Design of a Ladybug Shaped Circular Polarized Microstrip Antenna at 5.8 GHz as Microwave Power Transmitter to a MAV

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***Abstract*—This paper is based on a circular polarized microstrip patch antenna which is designed for microwave power transmission with resonating frequency of 5.8 GHz. The radiating patch of the antenna is based on a dual feed elliptical patch which is modified by adding quarter wavelength resonators and circular slots. The resultant patch resembles to a ladybug and hence the name "Ladybug antenna". The designed antenna has a gain of 6.88 dB and return loss of 25dB. It has 0.48 dB axial ratio at 5.8 GHz which shows that it has good circular polarization. The Ladybug antenna has omnidirectional radiation pattern which is suitable for short range MPT operation of Micro Aerial Vehicles (MAV).**

Keywords—Microstrip Antenna, Circular Polarization, MAV, MPT, Patch Antenna.

I. Introduction

In recent times, Micro Aerial Vehicles (MAV) or micro drones have gained popularity in the market for their low cost and compact size. These devices possess large potential mainly in the field of communication and they are massively used in various fields such as military, emergency search and rescue, photography etc. However, most of the commercial MAV's available currently have a major limitation as their flight time is dependent on the battery which provides 5-20 minutes of air time [1]. In order to tackle this drawback, wireless power transmission (WPT) system is used as it enables for a battery less flight.

For this specific application, resonant inductive coupling technique can be used although; the extra weight that would be implied to the device can be of a disadvantage. Microwave Power Transfer (MPT) is an adequate solution to this situation. As microwave frequencies are set at a selected GHz range, it enables for a small sized antenna. These antennas can be of different type and shape for example, dipole antenna [2], Yagi-Uda [3] or Microstrip [1] [4].

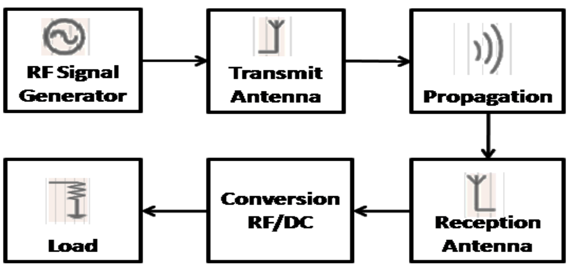
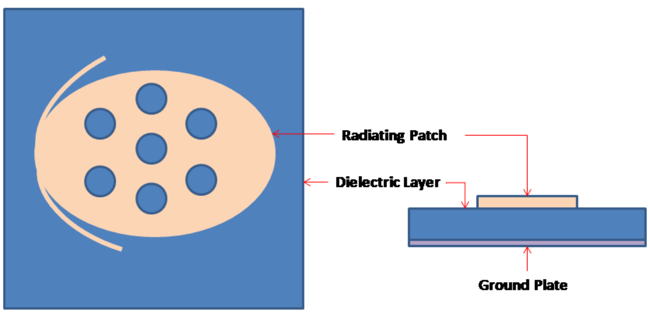


Figure 1: MPT system block diagram

In the MPT process the RF signal is generated and transferred via transmitter and the receiver on the MAV receives the signal and converts it into DC power for it to continue its operations. The process is shown in figure 1.

In this paper a microstrip patch antenna with circular polarization has been designed to operate as the Transmitting Antenna of MPT system. The antenna is designed to operate at a resonant frequency of 5.8 GHz. This frequency falls in the Industrial, Scientific and Medical (ISM) band which is the RF band that is not used for communication [5]. Microwave powered MAV works on two frequencies. The pilot or the operating signal is sent via 2.45 GHz frequency band. The 5.8 GHz band is used for wireless microwave power transfer [6].

Microstrip antennas are broadly used in communication and other fields due to their well-known benefits such as thin structure, light weight, low cost and their compatibility of being able to be designed in almost any shape [7]. For short range MPT operations of MAV require omni-directional antenna with gain close to 6.5 dB. To meet this requirement, several transmitter antennas have been designed in various shapes. In [[1], [8], [9]] the proposed transmitter antenna is a 5.8 GHz square microstrip antenna with a microstrip feed on one side. In [8] and [9] the transmitting antennas are not circular polarized. A double slot step shaped circular polarized has been used as MPT transmitter in [10] which also operates in 5.8 GHz band.



(a) (b)

Figure 2: (a) Proposed design for the ladybug shaped antenna, (b) Cross-section of the proposed antenna.

The proposed antenna in this paper has circular polarization. Circular polarized antenna has been used because it provides constant power at random polarization angles [11][12] which is essential for MPT system. The proposed antenna is a two feed elliptical shaped antenna. The

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ellipse is modified to take the shape of that of a ladybug which can be observed from figure 2. The design of the antenna is done using Advance Design System (ADS). The antenna simulation and performance analysis was also done using ADS.

The organization of the paper is given as follows: The first portion contains the design and the substrate structure of the antenna. In the second part, output parameters of the designed antenna is described and the result is compared with the outputs of other designs. And lastly the final section draws concluding remarks.

II. Antenna Design

A. Antenna structure

The proposed Ladybug shaped antenna design which is shown in figure 3 is based upon an elliptical shaped microstrip antenna. Elliptical shaped radiating patch of a microstrip antenna provides a circular polarization and an effective operating bandwidth [13]. The elliptical shape is modified to improve the performance of the antenna. The ellipse that the antenna is based on has a major axis of 32.5 mm and minor axis of 22.5 mm. The dielectric layer is square shaped with each side being of 40.75 mm. Two coaxial feed which is represented as Port 1 and Port 2 are provided on the two sides of the minor axis of the ellipse for microwave radiation. The ground plate is the same size as that of the dielectric layer.

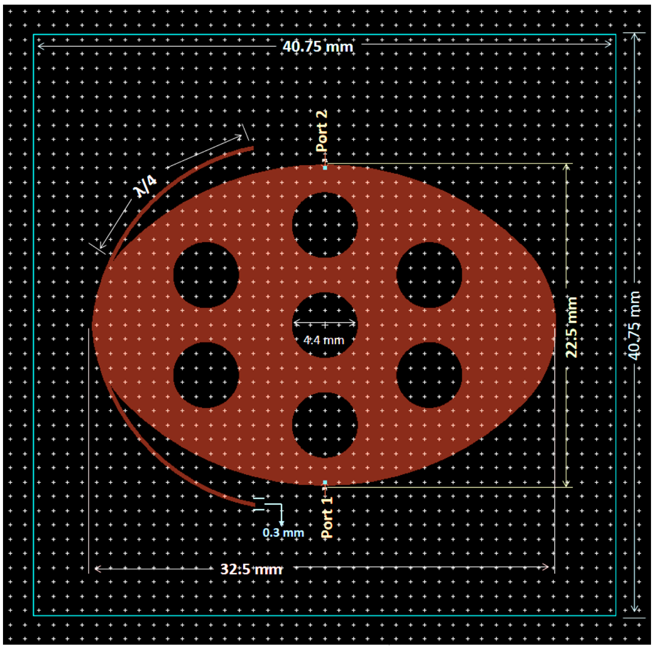

Figure 3: Structure of the proposed Ladybug Shaped Antenna

The elliptical patch is modified to obtain a better performance. Two resonators of quarter wavelength (λ/4) with length (12.9 mm) and 0.3 mm width are added on one side of the major axis. The resonators represent the two feelers (antennae) of the ladybug. The resonators are gap coupled to the radiating edge as a result it improve the overall axial ratio as well the effective angle of the antenna [14].

The radiating patch is then further modified by adding seven circular slots of 4.4 mm diameter. These circular slots represent the iconic polka dot of the ladybug. The seven slots are placed in such manner that their placement ratio is equal to the ratio of the major axis and the minor axis of the ellipse. Circular slots are added to the radiating patch to increase the bandwidth of the antenna as well as to improve the return loss [15] [16]. The changes can be observed from figure 4 and figure 5. Figure 4 depicts the $S_{(1\,1)}$ and $S_{(2\,2)}$ parameters of the antenna without the circular slots and figure 5 depicts the $S_{(1\,1)}$ and $S_{(2\,2)}$ parameter of the proposed "Lady Bug" shaped antenna with the feelers and the circular slots. From the both figures, it can be determined that after adding the slots, the return loss for $S_{(1\,1)}$ decreased from -22dB to -25.5 dB at 5.8 GHz frequency. And also after adding the seven circular slots, the return loss decreased from -24.5 dB to -25 dB for $S_{(2\,2)}$ parameter at 5.8 GHz frequency. The increase in the bandwidth after adding the slots can also be seen from figure 4 and figure 5.

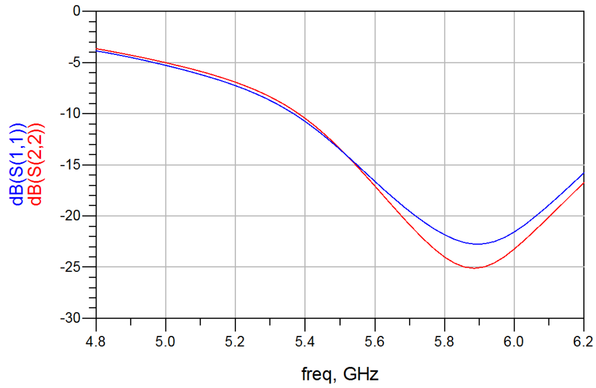

Figure 4: $S_{(1\,1)}$ and $S_{(2\,2)}$ parameter for the proposed Antenna without the circular slots

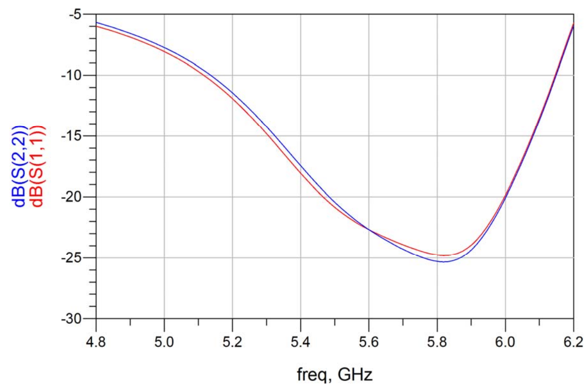

Figure 5: $S_{(1\,1)}$ and $S_{(2\,2)}$ parameter for the proposed Ladybug Shaped Antenna

After the adjustments the elliptical shaped radiating patch resembles a ladybug which can be observed from figure 3. For this reason the name of the antenna is given "Ladybug Antenna".

B. Substrate Layer

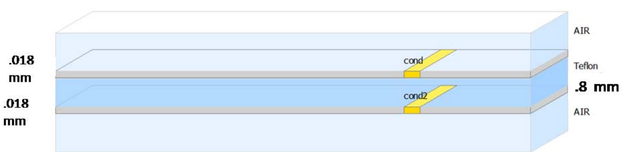

Figure 6: Substrate layer of the proposed Ladybug Shaped Antenna

The substrate layer for the proposed antenna can be observed from figure 6. The typical microstrip patch antenna is three layered where two conductive layers are separated by a dielectric layer. The ladybug shaped radiating patch is made of Copper with material height of 0.018 mm. The layer is depicted as "cond" in figure 6. The ground plate, which is depicted as "cond2" in figure 6, is also made of Copper. The height of the ground plate material is also 0.018 mm. Copper is used as it has the nearest properties to a perfect conductor.

The two conductive layers are separated by a dielectric layer of 0.8 mm height. The dielectric material used to design the designed antenna is Teflon which has a dielectric constant of 2.15.

III. ANTENNA PERFORMANCE

A. Performance Analysis

The main performances of the proposed antenna such as Return Loss, Axial ratio, Polarity are determined via simulation. The simulation was done within the range of 4.8 GHz – 6.2 GHz with 100 steps between them. As the antenna has two coaxial feed the impedance of the both feed were kept 50Ω. Both of the feeds were excited at the same time with input signals with the amplitude of 50V and with zero degree phase difference between them. The designed antenna operates at 5.8 GHz resonant frequency. At this resonant frequency of 5.8 GHz the antenna has a Gain of 6.839 dB and an effective angle of 2.8798 Steradian. The gain vs frequency curve of the proposed antenna with in the simulated frequency range is shown in figure 7.

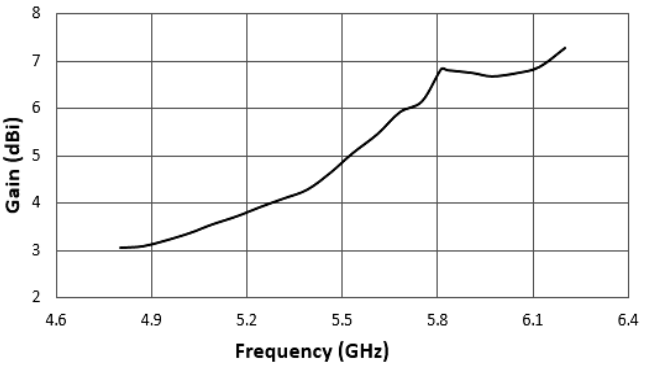

Figure 7: Gain vs frequency curve of the proposed Ladybug Shaped Antenna.

The $S_{(1\,1)}$ and $S_{(2\,2)}$ parameter of the two feed respectively are shown in figure 5. From figure 5 it can be observed that the return loss curves for both feeds are almost identical. The return loss values for both the feeds at 5.8 GHz are close to -25dB.

Figure 8 represents the smith chart for $S_{(1\,1)}$ an d $S_{(2\,2)}$ parameters. Similar to the return loss, the smith chart curves for $S_{(1\,1)}$ and $S_{(2\,2)}$ parameter are near identical. From the smith chart it can be observed that there is a depth in the curves shown in the smith chart [17]. The depth is situated near the value 1. This depth in the smith chart represents circular polarization. At the lowest part of the depth the impedance value is close to 1 with almost zero imaginary value which represents the best operating frequency for the antenna [18]. And this value is obtained at the resonant frequency of 5.8 GHz. A right hand circular polarization has been achieved with this antenna. The state of polarization can be observed from the antenna current distribution shown in figure 9. The arrows in figure 9 shows the current distribution throughout the antenna and by observing this it can be determined that the antenna is circular polarized.

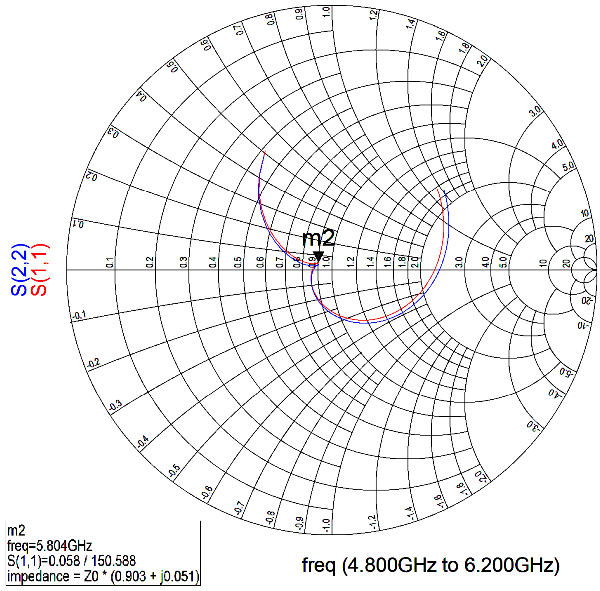

Figure 8: Smith Chart for $S_{(1\,1)}$ and $S_{(2\,2)}$ parameters.

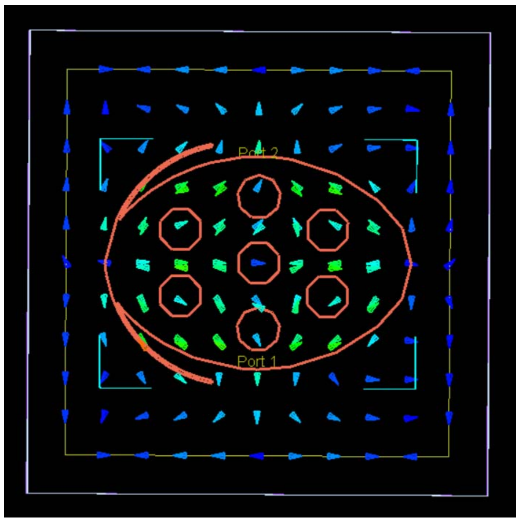

Figure 9: Current Distribution of the proposed Ladybug Shaped Antenna.

Figure 10 shows the plot of axial ratio values for different frequencies for the designed antenna. For 5.8 GHz resonant frequency, the axial ratio value obtained is 0.48dB.

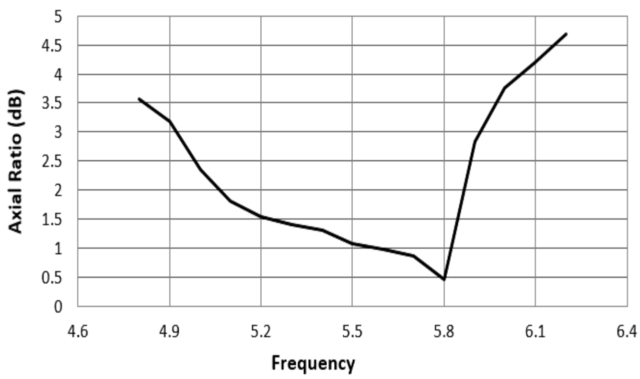

Figure 10: Axial Ratio for the proposed Ladybug Shaped Antenna.

B. Performance Comparision

Table I presents the comparison of the proposed Ladybug Shaped Antenna with other related works on microwave power transfer.

TABLE I. PERFORMANCE COMPARISION

Ref.	Operating Frequency (GHz)	S(1 1) Return Loss (dB)	Band-width (MHz)	Gain (dBi)	Polarization
Lady-bug	5.8	-25	`1000	6.839	Circular
[1]	5.8	-23.6	200	6.1	Linear
[9] [8]	5.8	-21	130	5.81	Linear
[10]	5.5	-17	600	7.3	Circular

From Table I it can be determined that the proposed Ladybug shaped antenna obtains the better quality and has overall better performance parameters than other MPT transmitter antenna proposed in some previous works. The proposed antenna also has dual feed compared to the single feed in the other works. The proposed antenna is also circular polarized, which is essential in MAV operations.

IV. CONCLUSION

In this paper a dual feed and circular polarized microstrip antenna has been designed to operate at 5.8 GHz resonating frequency. The design and simulation was done in Advanced Design System (ADS). The radiating patch of the antenna is a modified elliptical shape which resembles a Ladybug and thus it is given the name, Ladybug antenna. The antenna has a return loss of -25 dB, 6.88 dB Gain and 0.48 dB axial ratio. This low value of axial ratio proves that the proposed antenna is properly circular polarized. Therefore, it is clear from the above data that the proposed antenna has the compatibility to work as the transmitter antenna of microwave power transfer system. It has omnidirectional circular radiation pattern and so it is suitable for microwave power transfer to a MAV. The unique design of the antenna also stands out from the other antenna designs in this field. Hence, the research can be extended further by creating arrays with the Ladybug antenna and improving the gain in the near future.

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