Integrated Antenna with Inkjet-Printed Compact Artificial Magnetic Surface for UHF Applications

George Shaker [(1)], Hoseon Lee* [(2)], Kate Duncan[(3)], and Manos Tentzeris[(2)]
(1) University of Waterloo, Waterloo, Ontario, Canada
(2) Georgia Institute of Technology, Atlanta, GA, USA
(3) US ARMY, CERDEC S&TCD, Ft. Monmouth, NJ, USA

Introduction

An antenna integrated with a compact engineered surface encompassed of inkjet-printed split ring resonators is presented. The engineered surface behaves as an artificial magnetic conductor thus enabling a low profile antenna design. Inkjet-printing of silver nano-particles on paper substrates facilitates the realization of low-cost light-weight prototypes that are desirable in many real-world applications.

Inkjet Printing on Paper

Inkjet printing of conductive inks on paper sheets enables the realization of low-cost environment-friendly light-weight antennas. Paper possesses a number of intriguing attributes that makes it appealable for low-cost "green" electronics. It is one of the most abundant manmade materials which is truly ubiquitous in modern society. It is cellulose in nature, thus considered as a renewable resource. Additionally, paper can be easily processed in a reel-to-reel fashion enabling low-cost manufacturing solutions. Driven by the fact that it is challenging/cost-inefficient to apply photolithography techniques to paper, inkjet printing of conductive particles provides a promising solution [1]. It is widely known that one of the most common methods of digital printing is through inkjet printers. These printers are now widely used in consumer market, whether in home or at office. Interestingly, inkjet printing has been recently utilized in printing various functional materials, such as conductive inks. It has grown to be a viable technology for use in printed electronics such as flexible displays, RFIDs, sensors, solar panels, fuel cells, batteries, and most recently in antennas. Inkjet printing for RF applications is a challenging endeavor, where precise control on the achieved conductivity and surface roughness are needed. In this work, the Dimatix DMP-2800 printer (www.dimatix.com) is used for demonstration purposes. To ensure good RF properties, we have empirically developed an in-house recipe. To ensure good conductivity, the printed conductive ink was treated in a thermal oven for 5 hours at 120°C. The resulting ink thickness -measured using Wyko profilometer, was around 3 μm with a consistent measured conductivity of in the range $9*10^6$ S*m^{-1} - $1.1*10^7$ S*m^{-1}.

Engineered Surface Design

Unlimited Distribution

Artificial magnetic conductors, also known as high impedance surfaces, are structures that are capable of reflected the incident waves at zero reflection phase, unlike metals or any electric conductor that enforces phase reversal for reflected waves. This feature has been studied in the literature thoroughly for its potentials in realizing low-profile antennas. On the other hand, split ring resonators (SRRs) have been considered as means for producing metamaterial surfaces when integrated with a wire medium for applications in the microwave frequencies [2-3]. In this work, we utilize split ring resonators backed by a conductive metal plane to form a high impedance surface. The overall structure is relatively compact. In addition, it has the potential of extending the functionality to multi-band through the addition of multiple SRRs in the middle of the unit cell. Fig. 1 shows the SRR unit cell modeled and optimized for operation at in the low UHF band (300-400MHz) using a finite element solver (Ansoft HFSS). The numerical model accounted for the actual silver ink conductivity $1*10^7$ $S*m^{-1}$. As in [4], the dielectric constant (3.1) and loss tangent (0.06) of a 254micron sheet of paper were used. The unit cell has a size of 150mmX150mm. The SRR structure on paper was backed by a 25mm thick foam layer on top of a metallic ground plane. The resulting reflection phase is also shown in Fig. 1.

Antenna on High Impedance Surface

For demonstration purposes, and to realize a low profile antenna, a 300 mm dipole is placed horizontally 10 mm from a grid of 4X4 SRR unit cells (See Fig. 2). A technique similar to that presented in [5] is used in the design and optimization process. Simulated reflection coefficient and gain values are presented in figures 2 and 3. Note that the traditional placement of a horizontal dipole on metallic plane requires a quarter wavelength separation (187.5mm at 400MHz). This is much larger than the presented structure which has a combined height of 30mm. Measured characteristics of this antenna will be presented at the conference.

Conclusion

A low-profile antenna on HIS/AMC/EBG surface was developed for UHF applications. The surface is inkjet-printed on paper which produces a low-cost, light-weight, and environment-friendly solution. More compact unit cells (and thus smaller overall size) and/or wider antenna bandwidth can be realized using alternative unit cells/antenna configurations as discussed in [5-6].

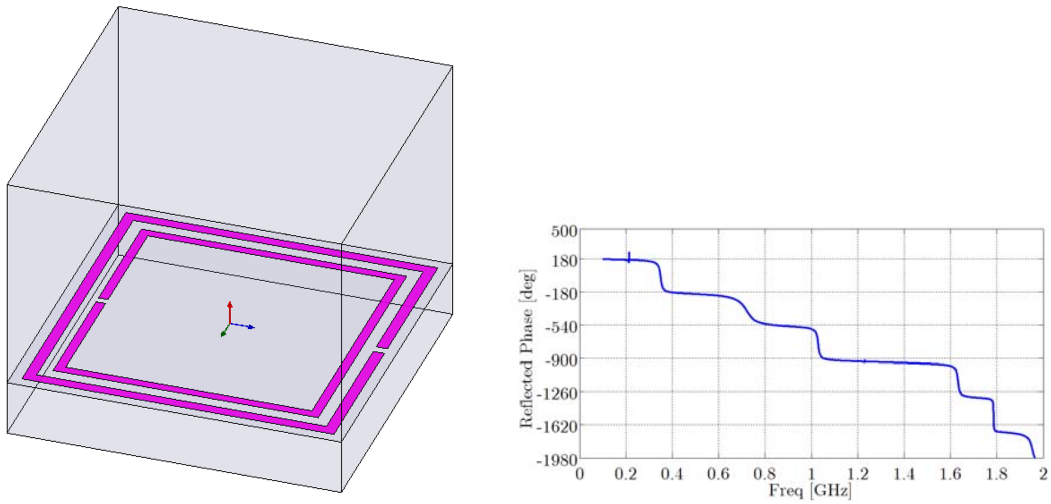

Fig. 1. Split ring resonator unit cell printed on paper, and the resulting reflection phase.

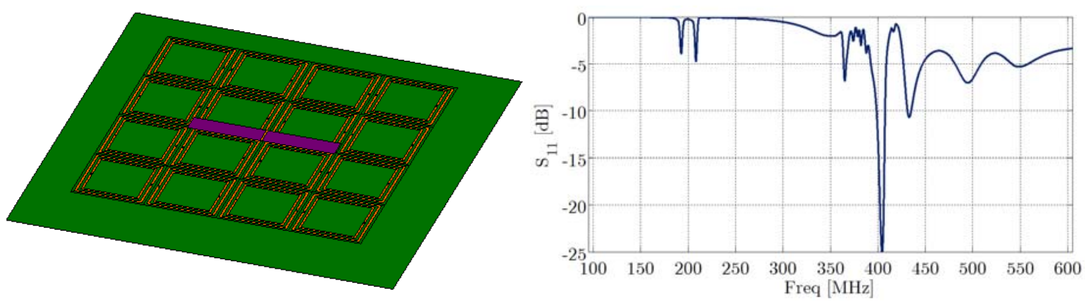

Fig. 2. Split ring resonators (4X4) unit cells forming a high impedance surface. A dipole is placed on the structure (feeding not shown) and the resulting antenna reflection coefficient is plotted.

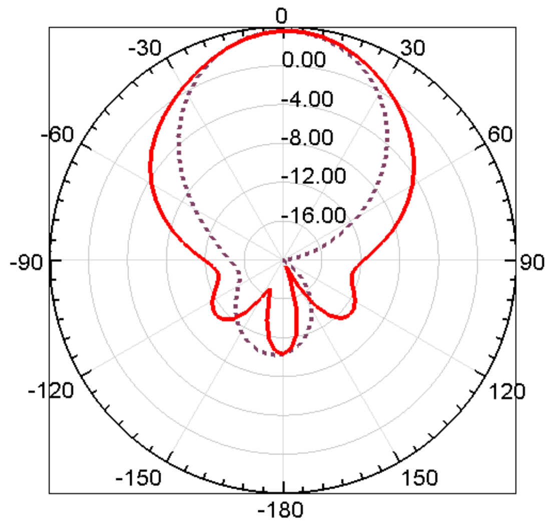

Fig. 3. The resulting gain of the antenna in the two vertical cuts to the HIS surface. A gain of about 3.5dBi is observed at 400MHz.

References:

[1] Mei. J., Lovell, M.R. and Mickle, M.H., "Formulation and processing of novel conductive solution inks in continuous inkjet printing of 3-D electric circuits," *IEEE Transactions on Electronics Packaging Manufacturing*, vol. 28, no. 3, pp. 265- 273, July 2005.

[2] Gay-Balmaz, P, Martin, O.J. F., "Electromagnetic resonances in individual and coupled split-ring resonators," *Journal of Applied Physics*, vol.92, no.5, pp.2929-2936, Sep 2002

[3] Simovski, C.R.; Belov, P.A.; Sailing He; , "Backward wave region and negative material parameters of a structure formed by lattices of wires and split-ring resonators," *IEEE Transactions on Antennas and Propagation,* vol.51, no.10, pp. 2582- 2591, Oct. 2003

[4] Li Yang, Rida, A., Vyas, R., Tentzeris, M.M., "RFID Tag and RF Structures on a Paper Substrate Using Inkjet-Printing Technology," *IEEE Transactions on Microwave Theory and Techniques,* , vol.55, no.12, pp.2894-2901, Dec. 2007

[5] Shaker, G.S.A., Busuioc, D., Safavi-Naeini, S., "Small antenna over an engineered ground plane," 2007 IEEE Antennas and Propagation Society International Symposium, vol., no., pp.4072-4075, 9-15 June 2007

[6] Shaker, George S. A., Safavi-Naeini, S., "Highly Miniaturized Fractal Antennas," 2007 IEEE Radio and Wireless Symposium, vol., no., pp.125-128, 9-11 Jan. 2007