Australian Journal of Basic and Applied Sciences, 8(4) Special 2014, Pages: 270-277

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

Investigation of Wideband Coplanar Antenna for Energy Scavenging System

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ARTICLE INFO

Article history:
Received 20 November 2013
Received in revised form 24 January 2014
Accepted 29 January 2014
Available online 5 April 2014

Key words:
Antenna; Energy harvesting; Rectifier; RF energy scavenging

ABSTRACT

This paper studies a wideband monopole antenna of ice-cream shape. It is integrated with a rectifying circuit to produce a DC voltage. This consolidation method has the potential to be used for RF energy harvesting system. The antenna is designed by using CST Studio Suite 2011 software and fabricated on a double sided FR-4 printed circuit board using an etching technique. A single diode rectifying circuit is designed, modelled and simulated in this work by using Agilent Advanced Design System (ADS) 2011. The design is then fabricated in house and measured. Simulation and measurement were carried out for various input power levels at the specified frequency band. The maximum DC voltage that has been achieved from the system is 1.969 V at 20 dBm of transmitting power where D = 30 cm.

To Cite This Article: Z. Zahriladha, Z. NurAishah, M. D. Bazilah, N. H. Mohd, Z. A. A. Mohamad, A. M. Mohamad, Centre for Telecommunication Research & Innovation (CeTRI), Faculty of Electronic & Computer Engineering, UniversitiTeknikal Malaysia Melaka (UTeM), Hang Tuah Jaya 76100, Durian Tunggal, Melaka, MALAYSIA.. ***Aust. J. Basic & Appl. Sci.,*** *8(4): 270-277, 2014*

INTRODUCTION

The RF energy harvesting system is known as remotely powered device that converts RF to DC power without requiring any internal source while extracting its power from propagating radio waves (Zakaria, Z. N. A. Zainuddin, M. N. Husain and M. Z. A. Abd Aziz, 2013). However, the electrical power generated by energy harvesting techniques is small and less than few milli-watts depending on the techniques. However the power derived is enough for small electrical or low power consumption devices.

Thus, energy harvesting technology promotes a promising future in low power consumer electronics and wireless sensor networks. Fig. 1 shows the basic block diagram of an energy harvesting system.

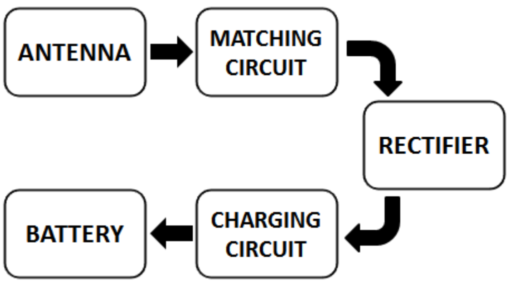

Fig. 1: Block diagram of energy harvesting system

RF energy harvesting is a green technology that suitable for a wide range of wireless sensing applications such as wireless sensor networks, wireless power as well as used in RFID tags and implantable electronics devices (Abd Aziz, M. Z. A., Z. Zakaria, M. N. Husain, N. A. Zainuddin, M. A. Othman and B. H. Ahmad, 2013; Hu, Y., M. Sawan and M. N. El-Gamal, 2005; Vullers, R. J. M. and R. van Schaijk; Balanis, C. A.,2005). The RF energy harvesting system is made up of a microwave antenna, a matching circuit, rectifying circuit and a resistive load.

The RF signals received by the antenna will be transformed into DC signals by a diode based rectifying circuit. In order to obtain an optimum power transfer, a matching circuit and rectifier will be used. The matching circuit is used in this stage to achieve impedance matching between the antenna and rectifier. However, for this wideband antenna for RF energy harvesting system, there are several range frequencies need to be covered

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particularly at 2.3GHz (WiMax), 2.4 GHz (WLAN), 2.6 GHz (LTE/4G) and also 5.2 GHz (WLAN). The applications particularly use as low-power sensor networks in remote areas (Pozar, D. M., 2012)

2. Antenna And Rectifier Design:

Antenna:

A coplanar ice cream cone antenna is chosen due to its wideband characteristic which could cover several ranges of frequencies. It is basically a combination of triangle, rectangle and circular shape patches attached to a microstrip feeding line.

The proposed wideband monopole antenna is fed by a coplanar waveguide (CPW) line where the central conductor is separated from a pair of ground planes. The CPW offers several advantages including the ability to work in lower frequencies and ease of fabrication.The physical parameters of the coplanar ice cream cone antenna are shown in Fig. 2.

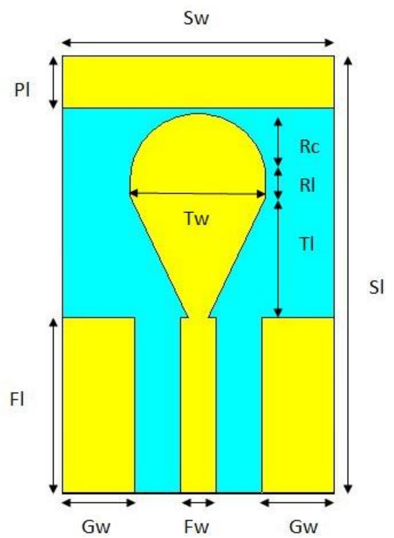

Fig. 2: The design parameters for the coplanar ice cream cone antenna

The dimensions of the antenna are determined by using certain equations. The antenna is then optimized through a parametric analysis. Table 1 shows the details of the dimension for coplanar ice cream cone antenna.

Table 1: The Dimensions of Coplanar Ice Cream Cone Antenna

Symbol	Design parameters	Dimension (mm)
Sw	Substrates width	30
Sl	Substrates length	50
Fw	Feedline width	4
Fl	Feedline length	20
Gw	Ground width	8
Pl	Patch length	6
Rc	Radius circle	7.521
Rl	Rectangle length	2
Tw	Triangle width	15
Tl	Triangle length	13.85

Rectifying Circuit:

Rectifier is an electrical circuit that converts RF power from a lower voltage to a higher DC voltage using a network of capacitors and diodes (Nintanavongsa, P.,et. al, 2012). A single diode rectifier is chosen to be integrated with the antenna where the HSMS-286B diode is used. The HSMS-286X family is classified as biased detector diodes that been designed and optimized for use from 915 MHz to 5.8 GHz frequency range. They are ideal for RFID and RF tag applications as well as large signal detection, modulation, RF to DC conversion or voltage doubling (Avago Technologies). Therefore, it is suitable for the energy harvesting system that been conducted at frequency range of 2 GHz to 4 GHz.

To design the rectifying circuit, the transmission line of the circuit needs to be calculated. The values are then used as the initial parameters in the ADS software before tuning them for optimized performance. For this rectifying circuit, the single stage rectifier design consists of one diode and one capacitor as shown in Fig. 3.

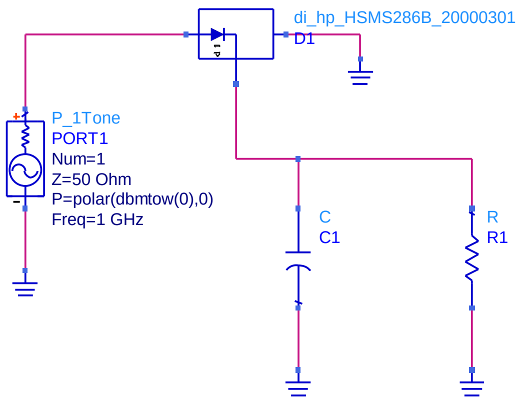

Fig. 3: The single diode rectifying circuit in schematic view

This circuit is chosen as it is less complex and minimizes the diode losses. Therefore, the diode which is used in this design is Schottky diode model HSMS-286B. The transmission line of the rectifying circuit is calculated using the formula given (Nintanavongsa, P.,et. al, 2012; Buonanno, A., M. D'Urso, 2012).

$$\theta = \frac{\omega}{c} = \frac{2\pi f}{c} \tag{1}$$

$$Z_{in} = j\left(\omega c - \frac{1}{\omega c}\right) \tag{2}$$

$$Z_0 = \sqrt{Z_{in} \times Z_L} \tag{3}$$

c	=	the free space speed of light, 3×10^8 m/s
Z_L	=	the impedance of 50 Ω
f	=	the resonant frequency

where

The design of rectifier circuit has been optimized and before converted into microstrip layout as shown in Fig. 4.

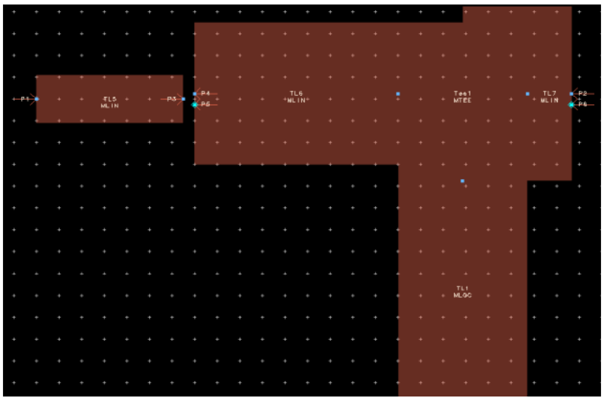

Fig. 4: The single diode rectifying circuit in momentum view

RESULTS AND DISCUSSIONS

The antenna is then fabricated in-house and the photograph of the prototype can be seen in Fig. 5. An experimental measurement also has been made to validate the simulation results.

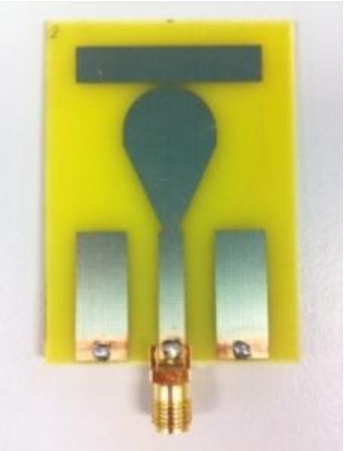

Fig. 5: Antenna prototype of coplanar ice cream cone antenna

Antenna:

Return loss, bandwidth and gain: S-parameter simulations of the antenna have been carried out using the Computer Simulation Tool 2011. Fig. 6 shows the simulated and measured return losses of the antenna.

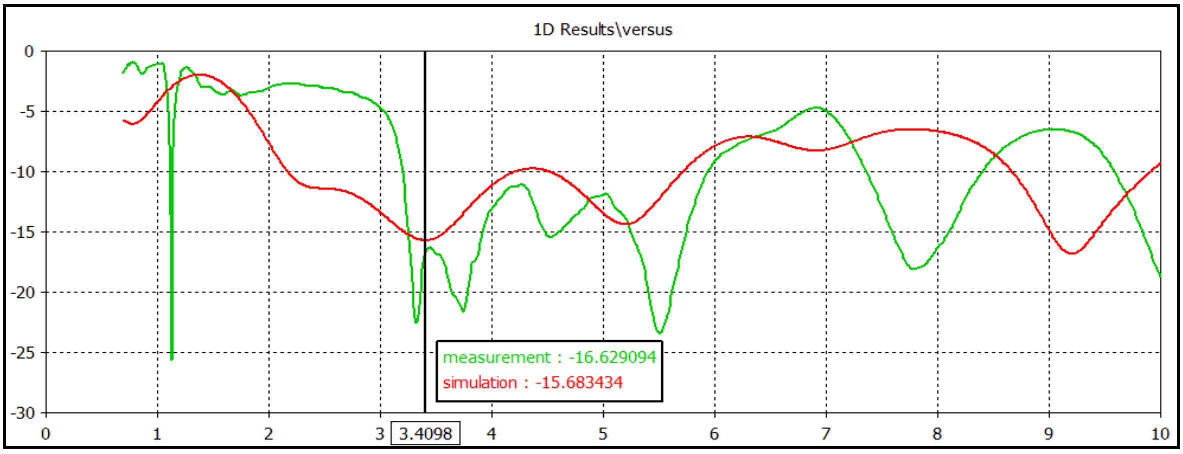

Fig. 6: Simulation and measured return loss of coplanar ice cream cone antenna

The measured return loss is in line with the simulation response where both manage to achieve lower than -10 dB. However, measurement result shows better return loss than the simulated one but the resonant frequencies were shifted.

From the simulated data, the coplanar ice cream cone antenna caters a frequency range from 2.17 GHz to 4.2 GHz with a bandwidth of 2.03 GHz. While from the measured data, a frequency range from 3.20 GHz to 5.99 GHz with a bandwidth of 2.79 GHz is successfully achieved. Table 2 shows the comparison of simulation and measurement result for the planar dual-band monopole antenna.

Table 2: Simulation and Measurement Result of Coplanar Ice Cream Cone Antenna

DesiredFreq.		Return Loss(dB)	Bandwidth(GHz)
2.3GHz	Sim.	-10.78	1.98
	Meas.	-3.14	NA
2.4GHz	Sim.	-11.46	1.98
	Meas.	-2.95	NA
2.6GHz	Sim.	-12.01	1.98
	Meas.	-2.73	NA
5.2GHz	Sim.	-14.14	1.98
	Meas.	-14.32	2.93

The differences between simulation and measurement result are caused by the losses influenced cables and connectors. However, the simulation results prove that the antenna is able to cater the operation of all four frequency bands.The radiation characteristics are also investigated and shown in Fig. 7.

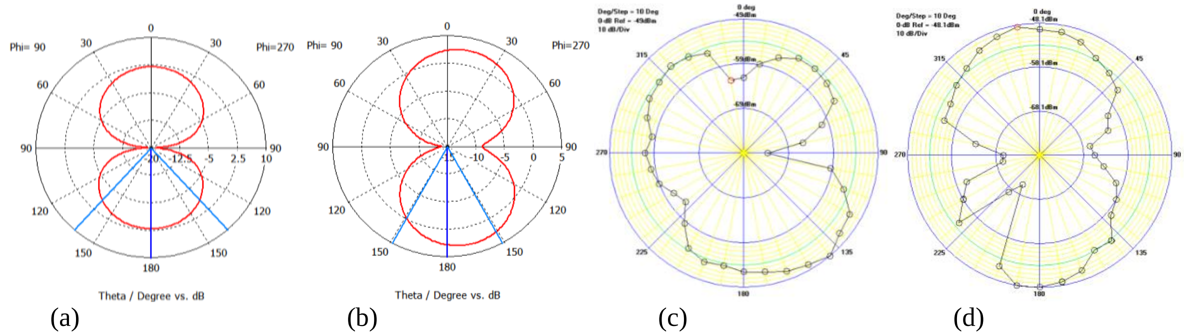

Fig. 7: Antenna's radiation patterns at 3.4 GHz for (a) e-plane simulation (b) h-plane simulation (c) e-plane measurement (d) h-plane measurement

Both simulated and measured radiation pattern indicates that the antenna radiates directionally. The different patterns of simulation and measurement are observable and this might be caused by the environment around the antenna such as metallic influence which affected the measurement process. Fig. 8 shows the surface current of the dual-band monopole antenna which shows that the antenna radiates efficiently at the triangular part of the antenna..

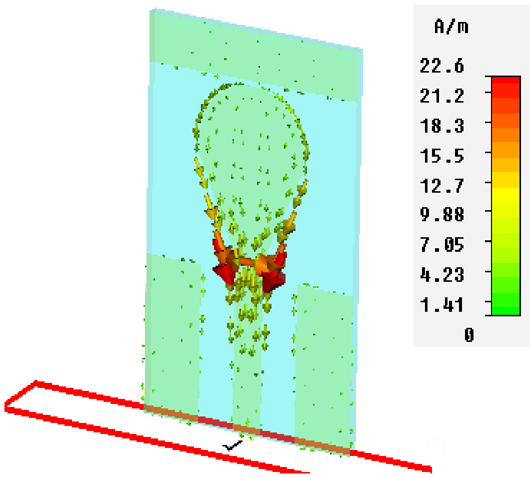

Fig. 8: Simulated surface currents of coplanar ice cream cone antenna

Rectifying Circuit:

The single diode rectifier is then fabricated in-house and the photograph of the prototype can be seen in Fig. 9. An experimental measurement also has been made to validate the simulation results.For rectifying circuit, the simulation results obtained from ADS needs to be analyzed in terms of its efficiency and the voltage output and compared it with the measurement values.

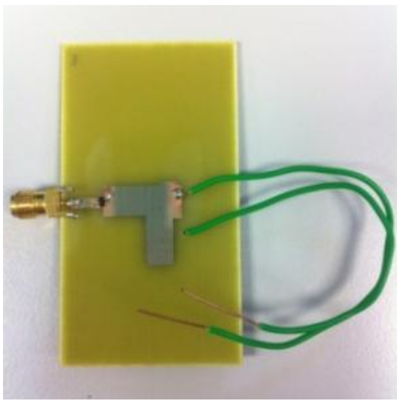

Fig. 9: The prototype of the rectifying circuit.

The simulation and measurement result of the single diode rectifier is shown in Fig. 10. From the graph, it can be observed that the maximum output voltage of both process are in line where they obtained an output voltage of approximately 3.174 V despite of the different rising time.

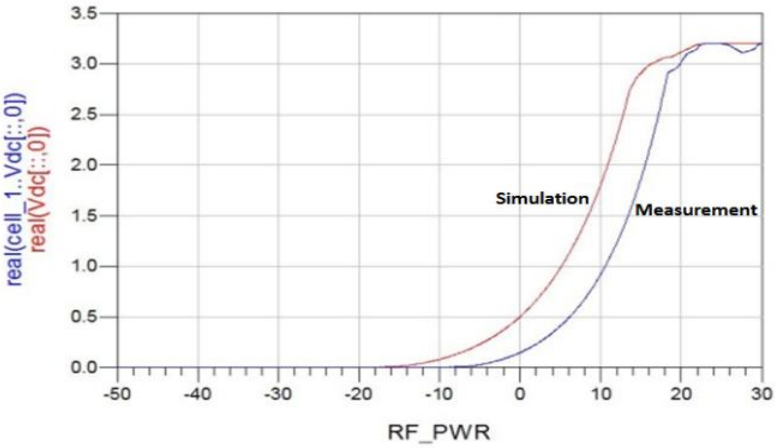

Fig. 10: The simulated and measured output voltage of the rectifying circuit

Integration of Antenna and Rectifier:

The coplanar ice cream cone antenna is then integrated with the rectifying circuit as shown in Fig. 10 and has been tested in the lab.

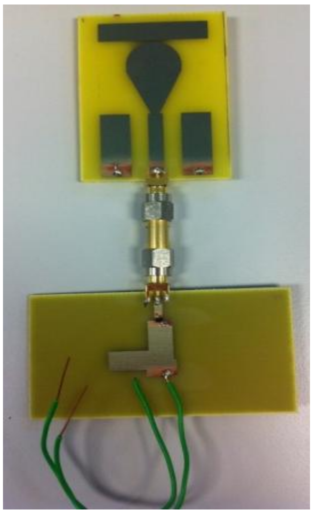

Fig. 11: The integrated antenna and rectifying circuit

An experimental test has been conducted by varying the distance, D between the transmitting and receiving antenna. The input power of transmitting antenna is injected directly from a signal generator ranged from -15dBm to 20dBm. The output DC voltage is then measured by using a digital multimeter. Table 3 shows the results of the output voltage recorded at the specified distances.

From Table 3, it can be observed that the variation of distance and input power will affect the output DC voltage. The voltage increased when the distance, D of the transmitter and the rectenna is reduced. The output voltage and power are also increased when the input power increased.

Hence, it can be concluded that the output voltage and output power is inversely proportional to the distance between transmitting antenna and the rectenna.

This experimental work is an early effort done for the antenna of an energy harvester. The performance may be improvised by designing antennas with optimum performance to capture as much energy as possible and able to capture more energy even further. It is recommended to discover and design the most suitable antenna topology in order to produce better output.

Table 3: The Output Voltage for Different Distances

Distance (cm)	Power transmit (dBm)	Output Result	
		P_o (dBm)	Voltage (mV)
30	-15	-58.13	0.3279
40		-58.89	0.3369
50		-58.78	0.3765
60		-58.97	0.3086
70		-59.28	0.3014
30	-10	-59.47	0.3369
40		-58.01	0.3159
50		-58.91	0.3052
60		-58.73	0.3638
70		-56.41	0.3633
30	-5	-58.62	0.3295
40		-58.24	0.3057
50		-57.43	0.3657
60		-58.94	0.4147
70		-55.72	0.4956
30	0	-57.18	0.3586
40		-57.43	0.2865
50		-58.69	0.3699
60		-54.65	0.4981
70		-51.91	0.5607
30	5	-54.57	0.4229
40		-58.65	0.2708
50		-56.69	0.4797
60		-51.87	0.6549
70		-55.76	0.3328
30	10	-51.61	0.6261
40		-59.06	0.2927
50		-51.85	0.5018
60		-48.67	0.9107
70		-56.73	0.3513
30	15	-47.33	1.0490
40		-58.05	0.3067
50		-48.89	0.8157
60		-44.16	1.4180
70		-57.31	0.3117
30	20	-41.85	1.9690
40		-58.33	0.3609
50		-43.89	1.5670
60		-39.73	2.0850
70		-55.84	0.4903

Conclusion:

In this paper, the performance of a coplanar ice cream cone antenna has been presented. The antenna operates well at several frequencies including at 2.3GHz (WiMax), 2.4 GHz (WLAN), 2.6 GHz (LTE/4G) and also 5.2 GHz (WLAN). The antenna's measured return loss is slightly better than the simulation value. However, the resonance frequencies are marginally shifted. Nevertheless, it is able to cover the frequency ranges of interest. The simulated antenna bandwidth represents 59.5% for $||S_{11}|| \leq 10$dB, while the simulated bandwidth 81.8% for $||S_{11}|| \leq 10$dB. The maximum DC voltage that has been achieved from the rectenna is 1.969 V at 20 dBm of transmitting power where D = 30 cm. Future works can be made to improve the DC voltage of the rectenna. A design of matching circuit can be proposed to match the impedance of the antenna with the rectifying circuit. This is to ensure the optimum power transfer can be delivered.

ACKNOWLEDGEMENT

The authors would like to thank UTeM for sponsoring this work under the CoE, research grant UTeM, PJP/2012/CeTRI/Y00001.

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