Inkjet Printed Dual-Band Origami Frog Antenna

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***Abstract*— A dual band antenna is inkjet printed onto paper and then folded to form an origami frog. The design consists of a wideband coplanar waveguide fed monopole antenna with a square slot in its main radiating element. A low-cost inkjet printer with cartridges containing nanoparticle silver ink is used to deposit the metallic layers. The antenna and paper size is optimized so that the antenna covers the top surface of the origami frog while meeting the required frequency bands. The final design operates at the 2.4 and 5.2 GHz of the wireless LAN band. The aim is to demonstrate an antenna solution for future origami based foldable jumping robots. The time domain solver included in CST microwave studio was used for the design and optimization of the antenna.**

Keywords—Inkjet printing; paper; origami antenna; CPW antenna

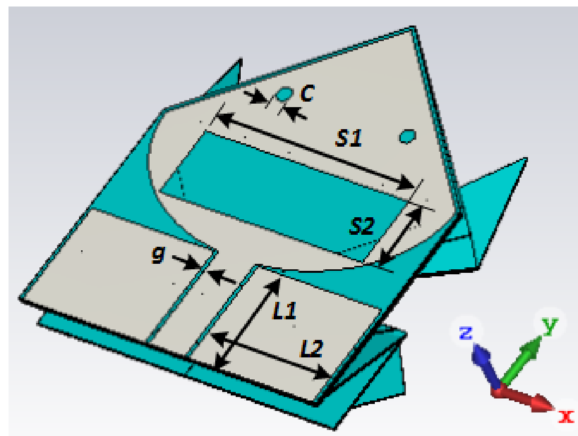
I. Introduction

Additive manufacturing (AM) is increasingly used in the fabrication of flexible electronic devices for the wireless communication systems. The technology offers low cost, multiple functionality and flexibility as compared to conventional lithographic technology. Inkjet printing is one of the most commonly used and developed AM technique. Inkjet printing has been reported for the fabrication of antennas for multiple bands and applications [1] – [4]. For example, a triband multiband antenna for wireless communications was discussed in [1], an LTE antenna was folded around a cylindrical form in [2], an ultrawideband (UWB) antenna was printed on paper substrate in [3], and an antenna was used for sensing applications in [4].

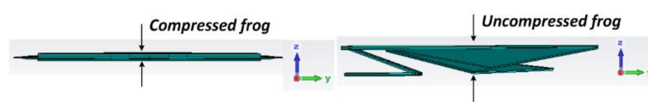
This paper proposes an inkjet-printed antenna on paper substrate for origami robot for jumping applications. The antenna is fabricated on the photo paper directly using low-cost inkjet printing technology and then folded to form an origami frog. The final origami frog antenna is tested and investigated with the conditions of uncompressed and compressed cases. The antenna design was optimized and simulation performance studies carried out using CST microwave studio.

II. Antenna Design

Fig. 1(a) illustrates the geometry and perspective view of the proposed origami frog antenna. The antenna and substrate were optimised so that the antenna could cover most of the top surface of the origami structure. A wideband coplanar waveguide (CPW) feed antenna was used.



(a)



(b)

Fig.1 Origami frog antenna (a) perspective view (b) side view under compressed and uncompressed conditions.

TABLE I
Antenna Dimension

	L1	*L2*	*S1*	*S2*	C	g
Dimensions (mm)	13.92	18.05	29.74	9.3	2	0.53

The main radiating element consists of a semicircle combined with a triangular shape with a centred square slot. The semicircle provides wide bandwidth necessary for the higher band, the slot creates the dual band operation and the triangle decreases the frequency for the lower frequency band. The main dimensions are shown in Table I. The antenna was simulated for two cases: compressed, and uncompressed as shown in Fig. 1(b). The origami shape was folded from an initial planar paper substrate of size of 92 mm × 132 mm. After folding, the overall dimension was 43.5 mm × 49.8 mm. The substrate had a dielectric constant of 3 and thickness of 0.177±12 µm. A coaxial cable was designed in the simulation to replicate the experimental results [5]. The dimension of the antenna were exported from CST microwave studio to ViewMate. The resulting PDF file was printed using a Brother MFC-J5910DW inkjet printer with the settings for best quality output. AgIC-CPO1A4 paper and AgIC-AN01 Silver Nano Ink were used for the fabrication of the antenna [6]. Fig. 2 shows the photograph of the antenna on the paper substrate, and folded to form the origami frog.. A 50 ohm SMA connector was connected to the antenna using silver epoxy conductive glue. The resistance between the two furthest end of the antenna was approximately less than 0.6 ohm.

Fig. 3 shows the simulated and measured reflection coefficient for the uncompressed and compressed substrates. Both cases are similar with the compressed case having slightly worse S_{11} than the uncompressed one. There is a frequency shift in the measurements which is mainly due to the fabrication tolerances. The measured impedance bandwidths (< -10dB) are from 2.30 to 3.15 GHz, and from 4.65 to 6.5 GHz in the compressed case. In the uncompressed case, the bandwidths are from 2.24 to 3.12 GHz and from 4.75 to 6.5 GHz. In all cases the antenna operates at the 2.4 and 5.2 GHz frequencies of wireless LAN bands. Fig.4 shows the radiation pattern in the three main orthogonal planes. All cases have similar radiation characteristics. Patterns were those of a vertical monopole antenna with a small ground plane.

(a) (b)

Fig.2 Photograph of the origami frog antenna for (a) planar substrate, and (b) the folded origami frog

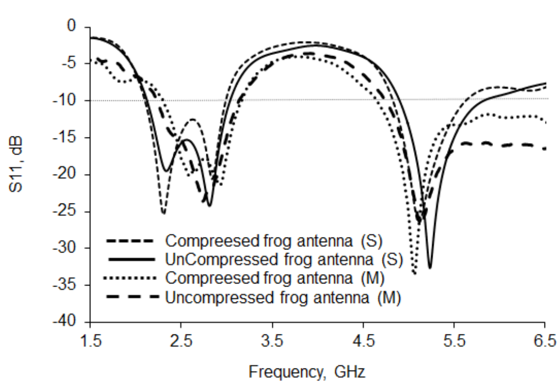
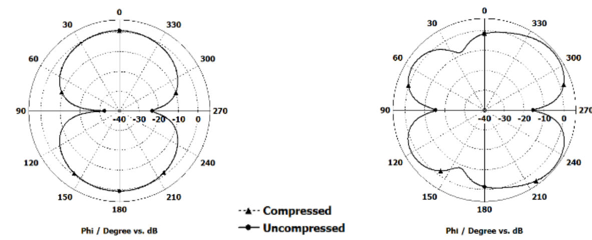
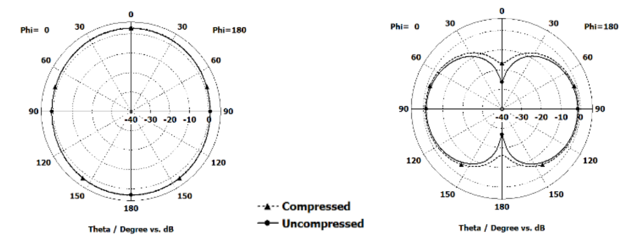


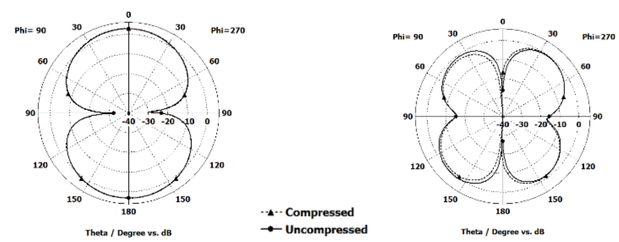
Fig. 3 Reflection coefficients (S_{11}), (S: Simulation, M: Measurement)



(a) x-y plane at 2.4 GHz (b) x-y plane at 5.2 GHz



(c) x-z plane at 2.4 GHz (d) x-z plane at 5.2 GHz



(e) y-z plane at 2.4 GHz (f) y-z plane at 5.2 GHz

Fig. 4 Computed radiation patterns

III. Conclusion

Low-cost Inkjet printing technology is demonstrated to be suitable for the fabrication of antennas for origami paper applications. A CPW–feed antenna has been optimised to the top surface of an origami frog. The antenna produces acceptable results when the frog is both compressed and uncompressed. These origami structures may contain printed electromechanical parts in the legs and become robots in the future. More cases such as the effect of the proximity to concrete floor on the S_{11} and radiation patterns will be investigated.

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