Wide Slot Circularly Polarized Conductive Oxide-based Transparent Antenna Design for ISM Band RFID Applications

Arpan Desai[1,2], Ismail Akdag[3], Merih Palandoken[3]

[1]Division of Computational Physics, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City 758307, Vietnam
[2]Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City 758307, Vietnam
arpandesai@tdtu.edu.vn, ismail.akdag@ikc.edu.tr, merih.palandoken@ikc.edu.tr

Cong Danh Bui[1,2], Jayshri Kulkarni[4], Truong Khang Nguyen[1,2,*]

[3]Department of Electrical and Electronics Engineering, Izmir Katip Celebi University, Izmir, Turkey
[4]Department of Electronics and Telecommunication Engineering, Vishwakarma Institute of Information Technology, Pune, India
congdanh19962007@gmail.com, *nguyentruongkhang@tdtu.edu.vn, jayah2113@gmail.com

Abstract— A novel wide slot transparent circularly polarized antenna is illustrated in this paper. Circular polarization is achieved by using a wide slotted S-shaped loop with diagonally trimmed edges, two separate mirrored U-shaped slots with feed location at the center of the conductive patch. Conductive oxide AgHT-8 is used as a feeding patch over a 1.48 mm thick transparent plexiglass substrate (ε_r = 2.3, tan δ = 0.000379). The antenna operates in the band spanning from 0.80 GHz – 1.05 GHz (~27.47%) with the axial ratio (AR) less than 3 dB within the same band. Numerical studies have been carried out to analyze the performance parameters of the antenna such as reflection coefficient, gain, axial ratio, radiation pattern and it has been observed that the results are satisfactory for RFID applications as an optically transparent CP antenna.

Keywords— ***transparent antenna, circular polarization, RFID, wide slot, ISM band.***

I. Introduction

RFID antennas combined with electronic devices are capable of forming multifunction systems in the field of healthcare, retail, transportation, manufacturing, and logistics. RFID system helps in automatically locating the business-critical items like hospital medications, store merchandise, and warehouse goods.

The antennas for such a system if blend with the environment can avoid the visual clutter and maintain the aesthetics. For instance, the integration of tag antennas on windshields of vehicles [1] helps in enhancing the aesthetic if they are transparent. Similarly, visually imperceptible tag antennas can protect the retail industry against counterfeiting. During dementia care and involuntary treatment, unnoticeable RFID antennas value users' convenience by being unobtrusive [2]. Optical transparency helps in achieving unobtrusiveness in the visual appearance of antennas. Transparent conductive oxides which are a blend of metal and oxides act as conducting layers instead of conventional non-transparent materials by permitting the flow of electric currents while retaining the optical transparency of the radiator. Various conductive oxides are available that can be used as a conductive layer over the transparent substrates like Tin oxide combined with Fluorine (FTO), Zinc oxide doped with Aluminum (AZnO), a combination of Tin oxide and Indium (ITO), and Silver Tin Oxide (AgHT-8). AgHT-8 having a sheet resistance of 8 Ω/sq and light transmission > 80% ensures decent antenna performances [3-4]. Moreover, it is readily available and no complex fabrication techniques like DC/RF sputtering or chemical vapor deposition needs to be used.

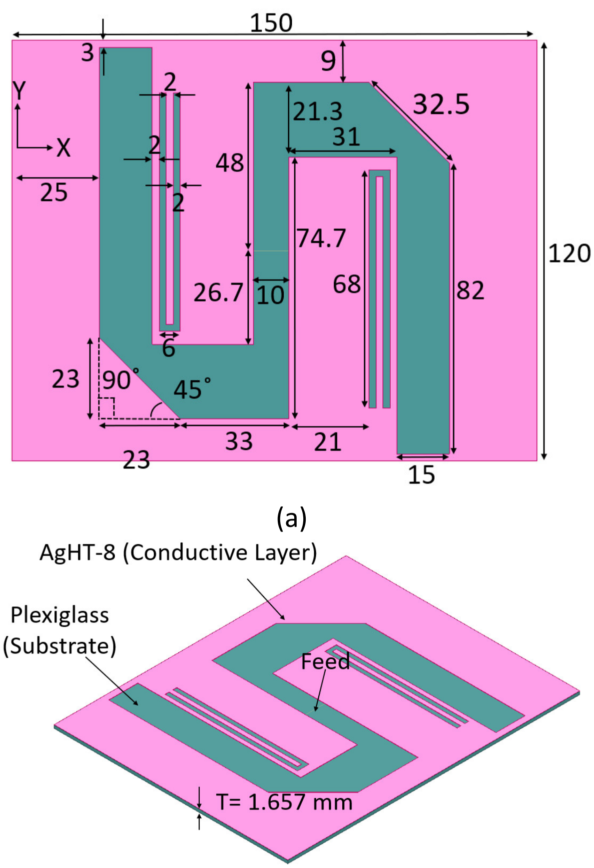
Transparent antennas owing to low conductivity value inhibit achieving high gains and efficiencies. The circular polarization (CP) helps in obtaining distance gain; due to its striving capability in multipath, high reflective, and scenarios with a line-of-sight communication as compared to linear polarization (LP) [5-6].

Various CP RFID non-transparent antennas are developed in [7-12] but the development of robust and transparent CP RFID antennas needs to be addressed. The transparent CP based antenna designs are reported in [13-18] where only [13] is proposed for RFID applications using transparent antenna while other transparent antennas are proposed for applications like WLAN [14-15], reflectarray [16], vehicular communication [17], and small satellites [18]. A transparent RFID antenna proposed in [13] achieves a good axial ratio, and gain however it is proposed for a frequency range spanning from 885–932 MHz whereas the proposed antenna covers all the bands used by various countries like which doesn't cover the 865-868 MHz band that is used in European and Indian RFID applications [19].

In this paper, a circular polarized wide slot transparent antenna operating in the frequency range of 0.80 GHz – 1.05 GHz is presented. The antenna achieves transparency > 80% which makes it suitable for its use in areas where its visual presence should be undetected.

II. Antenna Geometry and Parametric Variation

The CP-based transparent antenna geometry is depicted in Fig. 1. The antenna is a combination of plexiglass substrate (thickness = 1.48 mm, ε_r = 2.3, and tan δ = 0.000379) and AgHT-8 (Silver Tin Oxide) having a sheet resistance of 8 Ω/sq and thickness of 0.177 mm that forms a visually unnoticeable structure due to the transparency > 80%.



(b)

Fig.1 Antenna geometry (a) Top view (b) Perspective view (Dimension in mm)

The footprint size of the RFID antenna is 0.40λ × 0.32λ mm^2 (at the lowest operating frequency). The geometry of the antenna consists of a wide slotted S-shaped loop with diagonally trimmed edges, two separate mirrored U-shaped slots with feed location at the center of the conductive patch. The antenna dimensions and isometric view are depicted in Fig 1.

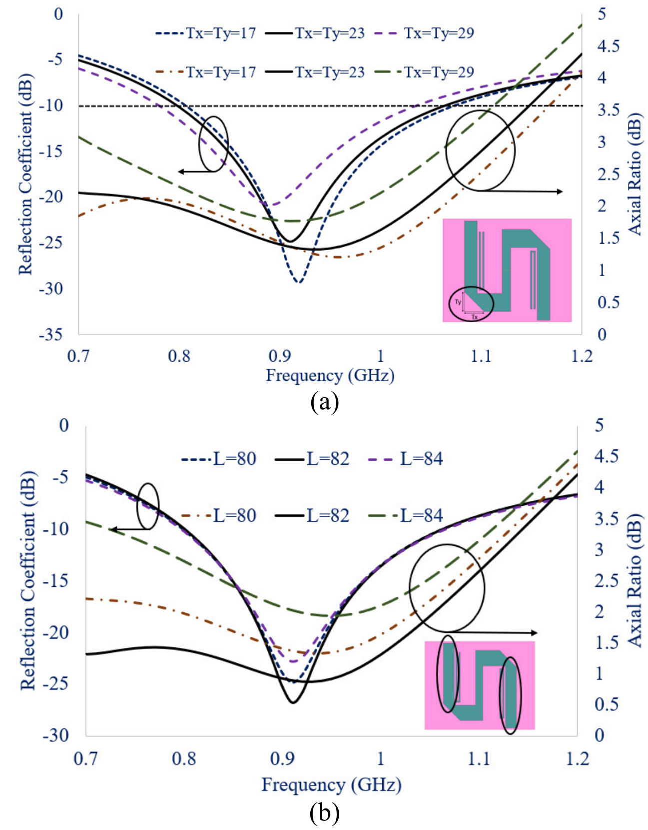


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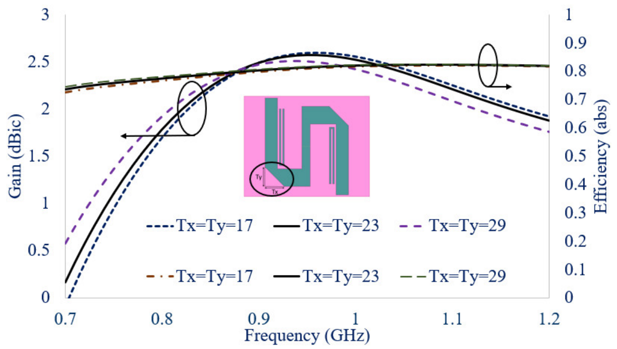
Fig. 2. Parametric analysis in terms of |S11| and Axial Ratio (Dimension in mm)

The analysis in terms of reflection coefficient and the axial ratio is carried out by varying various antenna geometrical parameters as shown in Fig 2 (a, b). The variation of two triangular-shaped diagonal edges leads to a shift in the resonant peak towards the higher side while the reflection coefficient value increases as the dimension are decreased (Fig. 2 (a)). However, as the dimension increases, the axial ratio increases, and at the higher frequency side, it achieves values > 3 which makes the antenna impractical for circular polarization applications. The optimum value of the triangular cut is selected as 23 mm to achieve the best performance.

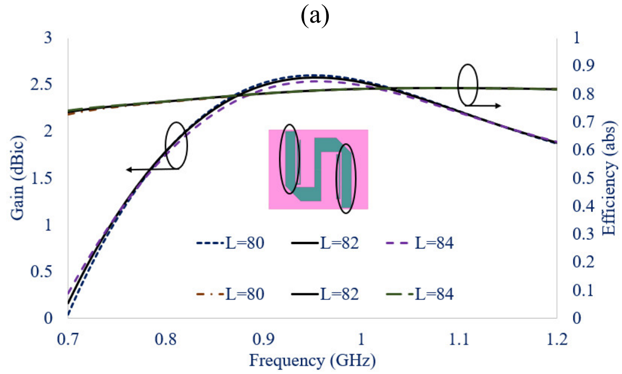
Fig 2 (b) depicts that the length of the vertical rectangular-shaped slot on the sides helps in achieving the reasonable reflection coefficient and axial ratio values. The optimum value of slot length at 82 mm gives the best result in terms of |S11| and Axial ratio having the values of -26.81 dB and 0.88 dB, respectively.

The analysis in terms of the effect on the gain and efficiency due to the variation of triangular sides and vertical L-shaped slot on the sides of an antenna is carried out as shown in Fig 3 (a-b). Fig 3 (a) depicts that as the triangular side length increases, the gain of the antenna is negatively affected while the efficiency of an antenna is not much affected. A side length of 23 mm gives the maximum gain and efficiency of 2.599 dBic and 82.1%, respectively.

Similarly, the gain of CP-based transparent RFID antenna decreases as the vertical slot length increases while efficiency



(a)



(b)

Fig. 3 Parametric analysis in terms of Gain and Radiation efficiency (Dimension in mm)

is least affected in the bands of interest. The optimum value of 82 mm is chosen that helps the antenna to achieve the realistic values of gain, efficiency along with |S11| and axial ratio <3dB.

III. Simulation Results

Fig. 4. depicts the reflection coefficient and axial ratio of the CP-based transparent antenna. The impedance bandwidth (S_{11}<-10 dB) for simulated results is approximately (27.47%) 0.80 GHz – 1.05 GHz that covers almost all the RFID bands used across the world. The axial ratio (AR) bandwidth < 3 dB is achieved within the same band. The value of axial ratio at resonant peak (0.911 GHz) is 0.89 dB, which specifies the satisfactory circular polarization of the antenna.

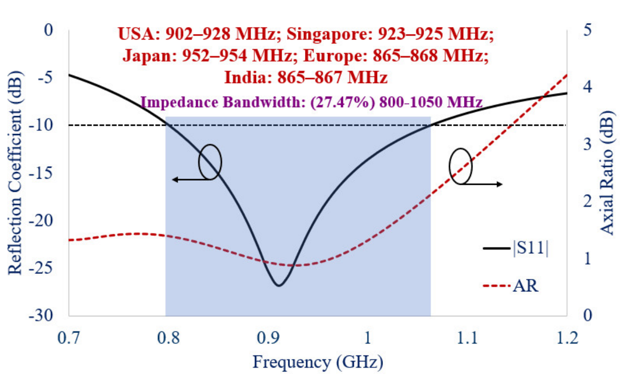


Fig. 4. Simulated $|S_{11}|$ and Axial Ratio Results.

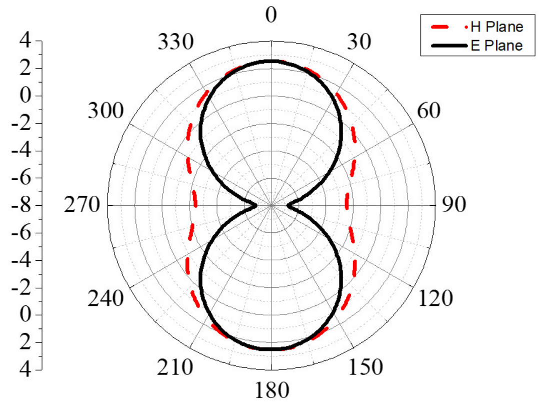
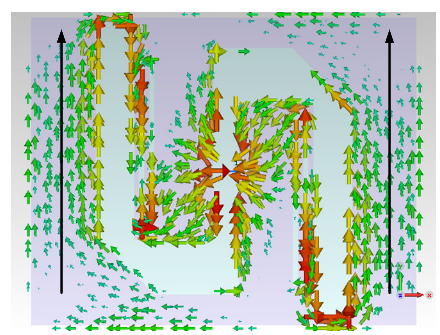


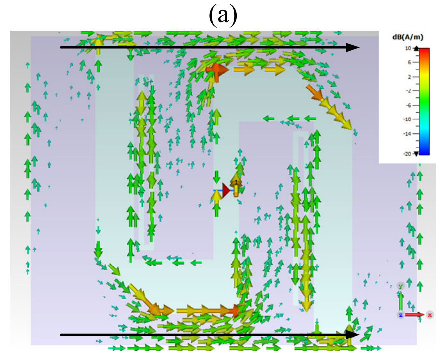
Fig. 5. Simulated radiation pattern at 0.91 GHz in E-plane and H-plane.

CP transparent antennas radiation patterns are shown in Fig. 5. Both E and H plane patterns are symmetrical with dipole shapes.

As shown in Fig. 6, the surface current distribution rotates clockwise. Specifically, at phase 0^0 (Fig. 6(a)), the current direction on the antenna is vertical vectors for the most part on the surface (indicated by the black arrow on the left and right side). With 90^0 phase difference (Fig. 6(b)), they are diminished and the current distribution on the antenna surface is mainly horizontal instead. It can be concluded that the proposed antenna supports the rotation of current distributed on the antenna surface and thus, exhibits circular polarization.



(a)



(b)

Fig. 6. Surface current distribution of the antenna at 0.91 GHz (a) at 0^0 (b) at 90^0.

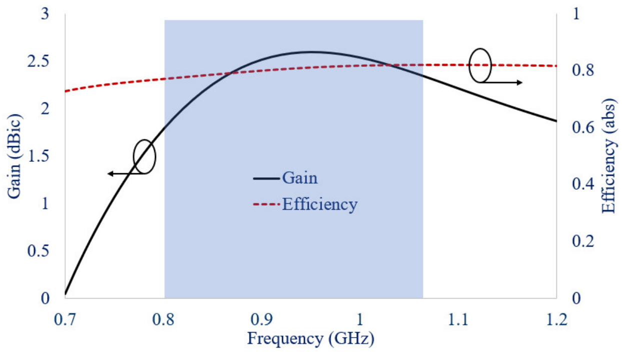


Fig. 7. Simulated Gain and Efficiency Over Frequency.

The CP gain and efficiency of the transparent RFID antenna are shown in Fig. 7 where the maximum CP gain is 2.57 dBic and the efficiency value is between 77.3% – 82.2% in the band of interest.

IV. Conclusion

In this paper, a conductive oxide-based transparent antenna is presented. The antenna has circular polarization operating in the band spanning from (27.47%) 0.80 GHz – 1.05 GHz with the axial ratio (AR) less than 3 dB within the same band. The transparent antenna has a bi-directional radiation pattern, an average gain of 2.40 dBic, and the lowest efficiency of 77.15% in the band of interest. The unobtrusive nature with satisfactory CP parameters makes the transparent antenna a decent contender for RFID applications in ISM band.

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