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Fabrication of Wearable Antennas through Thermal Deposition

Jeff Letcher, Dennis Tierney, Haider Raad

Abstract**—**Antennas are devices for transmitting and/or receiving signals which make them a necessary component of any wireless system. In this paper, a thermal deposition technique is utilized as a method to fabricate antenna structures on substrates. Thin-film deposition is achieved by evaporating a source material (metals in our case) in a vacuum which allows vapor particles to travel directly to the target substrate which is encased with a mask that outlines the desired structure. The material then condenses back to solid state. This method is used in comparison to screen printing, chemical etching, and ink jet printing to indicate advantages and disadvantages to the method. The antenna created undergoes various testing of frequency ranges, conductivity, and a series of flexing to indicate the effectiveness of the thermal deposition technique. A single band antenna that is operated at 2.45 GHz intended for wearable and flexible applications was successfully fabricated through this method and tested. It is concluded that thermal deposition presents a feasible technique of producing such antennas.

Keywords**—**Thermal deposition, wearable antennas, Bluetooth technology, flexible electronics.

I. Introduction

TODAY, there is significantly heightened interest in the field of flexible electronics, as well as wireless systems [1]. There is a demand for wearable electronics which can be achieved by integrating an antenna within [2], [3]. The flexibility and compactness of wearable antennas is technologically savvy and is of utmost necessity for our thriving culture. This can be cost-effective and reliable for data connectivity [5]-[8]. The aim of producing thinner and smaller products to accommodate the guidelines for wearable technology requires innovation to satisfy the ever increasing technological pace of our contemporary society. Wearable electronics serve a wide range of application including military, communication, and entertainment [10].

In a previous publication, the authors have proposed an Artificial Magnetic Conductor (AMC) wireless element based on Kapton Polyimide substrate. The design was intended for integration within wearable telemedicine, especially remote health monitoring systems [8]. The main characteristic of the design was its minimized Specific Absorption Rate (SAR) which is of paramount importance to eliminate the hazardous body exposure to electromagnetic waves in applications that are operated on moderate to high power.

Jeff Letcher and Dennis Tierney are with the Department of Physics, Xavier University, 3800 Victory Parkway, Cincinnati, Ohio 45207, USA.
Haider Raad is with the Department of Physics, Xavier University, 3800 Victory Parkway, Cincinnati, Ohio 45207, USA (phone: 513-745-3658; fax: 513-745-3695; e-mail: raadh@xavier.edu).

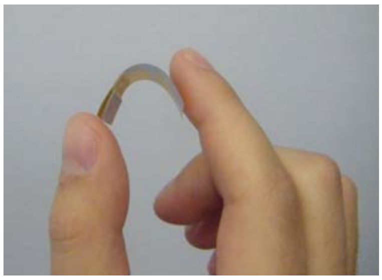


Fig. 1 Wearable inkjet-printed monopole antenna based on a Kapton Polyimide platform

Kapton was identified as the primary antenna deposition film due to its reasonable balance of mechanical and electrical characteristics in addition to its relatively lower loss factor over a large frequency range (tanδ is 0.002 at 2.45 GHz). Moreover, Kapton Polyimide is available at a very low profile (50.8 μm) with a good mechanical robustness and a tensile strength of 165 MPa at 73 °F (compared to 17 MPa for organic paper substrates), a dielectric tolerance of 3500-7000 Volts/mil, and a thermal rating of -65 to 150 °C [9]. However, the antenna reported in [8] is based on multiple layers and is appropriate for high power applications. Also, the antenna is not intended for integration within compact devices due to its relatively large dimensions.

In this paper, we present an ultra-thin/flexible printed monopole antenna for Bluetooth connectivity through the process of thermal deposition. The antenna design is a single band antenna, which is operated at 2.45 GHz, that is compact and suitable for applications of flexibility and commercial wireless connectivity. This is low profile and high performance antenna.

In Section II, we present the description for the fabrication method for our design. In Section III, we discuss the description of the designed 2.45 GHz flexible antenna, describing methodology and fabrication. In Section IV, we discuss the radiation characteristics and performance of the antenna. In Section V, we discuss the surface imaging of the antenna after and before flexing to allow for a comparison of efficiency. Finally, the paper is concluded in Section VI.

II. Antenna Fabrication by Thermal Deposition

In order to fabricate a 2.45 GHz Bluetooth antenna, a technique is needed to be used to produce a product with high material purity and is able to deposit a conductive material on a low profile, compact antenna substrate. Thermal deposition utilizes a vacuum system with a resistive heated boat to deposit a thin-film of source material (copper in our case), on a substrates surface. This resistive heated boat is needed to withstand an electric current in the order of 300-350 A to be able to vaporize copper material. To utilize this technique, a mask is needed to allow the desired antenna pattern to be produced. A 3D printed mask (shown in Fig. 3) was implemented for this specific process due to easy manipulation of measurements as well as reproducibility.

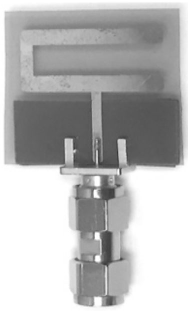


Fig. 2 The fabricated antenna using thermal deposition

Ultimaker 2+ was chosen for the 3D printing system since it exhibits traits of accuracy and speed for the type of masks needed for printing. Material used for printed masks was Polyactic Acid (PLA), which is a plastic filament made from renewable resources. PLA presents high tensile strength of 50 MPa, high melting point specifically for thermal deposition technique melting at 160 °C.

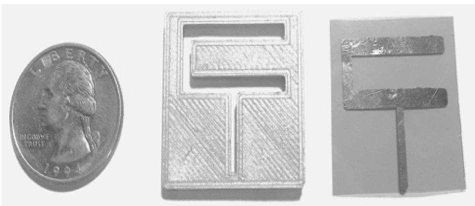


Fig. 3 A 3D printed mask used to produce the desired antenna pattern

Dimensions of the single band antenna and mask are depicted in Table I and Fig. 4.

TABLE I
SINGLE BAND ANTENNA DIMENSIONS IN MILLIMETERS

S_1	12.5	D_1	25
S_2	13.5	D_2	22
S_3	14	D_3	20
S_4	12	D_4	1.5
S_5	6		
S_6	3		

III. ANTENNA DESIGN

The proposed single band antenna is a design created by the co-author of this paper [4], which was fabricated by using the inkjet printing technology. Here, we are adopting the same design as a benchmark to assess the feasibility of the thermal deposition fabrication technique. This design is adopted since it is compact, flexible, and has a high performance radiation property. The printed single band antenna was printed on a dielectric substrate that was chosen to be Polymide Kapton. This substrate displays structural integrity, low loss factor over a wide frequency range and good properties of flexibility. The Kapton substrate chosen provided a thin structure (50.8 µm) that also offered great tensile strength of 165 MPa for flexing properties [9]. This dielectric substrate allowed good adhesion for the vaporized copper material to deposit on.

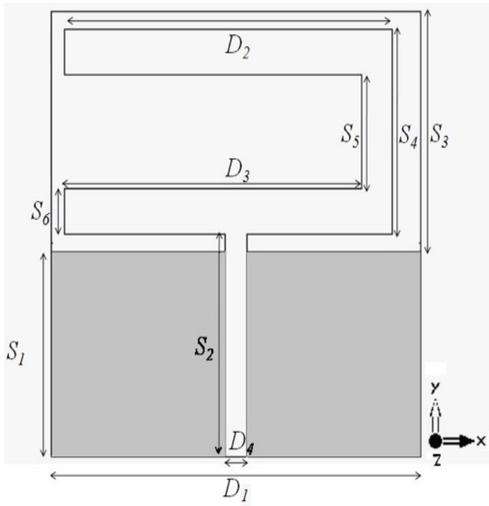


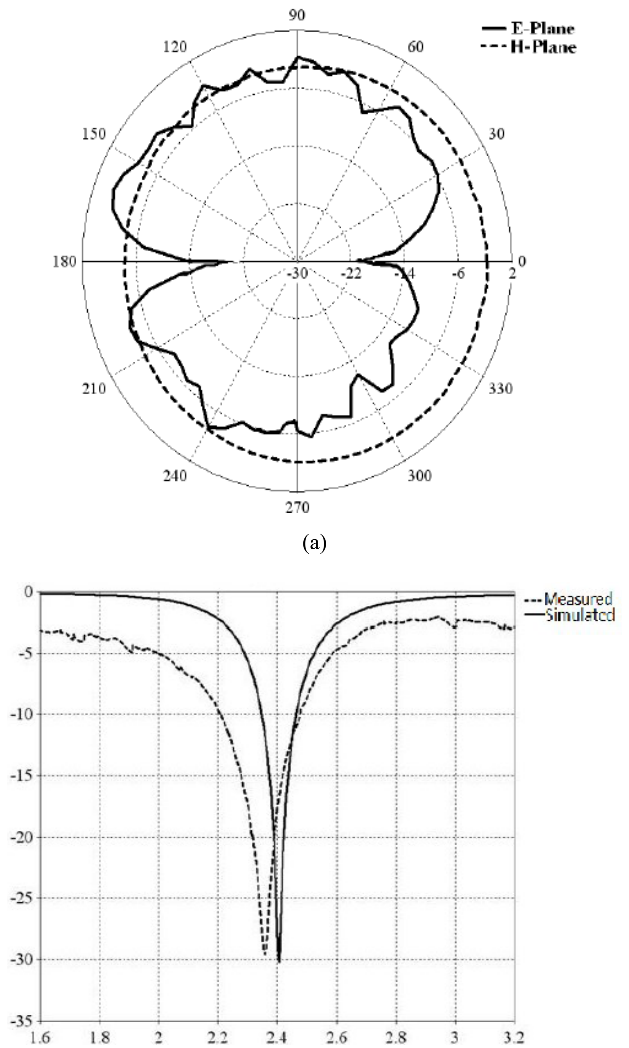
Fig. 4 Geometry and dimensions of the proposed wearable antenna [4]

The proposed antenna by [4] is suitable for Bluetooth connectivity in the 2.45 GHz region. Its u-shaped allows a miniaturization factor with no hindrance of efficiency. The antenna printed through thermal deposition was able to deposit copper material to the specific dimension indicated in Table I, as well as achieving a thickness of copper material of 4.213 k**Å** translating to 421.3 nm.

The polar far-field radiation patterns of the principal planes (E and H) were measured using an anechoic chamber. The Antenna Under Test (AUT) was positioned on an ETS Lindgren 2090 positioner and aligned to a highly directional horn antenna with polarization adjustment capability. E-plane (*YZ* cut) and H-plane (*XZ* cut) far-field radiation patterns for the 2.45 GHz are depicted in Fig. 5. It can be seen that the radiation power is omni-directional at the frequency under consideration. The antenna achieved a measured gain of 1.68 dBi which agrees with the simulated values.

IV. MEASUREMENTS

The measured return loss versus frequency for the proposed single band antenna is depicted in Fig. 6. The measured return loss for this antenna was seen to be -30.58 dB at 2. 20 GHz with a -10 dB bandwidth of 308 MHz. Here, a shift in the resonant frequency is observed due to possible fabrication discrepancies. However, the relatively large impedance bandwidth which extends to 2.52 GHz compensates for the shift.



(a)

(b)

Fig. 5 Measured and simulated E-plane (YZ) and H-plane (XZ) radiation patterns for the printed monopole at 2.45 GHz [4]

Alongside measuring the return loss for the antenna, surface imaging on the deposited material was also carried out. By using a high powered microscope, detailed surface imaging was possible, and we were able to determine discrepancies in the deposition that could contribute to shifts in frequency as well as narrowing or broadening of bandwidth. Fig. 7 depicts an image of the imperfection as well as distinct lines in the deposited material which indicate traits that might have affected the antenna's performance. Through further testing, it turned out that the distinct straight line in Fig. 7 is from the Kapton substrate itself which is translated through the deposition of copper material.

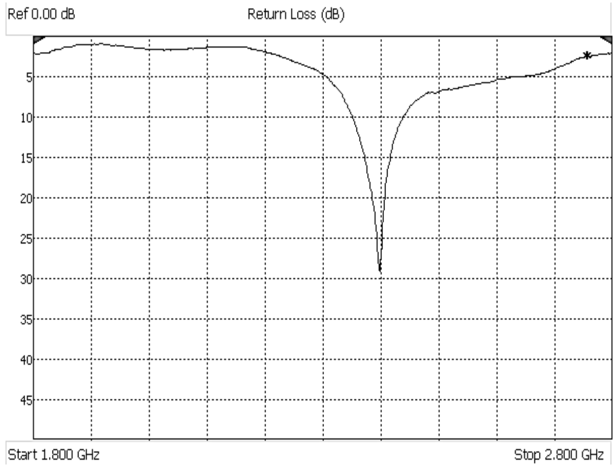


Fig. 6 Scattering parameters of the proposed wearable antenna

V. Comparative Study

The antenna proposed in this paper was compared to different printing techniques including fabrication methods of screen printing and ink jet printing. Given the application envisioned in this paper, the comparative study is focused on electrical properties, efficiency, and flexibility.

The flexible antenna introduced in this paper was fabricated using a pure condensed metal which gives rise to a higher electrical conductivity which in turns allow a higher radiation efficiency [10] compared to the other methods such as inkjet printing and screen printing [11]-[13]. The resulted pattern from thermal deposition introduced a mechanically robust design in addition to a high flexural strength and cost effectiveness.

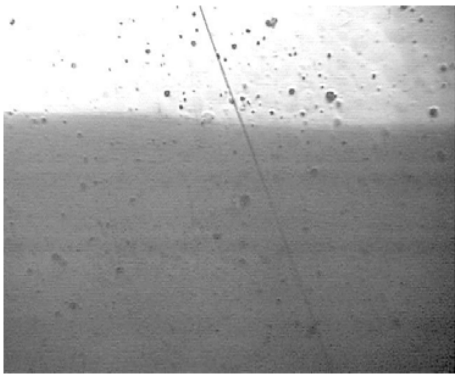


Fig. 7 A surface microscopic image of the fabricated antenna structure

VI. Conclusion

An ultra-flexible/thin printed monopole antenna was presented in this paper which was fabricated through the technique of thermal deposition. The design is a single band antenna which is operated at 2.45 GHz which is suitable for Bluetooth connectivity in wearable applications. Copper material was deposited on a Polyimide Kapton substrate which allowed for flexibility, compactness, and durability. Through a series of testing, it can be suggested that the antenna is suitable to be integrated in flexible and wearable electronics. The technique of thermal deposition represents a viable method of prototyping antennas with the attributes of flexibility and high electrical conductivity which can easily be adapted in wearable devices.

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Jeff Letcher is currently in his last year at Xavier University in Cincinnati pursuing his Bachelors of Science in Applied Chemistry. After graduation, he plans to obtain a Master's Degree in Chemical Engineering. He is presently contributing to the world of Science through his internships. First and foremost, he works with the Biomedical Lab Group Steel, Skeletal Tissue Evaluation Engineering Lab at the University of Cincinnati developing modern CPAP masks for local children's hospitals. In his second internship, he practices his research alongside the engineering Physics department, at Xavier University.

Dennis A. Tierney has been involved in scientific research for 45 years. He has spent the past 30 years at Xavier University Department of Physics in Cincinnati, Ohio as a research technician, supporting a wide range of projects in optics, solid state, and biophysics. He spent four years with Research Dynamics Incorporated doing a variety of projects from tar sands recovery systems research to qualification testing of safety related electrical systems for nuclear power plants. He began his career spending 11 years at Battelle Memorial Institute in Columbus Ohio. Research involving fluidized bed combustion pilot plant systems.

Haider K. Raad received the Ph.D. and M.S. degrees in telecommunication systems engineering from the University of Arkansas at Little Rock (UALR), Little Rock, AR, in 2012 and 2010, respectively; and the M.S. degree in electrical and computer engineering from New York Institute of Technology (NYIT), NY, in 2006, (highest honors). Currently, he serves as a faculty member in the Physics Department at Xavier University in Cincinnati, Ohio, where he also directs the Xavier Wearable Electronics Research Center (XWERC).

Dr. Raad is the author of the best-selling books `Innovation in Wearable and Flexible Antennas` and `Telemedicine: Emerging Technologies, Applications, and Impacts on Healthcare Outcomes`. He has also published several book chapters, and over 75 peer reviewed journal and conference papers on research fields of his interest which include: flexible and wearable antennas; antennas for telemedicine and Wireless Body Area Networks (WBAN), implantable antennas, metamaterials, Electromagnetic Band Gap (EBG) structures, Artificial Magnetic Conductors (AMC), antennas for MIMO systems, and global positioning systems. He is also the recipient of the first place award of the Institute of Engineering and Technology (IET) 2012 Present around the World competition, UALR's Outstanding Teaching Support Award, and AAMI/TEAMS Academic Excellence Award in 2012.