A 3D Printed Near-Isotropic Antenna for Wireless Sensor Networks

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Abstract **- A near isotropic 3D printed antenna on a cubic structure is presented in this work for the first time. The fully inkjet printed antenna has been realized by a unique combination of 3D inkjet printing of dielectric and 2D inkjet printing of metal. The antenna comprises a 1.5λ_0 dipole that is wrapped around the cube to achieve a near isotropic radiation pattern. The cube measures 2 cm x 2 cm x 2 cm, where each side of the cube corresponds to only 0.16 λ_0 (at 2.4 GHz). The cube geometry of the antenna is attractive for wireless sensing applications where it can also act as a functional package for the electronics of the sensor node.**

Index Terms **— 3D printing, near-isotropic antennas, wireless sensor networks (WSNs)**

1. Introduction

WSNs can play an effective role in dealing with emergency situations such as flooding, forest fires and industrial gas leaks. Cost is a major issue in the implementation of such wireless network infrastructure over large areas, which can be greatly reduced if a combination of few fixed nodes and many low cost disposable wireless sensors are used [1]. Therefore, wireless sensors are required that are very light weight and compact as they will be dispersed in large quantities. They should also be able to communicate independent of their orientation as they will be distributed in the environment without any means of controlling their orientation. So the antenna needs to radiate almost isotropically. Moreover, they also need to be extremely low cost in order to be disposable. Therefore cheap material and low cost mass manufacturing techniques have to be used. An attractive technique for easy, low cost and rapid fabrication of electronics that can enable mass production by roll-to-roll manufacturing is inkjet printing. The ability to additively deposit material in picolitre volumes on a variety of substrates using a mask-less process reduces the cost of fabrication significantly. Many planar inkjet printed antennas have already been demonstrated [2]. Moreover 3D inkjet printing has the capability to precisely deposit material layer by layer in order to build 3D objects. Many physical objects have been fabricated by 3D inkjet printing [3], but only a few RF devices have been fabricated. These include reflectors and lenses [4,5]. Recently, 3D inductors and capacitors have also been developed using inkjet printing [6]. 3D inkjet printing technique can also prove to be useful for developing the packages for electronic systems. Therefore, combination of 2D and 3D inkjet printing techniques can enable the development of

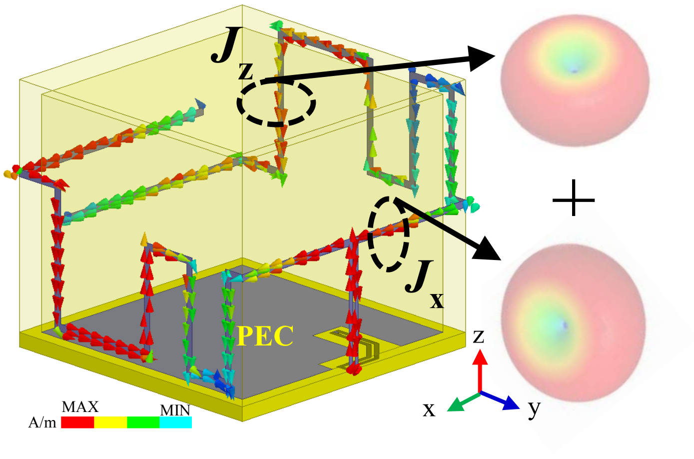


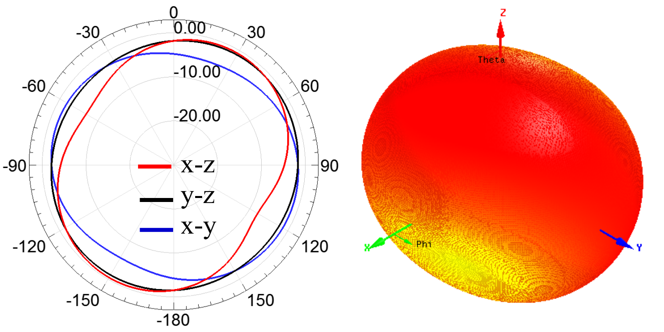
Fig. 1. Proposed 3-D antenna with current distribution, showing how radiation from current elements in different directions add up to give a near isotropic pattern

completely integrated, packaged wireless sensor systems.

This work demonstrates for the first time, a fully inkjet printed 3D near isotropic antenna using a unique combination of 2D metal inkjet printing and 3D dielectric inkjet printing. The cube shaped antenna can house wireless electronics inside for application in wireless sensor network

2. Antenna Design and Fabrication

The antenna comprises a novel 3-D implementation of a 1.5λ_0 dipole on a cube structure as shown in Fig. 1. The dipole has been wrapped on a cube of dimensions 2 cm x 2 cm x 2 cm. Since the embedded circuits are mostly metallic, a perfect electric conductor (PEC) has been included in the simulation to model the effect of circuits on the antenna. To fit the antenna on the cube surface, meandering has been done. Since meandering can cause cancellation of radiated fields, care has been taken that the meandered portion carries minimal current so as to have least effect on the radiation efficiency [7], as visible in Fig. 1 which also shows the current distribution on the antenna. The antenna impedance has been optimized to conjugately match the driving circuit impedance which mainly consists of a transmitter without the need of any external matching circuit elements. The impedance of the dipole can be changed by varying the width of the wire and the width of the dipole has been chosen to be 0.5 mm in order to have the required impedance.



(a) (b)

Fig. 2. (a) Radiation pattern in x-y, x-z and y-z planes (b). 3D radiation pattern.

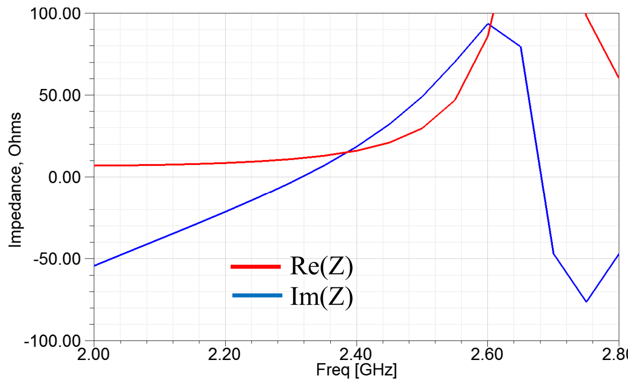


Fig. 3. Simulated antenna impedance

In order to illustrate the mechanism to achieve near isotropic radiation pattern from the antenna, the currents along the z- axis, J_z, and the x-axis, J_x are shown in Fig. 1 along with their associated radiation patterns. J_x produces an omnidirectional radiation pattern along y-z plane with nulls on the x-axis. Although, J_z is changing directions, it can be seen that the stronger currents are flowing in the same direction and will radiate in an omnidirectional pattern in the x-y plane with null on the z-axis. The patterns from these individual current elements add up to make a near isotropic pattern with minimized nulls. The antenna is fed by a coplanar strip line which extends from the circuit to the outside of the cube structure.

The cube structure is 3D printed using Stratasys® Objet260 Connex 1 3D printer. The printer uses Vero Black Plus proprietary material from Stratasys® that has a dielectric constant of 2.8 and loss tangent of 0.02. After 3D printing of the cube, the metal is inkjet printed using Dimatix® DMP-2831 materials printer. Silver organo-complex ink that has been developed in-house is used for printing the metallic traces of the antenna. 6 layers of ink are printed to achieve a conductivity of around 0.3 Ω /square. After printing of each layer, the traces are heated at about 80 ^{0}C for 5 minutes in order to evaporate the solvent in the printed ink.

3. Simulation and Results

Simulation has been carried out using Ansys® HFSS software. Fig. 2 shows the radiation patterns of the antenna in the x-z, y-z and x-y planes as well as the 3D pattern. There is very little variation in the gain along y-z plane. The larger variation in the x-z and x-y plane is probably due to the meandering of dipole which affect the radiation in these two planes. The simulated radiation pattern of the antenna shows a maximum gain of about -0.4 dBi which is close to that of an isotropic radiator (0 dBi gain), and the maximum variation in gain in any direction is around 8 dB. The 3D printed antenna, therefore exhibits a near isotropic radiation characteristics. The cross- polarization levels are 10 dB below the co-polarization levels in any direction.

The simulated impedance of the antenna is shown in Fig. 3. The impedance curves are close to the required impedance for matching the transmitter at 2.4 GHz. Although the impedance is varying with frequency, the bandwidth required for wireless sensing applications is typically small (few hundreds of kHz), so this changing impedance should not be an issue.

4. Conclusion

A 3D printed cube antenna design has been demonstrated comprising a dipole uniquely oriented on all the faces of a cube to achieve a near isotropic radiation pattern. The antenna is realized entirely by low cost additive manufacturing. Results show that the performance of the antenna is not affected by the presence of embedded electronics inside the cube. Hence, this antenna can be extremely useful for wireless sensing applications where it can also act as a functional package for sensor circuits.

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