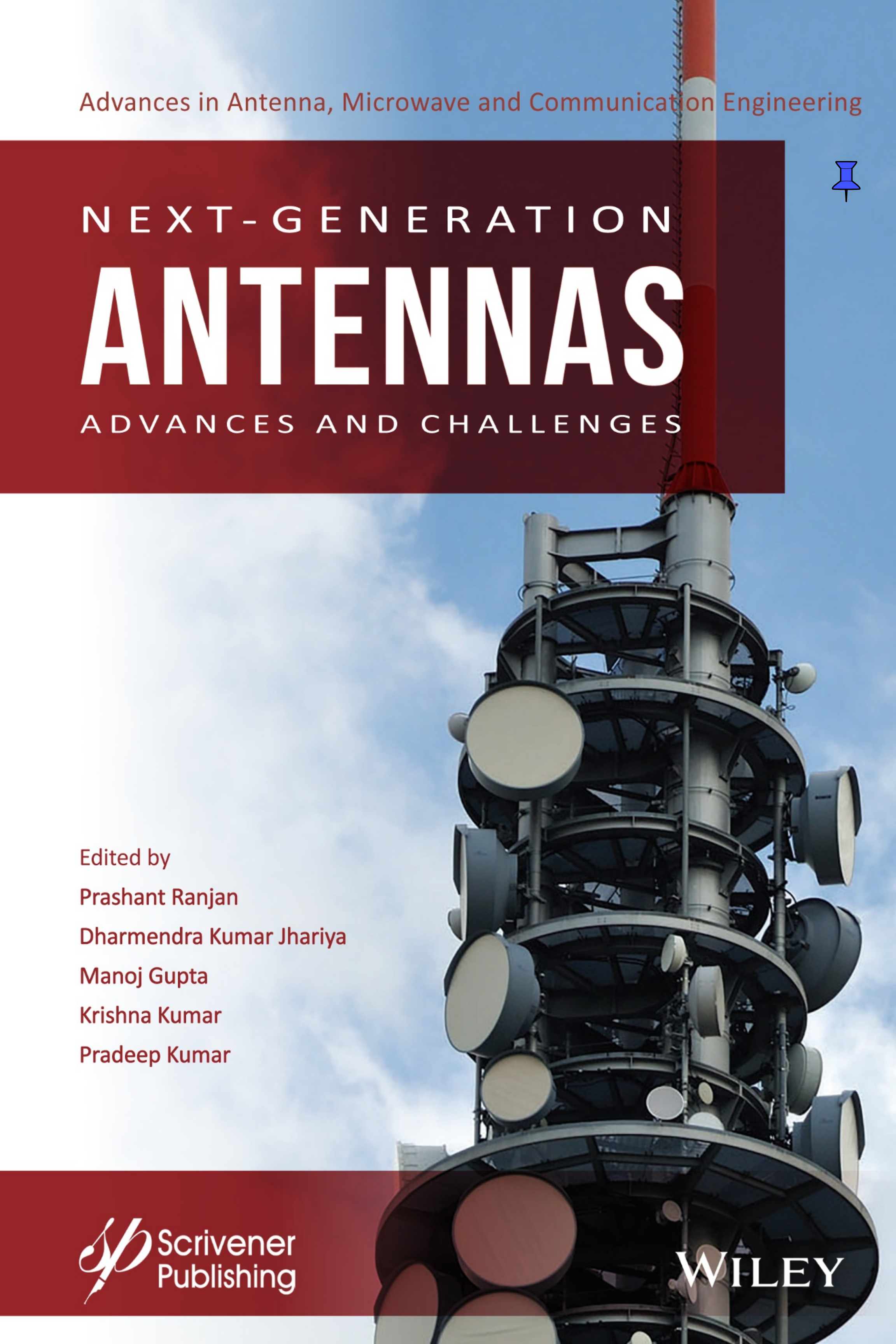

Advances in Antenna, Microwave and Communication Engineering

NEXT-GENERATION ANTENNAS

ADVANCES AND CHALLENGES

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

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Next-Generation Antennas

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Martin Scrivener (martin@scrivenerpublishing.com)
Phillip Carmical (pcarmical@scrivenerpublishing.com)

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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 validaed the miniaturized UWB antenna with the human breast model developed.
Chapter 14 gives an overview of joint transmit and receive MIMO beamforming 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[1]*, Krishna Kumar[2], Sachin Kumar Pal[3] and Rachna Shah[4]

[1]Department of ECE, University of Engineering and Management, Jaipur, India
[2]UJVN Ltd., Uttarakhand, India
[3]Bharat Sanchar Nigam Ltd., Guwahati, India
[4]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

**Corresponding author*: prashant.ranjan@uem.edu.in

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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 Marchandbalun 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 × 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 notchbands 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 gives more design flexibility. Centre frequencies of five bands are 0.6, 0.9, 1.2, 1.5, and 1.8 GHz. The insertion losses are approximately 2.8 dB, 2.9 dB, 2.9 dB, 2.6 dB, and 2.3 dB respectively. Wen *et al.* [20] proposed a six-band BPF based on semi-lumped resonators. The semi-lumped resonator included a chip inductor in the midpoint and two identical microstrip lines. Comparison between the semi-lumped resonator and conventional half-wavelength uniform resonator are presented. Harmonic frequencies are controlled by semi-lumped resonator. A distributed coupling technique is used to integrate bandpass filters. Low loading effects are achieved, which is essential for multiband circuits.

Wang *et al.* [23] proposed a compact UWB BPF having three notch bands by using a defected microstrip structure of U–shaped (UDMS). E–shaped MMR and interdigital coupled lines are used to obtain two transmission zeros at lower and upper passbands. The triple band-notched characteristics are achieved by introducing three parallel UDMSs. Notch band frequencies are 5.2, 5.8, and 8.0 GHz. A summary of previous work on multiband filters is given in the following Table 1.1.

1.2.2 Ultra-Wideband (UWB) Bandpass Filter

Wong *et al.* [27] proposed a UWB bandpass filter by using a quadruple–mode resonator. Two transmission zeros are generated by introducing two short-circuited stubs in MMR-based resonator. Two short-circuited stubs are used to control the fourth resonant mode and combining with the previous three resonant modes to make a quadruple–mode UWB filter. RT/Duroid 6010 substrate is used having a height of 0.635 mm, loss tangent 0.0023, and permittivity of 10.8. Interdigital coupled-lines are used to feed the MMR. Filter covers the frequency range of 2.8-11.0 GHz with a fractional bandwidth of 119%. Minimum insertion loss is found 1.1 dB within the UWB passband. Group delay Variation is found between 0.19 – 0.52 ns within UWB passband.

Table 1.1 Summary of multiband filters.

Sl. no.	Author	Year	Resonant frequencies	Technique used	No. of bands	Limitations
1	Chen *et al.* [2]	2006	2.3, 3.7, and 5.3 GHz	SIR	3	Poor insertion loss
2	Hao *et al.* [3]	2010	3.3, 3.5, and 3.7 GHz	Open-loop resonators	3	Poor selectivity
3	Chong *et al.* [5]	2013	2.1, 3.45, and 5.15 GHz	Coupled-Line Admittance Inverter	3	Very complex design
4	Jing *et al.* [6]	2016	0.7, 2, 3.2, 4.5, 5.8, and 7 GHz	MMR	6	Narrow bands
5	Jia *et al.* [7]	1996	2.46 GHz	Open-Loop Resonators	1	Poor insertion loss
6	Kuo *et al.* [8]	2005	2.45 and 5.8 GHz	SIR	2	Harmonics are present
7	Guan *et al.* [9]	2009	2.4, 3.8, and 5.7 GHz	SIR	3	Poor selectivity
8	Ko *et al.* [10]	2013	2.2, 4.2, 6.5, and 8.9 GHz	Open stubs	3	Narrow bands
9	Marjan *et al.* [21]	2006	2.65, 3, and 3.35 GHz	Coupled Resonators	3	Many resonators are used

(Continued)

Table 1.1 Summary of multiband filters. (*Continued*)

Sl. no.	Author	Year	Resonant frequencies	Technique used	No. of bands	Limitations
10	Zhang *et al.* [22]	2007	1.84 and 2.9 GHz	Stub-Loaded Resonators	2	Minimum return loss
11	Zhao *et al.* [23]	2014	UWB with three notch band	E-shaped MMR (EMMR)	3	Insertion loss is not good
12	Pal *et al.* [24]	2014	3.5 GHz, 5.5 GHz, and 6.8 GHz	asymmetrically positioned SLOR	3	The roll-off rate is poor
13	Tsai *et al.* [25]	2014	2.4, 3.5, and 5.2 GHz	SIR	3	Insertion loss is not good
14	Hsu *et al.* [26]	2015	1.5, 2.5, 3.5 GHz	MMR	3	many resonators are used
15	Prashant *et al.* [68]	2018	2.85, 5.9 and 8.15 GHz	Triple-band stub-loaded open-loop resonator (TBSLOR)	3	Small bandwidth at lower frequency
16	P. Ranjan [69]	2019	2.4, 4.85, 7.93, and 9.75 GHz	Ω-shaped stub	4	Insertion loss is not good

Xu *et al.* [28] presented a UWB bandpass filter with Koch island-shaped stepped impedance lines (SIL). A Koch fractal–shaped ring slot is cut in the ground plane of the filter to realize negative permittivity. The composite right/left-handed transmission line is arranged with the gap in the conductor strip to realize negative permeability. It included five-section SIL on each side with an asymmetrical structure. The passband frequency range is 2.5–11 GHz with a relative bandwidth of 126%. Deng *et al.* [29] proposed a quintuple–mode stub-loaded resonator-based ultra-wideband bandpass filter. Two odd modes and three even modes are generated. Stepped impedance open and short stub are used to adjust the even–mode resonance frequencies but the odd–modes are fixed. Two TZs near the lower and upper cutoff frequencies can be generated by the short stub. High resonant modes of the desired passband are adjusted by applying a low–impedance line of the MMR. The open stubs are used to improve the upper stopband transmission zero. The passband frequency range of the filter is 2.8–11.2 GHz. Group delay variation and insertion loss are achieved lower than 2 dB and less than 0.63 ns, respectively.

Hao *et al.* [30] proposed a UWB filter based on multilayer technology. A transmission zero at the upper stopband has been generated by designing a resonator on the middle layer. Lower stopband transmission zero has been generated by designing a shorted coupled line on the top layer. Multilayer liquid crystal polymer technology is used to fabricate the filter. Bandwidth from 3 to 9 GHz is achieved with a flat group delay. It is useful for wireless UWB systems. Chu *et al.* [31] proposed a UWB bandpass filter based on stub–loaded MMR.The MMR is loaded with three open stubs. A stepped–impedance stub is positioned at the center and two stubs at the symmetrical side are located. Three even modes, two odd modes, and two transmission zeros are generated by the stepped–impedance stub. The resonator is designed to locate the two odd modes within the UWB band. Parameters of the stepped–impedance stub at the center can be used to adjust the even modes only. Passband frequency is 3.1–11.1 GHz, with a fractional bandwidth of 117%. Group delay within the UWB passband is between 0.25–0.70 ns.

Zhang *et al.* [32] proposed a UWB filter by using shorted stepped impedance stubs cascaded with the interdigital coupled line. Four even modes and three odd modes are generated. Odd and even mode analysis is used to verify the circuit. UWB filter covers passband from 3.4 to 10.7 GHz. Zhu *et al.* [33] presented a UWB bandpass filter based on dual-stub-loaded resonators (DSLR). Two transmission zeros are generated at the lower and upper stopband by applying The DSLR. Lengths of the stubs can be used to control the bandwidth. The relative dielectric constant of substrate material used to fabricate is 2.55 with a loss tangent of 0.0019 and the height of the substrate is 0.8 mm. Fractional BW of the filter is 106% and insertion loss is less than 0.7 dB. Li *et al.* [34] proposed two UWB bandpass filters based on an improved model. This paper designed two UWB BPFs with a fractional bandwidth of 51% (3.1 to 5.2 GHz) and 108% (3 to 10 GHz). Four short-circuited stubs connected with transmission lines are included to improve the model. The first and fourth short-circuited stubs are used to generate two transmission zeros. Less than 3 dB insertion loss is found between 3.1 to 10 GHz and less than 0.4 dB is found between 3.1 to 5.2 GHz. The sizes of the filters are 19 mm × 14 mm and 15 mm × 15 mm, respectively. Matrix analysis and short-circuited stubs model with the improved distributed quarter wave is presented.

Saadi *et al.* [35] proposed a design technique to implement UWB bandpass filters based on an integrated passive device (IPD) technology. Hourglass filter theory and the inductors are included in the filter circuit with the zigzag method for miniaturization of the filter. The filter is designed in 0.18 μm CMOS technology. This filter exhibits enhanced selectivity and controllable transmission zeros. Design approaches to this filter can be divided into two groups. The first one has established an electrical circuit model and the second is manufacturing technologies. The electrical circuit model is used to obtain the filter electrical specifications that affect the filter's physical aspects. Bandwidth covered the entire UWB spectrum. Taibi *et al.* [36] proposed, stepped–impedance open stub (SIS) based ultra-wideband bandpass filter. SIS is connected in the center of a uniform impedance transmission line. For coupling enhancement three interdigital parallel coupled-lines below aperture–backed are connected at each side of the filter. The frequency range of the filter is 3.2–11.1 GHz having a fractional bandwidth of 115%.

Janković *et al.* [37] proposed a defective ground structure-based UWB bandpass filter, which is used to connect a square patch with a ground plane to generate a resonant mode at a frequency lower than the without grounded patch resonator of two fundamental modes. Fundamental resonant frequencies can be controlled independently. By creating slots in the patch the higher modes resonant frequencies can be decreased. The Taconic CER10 substrate material is used with a relative dielectric constant of 9.8 and a thickness of 1.27mm. Group delay is 0.25 ns and insertion loss is less than 0.9 dB. Passband frequency for UWB band is 3.09–10.69 GHz. Yun *et al.* [38] proposed a particle swarm optimization (PSO) process to design a UWB bandpass filter. One cell CRLH–TL resonator, stepped impedance (SI), and two spur lines are used to design the UWB filter. The one-cell CRLH–TL resonator has a wide passband filtering characteristic.

The harmonics at the outside of the UWB band are removed by using one SI and two spur lines. Less than 1.4 dB flat insertion losses within passband and 11.5 to 22 GHz stopbands are achieved.

Sekaret *et al.* [40] proposed a slow-wave CPW based notch band UWB filter. The filter provided improved skirt rejection and better stopband rejection by DGS. DGS is used to achieve attenuation of the signal from 11 to 16 GHz. A notch is created by using a bridge structure to reject WLAN interference at 5.65 GHz. A summary of previous work on ultra-wideband filters is given in the following Table 1.2.

1.2.3 Ultra-Wideband Filter with Notch Band Characteristic

Rabbi *et al.* proposed [41] a UWB bandpass filter with a reconfigurable notched band to reject unwanted signals. A PIN diode is used as a switch for the notch. The filter has a notched band at 3.5 GHz when the switch is in the ON state. In the OFF state, a full band response is obtained. A third-order BPF consists of a single $\lambda_g/2$ resonator placed between two $\lambda_g/4$ short-circuited resonators. A grounded end is added with L–shaped parallel coupled transmission line to remove the undesired signal at 3.5 GHz. Zhao *et al.* [42] proposed a UWB bandpass filter using E–shaped resonator with two sharp notches. Genetic algorithm (GA) based UWB BPF is designed in which a set of structures as a chromosome and a structure as a gene is defined. The dual notch bands are generated by adjusting resonant frequencies of the E–shaped resonator. Two notches at 5.9 GHz and 8.0 GHz are obtained.

Song *et al.* [43] proposed a notched bands ultra-wideband bandpass filter based on triangular-shaped DGS. Transmission zeros are produced at a higher frequency by assigning six tapered defected ground structures. The low impedance microstrip is connected with short-circuited stubs to generate a TZ at the lower cut-off frequency. By increasing and folding the arm of the coupled-line to create a notch at 5.3 GHz, and create another notched band at 7.8 GHz by using a slot of the meander line. To achieve stronger coupling used quasi-IDC with slots on the ground plane. Sarkar *et al.* [44] proposed a UWB bandpass filter having high selectivity and dual notch bands. Short SLR and open stub are used to realize the UWB BPF. Meandered shorted stub is applied to the size of the filter. Two odd modes and two even modes excitations are present. Both modes are combined to achieve UWB BPF. Open stub loaded resonators (OSLR) are used to control the even mode frequencies and two transmission zeroes but odd mode frequencies are fixed. SLR is used to control the odd mode frequencies. Spiral resonators shaped slots of half-wavelength long are cut in the ground plane to obtained a notch band at 5.13 GHz. A notch at 8.0 GHz is

Table 1.2 Summary of ultra-wideband filters.

Sl. no.	Author	Year	Technique used	Band covered	No. of the modes present	Limitation
1	Sai *et al.* [27]	2009	MMR with stubs	2.8–11.0 GHz	4	Poor rejection skirt at upper cut off
2	Xu *et al.* [28]	2010	Koch island-shaped SI-lines (fractal)	2.5-11 GHz	2	Poor roll off rate
3	Hong *et al.* [29]	2010	Quintuple-mode stub-loaded resonator	2.8–11.2 GHz	5	Insertion loss is maximum
4	Hao *et al.* [30]	2011	multilayer liquid crystal polymer technology	3.0 to 9.05 GHz	2	The entire UWB band not covered
5	Qing *et al.* [31]	2011	Stub loaded MMR	3.1–11.1 GHz	5	Insertion loss is maximum
6	Zhang *et al.* [32]	2012	MMR with SI-stub	3.4 to 10.7 GHz	3	The entire UWB band not covered
7	He *et al.* [33]	2013	Dual-Stub-Loaded Resonator (DSLR)	2.9 to 10.9 GHz	3	Poor selectivity
8	Li *et al.* [34]	2014	Short-Circuited Stubs	3 to 10 GHz	4	The entire UWB band not covered

(Continued)

Table 1.2 Summary of ultra-wideband filters. (*Continued*)

Sl. no.	Author	Year	Technique used	Band covered	No. of the modes present	Limitation
9	Saadi *et al.* [35]	2015	Zigzag technique	3.1–10.6 GHz	2	Insertion loss is maximum
10	Taibi *et al.* [36]	2015	Stepped-impedance open stub (SIS)	3.1–10.6 GHz	3	Poor selectivity
11	Janković *et al.* [37]	2016	Grounded square patch resonator	3.09 to 10.69 GHz	3	Poor selectivity
12	Young *et al.* [38]	2016	Composite right- and left-handed-transmission line (CRLH-TL) resonator	3.1–10.6 GHz With notch	2	The poor roll-off rate at lower cut off
13	Wen *et al.* [39]	2010	DGS	3.1- 10.6 GHz	3	Notch band present
14	Vikram *et al.* [40]	2011	Slow-wave CPW MMR	3.1 to 10.6 GHz	3	The poor roll-off rate at lower cut off