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AMBIENT RADIO FREQUENCY POWER HARVESTING BY YAGI ARRAY BROADBAND RECTENNA

R. Premalatha [a*], T. Jenish [b]

Department of Electrical and Electronics Engineering, Dr. M G R Educational and Research Institute, Chennai-95, Tamilnadu, India

[a] e-mail: premiselva@yahoo.com, [b] e-mail: jenish.25@gmail.com

Abstract

A high efficiency Yagi array rectenna that can harvest ambient radio frequency power of UMTS-2100 band effectively were presented. The rectenna consists of a broad band antenna and a rectifier circuit. The proposed rectenna is based on a 1x4 Yagi array antenna with bandwidth from 1.83 GHz to 2.20 GHz and high gain of 10.920 dBi at 2.14 GHz. The rectifier is designed to convert the harvested RF power into dc voltage and is then combined with 1x4 Yagi array antennas to form a high efficiency rectenna. Simulation results show the Power Conversion Efficiency (PCE) of 86.69% and DC voltage of 200 mV is achieved at the input power of -20dBm respectively. The radiation characteristic and efficiency of the proposed rectenna are suitable for the purpose of ambient RF power harvesting application.

Keywords: Energy Harvesting, Antenna Array, Yagi Antenna, Rectenna, Rectifier

1. Introduction

Wireless power harvesting has gained a lot of attention, since radio frequency (RF) power is widely broadcasted from numerous intentional or unintentional electromagnetic resources such as GSM-900, GSM-1800, UMTS-2100, WiFi (2.45GHz), DTV etc [1]. Therefore it is significant to collect this free ambient RF power and utilize it as the supply energy for many battery powered devices such as handset, wearable medical sensor and implantable medical devices. However, since the power density of the ambient RF power is very small, it is very challenging to design wireless power harvesting system with satisfying RF-to-dc power conversion efficiencies. The most important and indispensable component in a wireless power harvesting system is the rectifying antenna(rectenna) which harvest the RF power and then converts it into dc power. In recent years there have been many designs of rectennas for harvesting RF power [2]. A 2.45 GHz rectenna for WiFi energy harvesting, generates dc voltage at very low input power of -40 dBm [3]. In a dual band rectenna is designed by using 1x4 Yagi arrays which exhibited efficiency of 40% with power density is 455 μW/m2[4]. In a high efficiency rectenna was presented it operated at 1.8 GHz to 2.5 GHz with conversion efficiency of 55% at input power of -10 dBm [5]. Sun presented a new rectenna using beam width enhanced antenna array [6-9] to achieve efficiency of 50%, when the wave incident angle is between -38º and 35º. In rectifier was connected to antennas to collect RF power over the frequency band of 2.45GHz. The rectenna provides a maximum conversion efficiency of 83% with the input resistance of 1400Ω. Beside different antenna designs [10-12] and scalable antenna designs for RF energy harvesting have been investigated as well.

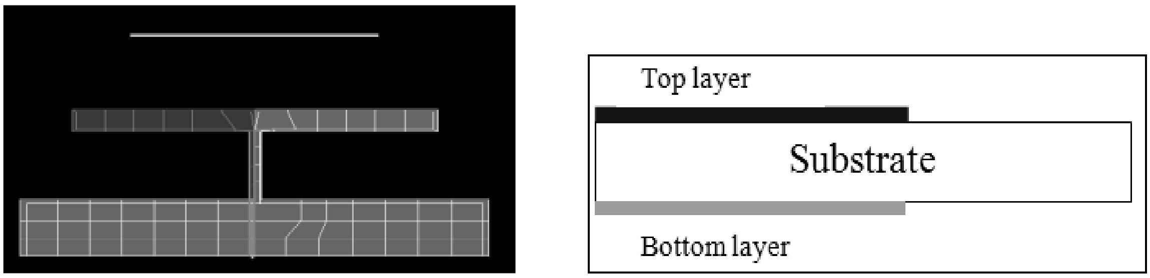
Table 1 Ambient Power Characteristics of Different Public Telecommunication Bands

Band	Downlink Frequency (MHz)	Antenna Gain (dBi)	Received Power (dBm)
GSM-900	952-960	2	-35 to -25
GSM-1800	1805-1880	10	-25 to -15
UMTS-2100	2110-2170	10	-25 to -15

In this article, Yagi array rectenna with high power conversion efficiency for ambient wireless power harvesting is proposed. In order to choose best ambient RF source, each ambient RF power transmission characteristics have been investigated as shown in Table 1. From the table, it can be found that the power density of UMTS-2100 band is apparently much larger than that of the GSM-900, GSM-1800 and WiFi. The proposed rectenna is focuses on UMTS-2100 band.

2. Yagi Array Antenna

2.1 Single Element Yagi Antenna



(a) (b)

Figure 1 Single Element Yagi Antenna (a) Top View (b) Side View

Figure 1 (a) and 1(b) shows the top and side view of the proposed single element Yagi antenna. The proposed antenna consists of microstrip feed line, two double- side parallel -strip feed lines, two dipole elements, two directors and a conductor ground plane . The conductor plane can be consists of partial ground plane and act as a reflector element, which make the antenna radiated forward and to achieve better frond-to -back ratio. The antenna is designed on a 1.5 mm-thick PTFE substrate with a dielectric constant of 2.1 and loss tangent of 0.0012. The geometrical parameters of single element Yagi antenna are shown in Table 2.

Table 2 Geometrical Parameters of Single Element Yagi Antenna

Parameter	Description	Dimension (mm)
X	Length of the ground plane	80
Y	Width of the Yagi antenna	112
L_{d1}	Length of the director	57.12
L_{d2}	Length of the driver	64.26
W_{d1}	Width of the director	0.5
W_{d2}	Width of the driver	8
W_f	Width of feed line	2.4
W_{gud}	Width of the ground plane	20
S_{d1}	Spacing between director and driver	42.84
S_{d2}	Spacing between ground plane and driver	35.7

S_{d3}	Spacing between each antenna element	26

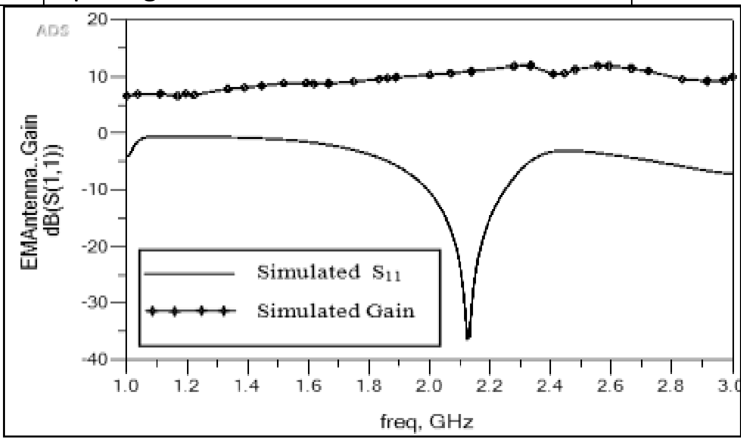


Figure 2 Simulated S11 and Gain of the Single Element Yagi Antenna

The single element Yagi antenna is simulated by using Advanced Design System (ADS 2015.01). The simulated S11 and gain of the single element Yagi antenna are illustrated in Figure 2. The simulated S11 is -36.430 dB and gain is 6.204 dBi at 2.13 GHz and -10dB bandwidth is from 1.99 to 2.250GHz.

2.2 Yagi Array Antenna

A 1x4 yagi antenna is designed by simply connecting four single element yagi arrays with T -Junction power divider to achieve the maximum gain. The 1x4 Yagi array antenna is shown in Figure 3. The Simulated |S11| and gain of the 1x4 yagi array are illustrated in Figure 4.

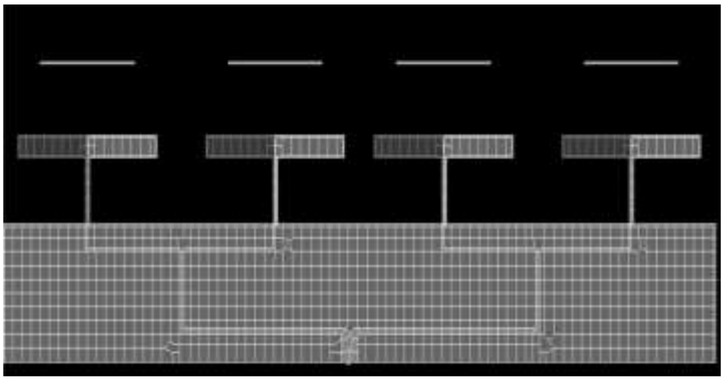


Figure 3 Layout of the 1x4 Yagi Array Antenna

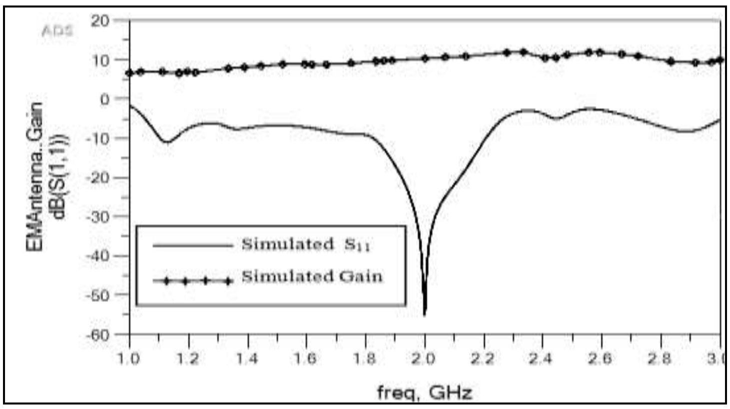


Figure 4 Simulated S11 and Gain of the 1x4 Yagi Array Antenna

The proposed 1x4 yagi array antenna operates at 2.14 GHz with a return loss of 55.24 dB. The simulation results show that -10 dB bandwidth is from 1.833 to 2.2 GHz, which covers the ambient RF power of UMTS- 2100 band. The highest gain of 10.920 dBi is achieved at 2.14 GHz. The use of high gain antenna is to receive more power for rectification.

3. Power Harvesting Circuit Design

Power Harvesting Circuit consists of a matching circuit followed by a rectifier and a DC filter which is connected to load and it is shown in Figure 5.

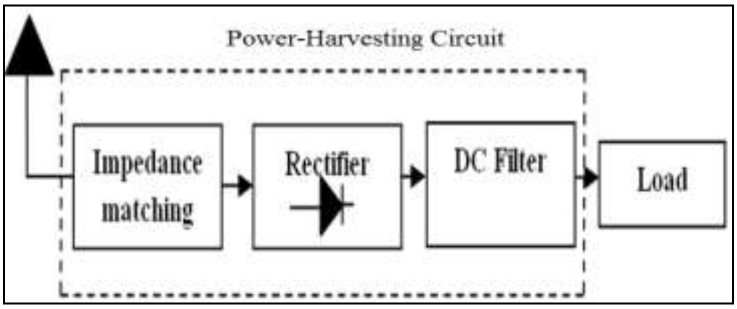


Figure 5 Block Diagram of Rectenna

Matching circuit is designed to match the impedance of the antenna to the impedance of the rectifier. Matching circuit helps in minimizing the losses due to reflection and also aids in maximum power transfer. In this paper, a series mounted diode topology is investigated. This topology is used to achieve high efficiency even when the input RF power is low. Matching circuit consists of a two-section T-shape microstrip transformer as shown in Figure 6.

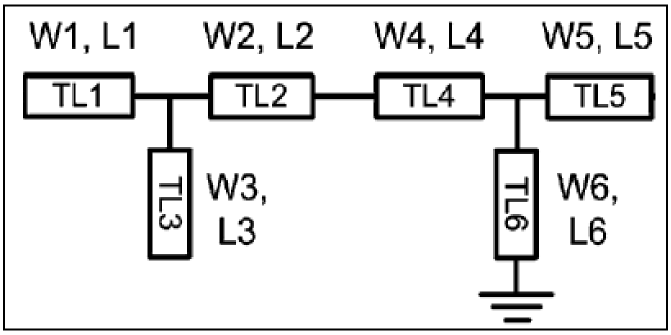


Figure 6 Topology of the Matching Circuit

Rectifier consists of a Schottky diode HSMS-2852 which has low built-in voltage of 0.15V and exhibits fast switching response compared to a pn-junction diode. The Schottky diode is used to convert RF power to DC power. The DC filter used is a third order stepped impedance low pass filter with a cut-off frequency of 2.14 GHz as shown in Figure 7. It is used to remove unwanted ac signal present if the input RF signal is not rectified properly. The output of the DC filter is sufficient to drive the resistive load.

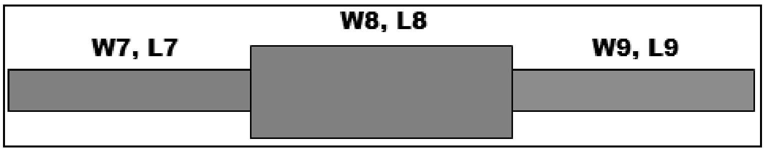


Figure 7 Stepped Impedance Low Pass Filter

The parameters of the matching circuit and DC filter are initially calculated using Advanced Design System(ADS) and later optimized to obtain high efficiency at 2.14 GHz. The optimized parameters are W1=8.3mm, L1=0.6mm, W2= 23.5mm, L2=3.9mm, W3=3.5mm, L3=13.4mm, W4=16.9mm, L4=10mm,W5=23.4mm,L5=6.35mm,W6=2mm, L6=11.3mm, W7=24.5mm, L7=0.44mm, W8=48.3mm, L8=9mm, W9= 24.5mm, L9=0.44mm. The substrate used is 1.5 mm-thick PTFE with dielectric constant of 2.1. The value of load resistance used is 5 kΩ. The simulated return loss plot of the rectifier is shown in Figure 8. It is observed that the matching circuit provides good matching with a return loss of 28.39 dB at 2.14 GHz.

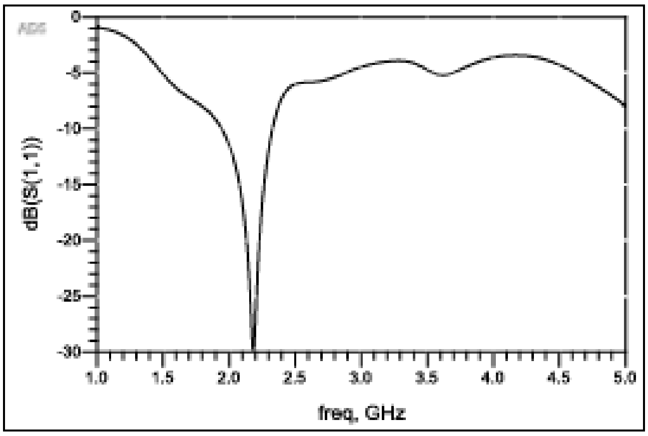


Figure 8 Simulated Return Loss of the Rectifier

The performance of the rectifier is evaluated with Power Conversion efficiency. Power Conversion Efficiency (PCE) of the rectifier can be calculated as:

$$\eta(\%) = \frac{V_L^2}{R_L} * \frac{1}{P_{in}} * 100 \qquad (1)$$

Where

VL is the output dc voltage on the load resistor,
RL is the value of load resistance and
Pin is the power level of the input signal given to the rectifier

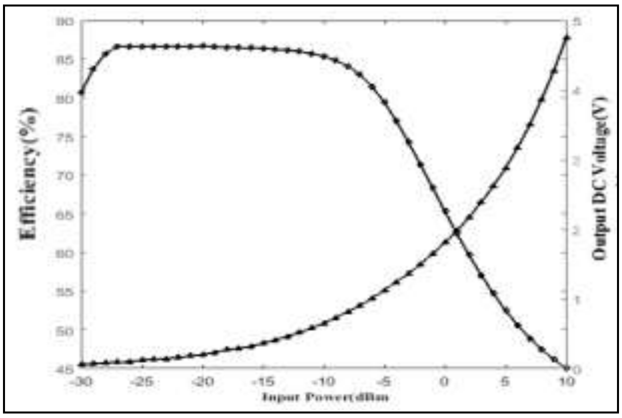


Figure 9 Simulated Efficiency and Output DC Voltage of the Rectifier for Different Input Power Levels

The input power levels are chosen in the range of -25 to 15 dBm since the ambient RF power of UMTS-2100 band is available in this range as shown in Table 1. The efficiency and output voltage of the rectifier for different input power levels are simulated and the results obtained are shown in Figure 9. The simulated output DC voltage varies from 120 mV to 360 mV and the overall efficiency is 86.6% for the range of input power level from -25 to -15 dBm. Hence the proposed rectenna can efficiently harvest ambient RF power of UMTS-2100 band.

4. Conclusion

A novel rectenna with a 1x4 Yagi antenna array and rectifier is proposed. First, a 1x4 Yagi antenna array is designed which exhibits a return loss of 55.24 dB at 2.14 GHz. Then, a rectifier is designed which provides output DC voltage of 120 mV to 360 mV and an overall PCE of 86.6%. Therefore, this rectenna can be readily employed in wireless charging applications to harvest ambient RF power in UMTS-2100 band.

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