Inkjet Printed Ultra Wideband Spiral Antenna Using Integrated Balun on Liquid Crystal Polymer (LCP)

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Abstract—**In this paper, an ultra wideband spiral antenna with a planar, integrated balun is inkjet printed on liquid crystal polymer (LCP) substrate and operates successfully from 1 GHz up to 8 GHz. An exponentially tapered spiral microstrip balun is used for, the matching of the 130 Ω input impedance, the characteristic impedance (Z_0) of 50 Ω, at the feed point. The equiangular spiral antenna is planar and low profile since a bulky balun is not required. Both the microstrip balun and the spiral arms are inkjet printed on LCP. The fabricated antenna covers a wideband frequency range (1~8GHz) that corresponds to L, S, and C bands.**

I. INTRODUCTION

Ultra wideband antennas have become very popular because they can be used in a variety of applications. The designed UWB band is defined by FCC between 3.1 GHz and 10.6 GHz but any antenna with fractional bandwidth larger than 50% can be considered as ultra wideband. One of the most popular applications is for high data rate communication transceivers because of their large bandwidth that can support very fast pulses. Another interesting and novel application is for RF power scavenging [1]. An antenna that can be used for power scavenging should have relatively high gain, and should cover the "busiest" frequencies of the spectrum such as cellular communications and wireless LAN bands.

Equiangular spirals have been of the first antennas to be used as UWB antennas because they are self-complementary [2] and therefore their input impedance is frequency independent, however they generally require a bulky external balun which makes the antenna big and high profile [3]. Instead of the conventional central feeding, it is possible to feed a spiral externally so the balun can be integrated into the antenna in order to overcome the need of a bulky balun [4]. In this paper, an equiangular spiral antenna is introduced covering a large frequency range [1GHz, 8GHz]. The proposed spiral is inkjet-printed on liquid crystal polymer (LCP) with a printed, low profile, exponentially tapered balun that maintains the low profile, planar shape of the antenna. The suggested design covers all L, S, and C bands and could potentially be used for RF power scavenging.

II. ANTENNA DESIGN

A. Equiangular Spiral Antenna

The fabricated spiral antenna is shown in Fig. 1. The substrate is 3-layered structure which consists of two layers of LCP and between them, one layer of paper as shown in the inset of Fig. 1. The two arms that consist the spiral antenna are inkjet-printed on the top LCP layer. On the bottom LCP layer a spiral trace, is inkjet-printed, centrally positioned under Arm1 (Fig. 1), forming an "equivalent microstrip feeding line". For the printouts, the commercially available printer (DMP2800) was used. Between the two 0.13 mm thick LCP layers a 0.23 mm thick paper substrate was intervened.

The photo paper was used to provide mechanical support and also increase the thickness of the substrate without changing the dielectric constant since both LCP [5] and photo paper [6] have been reported to have very similar dielectric constant ($\varepsilon_r = 3$). The thicker substrate is needed to make the dimensions of the metallic balun trace, feasible for the required Z_0. The characteristic impedance (Z_0) of the microstrip feeding line ranges from 50 Ω at the feed point to about 130 Ω at the spiral center. Their loss tangents (tanδ) are 0.025 for LCP and 0.07 for the paper. The three substrates are bonded using locally, small amount of glue spray that does not effectively change the dielectric constant.

The initial radius (at $\theta = 0$) of the spiral, r_i is set to 8 mm and the final (at $\theta = 3\pi$) radius is set to 32 mm. Each of the two identical arms is defined by two lines defined by equation (1) and (2) where independent variable θ is considered to increase in the clockwise direction.

$$\rho_o(\theta) = r_i e^{a\theta} \qquad [0, 3\pi] \qquad (1)$$

$$\rho_i(\theta) = r_i e^{a(\theta-\varphi)} \qquad [0, 3\pi] \qquad (2)$$

Here, ρ_o and ρ_i are the outer and inner radii of the spiral, respectively, θ is the angular position, r_i is the initial radius, and a is the tightness of the spiral arms. For the fabricated spiral the following parameters have been used; $a = 0.1471$, $r_i = 8$ mm, and $\varphi = \pi/2$. The narrower ends of the two arms are expanded into two, common vertex curve-sided orthogonal triangles to maintain the self-complementary shape of the spiral.

B. *Tapered Microstrip Balun Design*

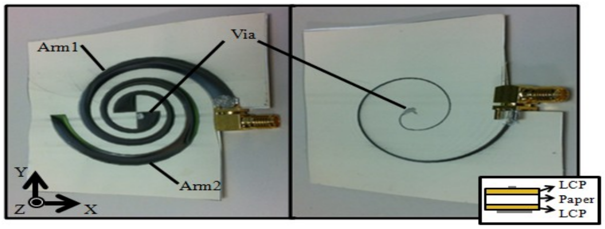
To avoid the bulky balun required for the centrally fed conventional spiral, a microstrip line balun is used to externally feed the spiral, exciting a microstrip line mode from the wider end of Arm1. The exponentially tapered microstrip balun is centrally placed on the opposite side of Arm1, forming a spiral shaped microstrip line where Arm1 is used as the ground for the resulted microstrip line. The initial width of the tapered signal connector that connects to the signal pin of the SMA connector is 1 mm resulting in 50 Ω characteristic impedance microstrip line. The narrower end of the arm, at the spiral center is only 0.1 mm wide, forming characteristic impedance of 130 Ω that matches the input impedance of the self-complementary spiral on LCP-paper, ($\varepsilon_r = 3$). For the calculation of Z_0, the 0.52 mm thick, stacked substrate with $\varepsilon_r = 3$ was used. The reason for matching 50 Ω to 130 Ω is that the input impedance of the spiral antenna is about 130 Ω ($Z_{in} = Z_{ant}/\sqrt{\varepsilon_{eff}}$ =132.9 Ω, $\varepsilon_{eff} \approx (\varepsilon_{air}+\varepsilon_{substrate})/2 = 2$, Z_{ant} is the input impedance of a spiral antenna and is equal to 188.5Ω in free space [2]). The exponential taper is designed in order to convert the 50 Ω characteristic impedance, to the 130 Ω, input impedance of the printed spiral. The exponential taper is designed using same equation (1) with different parameter values, $a = 0.1494$ for the outer contour and $a = 0.1464$ for the inner one. The taper begins from the wide side of Arm1 and ends at the center of the antenna as shown in Fig. 1(b). The narrow end of the tapered signal line is electrically connected to Arm 2 of the spiral through a via in order to differentially feed the two arms of the spiral antenna (180° phase difference).

III. MEASUREMENT AND RADIATION PATTERN

The designed antenna is fabricated and return loss (S_{11}) is measured. The size of fabricated antenna is 8cm x 8cm. The measurement and simulation results are shown in Fig. 2. The results indicate good matching between 1 GHz and 8 GHz exceeding the claimed L, S, and C bands. Simulated radiation patterns, in three different frequencies are presented in Fig. 3, showing the expected circularly polarized radiation pattern. The plots for planes XZ and YZ are normalized independently and θ=0 corresponds to Z-axis.

IV. CONCLUSION

In this paper, a spiral antenna using integrated microstrip balun is inkjet printed on LCP substrate. An external bulky balun is not required for this design because a planar, printed microstrip balun is integrated into the antenna that enables the antenna to maintain very low profile. The proposed planar antenna can be easily scaled to efficiently radiate at different frequency range.



(a) (b)

Fig. 1. Fabricated antenna: (a) front (b) rear

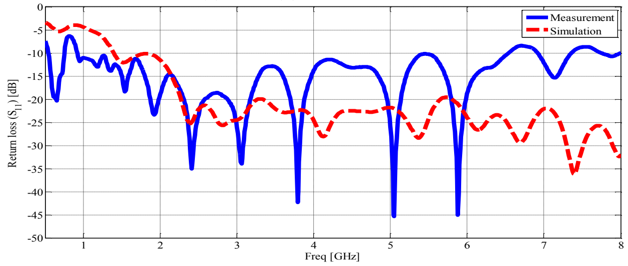
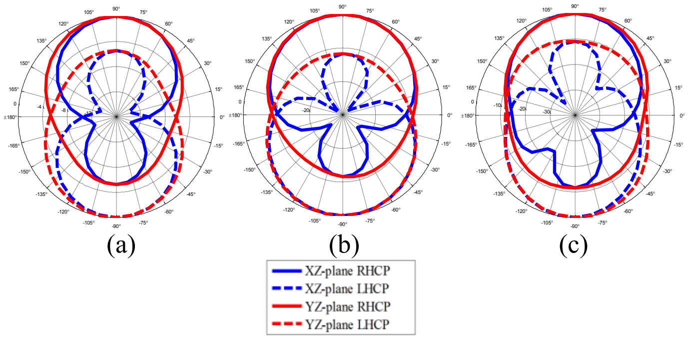


Fig. 2. Measured return loss (S_{11}) of the spiral antenna



(a) (b) (c)

Fig. 3. Radiation patterns on XZ- and YZ- plane at (a) 2GHz (b) 3GHz (c) 6GHz

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