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AN ORIGAMI INSPIRED RECONFIGURABLE SPIRAL ANTENNA

Christy D. Saintsing
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA 30332-250, U.S.A.
csaintsing@gatech.edu

Benjamin S. Cook
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA 30332-250, U.S.A.
bcook40@mail.gatech.edu

Manos M. Tentzeris
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA 30332-250, U.S.A.
etentze@ece.gatech.edu

ABSTRACT

Modern day systems often require reconfigurability in the operating parameters of the transmit and receive antennas, such as the resonant frequency, radiation pattern, impedance, or polarization. In this work a novel approach to antenna reconfigurability is presented by integrating antennas with the ancient art of origami. The proposed antenna consists of an inkjet printed center-fed spiral antenna, which is designed to resonate at 1.0GHz and have a reconfigurable radiation pattern while maintaining the 1.0GHz resonance with little variation in input impedance. When flat, the antenna is a planar spiral exhibiting a bidirectional radiation pattern. By a telescoping action, the antenna can be reconfigured into a conical spiral with a directional pattern and higher gain, which gives the antenna a large front-to-back ratio. Construction of the antenna in this manner allows for a simple, lightweight, transportable antenna that can expand to specifications in the field.

INTRODUCTION

An art form that began in the 17th century A.D. has recently become an inspiration for a new generation of electronics. Origami, the traditional Japanese art of paper folding, has received much attention from the engineering community as a new way to manufacture and implement electronics as it allows for flexibility and adaptability by folding.

There is a growing demand for consumer product miniaturization recently. Space inside devices, such as mobile phones, is becoming increasingly scarce and innovative ways must be created to fit electronics into a compact space. In order to achieve this goal, the effort has traditionally been centered around a reduction in the size of passive components and IC's in both horizontal dimensions as well as height.

Printing on thin flexible substrates such as paper presents another unique opportunity in addition to negating the height of a printed circuit board. Origami's bending and folding of paper has led to an idea that innovative configurations can be constructed allowing further space saving. In [1], conductive ink was utilized on paper in an arrangement such that when folded, an origami swan with LED eyes was created. This demonstrated that circuits can be constructed and the traces folded into unique configurations with the opportunity for space reduction by fitting into spaces with unusual geometries.

This work proposes to take the concept of origami and apply it not just to consumer products, but military applications as well. Modern day systems require flexibility in the operating parameters of transmit and receive antennas, such as the radiation pattern, impedance, polarization, or operating frequency. Historically, several antennas had to be used to accomplish this task, however, recent progress has been made in reconfigurable antennas through the use of moving parts, diodes, switches, and tunable permittivity/permeability materials. Even so, soldiers in the field are still required to carry bulky antenna systems.

Origami is the inspiration for creating a lightweight antenna on a paper based substrate with properties that can be reconfigured by changing the shape of the structure. This type of design would ease the burden for soldiers required to carry the antenna systems by limiting the weight and amount of materials they are required to carry.

The proposed antenna is a center fed spiral antenna, which is designed to resonate at 1.0 GHz and have a reconfigurable radiation pattern while maintaining the 1.0 GHz resonance with little variation in the input impedance. When flat, the antenna resembles an Archimedean planar spiral antenna which exhibits a bidirectional pattern. By freeing the arms of the spiral, and telescoping the antenna from the center, a conical spiral antenna is formed. The radiation pattern becomes increasingly directional in the direction of extension and the antenna exhibits larger gain as it further telescopes. Not only does the antenna allow for reconfigurability, but it also allows for a simple and lightweight method to make the antenna compact during transport, and expand to specifications in the field.

INKJET PRINTING

The interest in inkjet printing for electronics has spiked in the past few years. This new technology is a purely additive process that is safe from the harsh chemicals that are often used in typical manufacturing processes for electronics. The finished product is thin and lightweight, especially if a paper substrate is used. Combine this with the fact that paper is ubiquitous and of a relatively low cost, flexible product can be created. In addition, paper can be disposed of by incineration, thus proving to be easily disposable.

Inkjet printing on substrates to fabricate electronics offers another solution and has recently received much attention from researchers. This technology would allow conductive traces to be printed directly on a substrate and surface mount components [2] to be populated with an adhesive. There has also been research into fabricating passive and active components directly onto the substrate via inkjet printing. [3-6]. The substrates, such as paper, are generally much thinner than the current printed circuit boards in use today, such as FR4.

Figure 1. ARCHEMEDIAN SPIRAL (LEFT) AND AN EQUIANGULAR SPIRAL (RIGHT).

Several antennas have already been fabricated using inkjet printing and published on various substrates including liquid crystal polymer (LCP), paper based substrates, polyester/cotton, and Kapton [7-11]. These applications include RFID, sensor networks, wearable communications, and other wireless applications [12-14]. Inkjet printing allows the antennas to be smaller and easily portable, however, few have utilized the concept of origami in an attempt to make a reconfigurable antenna. One example is a foldable v-shaped antenna [15] which was inkjet-printed onto a substrate the author's called "nanopaper" using silver nanowire ink. The resonant frequency of the antenna was altered by folding the nanopaper which changed the length of the antenna lines.

SPIRAL ANTENNA

Spiral configurations are a popular choice for antennas when a broadband response is desired. They are frequently used in satellite communications, on aircraft for electronic countermeasure, radar, and in GPS applications. Spiral antennas are classified as "frequency independent" antennas, meaning they operate over a wide band of frequencies with little variance in input impedance. By nature, these antennas exhibit circular polarization which is highly desirable to combat changes in polarization that may result in a loss of data if linear polarization were used.

The two most common configurations for spiral antennas are the equiangular spiral and Archimedean spiral. The two types are shown in Fig. 1. From these two basic designs, additional arms can be added, and can be designed as planar, conical, or cavity backed antennas. .For this work, a two armed, center fed, Archimedean spiral antenna is designed.

The highest frequency that can be theoretically achieved by the spiral antenna is proportional to the inner radius. The lowest theoretical frequency is proportional to the outer radius.
The antenna radiates from the region where the circumference is equal to one wavelength. The equation [16] for the highest frequency is given in Eqn. (1) and Eqn. (2) is the equation for the lowest theoretical frequency where c is the speed of light and r is the radius.

$$f_{high} = \frac{c}{2\pi r_{inner}} \tag{1}$$

$$f_{low} = \frac{c}{2\pi r_{outer}} \tag{2}$$

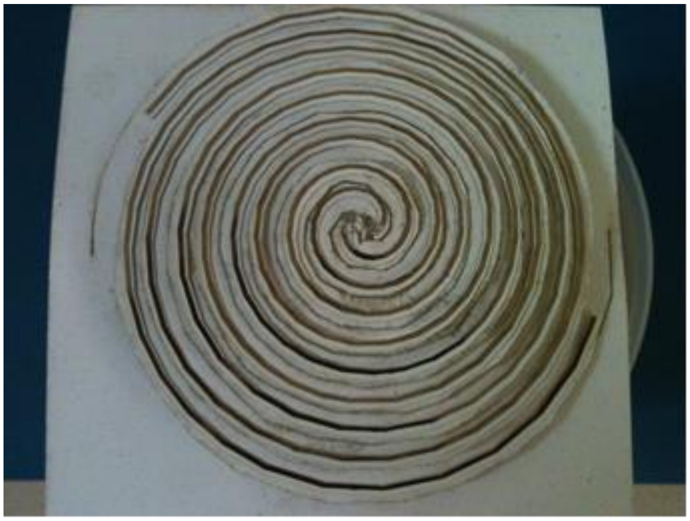

Figure 2. FABRICATED PLANAR INKJET PRINTED SPIRAL ANTENNA.

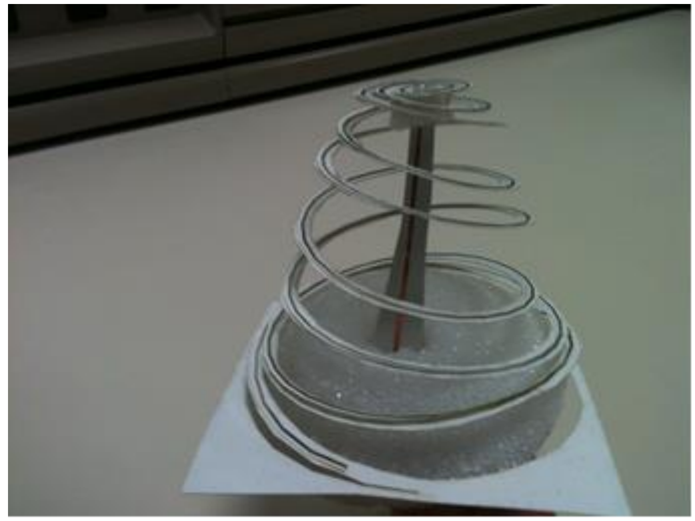

Figure 3. INKJET PRINTED SPIRAL ANTENNA TELESCOPED INTO A CONICAL SPIRAL.

From this description, it is obvious that the antenna can be designed in such a way to be very wideband, however, there are practical limitations to the bandwidth. The main limiting source for bandwidth comes from the feeding system for the antenna, as it is difficult to design a balun with a very large bandwidth. A 50Ω to 220Ω tapered microstrip to parallel strip balun is used in this work.

When initially printed, a planar spiral antenna exists. Once the arms are freed, allowing for a telescoping action, the antenna is transformed into a conical spiral. This adjusts the radiation pattern of the antenna from omnidirectional to directional

ANTENNA DESIGN AND SIMULATION

The spiral antenna was designed to operate at 1.0GHz, which equates to an outer radius of around 48mm. The spiral was simulated in Computer Simulation Technology's (CST) Microwave Studio.

Initially the spiral was simulated in the planar position without a balun and the resonance frequency was found to be around 1.06GHZ with an input impedance of around 250Ω. The S-Parameters were then renormalized to the input impedance. A wide band tapered microstrip to parallel strip balun was constructed to cover the frequency range. This was then simulated in CST and added to the planar spiral.

The simulations were then run for the spiral extended to 2.83cm with the balun. The S_{11} data and radiation pattern were obtained. This was again completed for the telescoped length of 11.31cm. The resonant frequency the various heights remained around 1.06GHz.

SPIRAL FABRICATION

ANP silver nanoparticle ink is printed on photo paper using a Fujifilm Dimatix DMP-2800 inkjet printing platform. A 1mm wide trace is printed using a 25μm drop spacing for both arms of the antenna. One layer of ink is deposited for a height of approximately 1.5μm. The printed antenna is then cured for one hour at 60°C.

A laser cutter is then used to cut a single line through the spiral pattern to free the arms of the spiral so that it may be telescoped. The planar spiral is shown in Figure 2. The spiral can be extended from the center in a telescoping fashion to form a conical spiral. This is shown in Figure 3.

RESULTS

A Rohde & Schwarz ZVA8 vector network analyzer (VNA) was calibrated and used to measure the S_{11} parameter of the spiral antenna with the balun feed system. The extension lengths used for the simulations were also used for the measurements (planar, 2.83cm, and 11.31cm).

S_{11} Simulations and Measurements

The S_{11} parameters were in close agreement for the three telescoped lengths in both simulation and measurements. Figures 4-6 show the simulated and measured S_{11} plots for the planar antenna. As can be seen, the S11stays below -10dB for frequencies greater than 1GHz, as designed. There are some differences between simulated and measured results, which ca primarily be attributed to balun fabrication. Since the balun was constructed by hand, there are tolerance issues with dimensions. In addition to this, the balun was composed of layers liquid crystal polymer (LCP) which were glued together to create the substrate for the microstrips, which can cause air gaps and changes in relative permittivity throughout the balun.

Radiation Patterns

The radiation patterns of the antenna were simulated using CST Microwave Suite. For the planar spiral, the radiation pattern is bidirectional, exhibiting equal amounts of radiation in both lobes. The realized gain was simulated to be 0.873dB.

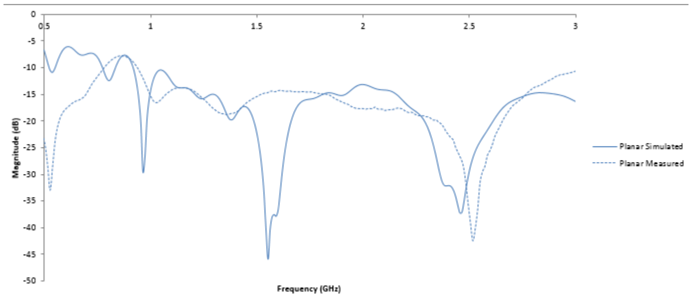

Figure 4. SIMULATED VERSUS MEASURED S11 PLOTS FOR PLANAR SPIRAL ANTENNA.

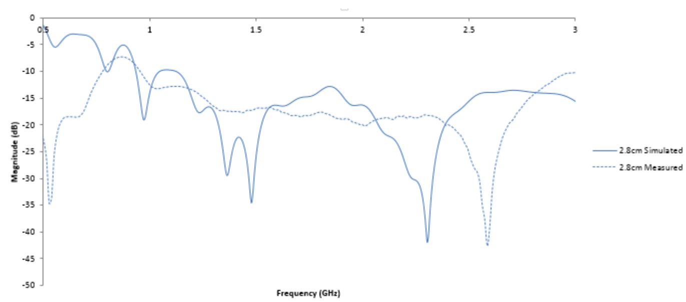

Figure 5. SIMULATED VERSUS MEASURED S11 PLOTS FOR SPIRAL ANTENNA TELESCOPED 2.83CM.

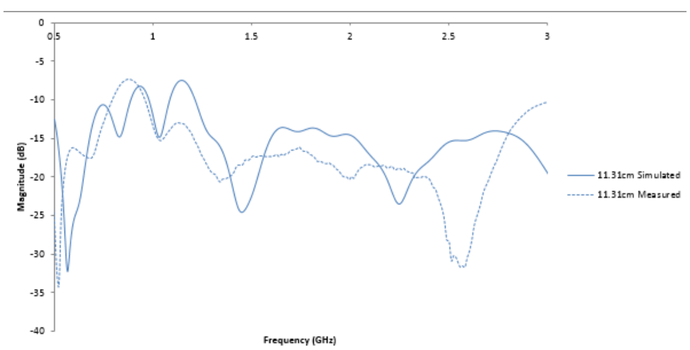

Figure 6. SIMULATED VERSUS MEASURED S11 PLOTS FOR SPIRAL ANTENNA TELESCOPED TO 11.31CM.

As the spiral antenna is telescoped, the gain becomes more directional and exhibits a pronounced main lobe. At an extended length of 2.31cm, the beginning of this pattern can be seen, as the radiation pattern starts to become more distinct in the direction of extension. The realized gain was simulated to be 1.72dB.

This change continues as the antenna is further extended. Again, the directivity is more pronounced at a telescoped length of 11.31cm. A realized gain of 2.37dB was recorded from simulations. The radiation patterns for the different telescoping lengths can be seen in Figure 7.

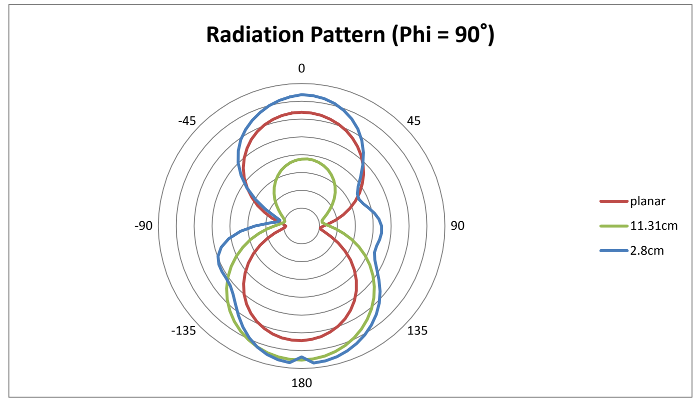

Figure 7. SIMULATED RADIATION PATTERN FOR SPIRAL ANTENNA.

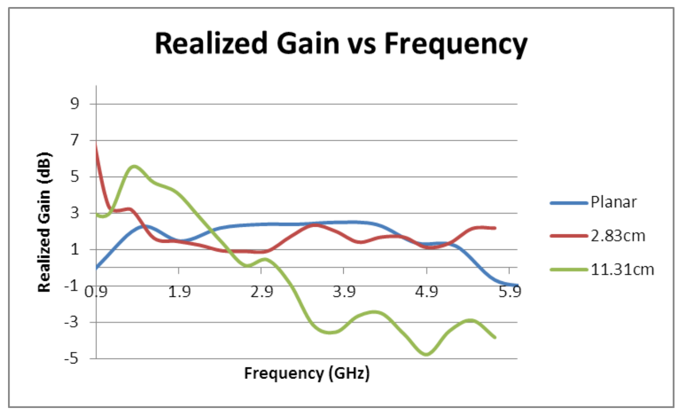

Figure 8. Realized gain versus frequency for the planar spiral antenna and two telescopic extensions.

Frequency vs Realized Gain

The realized gain was plotted versus frequency for the different telescoping lengths as simulated in CST. The plot is shown in Fig. 8. Notice the realized gain is higher around the resonant frequency and the farther the telescoping action, the higher the gain.

CONCLUSION AND FUTURE WORK

The main contribution of this work is the incorporation of inkjet printing of conductive ink on paper substrate with the art of origami to create a reconfigurable antenna by changing its shape. Starting at the planar position, the antenna possesses a bidirectional radiation pattern. When the antenna is telescoped into its conical form, the radiation pattern becomes more directional in the direction of extension. This leads to a larger gain. The antenna maintains a relatively constant resonant frequency and input impedance during the process. Printing the antenna on paper allows the structure to be very lightweight. This allows the antenna to be easily transported and is adaptable to specifications in the field.

For the future of this work, implementing an actuating system for reconfiguration would greatly simplify the shape changing operation of the antenna. This would allow the antenna to adapt to its requirements without a human operator performing a manual telescoping procedure.

This antenna can also be designed for a wide range of frequencies, so it is adaptable to different frequency bands. This is merely accomplished by changing the dimensions of the inner and outer radii. Inkjet printing allows for relatively rapid fabrication, so spiral antennas of various sizes can be quickly constructed.

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