AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electronics and Communications Engineering

RF Energy Harvesting Antennas

A Thesis submitted in partial fulfilment of the requirements of the degree
of Master of Science in Electrical Engineering
(Department of Electronics and Communications Engineering)
by

Eng: Mina Farouk Shaker Saied

B.Sc. of Electrical Engineering

(Electronics and Communications Engineering)

Faculty of Engineering, El Shorouk Academy, 2013

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Cairo - (2020)

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Statement

This thesis is submitted as a partial fulfilment of Master of Science in Electrical Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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ABSTRACT

Fossil fuels are finite and environmentally costly. Sustainable, environmentally safe energy can be derived from nuclear fission or captured from ambient sources. Large-scale ambient energy (Ex. solar, wind and mechanical), is widely available and large-scale technologies are being developed to efficiently capture it. At the other end of the scale, there are small amounts of ‘wasted’ energy that could be useful if captured. Recovering even a fraction of this energy would have a significant economic and environmental impact. This is where energy harvesting (EH) is taking place.

Antennas are good candidates for harvesting energy from the electromagnetic radiation sources. A single domain or multi-frequency band antennas with compact size are the proposed work in this study. Design and implementation of different forms of antennas are taking place.

The thesis demonstrates not only antennas but the whole rectenna system that is to be used for collecting sufficient amounts of available electromagnetic energy that can be used in WSN (Wireless Sensor Network) and many other low power applications. The work is achieved by design multiband antenna to capture a large amount of power and multiband rectifier to convert the power collected from antenna to DC voltage. The rectifier conversion efficiency for RF energy system, is dependent on input power intensity and load resistance. In this thesis, a single band rectenna with single band rectifier is designed and conversion efficiency at different input powers are investigated. Also multiband rectenna system is investigated with three different antennas with multiband rectifier. The rectenna is fabricated and measured. Comparison

between designed, analysed and fabrication results of antennas and rectifier shows good agreement in most cases.

This thesis consists of five chapters.

The first one is introduction, the second and third ones discussed the single band and multiband rectennas at Bluetooth, and WLAN frequency bands, respectively with practical results for designs verification. Finally, chapter 5 is the conclusion and future work.

Key words: Energy harvesting, antenna, rectifier circuit, matching circuit, low pass filter, Conversion efficiency and wireless sensor network application

Thesis Summary

This thesis presents a study for RF energy harvesting antennas. The RF energy accumulated from air-space is very limited, at less than 1µW. However, conducting several experiments by using highly efficient receivers could accumulate large amount of energy especially there are millions of RF wireless devices in the surrounding environment as mobile phones, Wi-Fi, WiMax and Bluetooth. Frequency selection is an important consideration in RF Energy Harvesting (RFEH) system. These might be more useful to outdoor rather than indoor locations for harvesting applications. Generally, in the modern building environment, GSM mobile phones signals are prevalent, and propagate well both indoor and out door of buildings. Other promising bands include Wi-Fi hotspots (2.4GHz sources), as well as cellular (850MHz, 900MHz bands), personal communications services PCS (1900MHz band) and WiMax (2.3/3.5 GHz) network transmitters. The thesis is composed of five chapters together with the table of contents, the lists of figures and tables and the references used in thesis.

Chapter1; illustrates types of wireless power transfer and explains each type depending on different sources. It presents summery for other chapters and achievements that are presented in this thesis.

Chapter 2, illustrates the energy harvesting meaning and different types of energy harvesting and explains briefly the energy harvesting systems and defines every component in the system. The first component is the antenna. Different types of antennas are explained as microstrip antenna with different feeding techniques. Second component defines matching circuit and types of matching circuits discussed. Third component is the rectifier, different types of rectifier that can be implemented are presented

and finally DC pass filter can be implemented by using fan shape or simply capacitor at the output of the circuit in order to remove harmonics generated by the nonlinear characteristics and to smooth the output signal.

In chapter 3, design of single band antenna is presented. The antenna was fabricated on FR4 substrate with total size 19 x 37 mm^2. Both simulation and measurements have confirmed the single band antenna operates at 2.1 GHz. The single band rectifier is also designed and fabricated at same frequency at 2.1GHz to collect high amount of power from UMTS (Universal Mobile Telecommunication Service)band (3G mobile network).

In the first part of chapter 4, multiband coplanar monopole antenna for energy harvesting have been designed. The first design is coplanar monopole antenna built on FR4 substrate with total size is 140 × 90 mm^2. The rectenna has been demonstrated. The conversion efficiency is significantly affected by the input power density and output load of rectenna. Further experimental results have been represented for the rectenna that has wideband rectification performance and the maximum rectenna conversion efficiency at 1.8GHz is more than 50% for input power density of 0dBm.

In second part of chapter 4, tri-band microstrip monopole antenna has been designed. The proposed antenna is fabricated on FR4 substrate with thickness 1.6 mm and total size of antenna is 90 × 80 mm^2. The feeding is transmission line with width of 2.8 mm that achieves standard 50 Ω input impedance. The antenna consists of two V shaped arms with different dimensions printed around the L shaped monopole by different optimizing angles. The distance between the two V shaped are adjustable to optimize the impedance bandwidth and the reflection coefficient. The rectifier is fabricated and integrated into the rectenna prototype that is fabricated and evaluated. The multiband rectifier is also fabricated on substrate FR4 with same thickness for commercial purposes. Total rectifier size is 10.3 ×7.4 cm^2. The rectenna resonates at quad frequency bands as (GSM 900/1800, WiFi band and WLAN bands) with power conversion efficiency up to 56.4% at 0 dBm input power with load resistance of 548 Ώ.

In third part of chapter 4, multi-Band rectenna have been designed. The proposed antenna design is fabricated on FR4 substrate with thickness 1.6mm. The total size of antenna is 48 × 42 mm^2 with feeding transmission line with length a=12 mm and width of b=2.9mm that achieves standard 50 Ω input impedance. The antenna consists of four radiating elements which are adjustable to optimize the impedance bandwidth and the matching reflection coefficients. Each arm is responsible for certain resonant frequency hence, independent resonating structure is achieved. The first element is with length L_1=14 mm and width W_1=2mm. It is responsible for 900 MHz resonance. The second element is with length L_3=13 mm and width W_3=3 mm which is responsible for resonant at 1.8 GHz. Then third element acts as L shaped with length L_2=18 mm, L_4=4 mm and width for both is W_4=2.6 mm that is responsible for resonance at 2.5 GHz. The fourth element with length L_6=14 mm, L_5=5.3 mm and width W_5=2.4 mm is responsible for resonant 5.2 GHz. Step modified ground plane with step t_1=4 mm and t_2=2 mm is used to improve reflection coefficient matching. The multiband rectifier is also fabricated on substrate FR4 with same thickness. The experimental system setup is assembled. A transmitting Log-periodic antenna that is connected to a digital signal generator with a variable frequency for testing. The rectenna under test is placed near the transmitting antenna with distance 40cm in between. The efficiency at different input power level for all designated rectenna structures was tested by measuring the output DC voltage at each input power step. Best conversion efficiency is achieved at the case of elliptical antenna at resonance frequency 1.8GHz. Detailed tables illustrating these results are included.

Chapter 5; presents the conclusion and future work.

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Mina Farouk Shaker
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