot

5. CONCLUSION

This work presents, different types of super wideband antennas that are inspected for 5G communication applications of published papers. Band notched antennas are used to enhance the wider bandwidth (0.9 to 100 GHz) with acceptable gain. The array antenna of different structures provides a higher gain compared to single structures but having a similar capability as a single antenna. To overcome the limitations of array antenna, MIMO antenna offers better solutions for 5G mobile communication applications. The substrate integrated waveguide (SIW) is the planar technology transformed from the non-planar conventional metallic waveguide having similar capabilities as classical waveguide provides the ease of integration and fabrication for higher frequencies. The SIW based antenna, arrays, and combined capabilities with MIMO structure is the better candidate for highly compact super wideband 5G antennas for smartphones. The simple SIW antenna proposed and simulated offers a wider bandwidth 21 to 50 GHz operating band and reflection coefficient $|S_{11}|$ at 28.66 GHz is -58.577 dB. In the future implementing different types of array antenna and MIMO antenna using the capabilities of the SIW structure.

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