

Compact 3-D Cubic Loop Antennas with Omnidirectional Patterns

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Abstract—Using simple geometrical structures, a group of novel three-dimensional (3-D) cubic loop antennas for operation at around 915 MHz ISM Band are proposed to achieve the omnidirectional patterns at compact electrical size (about 36% smaller than square loop antenna), due to the fact that cubic loop or cubic meander antennas have smaller sizes than the planar ones. The antennas are feasible as receiving antennas for applications in wireless sensing base stations, RFID, multiple-input-multiple-output (MIMO) communications, and electromagnetic energy harvesting for mostly orientation-independence. The prototypes are fabricated and measured.

I. INTRODUCTION

In harsh multipath environments, the propagating electromagnetic wave may change significantly after complicated multiple reflections or scattering. Thus the omnidirectional (or isotropic) antennas are desirable to achieve almost uniform distribution of power inside the regions for wireless sensing base station, wireless local area network (WLAN), RFID, or MIMO receiving applications, to harvest the electromagnetic resources and maximize a system's capacity. Meanwhile, many applications require antennas with compact electrical sizes (according to the wavelength in free space).

In recent years, a number of topologies for omnidirectional antennas have been investigated [1]. Their disadvantages are the fact that their electrical sizes are not sufficiently small. In the paper, by using 3-D space efficiently (instead of using only planar space), we propose a group of cubic loop antennas with compact electrical dimension of 0.15λ at 900 MHz, as well as omnidirectional patterns. The simulated gains are around 1.6 dBi (higher than most of those with similar electric sizes and omnidirectional patterns).

Originally from the thought of three mutual-orthogonal traditional one-dimensional (1-D) square loops with three ports, we integrate the three loops into one antenna with one port only and proposed the 3-D cubic loop antenna, with all half-line sections (along central lines of six faces) being reconnected. By the geometrical symmetry, we have all 22 possible combination cases of the 3-D cubic loop antennas

(considering the position of the port also): some have one whole loop only (e.g., Case 1), the others have one major loop with port plus one to three parasitic loops (e.g., Case 16).

One similar 3-D cubic loop antenna at around 600 MHz has been presented in literature [2]. The goal of this paper is to focus on the group of the novel compact 3-D cubic loop antennas at around 915 MHz with wide-beam patterns and to provide a comprehensive understanding by exhausting all possible cases. Also for size reduction by cutting a little section from the major loop of the 3-D loop antennas, we would obtain the corresponding cubic meander dipole antennas achieving smaller electrical dimension of around 0.13λ .

II. 3-D CUBIC LOOP ANTENNA

A. Antenna Design

Some proposed 3-D cubic loop antennas (for Cases 1 and 16) are shown in Fig. 1(a) and 1(b), where the black lines present the major loops and blue lines the parasitic loops. Each antenna structure is arranged outside a supporting dielectric cube with the edge length of 50 mm. The conducting strip width is 1 mm.

The traditional 1-D square loop antenna with 4 times edge length equal to one-wavelength in total, i.e., the edge is nearly a quarter of wavelength. Then the calculated resonant frequency of the square loop is 1.5 GHz in free space. The group of the proposed 3-D loop antennas would have frequency at around 900 MHz (as shown later), around 40% lower than that of 1-D square loop antenna, which shows that the proposed 3-D cubic loop antennas have around 40% smaller size than square loop antenna. Among all 22 possible combination cases, we present two typical types in the paper: Case 1 and Case 16 for briefly.

B. HFSS Simulations and Prototype Fabrication

The original HFSS models (see Fig. 1(c) for Case 1) use supporting foam (with $\epsilon_r = 1.3$ and $\tan \delta = 0.004$) cube with edge length of 50 mm. One of the fabricated prototypes is shown in Fig. 1(d): Over the supporting Styrofoam, there are

six FR4 covering boards of size 50mm×50mm×0.8mm bearing conducting strips with 1mm width. According to the fabrication, the modified HFSS model for case 1 is shown in Fig. 1(e), by considering the FR4 covering boards with thickness of 0.8 mm over the six faces of supporting Stryfoam (with electromagnetic parameters similar to those of air) cube.

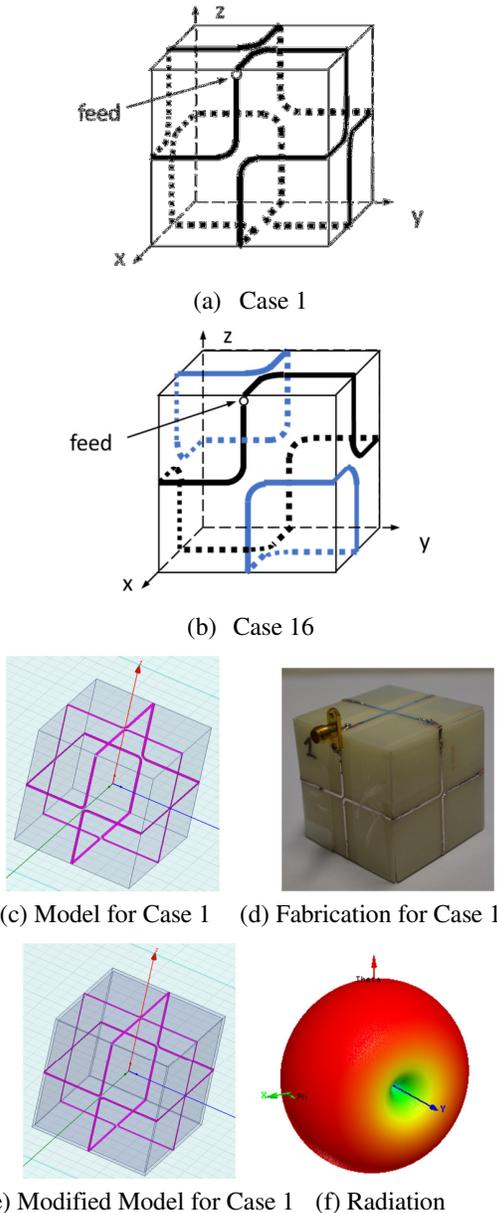


Fig. 1. 3-D Cubic Loop Antennas for Case 1 and Case 16.

C. Simulated and Measured Results

The simulated radiation pattern for the modified 1st case of 3-D cubic loop antennas is shown in Fig. 1(f): omnidirectional with the minimum almost on y-axis. The minimum is due to

the weaker current along the conducting strips on two faces perpendicular to y-axis. The other cases are similar only with shift directions on minimums, so we omit for briefly. Simulated and measured results are shown in Fig. 2 and summarized in Table 1. With the same size, 3-D cubic loop antennas have lower frequencies (measured 875 MHz for Case 1) than that of 1-D square loop antenna (measured 1375 MHz), due to the longer paths through which the current flows. It is shown by these resonant frequencies that the proposed cubic antennas have the electrical dimensions about 36% smaller than that of square loop antenna.

TABLE I. CHARACTERISTIC OF THE ANTENNAS.

3-D loop:	Case 1			Case 16
	Sim.	Sim. Modified	Mea.	Sim.
f_r (GHz)	1.01	0.90	0.875	1.05
max. E_θ (dBi)	0.10	0.56	0.19	1.24
max. E_ϕ (dBi)	0.46	0.57	0.31	1.15
max $ E $ (dBi)	1.59	1.64	1.18	2.03

III. CONCLUSION

A group of novel compact 3-D cubic loop antennas at around 915 MHz are proposed, achieving about 36% electrical size-reduction with respect to conventional square loop antenna. The result also shows that the group of proposed compact antennas have omnidirectional patterns, which make them feasible to be used as a receiving antenna in base stations, WLAN, RFID, MIMO communications, and electromagnetic energy harvesting for mostly orientation-independence.

REFERENCES

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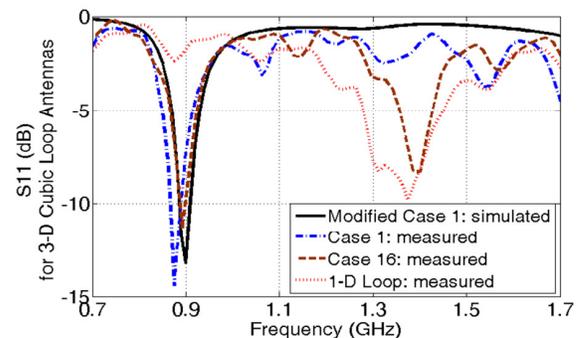


Fig. 2. Simulated and Measured S_{11} .