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An Investigation of Ultra-Wideband Filters for Cognitive Radio Networks

Uma Maheswari A[1] and Dr. Latha K[2]
[1]Assistant Professor, Department of Electronics and Communication Engineering,
[2]Assistant Professor, Department of Computer Science and Engineering,
Anna University Chennai-BIT Campus,
Tiruchirappalli, Tamilnadu, India
Email: [1]umamaheswaritrk@gmail.com, [2]erklatha@gmail.com

ABSTRACT

The requirement for radio spectrum has been increasing and this has resulted in the materialization of wireless applications with enhanced features and higher data rate. The spectrum is scant, and the current radio spectrum regulation is making its use inefficient. This necessitates the development of new dynamic spectrum allocation policies to better exploit the existing spectrum. According to the present spectrum allocation regulations, specific frequency bands are allocated to particular services and only approved users are granted access to licensed bands. Cognitive radio (CR) is expected to modernize the mode spectrum is allocated. In a CR network, the intelligent radio part allows secondary users (unlicensed users) to access spectrum bands allocated to the licensed primary users with the avoidance of interference. A solution to this inefficiency has been highly successful in the ISM (2.4 GHz), the U-NII (5–6 GHz), and microwave (57–64 GHz) bands, by making the unused spectra accessible on an unlicensed basis. However, in order to obtain spectra for unlicensed operation, new sharing concepts have been introduced to allow the usage of spectra by secondary users under the prerequisite that they limit their interference to the primary users. This would start by studying techniques employed in the design of UWB filters. This study is aimed to investigate the filters for overlay and underlay CR. This paper presents a comparative study of ultra-wideband filters for Cognitive Radio Networks.

KEYWORDS

Filter Antenna, CRN, Bandpass, Bandstop, Microstrip

1. INTRODUCTION

Cognitive radio (CR) technology is a key enabling technology that provides the capability to share the wireless channel with the primary users in an opportunistic way. CRs are predicted to be able to provide the high bandwidth to mobile users through heterogeneous wireless architectures and dynamic spectrum access techniques. In order to share the licensed user's spectrum without interference, and meet the diverse quality of service requirements of applications, each CR user in a CR network must:

- Determine the portion of spectrum that is available for use, which is called Spectrum sensing.
- Choose the best available channel, which is called Spectrum decision.
- Co-ordinate this channel access with other users, which are known as Spectrum sharing.
- Vacate the channel when a licensed user is detected to occupy, which is referred as Spectrum mobility.

To fulfill the all the four functions, a CR has to be intelligent, reconfigurable and self-organized. An example of the intelligent capability is the CR's capability to sense the spectrum and detect holes(aka white spaces) in the spectrum, which are those frequency bands not used by the licensed users. The reconfigurable ability can be summarized by the capability to dynamically choose the suitable operating frequency (frequency agility), and the ability to adapt the modulation/coding schemes and transmit power as needed. The self-organized capability has to do with the control of a good spectrum management scheme, a good mobility and connection management, and the ability to support security functions in dynamic environments.

Two approaches to sharing spectrum between licensed and unlicensed users have been considered: spectrum underlay and spectrum overlay. In the underlay approach, secondary users should operate below the noise floor of licensed users, and hence severe constraints are imposed on their transmission power. Ultra-wideband (UWB) technology is very suitable as the enabling technology for this approach. In the spectrum overlay approach, secondary users search for unused frequency bands, called white spaces, and use them for communication.

Developing reconfigurable filter for overlay and underlay CR would be the effective solution for sensing and sharing by ensuring security. This would starts by studying techniques employed in the design of UWB filters. The rest of the paper is organized as follows: Section 2 brings out the theory of UWB and Cognitive Radio. Filter geometries and performances are discussed in Chapter 3. Section 4 compares the results of existing developed filters available in the literature. Section 5 concludes the paper.

2. UWB FILTERS AND COGNITIVE RADIO

Ultra Wideband (UWB) has been regarded as one of the most promising and potential wireless technologies. On 14th February 2002, the Federal Communications Commission (FCC) of the United States adopted the first report and order, which permitted the commercial operation of UWB technology [1]. UWB systems are preferred for low power, low cost, high data rates and low interference requirements. Unlike conventional communication systems, UWB systems are based on exchanging data using short duration pulses of sub nanoseconds which cover a very wide bandwidth in the frequency domain. Similar to the conventional wireless communication systems, filter is the one of the primary and vital components in UWB systems [2]. Also, proper designing of filter reduces the system complexity.

However, owing to the large bandwidth occupied by the UWB system, there are more challenges and difficulties in designing the UWB filter than its narrowband counterpart. Growths of interest in developing commercial UWB terminals and latest communication systems have increased the demand for miniaturized filters. For portable UWB device applications, filters must be small enough to be compatible to the UWB unit. Reducing the UWB filter size with better performance is an interesting research area and deserves attraction [3-6]. A suitable UWB filter should be capable of operating over an ultra-wide bandwidth while providing high selectivity and lower scattering losses over the entire frequency range.

UWB has always been based on the principle of 'underlay' meaning that it must operate 'under' other services in the same spectrum without causing harmful interference to them. In the practical scenario, since, it operates with a low transmission power, it may be suppressed by neighborhood and/or overlapping systems such as Global Positioning Systems (GPS) at 1.6 GHz, Personal Communication Systems (PCS) at 1.85 GHz, IEEE 802.11b/g and Bluetooth at 2.4 GHz, IEEE 802.11a at 5 GHz etc.

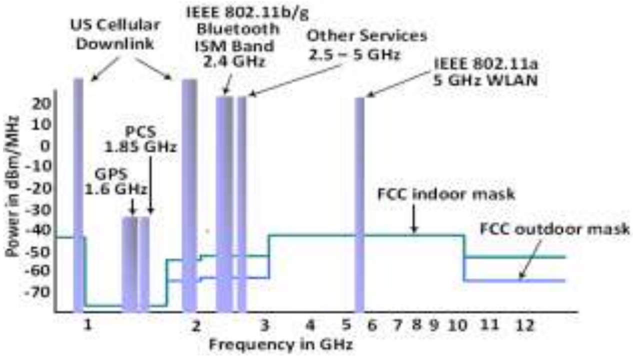

Fig.1. UWB spectrum distribution

UWB may not cause harmful interference to the above mentioned services. The challenge is that the frequency bands and their respective applications are differing among countries. For example, US recently allocated spectrum in the 3.6 GHz band for WiMAX, and Europe allocated 3.4 GHz to 4.2 GHz. But, Japan has no WiMAX spectrum defined in 3.5 GHz band. One should consider these also before realizing devices like filters. UWB spectrum distribution is depicted in Figure 1.

The filter should also be a linear phase filter with constant group delay and linear phase throughout the entire operating frequency band. Development of filter using microstrip line is much demanded due to its advantages of low cost, compact-size, light weight, planar structure and easy integration with other components on a single circuit board [7-10]. A compact filter with good performance is a vital component in microwave communication systems, particularly in wireless communications in order to suppress harmonics and spurious of power amplifiers and oscillators and to eliminate the out-band noise [11]. There are four steps involved in design of the filter.

- **Filter specifications:** Filter specifications such as insertion loss, return loss, FBW, group delay and phase are chosen based on the type of filter to be designed and developed
- **Filter prototype design:** With the help of the software package (IE3D is used in this research) for the chosen specification and application, the filter prototype is to be designed
- **Scaling and conversion:** Scaling to the desired frequency and proper impedance match is done in this step
- **Fabrication and testing:** This is the final step of the filter development. After the fabrication of the filter, its functional parameters are characterized using a network analyzer

Generally UWB filters with microstrip line technology uses Flame Retardant 4 (FR4) substrate, which is commonly used in Printed Circuit Board (PCB) to reduce the manufacturing complexities and cost. Section 3 elaborates the geometries of the available filters in the literature.

3. FILTER CONFIGURATIONS

In the literature review, a variety of filters have been studied based on different techniques and methods. However, developing such a filter is definitely a challenging work. The first difficulty is to achieve high selectivity requirement, which make some widely used techniques for broadband design. In [12-13], lowpass filters using Defect Ground Structure (DGS) with different specifications have been studied and reported as best in terms of performance and compactness but contain relatively large number of design parameters [14]. In addition to, DGS has the disadvantage of

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producing uncertain radiation, and take very long time to take the details of the physical structure. It is required to find possible ways to further reduce the size of the filter with better performances.

In the other studies, elliptical function lowpass filters using different types of resonators like semi-hairpin resonator [15], circular hairpin resonator [16], and modified hairpin resonator [17] are reported. Compact low-pass filters with wide stopband using double spiral resonant cells [18], microstrip resonant cell [19] are discussed. Also, compact microstrip low-pass filter with ultra-wide stopband using SIRs [20], and using interdigital capacitors [21] studied in the literature. A different approach to inducing adaptive nulls in a UWB pulse is through the use of reconfigurable bandstop (notch) RF filters.

Also, it is found that a compact microstrip lowpass filter is demonstrated by combining in cascade a T open stub with inverted T open stub accomplished by narrow strip line with a wide rejection band, desired scattering losses, and sharpness of cut-off frequency. The filter is distinctive in its structure and it has simple design with less number of design parameters.

Some of the filter geometry and photograph of the developed filters are depicted here for the better understanding. Ali H. Ramadan et al (2014) has developed tunable filter using open loop resonator. Reconfiguration is attained in the filter using Varactor diode and A 47 nH RF choke is incorporated to prevent any RF leakage to the DC supply. The other terminal of the tunable OLR is grounded through a via-hole. The snapshot of the filter depicted in the Fig.2.

Fig.2 Snapshot of the developed tunable filters

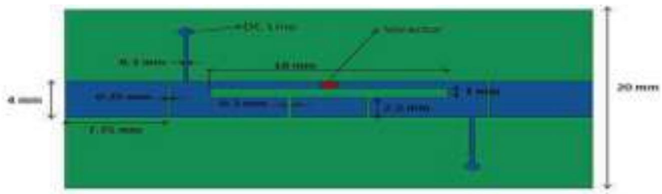

Fig. 3 Geometry of the varactor based tunable filter.

Due to the significant increase in the demand of tunable filters in modern multiband communication systems, several tunable band pass filters have been recently proposed with good tuning characteristics. There are many strategies and technologies to achieve tuning, including the use Micro Electro Mechanical Systems (MEMS), ferroelectric components, liquid crystals and split ring resonators and complementary split ring resonators among others [22]. Some of these strategies have been applied to the design of tunable filters by implementing varactor diodes [23]. The RFMEMS switched capacitor array reported in [22] as a RF component to achieve various kinds of tunable RF filters consists of RFMEMS direct contact switches and metal-insulator-metal capacitors.

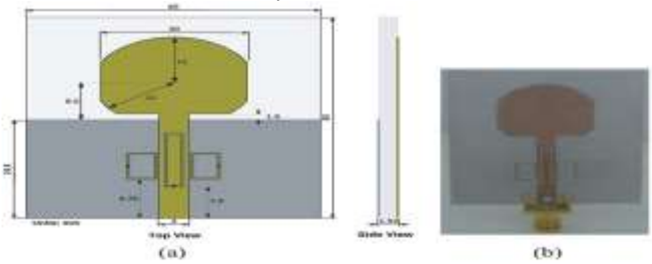

Fig. 4 (a) Geometry of the Bandstop filter, (b) Photograph of the fabricated filter

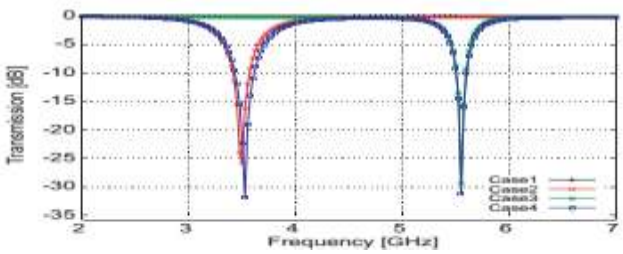

Fig. 5 Insertion loss of the developed filter

The authors in [17] show that open split ring resonators (OSRRs) and open complementary split ring resonators (OCSRRs) can be used to implement tunable filters in coplanar waveguide (CPW) technology. M. Y. Abou Shahine et al (2015) have developed varactor based microstrip bandpass filter for LTE, UMTS and WiFi applications. PI shaped slot integrated in a microstrip line between a pair of gaps as shown in Fig.3. A simpler and highly effective tuning approach is introduced which covers the range between 1.8 and 3 GHz.

Fig. 6 Photograph of triple band reconfiguarable filter

Split Ring Resonator based reconfigurable filter with integrated antenna for UWB-CR systems is proposed by M. Al-Husseini et al in 2012. Photograph of the geometry and fabricated filter is shown in Figs. 4 (a) and 4(b). It is clear from the Fig.5, the developed filter can cover both WiFi and WLAN frequencies.

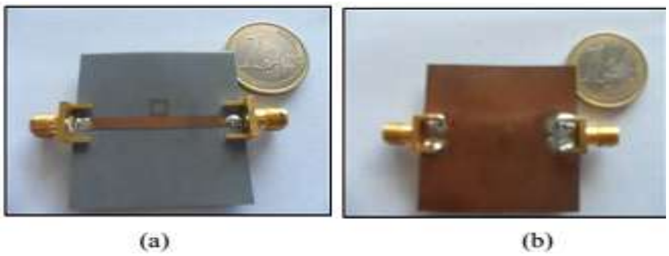

Fig.7 Photograph of the SRR based Bandstop Filter, (a) Top, (b) Bottom view

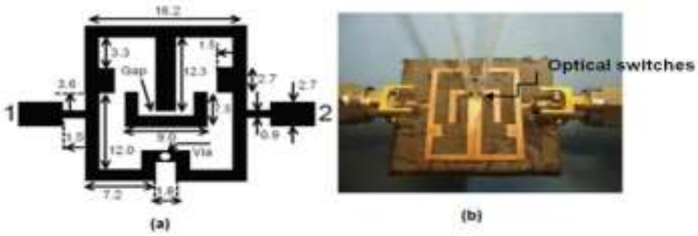

Fig.8 Optical switch based tunable bandpass filter, (a) Geometry, (b) Photograph of the developed filter.

The filter shown in figure 8 behaves as a bandpass filter in the band between 3.1 GHz to 5 GHz. Optical switches are activated with light which is transmitted from a trigger light source. Optically controlled silicon switches have many advantages such as immunity to electromagnetic interferences, low distorssion and costeffectiveness. Tunability based on optical switches has been used in microwave filters.

The authors in [14] discuss some of the possible antenna requirements for cognitive radio applications and outline some design approaches. In [25], the split-ring resonators [26] are employed in the design of UWB antennas with fixed notched bands. The authors in [27] present a design of a band notches antenna based on a ring slot etched in the patchHicham Lalj (2014) has proposed and developed SRR based bandstop filter with tuning abiltity for the range 4 to 10 GHz. The photograph of the developed filter is shown in Fig. 7.

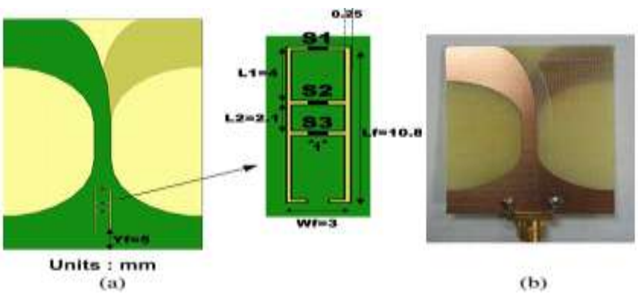

Fig. 8 (a) Filter Configuration, (b) Fabricated Prototype

CSRR based filter for UWB range is proposed by Safatly in 2012. In 2013, Yingsong Li has developed a triple band reconfigurable filter using defected microstrip strucrure that is integrated with an antenna for CRN applications.

Photograph of the filter is depicted in the Fig. 6. The designed antenna operates over the frequency band between 3.1 GHz and 14 GHz (bandwidth of 127.5%), with three notched bands from 4.2 GHz to 6.2 GHz (38.5%), 6.6 GHz to 7.0 GHz (6%), and 12.2 GHz to 14 GHz (13.7%). The functional and physical parameters of the developed filters available in the literature for CRN applications are studied and tabulated in Table-1.

The recent developments in cognitive radio system has encouraged new challenges in reconfigurable antenna design which can dynamically change the operating frequency keeping radiation pattern and gain to be same. Many designs have been proposed in literature which make use of Active switches(like PIN diodes, RFMEMS, Varactor diodes etc) ,Optical switches, mechanical switches. Based on the exhaustive study on filters for CRN applications it is consolidated the challenges and requirement of the filters, as below,

- Minimal insertion loss (<-0.5 dB)
- Minimal return loss (>-14 dB)
- Minimal group delay (<0.1ns)
- Linear phase in passband
- Deep attenuation at notching function (<-14 dB)
- Larger Bandwidth (1-14 GHz)
- Tunability/Reconfiguration with fast switching
- Compact Size
- Low Cost
- Less Complexity

Table 1: Comparative Study of UWB Filters Available in the Literature

Method/Structure/ Technology	**Transmission /Type/Tool**	**FBW/ Range** (GHz)	**|S21|** (dB)	**|S11|** (dB)	**Group Delay** (ns)	**Reference No.:/Fig.No:/ Author/Country/ Year**	**Size/ Substrate** (mm^2)	**Applications/ Remarks**
Microstripline/ π shaped filter (integrated with an antenna)	Bandstop filter (Triple band)	127.5/ 3.1-14	--	--	--	Yingsong Li et al/ China/2013	30×30	Proposed to suppress interference from C-band, WLAN, WiMAX. RFID
Defective Microstrip Structure/ T Shaped Filter (integrated with an antenna)	Bandpass filter (dual Band)	7.4-10.8	--	--	--	Zamudio et al/	65×40/ Taconic TLY	CRN applications
Inductively Coupling Circuits/ Multilayered PCB	Bandpass filter (dual Band)	105-181 MHz	1.83-2.45	--	--	Jaschke et al/2012	--	CRN
Shunt Coupled	Bandpass filter	81-139 MHz	3-3.6	>15	--	Tatiana Pavlenko/2013	15×11	UHF Band
Open loop Resonator (integrated with an antenna)	Bandstop filter	2-9	<-10	--	--	Ali H. Ramadan/USA/2014	60×60/ Taconic TLY	Overlay CRN
Defective Microstrip Structure/ T Slot (integrated with an antenna)	Notch Filter	2.4	--	--	--	V. Nagaraju et al/2014	50×30/ Rogers Duroid 5880	Overlay CRN
Microstripline/ Stepped Impedance Concentric Square Loop Resonators	Bandpass filter with rejection band	2.43/300 MHz	-0.02	-29	--	Yaqeen S.Mezaal et al/ 2014	196×196	Mobile Wireless Communication Systems

Complementary Split Ring Resonator	Bandstop filter	5.5	--	--	--	M. Al-Husseini et al/USA/ 2012	Rogers RO3203	UWB-CRN for interference mitigation
Microstripline/ π shaped filter	Bandpass filter with tunability	1.8-3	--	--	--	M. Y. Abou Shahine/2015	40×20 Rogers RO3203	LTE, UMTS, WiFi
Defective Microstrip Structure/ G Shaped Filter	Tunable Bandpass filter	3.4-13.2	--	<-15	--	Nishant Kumar/2016	FR4	CRN
Split Ring Resonator	Band Stop Filter	--	--	--	--	Hicham Lalj/2014	RT/Duroid	--

4. CONCLUSION

With increase in the demand for wireless connectivity and crowding of licensed and unlicensed spectra necessitates a new communication prototype to exploit the existing spectrum in better modes. The present approach for spectrum allocation is based on assigning a specific band to a particular service. The FCC Spectrum Policy Task Force reported vast temporal and geographic differences in the usage of allocated spectrum with utilization ranging from 15 to 85% in the bands below 3 GHz. In the frequency range above 3 GHz the bands are even more poorly utilized. In other words, a large portion of the assigned spectrum is used now and then, leading to an underutilization of a significant amount of spectrum. This inefficiency arises from the inflexibility of the regulatory and licensing process, which typically assigns the complete rights to a frequency band to a primary user. This approach makes it extremely difficult to recycle these bands once they are allocated, even if these users poorly utilize this valuable resource. Filter would be the effective method to sense and share the spectrum by ensuring security. Also, through the developed filter one could ensure the interference mitigation. The importance and need for filter for CR is clearly explained and the matrices of the same are listed in the table.

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AUTHORS PROFILE

A.UMA MAHESWARI is Assistant Professor, Department of Electronics and Communication Engineering, Anna University, Tiruchirappalli, TamilNadu, India..She is pursuing her Ph.D in the Faculty of Information and Communication Engineering from Anna University Chennai. She has M.E degree in the stream of Applied Electronics from Arunai Engineering College, Tiruvannamalai, Tamilnadu and B.E degree in Electronics and Communication Engineering from Regional Engineering College, Durgapur, West Bengal. Her interest includes Signal Processing, Wireless Networks and Wireless Communication.She is a life member of ISTE.

Dr.K.LATHA is Assistant Professor of Computer Science and Engineering Department, Anna University, Tiruchirappalli, TamilNadu, India. She is a graduate of B.E (ECE) from Bharathidasan University, and M.E (CSE) from Madurai Kamaraj University, Tamil Nadu, India. She earned her Doctorate from Anna University Chennai, TamilNadu, India. Her areas of interest include Information Retrieval, Data mining, Text mining, Web mining, Cloud computing and Network security. She has 17 years of teaching experience and produced several doctorates in Anna University, Chennai. She has published around 93 papers in International journals and conferences and received best paper award for 5 papers conducted by IEEE. Several publications of her are listed in reputed Thomson Reuters Indexed Journals. She delivered special lectures, keynotes, Presidential Address and acted as a resource and chairperson in many International conferences. She received Leader's Charity Award in academic excellence in Madurai Kamaraj University for Master of engineering in CSE; Awarded Outstanding Scientist for Data Mining from Venus International Foundation, Regd Trust in India vide Reg.No.18/BK-IV/2015 ISO 9001:2008 Certified, Chennai and Best Young Researcher (Female) award holder from South Indian ASDF Awards 2016 from the presenters of Association of Scientists, Developers and Faculties(ASDF) Global awards ,concentrating for the Research promotion in South Indian Zone Exclusively for India, Asia, Sydney, Australia, Bangkok, Thailand, Asia, London, UK Zones. She is closely associated with IIT Kanpur. She has received grant from AICTE, TEQIP and organized several workshops, seminar, and conferences. She has been appointed as a Research Advisory Council member by Anna University, Chennai. She has generated over 5 lakhs in research funding that includes a TEQIP –II Sponsored Young faculty research support scheme. She is a Principal Investigator of research proposals entitled "Sustaining Ecosystem from Species Extinction using Data Mining Techniques" under YFRSS; "Predicting Energy Consumption and analysis of Energy Demand with Economic growth of India"; "Personal Identification System for Authentication using Biometric Model" and "Face Liveness Detection using IOE variation". She has also received a grant from Minor Research Project category titled "Portal for Indian Legal System" from University Grant Commission (UGC), South Eastern Regional Office, Hyderabad, India. She has authored three Engineering technical scientific books on "Experiment and Evaluation in Information Retrieval Models-ISBN: 9781138032316, Publisher: Chapman and Hall/CRC Taylor and Francis Group, Editor: Chapman and Hall/CRC; "DATA WAREHOUSING AND DATA MINING FOR ENGINEERING APPLICATIONS" and "SYSTEM PROGRAMMING AND ORGANIZATION" by IK International Publishing House Pvt Ltd and Narosa Publishing House International Private Limited, Publishers of Science, Technology and Medicine, New- Delhi. She is also an editor of "Advances in Innovative Engineering and Technologies", ISBN No: 978-0-9948937-1-0, CAASR-Canadian Arena of Applied Scientific Research Ltd, Canada.

She is a Life Member in Professional bodies of The Institution of Engineers (India); Association of Scientists, Developers and faculties (ASDF) and Computer Society of India (CSI). She has been invited to deliver a keynote address and to chair a technical session for the international Conferences in Malaysia and Thailand countries. She has acted as an Expert in the Constitution of Oral Examination board for the conduct of Viva-Voce in respect of the Research Scholars for Ph.D Programme, Anna University, Chennai .She has been appointed as a Member of Inspection Committee for Inspection-CAI –Anna University, Chennai-Affiliation-Consideration of granting of provisional /permanent affiliation for Engineering Colleges. She has been Invited to Peer Review the articles of Journals like Springer, ASDF, Oxford University Press, ELSEVIER, ICTACT and Neural Computing etc.