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3-D PRINTED ANTENNAS FOR WIRELESS COMMUNICATION SYSTEM: A REVIEW

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Abstract

This letter presents several antennas for fifth-generation (5G) applications at different frequency bands. Most of the 5G antennas are mainly for the MIMO and millimeter-wave applications (mmW). The frequency bandwidth of the systems for mmW applications is 20-40 GHz whereas the bandwidth for the MIMO antennas lies in the range of 3-5 GHz. The MIMO and millimeter-wave application antennas are most widely used for 5G systems as they are more compatible with the frequency ranges that has been allotted for 5G communication systems. different feeding is used for distinct systems which makes it unique. novel fabrication method like 3d printing technologies has been used to make the antennas more modern, efficient and low-cost.

Keywords: MIMO, millimeter-wave (mmW), 5G, 3-D Printing.

Introduction

The fifth-generation (5G) is a promising technology that has geared up all the advancements that is perhaps possible today. The rapid increase in the growth of 5G in wireless communication has evolved the need of various antennas to operate at different frequencies. The main goal of 5G is to provide high transmitting rates and large area coverage. Frequency spectrum 3-300 GHz is used for 5G mobile communication [1]. The antennas designed for 5G are fabricated using 3-D printing technology which is considered to be more effective than the traditional practices. 3-D printing methods are verified as the constructive ways for manufacturing low-cost antennas.

To overcome bandwidth limitations in 5G applications, a significant number of antennas are designed specifically for millimeter-wave (mmW) frequency bands. Numerous antenna designs have been proposed for millimeter-wave applications. In [2], the Fabry–Pérot Cavity antenna is introduced, providing off-axis pencil beams with high gain in the 27-30 GHz bandwidth. [3] presents two small, lightweight, efficient, and cost-effective 3D printed antennas that operate at the 28 GHz band. These antennas are metallized using radio frequency interference (EMI/RFI) conductive spray paint technology. [4] discusses a wideband and polarization reconfigurable reflect array antenna for 5G mmW, which is also fabricated using 3-D printing technology. Reflect array antennas offer high gain without the need for complex feeding networks and provide reconfigurable beam capabilities. In [5], another reflectarray antenna is presented, featuring wide-angle beam scanning ability, deployability, and high gain. This antenna adopts a kirigami-inspired element structure and is 3-D printed using commercialized SLA (Stereolithography) technology. Furthermore, [6] proposes a wideband dual-polarized waveguide array for mmW applications. The introduction of loading ridges in this design significantly improves the bandwidth of the dual-polarized gap array. This low-cost and wider bandwidth array finds extensive usage in millimeter-wave applications.

Further, many MIMO antennas are fabricated for 5G applications using 3-D printing technology. Such antennas are designed, simulated, and optimized using the software HFSS. The bandwidth of the antenna lies in the range 3.5-5.1 GHz [7]. In this, a solution has been proposed to a problem that is the resin base station antenna requires both high power and temperature. The solution proposed was to use dense cell coverage technology as a result of which the base station require substantially less coverage area of about 100m and the power required will reduced to about 1W. In [8], an antenna array suitable for MIMO applications in 5G is thoroughly analyzed and implemented. The antenna array is designed as a high-isolation cavity-backed dual-polarized antenna, offering a bandwidth of approximately

20.18% while maintaining low levels of mutual coupling. The antenna employs Rogers RT/Duroid 5880 substrate as the chosen material.
In this letter, various antennas have been discussed that are fabricated and manufactured using 3-D printing technology. The antennas are designed for fifth-generation (5G) MIMO and millimeter-wave (mmW) applications. Different antennas for 5G millimeter-wave applications that have been reviewed are Fabry–Pérot Cavity antenna operating at frequency bandwidth of 27-30 GHz, Wideband and polarization reconfigurable reflect array antenna which has linearly polarised horn antenna as a feeding source in 22 - 40GHz bandwidth, wideband dual polarised waveguide array and, two efficient, light weight, small and low cost 3-D printed antennas which operate at 28 GHz bandwidth. Different 5G MIMO antennas that have been discussed are dual polarised and cavity-backed antenna both of these antennas work in 5 GHz and 3.5-5.1 GHz respectively. The 3D printing technologies make these antennas economical and efficient.

Antenna for the Millimeter-wave applications
Antenna 1 in the compact antennas is fabricated generally by using the metallic plate, and slot and the corrugations are drilled using micromachining [9] and CNC (Computer Numerical Control) milling. But for simple fabrication process, the antenna is 3D printed using the plastic material. This 3-D printed prototype is then metallized with the use of low-cost sprays paint with strong scratch resistance characteristics and adhesive properties [10]. The paint gets dried up within 5 minutes.
The second antenna is smaller and compact form of Antenna 1. It consists of two layers in which the first layer is the feeding structure and the second layer is the 3D printed radiating structure. The feeding layer is fabricated on the substrate Rogers RO4003C which has a dielectric constant of 3.38 and thickness of 0.508 mm. The spray RS EMI/RFI is used to metallize the antenna.
The polarization reconfigurable antennas play crucial role in wireless communication. To improve performance and to attain the polarization agility, a p-i-n loaded radiator is constructed. The UC proposed in Fig. 2 made up of air- perforated dielectric stud having a dielectric constant of 2.65 and a loss tangent of 0.01 in ka-band and a metal plate. For the proposed unit cell (UC), it seems to be equivalent to transmission line which help in analyzing reflection phase. TE and TM can be obtained using formula (a)(b) when electric field of incidence wave is parallel to y-axis or x-axis then reflection phases can be obtained. The four such formed UCs together construct RA antenna.

$$\theta_x = -\frac{4\pi h f}{c}\sqrt{\varepsilon_x (w, l)} + \varphi_x \qquad (1a)$$

$$\theta_y = -\frac{4\pi h f}{c}\sqrt{\varepsilon_y (w, l)} + \varphi_y \qquad (1b)$$

	l (mm)	*w* (mm)	Reflection phase
UC#1	4.4	1.55	-180 deg
UC#2	4.3	2.3	-90 deg
UC#3	4.3	3.0	0 deg
UC#4	4.5	3.5	90 deg

Table 1: Two Bit Reflection Phase Of The Proposed Uc At 30 Ghz Under Different Dimensions ((H = 16 Mm), L (Length) And W (Width))
The antenna consists of a reflective panel and a feeding source with complete reflectance and phase compensation characteristics. The centrally fed method is implemented in this particular design. For the frequency range of 22 to 40 GHz, a linearly polarized horn antenna is used as the feeding source. The configuration of antenna is based on the four UCs and phase distribution. Feeding source is held

in position with the help of 3-D printed fixture. With the help of UCs linearly polarized wave is converted into circularly polarizes wave. The various polarization, RHCP and LHCP can be achieved by rotating 3-D printed reflective panel with feeding source fixed. The offset-fed techniques are used to minimize the blockage effect of feeding source [11]-[13].

The design of the Fabry–Pérot Cavity antenna incorporates various components, including a metallic ring, a PRS (Planar Reflectarray Surface), an array of metallic shields, and a feeding structure. By arranging an array of RATWSAs (Reconfigurable Antenna Tightly Coupled to a Substrate) in a circular configuration, a cylindrical cavity is formed. In this particular design, five RATSWAs have been utilized, resulting in the creation of five switchable beams. It is worth noting that a greater number of feeder elements can enable the generation of additional beams. To enhance the radiation characteristics and optimize impedance matching, metallic shields are employed around the probes of the antenna. The antenna dimensions are specified as 27.1 $\lambda^2_c \times 0.68\ \lambda_c$, where λ_c represents the wavelength at the center frequency.

Antenna for the MIMO applications

The proposed antenna design demonstrates dual polarization through miniaturization and integration techniques. The design incorporates two dipole elements polarized at +/- 45 degrees, each measuring $27.2 \times 27.2 \times 17\ mm^3$. The dipoles are integrated into the same baluns and feature symmetrical holes to reduce overall weight. Adequate spacing between adjacent arms is implemented to prevent mutual coupling between the dipoles. The two feed pieces are positioned orthogonally on the antenna arms Fig.1. A 1mm gap is maintained between the two feeds, with dimensions of $3.2 \times 0.8 \times 10\ mm^3$.

To fabricate the model, a 3-D printer is utilized to convert the design into a 3-D solid sample using photosensitive resin. Each layer of the printed sample has a minimum thickness of 29 µm. Compared to traditional line-cutting processes, the 3-D printing method significantly reduces printing time, taking approximately 30 minutes. The printed sample is composed of a non-conductive hyaline VisiJet M3 Crystal material, which is subsequently metalized before being employed as an actual antenna. Then it is followed by Custom developed copper plating method and appropriate mechanical polish and at last, the sample is dipped into a solution of a chemical mixture in a certain proportion are CuSO4 ·5H2O, HCHO, NaKC4H4O6 ·4H2O, and NaOH. After cooling for 25 min and electroplate bath, the SMA connector is welded to antenna and low temperature soldering technique is employed at 180^o.

The cavity-backed crossed dipole antenna configuration includes unit element cross dipoles printed at 450 and 1350 on the substrate, which is then supported by a rectangular cavity with a square cross-section. To suspend the substrate within the cavity, a low-loss Cuming Microwave foam is utilized. The foam has a dielectric constant of 1.08 and a loss tangent of 0.001. The height of the tapered balun is carefully optimized to achieve impedance matching with the antenna's input impedance of 50 Ω. Additionally, the cavity's width is set to 30 mm, resulting in a degenerate mode frequency of 5 GHz.

A 4x4 subarray of cavity-backed dipole antenna is realized based on the single element. A distance of λ/4 is maintained between the metal cavity and the antenna aperture.

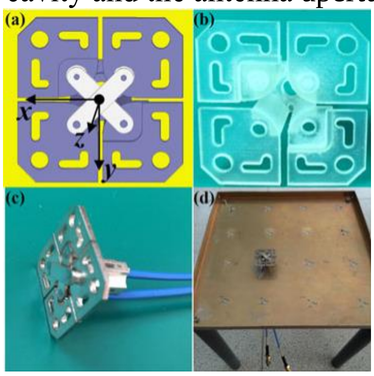


Figure 1: (a) Model representation of the proposed dual-polarized antenna. Photograph showcasing (b) a 3-D printed polymer sample, (c) a metal-coated antenna sample featuring two feeding pieces and coaxial cables securely attached to its arms, and (d) a copper plate with the antenna properly screwed onto it.

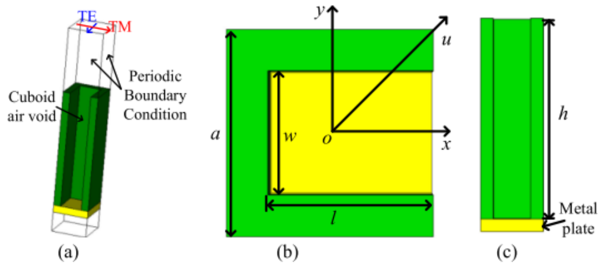
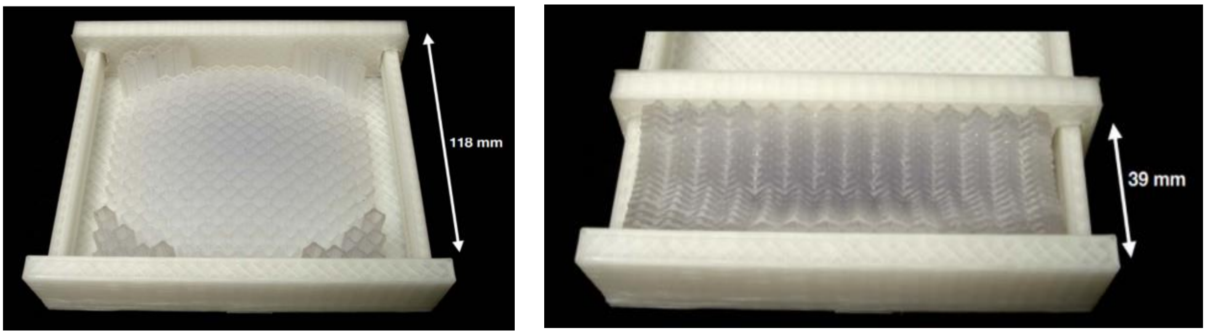


Figure 2: The geometries of the proposed unit cell (UC) are depicted as follows: (a) Perspective view, (b) Front view, and (c) Side view. The dimensions of the UC are specified as follows: a = 5.0 mm and h = 16.0 mm.



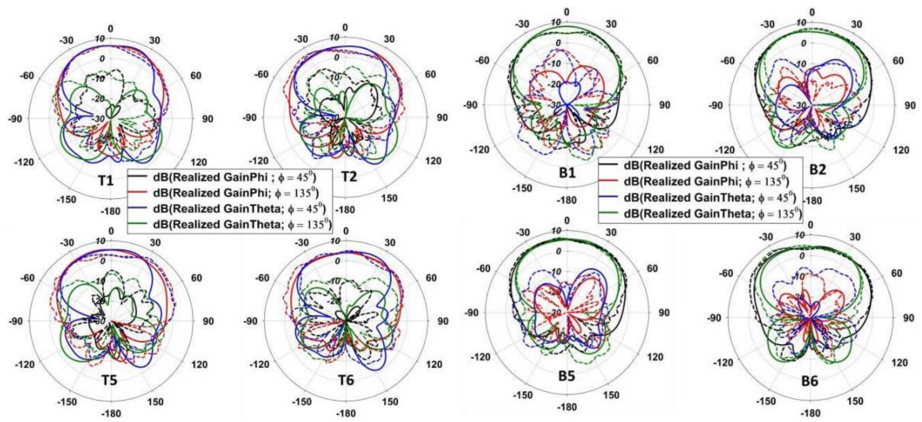
(a) (b)

Figure 3: Fabricated sample (a) front view (b) back view

Results And Discussion

Different antennas have been fabricated and manufactured using different 3-D printing technology and feeding structure. So, the measured results obtained during the process of fabrication of these antennas are unique and some lying within certain frequency bands.

In the cavity-backed dual slant polarized antenna configuration, all elements exhibit a matching level below -10 dB. The measured mutual coupling between the elements is approximately -20 dB. The coupling between the elements and TARC (Tuned Antenna Radiation Center) is utilized to gather information for various beam scan angles [14]. Figure 4 provides visual confirmation of the antenna's slant polarization.



(a) (b)

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Fig. 4. The 2-D radiation pattern of the simulated (solid lines) and measured (dashed lines) realized gain is presented. The following scenarios are shown: (a) Top dipoles T1, T2, T5, and T6 at 5.3 GHz (b) Bottom dipoles B1, B2, B5, and B6 at 5.3 GHz

The utilization of 3-D printing technology for manufacturing various 5G Multiple Input Multiple Output (MIMO) antennas has successfully addressed the challenges related to high power and elevated temperature in base station antennas made of resin materials. Additionally, as shown in Fig. 5, it is evident that the mutual coupling between the dipoles is below -18 dB. In their study, researchers have developed a cost-effective and high-performance antenna using millimeter-wave and MIMO technologies. Moreover, they have also proposed a solution for handling data traffic in mmW broadband dual-polarized dielectric resonator antennas through hybrid modes.

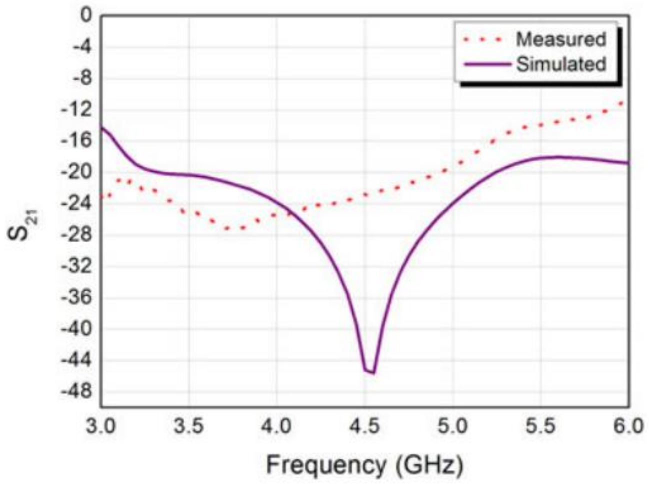

Fig. 5. The isolation between the two perpendicular dipoles of the antenna was evaluated using both experimental measurements and simulated data

Conclusion

Various types of antennas for 5G application have been discussed. Most of the antennas are fabricated for 5G MIMO and millimeter-Wave applications. So, numerous antennas for 5G millimeter applications that have been reviewed are Fabry–Pérot Cavity antenna operating at frequency bandwidth of 27-30 GHz, Wideband and polarization reconfigurable reflect array antenna which has linearly polarised horn antenna as a feeding source in 22 - 40GHz bandwidth, wideband dual polarised waveguide array and, two efficient, light weight, small and low cost 3-D printed antennas which operate at 28 GHz bandwidth. Different 5G MIMO antennas that have been discussed are dual polarised and cavity-backed antenna both of these antennas work in 5 GHz and 3.5-5.1 GHz respectively. All these antennas have been fabricated and manufactured using 3-D printing technologies.

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