A Review of Bandpass with Tunable Notch Microwave Filter in Wideband Application

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Abstract— In the last few years, several microwave filter design with band-pass response have been proposed for ultra-wideband (UWB) application. Among various microwave filter design, microstrip filter are mostly used by researcher due to their low profile, light weight, easy to fabricate and low cost. Conventional microstrip filter can be in any shape whether circular, rectangular or elliptical but some modification or additional variation in their basic design can be made for different purposes for example notch response and tunable characteristic in order to eliminate undesired signal. This paper proposed a compilation of important review about filter design for band-pass filter and discussion about various design with different method or technique used in order to achieve in wideband application range and tunable capabilities. The previous work will be examined and critically analyzed in terms of insertion and return losses, bandwidth, selectivity and tuning in order to proposed novel design of microwave filter with band-pass and tunable notch response in UWB application for future research work. Through this review, we hope that a better understanding of microwave bandpass filter can be established and therefore can have a huge contribution.

Keyword- Microwave filter, microstrip, band-pass filter, notch response, tunable filter.

I. INTRODUCTION

Wireless systems has during the past generations increased rapidly, which has resulted in a fully covered frequency spectrum for the range that most of today's technologies can handle [1].In communication, the system can be termed as wideband when the message bandwidth considerably exceeds the coherence bandwidth of the channel. The wideband bandwidth is forced to use for any communication link due to a high data rate. But another link may have slightly low data rates intentionally use a wider bandwidth in order to gain another advantage [2].

In early 2002, the U.S Federal Communications Commission (FCC) approved the unlicensed use of ultra-wideband (UWB) from 3.1GHz to 10.6GHz for commercial purposes. This caused an increase in academic and industrial research into various UWB devices. According to the FCC indoor limit, the FCC Frequency Mask mainly requires the rejection specs for an UWB filter design to be minimum -10 dB at 3.1 GHz and 10.6 GHz. To build an ultra-wide band microstrip filter which meets the FCC specs is a challenging task for design engineers.

Recently, the development of UWB enabling high data transmission rates and low power consumption, and simple hardware configuration in communication applications such RFID devices, sensor networks, radar and location tracking, have received attention. This rise in the field of UWB technology has pushed for the development of new UWB filters has increased via different methods and structures such as implementation of notch responses and tunable capabilities. [3-12]. In order to accurate, filter design already from lumped elements (resistance, capacitance and inductance) to microstrip components. Lumped-element filter design is generally unpopular due to the diffuculty of its use at microwave frequencies along with the limitations of lumped-element values [12]. Hence, conventional microstrip filters are often used. Figure 1 shows the block diagram of RF front-end receiver.

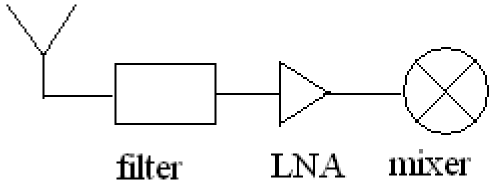

Fig 1. Block diagram of receiver

The motivation of this paper is driven by the fact that for the wideband technology which contribute to the selective frequency range. The design of wideband microwave band pass filter is very critical in order to achieve broad bandwidth while has the capabilities to remove any undesired signals also known as notch within the wideband frequency range. The spurious unwanted signal can be detected using reconfigurable band reject signal which can control the power of the resonant frequency in the same time maintain the bandwidth of band pass response. However, the conventional notch nowadays is usually fixed which means the removed signals is not varies. The wideband band pass filter will then be integrated with the band reject in order to have the mechanism to remove and control any undesired signals within the frequency range. Therefore, in this study the capabilities such of the integration technique to produce band pass and band reject in the same time can reconfigurable the band reject signal simultaneously will be analysed. However, the contribution of this research is not limited to reconfigurable of power band reject signal, but the bandwidth of the band pass response also can be tuned and reconfigured.

Basically, there are passive and active types of tunable bandpass filter. Passive tunable filters are including ring resonators and combline as well as interdigital. The mostly used actives filters are combline, microstrip coupled line and MMIC. However, most of those types of filter only tune the passband of signals not the band reject. In few years back, the development of bandpass filter in wideband application have really make a fast growth in terms of characteristic, technique, design, structure and methods [1-38] including tuning band reject. In order to avoid the interference with WLAN radio signal, different methods and structures have been used to develop a UWB bandpass filter as mention above. In UWB, it has some interference with other signal frequency. Researches on how to reject the unwanted signal has to be developed and studied.

In this paper, an effort is made to show the exciting advances in microwave filter in term of their technologies mostly focus for bandpass responses. All the methods and technique used from previous paper will be studied and reviewed for references purposes. All the reviewed data will be used in future work to design bandpass and bandstop in simultaneous response.

II. DEVELOPMENT OF BANDPASS FILTER IN WIDEBAND APPLICATION

The trends and development of bandpass microwave filter in recent years is presented in Table I. The filter can be analysed based on the concept that filters are designed using different methods and technologies. The studies are arranged chronologically, thus information on trends and development can be obtained.

TABLE I. Bandpass Microwave Filter in Wideband Application

No	Year	Scholar(s) Researcher(s)	Focus of Study	Specification
1	2007	Sai Wai Wong, Lei Zhu	UWB microstrip bandpass filter with three pairs of non-uniform and folded stubs	Fc 6.85 GHz Insertion loss <0.5 & <0.8 db for stage one and two respectively
2	2008	Zhihui Pan, Junhong Wang	BPF using coupled microstrip lines and U-shaped defected ground structure (DGS)	Insertion loss about 0.11 db Return loss >15 db
3	2008	I-Tseng Tang, Ding-Bing Lin, Chi-Min Li, and Min-Yuan Chiu	Microstrip bandpass filter using five short-circuited stubs with reverse double U-shape defected ground structure (RDU-DGS)	Insertion loss <-1.5 db
4	2008	L. H. Weng, Y. C. Guo, X. W. Shi, and X. Q. Chen	Overview of defected ground structure (DGS)	-
5	2009	Amin Abbosh, Marek Bialkowski, and David Thiel	Multi-layer microstrip-slot couplers combined with dumbell slots and H-shaped stubs	Insertion loss <0.5 db Return loss >25 db
6	2011	Tan Lin, Jin Long, Yang Guo-qing	Bandpass (BPF) filter using microstrip T-shaped stub has 6 GHz bandwidth.	Bandwidth 5.3 GHz
7	2013	Tong Chao, Li En	A compact fourth-order UWB bandpass filter with grounded middle stub E-shaped microstrip structure	Bandwidth 6.09 GHz Return loss > 14 db
8	2013	Koji Watanabe, Zhewang Mal, Chun-Ping Chen, Tetsuo Anada, Kato Masayuki, Yoshio Kobayashi	UWB bandpass filter with stub-loaded dual-mode ring resonator and parallel-coupled step-impedance two-mode resonators.	Return loss >15 db Insertion loss 1.6 db

Tan Lin (2011) has proposed a compact Ultra-Wideband (UWB) bandpass filter using microstrip T-shaped stub. In this paper author used microtrip T-shaped triple-mode resonators which consists of two parallel but oppositely T-shaped resonators and has a significantly widened passband. Author substituting the T-shaped stub for the open-ended stub to the coupling lines to create two strong reflection zeros in passband and two sharp transmission zeros at the band edge. The filters are designed on a 0.5-mm RO4350 substrate with a relative dielectric constant of 3.66 and a loss tangent of 0.004. The result with a T-shaped stub has bandwidth of 6 GHz (4.6—10.6 GHz) compared to a design without T-shaped stub has bandwidth of 5.3 GHz. However, the rejection levels in the upper stop-band are not so good because T-shaped stub created a complex zero close to the upper side of the passband.

Tong Chao (2013) has proposed analysis and design of a compact fourth-order UWB bandpass filter using E-shape microstrip structure. Author designed this filter by cascading three E-shape microstrip structures using short section of the microstrip line in order to achieve more easily simulation. Based on analysis in this paper, the E-shape microstrip structure can work as two coupled resonators. Author exploited the concept to develop high-order UWB bandpass filters by cascading E-shape microstrip structures using a short microstrip line section. There are three E-shape microstrip structure connected directly to the short microstrip line section that act as series inductor. As the result from simulation the insertion loss for passband (1.96-8.05 GHz) is about 0.55 dB and the return loss is better than 14 dB with an insertion loss about 0.39 dB at centre frequency (5GHz). Although all the result shows excellent agreement but this design is still not fabricated and the experimental result is yet to be known.

Sai Wai Wong and Lei Zhu (2007) proposed Ultra-Wideband (UWB) microstrip bandpass filters with improved upper-stopband and miniaturized size. The initial design of this paper is consist of three pair of stepped-impedance stubs and that are transversely attached to the middle of the multimode resonator (MMR). Then author linked the MMR with external feed lines via interdigital coupled lines. In the design, author varies the coupled-line lengths d=0.6 and 4.3mm respectively. As the result, the S21-magnitude curve in the UWB band gradually rises up towards the ideal 0-dB line if the coupled-line length (d) increases. In order to improve the rejection skirt and meet the FCC defined mask, author construct two-stage UWB bandpass filter using the MMR structure which two adjacent stubs-loaded-MMRs are coupled via parallel-coupled microstrip lines. Both measured result for one- and two-stage UWB filters shows good performance. The measured insertion loss achieves less than 0.5 dB in one stage filter and less than 0.8 dB in two-stage filter at the UVB center frequency 6.85 GHz. However, after observed the result carefully the frequency range covered for this filters is not fully cover UWB range which is 3.1-10.6 GHz but only 4-10 GHz.

Amin Abbosh (2009) proposed a multi-layer microstrip-slot coupler combined with dumbell slots in the ground plane and H-shaped stubs at the input-output ports to achieve high quality bandpass and band-rejection performance. The structure includes three conductive layers interleaved with two substrates. The coupled dumbell slot and H-shaped stubs was modified in this paper in purposed to achieve lowpass filter, which improves the high stopband characteristic. The insertion loss is less than 0.5dB and a return loss which is larger than 25dB. Although the results were quite impressive, this design is still in manufacturing stage. The actual design still not completed.

Tseng Tang (2008) proposed a UWB bandpass filter with a fractional bandwidth of about 110% using a microstrip structure. The filter structure using five short-circuited stubs with reverse double U-shape defected ground structure (DGS). In order to reduce filter size, bending connecting line and let five short-circuited stubs via the same hole. However, there was a spurious band occurred. In order to eliminate the spurious band, reverse double U-shape defected ground structure was used.

III. DEVELOPMENT OF NOTCH RESPONSES FOR BANDPASS FILTER IN WIDEBAND APPLICATION

The demand for notch responses in BPFs is increasing every year. As the technology develops, numerous researchers have take interest in notch responses. The most popular technique used by researchers to produces notch is defected ground structure (DGS) and defected microstrip structure (DMS). The summary of several studies related to notch in BPF is presented in Table II.

TABLE III. Notch Responses for Microwave Filter in Wideband Application

No	Year	Scholar(s) Researcher(s)	Focus of Study	Specification
1	2006	Kenneth A. Townsend, Leonid Belostotski, James W. Haslett, and John Nielsen	An LNA with integrated tunable notch filter targeted for UWB receivers using bridged-T band-reject structure	Notch range 3.5 – 7 GHz S11 <1db
2	2012	Luca Pelliccia, Fabrizio Cacciamani, Fabrizio Gentili, Paola Farinelli, Roberto Sorrentino	UWB filter based on external interdigital quarter-wavelength microstrip resonators and a central half-wave microstrip resonator embedding a reconfigurable open-circuited stub.	Return loss >13 db Insertion loss <0.3 db
3	2013	Mehdi Nosrati, Nahid Vahabisani and Mojgan Daneshmand	UWB filter with double notch bands on coplanar technology using MEMS capacitors	First notch range 7.5 – 6.5 GHz Second notch range 8.8 – 7.8 GHz
4	2013	Junding Zhao, Jianpeng Wang, Gang Zhang, and Jia-Lin Li	Microstrip ultra-wideband (UWB) bandpass filter (BPF) with two sharp notches using E-shaped resonator	Passband 3.24 – 10.88 GHz Notched band insertion loss >15 db
5	2013	He Zhu, Sai Wai Wong, Shenjie Wen, and Qing Xin Chu	UWB BPF composes of two pairs of microstrip short-circuited stubs and a CPW resonator with via-stub-loaded for notch-band	Insertion loss 1.8 db
6	2014	Jianpeng Wang, Junding Zhao and Jia-Lin Li	A BPF with triple sharply notched band using parallel U-shaped defected microstrip ground (UDMS)	Notched bands at 5.2, 5.8 and 8.0 GHz Insertion loss 15 db

Jianpeng Wang (2014) has proposed UWB bandpass filter with triple sharply notched bands. This paper using a parallel U-shaped defected microstrip structure (UDMS). This design comprises interdigital coupled liness and EMMR embedded three parallel UDMSs. Varying each UDMS dimension, the frequency location of the corresponding notched band can be widely adjusted, whereas the other two frequency locations of the notched bands remain almost unchanged. The three notched bands are centred at 5.2, 5.8 and 8.0 GHz, respectively. However, the insertion loss for this designed is very high which is over 15dB are achieved for each notched bands.

He Zhu (2013) proposed UWB bandpass filter consists of two pairs of microstrip short-circuited stubs which provide a microstrip-to-CPW transition, and a CPW resonator whose length is about half-guided-wavelength ($\lambda/2$) at 6.85 GHz. Author designed a novel via-stub-loaded structure to suppress WLAN signals around 5.2/5.8 GHz which act as a notch-band. The notch-band is controlled by tuning the length and position of the stubs. However, this designed can only suppress only one of WLAN band either 5.2 or 5.8 GHz. The result shows the notch is around 5.8 GHz and the insertion loss within UWB passband is quite high with 1.8 dB.

Mehdi Nosrati (2013) proposed a novel UWB filter with double tunable notch bands on coplanar technology using MEMs capacitors. UWB BPF is designed using CPW transmission line on alumina-based structure as shown in Figure 2 below. The first and second notch-band is established by integrating a MEMS capacitor C_1(420×350 μm2) and C_2(350×320 μm2) respectively. Refer to simulated result, while tuning one of the notches the performance of the filter remains untouched. By changing the first MEMS capacitor C_1 the first notch-band can be independently tuned. The first and second notch-band can be tuned from 7.5 GHz to 6.5 GHz and 8.8 GHz to 7.8 GHz respectively. However, the measured result is not nearly same as the simulated result. The increase of insertion loss compared to simulation can be attributed to the fabrication process.

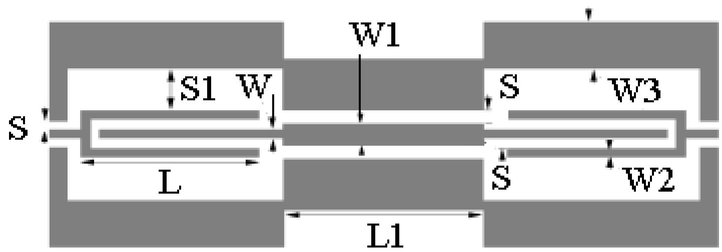

Fig 2. UWB Bandpass Filter

IV. DEVELOPMENT OF TUNABLE MICROWAVE NOTCH FILTER IN WIDEBAND APPLICATION

The development of tunable notch filter have been rapidly increase by years. As technology develops, many applications have to be supported using tunable notch filter. Several studies have been conducted recently and show promising results mostly in wideband application. Some of these studies are investigated in this paper. The summary of several studies related to tunable notch filters in recent years is shown in Table III below.

TABLE IIIII. Tunable Microwave Notch Filter in Wideband Application

No	Year	Scholar(s) Researcher(s)	Focus of Study	Specification
1	2008	Young-Hoon Chun, Hussein Shaman and Jia-Sheng Hong	A reconfigurable UWB BPF with switchable notch using PIN diodes for electronic switching	Insertion loss 2.38 db
2	2009	Mahmoud S. Rasras, Kun-Yii Tu, Douglas M. Gill, Young-Kai Chen, Alice E. White, Sanjay S. Patel, Andrew Pomerene, Daniel Carothers, James Beattie, Mark Beals, Jurgen Michel and Lionel C. Kimerling	Tunable multistage narrowband optical pole-zero notch filter that is fabricated in a silicon complementary metal oxide semiconductor (CMOS) foundry	Notch filter bandwidth 635 MHz
3	2010	Marcelino Armendariz, Vikram Sekar, Kamran Entesari	Tunable SIW filter implemented using PIN diodes switching elements	Insertion loss 5.4 db Return loss 14 db Tuning 25%
4	2011	Erwin H. W. Chan and Robert A. Minasian	Tunable RF/microwave photonic notch filter with low-noise performance using a dual-input electro-optic intensity modulator	SNR 114 db/Hz Notch width 0.55%
5	2012	Zhengzheng Wu, Yonghyun Shim and Mina Rais-Zadeh	UWB filters integrated with tunable notch filters using a silicon-based integrated passive device technology on a micromachined silicon substrate	Insertion loss 1.1 db Return loss >15 db Attenuation >30 db
6	2013	Jong-Hyun Lee, Jae-Won Choi, Xu-Guang Wang, and Sang-Won Yun	Tunable BPF using lumped elements and frequency tuning is realized by PIN diodes	Tune range 480–687 MHz Insertion loss varying 2.7-3.8 db
7	2014	Silas Christensen, Vitaliy Zhurbenko and Tom K. Johansen	Combining a bandpass and a notch filter using four short circuited stubs and a half wavelength transmission line connecting the stubs	Insertion loss 2.38 db Notch attenuation 23.52 db
8	2014	Lalithendra Kurra, Mahesh P. Abegaonkar, Ananjan Basu and Shiban K. Koul	The resonant nature of the EBG creates notch and it is tunable by means of a PIN diode or varactor diode	340 MHz tuning range Varactor diode varies from 0.14 pF to 1.1 pF
9	2014	Xun Luo, Sheng Sun, and Robert Bogdan Staszewski	Tunable microstrip bandpass filters based on a half-wavelength (λ/2) resonator with a center-tapped open-stub	Return loss 11.6 db Insertion loss 1.19 db

In Christensen (2014) there are two different designs being combined which are a bandpass and a notch filter. This design is developed to operate in the receiving band from 350-470 MHz. The bandpass filter was designed to have three reflection zeros. The main concept used for the development of the notch filter is based on the shunted RLC-resonator. The series RLC-resonator will have the desired bandstop filter response, which may be obtained from a λ=4 microstrip stub-resonator, as the one shown in Figure 3 below.

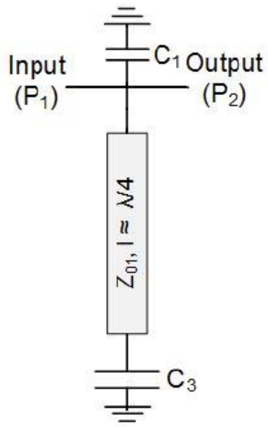

Fig 3. Series RLC-resonator

Although there were no greater differences were observed when both filter designed in ADS and CO-simulation model. However, the integration of the two filters have cause the notch attenuation to be lowered when measured. The other disadvantage for this design is it only operated in low operating frequency which is from from 350 to 470 MHz.

Young (2008) presented a reconfigurable UWB bandpass filter with switching notch for UWB system. Author designed the filter which consisting of five short-circuited stubs and four connecting lines on microstrip. Two identical switchable notch structures are integrated into the two connecting lines as shown in Figure 4 below.

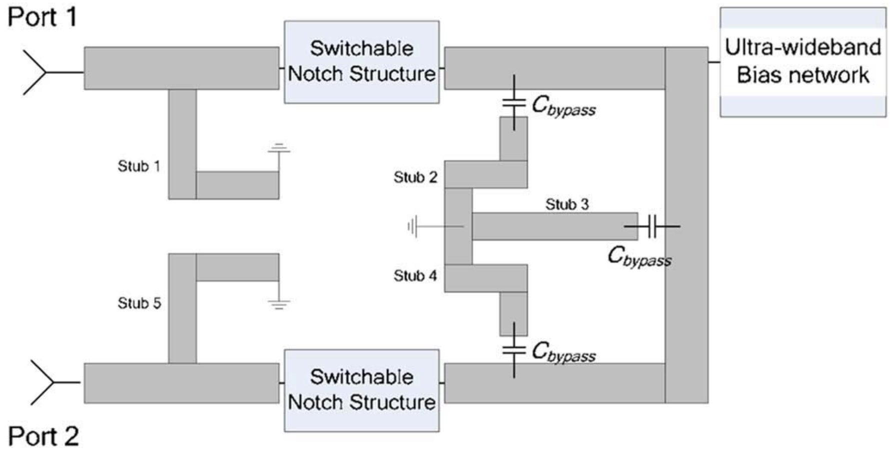

Fig 4. Schematic diagram of a reconfigurable UWB BPF with switchable notch structures

A PIN diode is attached at the open-end of the embedded stub. Author used two bypass capacitors to avoid a short circuit for the dc bias applied to the PIN diode. The measured result is not same with simulated result due to effect from fabricated tolerance, parasitic of PIN diode, chip inductors and capacitors.

Xun Luo (2014) proposed tunable microstrip bandpass filter with two adjustable transmission poles and compensable coupling. This design consists of a λ/2 resonator with an open-stub tapped at its centre and two λ/4 PCMLs connected to the input/output (I/O) ports. Tuning varactors are connected at various internal nodes to adjust the filter’s centre frequency and bandwidth over a wide tuning range. Two second-order microstrip tunable filters have been fabricated. However, the passband frequency for this filter is too narrow which is from 0.58-0.91 GHz and the tuning range measured is not too wide as designed.

Marcelino (2010) introduces a novel tunable SIW filter implemented using PIN diode switching elements. Author claim that this paper presents the first fully tunable SIW filter based on perturbing via posts located inside the cavities. All the previous research is limited for tunable SIW filters with no physical evidence of tuning multi-cavity SIW filters. Tuning the PIN diode on and off provides the same type of tuning mechanism. Four PIN diodes per SIW cavity provide six states with 25% tuning range. Insertion and return loss is better than 5.4 dB and 14 dB, respectively for all tuning states. Each PIN diode circuit adding approximately 0.25 dB insertion loss that cause the insertion loss to be high as 5.4 dB. Author suggest in order to improve filter loss and tuning range, a more integrated switching network with lower parasitic elements.

V. CONCLUSION

In this paper, an effort has been made to relate some of the previous works regarding microwave filter especially in wideband application. Microwave filter plays important roles in wireless communication system. Design modifications can yield a compact size, high bandpass performance and good measurement results. Various designed are currently being review mainly focus on miniaturized design and good performance. Several design are being developed based on previous designed by modified and improved them. Some of the researchers refer previous designed and combined two or more designed together to enhance the performance of the filter. The proposed hybrid technique can be implied not only to UWB but in wideband application particularly in microwave medical imaging, civilian and military radar.

ACKNOWLEDGMENT

The authors would also like to thank UTeM for sponsoring this work under research grants PJP/2014/FTK(2B)/S01300.

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