Design, Integration, and Packaging of a Wireless Module for Location Finding and Healthcare Applications

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***Abstract*— This paper presents a solution for a low cost wireless module using a zigbee/IEEE 802.15.4 wireless microcontroller and inkjet printing on low cost substrate for the Radio Frequency (RF) circuit, antenna, as well as printed traces used for signal routing. The simplicity of the design outlined in the paper as well as the fabrication technique used could potentially improve prototyping as well as production techniques for such wireless modules.**

I. Introduction

Flexible electronics are becoming more essential in today's growing market especially in mobile devices and in applications that demand flexibility, light weight, and space savings [1]. Flex electronics also allow the screen printing and more recently the inkjet printing on substrates such as paper and Liquid Crystal Polymer (LCP). These are especially important in communication systems' design where a planar antenna that meets the specifications of a certain application is physically non-realizable, enforcing the utilization of a conformal antenna.

The substrate material and integration techniques are becoming more of a critical materials research topic and that is due to the ever growing demand for low cost, flexible and power-efficient broadband wireless electronics almost in a ubiquitous fashion. This demand may also be further enhanced by the need for inexpensive, reliable, and durable wireless automatic identification (i.e. RFIDs) and communication devices (i.e. mobile Wireless enabled systems).

Inkjet printing technology is a generally fast and predicted to become a lower cost technology than other additive manufacturing techniques, not to mention it's speed and ease of use, that is after establishing a certain printing process specific for the material printed (such as the conductive ink) and the material to be printed on (such as paper). The characterization of inkjet printing has been achieved in [2] and the conductivity of the conductive ink has been observed to vary from 0.4~2.5x107 Siemens/m depending on the curing temperature and duration time.

In this paper a system level solution for an integrated wireless sensor module on flexible substrate is described. The outcome is an in house system on (flexible) package operating at 2.4 GHz (zigbee or zigbee PRO). A system-on-chip commercial solution is used as the wireless microcontroller that is interfaced through a 4Mbit flash memory and off chip components; mainly decoupling capacitors and a 32 MHz crystal for the operation of the wireless microcontroller, and finally a single coin lithium cell battery. The packaging substrates used are: Liquid Crystal Polymer (LCP) as well as paper. LCP as a substrate offers a unique, low-cost, all-in-one solution for high frequency designs due to its low loss, near hermetic characteristics as a packaging substrate, mechanical flexibility, and thermal stability which are excellent specifications for several applications such as wireless sensing, automotive, and space [3]. Paper on the other hand offers a more low cost solution and has been demonstrated for good printing resolution and RF performance [2].

The application features a demonstration of indoor location finding targeting healthcare and hospitals. This choice of application is also backed up by the fact that the Zigbee Alliance and the Continua Health Alliance announced a liaison agreement to expand their relationship and collaborate further on defining interoperable communication standards for personal health solutions based on low-power wireless local area networks (WLANs) [4].

Previous work features inkjet printing of circuit and microwave structures on paper-based substrates in the implementation of a complete low-cost wireless transmitter for sensors at 915 MHz [5]. In the previous work, the system-level design of the module including the amplifier characterization were carried out to ensure optimum performance of the sensor modules in the UHF bands used in RF identification communication. These results were then used to design two different antenna structures; of these two the smaller one that uses a dipole configuration for the radiator is shown in Fig. 1. These transmitter modules were then printed on paper along with their respective circuit layouts using inket-printing technology. Different techniques were investigated for the assembly of circuit components on the silver printed layouts. Finally, wireless link measurements on the assembled prototypes verified the good performance on the wireless and sensing sides.

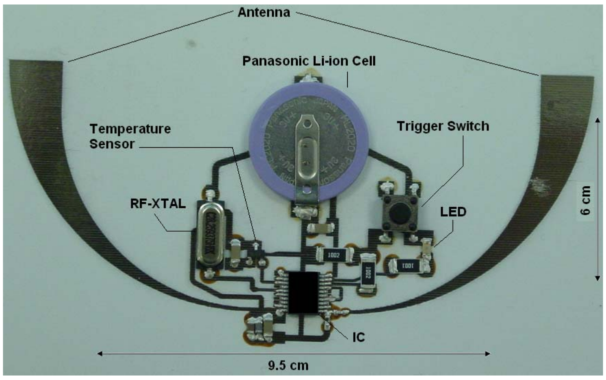


Fig.1: Previous work [5] showing wireless-sensor transmitter prototype on a paper substrate, using inkjet-printing technology [dimensions: 9.5 cm x 6 cm].

This work is a continuation and enhancement of the previous work in several methods. First and foremost in order to build a transceiver module for sending/receiving at 2.4 GHz and using Zigbee Network, a low cost but higher quality (lower loss) substrate is used. This is where the choice of LCP comes in. Second, unlike previous work that only included a transmitter module and an off-chip temperature sensor, this work demonstrates a packaging solution for a 56 pin QFN configuration system-on-chip wireless microcontroller with a built in temperature sensor leading to several orders of magnitude in resolution improvement of the inkjet printing. Third, the module's overall dimensions are smaller of that shown in Fig. 1, and if packaged in the proper manner will be conveniently utilized in small compartments.

II. Design and Fabrication of Wireless Module

Fig. 2 shows the suggested outline for the entire module on LCP or paper substrate. Fig. 3 shows the simulation layout; specifically speaking it is showing a snapshot taken from the HFSS simulation used. A differentially fed Antenna is interfaced to the chip through one of its 56 pins [6] on the top layer as depicted in Fig. 3. IEEE802.15.4 standards define (in the 2.4 GHz band) 16 ZigBee channels, with each channel requiring 5 MHz of bandwidth, and so an 80 MHz operational bandwidth is required for this Antenna. Fig. 4 shows the S_{11} plot for the antenna on a 4 mils (~100 um) thick LCP or 10 mils (~250 um) thick paper substrate covering well above the required bandwidth as described by the -10 dB line. It is to be noted that the data shown in Fig. 4 takes into consideration the simulation of the entire module as shown in Fig. 3, where the black color represents the integrated antenna configuration while the grey represents the circuit layout used for signal routing plus their ground (DC ground). Furthermore, the simulation assumes a matching network consisting of an LC circuit in order to create a 50 Ohm match.

Fig. 5 shows the directivity of the antenna at 2.4 GHz indicating good coverage for location finding applications.

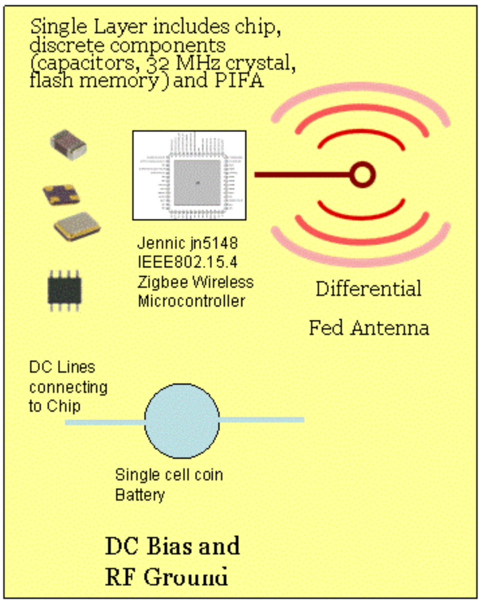


Fig.2: Suggested Outline for the wireless module.

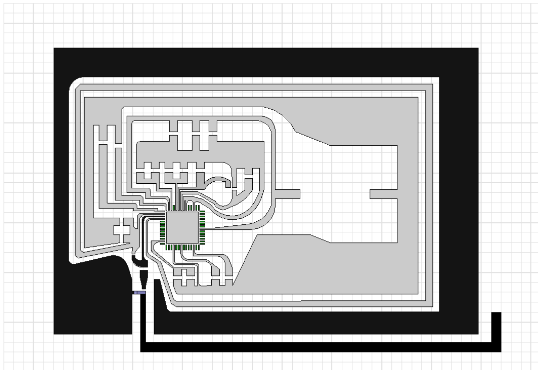


Fig.3: Simulation Layout for the wireless module [dimensions 8.5 cm x 5.5 cm].

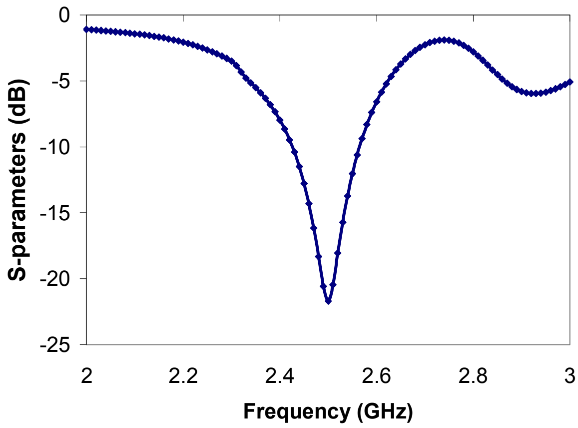


Fig.4: S11 for the antenna plus module.

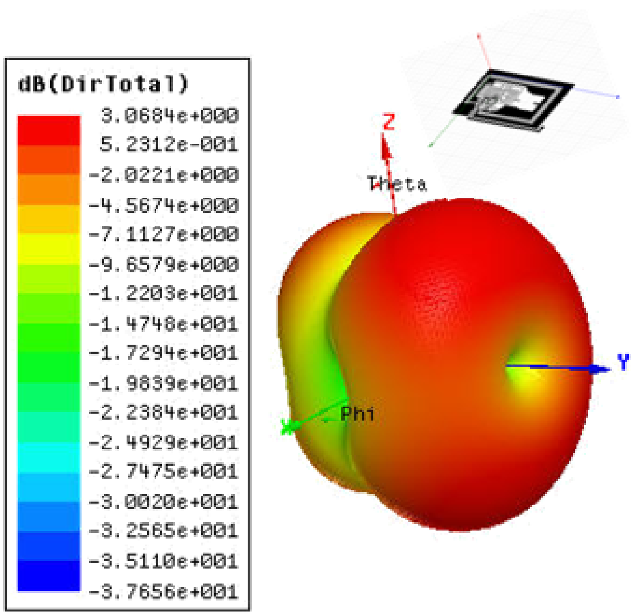
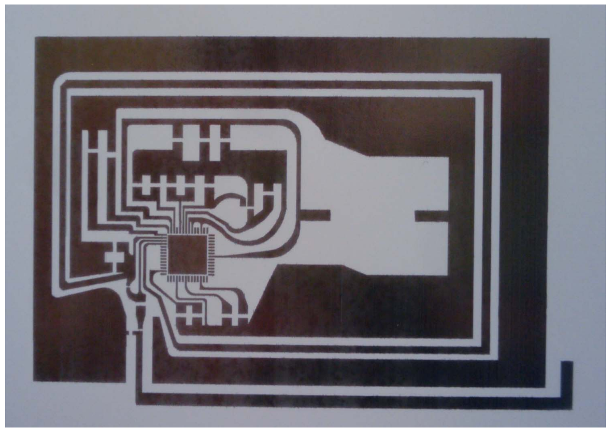


Fig.5: Directivity of the antenna simulated at 2.4 GHz.

The module was then inkjet printed on paper and LCP substrates. This required very precise and detailed settings that are different for each substrate. This is due to the differences in cohesive properties of the substrate material. The smallest dimension that was inkjet printed is ~125 um and pertains to the gaps/traces of the QFN package wireless zigbee microcontroller. The photos of the two inkjet printed samples are shown in Fig. 6.

III. Conclusions/ Future Work

A system level solution for an integrated wireless sensor module on flexible substrate has been described. A layout has been generated and simulated for optimum operation at 2.4 GHz zigbee channels. This work aims to demonstrate a novel lightweight wireless sensor module operating at 2.4 GHz Zigbee Network and the assembly of the circuit components is underway. Those results/findings will be presented at the conference.


(a)

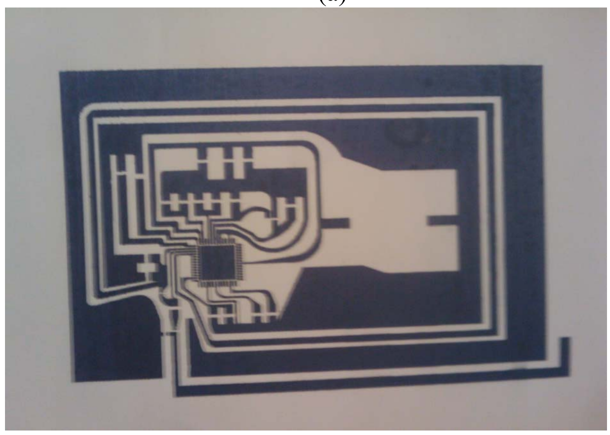

(b)

Fig. 6. Photograph of the inkjet printed wireless module on (a) paper substrate and (b) LCP substrate.

References

[1] M. Mantysalo, P. Mansikkamaki, J. Miettinen, K. Kaija, S. Pienimaa, R. Ronkka, K. Hashizume, A. Kamigori, Y. Matsuba, K. Oyama, N. Terada, H. Saito, M. Kuchiki, and M. Tsubouchi, "Evaluation of Inkjet Technology for Electronic Packaging and System Integration" in *57th Electronic Components and Technology Conference*, 2007, pp: 89-94.

[2] L. Yang, A. Rida, and M.M. Tentzeris, *Design and Development of Radio Frequency Identification (RFID) and RFID-Enabled Sensors on Flexible Low Cost Substrates* Synthesis Lectures on RF/Microwaves #1, Morgan and Claypool Publishers, 2009.

[3] D. Thompson, O. Tantot, H. Jallageas, G. Ponchak, M. M. Tentzeris, J. Papapolymerou, "Characterization of LCP material and transmission lines on LCP substrates from 30 to 110GHz," *IEEE Trans. Microwave Theory and Tech.*, vol. 52, no. 4, April 2004, pp. 1343-1352.

[4] Zigbee Supports Healthcare Networks, Microwaves and RF, online article, October 8, 2009, available URL: http://mwrf.com/Article/ArticleID/21946/21946.html

[5] R. Vyas, V. Lakafosis, A. Rida, N. Chaisilwattana, S. Travis, J. Pan, and M.M. Tentzeris, "Paper-Based RFID-Enabled Wireless Platforms for Sensing Applications" *IEEE Transactions on Microwave Theory and Tech.*, vol. 57, no. 5, May 2009, pp. 1370-1382.

[6] Jennic IEEE802.15.4 Wireless Microcontroller Datasheet: JN5148-001 Preliminary, Available URL: http://www.jennic.com/files/support_files/JN-DS-JN5148-1v