Fully Inkjet-Printed Multilayer Microstrip Patch Antenna for Ku-Band Applications

Jo Bito, Bijan Tehrani, Benjamin Cook, Manos Tentzeris
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA Unites States of America
jbito3@gatech.edu

***Abstract*—A fully inkjet-printed multi-layer microstrip patch antenna with a CPW to microstrip line transition is designed and demonstrated for the first time in this paper. Both metallic layers and SU-8 substrate are fabricated with an additive inkjet printing process. The patch antenna is designed to operate at 14 GHz, and the operation of the antenna is confirmed in measurement validating that fully additively-processed RF devices are a new option for post processing RF devices with substrate independence.**

I. Introduction

The inkjet printing technology for circuit fabrication has been rapidly obtaining focus of electronic device fabrication community over the last decade. By utilizing a fully additive process with micron-scale droplets of specialized inks onto different types of substrates it is becoming possible to replace the conventional circuit fabrication process which requires clean rooms with new fabrication processes. The new fabrication method can create complex electronic structures with low cost, fast and environmentally preferable process. It has been already reported that multilayer passive RF components, microfluidic structures, and high-gain millimeter-wave antenna arrays can be achieved by utilizing conductive silver nanoparticle-based ink and dielectric polymer-based ink [1]-[3]. However, fully inkjet-printed RF devices, where the metallization layers and microwave substrate are printed in a single integrated process have yet to be demonstrated. By removing the need for RF laminates, fully-printed multi-layer RF devices can be demonstrated on top of Silicon RF devices, flexible substrates, and disposable organics with a low independence on the properties of the host substrate.

There are a couple of examples of inkjet-printed electronics on top of different types of substrate such as paper, glass and LCP with the conductive silver nanoparticle ink. However, there still be the room for improvement to achieve better parameters as off the shelf circuit components only with inkjet printing technology. In the past research of printed antenna, commercially used circuit board and paper are utilized as substrate [3]. On the other hand, the first fully additive, multi-layer patch antenna including both circuit pattern and substrate is printed on 5cm by 7cm base glass substrate in this paper. The antenna is designed to operate at Ku-band (14 GHz). The fully printed antenna consists of the following layers. The RF ground plane is printed directly on glass. On top of it, about 40um thick dielectric substrate is printed using a customized dielectric ink which can print layers over 20 times thicker than previously demonstrated dielectric inks [3]. Finally on top of the printed SU-8 substrate the microstrip fed patch antenna is printed with conductive silver nano-particle ink. This achievement suggests the possibility of making microwave electronic elements, such as RF passive components and filters only with inkjet printing processes.

II. Fabrication Process

The vertically-integrated inkjet fabrication process utilizes a piezoelectric drop-on-demand inkjet system, Dimatix-2831 (www.dimatix.com), provided by Fujifilm. The silver nano-particle ink used to print the patch antenna and the ground plane is ANP Silverjet DGP-40LT- 15C (ANP Corporation, Sejong-si, South Korea), which contains 30-35 w% silver nanoparticles dispersed in a TGME (triethylene glycol monoethyl ether) solvent. This ink has a viscosity of 10 cP and a surface tension of 35 dyn/cm. Once the metallic patterns are printed, the metallic ink is sintered in a thermal oven at 180 °C for one hour, yielding thickness of 800 nm per layer with a specific resistivity of 11 μΩ-cm.

The dielectric ink used to pattern insulating layers is a long-chain polymer ink formulated to produce dielectric layers with thickness more than 100 μm, while also maintaining desirable surface properties that allow printing of silver nanoparticle ink [3]. The polymer ink is a formulation of 35 w% SU-8 polymer (MicroChem, Newton, MA, USA) in cyclopentane with a UV-cross-linking agent, yielding an ink with a viscosity of 13.4 cP and a surface tension of 30 dyn/cm. Once printed, the dielectric ink is heated to 120 °C for 10 min before being exposed to a thickness-dependent amount of 365 nm UV light, followed by a post exposure bake at 120 °C for 5 min, yielding layer thicknesses from 4 to 6 μm.

III. Patch Antenna Design

As one of the applications of vertically-integrated, fully inkjet-printed microwave structure, a patch antenna operating at 14 GHz (Ku-Band) is designed and fabricated on a printed SU-8 substrate which has relative permittivity of 2.7 and loss tangent of 0.04 at 10 GHz [1]. The thick SU-8 substrate which has averaged thickness of 40 um is fabricated by printing 7 layers of SU-8. The frequency is picked up to satisfy the size restriction of the glass substrate under the printed structure. In order to achieve the transition from CPW for 500um pitch GSG probe to a microstrip line which is required for a measurement with a feasible microstrip line width and CPW gap, the thickness of SU-8 is selected. The design of the patch antenna and the CPW-to-microstrip line transition and printed patch antenna are shown in Fig.1. The physical dimension of the patch is 6.3 mm by 6.3 mm square shape [4]. The width of microstrip line is 0.23 mm and the width of the gap of CPW is 0.10mm.

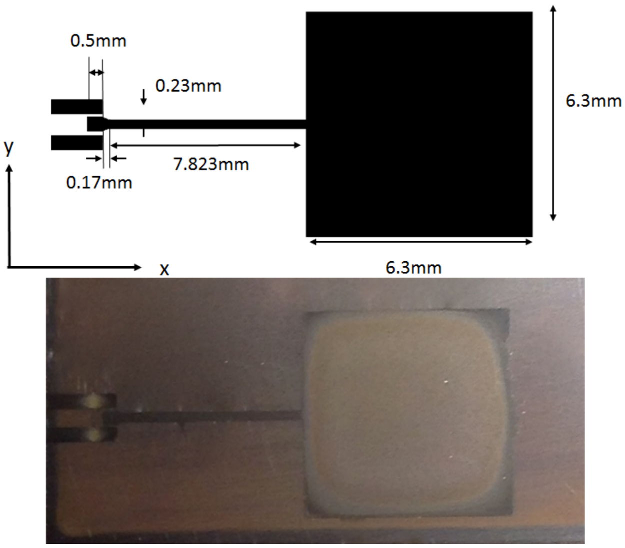

Fig. 1. Physical dimention of patch antenna and CPW to microstrip line transition structure and printed antenna.

IV. MEASUREMENT RESULT

In order to specify the reflection coefficient of the patch antenna, a 37369A vector network analyzer provided by Anritsu was utilized. The measurement and the simulation results are shown in Fig. 2.

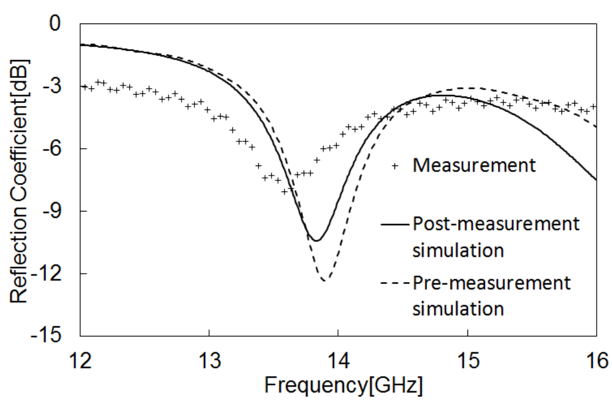

Fig. 2. Measured and simulated reflection coefficient (S_{11}) of the fully inkjet-printed patch antenna.

A 3D full wave simulator, CST 2013, is used to design and simulate the antenna. The peak value of measured return loss of -8.07dB is observed at 13.58 GHz, and the peak value of simulated return loss of -10.3dB is observed at 13.85 GHz. The peak frequency of measurement and simulation is quite well matched. However, there is difference in minimum reflection coefficient values, and this mismatch can be overcome with the further characterization of printed dielectric material. The normalized E-plane and H-plane of the patch antenna is shown in Fig.3.

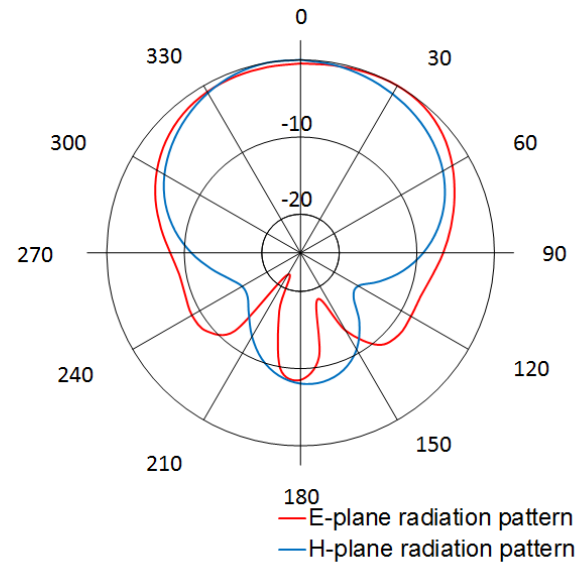

Fig. 3. Normalized E-plane and H-plane radiation pattern of printed patch antenna.

V. CONCLUSION

In this paper, first fully inkjet-printed multilayer microstrip patch antenna designed for 14 GHz is printed on 50 µm thick SU-8 substrate with conductive silver nano-particle ink is demonstrated. It provided the vertically-integrated inkjet fabrication process can be applied for the fabrication of antenna which is one of the most popular microwave structures. This suggests the possibility of this technology for further application such as fully printed RF passive components and filters for ultra-low cost sensor network and mobile communication devices.

REFERENCES

[1] Cook, B.S.; Cooper, J.R.; Tentzeris, M.M., "Multi-Layer RF Capacitors on Flexible Substrates Utilizing Inkjet Printed Dielectric Polymers," *IEEE Microw. Wireless Compon. Lett.,* , vol.23, no.7, pp.353-355, July 2013.

[2] Cook, B.S.; Cooper, J.R.; Tentzeris, M.M., "An Inkjet-Printed Microfluidic RFID-Enabled Platform for Wireless Lab-on-Chip Applications," *IEEE Trans. Microw. Theory Techn.* vol.61, no.12, pp.4714-4723, Dec. 2013.

[3] Cook, B.S.; Tehrani, B.; Cooper, J.R.; Tentzeris, M.M., "Multilayer Inkjet Printing of Millimeter-Wave Proximity-Fed Patch Arrays on Flexible Substrates," *IEEE Microw. Wireless Compon. Lett.*, vol.12, no., pp.1351-1354, 2013

[4] C.Balanis,AntennaTheory.:Wiley,1997,ch.11,pp.569-588.