

Advances in Antenna, Microwave and Communication Engineering

NEXT-GENERATION  
**ANTENNAS**  
ADVANCES AND CHALLENGES

Edited by  
Prashant Ranjan  
Dharmendra Kumar Jhariya  
Manoj Gupta  
Krishna Kumar  
Pradeep Kumar

 Scrivener  
Publishing

**WILEY**



# Table of Contents

[Cover](#)

[Title Page](#)

[Copyright](#)

[Preface](#)

[1 Different Types of Microstrip Filters for UWB Communication](#)

[1.1 Introduction](#)

[1.2 Previous Work](#)

[1.3 Conclusions](#)

[References](#)

[2 Design, Isolation Analysis, and Characterization of 2×2/4×4 MIMO Antennas for High-Speed Wireless Applications](#)

[2.1 Introduction](#)

[2.2 Understanding 2×2 MIMO Antenna Configuration](#)

[2.3 Diversity Performance Analysis of 2×2 UWB-MIMO/Dual-Polarization/UWB: Single, Dual, Triple, and Four Notched Bands](#)

[2.4 4×4 MIMO Antenna](#)

[2.5 Conclusions](#)

[References](#)

[3 Various Antenna Array Designs Using Scilab Software: An Exploratory Study](#)

[3.1 Introduction](#)

[3.2 Scilab: An Open-Source Software Solution](#)

[3.3 Antenna Array Design Using Scilab: Codes and Results](#)

[3.4 Conclusions](#)

[References](#)

[4 Conformal Wearable Antenna Design, Implementation and Challenges](#)

[4.1 Introduction](#)

[4.2 Conformal Antenna](#)

[4.3 Characteristics of Conformal Antenna](#)

[4.4 Design Methodology - Antenna Modeling](#)

[4.5 Wearable Conformal Antenna](#)

[4.6 Textile and Cloth Fabric Wearable Antennas](#)

[4.7 Design of Liquid Crystalline Polymer \(LCP\) Based Wearable Antenna](#)

[4.8 Result Discussion and Analysis](#)

[4.9 Challenges and Future Needs](#)

[4.10 Conclusion](#)

[References](#)

[5 Design and Analysis of On-Body Wearable Antenna with AMC Backing for ISM Band Applications](#)

[5.1 Introduction](#)

[5.2 Design of Star-Shape with AMC Backed Structure](#)

[5.3 Discussion of Results of Star-Shaped Antenna with AMC Structure](#)

[5.4 On-Body Placement Analysis of Proposed Antenna with AMC Structure](#)

[5.5 Transmitting Signal Strength](#)

[5.6 Conclusion](#)

[References](#)

## 6 Antenna Miniaturization for IoT Applications

### 6.1 Introduction

### 6.2 Issues in Antenna Miniaturization

### 6.3 Antenna for IoT Applications

### 6.4 Miniaturize Reconfigurable Antenna for IoT

### 6.5 Conclusion & Future Work

### References

## 7 Modified Circular-Shaped Wideband Microstrip Patch Antenna for Wireless Communication Utilities

### 7.1 Overview of Wireless Communication

### 7.2 Introduction to Microstrip Patch Antenna

### 7.3 Literature Review

### 7.4 Design and Implementation of Projected Antenna

### 7.5 Results and Discussion

### 7.6 Parametric Analysis

### 7.7 Summary

### References

## 8 Reconfigurable Antenna for Cognitive Radio System

### 8.1 Introduction

### 8.2 Antenna

### 8.3 Antenna Reconfigurations

### 8.4 Uses and Drawbacks of Reconfigurable Antenna

### 8.5 Spectrum Access and Cognitive Radio

### 8.6 Cognitive Radio

### 8.7 Spectrum Sensing and Allocation

### 8.8 Results and Discussion

### 8.9 Conclusions

### References

## 9 Ultra-Wideband Filtering Antenna: Advancement and Challenges

### 9.1 Introduction

### 9.2 Ultra-Wideband Filtering Antenna

### 9.3 Ultra-Wideband Filtering Antenna with Notch Band Characteristic

### 9.4 Conclusions

### References

## 10 UWB and Multiband Reconfigurable Antennas

### 10.1 Introduction

### 10.2 Need for Reconfigurable Antennas

### 10.3 RF PIN Diode and MEMS Switch as Switching Devices

### 10.4 Triple Notched Band Reconfigurable Antenna

### 10.5 Tri-Band Reconfigurable Monopole Antenna

### 10.6 Conclusions

### References

## 11 IoT World Communication through Antenna Propagation with Emerging Design Analysis Features

### 11.1 Introduction

### 11.2 Design and Parameter Analysis of Multi-Input Multi-Output Antennas

### 11.3 Measurement Analysis in 3D Pattern with IoT Module

### 11.4 Comparison of Antenna Design Concerning the IoT Data Transmission

### 11.5 Conclusions

### Acknowledgement

### References

## 12 Reconfigurable Antennas

[12.1 Introduction](#)

[12.2 Reconfigurability of Antenna](#)

[12.3 Polarization Reconfigurable Antenna \(RA\)](#)

[12.4 Compound Reconfigurable Antennas \(RAs\)](#)

[12.5 Reconfigurable Leaky Wave Antennas](#)

[12.6 Reconfigurable Antennas - Applications in Wireless Communication](#)

[12.7 Optimization, Control, and Modeling of Reconfigurable Antennas](#)

[12.8 Conclusions](#)

[References](#)

[13 Design of Compact Ultra-Wideband \(UWB\) Antennas for Microwave Imaging Applications](#)

[13.1 Introduction](#)

[13.2 Microwave Imaging](#)

[13.3 Antenna Design Implementation](#)

[13.4 Design of a UWB-Based Compact Rectangular Antenna](#)

[13.5 Validation of the Miniaturized UWB Antenna with the Human Breast Model Developed](#)

[13.6 Conclusions](#)

[References](#)

[14 Joint Transmit and Receive MIMO Beamforming in Multiuser MIMO Communications](#)

[14.1 Introduction](#)

[14.2 System Model: Proposed MIMO Beamforming Architecture](#)

[14.3 MIMO Beamforming Based on Generalized Least Mean \(GLM\) Algorithm](#)

[14.4 Mean and Mean Square Stability of the GLM](#)

[14.5 Simulation Results](#)

[14.6 Summary](#)

[References](#)

[15 Adaptive Stochastic Gradient Equalizer Design for Multiuser MIMO System](#)

[15.1 Introduction](#)

[15.2 Related Literature Review](#)

[15.3 System Model](#)

[15.4 Derivation for the Probability of Error](#)

[15.5 Design of Adaptive Equalizer by Minimizing BER](#)

[15.6 Simulation Results](#)

[15.7 Summary](#)

[References](#)

[About the Editors](#)

[Index](#)

[End User License Agreement](#)

## List of Illustrations

Chapter 2

[Figure 2.1 \(a\) Rotated view of single unit MIMO cell \(b\) 2×2 MIMO antenna rotate...](#)

[Figure 2.2 \(a\) Re-Img, impedance curve \(b\) ECC \(c\) DG \(d\) TARC \(e\) CCL \(f\).](#)

[Figure 2.3 Arrangement of T×T MIMO antenna configuration.](#)

[Figure 2.4 Arrangement of T×T MIMO antenna configuration.](#)



[Figure 2.5 Arrangement of 4×4 MIMO antenna configuration \(a\) S-Parameters \( \$S\_{11}, \dots\$](#)

### Chapter 3

[Figure 3.1 Evolution of Scilab \[11\].](#)

[Figure 3.2 Statistics of Scilab usage in India \[14\].](#)

[Figure 3.3 \(a\) Scilab code for radiation pattern \(rectangular plot\) of circular ...](#)

[Figure 3.4 \(a\) Scilab code for radiation pattern \(polar plot\) of concentric circ...](#)

[Figure 3.5 \(a\) Scilab code for radiation pattern \(rectangular plot\) of square ar...](#)

[Figure 3.6 \(a\) Scilab code for radiation pattern \(rectangular plot\) of hexagonal...](#)

[Figure 3.7 Feedback from the students on Scilab programming.](#)

### Chapter 4

[Figure 4.1 Structure of planar microstrip patch antenna.](#)

[Figure 4.2 Structure of planar microstrip patch antenna.](#)

[Figure 4.3 Structure of Conformal MSA having E- and U-shape slot.](#)

[Figure 4.4 Return loss \( \$S\_{11}\$ \) of the microstrip patch antenna for varying  \$L\_p\$ .](#)

[Figure 4.5 Health monitoring system for body-worn application.](#)

[Figure 4.6 Flexible wearable antenna \[28\].](#)

[Figure 4.7 A defective ground slot with polymer substrate  \$\epsilon\_r\$  of 2.9.](#)



[Figure 4.8 A defective planar and conformal wearable antenna with a polymer subs...](#)

[Figure 4.9 Scattering parameter  \$S\_{11}\$  for different textile substrate.](#)

[Figure 4.10 Radiation characteristics of the wearable antenna \(a\) Polyester; \(b\)...](#)

## Chapter 5

[Figure 5.1 Designed antenna by iteration \(a\) Circular ring \(b\) Inserted star sha...](#)

[Figure 5.2 Structural view of the unit cell.](#)

[Figure 5.3 Proposed AMC phase diagram of AMC unit cell.](#)

[Figure 5.4 AMC structure \(a\)  \$2 \times 2\$  array AMC structure \(b\) Fabricated AMC.](#)

[Figure 5.5 Gap variations among the AMC unit cell structure.](#)

[Figure 5.6 Reflection coefficient of proposed antenna iterations.](#)

[Figure 5.7 Bending analysis of the star-shaped design with AMC backed.](#)

[Figure 5.8 Variation of reflection coefficient antenna at different bending cond...](#)

[Figure 5.9 Star-shaped antenna placed on the human body backed with AMC structur...](#)

[Figure 5.10 Specific absorption rate analysis \(a\) without AMC \(b\) with AMC struc...](#)

[Figure 5.11 On-body gain of the antenna without and with AMC structure.](#)

[Figure 5.12 Far-field characteristics of antenna in different planes.](#)

[Figure 5.13 Experimental setup for measuring received power of a star-shaped ant...](#)

[Figure 5.14 Measured performance of received power with and without a human body...](#)

## Chapter 6

[Figure 6.1 Inverted F application.](#)

[Figure 6.2 Inverted F design layout.](#)

## Chapter 7

[Figure 7.1 Evolution stages \(a\) Antenna-1 \(b\) Antenna-2 \(c\) Projected Antenna.](#)

[Figure 7.2 Schematic of Projected Antenna.](#)

[Figure 7.3 View of Projected Antenna in HFSS software.](#)

[Figure 7.4  \$S\_{11}\$  characteristics of Antenna 1, Antenna 2, and Projected Antenna.](#)

[Figure 7.5 3-Dimensional gain plots at \(a\) 5.52 GHz \(b\) 11.36 GHz \(c\) 15.76 GHz ...](#)

[Figure 7.6 Comparison of gain values of Antenna 1, Antenna 2, and Projected Antenna...](#)

[Figure 7.7 Radiation patterns of Projected Antenna in E and H planes at \(a\) 5.52 ...](#)

[Figure 7.8 Current distribution of Projected Antenna in E and H planes at \(a\) 5.5...](#)

[Figure 7.9 Axial ratio versus frequency of Projected Antenna.](#)

[Figure 7.10 Group delay versus frequency of Projected Antenna.](#)

[Figure 7.11 S11 characteristics with 'R<sub>p</sub>' = 11, 12, and 13mm.](#)

[Figure 7.12 S<sub>11</sub> characteristics with 'F<sub>w</sub>' = 2.5, 3, and 3.5 mm.](#)

[Figure 7.13 S11 characteristics with 'L<sub>PG</sub>' = 28, 29, and 30 mm.](#)

[Figure 7.14 S<sub>11</sub> characteristics obtained with FR4, Glass and Arlon AD410 \(tm\).](#)

## Chapter 8

[Figure 8.1 Typical structure of the antenna \[6\].](#)

[Figure 8.2 Antenna circuit as a whole structure \[7\].](#)

[Figure 8.3 Reconfigurable antennas.](#)

[Figure 8.4 CR construction with parallel sensing.](#)

[Figure 8.5 CR construction with combined sensing.](#)

[Figure 8.6 Base module without switch.](#)

[Figure 8.7 Reconfigurable UWB with four switch.](#)

[Figure 8.8 S-parameter when all switches are off.](#)

[Figure 8.9 S-parameter when three switches are ON and one switch is OFF.](#)

[Figure 8.10 S-parameter when all switches are ON.](#)

## Chapter 10

[Figure 10.1 \(a\) Photograph of manufactured PIN diode \(Courtesy: NXP Semiconducto...](#)

[Figure 10.2 \(a\) Image of packaged SP4T switch \(ADGM1304\) \(b\) Cross-sectional vie...](#)

[Figure 10.3 Antenna configuration.](#)

[Figure 10.4 \(a\) Step 1 \(b\) Step 2 \(c\) Step 3 \(d\) Step 4 \(e\) result comparison.](#)

[Figure 10.5 \(a\) Reconfigurable monopole antenna \(b\) Radiating view \(c\) Ground vi...](#)

[Figure 10.6 Reconfigurable multiband antenna \(a\) Slant view with PIN diodes \(b\) ...](#)

## Chapter 11

[Figure 11.1 Sensor node connected with antenna coverage area with the gateway.](#)

[Figure 11.2 Amplitude distribution of microstrip antenna with two analyzing plat...](#)

[Figure 11.3 3D pattern-based radiation of the manhole antenna wave propagation.](#)

[Figure 11.4 Polarization effects of wave distribution of the antenna in the 2D p...](#)

[Figure 11.5 Parameter estimation in far-field directivity with gain estimation.](#)

[Figure 11.6 Efficiency computation of the microstrip antenna design concerning f...](#)

## Chapter 12

[Figure 12.1 Classification of reconfigurable antennas.](#)

[Figure 12.2 Microstrip patch antenna with differentially fed frequency-agile \[7\]...](#)

[Figure 12.3 Reconfigurable antenna with circular patch: \(a\) Top layer; \(b\) Botto...](#)

[Figure 12.4 \(a\) Annular slot antenna - Front side, \(b\) Impedance matching networ...](#)

[Figure 12.5 Output of leaky-wave antenna.](#)

[Figure 12.6 ESPAR for MIMO communications \[26\].](#)

[Figure 12.7 The cognitive radio cycle.](#)

[Figure 12.8 MIMO-based reconfigurable filtenna \[29\].](#)

[Figure 12.9 Proposed reconfigurable sensing antenna.](#)

[Figure 12.10 “mm” wave antenna \[34\].](#)

## Chapter 13

[Figure 13.1 Structure of reflector-based antipodal bowtie antenna.](#)

[Figure 13.2 Fabricated slotted bowtie antenna with reflector: \(a\) top region and...](#)

[Figure 13.3 Simulated and measured return loss.](#)

[Figure 13.4 Simulated antipodal bowtie antenna return loss of effect in length o...](#)

[Figure 13.5 Simulated antipodal bowtie antenna return loss of effect in length t...](#)

[Figure 13.6 Simulated antipodal bowtie antenna return loss of effect in height o...](#)

[Figure 13.7 Simulated return loss of effect in the width of the cross slot 1  \$W\_4\$  ...](#)

[Figure 13.8 Radiation pattern: \(a\) 4GHz, \(b\) 6.6GHz and \(c\) 8.92GHz.](#)

[Figure 13.9 Evolution of the Rectangular MPA: \(a\) Rectangular MPA, \(b\) MPA with ...](#)

[Figure 13.10 Layout of the miniaturized ultra-wideband antenna with DGS.](#)

[Figure 13.11 Effect of varying the strip length  \$L\_{st}\$ .](#)

[Figure 13.12 Effects of varying: \(a\) slot length  \$L\_1\$  and \(b\) slot position  \$d\_s\$ .](#)

[Figure 13.13 Effects of varying the second slot: \(a\) length  \$L\_2\$  and \(b\) width  \$W\_2\$ ...](#)

[Figure 13.14 Proposed miniaturized UWB patch antenna: \(a\) Antenna layout and \(b\)...](#)

[Figure 13.15 Comparison of simulated and measured results of frequency vs. retur...](#)

[Figure 13.16 Comparison of simulated and measured results of frequency vs. VSWR ...](#)

[Figure 13.17 Radiation patterns in the E plane and H plane of the UWB antenna at...](#)

[Figure 13.18 Proposed UWB patch antenna with Debye testbed model: \(a\) Lower diel...](#)

[Figure 13.19 2D power spectrum plot using MUSIC algorithm for the signals receiv...](#)

## Chapter 14

[Figure 14.1 MIMO channel beamforming architecture with decision-directed mode \[1...](#)

[Figure 14.2 Mean square error with different values of  \$K\$ .](#)

[Figure 14.3 Mean-square-error for different values of  \$\mu\$ .](#)

[Figure 14.4 Mean square error with different number of transmitter and receiver ...](#)

[Figure 14.5 Mean square error versus SNR for the same iteration.](#)

[Figure 14.6 Decrease in bit error rate with the increase in number of transmitters...](#)

## Chapter 15

[Figure 15.1 \(a\) Single-User system, \(b\) Multi-User MIMO system.](#)

[Figure 15.2 Block diagram of MU-MIMO uplink systems.](#)

[Figure 15.3 Comparison of the probability of error using interior point based eq...](#)

[Figure 15.4 Comparison of the probability of error perform over Interior point a...](#)

## List of Tables

### Chapter 1

[Table 1.1 Summary of multiband filters.](#)

[Table 1.2 Summary of ultra-wideband filters.](#)

[Table 1.3 Summary of ultra-wideband filters with notched band.](#)

### Chapter 2

[Table 2.1 Tabulated diversity performance.](#)

[Table 2.2 Diversity performance comparison of 2×2 UWB and Multiband MIMO Antenna...](#)

[Table 2.3 Dual polarization MIMO antenna.](#)

[Table 2.4 UWB single/dual/triple/four notched bands 2×2 MIMO antenna.](#)

[Table 2.5 Comparison of 4×4 MIMO antenna configuration.](#)

### Chapter 3

[Table 3.1 Learning Outcomes of antenna engineering course.](#)



## Chapter 4

[Table 4.1 Dimension parameter of the patch.](#)

[Table 4.2 Density and thickness of arm tissues mass \[31\].](#)

[Table 4.3 Arm tissues parameters at distress signal frequency\\_\(0.406GHz\)\\_\[31\].](#)

[Table 4.4 Dimensions of the proposed planar antenna.](#)

## Chapter 5

[Table 5.1 Variables of the designed antenna and AMC.](#)

## Chapter 7

[Table 7.1 Simulated results of the antenna at different stages \(Antenna 1, Anten...](#)

[Table 7.2 Comparison of Projected Antenna with few published multi-band antennas...](#)

## Chapter 8

[Table 8.1 Comparison of impedance bandwidth for the three switching.](#)

## Chapter 9

[Table 9.1 Summary of ultra-wideband filtering antenna.](#)

[Table 9.2 Summary of ultra-wideband filtering antenna with notch band characteri...](#)

## Chapter 10

[Table 10.1 Comparison of an RF PIN diode and MEMS switch.](#)

[Table 10.2 Reconfigurable characteristics of reconfigurable notched band super w...](#)

[Table 10.3 Comparison of notched band reconfigurable monopole antennas.](#)

[Table 10.4 Multiband reconfigurable antenna.](#)

## Chapter 13

[Table 13.1 Design parameters of antipodal slotted bowtie antenna \[23\].](#)

[Table 13.2 Optimal dimensions of the miniaturized UWB antenna design.](#)

## **Scrivener Publishing**

100 Cummings Center, Suite 541J  
Beverly, MA 01915-6106

## **Advances in Antenna, Microwave, and Communication Engineering**

**Series Editors: Manoj Gupta, PhD, Pradeep Kumar, PhD**

Scope: This book series represents an exciting forum for the presentation and discussion of the most recent advances in the antenna, microwave, and communication engineering area. In addition to scientific books, contributions on industrial applications are strongly encouraged, covering the above listed fields of applications. This book series is aimed to provide monograph, volumes, comprehensive handbooks and reference books that are empirical studies, theoretical and numerical analysis, and novel research findings for the benefit of graduate and postgraduate students, research scholars, hardware engineers, research and development scientists, and industry professional working towards the latest advances in antenna, microwave, and communication engineering and for their industrial applications.

*Publishers at Scrivener*

Martin Scrivener ([martin@scrivenerpublishing.com](mailto:martin@scrivenerpublishing.com))

Phillip Carmical ([pcarmical@scrivenerpublishing.com](mailto:pcarmical@scrivenerpublishing.com))

# **Next-Generation Antennas**

## **Advances and Challenges**

Edited by

**Prashant Ranjan,**

**Dharmendra Kumar Jhariya,**

**Manoj Gupta,**

**Krishna Kumar,**

**and**

**Pradeep Kumar**



**WILEY**

This edition first published 2021 by John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA and Scrivener Publishing LLC, 100 Cummings Center, Suite 541J, Beverly, MA 01915, USA

© 2021 Scrivener Publishing LLC

For more information about Scrivener publications please visit

[www.scrivenerpublishing.com](http://www.scrivenerpublishing.com).

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, except as permitted by law. Advice on how to obtain permission to reuse material from this title is available at <http://www.wiley.com/go/permissions>.

### **Wiley Global Headquarters**

111 River Street, Hoboken, NJ 07030, USA

For details of our global editorial offices, customer services, and more information about Wiley products visit us at [www.wiley.com](http://www.wiley.com).

### **Limit of Liability/Disclaimer of Warranty**

While the publisher and authors have used their best efforts in preparing this work, they make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives, written sales materials, or promotional statements for this work. The fact that an organization, website, or product is referred to in this work as a citation and/or potential source of further information does not mean that the publisher and authors endorse the information or services the organization, website, or product may provide or recommendations it may make. This work is sold with the understanding that the publisher is not engaged in rendering professional services. The advice and strategies contained herein may not be suitable for your situation. You should consult with a specialist where appropriate. Neither the publisher nor authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read.

### ***Library of Congress Cataloging-in-Publication Data***

ISBN 9781119791867

Cover image: (Antenna Tower): Carmen Hauser | [Dreamstime.com](http://Dreamstime.com)

Cover design by Kris Hackerott

Set in size of 11pt and Minion Pro by Manila Typesetting Company, Makati, Philippines

Printed in the USA

10 9 8 7 6 5 4 3 2 1

# Preface

In the 21st century, the world is facing many challenges and developments. People moving into urban areas are keen to experience the new changes in cities, where facilities are more user-friendly and comfortable. It has led to the existence of next-generation antennas, and researchers in this field are working towards developing these antennas for industrial applications. Keeping this in view, the present book is aimed at exploring the various aspect of next-generation antennas, and their advances, along with their challenges, in detail.

Antenna design and wireless communication have recently witnessed their fastest growth period ever in history, and this trend is likely to continue for the foreseeable future. Due to recent advances in industrial applications as well as antenna, wireless communication and 5G, we are witnessing a variety of new technologies being developed. Compact and Low-cost antennas are increasing the demand for ultra-wide bandwidth in next-generation (5G) wireless communication systems and the Internet of Things (IoT). Enabling the next generation of high-frequency communication, various methods have been introduced to achieve reliable high data rate communication links and enhance the directivity of planar antennas. 5G technology can be used in many applications such as smart city and smartphones, and many other areas as well. This technology can also satisfy the fast rise in user and traffic capacity in mobile broadband communications.

Therefore, different planar antennas with intelligent beamforming capability play an important role in these areas. The purpose of this book is to present the advanced technology, developments, and challenges in antennas for

next-generation antenna communication systems. This book is concerned with the advances in next-generation antenna design and application domain in all related areas. It includes a detailed overview of the cutting age developments and other emerging topics, and their applications in all engineering areas that have achieved great accuracy and performance with the help of the advances and challenges in next-generation antennas.

## **Readers**

This book is useful for the Researchers, Academicians, R&D Organizations, and healthcare professionals working in the area of Antenna, 5G Communication, Wireless Communication, Digital hospital, and Intelligent Medicine.

The main features of the book are:

- It has covered all the latest developments and future aspects of antenna communication.
- Very useful for the new researchers and practitioners working in the field to quickly know the best performing methods.
- Provides knowledge on advanced technique, monitoring of the existing technologies and utilizing the spectrum in an efficient manner.
- Concisely written, lucid, comprehensive, application-based, graphical, schematics, and covers all aspects of antenna engineering.

**Chapter Organization** [Chapter 1](#) gives an overview of Microstrip filters for UWB communication. It also describes the Multiband Microwave filter, Ultra-Wideband (UWB) bandpass filter, and ultra-wideband filter with notch band characteristic. [Chapter 2](#) describes the introduction of



2×2 MIMO antenna configuration, and their diversity performance analysis.

**Chapter 3** explains the Scilab open-source software and antenna array design.

**Chapter 4** gives an overview of conformal antenna, explains characteristics of conformal antenna, wearable technology, cloth fabric wearable antennas, and simulated radiation pattern.

**Chapter 5** gives an overview of On-Body wearable antenna for ISM band applications, explains design of star-shape with AMC backed structure, characterization of AMC unit cell, bending analysis of star-shaped antenna with AMC backed structure, and on-body placement analysis of the antenna with AMC structure.

**Chapter 6** gives an overview of antenna miniaturization for IoT applications, issues in antenna miniaturization, antenna for IoT applications, and miniaturize reconfigurable antenna for IoT.

**Chapter 7** gives an overview of wireless communication, Microstrip patch antenna, design & implementation of projected antenna, and observe the effect of different substrate materials.

**Chapter 8** provides understanding of reconfigurable antenna for cognitive radio system, uses and drawbacks of reconfigurable antenna, and spectrum access and cognitive radio.

**Chapter 9** describes the Ultra-Wideband filtering antenna, and Ultra-Wideband filtering antenna with notch band characteristic.

**Chapter 10** describes the UWB and multiband reconfigurable antennas, need for reconfigurable antennas,

triple notched band reconfigurable antenna, and tri-band reconfigurable monopole antenna.

**Chapter 11** highlighted the IoT world communication through antenna propagation with emerging design analysis features, design and parameter analysis of multi-input multi-output antennas, measurement analysis in 3D pattern with IoT module.

**Chapter 12** gives an overview of reconfigurable antennas, polarization reconfigurable antenna, compound reconfigurable antennas, and reconfigurable leaky wave antennas.

**Chapter 13** gives an overview of design of compact Ultra-Wideband (UWB) antennas for microwave imaging applications, design of a UWB-based compact rectangular antenna, and validated the miniaturized UWB antenna with the human breast model developed.

**Chapter 14** gives an overview of joint transmit and receive MIMO beam-forming in multiuser MIMO communications, and system modeling for MIMO beamforming architecture based on generalized least mean algorithm.

**Chapter 15** describes the adaptive stochastic gradient equalizer design for multiuser MIMO system, and design of adaptive equalizer by minimizing BER.

# 1 Different Types of Microstrip Filters for UWB Communication

Prashant Ranjan<sup>1\*</sup>, Krishna Kumar<sup>2</sup>, Sachin Kumar Pal<sup>3</sup> and Rachna Shah<sup>4</sup>

<sup>1</sup>*Department of ECE, University of Engineering and Management, Jaipur, India*

<sup>2</sup>*UJVN Ltd., Uttarakhand, India*

<sup>3</sup>*Bharat Sanchar Nigam Ltd., Guwahati, India*

<sup>4</sup>*National Informatics Centre, Dehradun, India*

## ***Abstract***

Many filters such as triple-band filter, multiband filter, UWB filter, and notch band filters have been investigated in recent decades [1]. Bandpass filters with the features of good performance, micro-package, ease of use, and low cost have been the focus of device miniaturization.

However, most of these UWB filters with band-notched have been designed by using various slots either in the ground plane or radiating patch, slit on feeding line, or integration of filter in feed line of the antenna. Slotted methods can be used for frequency rejection but it may distort the radiation patterns because of the electromagnetic leakage of these slots. In this chapter, a survey of multiband filter, UWB filter, and UWB with notch band filter are presented.

**Keywords:** Ultra-wideband, bandpass filter, microstrip patch, multiband, multiple-mode resonator, and transmission zeros

## **1.1 Introduction**

The system can be streamlined and the physical dimension of the circuit minimized by triple-band microwave filters, thereby increasing the demand for triple-band microwave filters in modern communication systems. Recently, in many research papers, triple and multiband microwave filters have been widely studied. The use of alternately cascaded multiband resonators is one way of designing a triple-band filter. Coupling systems are used to achieve two and three frequency bands with Quasi-elliptic and Chebyshev frequency responses [2].

## **1.2 Previous Work**

Various researchers have worked on the Microstrip filters for UWB communication.

### **1.2.1 Multiband Microwave Filter for a Wireless Communication System**

Hao Di *et al.* [3] presented a technique to achieve a triple passband filter. In this method, a frequency transformation from the normalized frequency domain to the actual frequency domain is used. Applying this transformation, filter circuits with cross-coupling having triple-passband have been constructed. Cross coupled tri-band filter topology is presented, which consists of parallel resonators and admittance inverters. By using expressions, the external quality factors and coupling coefficients can be calculated. Three passbands 3.3–3.4, 3.5–3.6, and 3.7–3.8 GHz, with more than 20 dB return loss have been reported in this paper.

Hsu *et al.* [4] proposed asymmetric resonator-based one wideband and two tri-band BPFs. The resonator contains microstrip sections with different electrical lengths. Three resonant modes can be shifted to the desired center

frequencies by varying the stub length of the first filter. In the second filter, asymmetrical resonators are used to achieve a wide stopband. For the third filter, wideband BPF is designed using multi-mode resonances and transmission zeros (TZs) of the asymmetrical resonator. It suppressed the higher-order harmonics. The three passbands 1.5, 2.5, and 3.5 GHz are achieved using four resonators.

Liou *et al.* [5], proposed a Marchand balun filter with the shorted coupled line to achieve triple passbands. The filter is constructed with a triple-band resonator to exhibit the triple-band admittance inverter characteristic. The compensation techniques for phase-angle and impedance matching are used to improve the phase and amplitude responses of the existing three passbands. The defected ground structure stubs and microstrip coupled-line sections is used to realize the filter. Jing *et al.* [6] proposed a single multimode resonator-based filter with six passbands. The proposed MMR is a SIR (stepped impedance resonator) with two symmetrical open-circuited stubs positioned at two sides and one shorted stub connected in the middle. The electrical lengths of two open stubs are increased to excited the transmission zeros (TZs) and transmission poles (TPs). The TZs are separated from TPs by introducing open stubs; therefore, a six-band BPF is designed. Two input-output tapped branches and radical stub-loaded shorted lines are adjusted to improve filter performance.

Hong *et al.* [7] proposed a cross-coupled microstrip filter by using square open-loop resonators. In this paper coupling coefficients calculation of the three coupling structures of filters is developed. Empirical models are presented to estimate the coupling coefficients. A four-pole elliptic function type filter is designed. Three types of coupling characteristics, the electric, magnetic, and mixed couplings, have been reported. Kuo *et al.* [8] presented a microstrip

filter with two frequency passband response based on SIR. SIR is in parallel-coupled and vertical-stacked configuration. Resonance characteristics of the second resonant frequency can be tuned over a wide range by adjusting its structure parameters. Tapped input/output couplings are used to match-band response for the two designated passbands. Both coupling length and gap are adjusted together to meet the required coupling coefficients of two bands. Fractional bandwidth design graphs are used to determine geometric parameters. Two passband resonant frequencies are 2.45 and 5.8 GHz with a fractional bandwidth of 12% and 7%, respectively. The measured insertion loss for the first passband is 1.8 dB and for the second passband is 3.0 dB. Higher-order filters are also designed using this design procedure.

Guan *et al.* [9] proposed a triple-band filter using two pairs of SIRs having single transmission zero. The first and the third frequency bands are realized by using Parallel coupled microstrip lines and the second frequency band is realized by using an end-coupled microstrip line. Single TZ is generated due to the antiparallel structure of the microstrip line. 2.4 GHz and 5.7 GHz are generated by longer resonators and 3.8 GHz is generated by the shorter resonators. By changing the impedance ratio of the resonator, the passband position of the filter can be adjusted. The filter bandwidths can be adjusted by adjusting the distance between resonators.

Ko *et al.* [10] presented two coupled line structures with open stubs to design a triple-band filter but insertion losses and bandwidths are poor. The third resonance frequency is shifted from 8.9 GHz to 6.5 GHz by variation in the lengths of two open stubs. A gap between transmission lines is used to adjust the second resonance frequency at 4.2 GHz. The first resonance frequency (2.4 GHz) can be adjusted using the coupled line length.

Lin *et al.* [11] proposed a triple-band BPF based on SIR. Hairpin type structure is used to reduce the size of the filter. Three passbands are 1.0, 2.4, and 3.6 GHz with an insertion loss of 2.2, 1.8, and 1.7 dB, respectively. Wibisonoet *et al.* [12] proposed a triple band BPF using cascaded three SIR. Filter passband frequencies are 900 MHz, 1800 MHz, and 2600 MHz simultaneously. Riana *et al.* [13] proposed a split-ring resonator to create three passband frequencies having two TZs. The filter coupling model approach is used to design filter and control passbands. Additional transmission zeros can be introduced by adjusting the position of the coupled resonators. Using triple-mode SRRs two filter topologies have been described. Using the lumped-element model to design the mainline and cross-couplings topology is presented in this paper. Two independent extraction methods, a de-tuning method, and a parameter-extraction method are used to determine coupling coefficients. Three passbands are 1.7, 2.4, and 3 GHz.

Liu *et al.* [14] proposed a triple band HTS (high temperature superconducting) filter using stub-loaded multimode resonator. The odd-even mode method is used to investigate the characteristics of the multimode resonator. A nonresonant node with a source-load coupling configuration is used to create TZs. Three passband resonant frequencies of the HTS filter, 2.45, 3.5, and 5.2 GHz, are presented. Insertion losses of the first, second, and third passbands are 0.16 dB, 0.55 dB, and 0.22 dB, respectively. The overall size of the filter is 8.3 mm  $\times$  8.6 mm. Qiang *et al.* [15] proposed a design of a wideband 90° phase shifter, which consists of open stub-based stepped impedance and a coupled-line to achieve wideband. The impedance ratio of the SIOS is used to analyze the bandwidths of return loss and the coupling strength of the coupled-line is used to analyze the phase deviation. The



bandwidth of the phase shifter is 105% (0.75 to 2.4 GHz) with an insertion loss of 1.1dB.

Haiwen *et al.* [16] presented a triple band HTS filter by using a multimode stepped impedance split ring resonator (SI-SRR) to achieve the wide stopband property. Even and odd mode analysis is used to analyze the equivalent circuit model. This filter can be operated at 2 GHz, 3.8 GHz, and 5.5 GHz. The measured insertion losses can be obtained as approximately 0.19 dB, 0.17 dB, and 0.3 dB respectively at the center frequency of each passband. Zheng *et al.* [17] proposed a UWB BPF by creating triple notch-bands to make the multiband filter. SIR and four shorted stubs having a length of  $\lambda/4$  are used to design the basic UWB filter. Open load stubs and E-shaped resonator are used to achieve triple band-notched performance. Three notched bands are at 4.8 GHz, 6.6 GHz, and 9.4 GHz. The minimum insertion loss of 0.6dB and a maximum ripple of 0.88 dB are reported.

Guan *et al.* [18] proposed a triple band HTS filter based on a coupled line SIR (C-SIR) to control transmission zeros. Three harmonic peaks are generated using C-SIR. Even-odd analysis method is applied to analyze the filter. An interdigital structure between the feed lines and C-SIR is used to increase the selectivity of the filter. Spiral-shaped lines are used for better coupling of the second-order resonator. Three frequency bands 1.57 GHz for GPS, 3.5 GHz for WiMAX, and 5.5 GHz for WLAN are achieved. Insertion losses are found to be 0.10, 0.20, and 0.66 dB at each passband, respectively.

Chen *et al.* [19] proposed multiband microstrip bandpass filters with circuit miniaturization. Five compact triple modes stub-load SIRs (SL-SIRs) are used to achieve five bands filter. The coupling scheme presented in this paper provides multiple paths for different frequency bands which