Development of Ultra-wideband (UWB) Filters

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Abstract

Ultra-wideband (UWB) bandpass filters play a key role in the development of UWB systems. In this paper, we present a review on their development since the release of UWB band for indoor and hand-held systems by Federal Communications Commission (FCC) in 2002.

1. Introduction

Ultra-wideband (UWB) from 3.1 GHz to 10.6 GHz is released by the Federal Communications Commission (FCC) in 2002 for the use of indoor and hand-held systems [1]. Wireless communication utilizing UWB signals has obtained great attention among industry groups, academia, and standardization and regulation bodies. UWB technology has obtained great development with intensive research and development work on UWB components and systems. The UWB bandpass filter with the same frequency range (3.1 GHz - 10.6 GHz) becomes indispensable in order to enable the transmission of signals using UWB frequency range. Therefore, it is a fast growing research field in the pass three years. In the paper, a comprehensive review is presented on the development of UWB bandpass filters since 2002 when UWB was released by FCC.

2. Development of UWB Bandpass Filters

After the release of UWB, bandpass filters with a passband of the same frequency range (3.1 GHz - 10.6 GHz, a fractional bandwidth of 110%) were challenges for conventional filter designs. Before mid 2003, the bandwidth of the passband for a bandpass filters was extended from 40% to 70% [2]. These filters are named broad bandpass filters. They were not covering the whole UWB frequency range yet. In [3], a bandpass filter covering the whole UWB frequency range with a fractional bandwidth of 110% was realized by fabrication signal lines on a lossy composite substrate. A successful transmission of the UWB pulse signal was demonstrated using the proposed bandpass filter. This is one of the early reported filters that possess an ultra-wide passband. However, it has a high insertion loss in the passband due to the lossy substrate. Not much research work was reported in 2003 and 2004. In 2004, a ring resonator with a stub was proposed which shows a bandwidth of 86.6% [4]. A bandpass filter covering the whole UWB frequency band was a challenge for microwave filter designers and researchers in that period of time.

In 2005, there are 11 conference papers in total published in International Microwave Symposium, International Conference on Ultra-Wideband, Asia-Pacific Microwave Conference, or European Microwave Conference. In the same year, there are four journal publications. There are mainly four types of structures that are able to realize an ultra-wide passband. One is a microstrip structure shown in Fig. 1 [5]. It consists of a microstrip multi-mode resonator (MMR) and a parallel-coupled line at each end of the network. The MMR has two identical high-impedance sections with a length of quarter guided wavelength at two sides and a low-impedance section with a length of half guided wavelength in the middle. The MMR in the filter generates first and third resonant mode at the edges of the UWB passband. The parallel-coupled lines are modified to obtain the ultra-wide passband. This could be done by adjusting the coupling length, *Lc* [5], for example. The second type is a hybrid coplanar waveguide (CPW) and microstrip structure. This type of structure consists of a CPW MMR on one side and a microstrip input and output on the other side [6]. The CPW MMR is responsible for generating the first and third resonant mode for the UWB passband, which is similar to a microstrip MMR in [5]. Its geometry can be varied. Fig. 2 shows the CPW MMR in [6]. The third type of filter which is also able to have a fractional bandwidth of 110% is the broadside-coupled microstrip-CPW structure [7] shown in Fig. 3. There is a broadside-coupled microstrip line

on one side of the substrate [see Fig. 3 (a)] and an open-end CPW on the other side of the substrate [see Fig. 3 (b)]. The length of the coupled line equals to λg/2 in order to obtain a 110% bandwidth. The last type of filters that has a bandwidth as high as around 100% is the combination of a highpass filter and a lowpass filter [8]. In [8], a stepped-impedance lowpass filter is embedded into a highpass filter with quarter-wavelength short-circuited stubs, achieving a passband from 3 GHz to 10 GHz. New fabrication technique, such as Low Temperature Co-fire Ceramic (LTCC), is applied in UWB bandpass filter designs [9]. In [9], a LTCC bandpass filter shows a bandwidth of 48.75%. This filter has a small physical size due to the multi-layer configuration. However, the bandwidth of the passband is relatively small compared to other UWB bandpass filters and the insertion loss is as high as around 2.2 dB.

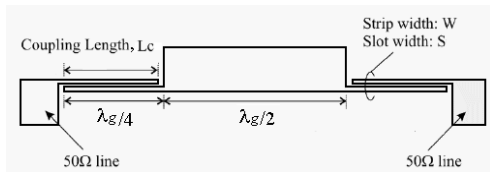


Fig. 1 The schematic of a microstrip multi-mode resonator (MMR) and two parallel-coupled lines at two ends [5].

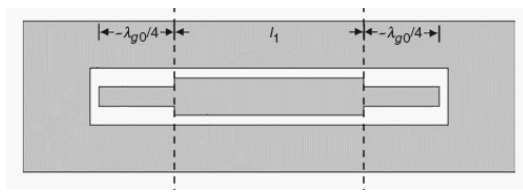
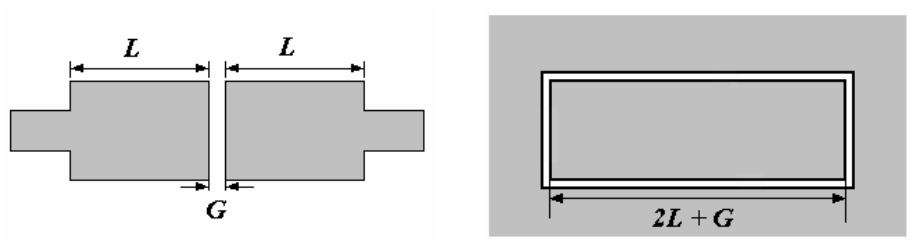


Fig. 2 The schematic of a CPW MMR in [6].



(a) (b)

Fig. 3 The schematic of the proposed broadside-coupled microstrip-CPW structure in [7], (a) top view, (b) bottom view.

In 2006, microstrip MMR based UWB bandpass filters are further optimized with improvement in the rejection of the upper stopband. It can be done by introducing interdigital microstrip coupled lines at the two sides of the MMR in [10]. A highpass filter consisting of a transmission line with two embedded U-shaped slots is cascaded with a lowpass filter which is a dumbbell-shaped defected ground structure array in the ground plane, to obtain a passband from 3 GHz to 10.9 GHz [11]. With novel highpass and lowpass structures, the bandpass filter obtains a wider bandwidth than the filter taking a similar approach in 2005 [8]. With regards to the UWB bandpass filter designs by cascading a highpass and a lowpass filter, a systematic consistent and analytical method is proposed [12]. There are a good number of new structures proposed that exhibit an ultra-wide passband [13] – [16]. In [13], 3λg/4 parallel-coupled line resonators shown in Fig. 4 are used to realize a passband from 3 GHz to 10 GHz. With the introduction of lumped components to a microstrip line, a miniaturized UWB BPF with a length of 0.18λg is realized at a fractional bandwidth of 127% at a center frequency of 6.5 GHz [14]. The small physical size is attributed to the lumped components used. A broadside coupled line in suspended substrate stripline [15] can also be used to realize an UWB bandpass filter. A filter with short-circuited stubs could give rise to a UWB bandpass

filter. Fig. 5 shows a filter with five short-circuited stubs arranged to realize a bandpass filters with a bandwidth of 110% [16].

In 2007, there are 26 papers reporting new UWB bandpass filters which is much more than the previous two years (15 papers in 2005, 18 papers in 2006). UWB bandpass filters with a notch stopband from 5 GHz to 6 GHz for filtering the wireless local-area network (WLAN) is a new topic branched out in this area [17] - [19]. Additional components are introduced providing the notch stopband at the desired frequency. In [17], an embedded open-circuit stub is proposed providing a sharp notch stopband. It is integrated into a UWB bandpass filter providing the stopband from 5 GHz to 6 GHz. A stub is introduced in the broadside-coupled microstrip-CPW structure [18] to generate a notch stopband at WLAN frequency range. Other than adding stubs to the structure, in [19], a notch stopband is generated in the UWB passband by an asymmetric parallel-coupled line at two sides of a microstrip MMR.

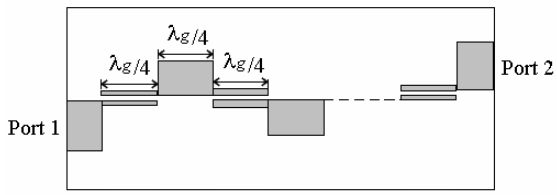


Fig. 4 Schematic of UWB bandpass filters in [16] using 3λg/4 parallel-coupled line resonators.

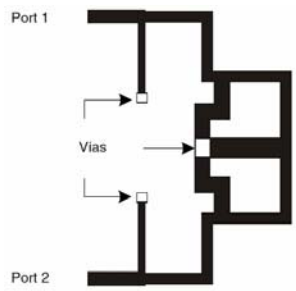


Fig. 5 Schematics of UWB bandpass filters with five short-circuited stubs in [16].

3. Conclusions

In this paper, the development of UWB bandpass filters in the past three years are reviewed. There are three main existing approaches to realize a UWB bandpass filter. One is a microstrip or CPW MMR with the assistance of coupling mechanisms, such as microstrip coupled line or coupling at the transit between a microstrip line and a CPW. Broadside-coupled microstrip line with a CPW at the back is another important configuration. The third one is a direct or indirect combination of a lowpass and a highpass filter. In terms of miniaturization, the employment of LTCC or lump components is an effective means to significantly reduce the size of the structure. For future development and research in this area, miniaturization of UWB filters is important for the application in hand-held devices. A system integrating both filters and antennas in UWB frequency range is very attractive to wireless communications using signals in this frequency band.

7. References

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