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FRACTAL ANTENNA FOR RECTENNA SYSTEM APPLICATIONS

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By

MOHAMMED SAADI ISMAEL

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

This thesis is dedicated to my precious father, my beloved mother, my brother and sister for continually evaluating and inspiring me to work hard in my studies. I thank almighty Allah every day for blessing me with you and I love you all very much.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

FRACTAL ANTENNA FOR RECTENNA SYSTEM APPLICATIONS

By

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October 2020

Chairman : Associate Professor Shaiful Jahari b. Hashim, PhD
Faculty : Engineering

There are several challenges in developing an antenna for rectenna systems that are need to be addressed in such as low efficiency and large size of the antenna at the lower ISM frequency band. Hence, in this work a compact size and high efficiency antenna has been developed. As a result, a microstrip antenna structure based on a printed fractal patch geometry on an FR-4 epoxy substrate is proposed for radio frequency (RF) rectenna systems. The antenna circuitry is developed as triangular patch filled with conductive circles fed with a microstrip line and backed with a ground plane. Two matching circuit impedance are centred in the patch for enhancing the antenna bandwidth and tune the frequency modes. The proposed antenna performs two frequency modes at 920 MHz and 2.45 GHz to suite the rectenna system applications. A numerical simulation based on a Finite Integral Technique (FIT) of CST MWS formulations is conducted to study the antenna performance. The antenna is realized on FR-4 substrate with thickness of 1.6 mm. The measured return loss of 10 dB, gain of 4.47 dB, and efficiency of 92 % are achieved at these two bands. A compact size of (87.5 × 55) mm² is obtained. Finally, an omni-directional beam is obtained at 920 MHz and 2.45 GHz that would benefit the rectenna system applications.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ANTENA FRAKTAL UNTUK APLIKASI SISTEM REKTENA

Oleh

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Terdapat beberapa cabaran dalam mengembangkan antena untuk sistem rektena yang perlu ditangani seperti kecekapan rendah dan ukuran besar antena pada jalur frekuensi ISM yang lebih rendah. Oleh itu, dalam karya ini antena bersaiz padat dan kecekapan tinggi telah dikembangkan. Hasilnya, struktur antena mikrojalur berdasarkan geometri tampalan fraktal bercetak pada substrat epoksi FR-4 dicadangkan untuk sistem rektena RF. Litar antena dikembangkan sebagai tampalan segitiga yang diisi dengan bulatan konduktif yang diberi garis mikrojalur dan disokong dengan satah tanah. Dua impedans litar sepadan berpusat di TAMPALAN untuk meningkatkan lebar jalur antena dan menyesuaikan mod frekuensi. Antena yang dicadangkan melakukan dua mod frekuensi pada 920 MHz dan 2.45 GHz untuk menyesuaikan aplikasi sistem rektena. Sebuah simulasi berangka berdasarkan kepada Finite Integral Technique (FIT) formulasi CST MWS dilakukan untuk mengkaji prestasi antena. Antena direalisasikan pada substrat FR-4 dengan ketebalan 1.6 mm. Kerugian pulangan yang diukur 10 dB, gandaan 4.47 dB, dan kecekapan 92% dicapai pada dua jalur ini. Saiz padat (87.5 × 55) mm² diperoleh. Akhirnya, pancaran omni-arah diperoleh pada 920 MHz dan 2.45 GHz yang akan menguntungkan aplikasi sistem rectenna.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AC	Alternating current
CCRC	Compact Coplanar waveguide Resonant Cell
CST	Computer Simulation Technology
DC	Direct Current
FG-CPW	Finite Ground Co-Planner Waveguide
FIT	Finite Integral Technique
QWT	Quarter Wavelength Transformer
RF	Radio Frequency
RFID	Radio Frequency Identification
TVWS	TV White Space
VNA	Vector Network Analyser
WSN	Wireless Sensor Network

CHAPTER 1

INTRODUCTION

1.1 Research Background

Currently, the electromagnetic waves is occupied a great attention due to the wide expansion in the modern wireless communication services [1]. A great portion of the radiated energy is wasted in the air while a small amount of it is received by current devices [2]. If such energy, radio frequency (RF), can be harvested and used wisely, it could be reused and added to the natural harvested energy such as solar and wind resources [1, 2]. In many low power consumption devices, including sensor networks [3], radio frequency identification RFID [4], Internet-of-Things [5], and electric clock [6], the harvested RF energy is considered the main power resource. The harvested RF energy can provide sufficient power for their entire life span. Several researches have been conducted on developing single-band rectennas, multiband rectennas, and arrays as proposed in [4] - [8]. Since, the harvested energy is usually from different directions [5] and different sources [6], omni-directional of multi-band RF receptors are preferable [5]. A rich multi-path signal environment in combination with the uncertain source position makes an omni-directional antenna the ideal candidate to harvest ambient RF energy [6]. Energy efficiency can be increased significantly, if the antenna design is determined by fractal geometry [7]. Fractal geometries have been extensively employed in antenna architecture due to their self-similarity and space-filling features which permit antenna. Generally, microstrip technology is widely used to realize the antenna in rectenna systems. Different structures and designs have been proposed in [8-15]. However, these designs limit the performance of the rectenna system by producing a big or bulky size of the whole network beside a single frequency resonance. Therefore, an alternative of using Fractal geometries with several techniques to overcome these problems is presented in [16-20].

1.2 Research Motivation

Due to the rapidly increasing need for green energy harvesting as a new resource for self-powered wireless systems. This research is conducted on antenna part of the rectenna RF systems. This study has been motivated by a need to design an antenna with high efficiency, gain, and bandwidth to be mounted on a substrate. This technique prompted to develop a compact dual-band antenna for RF energy harvesting which would have the capability to benefit the required rectenna system needs. Moreover, the proposed structure is based on an efficient antenna of an omni-direction pattern to support the RF energy harvesting from different directions at different frequency bands.

1.3 Problem Statement

Currently, the demands for increasing energy requirements to meet the population increasing has been driven the researchers to find an optimal energy source without minimum energy loss. Consequently, Rectenna RF energy had become an interesting topic to produce clean and low cost energy for RF applications. One of the suggested solutions is to use low profile and compact size of devices in Rectenna systems, which has great potentials in the engineering applications. However, rectenna systems have a few challenges such as being low efficiency and big size due to its antenna design structures [21, 22]. Additionally, the rectenna systems are usually designed at lower ISM band for example 0.92 GHz and 2.45 GHz which produces a low gain and low efficiency comes from the common planar technology used. Hence, the antennas with a compact size, low profile, low cost, and high performance can be developed [23]. Therefore, the fractal planar technology is proposed to implement the antenna in the rectenna systems. The antenna in rectenna system plays an important role especially in the receiver part. Antenna in receiver part should provide a compact size and high efficiency performance with omni-directional radiation pattern to ensure signal receiving from everywhere [24]. Common microstrip antenna structures such as slot, square, circle, and patch are introduced for rectenna system. However, these structures are suitable for the antenna in the transmitter part of the rectenna system with high gain and directional beams. Hence, in this work a fractal antennas with a capability to provide a compact size and omni-directional beam is proposed for the antenna in the receiver part. A well-designed antenna with compact size, acceptable gain, bandwidth, low profile, low cost, and efficiency is carefully needed to be implemented in the receiver part of rectenna system.

1.4 Research Aim and Objectives

The aim of this project is to design an optimal antenna that can be used in the rectenna system applications at 0.92 GHz and 2.45 GHz. The following are the research objectives.

1. To design, simulate, fabricate, measure, and analyses the performance of a compact microstrip fractal antenna with good gain and high efficiency for rectenna systems applications at 0.92 GHz and 2.45 GHz.
2. To compare the performance of the proposed microstrip fractal antenna with related recent works in terms of return loss, gain, size, and efficiency that would benefit the wireless rectenna system applications.

1.5 Scope of Work

The scope of the proposed work is limited to the antenna design of fractal geometry that will be connected in the future to the RF harvester at 920MHz and 2.45 GHz. Therefore, the design of the proposed antenna is investigated by using Computer Simulation Technology based Microwave Studio (CST MWS) of Finite Integral

Technique (FIT) to realize the antenna performance. Nevertheless, the antenna designed based on Minkowski fractal of elliptical geometry inside a triangular structure. The antenna is then fabricated using microstrip FR-4 substrate and measured using standard vector network analyzer (VNA) to compare the performance with the simulation response.

1.6 Significance of the Study

The significance of the study is focused on using a dual-band band patch antenna based on microstrip fractal geometry or composed of metamaterial structure. It aims to enhance the capability of the antenna bandwidth and gain for receiving different frequency bands, as well as reducing the size of the antenna and the shadowing effect of the patch layer on the substrate.

1.7 Thesis Layout

This thesis comprises five chapters.

Chapter 1 introduces current background and problems of the rectenna systems. Followed by the research aim and objectives, and the scope of work.

Chapter 2 focuses on the literature review of the current fracture antenna on microstrip technology, then the current problems and gaps in the rectenna systems as antenna design point of view.

Chapter 3 presents the research methodology which starts with the antenna design flowchart. In addition to the details equations of the proposed design. Then the details of simulation and fabrication processes are briefly discussed.

Chapter 4 shows the optimized antenna with simulation and measurement results. This chapter discuss the performance of the proposed antenna in terms of reflection coefficient, gain, bandwidth, and efficiency.

Chapter 5 concludes the findings of this research and presents the limitations and recommendation for future work. The findings are related to the aim and objectives of this research in such way that it has been achieved.

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