Ultra-Wideband (UWB) Bandpass Filters Using Multiple-Mode Resonator

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***Abstract*—A novel microstrip-line ultra-wideband (UWB) bandpass filter is proposed and implemented using a multiple-mode resonator (MMR), aiming at transmitting the signals in the whole UWB passband of 3.1–10.6 GHz. In the design, the first three resonant frequencies of this MMR are properly adjusted to be placed quasiequally within the UWB. Then, the parallel-coupled lines at the two sides are longitudinally stretched so as to raise the frequency-dispersive coupling degree with the coupling peak near the center of the UWB. After optimization of this filter, a good UWB bandpass behavior with five transmission poles is theoretically realized and experimentally confirmed. Within the whole UWB passband, the return loss is found higher than 10 dB, and the group delay variation is less than 0.23 ns.**

***Index Terms*—Multiple-mode resonator (MMR), parallel-coupled microstrip line and size compactness., ultra-wideband (UWB) bandpass filter.**

I. INTRODUCTION

ULTRA-WIDEBAND (UWB) technology has great potential in the development of various modern transmission systems, for instance, through-wall imaging, medical imaging, vehicular radar, indoor, and hand-held UWB systems, etc [1]. In February 2002, the U.S. Federal Communications Commission (FCC) authorized the unlicensed use of UWB devices for a variety of applications [1]–[3]. For the indoor and hand-held UWB systems, the FCC required that the UWB bandwidth must be strictly contained between 3.1 and 10.6 GHz. To meet these requirements on the emission level as defined in [1], special research interests in the microwave society have been recently aroused on the development of UWB bandpass filters [4]–[6], covering the whole UWB passband with the fractional bandwidth of 109.5% at the center frequency of 6.85 GHz.

The traditional filter theory was systematically established under the assumption of narrow passband, and it has been found to be very powerful in the design of filters with various passbands. In [7], a filter with tightened coupling extent via a three-line coupling section was reported to originally show its capacity in realizing a wide passband of 40% to 70%. In [8], a wideband passband of 49.3% was achieved in terms of two stopbands of a filter block with the two tuning stubs on a ring resonator. However, this filter configuration was found theoretically difficult to be directly employed for the design of such a UWB filter with a bandwidth of about 110.0%. To the best of our knowledge, only these two types of filters have been reported today in [4]–[6] to have reasonably achieved such a UWB passband. In [4] and [5], a microstrip ring filter with the dual stopbands below 3.1 GHz and above 10.6 GHz was constructed to make up the most initial UWB filter. However, this filter in fact has many problematic issues, such as unexpected passbands below 3.1 GHz, narrow lower/upper stopbands, large size, complexity in configuration, and so on. Later on, an alternative UWB filter was presented in [6], which was constructed by mounting the microstrip line in the lossy composite substrate so as to attenuate the signals at high frequencies. The reported performances in [6] showed that this filter had an insertion loss higher than 6.0 dB in the UWB passband and the return loss as high as 4.5 dB in the upper stopband above 10.6 GHz.

In this letter, we present a novel compact UWB bandpass filter using a microstrip-line multiple-mode resonator (MMR) [9]–[11]. It was initially exhibited in [9] that the first two resonant modes of the constituted MMR could be utilized together with the input/output parallel-coupled lines to achieve a 70% wide passband with four transmission poles. In [10] and [11], the first three resonant modes of an improved MMR were newly constructed to realize five transmission poles with lowered return loss in the whole passband. Following the works in [10] and [11], the MMR here is to be properly modified in configuration so as to reallocate its first three resonant modes close to the lower-end, center, and upper-end of the targeted UWB passband. Also, the coupling degree of the input/output parallel-coupled line sections is largely raised, good UWB passband performances are realized and demonstrated in theory. Later on, all the predicted parameters, i.e., insertion/return loss and group delay, are experimentally verified in a wide frequency including the UWB passband.

II. PROPOSED UWB FILTER

Fig. 1 depicts the schematic of the proposed microstrip-line UWB bandpass filter. At the central frequency of the UWB passband, i.e., 6.85 GHz, the MMR consists of one half-wavelength ($\lambda/2$) low-impedance line section in the center and two identical $\lambda/4$ high-impedance line sections at the two sides. With respect to its configuration, this proposed MMR may be categorized as a so-called stepped-impedance resonator (SIR) [12]. As a nonuniform transmission line resonator, the SIR was proposed in [8] to enlarge the frequency spacing between the first- and second-order resonant modes so as to effectively widen

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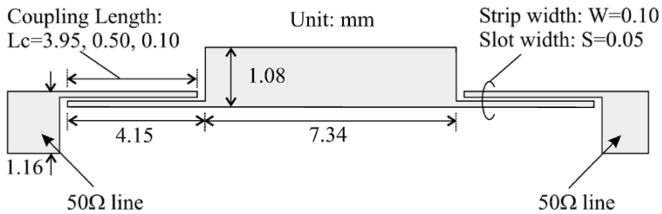

Fig. 1. Schematic of the compact microstrip-line UWB bandpass filter. Substrate: $\varepsilon_r = 10.8$, thickness = 1.27 mm.

the upper stopband above the dominant passband of a bandpass filter. In this aspect, only the first-order resonant mode is actually utilized in the filter design, whereas the second-order and the other resonant modes lead to the emergence of multiple-band spurious harmonics in the designed filter. However, in our MMR, all the first three resonant modes are taken into account together and they are applied to make up a wide dominant passband. In this case, the first- and third-order resonant frequencies basically determine the lower and upper cutoff frequencies of a wide passband, as discussed in [9]–[11]. By further introducing the two additional transmission poles in the $\lambda/4$ parallel-coupled lines, a UWB filter can be built up with good insertion and return loss in the entire passband of concern [11].

In the proposed, UWB filter as shown in Fig. 1, the strip widths of the two identical high-impedance lines at the two sides of this MMR are selected as 0.10 mm while their lengths are reasonably stretched to about $\lambda/4$ (λ: guided-wavelength) at the central frequency of 6.85 GHz. The central low-impedance line portion in this MMR has 1.08 mm in width and approximately $\lambda/2$ or 7.34 mm in length. To have a degree of freedom in tightening the coupling degree as inquired later on, the strip and slot widths in the coupled lines are chosen as 0.10 mm and 0.05 mm, respectively. In the following full-wave simulation, a strip conductor thickness of 17 μm is also considered. In order to quantitatively investigate the multiple-mode resonance behaviors of this MMR, the coupled-line length (Lc) is at first selected much shorter than $\lambda/4$ with respect to 6.85 GHz. Fig. 2 plots the simulated S_{21}-magnitudes in the wide frequency range (1.0 to 13.0 GHz) under the three different coupling lengths, i.e., $Lc =$ 0.1, 0.5, and 3.95 mm. It needs to be pointed out that the two dash-dot lines in Fig. 2 indicate the desired insertion loss configurations of the ideal UWB filters for the indoor and hand-held UWB systems [1], respectively. Looking at the two weak coupling cases with $Lc = 0.1$ and 0.5 mm, the three resonant frequencies with the peak S_{21}-magnitudes are observed to occur at around 4.23, 6.66, and 9.26 GHz, respectively. As Lc increases from 0.1 to 0.5 mm, the S_{21}-magnitude curve slightly rises. As Lc largely increases to 3.95 mm that approximately equals to $\lambda/4$ at 6.85 GHz, the whole S_{21}-magnitude realizes an almost flat frequency response near the 0-dB horizontal line over the desired UWB band. Moreover, the overall length of this UWB filter is approximately equal to one full wavelength at 6.85 GHz, that is much smaller than those reported in [4]–[6].

III. Experimental Verification

After slight adjustments of certain dimensions are made, the UWB bandpass filter with improved performance is designed, fabricated, and measured. Fig. 3(a) illustrates the top-view photograph of the fabricated UWB filter. The length between the two reference planes of this filter is 16.0 mm. Predicted and measured frequency responses of insertion and return losses as

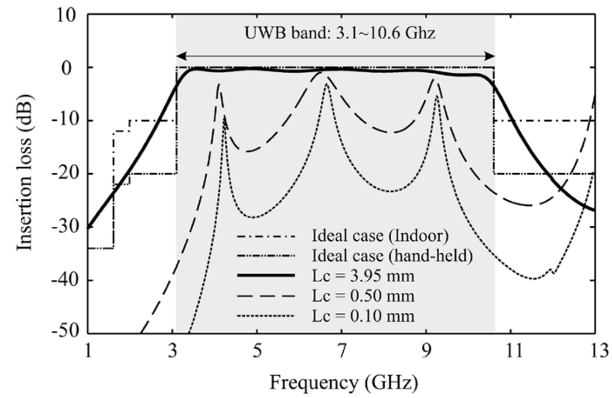

Fig. 2. Insertion loss of the microstrip-line UWB bandpass filter with different parallel-coupled line lengths (Lc).

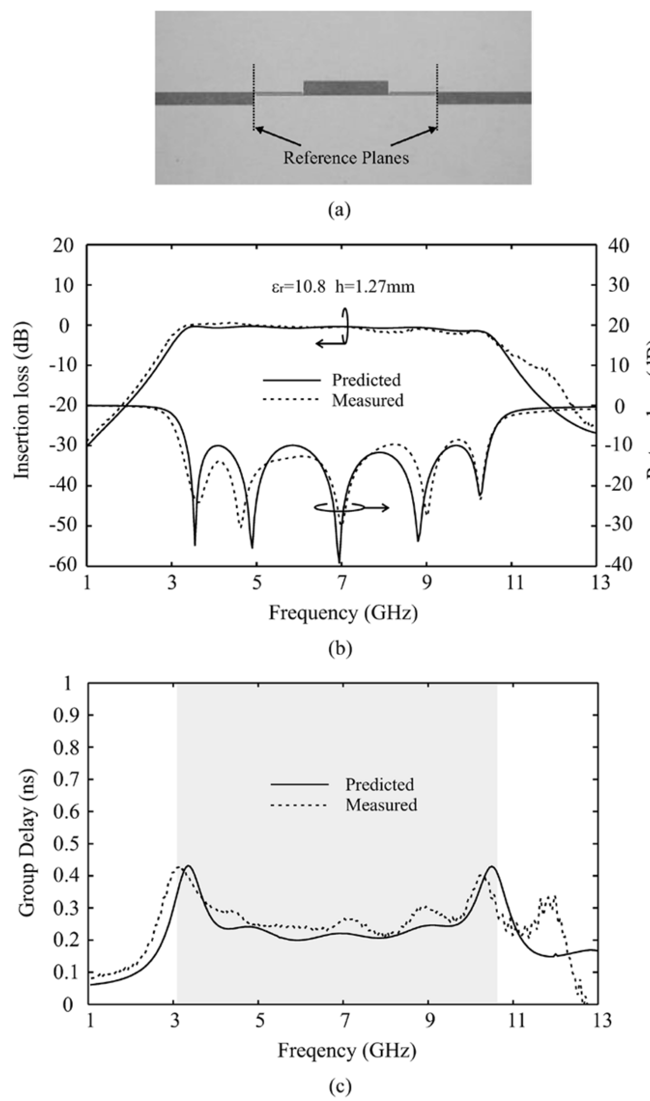

Fig. 3. Predicted and measured results of the designed microstrip-line UWB bandpass filter. (a) Photograph. (b) Insertion and return losses. (c) Group delay.

well as group delay are plotted together in Fig. 3(b) and (c) for quantitative comparison. Over the wide frequency range of 1.0 to 13.0 GHz, the predicted and measured results are found to be in good agreement with each other. In the measurement, the lower and higher cutoff frequencies of the UWB passband are equal to 2.96 GHz and 10.67 GHz, respectively, as can be observed in Fig. 3(b). This indicates that the relevant fractional bandwidth achieves about 113%. At the central frequency of 6.85 GHz, the measured insertion loss is found as 0.55 dB which is much better than 6.7 dB in [6]. Over the UWB passband, the return loss in simulation and measurement are both higher than 10 dB with five transmission poles. Following the discussion in [11], one can figure out that the first-, third-, and fifth-order poles are brought out by the first three resonant modes in the constituted MMR resonator. Meanwhile, the second and fourth poles are contributed by the two quarter-wavelength coupled line sections with enhanced coupling degree [9]–[11]. On the other hand, within the UWB passband, the predicted and measured group delay are both less than 0.43 ns with the maximum variation of about 0.23 ns, thus implying the good linearity of this proposed UWB bandpass filter.

IV. Conclusion

In this letter, a novel microstrip-line UWB bandpass filter with compact size is proposed, designed, and implemented. By forming a MMR and introducing quarter-wavelength parallel-coupled lines in the input and output ports, a UWB passband with five transmission poles is achieved as illustrated in theory and verified in experiment. Within the UWB passband, the measured insertion and return losses are lower than 2.0 dB and higher than 10.0 dB, respectively, while the group delay varies in between 0.20 and 0.43 ns. All these derived results demonstrate that the proposed UWB filter is much better than the two existing ones reported in [4]–[6] in the electrical performances of UWB passband and lower/upper stopbands as well as geometrical configuration and design principle. To reduce the radiation-caused insertion loss at the upper end of the UWB passband, aperture compensation and/or suspended stripline techniques [9]–[11] will be employed in the future to design such a UWB filter on a thin dielectric substrate.

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