Inkjet-Printed Planar Antenna for a Wireless Sensor on Paper Operating at Wi-Fi Frequency

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Abstract—**Organic substrates is one of the leading solutions to realize ultra-low-cost and "green" wireless sensor applications. Inkjet printing on paper would be particularly economically appealing if commercial antennas could be replaced with printed antennas with similar performance. This paper presents the replacement of an inkjet-printed, planar, inverted-F antenna (PIFA) for a conventional commercially available, three dimensional (3D) monopole used in a Smart Wireless Integrated Module (SWIM). Both the sensor layout and PIFA antenna are inkjet-printed on paper substrate, in a first successful step towards the implementation of a fully operational, fully planar wireless sensor on paper at Wi-Fi frequency (2.4 GHz).**

I. Introduction

Recent research in printed electronics has revealed the potential of System-on-Package (SoP) solutions on organic substrates applied to wireless sensors networks (WSNs) [1][2], Ultra Wide Band (UWB) modules [3], wireless transmitters using embedded passives on organic substrates [4], and even miniature biomedical sensors [5] among others.

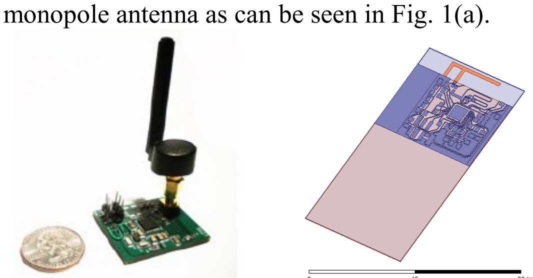
Organic substrate packaging brings benefits to engineers such as the advantage of using paper as a substrate for SoP solutions. Paper is one of the cheapest organic materials available and in addition it is recyclable [6]. Remarkably, it allows inkjet printing, a fast prototyping and packaging technique which is similar to the one found in residential printers, but that is being refined and optimized with more capable printers in laboratories so that it can be applied to circuits [1].

In terms of low-cost packaging, and the need for low profile transceivers, inkjet printing on paper could be particularly appealing if three dimensional antennas could be replaced with planar, printed antennas. This paper presents the replacement of a commercial 3D monopole antenna, operating at 2.4 GHz, and used in a Smart Wireless Integrated Module (SWIM) [7], with a printed planar inverted-F antenna (PIFA) antenna.

II. Antenna Design and Sensor Module

The printed PIFA antenna was designed for SWIM, the first 2.4GHz SoP wireless sensor node design on paper. SWIM is based on a system-on-chip (SoC) tailored for IEEE 802.14.4 and ZigBee applications. An analog temperature sensor on the SoC can be configured to read and broadcast sensor readings wirelessly. A matching network described in [8] consisting of three inductors and one capacitor was used to match the differential impedance of the RF module to a 50 Ω antenna. Additional components of the SoP include loading capacitors for the crystal oscillators, decoupling capacitors, and resistors for the RF module and oscillator(s) current reference.

SWIM was previously designed in Altium Designer and a prototype was realized and tested successfully in FR-4 using a 3D monopole antenna as can be seen in Fig. 1(a).



(a) (b)

Figure 1. SWIM module on (a) FR-4 with 3D antenna, and (b) on paper with printed antenna in HFSS

The traces of the paper-based module had to be re-designed considering the fabrication limitations of current inkjet printing technology. In addition to the 3D antenna which was replaced, the sensor layout had to be redesigned by making the printed traces 100µm thinner than on the FR-4 prototype. This was necessary because the silver ink used in SWIM expands approximately by 100µm after it is printed. The Gerber file of the paper-based sensor module layout was created in Altium and then imported into HFSS for the design and integration of the planar PIFA antenna. The PIFA was matched to 50 Ω and was designed using full wave simulation with the entire layout modeled as perfect electric conductor (PEC) in HFSS as seen in Fig. 1(b) and Fig. 2.

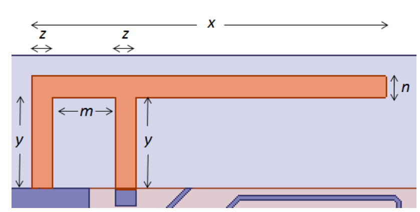


Figure 2. PIFA antenna schematic

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The paper substrate used was 0.5 mm thick, with a dielectric constant of, εr=3.3, and a 0.07 tangent loss (tanδ) [9]. The dimensions of the module and antenna are described in detail in Table I.

TABLE I. ANTENNA CONFIGURATION DIMENSIONS

Part	Dimension
z in Fig. 2 in the short to ground, and n	1.48
y in Fig. 2 in the antenna feed	6.42mm
x in Fig. 2 in the radiating element	25mm
m in Fig. 2 in between short and feed	4.44mm
Top ground plane in Fig. 1(b)	49.3mm x 34.3mm
Bottom ground plane in Fig. 1(b)	49.4mm x 89.32mm

III. RESULTS

The FR-4 prototype shown in Fig. 2 uses a commercial 2.45 GHz 3D monopole antenna with 2.2 dBi peak realized gain, 80% efficiency, and -13 dB maximum return loss.

One of the advantages of the co-design process of the antenna with the integrated layout is the capability to modify and ultimately control numerous unique parameters. The optimization process indicated that the bottom ground plane had the most significant role in the S11 characteristic that is shown in Fig. 3. The reported S11 at 2.45 GHz is better than -18 dB –better than the 3D model's. The ground plane is much larger in the paper-based solution; on paper the bottom ground is 49.4mm x 89.32mm and in FR-4 the ground size is 34.4 mm x 36.42mm. Keeping the ground plane of the paper based module the same size shifts the resonant frequency of the antenna.

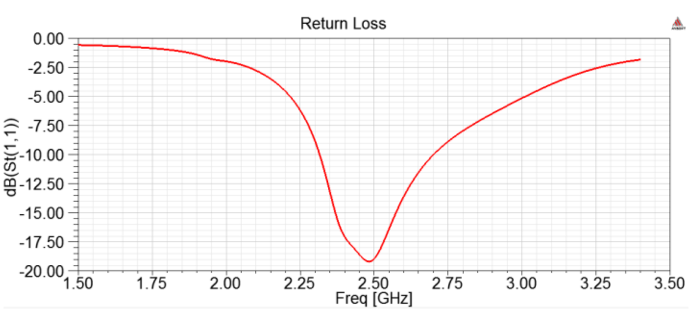
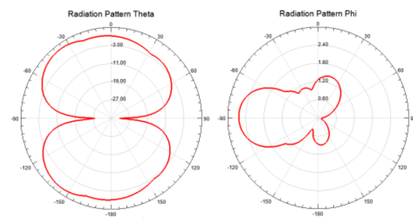


Figure 3. S_{11} characteristic of printed PIFA antenna in HFSS

The radiation patterns that can be seen in Fig. 4 have a fairly omni-directional pattern in agreement with the reported patterns for the FR-4 sensor. Our simulated results showed that the maximum return loss is -19dB, the efficiency is 78%, the back-to-front ratio is 2.2, and the peak realized gain is 2.9 dBi as it can be seen in in Fig. 4.



(a) (b)

Figure 4. Radiation patterns of PIFA peak realized gain (a) theta and (b) phi in HFSS

IV. CONCLUSIONS

The present paper has demonstrated that the implementation of the layout of a commercial sensor on FR-4 with a 3D antenna can be inkjet-printed on paper substrate using a planar PIFA antenna. Despite the need for a larger ground plane the reported planar antenna on paper in combination with the adjusted layout, has better return loss, better gain, wider bandwidth and similar radiation efficiency with the antenna used for the FR-4 module. This work presents the first successful steps towards the implementation of a fully planar, fully operational sensor on paper substrate operating at Wi-Fi frequency.

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