Design and Analysis of 3D Posts Based Antenna

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***Abstract*— Three dimensional (3D) antenna refers to an assembly of radiating element on one layer and feed line on another layer and was introduced to minimize the antenna design space. This configuration allows room to integrate more devices and thereby enhances the chip functionalities for an system on chip (SoC) radio frequency (RF) applications. The designed 3D antenna element is composed of vertical metal supports or posts and combination of copper pads connecting multiple supporters. The 3D posts based antenna was designed for 24 GHz ISM band applications and its performance was computed by changing the number of posts. The antenna performance was improved by the inclusion of novel 3D posts and the footprint of overall antenna design was reduced to 2.75 mm × 2.75 mm. To verify the architecture, a similar posts based antenna was fabricated for 2.5 GHz frequency and antenna performance was measured. Experimentally measured antenna parameters and simulated results were found to be in agreement.**

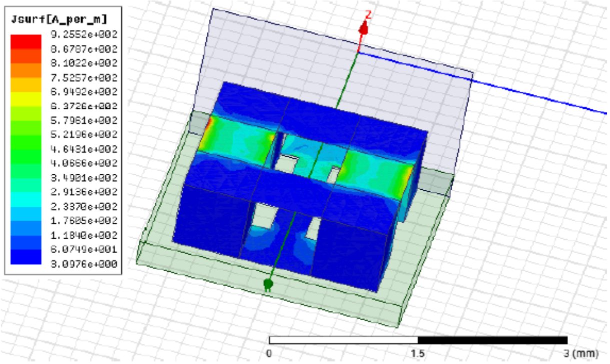
Keywords—3D antennas; high frequency antennas; 24 GHz; 2.5 GHz; broadband antennas

I. INTRODUCTION

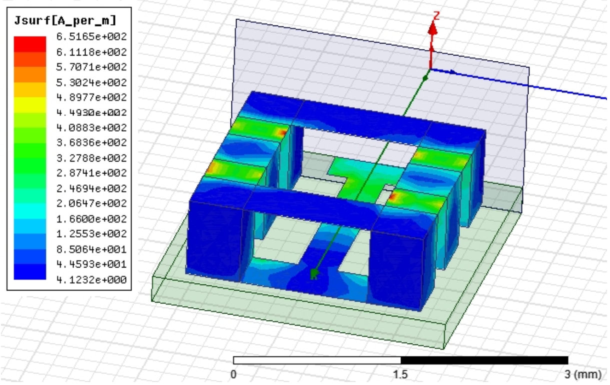
The paper demonstrates design of a 24 GHz 3D antenna with a feed and transmission line on a plane, and a radiating element formed of 3D copper structures surrounding the transmission line on three sides. A 24 GHz communication system is considered highly useful for various applications and has several advantages including smaller physical size, and less delay spread for near-field applications [1]. The low dimensions of antenna encourages to integrate 24 GHz antenna in system on chip (SoC) radio frequency (RF) applications using existing CMOS technology. A compact transceiver design with an inbuilt antenna will provide space to add more functionalities [2], [3], [4], [5]. The increasing demand of adding more features in a chip requires not only innovation in devices and circuits, but also a change in overall antenna design. The 3D antenna is derived from the Yang's work [6], [7] on cylindrical posts for 3D integration. The 3D integration technology allows designer, the flexibility to wire and place devices independent of circuit design in other layer [8]. [9], [10], [11], [12]. 3D structures were used by Covert and Lin [13] to realize dual role; one as radiating element and another as a heat sink to improve thermal dissipation. The 3D heat sink fin structures were mounted on planar patch antenna and a transmission line was designed in the plane to perfectly match the impedance. The architecture served to improve the antenna performance, such as radiation efficiency and directivity, and reduced the thermal dissipation, yet the substrate footprint were comparable to the conventional patch antenna design. As the technology is progressing towards 3D devices, and circuits, an appropriate posts based radiating element to electrically connect transmission line is valuable for the modern antenna design and radio frequency (RF) circuits [14], [15]. The design of posts that are 3D in nature is a natural fit for novel antenna system. In this work, 3D copper posts were positioned on either side of the transmission line thereby reducing the design space and enhancing the electromagnetic radiation due to the addition of vertical metal conductors.

II. DESIGN OF ARRAY OF POSTS FOR 3D ANTENNA

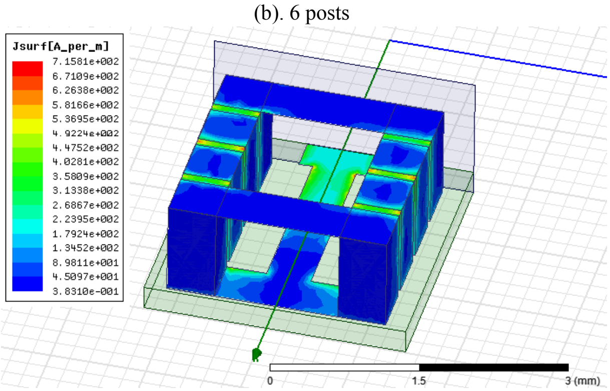
Our earlier work [16] showed a preliminary idea that 3D antennas can be built on electrical posts. The fabrication complexity led to a mismatch in simulation and measurement results. The present work focusses on improvement in design so as to obtain a robust antenna with smaller profile and foot print. The coax fed quarter wave line on the bottom plane drives the electrical signal to 3D structured radiating element via a transmission line as shown in Figure 1. A study to determine an optimum number of posts to form an electromagnetic component was performed. The study was conducted by varying the antenna design to contain four, six, eight and ten number of 3D posts. The antenna performance was effective when the posts were arranged symmetrically. Hence all designs were configured to two sets of 3D posts, with each set arranged collinearly as shown in the Figure 1. The dimensions of the posts in individual antenna design were optimized to provide maximum power transfer to radiating element from the feed point. The base sides of all raised posts in a given design were fixed to same size and the height of the



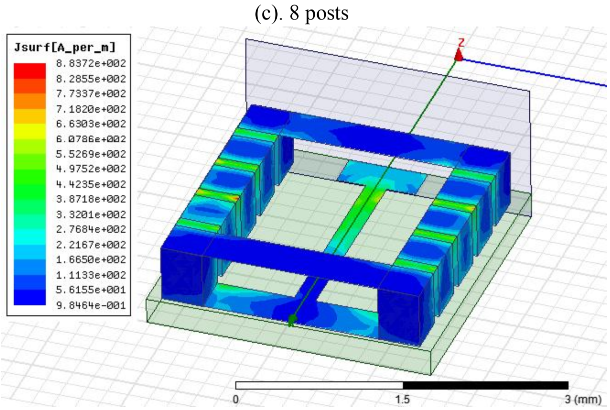
(a). 4 posts



(b). 6 posts



(c). 8 posts



(d). 10 posts

Fig. 1. Surface current distribution of array of posts designed for 3D antenna operating at 24 GHz.

TABLE 1: COMPARISON OF ANTENNA PARAMETERS FOR PATCH ANTENNA AND ARRAY OF POSTS DESIGNED FOR 3D ANTENNA RADIATING AT 24 GHZ

Parameters	Patch	4 posts	6 posts	8 posts	10 posts
Frequency (GHz)	23.78	23.78	23.78	23.78	24.12
Peak Directivity (dBi)	3.67	2.70	2.63	2.61	2.48
Peak Gain (dBi)	3.31	2.62	2.56	2.53	2.39
Radiated Power (W)	0.90	0.97	0.97	0.97	0.96
Accepted Power (W)	0.99	0.99	0.99	0.99	0.99
Radiation efficiency	0.90	0.97	0.97	0.97	0.96
Bandwidth (GHz)	0.61	1.84	2.15	2.40	1.84

posts was varied to ease the optimization process. The optimized dimensions of each posts in four, six, eight and ten posts antenna designs are: 0.7 × 0.7 × 0.7 mm^3, 0.5 × 0.5 × 0.75 mm^3, 0.5 × 0.5 × 1.025 mm^3, and 0.4 × 0.4 × 0.55 mm^3 respectively. The array of 3D posts in two sets was varied from two to five and antenna parameters with reflection coefficients were studied as shown in Table I. The antenna parameters and Figure 2 suggests that array of 6-posts and 8-posts design offers bandwidth of more than 2 GHz (8.4 % bandwidth). The aspect ratio, which is determined as the ratio of the height of the posts to one of the base dimensions, was high for 6 posts and 8 posts designs. The slight improvement in bandwidth for six and eight posts design was attributed to higher aspect ratio of posts based antenna. Eight posts antenna with an aspect ratio of 2.05 shows the highest bandwidth of 2.4 GHz. The substrate size of the 3D antenna was reduced to 2.75 × 2.75 mm^2 as compared to patch antenna covering 7.27 × 7.27 mm^2. It was also observed that with increase in the number of posts, directivity and peak gain were compromised. However gain of the 3D antenna can be improved by increasing the ground plane dimensions, considered to be a part of larger chip area with other devices around. Six 3D posts were considered appropriate as compared to other posts design, for further experimental validation.

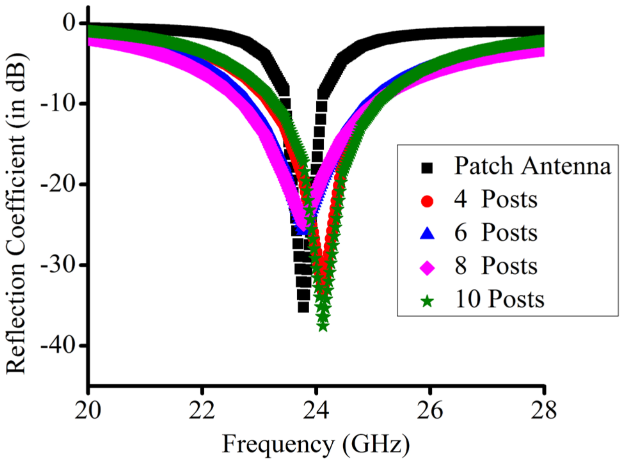


Fig. 2. Return loss of patch antenna and different array of posts designed for 3D antenna operating at 24 GHz.

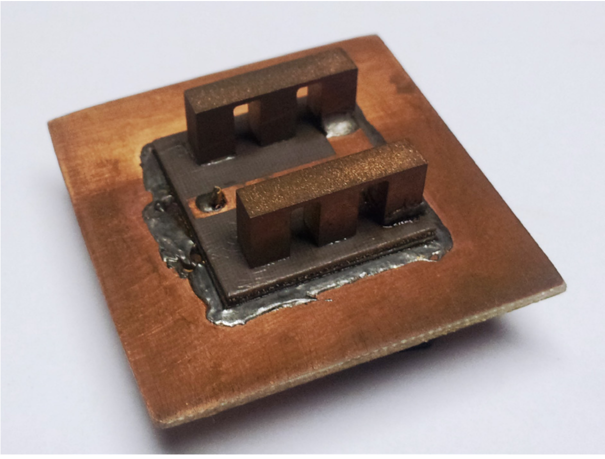


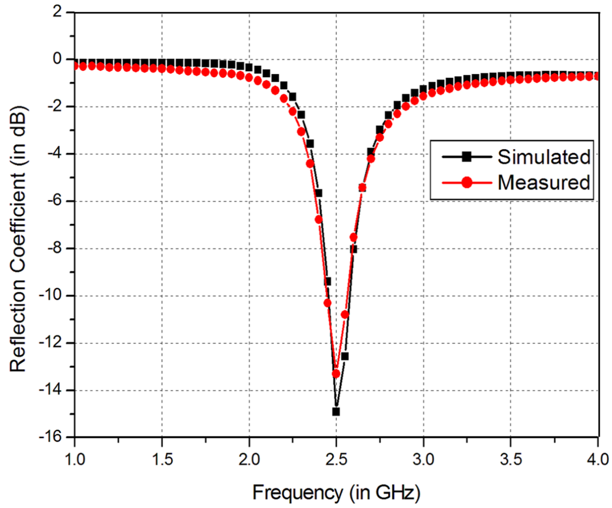
Fig. 3. Photograph of the fabricated antenna operating at 2.5 GHz.

III. Experimental Results

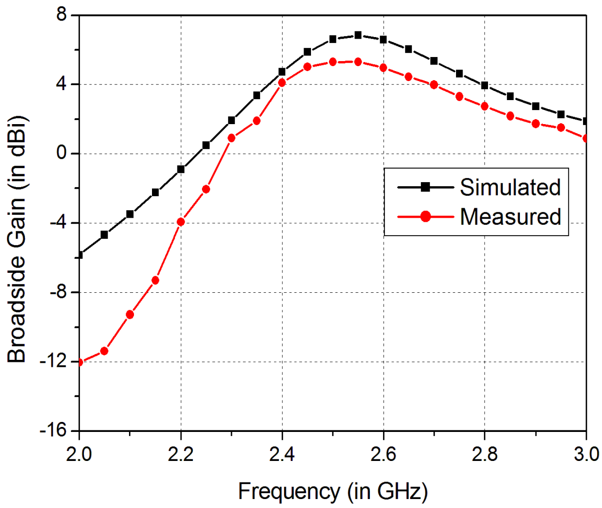
Experimental verification of 3D antenna at higher frequency was difficult to achieve, due to limitations in fabricating 3D posts of micron scale. Developing 3D posts on a substrate with patterned metal at lower scale requires elaborate study on various fabrication techniques. Hence, 3D antenna with six posts, which occupied a footprint of 26 × 26 mm^2 were fabricated for lower frequency of 2.5 GHz. A part of the antenna was printed on a Duroid substrate having a relative permittivity of 2.2 and thickness of 2.57 mm. The posts and the connecting pads were machined from a copper block and soldered on to the printed pattern as shown in the Figure 3. In the fabricated version, the ground plane size was increased to 46 × 46 mm^2, to emulate the situation of the antenna mounted on a larger ground plane, which could be part of the larger printed circuit board. Two copper pads connecting the 3D posts at the top, that were perpendicular to 2D feed line exhibited low surface current and low radiation effects, were eliminated to ease the fabrication process. Presence of a larger ground plane provides a better ground reference for connecting the coaxial cable. To verify the results, six posts based 3D antenna design integrated with ground plane of same dimensions was simulated in HFSS^{TM} software, and fabricated antenna results were plotted with simulation results.

The simulated and measured reflection coefficient results show close agreement as shown in Figure 4(a). The fabricated 3D antenna demonstrated a gain of 6 dBi at 2.5 GHz operational frequency, as shown in the Figure 4(b). The measured results show a bandwidth of 135 MHz which is more than the 40 MHz offered by a patch antenna operating at similar frequency but occupying larger footprint.

The radiation pattern of the 3D antenna was measured in anechoic chamber. The radiation pattern is similar to that of microstrip patch antenna, demonstrating radiation in broadside direction. A good agreement is seen between the measured and simulated radiation patterns (Fig. 5). The cross polarization level is at least 20 dB below the co-polarization level. The antenna performance of the fabricated 3D posts based 2.5 GHz antenna are in accordance with simulation results, which hints that 24 GHz frequency based 3D antenna design should yield similar results as that of simulation mentioned in this paper.



(a). Reflection Coefficient

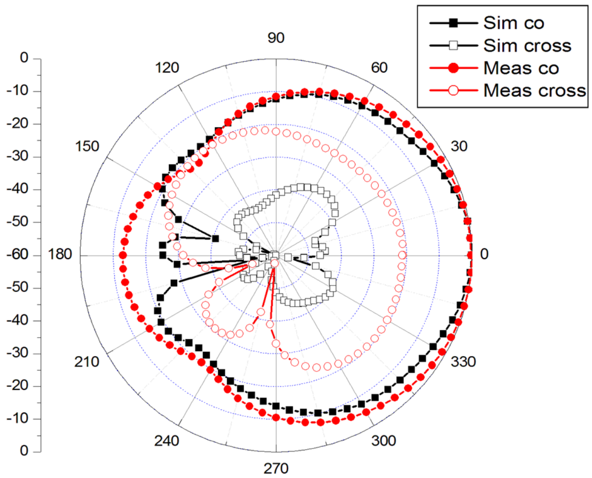


(b). Realized Gain

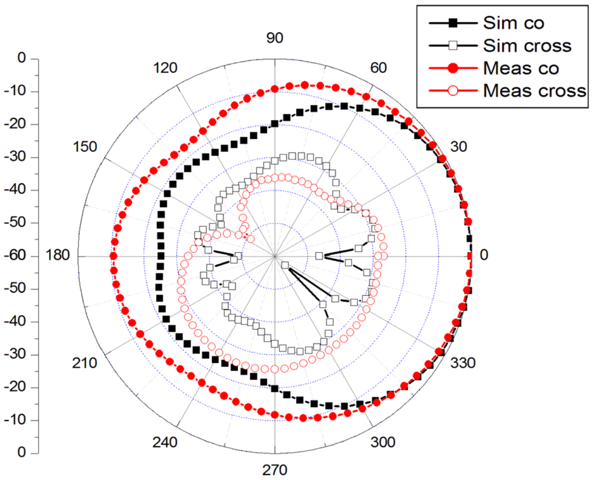
Fig. 4. Comparison of simulated and measured reflection coefficient and gain of the antenna.

IV. Conclusion

A novel 3D posts based antenna was simulated in HFSS^{TM} software and fabricated to confirm significant improvement in antenna performance over conventional patch antenna. Array of 3D posts based antenna demonstrated wide bandwidth, and reduced substrate dimensions. Within the four different posts type of 3D antennas, six posts and eight posts design demonstrated bandwidth of over 2 GHz. The slight increase in bandwidth was attributed to higher aspect ratio of post structures. The fabricated 3D antenna with a larger ground plane, operating at 2.5 GHz, demonstrated high gain and wider bandwidth, which is close to simulated design. Hence 3D antenna operating at higher frequency of 24 GHz is expected to offer antenna parameters described in this paper. The novelty in making the antenna design compact will be useful for various system-on-chip (SoC) and Internet of Things (IoT) applications.



(a). Reflection pattern in XZ plane



(b). Reflection pattern in YZ plane

Fig. 5. Comparison of experimental measurement of 3D fabricated antenna operating at 2.5 GHz with simulation results.

Acknowledgment

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