Design of Ultra-Wideband (UWB) Bandpass Filters Based on Interdigital Edge Coupled Lines: A Review

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ABSTRACT
Since several decades ago, parallel coupled lines have found an extensive range of applications in order to design microwave circuits such us filter, impedance transformers and couplers. It gives advantages in term of low cost, easier integration with other devices and controllable performances by changing coupling coefficient between lines. This paper presents a review of parallel two and three interdigital coupled lines bandpass filters for ultra-Wideband (UWB) communication systems during previous years to achieve a fraction passband from 3.1 GHz to 10.6 GHz and then a FBW that can reach 109%. Different structures such as multiple-mode resonator, Short Circuited Stubs, Open stub, Stepped-impedance resonators and Rectangular Ring have been reportedly used to ameliorate the performances of developed filters.

Keywords: *Interdigital coupled lines, Ultra-wideband (UWB) bandpass filter, Federal Communications Commission (FCC).*

1. INTRODUCTION

In February 2002 [1], the Federal Communication Commission (FCC) announced the unlicenced use of ultra-wideband (UWB) devices for several commercial applications. The FCC required that for the indoor and hand-held UWB systems, the passband should be contained between 3.1 and 10.6 GHz and the average power must not exceed -41.3 dBm/MHz (75 nW/MHz) [2] as defined in figure 1.

As one of the most important millimeter wave circuit, bandpass filters with ultrawide bandwidth, hight return loss, low insertion loss, flat group delay, sharp and deep stop band attenuation and compact size are highly desirable in UWB technology. Several structures that combined with two [3] [4] or three [5] [6] interdigital coupled lines are designed and analyzed by researchers as a means to design an ultra-wideband bandpass filter that transmits the signals in the whole UWB passband with a fractional band-width of 109.5% at center frequency of 6.85 GHz to fulfill the ultra-bandwidth constraints sited by Federal Communication Commission.

This paper is organized as follows: Section 2 presents a review of UWB bandpass filters that use two coupled lines followed by Section 3 which describes the review study of filters based on three interdigital coupled lines and their advantages in compared with the two ones. The comparative analysis and conclusion are presented in Sections 4 and 5, respectively.

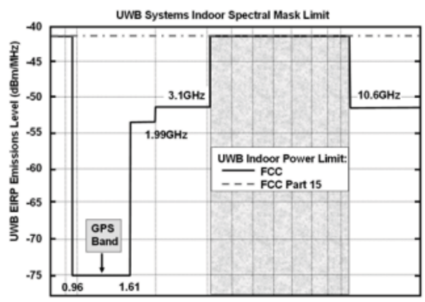

Figure 1 Federal Communications Commission indoor spectral mask in [1].

2. UWB BANDPASS FILTERS USING TWO COUPLED LINES

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Various designs of parallel coupled lines bandpass filters for ultra-Wideband communication systems are being proposed by researchers during previous years based on different structures. Lei Zhu developed an Ultra-Wideband (UWB) Bandpass Filters with compact size in 2005 [7]. The design filter was implemented using a multiple-mode resonator (MMR) in the middle of quarter-wavelength parallel coupled line on each end with center frequency of 6.85 GHz. Three transmission poles have been achieved from MMR were only the first and third-order resonant mode determine the lower and upper cut-off frequencies of a wide passband, as mentioned in [8] & [9], while the additional poles are introduced by the coupling of the parallel coupled lines with MMR at the two sides to get desired characteristic. Based on the measurement results, it is found that the minimum insertion loss is less than 2 dB with a fractional bandwidth of 113% (BW=2.96GHz-10.67 GHz), while the return loss is found higher than 10 dB. On the other hand, the group delay varies between 0.20 and 0.43 ns which hint the good linearity of this developed structure. However, since the operation mechanism of the proposed structure characteristics is provided by physical explanation and the filter is construed by one section, this last doesn't meet the FCC spectrum limit particularly at lower frequency band. In addition, a strong coupling coefficient was gated between coupled lines (S<<0.1 mm) which will augment the difficulties in the fabrication cost.

By applying the short-circuited stub, the gaps dimensions between the coupling lines will be enlarged from 0.05mm [11] to 0.15mm.

In 2007 [10], a distributed-transmission-line-based synthesis theory was proposed to design an UWB band pass filter to meet the indoor stopband regulation of the Federal Communications Commission (FCC). The configuration of the proposed filter is constructed by multi-stage stepped impedance resonators (SIRs) connected by symmetrical parallel coupled line. The unsymmetrical SIR structure is used to replace symmetrical one [7] [12] to enlarge gaps dimension. The reported performances in [10] showed that the insertion loss is 0.9 dB (low insertion loss), the group delay is flat (smaller than 0.5ns) and FCC spectrum mask limit is satisfied.

Another approach of multi-stage resonators is proposed in [13] for developing UWB BPF with harmonic suppression. A succession of two stage of stepped impedance coupled-line formed by three subsections with different lengths and coupling factors is used to suppress the second and third harmonic response and then the problem of the limited width- especially when a high dielectric constant is utilized - of upper stopband can be resolved. The resultant S-parameters [13] reveals an insertion loss that is lower than 1 dB, a return loss more than 18 dB, a flat group delay of 0.12 ns and a fraction passband that is ranging from 3.1 to 10.6 GHz (FCC limit). Three transmission poles at the passband and three transmission zeros at the upper stopband were created. The upper stopband extends up to 28 GHz.

As conclusion from [10] & [13], at least 2 two sections of resonators must be used to construct UWB bandpass filter with desired performances. However, geometrical sizes will be relatively large.

Zhewang Ma was proposed a novel UWB bandpass filter based on stub-loaded three-mode resonator in 2009 [14] to meet the FCC limit and with a miniaturized size in compared of [10] & [13]. The proposed structure [14] is configured by adding a short-circuited stub and an open stub to a half-wavelength resonator which create three resonant modes to realize a very wide passband. Feeding the resonator with coupled parallel lines, two other reflection zeros are obtained and two slotted lines are used to reduce the passband reflection. The fabricated filter has a compact size, low cost fabrication -due the enlarged gap- and low loss. The insertion loss and return loss are better than 0.6dB and 12dB respectively and the group delay is very flat. Furthermore, a sharp passband skirts is obtained and the FCC spectrum limit is satisfised.

Several radio signal such as WiMAX (i.e., 3.3-3.6 GHz), WLAN (i.e., 5.15-5.825 GHz), and C-band (i.e., 4-8 GHz) can interfere with UWB range defined by FCC (i.e., 3.1-10.6 GHz). In order to reduce this interference, an UWB bandpass filter with dual notched band by coupling E-shaped resonator on MMR was proposed in 2016 [15]. By tuning the stub length (L7, L8, L9) of E-shaped resonator, two notched bands are achieved. The first one is obtained by decreasing the value of (L7) which can leads to reduce the C-band interference in 6.7 to 7.3GHz. Concerning the second notched band, and by tuning separately the stub length of (L8) and (L9), The WiMAX band interference in 3.3 to 3.6GHz can be reduced. The simulated results of the developed filter achieved a good performance with an insertion loss less than 0.8dB [15].

A recent development of ultra-wide stopband bandpass filter is suggested by Akram Sheikhi in 2020 [16]. The proposed filter is designed, simulated and fabricated using two five stages stepped impedance resonators which are capacitively coupled to each other's to have miniaturized size (0.128 λg×0.378 λg) as well as suppression of harmonics and located at the end of the parallel coupled lines. The reported performances in [16] showed that the filter has a return loss of -19 dB with insertion loss less than 0.42 dB. The rejection level is rather then -17.5 dB up the 100 GHz. The FBW is 97% and the upper stopband extends up to 100 GHz.

2. UWB BANDPASS FILTERS BASED ON THREE PARALLEL COUPLED LINES

The use of parallel coupled lines bandpass filters in ultra-wideband systems require a very narrow coupling gaps between the coupled lines in order to have a strong couplings and broad passband, which will make serious difficulties in the fabrication cost. Thus, when the gap size becomes a limitation in fabricating a UWB parallel coupled two-line filter, the three-line sections can provide an effective solution [17], which can realize a stronger coupling compared with the two-line structure [18]. A three-edge-coupled microstrip lines can give a greater bandwidth than two coupled lines [19].

Extensive methods that use three-lines structures have been made to develop a variety of UWB bandpass filters. Sheng Sun proposed in 2006 [20] a novel ultra-wideband bandpass filter to achieve tight coupling degree and to enhance the out-of-band performance of [7] by attaching two capacitive-ended three coupled lines with multimode resonator MMR. The Frequency response results display that the proposed filter has the capability to suppress the first-order spurious pass-band and reducing the insertion loss in the passband (< 1.3 dB). The return loss is found to be higher than 14 dB and the group delay varies between 0.35 and 0.65 ns. Moreover, the insertion loss is above 20 dB occupies an enlarged range of 11.8 to 15.9 GHz. The upper stopband extends up to 16 GHz.

In 2007 [19], a planer UWB bandpass filter based on three coupled microstrip lines for enhancing coupling in the middle of stepped impedance open stubs on each end to realize two trasmission zeros is proposed. From the results in [19], it is found that the filter has a low insertion loss (< 0.5 dB), ultra-wide bandwidth, sharp stop band, high return loss that is around 18 dB, flat group delay and a compact size in compared with [20]. the upper stopband extends up to 16 GHz.

Despite this, the bandpass filter still suffers from narrow upper-stopband due to the periodic appearance of multiple passbands. Furthermore, it has an impractical electrical size.

In order to that a novel compact UWB bandpass filter with improved upper stopband performances was developed in 2008 [21]. The proposed structure is configured by attaching a multiple-mode resonator (MMR) that consists of a folded SIR and three open-ended stubs with aperture backed parallel-coupled lines for coupling enhancement [22] at both ends of the of the MMR. Based on the S-parameters results, it shown that the proposed filter has a wide and deep upper stop band that extends up to 20 GHz with insertion loss higher than 20 dB in the 11.7 to 19.0 GHz range in compared of [19] and [20]. Moreover, the parallel coupled lines gap size is enlarged to 0.2mm (while 0.08 mm in [20] and 0.1 mm in [19]) and total with a very compact size ($0.27\lambda_g \times 0.33\lambda_g$). The insertion loss in the passband less than 2 dB.

In 2015 [23], A novel ultra-wideband bandpass filter with notched band at 802.11a Frequency Spectrum is developed in order to reduce the interference of WLAN around 5.15–5.35 GHz and 5.725–5.825 GHz. The proposed filter is designed, simulated and fabricated using rectangular ring resonator combined with interdigital three coupled line at the both side of the ring. The reported performances in [23] showed that the pass-band of the proposed filter is obtained at frequency range of 3.78-7.94 GHz with notched band at 4.3- 5.9 GHz which is useful to reject WLAN over the UWB Applications.

4. CONPARATIVE ANALYSIS

Lastly, as shown in table 1, a comparative study will be developed based on the different methods and design techniques discussed above.

5. CONCLUSION

In this paper, different structures and techniques of designing interdigital parallel coupled lines band pass filters in the UWB frequency range (3.1-10.6 GHz) have been reviewed. Each of the presented filters has its own merits in term of insertion loss, return losses, fractional bandwidth, group delay, upper-stopband rejection, transmission zeros at lower-stopband, and size.

Table 1. Comparative analysis

Ref. No,	Technique used	Advantage	Disadvantage
[7]	Multiple-mode resonator - Parallel coupled two-lines	Good passband characteristic with five transmission poles - Hight performance with a good linearity	FCC indoor spectral mask not successfully meted - Very small coupling gaps - Expensive fabrication cost
[10]	Multi-stage step impedance resonator - Parallel coupled two-lines	Enlarged gaps dimension - FCC spectrum limit is satisfied	Limited width of the upper stopband - Large geometrical size
[13]	Stepped-impedance parallel coupled lines	UWB BPF with harmonic suppression - Wider stopband up to more than 28 GHz and insertion loss less than 1 dB	Large geometrical size – Loose coupling in the side subsections
[14]	Short circuited stub - Open stub - Coupled parallel two-lines	Small size - Insertion loss < 0.6 dB - Very flat group delay - Very sharp passband skirt - Low cost fabrication	
[15]	E-shaped resonator - Multiple-mode resonator - Coupled parallel two-lines	The WiMAX and C-band interferences reduced – good performance with insertion loss less than 0.8 dB	Don't reject all the desired C band interference
[16]	Five stages stepped impedance resonators - Parallel coupled two-lines	Wider stopband up to more than 100 GHz and insertion loss less than 0.5 dB - Compact size	
[20]	Multimode resonator - Parallel coupled three-lines	Three coupled lines with strong couplings - Improved out-of-band filter performances	Narrow upper-stopband - Large geometrical size - Slow attenuations in the stopbands
[19]	Three coupled microstrip lines - Stepped impedance open stubs	Cover the entire range of the UWB with a low insertion loss (< 0.5 dB) and high return loss	Narrow upper-stopband - Large geometrical size
[21]	Folded SIR - Three open-ended stubs - Aperture backed parallel-coupled three-lines	Wide and deep upper stop band that extends up to 20 GHz - Very compact size	Slow increase in attenuation - No longer enough degrees of adjusting freedom to control resonant frequencies - complicated backside-aperture fabrication
[23]	Rectangular ring resonator - Interdigital three coupled lines	WLAN interference reduced	Only one notched band is obtained

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