DESIGN OF A MULTI-BAND RF ENERGY HARVESTING RECTENNA WITH HARMONICS SUPPRESSION CAPABILITY

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MASTER OF SCIENCE IN ELECTRONIC ENGINEERING

2020

Faculty of Electronic and Computer Engineering

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**A thesis submitted
in fulfillment of the requirements for the degree of Master of Science in
Electronic Engineering**

Faculty of Electronic and Computer Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

DECLARATION

I declare that this thesis entitled "Design of A Multi-band RF Energy Harvesting Rectenna with Harmonics Suppression Capability" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : …………………………………………….…

Name : FAZA SYAHIRAH BINTI MOHD NOOR

Date :…………………………………………...…

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature : ……………………………………

Supervisor Name : PROFESSOR DR. ZAHRILADHA BIN ZAKARIA

Date : …………………………………...

DEDICATION

The name of ALLAH Almighty creator,

My beloved father, Mohd Noor Radiman and mother, Zalinawati Kosnan,

My supportive family members for your encouragement and undying supports.

And to everyone.

ABSTRACT

In recent years, rectenna with the ability of energy harvesting has been gaining tremendous interests by researchers. Constant availability of radio frequency (RF) signals at which it is being deployed both at indoor and outdoor environment favors these types of signals as the optimum choice of energy to be harvested considering its continuous operation. The design and development of RF energy harvesting is fit to describe the transmission of power wirelessly. RF signals which is in form of alternating current (AC) is being radiated through electromagnetic (EM) waves into the environment and rectenna structure will capture the RF signals and therefore converts it into direct current (DC) signals. Rectenna which constructed upon the integration of antenna and rectifier structure within the same physical structure explains the ability of rectenna in harvesting and rectifying AC signals into DC signals. The antenna is to receive or capture the RF signals at which it is then being rectified into DC signals by the rectifier. The integration of both antenna and rectifier structures contribute to the creation of harmonics due to the non-linear behavior of active elements such as Schottky diode and capacitor at the rectifier circuit. Hence, harmonics suppression filter design is proposed to suppress the harmonics generated. This thesis presents a design of rectenna structure with multi-band characteristics and harmonics suppression capability. Multi-band characteristics of operating frequency at 2.45GHz and 5.80GHz are achieved using inverted π-shaped coupling slot while the ability of harmonics suppression is achieved through the introduction of embedded U-slot and asymmetrical right-and-left-handed stubs at the antenna transmission feedline. The addition of slot and stubs at the transmission feedline has replaced the conventional filter structure which is larger in size. In order to enhance the gain of antenna, aperture-coupled antenna is constructed with air gap through the simulation using Computer Simulation Technology (CST) software. Meanwhile, the rectifier of double-diode configuration circuit of the rectenna is designed and simulated using Advanced Design System (ADS) with rectifying element HSMS286B Schottky diodes and interdigital capacitor. The structure interdigital capacitor in the form of transmission line is applied to replicate the series-configuration active capacitor component. The development of the rectenna prototype is executed using FR-4 substrate material with dielectric constant of 4.3 and thickness of 1.6mm. The antenna is able to suppress third and higher-order harmonics ranging from 6.12GHz up to 10.00GHz and achieve the gain of 7.05dBi and 0.94dBi at the operating frequency 2.45GHz and 5.80GHz, respectively. The double-diode rectifier prototype can be operated at both 2.45GHz and 5.80GHz hence, maximum RF-to-DC conversion efficiency of 92.26% for frequency 2.45GHz and 30.14% for frequency 5.80GHz is achieved, each with the RF input power of 20dBm and 25dBm respectively. The rectenna design proposed does not only possessed the characteristic of a multi-band, but also the has the harmonics suppression ability for the purpose of improving the RF-to-DC conversion efficiency thus makes it appropriate for the application of wireless power transmission.

ABSTRAK

Kebelakangan ini, rektena berkebolehan penuaian tenaga telah menarik perhatian para penyelidik. Kebolehdapatan isyarat frekuensi radio (RF) di mana ianya diguna pakai untuk persekitaran dalam dan luar memberi kelebihan pada isyarat-isyarat ini sebagai pilihan yang optimum untuk proses penuaian berikutan sistem operasi yang berterusan. Rekabentuk dan pembangunan penuaian tenaga RF ini sesuai bagi menerangkan penghantaran tenaga secara wayarles. Isyarat RF dalam bentuk arus ulang-alik (AC) dipancarkan ke persekitaran melalui gelombang elektromagnetik (EM) dan struktur rektena akan menangkap dan seterusnya menukar isyarat tersebut ke dalam bentuk isyarat arus terus (DC). Rektena berdasarkan integrasi struktur antena dan penerus pada struktur fizikal yang sama menggambarkan kebolehan rektena dalam penuaian dan penukaran isyarat AC kepada isyarat DC. Antena berfungsi untuk menerima atau menangkap isyarat RF di mana ianya ditukarkan kepada isyarat berbentuk DC oleh penerus. Integrasi struktur antena dan penerus menyumbang kepada penciptaan harmonik berikutan perilaku ketaklelurusan elemen-elemen aktif seperti diod Schottky dan kapasitor pada litar penerus. Berikutan itu, rekabentuk penapis penindasan harmonik telah dicadangkan untuk menindas harmonik yang terhasil. Tesis ini membentangkan rekabentuk struktur rektena bersama ciri jalur pelbagai dan kebolehan penindasan harmonik. Ciri jalur pelbagai pada operasi frekuensi 2.45GHz dan 5.80GHz dicapai menggunakan bentuk songsang "π" sebagai gandingan lubang alur manakala kebolehan penindasan harmonik dicapai melalui pelaksanaan lubang alur berbentuk "U" dan puntung tangan kanan dan kiri tidak simetri pada talian suapan transmisi antena. Penambahan lubang alur dan puntung pada talian suapan antena telah menggantikan struktur lazim penapis yang lebih besar. Bagi meningkatkan gandaan antena, struktur "aperture-coupled" dibina bersama jurang udara melalui simulasi perisian Computer Simulation Technology (CST). Litar penerus berkonfigurasi dual-diod pada rektena pula dibina dan disimulasi menggunakan perisian Advanced Design System (ADS) bersama elemen penerus diod Schottky HSMS286B dan kapasitor interdigital dalam bentuk garis penghantaran diaplikasi bagi menghasilkan replika konfigurasi siri komponen aktif kapasitor. Pembangunan prototaip rektena dilaksana menggunakan bahan substratum FR-4 di mana pemalar dielektrik adalah 4.3 dan berketebalan 1.6mm. Antena ini berkebolehan menindas harmonik ketiga dan harmonik tertib lebih tinggi pada julat frekuensi 6.12GHz sehingga 10.00GHz dan juga mencapai gandaan antena 7.05dBi dan 0.94 dBi setiap satu pada operasi frekuensi 2.45GHz dan 5.80GHz. Prototaip penerus dual-diod boleh beroperasi pada operasi frekuensi 2.45GHz dan 5.80GHz seterusnya kecekapan penukaran tenaga RF kepada tenaga DC mencapai bacaan maksimum 92.26% bagi frekuensi 2.45GHz dan 30.14% bagi frekuensi 5.80GHz setiap satu berdasarkan paras kuasa masukan isyarat RF pada 20dBm dan 25dBm. Rekabentuk rektena yang dicadangkan bukan sahaja mempunyai ciri-ciri jalur pelbagai malah turut mempunyai kebolehan penindasan harmonik bagi meningkatkan kecekapan penukaran tenaga RF kepada tenaga DC, justeru membuatkan rekabentuk ini bersesuaian bagi aplikasi penghantaran tenaga wayarles.

ACKNOWLEDGEMENTS

First and foremost, I would like to take this opportunity to express my deepest gratitude to my main supervisor, Professor Dr. Zahriladha bin Zakaria from Faculty of Electronic and Computer Engineering (FKEKK), Universiti Teknikal Malaysia Melaka (UTeM) and my co-supervisor Dr. Herwansyah bin Lago from the Faculty of Engineering, Universiti Malaysia Sabah (UMS) for their undying support and essential research guidance throughout the project execution and encouragement towards the completion of this research work and thesis.

Special acknowledgement to the postgraduate students, staffs and friends from Faculty of Electronic and Computer Engineering (FKEKK) which are Dr. Sam Weng Yik, Nurhasniza, Ameer Farhan, Associate Professor Dr. Mohamad Zoinol Abidin, Dr. Nornikman, Mohd Khairy, Sulaiman Ali Mohammad, Seah Boon York, Muhammad Haziq, Dinesh Periannan, Nurul Shafnie, Husna 'Izzati, Siti Allyna and Syazwani for their knowledge contribution, technical and spiritual support.

I would also like to take this opportunity to thank my parents, Mohd Noor bin Radiman and Zalinawati binti Kosnan and family members, Faza Syazwina, Faza Arif Putra and Faza Ammar Putra for their continuous support, encouragement and prosperous prayers all of these years through the course of my master journey. The journey is made possible with them continuously cheering by my side.

I am thankful to laboratory assistance, Imran and Muhd Sufian together with technician Research Lab I Khairul Zaman for their assistance throughout the fabrication and measurement procedures.

Finally, I would like to acknowledge Ministry of Education, Malaysia government and Universisti Teknikal Malaysia Melaka (UTeM) for the research funds. Deepest gratitude to everyone who had contributed either directly or indirectly to this research work.

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