A Wideband Circularly Polarized Rectenna for Wireless Power Transmission to Embedded Sensors

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Abstract

A wideband circularly polarized microstrip patch antenna is introduced which can simultaneously support dual functionalities for an embedded wireless sensor. The 8 dBi circularly polarized antenna with 8% axial ratio and 11.6% return-loss bandwidth can easily support high-speed wireless data telemetry in the 5.15-5.35 GHz band. The same antenna has also been tested for wireless power delivery at 5.5 GHz.

1. Introduction

Recently considerable emphasis has been placed on studying the quality and safety issues of infrastructures [1]-[4]. A careful evaluation of the life span and current condition of steel reinforcement tendons inside infrastructures is crucial to ensure public safety. The solution for this problem calls for the deployment of miniaturized embedded sensors within the structure itself during the construction process. An RFID (radio frequency identification) type passive sensor utilizes a narrowband tank circuit. Thus the presence of other metallic objects can cause a significant frequency shift as a result of which the sensor may not operate properly. Also due to the availability of low power only a very limited amount of data transmission is possible. In contrast, a 5-6 GHz WLAN type sensor is not limited in data rate and does not have the constraints of a narrowband LC tank circuit. However, for proper functioning of the circuitry there must be a mechanism to: (1) remotely charge (wireless power delivery) the transceiver battery as needed and (2) data communication in between the embedded sensor and the interrogator. In this paper we propose a wideband circularly polarized microstrip patch antenna which can function as a rectenna for wireless battery charging at 5.5 GHz and data telemetry in the 5.15-5.35 GHz WLAN band. Recent research suggests that CP antennas are more fade resistant than linearly polarized antennas [5]. Our proposed antenna is only 14.8 mm by 14.8 mm by 3 mm in size which can be readily integrated within the sensor circuit board.

2. Antenna Geometry

The geometry of the proposed antenna along with its parameters is shown in Fig. 1. The antenna was designed and developed on 3.175 mm thick Duroid 5880 (ε_r=2.2) substrate and fed by a coaxial probe. Before fabrication the antenna characteristics were optimized for wide return loss and circular polarization bandwidth by conducting a parametric study using Ansoft HFSS. The antenna design is based on our previous work presented in [6, 7]. The two slots positioned along the right diagonal of the microstrip patch generate left-hand circular polarization. Positioning the slots along the left diagonal generates right hand circular polarization.

3. Results

Computed and measured S11 (dB) data of the proposed antenna on 3.175 mm thick Duroid 5880 substrate are shown in Fig. 2. These data are generally in good agreement. The measured bandwidth within S11 = -10 dB is about 11.6 %. The fabricated antenna clearly supports the 5.15-5.35 GHz WLAN frequency bands.

Computed axial ratio data for this antenna are shown in Fig. 3. The 3 dB axial ratio bandwidth extends from 5.14 to 5.56 GHz (8%), which is very good for a single-fed patch. The antenna is left-hand circularly polarized for the 5.15-5.35 GHz WLAN data communication. It is also circularly polarized for the 5.5 GHz wireless power transmission scheme. Computed normalized radiation patterns of this antenna at 5.5 GHz are shown in Figs. 4(a) and (b). The antenna is placed on a 40 mm by 40 mm ground plane. The E_θ and E_φ components are very close to each other in magnitude as expected. The peak gain of the antenna is 8 dBi LHCP at 5.5 GHz. The front to back ratio is 20 dB or better.

Computed E field distributions of the proposed antenna are shown in Fig. 5. Stronger fields are concentrated close to the feed with a counterclockwise rotation sense. The two slots create unequal lengths for two separate current paths. These current paths correspond to two hybrid operating modes which result in wideband characteristics. This was also confirmed when E-field animation was observed in HFSS. This particular geometry with its slot orientation results in left-hand CP. If a mirror image case is considered, right-hand CP will result with stronger field concentration along the other diagonal.

The wideband circularly polarized microstrip patch antenna described above was used to design and develop a rectenna circuit to demonstrate wireless power transmission at 5.5 GHz. We chose to develop the RHCP version of the proposed antenna which is shown in Figs. 6 and 7. The rectenna circuit is also shown in Fig. 6. For rectification a high efficiency M/A COM detector diode MA4E1317 was used. The diode converted the incoming 5.5 GHz microwave energy into dc. The width of the microstrip transmission line was chosen based on the input impedance of the diode (172 Ω). The line length was so chosen as to achieve a good impedance match between the diode and the antenna. The bottom side of the diode was connected to a wide stub which is connected to the ground plane using a via. The converted DC was collected from the right edge to avoid directly interfering with the incident waves. Proper capacitor and resistors values were chosen to match the reactance part of the diode and maximize the output dc voltage.

The experimental test-bed on the transmitter side consisted of a 7 W power amplifier operating at 5.3-5.9 GHz, an Agilent 8719 ES vector network analyzer, and a 12 dBi gain RHCP microstrip antenna array. A simple test for wireless power beaming at 5.5 GHz was conducted where 2.8 V dc was received across a 280 Ω¸resistor over a distance of 40 cm. This demonstrated that the proposed antenna worked well in wireless power transmission.

4. Conclusion

A wideband circularly polarized microstrip patch antenna is introduced that can function as a WLAN antenna in the 5.15-5.35 GHz and as a rectenna at 5.5 GHz. Antenna designed on Duroid 5880 substrate with single feed provides a return loss bandwidth of 11.6 % and axial ratio bandwidth of 8%, respectively. Tests were conducted to demonstrate RF to dc conversion at 5.5 GHz. In the rectenna mode of operation 2.8 V was received across a 280 Ω resistor at a distance of 40 cm.

Acknowledgement

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5. References

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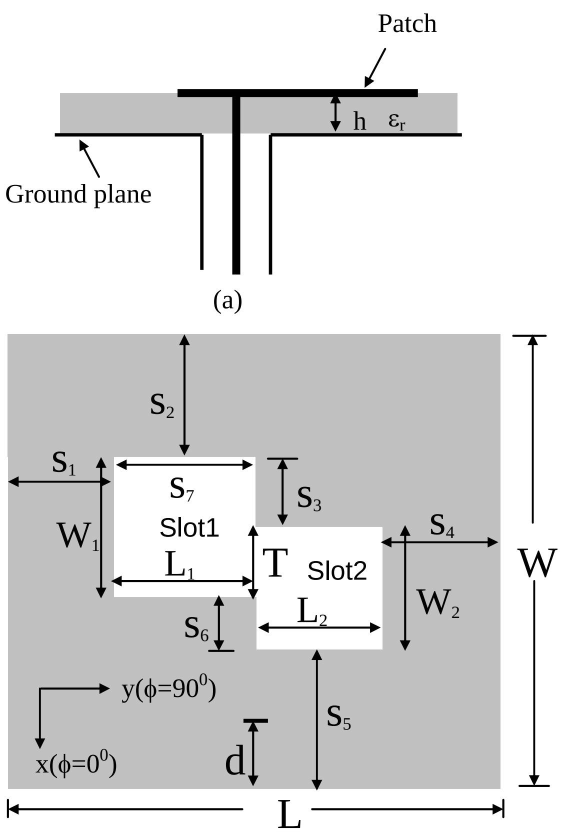


Figure 1: Antenna geometrical configuration. (a) cross-section, (b) top view. Parameters: L=14.8mm, W=14.8 mm, s_1=2.95 mm, s_2=3.65 mm, s_3=2.45 mm, s_4=2.95 mm, s_5=3.65 mm, d=2.84 mm, s_6=2.1 mm, s_7=5.0 mm, h=3.175, ε_r=2.2

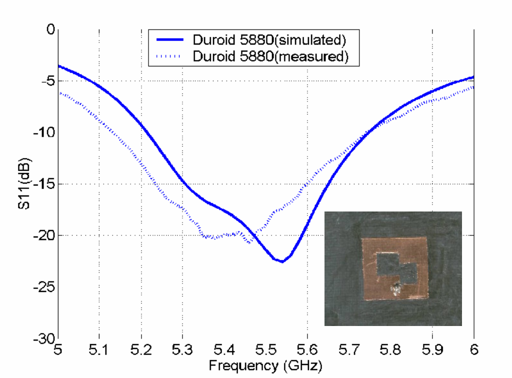


Figure 2**:** Computed and measured return loss versus frequency for the antenna on Duroid 5880.

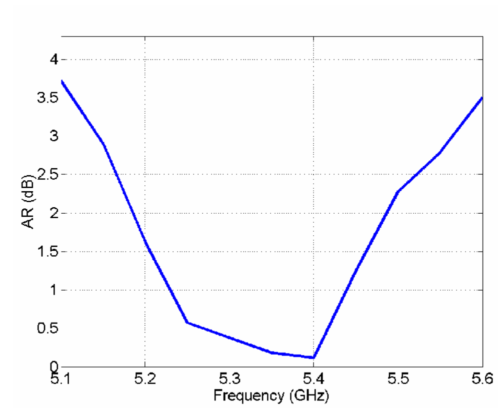
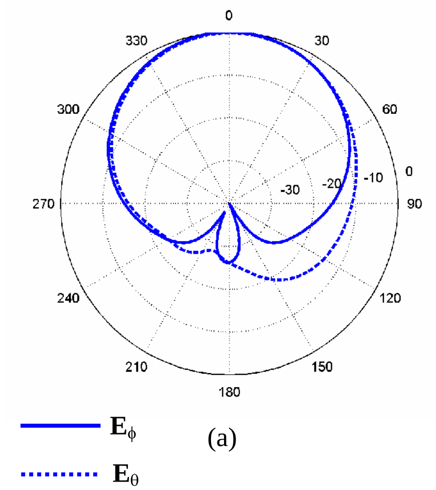
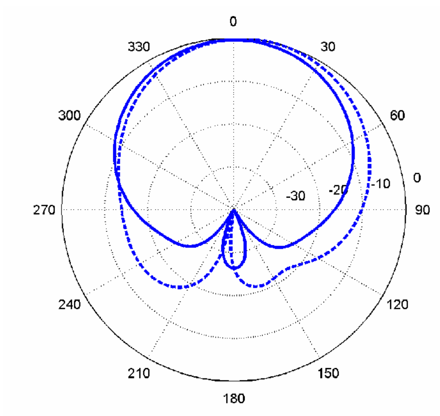


Figure 3: Axial ratio of the antenna on Duroid 5880 substrate.



(a)



(b)

Figure 4: Computed radiation patterns of antenna on Duroid 5880 substrate at 5.5 GHz at (a) $\phi=0^0$ and (b) $\phi=90^0$.

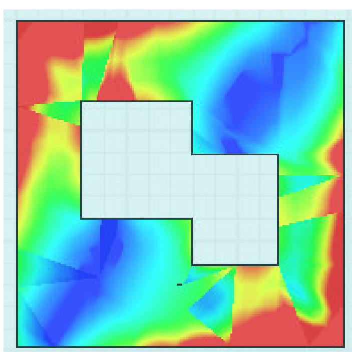


Figure 5: Computed E field distribution of antenna on Duroid substrate (ε_r=2.2) at 5.5 GHz.

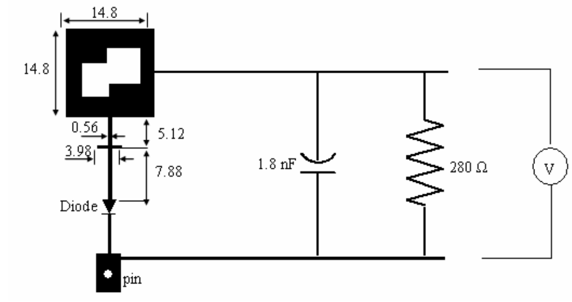


Figure 6: Geometry of the CP rectenna

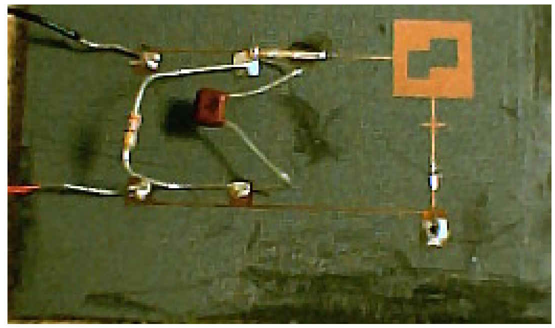


Figure 7: Fabricated rectenna prototype.