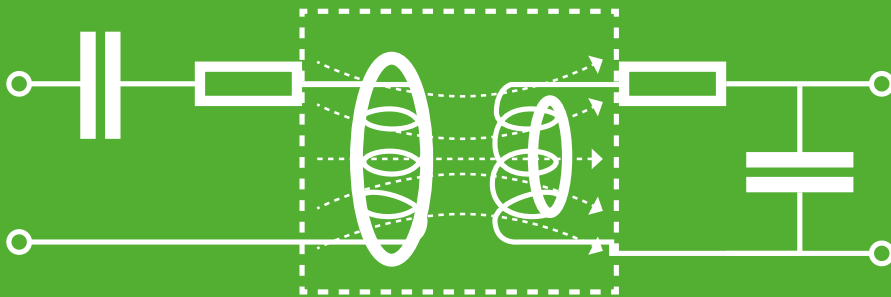


Wireless Power Design

From Theory to Practical Applications
in Wireless Energy Transfer
and Harvesting



Academy Pro Title by
Mohamed Zied Chaari

Wireless Power Design

From Theory to Practical Applications in Wireless Energy Transfer and Harvesting



Mohamed Zied Chaari

-
- This is an Elektor Publication. Elektor is the media brand of

Elektor International Media B.V.

PO Box 11, NL-6114-ZG Susteren, The Netherlands

Phone: +31 46 4389444

- All rights reserved. No part of this book may be reproduced in any material form, including photocopying, or storing in any medium by electronic means and whether or not transiently or incidentally to some other use of this publication, without the written permission of the copyright holder except in accordance with the provisions of the Copyright Designs and Patents Act 1988 or under the terms of a licence issued by the Copyright Licensing Agency Ltd., 90 Tottenham Court Road, London, England W1P 9HE. Applications for the copyright holder's permission to reproduce any part of the publication should be addressed to the publishers.

- **Declaration**

The author and publisher have made every effort to ensure the accuracy of the information contained in this book. They do not assume, or hereby disclaim, any liability to any party for any loss or damage caused by errors or omissions in this book, whether such errors or omissions result from negligence, accident, or any other cause. The author expresses his sincere gratitude to Arrow Electronics and Trenz Electronic for granting permission to include various tables, figures, and program codes in this book.

- **ISBN 978-3-89576-668-8** Print

ISBN 978-3-89576-669-5 eBook

- © Copyright 2025 Elektor International Media

www.elektor.com

Editor: Ferdinand te Walvaart

Prepress Production: D-Vision, Julian van den Berg

Printers: Ipskamp, Enschede, The Netherlands

Elektor is the world's leading source of essential technical information and electronics products for pro engineers, electronics designers, and the companies seeking to engage them. Each day, our international team develops and delivers high-quality content - via a variety of media channels (including magazines, video, digital media, and social media) in several languages - relating to electronics design and DIY electronics. www.elektormagazine.com

Contents

General Introduction	10
Section 1: An Overview of Wireless Power Technology and Its History	11
Chapter 1 • Early History of Wireless Transmission of Electrical Energy	12
1.1 Heinrich Hertz	12
1.2 Nikola Tesla	12
1.3 William Brown	13
Chapter 2 • Microwave Technology Based on Wireless Power Transfer	14
2.1 The Microwave Station	18
2.2 Antennas for Microwave Energy Transmission	18
2.3 The Rectenna (Rectifying Antenna)	18
2.4 Cyclotron Wave Rectifier (CWC)	19
Chapter 3 • Wireless Power Transfer-Based Electromagnetic Induction Technology	21
Chapter 4 • Industry Applications of WPT	23
4.1 Ground-to-Ground Microwave Transmission.	23
4.2 Wireless Charging of an Electric Vehicle (Inductive Solution)	24
4.3 Drone Wireless Power Charging (Inductive Solution)	25
4.4 Wireless Charging Mobile Phone (Inductive Solution)	25
4.5 Laser Wireless Power Transmission	26
4.6 Ultrasonic Wireless Power Transfer	27
Chapter 5 • Concerns Regarding Safety and Security	29
5.1 Beam Safety	29
5.2 Frequency Allocation	29
5.3 WPT and Sustainability	29
5.4 Conclusion	30
Section 2: Investigation and Construction of Microwave Transmitter Sources	31
Chapter 6 • Introduction	32
Chapter 7 • Microwave Transmitter Source	33
7.1 Gyrotron	33
7.2 Klystron	34

7.3. Magnetron Source	35
7.3.1 The operating frequency	36
7.3.2 Operation of magnetrons	36
7.3.3 Effect of the Magnetic Field	37
7.3.4 Magnetron power supply	38
7.3.5 Description of the operating sequence	39
7.4 Conclusion	41
Section 3: Rectenna and Energy Harvesting Circuit.	42
Chapter 8 • Introduction	43
Chapter 9 • Conventional Rectenna (Rectifying Antenna).	44
9.1 Matching Circuit Designs Using an Advanced Design System (ADS)	44
9.2 The Diode Choice.	45
9.3 Diode Model Analysis	47
9.4. Linear Equivalent Circuit of the HSMS 2820 Schottky Diode.	49
9.5 Voltage Multiplication Circuit Overview	50
9.6 Simulation of Multiplication Circuit	54
9.7 Storage Element for WPT	56
9.8 Conclusion	57
Section 4: Five Wireless Power Harvesting Circuits.	58
Chapter 10 • Project 1: Wireless Powering of Advanced IoT Devices	59
10.1 Objective of This Project:	59
10.2 Transmitter Antenna Fabrication, Experimental and Simulation	59
10.3 Harvesting Antenna Fabrication, Experimental Measurements, and Simulation Techniques.	67
Twin Antenna Without an Inset-Fed Patch	67
10.4.1 Directivity	69
10.4.2 Reflection coefficient of the antenna	69
10.4.3 3D radiation pattern	70
10.4.4 Current distribution	70
10.4.5 Smith plot	71
10.5 Twin Inset-Fed Patch Antenna	72
10.5.1 Directivity	73

10.5.2 The reflection coefficient of the antenna	74
10.5.3 Radiation pattern 3D	74
10.5.4 Current distribution	75
10.5.5 Smith plot	75
10.6 Power Budget	77
10.7. Rectifier Investigation.	78
10.7.1 Single-stage voltage double RF energy harvesting circuit.	79
10.7.2. RF harvesting circuit design uses a bridge rectifier.	80
10.7 Prototype result and discussion	82
10.9. Conclusion:	85
Chapter 11 • Project 2: Wireless Powered Devices on the Frontline: The Future and Challenges	86
11.1 Objective of This Project	86
11.2 Soldier and Battery in the Battlefield	86
11.3 Power Budget	88
11.4 RF Microwave Transmitter System	92
11.5 Power Harvesting Circuit.	95
11.5.1 Rectangular Patch Antenna	96
11.5.2 Rectifier Investigation	97
11.6 Prototype Results and Discussion.	100
11.7 Conclusion	103
Chapter 12 • Project 3: Wireless Powering of Devices Using Inductive Technology.	104
12.1 Objective of This Project	104
12.2 Theory	104
12.3 Design Process	105
12.4 Transmission Circuit.	106
12.4.1 Frequency oscillator	106
12.4.4 Switched mode power amplifier circuit.	107
12.5 Receiver Circuit	108
12.6 Test System and Implementation.	109
12.7 Discussion and Results	111

12.8 Warming a Coffee Mug	112
12.9 Conclusion	114
Chapter 13 • Project 4: Wireless Power Transmission for IoT Devices	116
13.1 Objective of This Project	116
13.2 The Impact of WPT on IoT or 4.0 Technologies	116
13.3 Design of the Harvester Coil Antenna	117
13.4 Dimension of the Receiver Coil Antenna	118
13.4.1 Simulation and discussion.	119
13.4.2 Directivity	119
13.4.3 Reflection coefficient of the antenna:.	119
13.4.4 VSWR plot	120
13.4.5 Radiation pattern 3D	120
13.4.6 Current distribution:	121
13.5 Energy Harvester Circuit	121
13.6 Prototype Results and Discussion	124
13.7 Conclusion	128
Chapter 14 • Project 5: Charging Robot Crawler Inside the Pipeline	129
14.1 Objective of This Project	129
14.2 Pipeline Inspection System	129
14.2.1 X-ray radiography inspections of pipelines	129
14.2.2 Pipe robot crawler	130
14.2.3 Robot crawler problem.	131
14.3 Pipeline as a Transmission Line	132
14.4 Study and design of the Tx and Rx conical horn antenna.	140
14.4.1 Simulation and results	140
14.4.2 S-Parameter.	141
14.4.3 Current distribution	142
14.5 Construction setup of Rx and Tx antenna.	143
14.6 Rectifier Circuit	144
14.6.1 A multistage voltage multiplier design rectenna.	145
14.6.2 Assembly system of a rectifier circuit (receiver).	148
14.7 Testing and Measurements Phase	150

14.8 Conclusion 152

Chapter 15 • Conclusion and Final Remarks 154

Index 155