EBG-Embedded UWB Bandpass Filter with Widened Upper-Stopband

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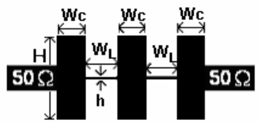
Abstract

An EBG-embedded multiple-mode resonator (MMR) is proposed to constitute an upper-stopband-improved and size-miniaturized ultra-wideband (UWB) bandpass filter on microstrip line. After the bandstop behaviour of such an EBG structure is characterized, a composite MMR is studied, aiming to relocate its first three resonant modes within the concerned UWB passband, i.e., 3.1-10.6GHz while placing its 4^{th} resonant mode appearing at the coupling zero of interdigital coupled-lines. In addition, the 5^{th} resonant mode is fully rejected by virtue of the distinct stopband behavior of the EBG itself. As such, a modified UWB bandpass filter with widened upper-stopband, sharpened upper rejection skirt and lowered transmission loss is finally constituted, designed and fabricated. The measured results show that the insertion loss is lower than 0.9dB in the UWB passband and higher than 15.0dB in the upper-stopband (11.4 to 20.0GHz) while the relevant group delay variation in the UWB is less than 0.2ns.

I. INTRODUCTION

As the unlicensed use of ultra-wideband (UWB: 3.1 to 10.6 GHz) frequency spectrum for indoor and hand-held wireless communications was released in 2002 [1], a tremendous interest has been recently arousing itself in the exploration of a variety of UWB bandpass filters (BPFs) with a fractional frequency bandwidth of about 110% [2-8]. The first UWB bandpass filter is actally a dual-stopband filter with several cascading microstrip ring resonators with loaded open stubs in periodical intervals [2]. Later on, such a type of wideband filter with the specified UWB passband is constructed by directly cascading a single lowpass filter with a single highpass filter on microstrip line [3] or suspended stripline [4], cascading several broadside-coupling microstrip-to-CPW interconnect sections [5] and non-periodically interrupting several short-circuited stubs with a uniform microstrip line in [6]. In parallel, the concept of a multiple-mode resonator with stepped-impedance configuration is originally presented in [7] to make up a UWB filter using its first three resonant modes together with two distributed parallel-coupled lines. In [8], a tapered coupled line topology is formulated to allocate its coupling zero to the 4^{th}-order, thus raising the upper-end of the concerned upper-stopband from 13.8 to 15.9 GHz [8].



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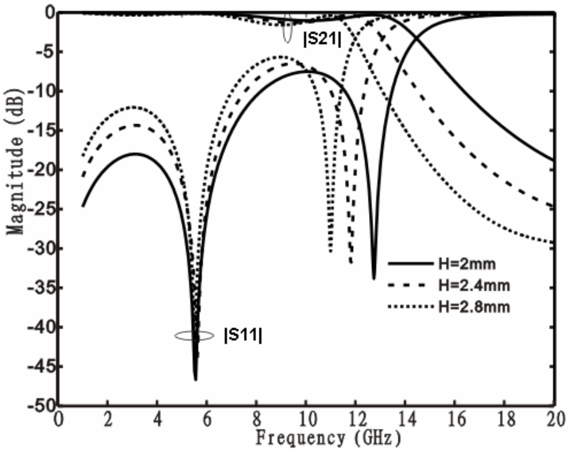


(b)

Fig. 1. Schematic and simulated frequency responses of the 5^{th}-order EBG structure on microstrip line. W_c=0.7, W_L=0.8, h=0.1 (all in mm)

Nevertheless, all the UWB bandpass filters reported in [2]-[8] are still embarrassed by the existence of a relatively narrow upper-stopband due to periodical appearance of multiple passbands, including the dominant and spurious passbands, in these transmission-line-resonator based filter blocks. Plus, all of these reported filters are electrically large in size, which is impractical in the implementation of hand held UWB devices. To circumvent these problematic issues, a periodic structure with shunt-capacitive loading or called electromagnetic bandgap structure [9]-[10], as shown in Fig.

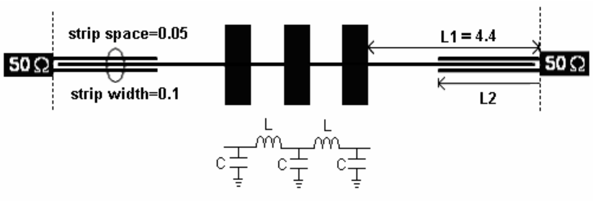
1(a), is utilized herein to replace the wide strip section in the initial MMR [7], aiming to construct an improved EBG-embedded MMR. This EBG structure has a 5th-order stepped-impedance low pass filter behavior which is shown in Fig. 1(b) with different values of H. In this way, the cut-off frequency can be increased from 12.0 to 13.0GHz as H is reduced from 2.8 to 2.0 mm. In this case, the insertion loss within the passband can also be reduced to certain degree. In the remaining part of this paper, a novel EBG-embedded MMR UWB filter is designed using the Agilent ADS-Momentum software and it is implemented on the RT/Duroid 6010 substrate with a dielectric constant of 10.8 and a thickness of 0.635 mm. The results obtained in simulation and experiment show that this proposed UWB bandpass filter has three attractive features against those filters in [2]-[8], i.e., 1) small insertion loss (<0.5dB) within the 3.1-10.6GHz UWB passband; 2) wide and deep upper-stopband with an insertion loss (>20dB) in the 11.0-20.0GHz range; 3) miniaturized overall length (12.5mm against 15.8mm in [7]).

II. EBG-EMBEDDED UWB FILTER

The EBG structure shown in Fig. 1(a) is placed in the central part of the so-called MMR [7] to replace the wide-strip section in [7], thus making up a modified MMR with lowered radiation loss and small size. This EBG-embedded MMR is then driven by two interdigital coupled microstrip lines with the coupling length (L_2) at two sides, as shown in Fig. 2(a). As a consequence, a novel UWB filter can be constituted. Generally speaking, the proposed UWB filter consists of two distinctive parts, i.e., EBG-embedded MMR and interdigital coupled-lines. The MMR is formed by attaching three open-circuited stubs with the high-impedance microstrip line in center. The equal length of these stubs is properly chosen so as to allocate first three resonant modes of the complete MMR within the 3.1-10.6GHz UWB passband.

Fig. 2(b) shows the simulated S_{21}-magnitude of the MMR circuit under different coupling lengths, i.e., L_2 =0.1, 1.0 and 4.3mm, respectively. First of all, the peaks in relation to the first four resonant frequencies can be observed in all the three plotted cases and the whole S_{21}-magnitude curve gradually rises up as the coupling length is lengthened or coupling degree is raised. Then, follow the previous work in [7], we can well understand that the first three resonant frequencies, namely, f_{m1}, f_{m2} and f_{m3}, roughly ranging in the 3.1-10.6GHz band, can work together to make a UWB passband. In the meantime, the 4th one, i.e., f_{m4}, is located around 12.0 GHz and it usually contributes to the first spurious passband beyond the dominant UWB passband in the initial UWB bandpass filter [7] as can be observed from Fig. 2(b). This first harmonic may be rejected by the coupling zero of distributed coupled lines [8].

On the other hand, an interdigital coupled-line is studied and utilized herein as a tightened and distributed coupling element to drive the constituted MMR later on. Its S_{21}-magnitude frequency response is also plotted in Fig. 2(c). It can be observed that its first coupling zero happens around 14.1GHz where the coupling length is approximately equal to one half-wavelength. This coupling zero is slightly higher than f_{m4} =12.0 GHz, but it can be reduced to approach the 4th mode f_{m4} if some dimensions are adjusted. As such, these comparative curves provide us with a hint in suppressing this undesired f_{m4} by reallocating f_{m4} to the coupling zero.



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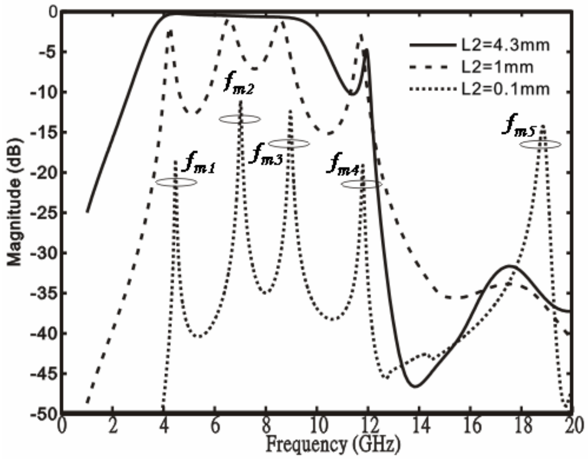

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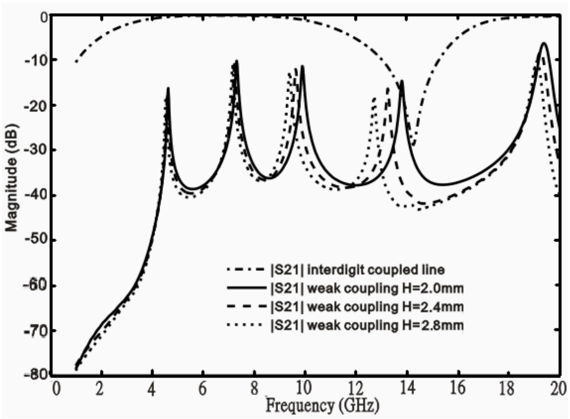


(C)

Fig. 2. (a) Schematic and equivalent model. (b) S_{21}-magnitude of different coupling lengths (L_2) under H=2.8 (c) S_{21}-magnitude of interdigital coupled-line (dotted-line) and EBG-embedded MMR circuit under weak coupling (solid-line). (all in mm)

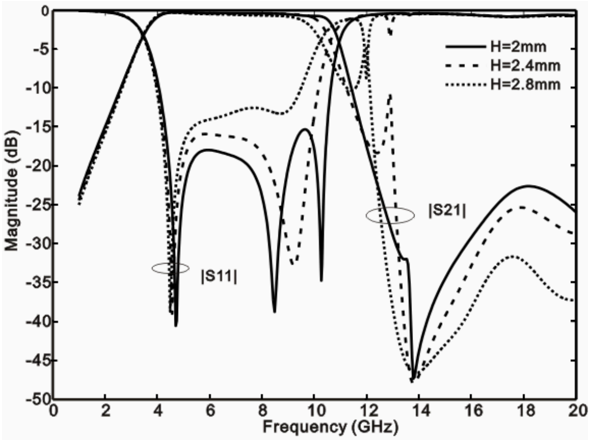
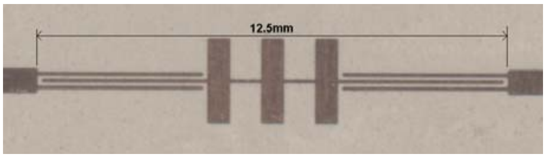


Fig. 3. Comparative studies of an EBG-embedded MMR UWB bandpass filter with respect to varied stub lengths (H).

In fact, the EBG-embedded MMR in Fig. 2(a) can be considered as an equivalent cascaded shunt-capacitance and series-inductance network in the low frequency range, as shown in Fig. 2(a). As the stub length is shortened, the phase velocity of the central EBG section becomes slow so as to shorten its relevant electrical length [9]-[10] at the fixed frequency. As such, the first a few resonant-mode frequencies may be shifted up to different extents by virtue of this stub length. Fig. 2(c) depicts the simulated S_{21}-magnitude of this MMR with respect to different stub lengths, i.e., H=2.8, 2.4 and 2.0 mm. As H deceases, the first four resonant frequencies, i.e., f_{m1}, f_{m2}, f_{m3} and f_{m4}, get to be raised in an accelerated manner. In particular, f_{m4} approaches the coupling zero at 14.1GHz. Meanwhile, the 5th resonant frequency is almost unchanged around 19.0GHz. This result ensures us a capability in fully removing the lowest spurious passband, caused by f_{m4}, in the UWB filter design.

Fig. 3 shows the S_{21}-magnitude of such a UWB filter under optimized strong coupling case with L_1=4.4mm & L_2=4.3mm as also indicated in Fig. 2(a), where H=2.8, 2.4 and 2.0mm, respectively. As H is shortened, the spurious peak near the upper cut-off frequency is gradually reduced from -5.0 to -10.0 and -32.0 dB in final, resulting in the full rejection of this undesired harmonic passband. Moreover, as the coupling zero is close to the upper-end edge of the UWB passband, the upper rejection skirt gets to be significantly sharpened at the case of H=2.0mm. As shown in Fig. 3, the band-gap behavior of the EBG structure, placed in the center of the constituted MMR, actually suppresses the 5th resonant frequency at 19.0GHz, thus successfully making up a wide upper stopband covering 11.0 to 20.0GHz. Looking closely at Fig. 3, we can further observe that the insertion loss achieves higher than 20.0dB in the upper stopband and lower than 0.5dB in the UWB passband.



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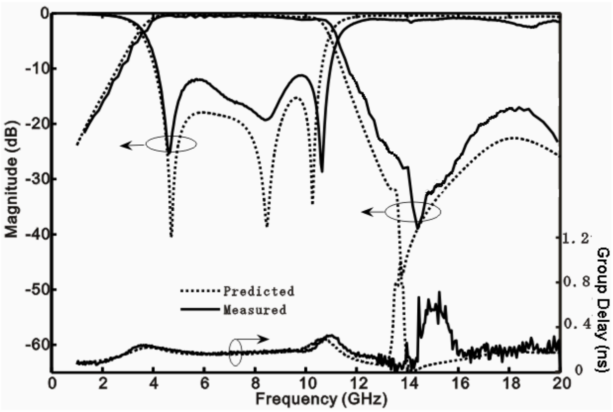

(b)

Fig. 4. (a) Photograph; (b) predicted & measured result of the optimized UWB bandpass filter.

III. Simulated and Measured Results

To provide an evident verification on the above predicted UWB passband and upper-stopband performances, a prototype filter circuit is designed, fabricated and measured. The photo of the fabricated filter is illustrated in Fig. 4(a). It is compact with only 12.5 mm in overall length due to the slow-wave behavior of the EBG section introduced in center. Fig. 4(b) shows the comparison between the predicted and measured frequency responses of S_{21}- and S_{11}-magnitudes as well as group delay over a wide frequency range of 1.0 to 20.0GHz. They are found in very reasonable agreement with each other, thereby confirming the actual realization of the FCC-specified UWB passband and extended upper-stopband bandwidth. Furthermore, the upper-stopband in experiment is greatly extended up to and beyond 20.0 GHz with an insertion loss larger than 15.0 dB. The measured insertion loss is found less than 0.9 dB over the UWB passband and the spurious passband near the upper cut-off frequency is totally eliminated as verified in experiment.

Meanwhile, the group delay varies between 0.25 and 0.35 ns within the UWB passband, showing a very reasonably good linearity. Similarly to those shown in [2-8], this parameter reaches to maximum peaks as the frequency moves to the lower and upper ends of this UWB passband. It is primarily caused by an inevitable trade-off between sharp rejection skirt and small group delay variation around cut-off frequencies, as studied before [10].

IV. CONCLUSIONS

In this work, a compact UWB bandpass filter with improved upper-stopband performances is proposed and designed using an EBG-embedded multiple-mode resonator (MMR). The first three resonant modes of this modified MMR are studied and utilized to make up the 3.1-10.6GHz UWB passband. Meanwhile, its 4th mode is cancelled by the half-wavelength coupling zero of interdigital coupled-lines and its 5th mode is effectively rejected by the bandgap or bandstop behavior of the embedded EBG. After optimization design is carried out, a prototype UWB filter is fabricated and measured to give an experimental demonstration of its actual UWB passband and upper-stopband performances. The insertion loss achieves less than 0.9 dB in the 3.1-10.6 GHz passband and higher than 15.0 dB in the upper-stopband of 11.4~ 20.0 GHz. In addition, its overall length is reduced from 15.8mm in [8] to 12.5mm

REFERENCES

[1] Federal Communications Commission, "Revision of part 15 of the commission's rules regarding ultra-wideband transmission systems," Tech. Rep., ET-Docket 98-153, FCC02-48, Apr 2002.

[2] H. Ishida and K. Araki, "Design and analysis of UWB bandpass filter," in *IEEE Topical Conf. on Wireless Comm. Tech.*, Oct. 2003, pp. 457-458.

[3] C. –L. Hsu, F. –C. Hsu, and J. –T. Kuo, "Microstrip bandpass filters for ultra-wideband (UWB) wireless communications," in *IEEE MTT-S Int. Dig.*, June 2005, pp. 679-682.

[4] W. Menzel, M. S. R. Tito, and L. Zhu, "Low-loss ultra-wideband (UWB) filters using suspended stripline," in *2005 Asia-Pacific Microwave Conf. Proc.*, vol. 4, December 2005, pp. 2148-2151.

[5] K. Li, D. Kurita, and T. Matsui, "An ultra-wideband bandpass filter using broadside-coupled microstrip-coplanar waveguide structure," in *IEEE MTT-S Int. Dig.*, June 2005, pp. 675-678.

[6] J. –S. Hong and H. Shaman, "An optimum ultra-wideband microstrip filter" *Microwave Optical Tech. Lett.,* vol. 47, no. 3, pp. 230-233, Nov. 2005.

[7] L. Zhu, S. Sun and W. Menzel, "Ultra-wideband (UWB) bandpass filters using multiple-mode resonator," *IEEE Microwave Wireless Compon. Lett.,* vol. 15, no. 11, pp. 796-798, Nov. 2005.

[8] S. Sun and L. Zhu, "Capacitive-ended interdigital coupled lines for UWB bandpass filters with improved out-of-band performances," *IEEE Microwave Wireless Compon. Lett.,* vol. 16, no. 8, pp. 1-3, Aug. 2006.

[9] L. Zhu, "Guided-wave characteristics of periodic coplanar waveguides with inductive loading: unit length transmission parameters," *IEEE Trans. Microwave Theory Tech.*, vol. 51, no. 10, pp. 2133-2138, Oct. 2003.

[10] J.-S. Hong and M. J. Lancaster, "transmission line filters with advanced filtering characteristics," in *IEEE MTT-S Int. Dig.*, June 2000, pp. 319-322.