3D Printed Antenna-on-Package with Near-isotropic Radiation Pattern for IoT (WiFi Based) Applications

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***Abstract*—Futuristic IoT applications demand antenna designs to fulfill a number of challenging performance metrics. The antennas for such applications must be small to be easily integrate-able with miniaturized devices, have near-isotropic radiation pattern to be able to communicate in an orientation insensitive way, provide sufficient bandwidth (4% for 2.4 GHz WiFi) requisite of concerned communication protocol and be low cost enough to be implemented in billions of devices. Also, as these antennas integrate with the devices in very small spaces, so the effect of components (such as battery, chips etc.) also require consideration in design. This paper presents for the first time, a WiFi 2.4GHz near-isotropic T-shaped monopole antenna additively manufactured on the package. The antenna is designed whilst taking battery and WiFi chip effect into consideration. The maximum gain is 1.78 dBi with a gain deviation of 6.84 dB. The VSRW=2 bandwidth is achieved from 2.4 to 2.7 GHz.**

Keywords—T-shaped monopole antenna; near-isotropic radiation pattern; additive manufactured antenna.

I. INTRODUCTION

Internet of Things (IoT) is an exciting paradigm, where a large number of small devices of everyday use, such as dishwasher, cabinets, coffee maker etc., are connected together to deliver smart services. A significant portion of these devices uses WiFi for the connectivity, as it is predominantly available in most indoor locations. The requisite antenna design needed by these devices is quite challenging, as it must be small in size for easy integration with miniaturized IoT devices, provide near-isotropic radiation pattern for orientation insensitive communication capability, be able to cover complete requisite WiFi band from 2.4 to 2.5 GHz, and be low cost enough for implementation on billions of devices.

Certain antenna designs that provide near-isotropic radiation patterns, and thus are suitable for orientation insensitive communication, have been previously reported in the literature [1-7]. Table 1 provides a brief comparison of these designs. As can be seen, the designs from [1, 3, 4] provide sufficiently wide bandwidth (BW > 4%). These are, however, 2D antennas with large electrical lengths. 2D Antennas are inherently in-advantageous as compared to 3D Antenna designs, as they take up a large planer space and lose communication completely if antenna face is placed on the ground. Also, the designs from [1, 3, 4] do not benefit from the antenna on package (AoP) concept or additive manufacturing for cost reduction and miniaturization [8, 9]. Papers [2, 5] have reported additively manufactured 3D wire AoPs with near-isotropic radiation patterns. These antennas, however, have narrow (less than 2%) bandwidth. Papers [6, 7] have presented electrically small antennas with 3D antenna geometry and near-isotropic radiation patterns. However, these antennas are neither additively manufactured nor AoP. Also, the achieved BW is very narrow (less than 2%). Summarizing, an additively manufactured 3D AoP with near-isotropic radiation pattern with sufficiently wide BW has not been reported in the literature before.

In this paper, we present an additively manufactured T-shaped monopole 3D AoP. The presented antenna design takes effect of WiFi chip and battery present inside the IoT device package into consideration. The antenna has a near-isotropic radiation pattern at the frequency of 2.4 GHz and provides a bandwidth of 11.7%. The increased bandwidth ensures that antenna remains properly matched at requisite frequencies, even if the working band slightly shifts because of proximity to a human body or some other external element.

Table 1: Comparison of antennas with near-isotropic radiation patterns

Paper	Geometry	Length	BW	Additive manufacturing	AoP
[1]	2D	$>\lambda/2$	8.5%	No	No
[2]	3D	$\lambda/2$	1.3%	Yes	Yes
[3]	2D	$>\lambda$	11%	No	No
[4]	2D	$>\lambda$	20.82%	No	No
[5]	3D	1.5λ	N/A	Yes	Yes
[6]	3D	$\lambda/4$	1.125%	No	No
[7]	3D	0.4λ	1.8%	No	No
This work	3D	0.5λ	11.7%	Yes	Yes

II. The Antenna Design And Results

A. The Design of The Antenna on Package

A T-shaped monopole AoP has been designed in Ansoft HFSS software with a battery and a WiFi chip inside the package (Fig. 1 (a)). The package has the dimensions (in mm):

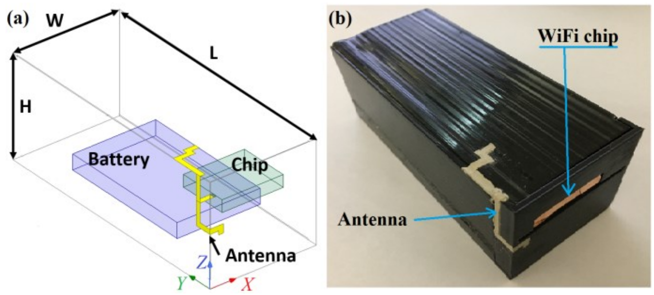

Fig. 1. (a) the AoP design; (b) photo of the additively manufactured AoP.

L=106.8, W=43.6, H=40. The battery is a standard BL-5C Li-Ion battery (the dimensions of the battery are: 54x34x6 mm), and the WiFi chip is RN171 WiFi SOC from Microchip (the dimensions of the chip are: 25x20x4.8 mm). Since both these components have metallic shields, they are simulated as perfect electric conductors in the design. The antenna consists of two arms: the upward and the downward arm (along Z-axis, relative to WiFi chip). The upward arm of the antenna has a length of 31.2 mm, and downward arm has a length of 25.6 mm. The WiFi chip acts as a ground for the antenna. The radiation pattern of the T-shaped monopole is formed by the segments that are located along Z- and Y-axes. The antenna is bent along the X-axis for matching.

B. The Additively Manufactured Prototype

The AoP was fabricated using Stratasys Objet260 Connex1 3D printer (Fig. 1 (b)). The printer uses propriety 'Vero Black Plus' material (the permittivity is 2.8, and the loss tangent is 0.02 at the frequency of 1 GHz), and provides 30 um minimum vertical resolution. The T-shaped monopole antenna was screen printed on the 3D printed package using propriety silver ink from DuPont with resistivity smaller than 10 mΩ/sq/25um.

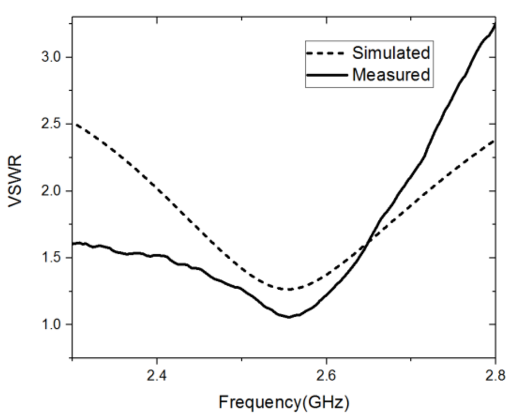

Fig. 2. VSWR of the T-shaped monopole AoP.

C. The Simulated and Measured Results

Fig. 2 shows simulated and measured voltage standing wave ratio (VSWR) of the T-shaped monopole AoP. The simulated bandwidth of 11.7% for the level of VSWR less than 2 is achieved for the frequencies of 2.4-2.72 GHz. Fig. 3 shows the simulated radiation pattern of the AoP at the frequency of

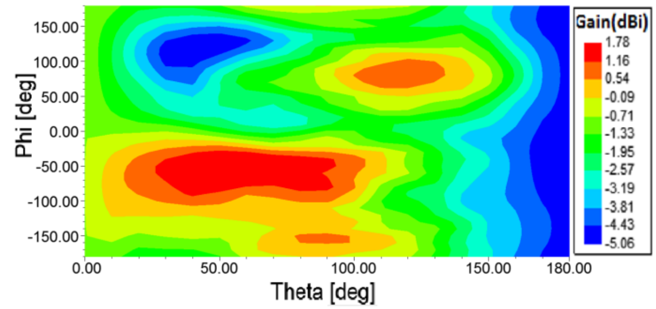

Fig. 3. Simulated radiation pattern of the AoP at the frequency of 2.45 GHz.

2.45 GHz. A maximum gain of 1.78 dBi with a minimum gain of -5.06dBi is achieved (the gain deviation is 6.84 dB).

III. Conclusions

A T-shaped monopole antenna on the package, which provides a near isotropic radiation pattern with a simulated gain deviation of 6.84 dB and a maximum gain of 1.78 dBi inside the frequency band of 2.4-2.72 GHz, is presented. A prototype of the antenna on the package was fabricated using 3D and screen printing techniques.

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