



**Faculty of Electronic and Computer Engineering**

**DESIGN OF RECTENNA WITH IMPROVED RF-TO-DC POWER  
CONVERSION EFFICIENCY FOR RF ENERGY HARVESTING**

**Maizatul Alice binti Meor Said**

**Doctor of Philosophy**

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**DESIGN OF RECTENNA WITH IMPROVED RF-TO-DC POWER CONVERSION  
EFFICIENCY FOR RF ENERGY HARVESTING**

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**A thesis submitted  
in fulfillment of the requirements for the degree of Doctor of Philosophy**

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**2018**

## DECLARATION

I declare that this thesis entitled “Design of Rectenna with Improved RF-to-DC Power Conversion Efficiency for RF Energy Harvesting” 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 : Maizatul Alice binti Meor Said

Date : ..... August 2018.....

## 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 Doctor of Philosophy.

Signature : .....

Supervisor Name : Profesor Dr. Zahriladha bin Zakaria

Date : ..... August 2018.....

## DEDICATION

*The sake of Allah, my Creator and my Master,*

*My great messenger, Muhammad S.A.W who taught us the purpose of life,*

*My beloved husband Mohamad Harris,*

*My beloved childrens Nurrah Airis, Mohamad Nazra Aiden, Mohamad Nazra Airell and*

*Naurah Airaa,*

*All the people in my life who touch my heart,*

*I dedicate this research.*

## ABSTRACT

This thesis presents novel techniques for the design of rectenna for RF energy harvesting which allow for the realization of wireless microwave energy transfer. Energy harvesting is a rapidly growing area in many scientific and engineering related fields due to the need for finding solutions to the world's power issues. Based on the previous works, there are many limitations and drawbacks exists in currently used technique such as low RF-to-DC power conversion efficiency or increase in the number of antenna elements enlarges the overall aperture size of the rectenna, the resulting devices are large and more difficult to install which limits the potential of further enhancement in the conversion efficiency. Therefore, the overall objective of this research work is to develop an effective rectenna for RF energy harvesting system. These rectenna have an advantage of high gain and high efficiency properties which optimized the overall rectenna performance. All the rectenna designs were developed based on stacked air-gap rectenna technology by integrating the rectifying circuit with the high gain antenna. In order to validate the concept, all rectenna designs were manufactured and measured. The experimental results show excellent agreement with the simulated performance. Both antennas and rectifiers have been designed by using Computer Simulation Technology (CST) and Advance Design System (ADS) respectively. A low cost 4.6 permittivity FR4 substrate has been used in the fabrication process. For rectifier, the highest output voltage that can be achieved is 14.52 V when the input power is at 30 dBm. On the other hand, the most optimized antenna amongs all can achieved gain of 9.01 dB and return loss of more than -22 dB. The highest measured RF-to-DC conversion efficiency of the optimized rectenna design is 85% when the input power is 20 dBm applied to the circuit. The main benefit of the rectenna designs are high gain, high RF to DC power conversion efficiency, high DC output voltage as well as being able to easily integrate with other planar devices at a low cost and using standard printed circuit board process. This new class of rectenna is considered suitable for applications, particularly where the gain can be tolerated and the RF-to-DC power conversion efficiency is very important, such as in the case of agriculture and health sensors of wireless sensor network.

## **ABSTRAK**

*Tesis ini membentangkan teknik-teknik baru rekabentuk “rectenna” untuk penuaian tenaga frekuensi radio yang membolehkan penjanaan pemindahan tenaga gelombang mikro tanpa wayar. Penuaian tenaga adalah bidang yang berkembang dengan pesat dalam banyak bidang saintifik dan yang berkaitan dengan kejuruteraan berdasarkan keperluan untuk mencari penyelesaian kepada isu bekalan kuasa dunia. Berdasarkan kerja-kerja yang lalu, terdapat banyak batasan dan kelemahan dalam teknik yang digunakan seperti kecekapan penukaran kuasa RF-ke-DC yang rendah atau peningkatan bilangan bahagian antena yang membesarkan saiz bukaan keseluruhan “rectenna”, peranti yang dihasilkan adalah besar dan lebih sukar untuk dipasang yang menghadkan potensi peningkatan selanjutnya dalam kecekapan penukaran. Oleh yang demikian, objektif keseluruhan kerja penyelidikan ini adalah untuk membangunkan “rectenna” yang efektif untuk sistem penuaian tenaga frekuensi radio. “Rectenna” ini mempunyai kelebihan sifat dapatan tinggi dan kecekapan tinggi yang mengoptimumkan prestasi “rectenna” keseluruhannya. Rekabentuk-rekabentuk rectenna dibangunkan berdasarkan teknologi jurang udara “rectenna” yang disusun dengan mengintegrasikan litar penerus dengan antena dapatan tinggi. Untuk mengesahkan konsep itu, semua rekabentuk “rectenna” dibuat dan diukur. Keputusan eksperimen menunjukkan persetujuan yang sangat baik dengan prestasi simulasi. Kedua-dua antena dan penerus masing-masing telah direka dengan menggunakan Computer Simulation Technology (CST) dan Advance Design System (ADS). FR4 substrat kos rendah dengan ketelusan 4.6 telah digunakan dalam proses fabrikasi. Untuk penerus, voltan keluaran tertinggi yang boleh dicapai ialah 14.52 V apabila kuasa masukan berada pada 30 dBm. Sebaliknya, antena yang paling dioptimumkan di antara semua boleh mencapai dapatan 9.01 dB dan kehilangan balik lebih daripada -22 dB. Kecekapan penukaran RF-ke-DC tertinggi yang diukur dengan rekabentuk “rectenna” yang dioptimumkan adalah 85% apabila kuasa masukan adalah 20 dBm yang diberikan pada litar. Manfaat utama rekabentuk-rekabentuk “rectenna” adalah dapatan tinggi, kecekapan penukaran RF-ke-DC yang tinggi, voltan keluaran DC yang tinggi serta dengan mudah dapat diintegrasikan dengan peranti planar lain pada kos yang rendah dan menggunakan proses papan litar bercetak biasa. Kelas “rectenna” baru ini dianggap sesuai untuk aplikasi, terutamanya dimana dapatan boleh diterima dan kecekapan penukaran kuasa RF-ke-DC adalah sangat penting, seperti dalam sektor pertanian dan penderia kesihatan untuk rangkaian penderia tanpa wayar.*

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## TABLE OF CONTENTS

	PAGE
<b>DECLARATION</b>	
<b>APPROVAL</b>	
<b>DEDICATION</b>	
<b>ABSTRACT</b>	i
<b>ABSTRAK</b>	ii
<b>ACKNOWLEDGEMENTS</b>	iii
<b>TABLE OF CONTENTS</b>	iv
<b>LIST OF TABLES</b>	vii
<b>LIST OF FIGURES</b>	ix
<b>LIST OF APPENDICES</b>	xix
<b>LIST OF ABBREVIATIONS</b>	xx
<b>LIST OF SYMBOLS</b>	xxi
<b>LIST OF PUBLICATIONS</b>	xxii
<b>CHAPTER</b>	
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 Research Background and Motivation	1
1.2 Types of Wireless Power Transfer	2
1.3 Problem Statement	11
1.4 Research Objectives	13
1.5 Scope of Research	14
1.6 Contributions	14
1.7 Thesis Organization	15
<b>2. LITERATURE REVIEW</b>	<b>17</b>
2.1 Introduction	17
2.2 Energy Harvesting System	17
2.3 Design of the Rectifier	18
2.4 Review of Rectifying Circuit	21
2.5 Design of the Antenna	31
2.5.1 Mathematical Calculation	34
2.6 Review of Antenna	35
2.6.1 Gain of the Antenna	38
2.6.2 Return Loss of the Antenna	39
2.6.3 Antenna Radiation Pattern	39
2.6.4 Polarization of the Antenna	40
2.7 RF-DC Conversion Efficiency of the Rectenna	42
2.8 Rectenna Design History	44
2.9 Rectenna Recent Studies	47
2.10 Past Studies of Rectenna Based on Performance And Limitations	60
2.11 Summary	65
<b>3. RESEARCH METHODOLOGY</b>	<b>67</b>
3.1 Introduction	67
3.2 Flow of Project	69
3.3 RF-to-DC Rectifier Design	74

3.3.1	Diode Selection	75
3.3.2	Impedance Matching	76
3.3.3	Input Impedance of Voltage Doubler Rectifier	77
3.3.4	Design of the Matching Network	78
3.3.5	RF-to-DC rectifier simulation	79
3.4	Single Diode Rectifier	80
3.5	Integration of Power Divider and Rectifier at 2.45 GHz	81
3.6	Methodology of Antenna Designs	82
3.6.1	Microstrip Stacked Antenna Design Structure	82
3.7	Integration of the Rectifier and Antenna	86
3.8	Simulation of the Designed Rectenna	87
3.9	Fabrication and Measurement of the Designed Rectenna	88
3.10	Rectenna Measurement	90
3.11	Summary	93
<b>4.</b>	<b>RESULTS AND DISCUSSION</b>	<b>94</b>
4.1	Introduction	94
4.2	RF-to-DC Rectifier Measurement	95
4.2.1	Voltage Doubler Rectifier at 2.45 GHz	97
4.2.2	Voltage Doubler Rectifier at 1.8 GHz	97
4.2.3	Power Divider at 2.45 GHz	99
4.2.4	Dual band Power Divider at 1.8 and 2.45 GHz	102
4.2.5	Power Combiner at 2.45 GHz	104
4.2.6	Integration of Power Divider and Voltage Doubler Rectifier at 2.45 GHz and 1.8 GHz	105
4.2.7	Integration of Power Combiner and Voltage Doubler Rectifier at 2.45 GHz	110
4.2.8	Integration of Power Combiner and Voltage Doubler Rectifier at 1.8 GHz	112
4.2.9	Voltage Doubler Rectifier (reduce size)	113
4.2.10	Integration of Power Divider and Voltage Doubler Rectifier double stage (reduce size)	115
4.3	High Gain Microstrip Stacked Antenna Results	117
4.3.1	Square Microstrip Patch Stacked Antenna	119
4.3.2	Rectangular Microstrip Patch Stacked Antenna	126
4.3.3	Circular Microstrip Patch Stacked Antenna	131
4.3.4	Dual-band Stacked Antenna	136
4.3.5	Rectangular Slot Stacked Antenna	143
4.3.6	1.8 GHz Stacked Antenna	148
4.3.7	Stacked Array Antenna	153
4.4	Rectenna Results	161
4.4.1	Integration of Rectangular Slot Antenna and Rectifier 2.45 GHz	161
4.4.2	Integration of Rectangular Antenna and Rectifier 2.45 GHz (reduce size)	163
4.4.3	Integration of Rectangular Antenna and Rectifier 2.45 GHz (double stage)	165
4.4.4	Integration of Rectangular Antenna and Rectifier 2.45 GHz (reduce size: 5.5 cm) (double stage)	166

4.4.5	Stacked feedline Rectenna for RF Energy Harvester (reduce size : 5.5 cm)	168
4.4.6	A 2.45 GHz Stacked Rectenna for RF Energy Harvester (reduce size : 5.5 cm)	169
4.4.7	A 2.45 GHz Stacked Rectenna for RF Energy Harvester (reduce size : 5.5 cm) (double stage)	171
4.5	Past Studies Designs Comparison	174
4.6	Summary	175
<b>5.</b>	<b>CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK</b>	<b>176</b>
5.1	Conclusion	176
5.2	Suggestion for Future Works	179
	<b>REFERENCES</b>	<b>183</b>
	<b>APPENDICES</b>	<b>213</b>

## LIST OF TABLES

<b>TABLE</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Overview of rectennas in the previous literature	48
2.2	Return loss and maximum gain of the proposed antenna (Fu-Jhuan Huang, 2012)	58
2.3	Literature review results summary	60
2.4	Proposed rectenna design specifications	64
3.1	Rectifier design specification	71
3.2	Antenna design specification	72
3.3	Description of the parameters design of the interdigital capacitor	80
4.1	Square microstrip patch stacked antenna design specification	121
4.2	FR4 substrate properties	123
4.3	Rectangular microstrip patch stacked antenna design specification	127
4.4	Circular microstrip patch stacked antenna design specification	132
4.5	Dual-band microstrip patch stacked antenna design specification	137
4.6	Rectangular Slot microstrip patch stacked antenna design Specification	144
4.7	1.8 GHz microstrip patch stacked antenna design specification	149
4.8	Array microstrip patch stacked antenna design specification	154
4.9	Design parameters of the bottom view of the array antenna	154
4.10	Comparison of the aperture coupling slots antennas simulated	159

	return loss	
4.11	Comparison of the aperture coupling slots antennas high gain Property	160
4.12	The proposed rectenna with past research work comparison	174

## LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Types of Wireless Power Transfer	3
1.2	Far Field Wireless Power Transfer Applications	4
1.3	RF Energy Harvesting Basic Block Diagram	5
2.1	Free RF Energy Sources (Anonymous, 2015)	18
2.2	RF energy harvesting system basic block diagram	18
2.3	Type of rectifier: (a) Basic rectifier (b) Voltage doublers (c) Voltage multiplier (Zakaria et al, 2015)	20
2.4	(a) Output voltage (b) Efficiency of rectifier vs. input power (Zakaria et al, 2015)	20
2.5	(a) N gain stages in cascade rectifier (b) Number of rectifier stages effect on output DC voltage (Triet Le, 2008)	22
2.6	(a) Doubler rectifier (b) Comparison of proposed model with spice simulation and output voltage, $V_{DC}$ (Barnett, 2009)	29
2.7	(a) Equivalent circuit of RF energy harvesting system with crystal resonator and two diodes (b) Measured overall efficiency at different input power levels (Tolgay, 2009)	29
2.8	(a) Layout of the two stage voltage doubler in ADS using impedance matching (b) Simulated value of $P_{in}$ vs $V_{out}$ when load is 20 k $\Omega$ (Naimul, 2012)	30

2.9	Radiation pattern of the antenna (Hyperphysics, 2016)	40
2.10	Polarization of the antenna (a) Linear polarization electromagnetic wave (b) Circular polarization electromagnetic waves (Hyperphysics, 2016)	42
2.11	(a) Geometry of proposed 3x3 antenna array (b) Simulation result of rectifier efficiency versus input power (Sennouni et al., 2014)	54
2.12	(a) Configuration of the GCPW rectenna (b) Simulated and measured gains versus frequency of the antenna (c) Measured efficiency and output voltage versus received power of the rectenna at 2.45 GHz (Mei Juan Nie, 2015)	56
2.13	(a) Class-F load rectifier circuit (b) Experimental equipment used to measure the efficiency of the RF-DC-DC circuit (Yong Huang, 2014)	57
2.14	(a) Rectenna configuration and experiment setup (Fu-Jhuan Huang, 2012)	58
2.15	(a) Manufactured RF-DC printed circuit board (b) Back view of the hybrid FSS and rectenna energy harvesting prototype (David Ferreira, 2016)	59
3.1	The general flows of the research work	69
3.2	Voltage doubler rectifier (Sharif et al, 2017)	71
3.3	Geometry of the proposed rectenna (a) top view, (b) bottom layer (c) side view	72
3.4	(a) Conventional single series diode rectifying circuit integration with antenna (b) Voltage doubler rectifying circuit integration with antenna	73
3.5	Rectenna measurement setup	74
3.6	HSMS286B Schottky diode equivalent circuit (Baliga, B. Jayant., 2009.	76

3.7	Input impedance block in ADS	78
3.8	Input impedance block of voltage doubler rectifier	78
3.9	Interdigital capacitor structure (Matthew Sadiku and Charles Alexander., 2012. <i>Fundamentals of Electric Circuits</i> , 3 <sup>rd</sup> ed., New York: McGraw Hill education.)	79
3.10	Topology of the single diode rectifier model in ADS (Sharif et al, 2017)	81
3.11	Topology of the integration of power divider and rectifier model in ADS	82
3.12	(a) Top view (b) Bottom view of the microstrip patch stacked antenna	83
3.13	(a) Side view (b) Bottom view of the aperture coupling antenna	84
3.14	(a) Side view (b) Top view of the circular microstrip patch antenna	85
3.15	Exporting CST antenna results into ADS	87
3.16	Antenna results and single diode rectifier circuit integration	87
3.17	Antenna results and voltage doubler rectifier circuit integration	88
3.18	Fabricated of rectenna	90
3.19	Measurement set up of the rectenna	91
3.20	Return loss and radiation pattern measurement set up	92
3.21	Indoor far field antenna measurement set up in the anechoic chamber room	92
4.1	Efficiency vs. Input power for rectifier circuit with different load resistance values	96
4.2	900 $\Omega$ is used for optimum efficiency performance	97
4.3	Topology of the voltage doubler rectifier model in ADS (Sharif et al, 2017)	98



4.4	Voltage doubler rectifier DC output voltage in ADS	98
4.5	Output voltage of voltage doubler rectifier at 1.8 GHz (measured)	99
4.6	Topology of the power divider model in ADS	100
4.7	$S_{11}$ of the power divider model in ADS	100
4.8	Prototype of 2.45 GHz power divider	101
4.9	2.45 GHz power divider return loss	101
4.10	Topology of the dual band power divider 2.45 GHz and 1.8 GHz model in ADS	102
4.11	$S_{11}$ of the dual band power divider 2.45 GHz and 1.8 GHz model in ADS	103
4.12	Prototype of power divider at 1.8 and 2.45 GHz	103
4.13	Return loss of power divider at 1.8 and 2.45 GHz	104
4.14	Prototype of 2.45 GHz power combiner	104
4.15	2.45 GHz power combiner return loss	105
4.16	Topology of the integration of power divider and rectifier at 2.45 GHz and 1.8 GHz model in ADS	106
4.17	DC output voltage of the integration of power divider and rectifier at 2.45 GHz and 1.8 GHz model in ADS	106
4.18	Prototype of integration of power divider and voltage doubler rectifier at 2.45 GHz and 1.8 GHz	107
4.19	Output voltage of integration of power divider and voltage doubler rectifier at 1.8 and 2.45 GHz	107
4.20	Output voltage of integration of power divider and voltage doubler rectifier at 2.45 GHz (single stage)	108

4.21	Output voltage of integration of power divider and voltage doubler rectifier at 1.8 GHz (single stage)	108
4.22	Output voltage of integration of power divider and voltage doubler rectifier at 2.45 GHz (double stage)	109
4.23	Output voltage of integration of power divider and voltage doubler rectifier at 1.8 GHz (double stage)	109
4.24	Topology of the integration of power combiner and rectifier model in ADS	110
4.25	DC output voltage of the integration of power combiner and rectifier model in ADS	110
4.26	Prototype of integration of power combiner and voltage doubler rectifier at 2.45 GHz	111
4.27	Output voltage of integration of power combiner and voltage doubler rectifier at 2.45 GHz	111
4.28	Topology of the integration of power combiner and rectifier model in ADS	112
4.29	Output voltage of integration of power combiner and voltage doubler rectifier at 1.8 GHz	112
4.30	Simulation output voltage of voltage doubler rectifier (reduce size)	113
4.31	Prototype of voltage doubler rectifier (reduce size)	114
4.32	Output voltage of voltage doubler rectifier (reduce size)	114
4.33	Simulation and measurement output voltage of voltage doubler rectifier (reduce size)	114
4.34	Prototype of voltage doubler rectifier (double stage and reduce size)	115

4.35	Simulation output voltage of voltage doubler rectifier (double stage and reduce size)	116
4.36	Measurement output voltage of voltage doubler rectifier (double stage and reduce size)	116
4.37	Simulation and measurement output voltage of voltage doubler rectifier (double stage and reduce size)	117
4.38	Parametric study on the antenna gap that contribute to the antenna return loss	118
4.39	Top view of the square microstrip patch stacked antenna	120
4.40	Bottom view of the square microstrip patch stacked antenna	120
4.41	Square stacked antenna with aperture coupling slot simulated gain	122
4.42	(a) E-plane and H-plane simulated radiation patterns of the square stacked antenna with aperture coupling slot (b) E-plane and H-plane measured radiation patterns of the square stacked antenna with aperture coupling slot	124
4.43	Prototype of square stacked antenna	125
4.44	Square antenna return loss with triangular aperture coupling slot	126
4.45	Top view of the rectangular microstrip patch stacked antenna	126
4.46	Bottom view of the rectangular microstrip patch stacked antenna	127
4.47	Rectangular stacked antenna with aperture coupling slot simulated gain	128
4.48	(a) E-plane and H-plane simulated radiation patterns of the rectangular stacked antenna with aperture coupling slot (b) E-plane and H-plane measured radiation patterns of the rectangular stacked antenna with aperture coupling slot	129

4.49	Prototype of rectangular stacked antenna	130
4.50	Rectangular antenna return loss with triangular aperture coupling slot	131
4.51	Top view of the circular microstrip patch stacked antenna	131
4.52	Bottom view of the circular microstrip patch stacked antenna	132
4.53	Circular stacked antenna with aperture coupling slot simulated gain	133
4.54	(a) E-plane and H-plane simulated radiation patterns of the circular stacked antenna with aperture coupling slot (b) E-plane and H-plane measured radiation patterns of the circular stacked antenna with aperture coupling slot	134
4.55	Prototype of circular stacked antenna	135
4.56	Circular antenna return loss with triangular aperture coupling slot	136
4.57	Top view of the dual-band stacked antenna	136
4.58	Bottom view of the dual-band stacked antenna	137
4.59	Dual-band stacked antenna with aperture coupling slot simulated gain	139
4.60	(a) E-plane and H-plane simulated and measured radiation patterns of the 1.8 GHz dual-band stacked antenna with aperture coupling slot (b) E-plane and H-plane simulated and measured radiation patterns of the 2.45 GHz dual-band stacked antenna with aperture coupling slot	141
4.61	Prototype of dual-band stacked antenna	142
4.62	Dual-band antenna return loss with triangular aperture coupling slot	143
4.63	Top view of the rectangular slot stacked antenna	143
4.64	Bottom view of the rectangular slot stacked antenna	144
4.65	Rectangular slot stacked antenna with aperture coupling slot simulated gain	145

4.66	(a) E-plane and H-plane simulated radiation patterns of the rectangular slot stacked antenna with aperture coupling slot (b) E-plane and H-plane measured radiation patterns of the rectangular slot stacked antenna with aperture coupling slot	146
4.67	Prototype of rectangular slot stacked antenna	147
4.68	Rectangular slot antenna return loss with triangular aperture coupling slot	148
4.69	Top view of the 1.8 GHz stacked antenna	148
4.70	Bottom view of the 1.8 GHz stacked antenna	149
4.71	1.8 GHz antenna with aperture coupling slot simulated gain	150
4.72	(a) E-plane and H-plane simulated radiation patterns of the 1.8 GHz stacked antenna with aperture coupling slot (b) E-plane and H-plane measured radiation patterns of the 1.8 GHz stacked antenna with aperture coupling slot	151
4.73	Prototype of 1.8 GHz stacked antenna	152
4.74	1.8 GHz antenna return loss with triangular aperture coupling slot	152
4.75	Top view of the array stacked antenna	153
4.76	Bottom view of the array stacked antenna	153
4.77	Stacked array antenna with aperture coupling slot simulated gain	156
4.78	(a) E-plane and H-plane simulated radiation patterns of the stacked array antenna with aperture coupling slot (b) E-plane and H-plane measured radiation patterns of the stacked array antenna with aperture coupling slot	157
4.79	Prototype of stacked array antenna	158

4.80	Stacked array antenna return loss with triangular aperture coupling slot	159
4.81	Prototype of integration of rectangular slot antenna and rectifier 2.45 GHz (8.5 cm)	162
4.82	DC output voltage of integration of rectangular slot antenna and rectifier 2.45 GHz	163
4.83	Prototype of integration of rectangular slot antenna and rectifier 2.45 GHz (reduce size : 5.5 cm)	164
4.84	DC output voltage of integration of rectangular slot antenna and rectifier 2.45 GHz (reduce size)	164
4.85	Prototype of integration of rectangular slot antenna and rectifier 2.45 GHz (double stage)	165
4.86	DC output voltage of integration of rectangular slot antenna and rectifier 2.45 GHz (double stage)	166
4.87	Prototype of integration of rectangular slot antenna and 2.45 GHz rectifier (reduce size: 5.5 cm) (double stage)	167
4.88	DC output voltage of integration of rectangular slot antenna and 2.45 GHz rectifier (reduce size: 5.5 cm) (double stage)	167
4.89	Prototype of stacked feedline rectenna for RF energy harvester (reduce size)	168
4.90	DC output voltage of stacked feedline rectenna for RF energy harvester (reduce size: 5.5 cm)	169
4.91	Prototype of novel stacked rectenna for RF energy harvester (reduce size: 5.5 cm)	170
4.92	DC output voltage of novel stacked rectenna for RF energy harvester	170

	(reduce size: 5.5 cm)	
4.93	DC output voltage and conversion efficiency of novel stacked rectenna for RF energy harvester (reduce size: 5.5 cm)	171
4.94	Prototype of novel 2.45 GHz stacked rectenna for RF energy harvester (reduce size: 5.5 cm) (double stage)	172
4.95	DC output voltage of novel 2.45 GHz stacked rectenna for RF energy harvester (reduce size: 5.5 cm) (double stage)	173
4.96	DC output voltage and conversion efficiency of novel 2.45 GHz stacked rectenna for RF energy harvester (reduce size: 5.5 cm) (double stage)	173
5.1	Air-filled substrate integrated cavity resonator (SIW) (Majid Ndoye, 2017)	180
5.2	(a) PBG (b) EBG and (c) AMC antennas (Aisyah, 2016; Hang Jin, 2018 and Yuwei Chen, 2017)	181
5.3	(a) Dual-band and (b) Multi-band rectenna (Ping Lu, 2015 and A. Okba, 2016)	182

## LIST OF APPENDICES

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Datasheet of HSMS286B Schottky Diode	213
B	Datasheet of FR4-86 UV BLOCK	230
C	Design and Simulation Tools	232
D	Fabrication and Measurement Tools	236
E	Default Setting of the Horn Antenna	240