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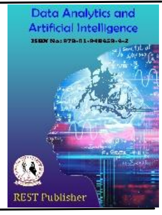

Design of Rectangular Shaped Rectenna for RF Energy Harvesting

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Abstract: Wi-Fi signals are present everywhere we go and everywhere we are and that untapped energy hasn't been harnessed to its full potential. To date, this energy is exclusively used for internet access and communication. However, energy harvesting is a possibility for the efficient use of the energy. The primary focus of this study is on obtaining usable energy from wireless transmissions. The goal of this project is to develop the first power over Wi-Fi system, compatible with current Wi-Fi chipsets that can supply electrical power to low-power sensors and other low-power devices. This paper focuses on design of retina and matching network circuit to harvest RF energy from the ambient.

1. Introduction

The potential of wireless signals and other RF signals is not completely utilised. These RF signals from the environment can be captured and used to power low power devices. The RF signals coming from radio towers, wireless networks, microwave ovens, etc. are not completely exploited. Using the right antenna, this ambient RF energy can be captured and used to power low power devices. Energy harvesters can use the free, ambient background energy that is already there. For short-term or long-term use, the converted energy can be kept in a capacitor or battery, respectively. This will be the best solution for the increasing energy crisis. This research presents the first power over Wi-Fi system that delivers power to low-power sensors and devices and works with existing Wi-Fi chipsets. Specifically, shows the ubiquitous part of wireless communication infrastructure, the Wi-Fi router, can provide far field wireless power without significantly compromising the network's communication performance. Rectenna design is one of the most important methods for electrical energy harvesting, which is of utmost importance. A rectenna combines an antenna with a rectifier. The antenna picks up wireless energy, which the rectifier then converts to a DC output. A low pass filter in the circuit also matches the load to the rectifier. Rectifying diodes turn around incoming signals to produce DC current. In addition to removing unnecessary components, the low-pass filter performs another crucial task: it matches the rectifier's load. In order to achieve high energy conversion efficiency, it also suppresses the diode's high order harmonics. The most significant aspect for devices that harvest energy from wireless energy is this high energy efficiency conversion. The system must deliver the maximum power without compromising Wi-Fi performance. As rectenna proves to be efficient for RF energy harvesting and it has few other advantages too. The primary and most important advantage of rectenna is its lifetime. The lifetime of the Rectenna is unlimited unlike other energy sources. The energy that we are harvesting wouldn't affect the environment and hence rectenna is green way to harvest energy. A long-range dual-band rectenna have been used for harvesting ambient RF energy from GSM/900 and GSM/1800 in previous works. Also it is learnt that with the help of a partial ground plane approach the antennas return loss and bandwidth could be increased. In a few cases, an E-shaped microstrip antenna was joined to an L-shaped structure operated on GSM/900. In another study we learnt that battery-free temperature and camera sensors were powered with Wi-Fi at ranges of 20 and 17 feet respectively providing far field wireless power. Along with it there are power feeding circuits designed for Wi-Fi devices operating at 2.4 GHz standard**.** A hemispherical array of multiband, coupled-resonator monopole was used to target frequency bands with the high energy densities. Another work showed a triangular monopole antenna showing good gain. In 2010, a work of rectenna based on modified bridge rectifier with four Schottky diodes was developed with electromagnetic and circuit approaches.

2. Rectenna Design

The design of the rectenna primarily consists of two major parts, receiving antenna and rectifier. The antenna is micro strip patch antenna that radiates at 2.4 GHz frequency. The antenna and rectifier circuit was designed using Agilent ADS2011 simulation software. The rectangular patch antenna was selected for the design using various optimizationsand the width and length of the proposed antenna was calculated using relevant equations for the required 2.4 GHz frequency. A rectifier is often made up of a combination of Schottky diodes, an input low pass filter, an output bypass capacitor and a resistive load. Usually, the input a low pass filter (LPF) which rejects harmonics created by the diode and acts as a matching circuit betweenthe antenna and the rectifying circuit.

Antenna design: Patch antennas offer effective low profile designs for a wide range of wireless applications because of them being inexpensive to fabricate light in weight, suitable for high frequency applications and support multiple function circuits. Electronics like LNA's and SSPA's can be integrated with these antennas quite easily. It consists of a rectangular sheet called as patch which is mounted over a bigger sheet of metal called a ground plane.It is well known that the narrow bandwidth is the main shortcoming of patch antenna and several techniques with various configurations at different radio frequencies have been proposed to address this problem by researchers. A simple micro-strip patch antenna consists of a conducting patch and ground plane between them is a dielectric medium called the substrate having a particular value of dielectric constant. The designed antenna is shown in Fig 1.

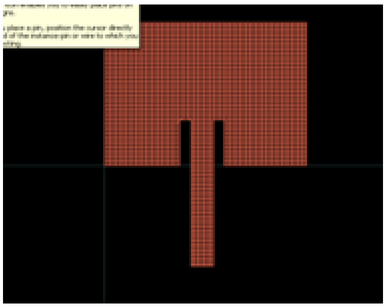

FIGURE 1. Rectangular Patch Antenna

In comparison to the substrate and ground, a patch is smaller in size. The dimension of a microstrip patch antenna was determined by its resonance frequency and the dielectric constant.. The distance between the patch and the ground plane – the substrate or dielectric height h – determines the bandwidth. A thicker substrate increases the gain to some extent, but may lead to undesired effects like surface wave excitation: surface waves decrease efficiency and perturb the radiation pattern. The ground plane should extend beyond the edges of the patch by at least 2 to 3 times the board thickness for proper operation. A ground plane that is too small will result in a reduced front to back ratio. Making the ground plane larger also increases the gain, but as the ground plane size increases, diffraction near the edges plays less of a role and increasing the size of an already large ground plane has very little effect on gain. The dimensions of the proposed rectangular patch antenna using the substrate RT DUROID 5886 is given in the following table 1

TABLE 1. Dimensions of rectangular patch antenna

Parameter	Values
Length	14 mm
Width	22 mm
Er	2.2
TAN D	0.0009
Thickness	3.5 mm
Frequency	2.4 GHz

Rectifier Design: The rectifier is designed using a microstrip lines, a diode normally a schottky one which has a low recovery time, quarter wave length microstrip line, a matching microstrip line and a low pass filter in the output. Normally the rectifier circuit is printed on FR4 substrate. A single frequency voltage source was used as the input source of the rectifier. The proper impedance matching circuit in the form of transmission line was essentially required for the designed length and width. Transient analysis was used in the simulation of rectifier circuit. Losses play a vital role in the efficiency of the rectenna design. The efficiency lies in the conversion of usable DC power using the output voltage drop across the load, the load resistance, the received RF input power at the antenna and the DC power entering the load.

Matching Network: In order to optimize the rectenna for maximum power transfer, the antenna impedance must be matched to the impedance of rectifier diode. Alpha SMS7630-079 Schottky diodes were used for rectification, and a source-pull simulation was used to obtain the diode input impedance. For a variable input power, the resulting DC voltage is quantified for each source impedance. The results shown on the Smith Chart indicate that the optimum source impedance has to be presented to each diode moving counter-clockwise with an increase in frequency, and closer to the centre of the Smith Chart with an increase in input power. The region of optimal source impedance is used to optimize the antenna design which needs to match the diode impedance. The final matching circuit is given in fig 2.

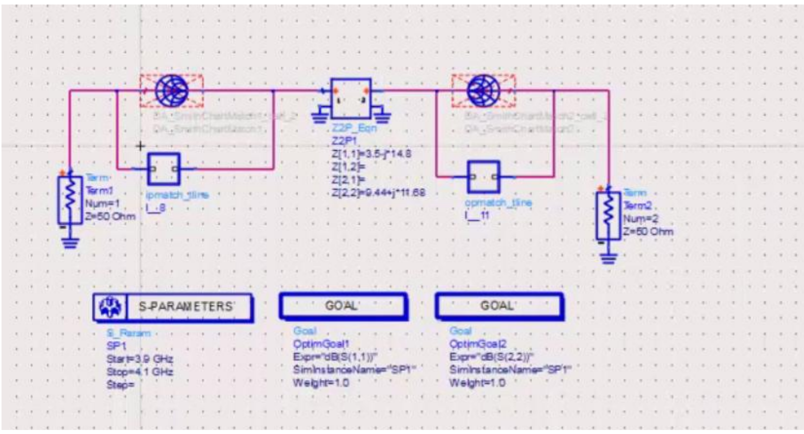

FIGURE 2. Design of Rectifier with Matching Network

Results and Discussion: The rectangular patch antenna was designed and optimized in ADS environment. The return loss is one of the important parameter of an antenna and it defines how much the antenna would reflect the signals that it receives. The simulated return loss of the proposed rectangular patch antenna shown in Fig 3 was found to be -39 dB which was well suited for the required application.

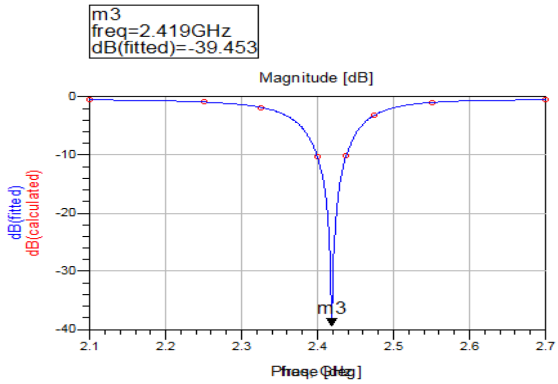

FIGURE 3. Return loss of the proposed antenna

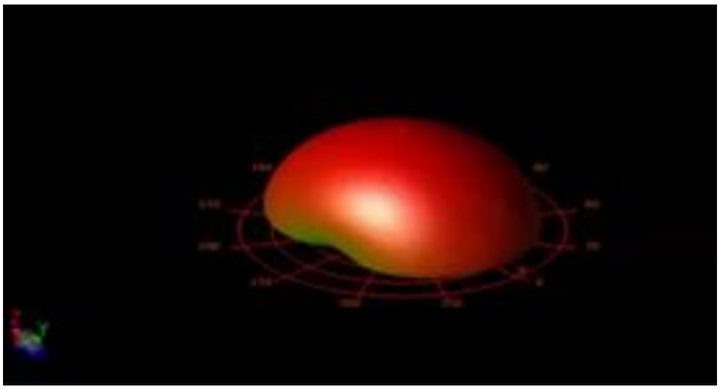

FIGURE 4. Radiation pattern of the proposed antenna

Fig 4 shows the radiation pattern of the proposed rectangular patch antenna with a good directivity.
The other parameters of the antenna were tabulated as below.

TABLE 2. Simulation results of rectangular patch antenna

Parameters	Values
Return loss	-39 dB
Gain	6.09 dBi
Directivity	7.61 dBi
Bandwidth	0.4 GHz
Power Radiated	0.004W
Efficiency	70.384%

The current distribution of the proposed rectangular patch antenna is shown in Fig 4 which clearly shows the current distribution is uniform throughout the antenna and especially near the feed.

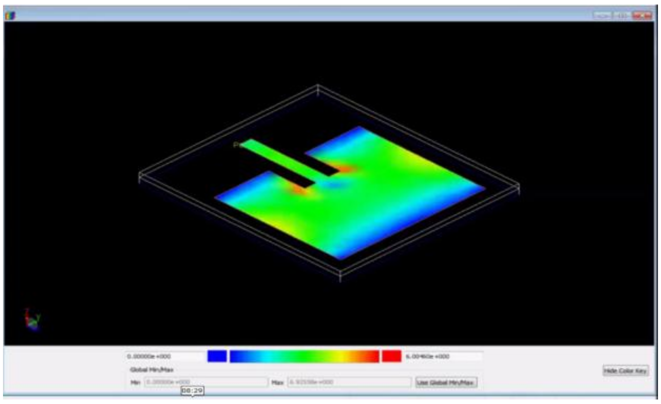

FIGURE 5. Current distribution of the proposed Antenna

For the proper working of the rectifier circuit, the matching network must be working properly so that maximum usable voltage will be generated. Fig 5 and Fig 6 shows the impedance matching circuit before and after optimization which clearly shows that input and output impedance matches perfectly after optimization.

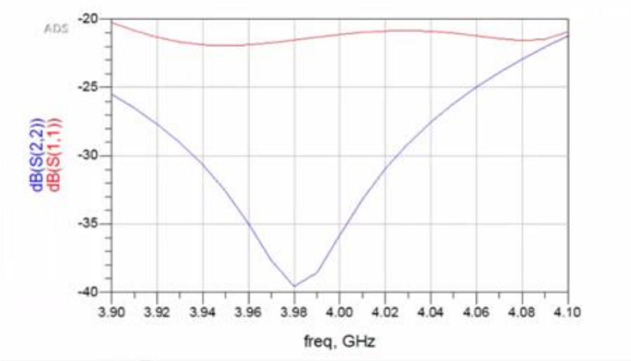

FIGURE 6 . Impedance Matching before Optimization

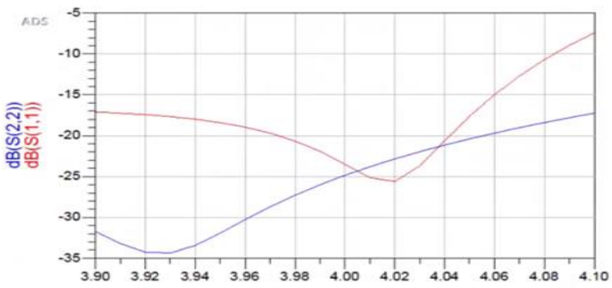

FIGURE 7. Impedance Matching after Optimization

3. Conclusion

The research work discuss about the rectenna design for RF energy harvesting. A Rectangular patch antenna with return loss of -39 dB was designed and simulated using ADS. The current distribution and radiation analysis was done and the antenna was found well suited for harvesting the RF signals. The rectifier with impedance matching circuit was also designed and the input and output impedance matched perfectly after the optimization. The designed rectenna (antenna and rectifier) was found best for RF energy harvesting applications.

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