RF HARVESTER FOR DC SUPPLY

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by

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LIST OF ABBREVIATIONS

DC	Direct Current
AC	Alternating Current
RF	Radio Frequency
FR	Flame Retardant
ADS	Advance Digital System
ISM	Industrial, Scientific and Medical
MOSFET	Metal-Oxide Semiconductor Field Effect Transistor
NASA	National Aeronautics and Space Administration
CMOS	Complementary Metal Oxide
PET	Polyethylene Terephthalate
IEEE	Institute of Electrical and Electronic
AM	Air Mas Coefficient
OEFS	Opto-electric Field Sensor
PV	Photovoltaics
GSM	Global System for Mobile Communications
WSN	Wireless Sensor Network
WLAN	Wireless Local Network
WiMAX	Worldwide Interoperability for Microwave Access
3G	Third-Generation
MWS	Microwaves
PCB	Printed Circuit Board

LIST OF SYMBOLS

Hz	Unit of frequency
V	Voltage
Vrms	Root Mean Square Voltage
R	Resistance
dB	Decibel
dBm	Decibels-meter
dBi	Decibels-isotropic
L	Length
ℓ	Inset length
l	Line length
D	Diameter
S	Spacing of inner winding
C	Circumference of helix
Ω	Ohm
°C	Degree Celsius
α	Pitch angle
a	Radius
f	Frequency
ε	Dielectric constant
ε_e	Effective dielectric

ε_r	Dielectric permittivity
ε_{reff}	Effective relative permittivity of dielectric
C	Capacitance
c	Speed of sound in the air
W	Width
H	Height
d	Thickness
Z_o	Impedance
λ	Wavelength
μ	Permeability in free space
β	Phase constant
G_1	Microstrip radiator conductance
G_2	Mutual conductor between the two slot
I_1	Current into microtrip
N	Number of antenna
k_c	Cutoff wave number

Penuaian Frekuensi Radio Untuk Bekalan Mudahalih Arus Terus

ABSTRAK

Projek ini menekankan pada rekabentuk rectenna pada frekuensi 2GHz dengan penuaian isyarat frekuensi radio. Isyarat 2GHz adalah merupakan isyarat bagi rakaian 3G dan lebar jalur ISM yang mudah didapati di kawasan bandar. Rectenna adalah gabungan beberapa antenna mikrojalur jenis segiempat tepat, litar gabungan kuasa dan litar gandaan voltan. Antenna ini telah direkabentuk menggunakan perisian CST Microwave Studio 2012. Antara parameter yang diukur melalui proses simulasi adalah: kadar kehilangan balikan lebar jalur, lebar jalur galangan, bentuk radiasi, nisbah gelombang berdiri, gabungan masukan dan pengutuban. Litar gabungan kuasa telah direkabentuk menggunakan kuasa pemisah jenis Wilkinson. Satu gabungan kuasa bagi tiga-peringkat dengan 64 masukan telah dicadangkan, direkabentuk dan dinilai. Perlaksanaan ini telah dilakukan dengan menggunakan proses simulasi menggunakan perisian ADS 2009. Dua, tiga dan enam-peringkat litar gandaan voltan telah direkabentuk dan dinilai juga menggunakan perisian yang sama. Selepas merekebentuk dan melakukan simulasi, beberapa keputusan telah diperolehi. Rekabentuk antenna yang telah disimulasi mempunyai kehilangan balikan sebanyak 44.4dB dengan lebar jalur galangan sebanyak 400MHz, nisbah gelombang berdiri pula mempunyai nilai nisbah sebanyak 1.01:1, manakala nilai bagi galangan masukan mempunyai sebanyak 50Ω, dan arah pengutuban untuk bentuk radiasi adalah 6.202dBi. Perincian terhadap kuasa gabungan telah dilakukan dan keputusan bagi simulasinya dibentangkan. Rekabentuk bagi litar gabungan kuasa telah disimulasi dan memperolehi 9dB dari faedah keluar terhadap tiga-peringkat gabungan kuasa. Manakala keputusan bagi enam-peringkat gandaan voltan yang telah disimulasi mempunyai voltan keluaran sebanyak 3.901V dengan setiap voltan masukan sebanyak 1V. Kuasa yang dihasilkan oleh penuai ialah 20 mW. Walaubagaimanapun, didapati masih terdapat gangguan yang dipaparkan dari olahan di graf. Olahan ini boleh dikurangkan dengan penambahan nilai kapasitor yang lebih tinggi. Kesimpulannya, rekabentuk yang dicadangkan ini telah berjaya direkabentuk dan keputusan dari simulasi telah diperolehi mengikuti spesifikasi yang ditetapkan.

RF Harvester for DC Supply

ABSTRACT

This project focuses on the design of 2GHz rectenna for harvesting RF signal. This 2GHz signal is from a 3G signal and ISM band that is easy to be found in town areas. The rectenna comprises an array of rectangular patch of microstrip antenna, power combiner and voltage multiplier. Patch antenna was designed using a CST Microwave Studio 2012. The following parameters: return loss, bandwidth, radiation pattern, voltage standing wave ratio (VSWR), input impedance and antenna polarization were obtained from simulation. The power combiner circuit was designed using a Wilkinson power splitter. A power combiner for six stages and 64 inputs was proposed, designed and evaluated. The performance was done by simulation using ADS 2009 software. Two multipliers, three and six stages voltage multiplier were designed and evaluated using the same software. After designing and simulating, the following results were obtained. The designed antenna was simulated and it obtained 44.4dB of return loss with 400MHz of bandwidth, 1.01:1 of VSWR, 50Ω input impedance and 6.202dBi of directivity for the radiation pattern. A full analytical study of power combiner was done and simulation results are presented. The design of the power combiner obtained a 9dB output gain for three stages power combiner. A six-stage voltage multiplier has been simulated and it had a 3.901V of output voltage for the input voltage of 1V. The power produced by the harvester is 20mA. However, there were some harmonics shown by the ripples on the graph. The ripples can be reduced by adding the capacitor of a higher value. In conclusion, the proposed designs have been successfully designed and the simulated results have been obtained within the specifications.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The common types of energy sources such as solar and wind are both renewable and conventional energy sources. Radio Frequency (RF), vibration, temperature gradient, thermoelectric and acoustic are not common energy sources. Some of these energy sources are only available in ambient quantities that will not be able to supply sufficient energy to power useful system without some forms of voltage condition (Sika Shrestha, 2013). Even those which are available in large useful quantity would still require a conversion to become a useful electrical form. The technology used to capture the condition and the use of these energy sources was not known until recently. This technology is being referred as energy harvesting (Soudeh, 2010).

The definition of energy harvesting is the process of scavenging ambient amount of energy from the environment, accumulating it and storing it for later use. Energy harvesting devices are used to trap or capture these ambient energies efficiently and effectively before being stored for immediate or later use. The stored energies are processed and managed, and later being supplied in a form that could perform useful tasks (N.M. Din, 2012).

The energy harvesting devices perform this harvesting task using diverse forms of sensors and control circuits. An energy harvesting device charges up a super capacitor or a rechargeable battery that is used to power the sensor nodes or the RF transceivers. Part of the advantages of energy harvesting are increased efficiency with recent technical developments, cheaper, and free maintenance; can be used as a backup generator in power systems; can be used as independently as in the traditional plug-based electricity sources (S. Sheik Mohammed, 2010).

However, in this research, the RF will be further discussed. Nowadays, converting an RF signal to a DC electrical current is one of the sophisticated technologies in communication. RF energy can be harvested from the air and processed to achieve levels of energy to charge up a low-power electronic circuit. However, the ability of an RF energy harvester to maintain efficiency of the RF for a DC conversion is an important performance aspect.

This project focuses on the design of an RF harvest for DC supply that operates in the 2GHz 3G mobile network or the ISM Band. The reason of choosing 2GHz is the state of being rare for researchers to actually harvest this frequency range in their project. Some researchers are interested to harvest on the 2.4GHz and above frequency because they are a lot easier to be captured by the antenna in maximum amount. This project does not come with any demonstrator. It is exclusively developed with software to estimate the performance through simulation. Then, the characterization from the simulation is reported. The basic architecture of the RF harvester is presented in Figure 1.1. The technique significantly reduces the costs of replacing batteries periodically.

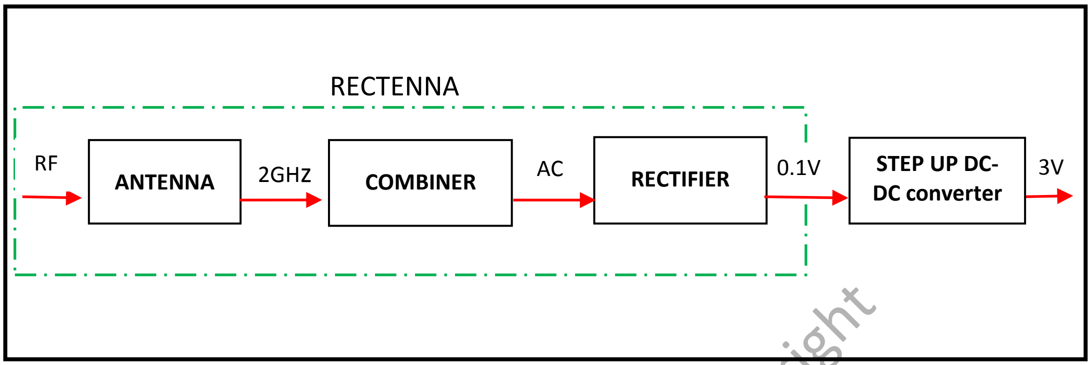

Figure 1.1: General structure of RF energy harvesting system

1.2 Problem Statement

Nowadays, many electronic devices have been miniaturized and powered by batteries. However, these devices need to be recharged periodically, and in the end it will be used up and need to be replaced by new ones. The batteries then will become the waste and will pollute the earth. The solution to solve this problem is to harvest the energy from the environment and to use it to charge the batteries or to use it directly to power up the electronic circuit. However the ambient RF would be from broadcasting stations such as TV, radio and mobile phone base stations. The signal received is very small which around -40 to -60dBm. A special antenna should be designed in order to amplify the signal to be more than 0.5V as to operate the rectifying diode circuit.

1.3 Research Objectives

The research objectives are given below:

i. To design and to simulate the microstrip patch antenna.

ii. To design a power combiner for 64 antennas.

iii. To design and to simulate a voltage multiplier circuit that can be used to convert the harvested energy from ambient radio frequency to DC voltage.

In order to achieve these objectives, the Advance Digital System and CST Microwave software are used as the simulation tool. The result and the performance of the antenna and the rectifier were investigated.

1.4 Scope of Project

The scopes of the project aim to design an antenna to pick up 2GHz low RF energy. The input impedance matching is at 50Ω. The simulation of patch antenna needs to be done using CST Microwave Studio Suite 2009.

The next stage is to design a power combiner. This combiner needs to be newly designed, and should consists of 64 antennas. The circuit is used to combine the sources of the antenna before converting them into DC using voltage multiplier (rectifying and stepping up the voltage). Next is to design the voltage multiplier circuit that is used to convert the harvested energy from the ambient radio frequency to DC voltage. Firstly, the components were chosen to suit the Dickson circuit. A model of a rectifier consists of a capacitor and a diode is selected from the electronic datasheet. Then, the components and the circuit need to be simulated to perform the circuit in order to function and give an output above 3V. The design of the electronic circuit and the power combiner will be done via the Advance Digital System (ADS) 2009.

1.5 Thesis Outlines

This dissertation is organized into five chapters to report on the whole research activities and to discuss on radio frequencies that can be harvested using the matching network between the antenna, the combiner and the electronic circuit.

Chapter 1 discusses the introduction of the project. This part also includes the objectives, as a guideline to complete the project, followed by the discussion on the problem statement of the project and lastly, the scope of the project is discussed on designing the electronic circuit and the power combiner of the antenna.

Chapter 2 is a review of related literatures of previous projects on RF harvester. This chapter will explain the analysis of the ambient RF energy harvesting techniques according to various methods. All the information in this chapter is based on the related journals and conferences. It discusses the advantages and disadvantages of the current work and also the improvement of that particular work. This chapter is truly important in giving some idea to complete the analysis.

Chapter 3 discusses about the methodology and the overall project to complete the analysis. There is a flowchart of the progress of this project, and also the explanation on the process of simulation using software ADS 2009 and CST Microwave Studio 2012.

The results, the analysis, and the discussion is explained in Chapter 4. The result of the simulation will be arranged in tables and figures for each bus test system. There is also a graph to simplify the analysis of the results.

Finally, Chapter 5 includes the conclusion and the recommendations. This chapter discusses the improvement of the project and the achievement of the project objectives. Some recommendations are also discussed to give some idea to conduct further research on the analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In the late 19th century, wireless power transmission started off as an alternative to the transmission line for the power distribution. In early 1891, the first person that had conceived the idea for the Wireless Power Transmission and had demonstrated the "transmission of electrical energy without wires was Nikola Tesla. He was known as "Father of Wireless". Two years later, at the World Columbian Exposition in Chicago, Tesla had demonstrated the illumination of vacuum bulbs without using any wires for the power transmission (S.Sheik Mohammed, 2010). His idea was fabricated and was constructed into a tower for the wireless transmission of electrical power rather than for telegraphy, which is later known as the Wardenclyffe Tower.

In 1961, William C. Brown invented a rectenna which directly converts microwaves to DC current. In 1964, Brown demonstrated the ability of a rectenna by powering a helicopter solely using microwaves (S.Sheik Mohammed, 2010). He has contributed a lot to the modern development of microwave power transmission. In 1982, Brown and James F.Trimer developed a thin film plastic rectenna using printed circuit technology that weighed only one-tenth of the previous one. Stationary High

Altitude Relay Platform (SHARP) had led the development of a lighter weight rectenna. Experiments in power transmission without wires in the range of ten kilowatts had been performed twice at Goldstone in California in 1975, and at Grand Bassin, Reunion Island in 1997 (J.D Lan Sun Luk, Oct. 1997). In 2003, Dryden Flight Research Centre of NASA demonstrated a laser powered model airplane indoors. In 2004, Japan proposed wireless charging for electric motor vehicles using Micro Power Transmission. In 2007, a new company, Powercast introduced wireless power transfer technology using the RF energy at the Consumer Electronics Show. Recently in 2008, Intel reproduced the Massachusetts Institute of Technology (MIT) group's experiment using wireless powering to light a bulb with 75% efficiency at a shorter distance (S.Sheik Mohammed, 2010).

2.2 Energy Sources

Energy sources have been explored and energy transducers have been designed for various sources. The common types of energy sources in wireless power transmission are solar, wind, Radio Frequency (RF), vibration, temperature gradient, thermoelectric and acoustic as shown in Figure 2.1.

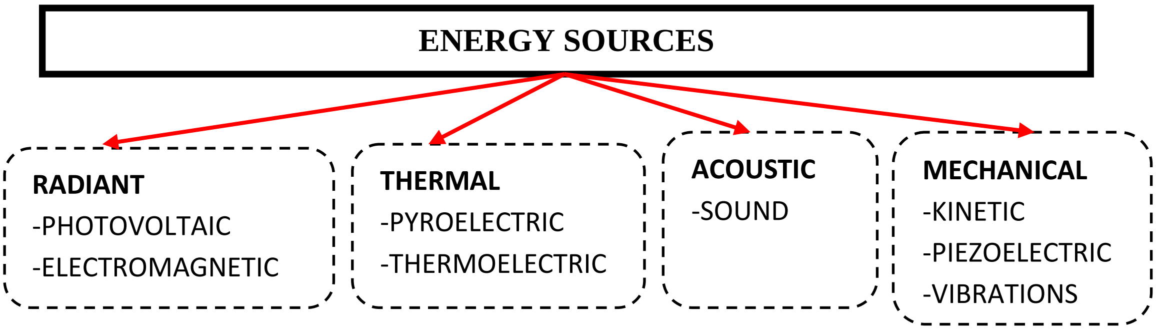

Figure 2.1: Energy sources