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Wireless Far-field Charging of Quadcopters: WPT system

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ABSTRACT

In this study, wireless power transfer using a transmitting horn antenna and receiving module is designed and analyzed. The module comprises transmitting (horn) and receiving antennas, rectifier, and power management unit. The receiving antenna is used at a frequency of 2.45 GHz which seems to be the most efficient one. The integrated system being low in weight is suitable to be placed on any system having a battery with recharging characteristics. The compact system is designed and simulated using CST STUDIO. The receiving module is used for the conversion of microwave power to DC power for the easy charging of a Quadcopter. Drones always carry a minimal amount of payload and hence require a low weight power receiving system. The integration of 3 by 4 antenna array with the power management circuit makes it of minimal weight which is effective for UAVs. The distance taken into consideration is from 1 to 6m which works in relation to the power transmitted. Far-field transfer is designed and calculated but the method of improving the efficiency to a greater distance is still a concern of research.

Keywords: Far-field, Wireless power transfer, Quadcopter battery, Distance, Antenna Array

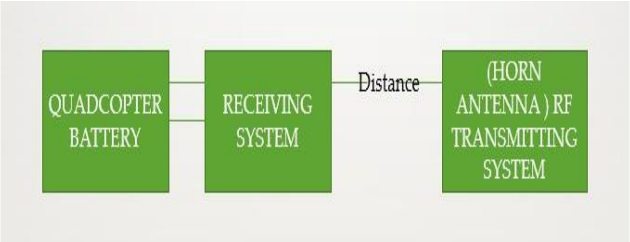
INTRODUCTION

Wireless Power Transfer (WPT) is a wide concept of power transmission without wires. In short, it can be carried out using far-field transferring or using coupled transmission. This research stabilizes the propagation of power using far-field characteristics. Therefore, WPT stated here mentions the far-field WPT system and not the coupled one. There are certain advantages of using this type of system which are mentioned below:

1. They can transmit the power without wires at a certain distance.
2. No involvement of wires for power distribution.
3. No need for battery replacement of regular intervals due to charging techniques.
4. Charging devices can be installed permanently into the body structures of UAVs or humans.

In the 1950s, Rectenna - a combination of antenna with rectifier circuits was developed. Since then, the concept of charging a quadcopter originated on wireless terms. Rectenna is composed of receiving antenna and rectifier circuits. The role of the receiving antenna is to collect the RF power which is then passed through the rectifier circuit which converts the RF power to DC power. Also, there is a wide variety of research work carried out for the effective charging techniques using high and low WPTs. This work presents the use of high power WPTs. The whole WPT consists of transmitting and receiving modules. The transmitting module carries amplifiers, antennas, and signal generators whereas the receiving module consists of an antenna array, rectifiers, and power management unit. The block diagram stated below shows the architecture of WPT.

Fig.1 Architecture of WPT



The design of receiving module includes:

1. A light weight receiving antenna array (3 by4)
2. A rectifier circuit
3. A power management circuit

The design of transmitting modules consists of:

1. Transmitting antenna(horn)
2. Signal generators

The whole wireless charging system consists of receiving, transmitting modules and batteries to be charged. The figure depicts charging on a wireless basis.

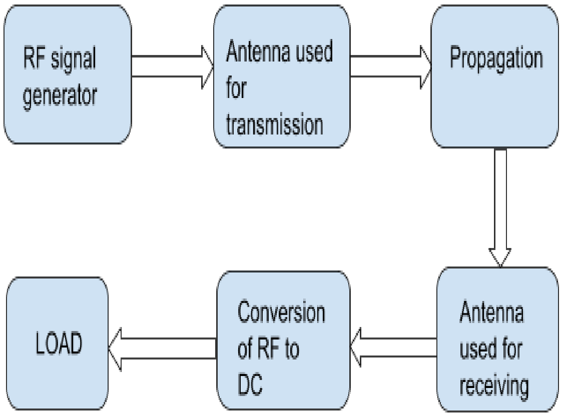


Fig.2 Block diagram of wireless charging

SELECTING FREQUENCY

The microwave range used for transmission often uses frequencies such as 2.45, 5.8, 8.5 GHz etc. 2.45Ghz is the most efficient one for the transmission according to [8,9].

MECHANISM OF WIRELESS CHARGING[11,12,13]

The process begins when the patch antenna ported on the quadcopter sends signals of 2.45 GHz to the receiving antenna (horn). The horn antenna hence tracks the accurate location of the UAV based on distance. The microwave radiations are sent to the UAV module in the form of charging information though the ground-based horn antenna and the rectenna array connected to the UAV battery receives it and the RF rays are converted to DC current for charging.

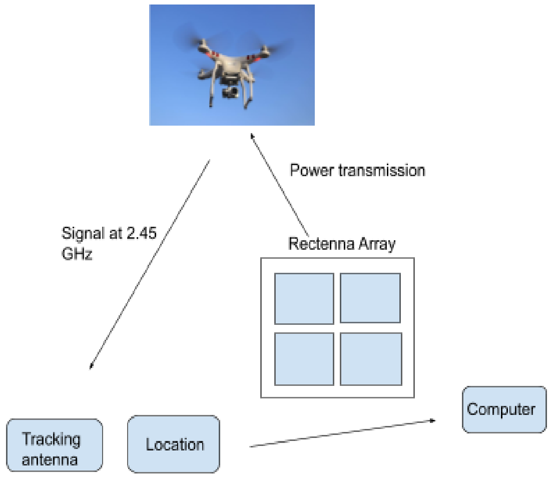


Fig.3 Wireless power transmission in a Quadcopter

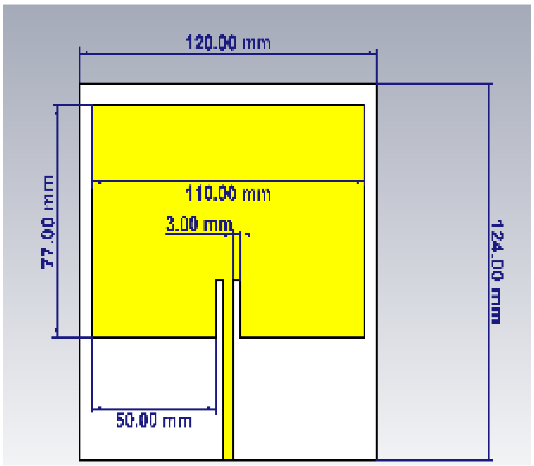


Fig.4 Front view of patch antenna

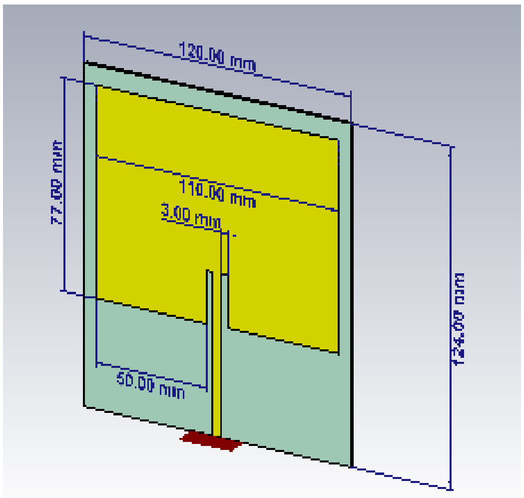
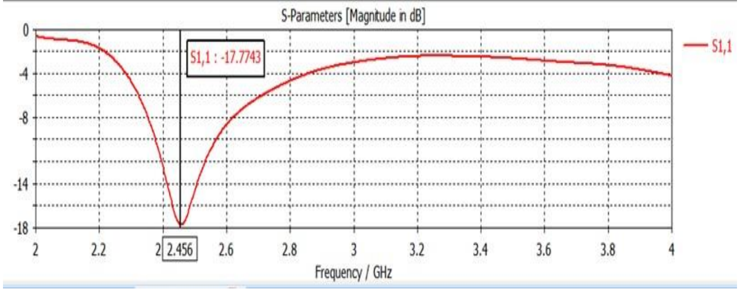


Fig.5 Orthogonal view with dimensions



RECEVING MODULE

(i) Patch antenna

As mentioned above, a patch antenna is designed for a rectenna array grid. For better efficiency, copper is selected for the patch and the substrate material is taken as Rogers300C (loss free) [3]. The port is placed on the feed line for polarization. Fig.6 shows the S1-parameter results with a return loss of -17.773 for 2.45 Ghz. The gain calculated is 10.976 dBi.

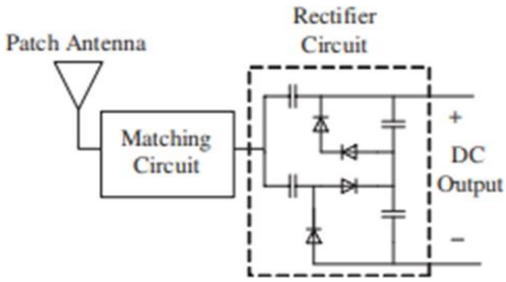


Fig.6 S1-parameter result from CST simulation

Type	Material	Xmin, Xmax	Ymin, Ymax	Zmin, Zmax
Substrate	Rogers300C (loss free)	-60,60	-62,62	0, 1.524
Patch	Copper	-55,55	-22,55	1.524, 1.524+0.038

Table 1. Overall dimensions of the designed patch antenna

(ii) Rectifier circuit

The compatible rectifier based on antenna properties is Skyworks SMS7630-079LF (max forward voltage: 240 mV, max forward current: 50 mA) and the circuit is designed based on the observations from [14]. The substrate of the rectifier circuit is of RO4003 material and is easily available. For measuring the rectifier efficiency, there is a need to vary the input power and load

resistance of the output in the circuit. If the input power increases, the efficiency deteriorates. This rectifier is used now for the formation of a rectenna array using the patch antenna designed above.

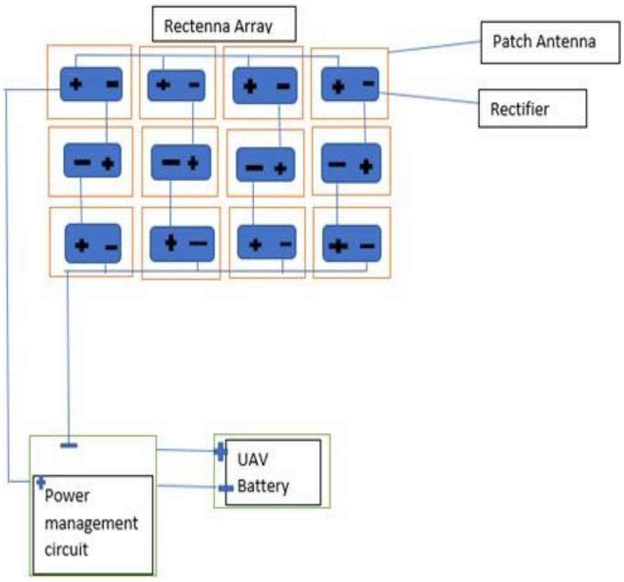


Fig.7 Circuit of Skyworks SMS7630-079LF

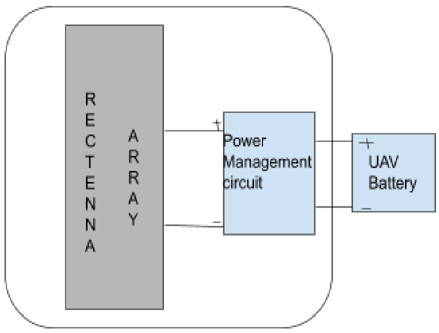


Fig.8 Circuit Integration of Patch antenna and Rectifier

(iii) Developing a Rectenna Array

Every 4 rectennas in a row are connected parallelly, and every 3 rectennas in a column are in a series connection. The connection made electrically is referred to according to [15] and is shown in Fig.8. Also, Fig.9 depicts the whole system integration of the receiving part.

TRANSMITTING MODULE

For designing a horn antenna, a rectangular waveguide of cross-sectional area is considered in mm^2. The rectangular aperture used gives a perfect pattern of radiation with only one mode of operation. All the dimensions are taken into mm. As this is only operated in one mode, the maximum power will only remain in the same mode rather than getting distributed with others. This will improve the wireless power charging efficiency [4]. The simulated result of S1 parameter is shown in Fig.11 which gives the low return loss of -25.72 at 2.45 GHz. The gain obtained from the analysis is found to be 14.93 dBi.

Fig.9 Complete receiving module

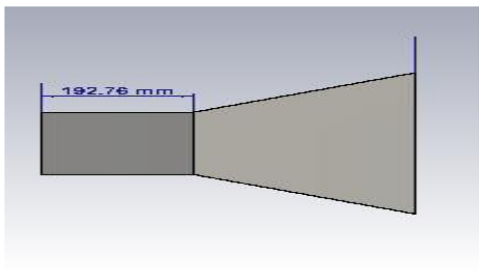


Fig.10 Different views of designed horn antenna

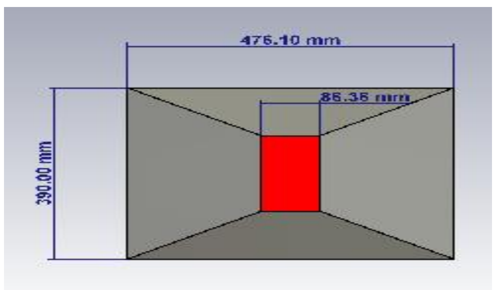


Table 2. Dimensions of horn antenna

Type	Material	Xmin, Xmax	Ymin, Ymax	Zmin, Zmax
Horn	PEC	90,92	-195,195	-238.05,238.05
Waveguide	PEC	-385.52, 192.76	-86.36, 86.36	-43.18,43.18

Table 3. Description of Horn Antenna

Description	Value in mm
Width of Waveguide	172.72
Height of Waveguide	86.36
Aperture length of horn antenna in H-plane	476.10
Aperture length of horn antenna in E-plane	390.00

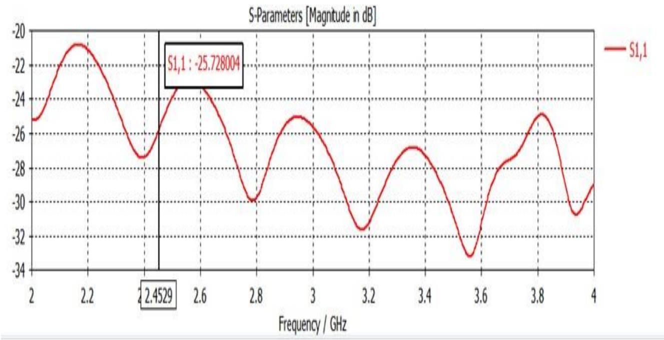
CALCULATIONS

The given calculation uses the Friss equation which is of transmission. Friss equation is:
where, Gt= Transmitting gain; Gr= Receiving gain; Pt= Power transmitted, Pr= Power received; R=Distance

$$P_r = \left(\frac{\lambda}{4\pi R}\right)^2 G_t G_r P_t.$$

Table 4: Power received

Distance R(m)	Pt (W)	Pr (W)
6	12000	27.57
4	9000	20.68
2	5000	45.95
1	1000	36.76
2	500	4.595
4	323	0.7421
6	133	0.1358



As compared to the results obtained in [2], it can be said that 12kW or more transmitting power is required for successful charging of quadcopter batteries exceeding 4m distance from the transmitting system.

CONCLUSION

A complete system consisting of patch antenna arrays, rectifiers and power management circuit has been designed and integrated with the receiving system. The process of conversion of RF wave signal to DC power is calculated and demonstrated in the study. For achieving a good amount of received power, the only solution is to increase the number of patch antennas and rectifiers short of rectenna arrays but only at the cost of heavy weight. This could be a drawback for the Quadcopter during the lift-off condition as the take-off weight will increase in proportional to the addition of rectennas. Various designs based on different frequencies can be tried with suitable designing techniques. The designs of rectenna arrays can also be modified for increasing the power efficiency resulting in low power transmission. This study can also be elaborated further with improved designs, results, and fabrication.

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