

Flexible Dual-Band LCP Antenna for RFID Applications

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Abstract—A dual-band antenna is developed on a flexible Liquid Crystal Polymer (LCP) substrate for simultaneous operation at 2.45 and 5.8 GHz in high frequency Radio Frequency Identification (RFID) systems. The response of the low profile double T-shaped slot antenna is preserved when the antenna is placed on platforms such as wood and cardboard, and when bent to conform to a cylindrical plastic box. Furthermore, experiments show that the antenna is still operational when placed at a distance of around 5cm from a metallic surface.

I. INTRODUCTION

Tagging of objects and people by means of Radio Frequency Identification (RFID) systems is developing rapidly and will soon become a pervasive trend. RFID systems were initially developed at the low frequency of 13.56 MHz and most systems are now designed for the UHF band [1-7], with a few being recently developed on a flexible substrate [4-7]. However, operating at a lower frequency limits the amount of information that can be transmitted. As RFID systems are being widely adopted, larger amounts of information will be requested for transmission, especially when intelligent packaging systems are deployed, and increasing the frequency of operation would appear to overcome the information transfer limitation.

In order to enable larger transmission rates, antenna systems have in recent years been proposed at the upper frequencies of 2.45 and 5.8 GHz [8-10]. However, these antennas being typically based on the FR4 substrate are therefore rigid and do not lend themselves to be mounted on objects that are inherently curved. It is therefore important that the RFID antenna systems developed at higher frequencies be as well flexible and conformal. However, with the exception of the advanced RFID paper-based antenna proposed in [11], which is both flexible and dual-band in the 2.4 and 5 GHz frequency bands, to the authors' knowledge, no other flexible RFID antenna operating at higher frequencies can be found in the literature.

Liquid Crystal Polymer (LCP) is a strong, very flexible and low-loss organic material which is also environmentally friendly (an important point for devices that promise to be ubiquitous) with a low permittivity. Due to its low losses, LCP can withstand a rise in frequency of operation and has been shown to be well suited for RFID antennas in the UHF band as well as for antennas at much higher frequencies, as demonstrated by the fundamental and pioneering work done by Manos M. Tentzeris and his team [6].

In this contribution, the rigid dual band RFID slot antenna designed for operation at higher frequencies using FR4 in [10] is considered, and re-designed on a flexible low profile LCP substrate using the Finite-Difference Time-Domain (FDTD) technique. The difference in permittivity and especially thickness between FR4 and LCP resulted in a challenging translation. Experimental validation was carried out at the two target frequencies of 2.45 and 5.8 GHz and showed good performance in terms of reflection coefficient. Like the original FR4 antenna, radiation patterns exhibit a quasi-isotropic behaviour at both frequencies. The manufactured antenna was tested on a range of materials including cardboard and wood so as to ascertain that it was suited for a wide range of environmental backgrounds. The antenna was folded on a plastic box and tested in curvature. As it is widely recognised that the performance of RFID antennas is degraded when metallic parts are present in the vicinity [3], the antenna was therefore positioned above a metal plate and the minimum distance at which it could still work effectively was determined.

II. ANTENNA DESIGN

The basis for this work was the FR4 double T-shaped slot antenna proposed in [10] and the geometry was altered in successive steps so as to produce the flexible LCP antenna shown in Fig. 1.



Fig. 1. The flexible LCP RFID antenna

In a first step, the FR4 antenna was simulated by the FDTD software developed at the University of Bristol with initial dimensions taken from [10] so as to make sure that the rigid

antenna was operating in the expected frequency bands and that further transformation of the antenna would be reliable. Fig. 2 shows a comparison of the FDTD simulated responses obtained with FR4 (dielectric constant: 4.4, thickness: 1.6 mm) and the early response of the LCP antenna with the same topology but considering a dielectric constant of 2.9 and thickness of 0.1 mm, as specified for the LCP substrate.

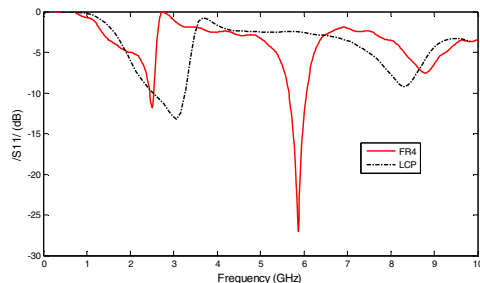


Fig. 2. The effect of changing the substrate from FR4 to LCP

It can be seen that the predicted response of the FR4 antenna in terms of reflection coefficient is in good agreement with the results included in [10] with a dual band response at 2.45 and 5.8 GHz. Modifying the substrate alone shifts the operating bands towards higher frequencies with the upper band disappearing in the process. Re-designing the antenna to fine tune it back to the original response was therefore a requirement.

In a second step, all antenna dimensions were enlarged by factors of 1.2 and 1.4 in an attempt to bring the response down in frequency as shown in Fig. 3. The optimum value was determined to be 1.2 as it produced the correct response for the lower band.

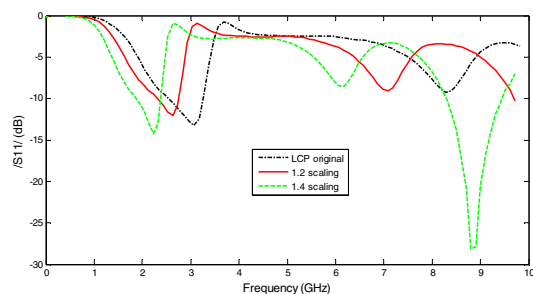


Fig. 3. Reflection coefficient variation with successive enlargements

In a third step, all geometrical features were altered and a parametric analysis was performed. The most significant variation was obtained when the length of the smallest T-shaped slot (closer to the feed) was increased by up to 8 mm, which shifted the upper response down in frequency while maintaining the lower band intact, as illustrated in Fig. 4. The value of 8 mm produced a resonance close to 5.8 GHz. However, as the lower band response was degraded by this change, the size of the metal next to the feed line was

subsequently modified, which had the effect of deepening the resonances at both frequencies, as shown in Fig. 5 where a satisfactory response was achieved for the LCP antenna with a value of 6 mm for the track.

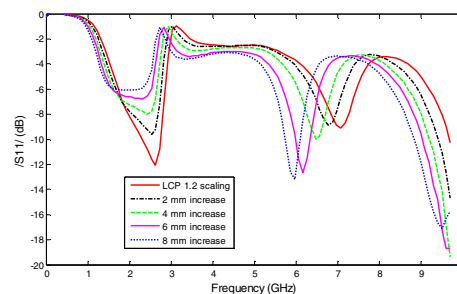


Fig. 4. Effect of increasing the small T-shaped slot antenna

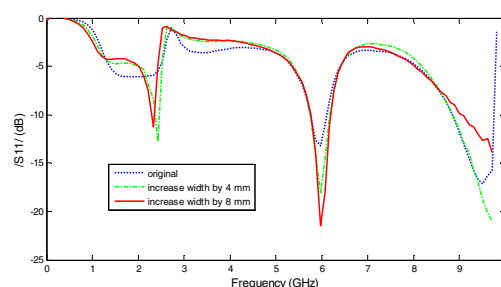
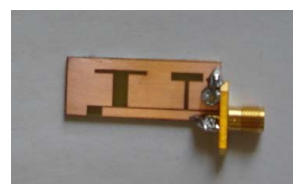


Fig. 5. Effect of increasing the metal part at the side of the feed line

Both antennas were manufactured and are displayed in Fig. 6. The LCP antenna is slightly less compact (with a size of 19×50 mm as opposed to 12.5×33.5 mm for the FR4 antenna), due to the very different LCP substrate which is notably thinner with only 0.1 mm thickness. It can however be noted that the feed line length was arbitrarily made longer for these measurements but could nevertheless be shortened in practical RFID implementations.



FR4 antenna with dimensions from [10]



Re-designed LCP antenna

Fig. 6. Manufactured rigid and flexible dual-band RFID antennas

III. EXPERIMENTAL VALIDATION

Both antennas were measured in isolation and a comparison between the FDTD predicted and experimental reflection coefficients results is carried out in Fig. 7. It can be seen that the agreement between predicted and measured data is very good especially for the FR4 antenna. For robustness, the flexible LCP antenna was positioned on a thin transparent plastic sheet of thickness 2 mm and permittivity close to 1 in this measurement. It can be noted that the experimental response shows some extra resonances compared to the FDTD prediction. These are however believed to be due to the transition from connector to feed line which might require further care (improving this will be left as a future work). The two frequencies of 2.45 GHz and 5.8 GHz are however clearly present, showing the validity of the new design.

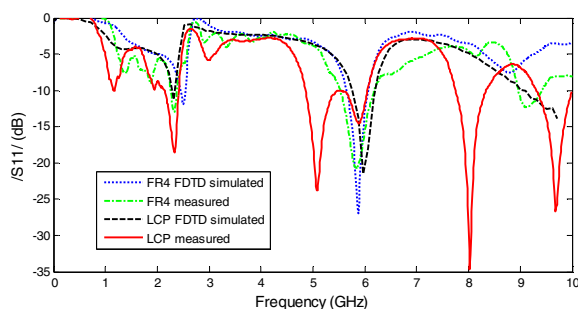


Fig. 7. Experimental validation of FR4 and LCP antennas

Three- and two- dimensional radiation patterns are shown for the LCP antenna at 2.5 and 5.8 GHz in Fig. 8, where measurements were done in the anechoic chamber, the antenna being placed on a Radio Absorbent Material (RAM) to isolate the antenna from its supporting metal post. The patterns are fairly isotropic especially at 2.45 GHz, despite the attenuation produced by the RAM (more visible at 5.8 GHz).

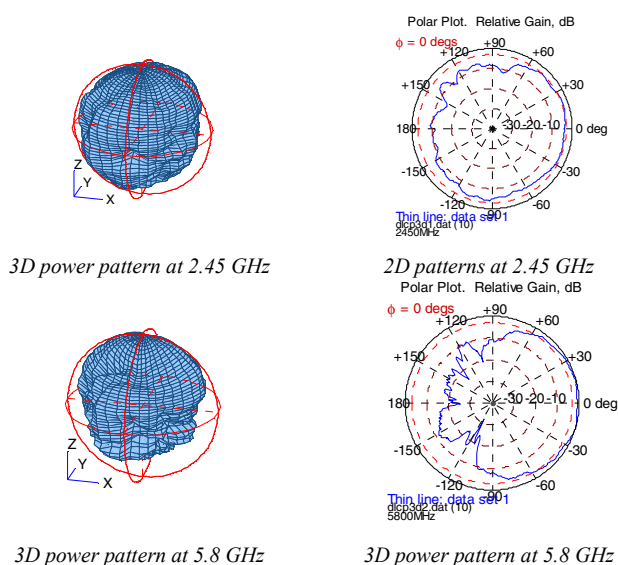


Fig. 8. Measured radiation patterns of the flexible LCP antenna

In order to check the influence of the environment of the response of the antenna, the flexible LCP prototype was positioned on a range of materials such as wood, cardboard and the plastic sheet mentioned earlier, given that these are commonly found in typical retail chains. It was observed that the antenna was fairly insensitive to the material that was placed beneath, as can be judged from Fig. 9 where all tests are compared. Wood was probably the worst case scenario, producing some slight deterioration in the upper band, but nevertheless maintaining the response at an acceptable level of around -10 dB.

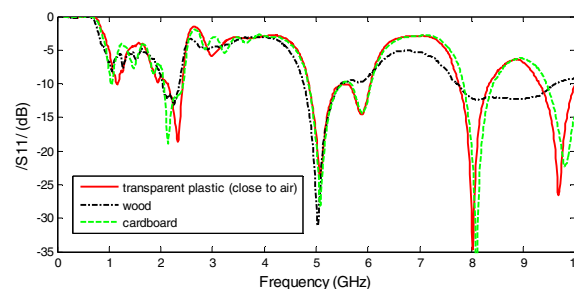


Fig. 9. Response of LCP antenna on wood, cardboard and plastic

A more drastic experiment was subsequently carried out by positioning the antenna above a metallic plate, as sketched in Fig. 10. It was observed that the antenna stopped emitting when directly positioned on the metal, or even when at a distance of 2 cm from it, as can be appreciated in Fig. 11. However, the response was totally recovered as soon as the antenna was at a minimum distance of 5 cm above metal, indicating that metal objects can be in fairly close proximity to the antenna without disturbing its performance.

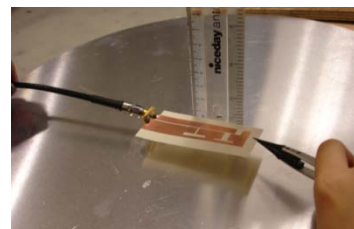


Fig. 10. Approaching the LCP antenna close to a metal plate

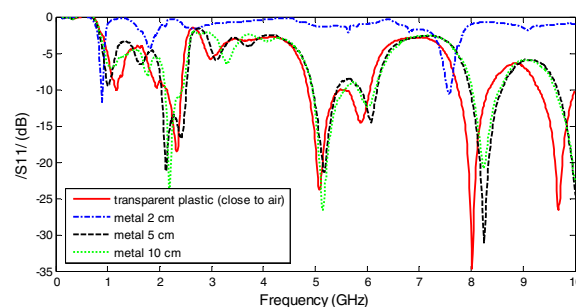


Fig. 11. Response of LCP antenna above metal

Finally, the flexible LCP antenna was tested in curvature and bent at angles of 30 and 60 degrees. Fig. 12 shows that the response was little affected, remaining the same for all bending angles, which was a rather pleasing outcome for this experiment.

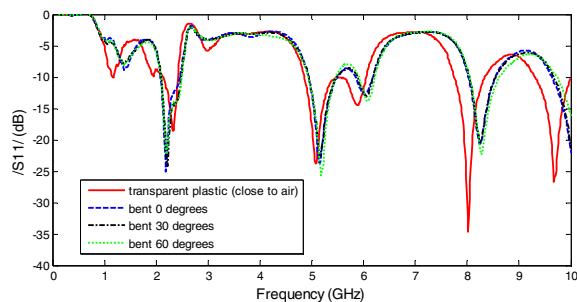


Fig. 12. Response of LCP antenna when submitted to curvature

As RFID antennas often need to be positioned on a cylindrical support, which is the case for example of many pill plastic cases, the LCP antenna was therefore tested in this configuration and conformed to a plastic box of radius of curvature close to 3.5 cm, as illustrated in Fig. 13.

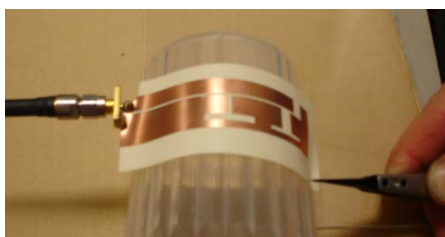


Fig. 13. LCP antenna folded on a cylindrical plastic box

The response in this configuration is displayed in Fig. 14 and again, is hardly affected by curvature showing its suitability for this type of environment.

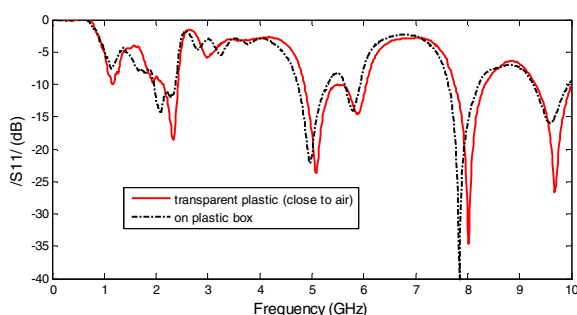


Fig. 14. Reflection coefficient for LCP antenna on cylindrical plastic box

IV. CONCLUSION

This paper presented the development of a flexible antenna suitable for high data rate RFID applications. Antenna design

was detailed with full experimental validation of the prototype at 2.5 and 5.8 GHz showing good performance in terms of reflection coefficient and radiation patterns at both frequencies.

The antenna is fully flexible showing identical reflection when bent at angles of up to 60 degrees or folded onto a plastic box with 3.5 cm radius of curvature. Finally, although admittedly the antenna response disappears when placed directly in contact with a metallic plate, the performance is maintained when the distance to the plate is larger than 5 cm, which means that metal parts can be present in the environment without affecting the antenna.

Furthermore, while the RFID antenna was designed on a LCP substrate for flexibility and robustness, this design could easily be translated to paper substrates for a low cost solution.

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