Compact UWB BPF with a Tunable Notched Band based on Triple-mode HMSIW Resonator

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Abstract

A novel triple-mode resonator based on the half-mode substrate integrated waveguide (HMSIW) structure is proposed to design the ultra-wideband (UWB) filters. The UWB filter topology is given by analyzing the resonant frequencies of the three modes and the signs of the coupling between the three modes and the input/output ports. With the filter synthesis method, a triple-mode UWB filter with passband from 3.1-10.6 GHz is effectively realized with two transmission zeros at the upper stopband. To block the existing undesired narrowband radio signals in FCC UWB range, a notched band can be easily generated and controlled by a loaded stub-capacitor. For demonstration, an UWB filter with a tunable notched band from 3.7 to 7.7 GHz and compact size is designed and fabricated. Both simulated and measured results indicate that the proposed new filter has the properties of wide tuning range of the notched band and sharp roll off.

Index Terms: Filter; Half-mode substrate integrated waveguide (HMSIW); Tunable notch; Ultra-wideband (UWB).

I. Introduction

Substrate integrated waveguide (SIW) techniques have been successfully applied to design various filters with low loss and high integration [1-3]. Wide bandwidth is one of the challenges in the design SIW filters as the week coupling between the SIW resonators. Electromagnetic bandgap (EBG) structure is used to design SIW filters with wide bandwith [4-6], which complicated the design and fabrication. Innovative SIW structures, such as the U-slotted SIW cavities [7] and the ridged half-mode substrate integrated waveguide (RHMSIW) [8] are recently reported to design wideband bandpass filters. However, the fractional bandwidth (FBW) is less than 50%. Therefore, to design SIW filters with wide bandwidth is very meaningful.

Since the Federal Communication Commission (FCC) officially assigned an unlicensed use of ultra-wideband (UWB) communication spectrum from 3.1 to 10.7 GHz in 2002, various UWB filters have been

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reported [9-21]. Due to the existing undesired narrow band radio signals such as WLAN that may interfere with the FCC UWB range, UWB filters with a notched band are desired. The notched bands have been realized through various techniques, such as an embedded parasitic coupled line [12], an embedded λ/4 slotline [13,14], a simplified composite right-/left-handed resonator [15], and asymmetric parallel-coupled lines [16,17]. As the existing undesired parasitic signals in the FCC UWB range change from place to place and from time to time, UWB filters with tunable notched band have been studied [18-21]. In [18,19], UWB filters with tunable notch have been developed with advanced technology such as silicon-based integrated passive device (IPD) and microelectromechanical system (MEMS), which require high cost and hybrid technology. Tunable notched UWB bandpass filters (BPFs) have been reported based on microstrip line in PCB technology in [20, 21]. However, they have suffered from narrow tuning rang of the notched band and poor attenuation of the passband edges.

In this letter, a novel triple-mode resonator based on half-mode substrate integrated waveguide (HMSIW) is proposed to design UWB filters. To our best knowledge, multiple-mode resonator (MMR) with HMSIW structure has not been studied in past literature thus far. By analyzing the resonant frequencies of the three modes and the signs of the coupling between the three modes and the input/output ports, the UWB filter topology is given. With the filter synthesis method, a triple-mode UWB filter with passband from 3.1-10.6 GHz is effectively realized with two transmission zeros at the upper stopband. To block the existing undesired narrowband radio signals in FCC UWB range, a notched band can be easily generated and controlled by a loaded stub-capacitor. For demonstration, an UWB filter with a tunable notched band from 3.7 to 7.7 GHz and compact size is designed and fabricated. The UWB filter with high performance and wide tuning rang of the notched band are demonstrated in both simulated and measured results.

2. Uwb Filter Design and Analysis

A. *Triple-mode HMSIW resonator*

Fig. 1(a) shows the proposed triple-mode resonator, which consists of one section of HMSIW structure with length of l_1 and width of w_1, and two loaded stubs with length of l_2 and width of w_2. The electric field distributions of the first three excited modes are shown in Fig. 2. The field distributions of the first mode (Mode I) inside the resonator is similar to that of TE10 mode. The resonant frequency f_I of Mode I can be expressed as

$$f_\text{I} = \frac{c}{4l_{\text{I}eq}\sqrt{\varepsilon_r}} \tag{1}$$

where c is the speed of light in free space, ε_r is the effective dielectric constant of the substrate, and $l_{I\text{eq}}$ denotes the effective length of the triple-mode resonator for Mode I, which is a little less than $l_1 + l_2$.

While for the second mode (Mode II), the electric field distributes mainly on the loaded stubs. Thus, Mode II is excited by the quarter wavelength of the loaded stubs. The resonant frequency f_II of Mode II can be expressed as

$$f_\text{II} = \frac{c}{4l_2\sqrt{\varepsilon_r}} \tag{2}$$

While the third mode (Mode III) is the third harmonic of Mode I. The resonant frequency f_III of Mode III can be expressed as

$$f_{III} = \frac{3c}{4l_{IIIeq}\sqrt{\varepsilon_r}}$$

(3)

where l_{IIIeq} denotes the effective length for Mode III, which is approximate to $l_1 + l_2$.

As an example, Roger 5880 substrate with 0.787 mm thickness is adopted with w_1=6.5 mm, l_1=10.5 mm, w_2=0.8 mm. The resonant frequencies of the first three excited modes versus l_2 are shown in Fig. 3 using Eigen-mode simulator in HFSS software (keeping $l_1 + l_2$ unchanged). The resonant frequency of the first mode increases slightly, and the third mode decreases slightly, while the second mode decreases greatly with the increase of l_2.
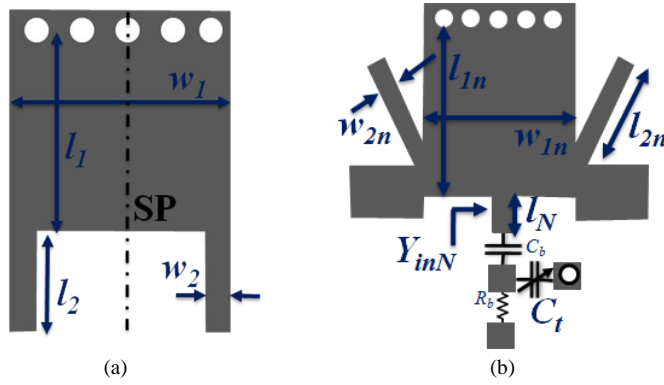

Fig.1. Geometry of the proposed (a) Triple-mode resonator and; (b) UWB filter with a tunable notched band.
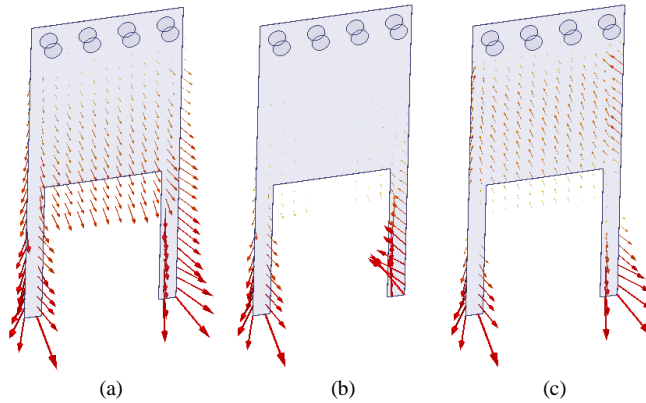

Fig.2. Distributions of electric field magnitude inside the triple-mode resonator. (a) Mode I ;(b) Mode II; (c) Mode III.

B. UWB filter design

As can be observed from Fig. 2, the electric field distribution of Mode I and Mode III is even-symmetric, while Mode II is odd-symmetric with respect to the symmetrical plane [SP in Fig. 1(a)]. Therefore, the signs of coupling coefficients between Mode I or Mode III and input/output are the same, while the signs of coupling coefficients between Mode II and input/output are opposite. Based on the phenomenon described, coupling

scheme of the UWB filter based on triple-mode HMSIW resonator can be defined as illustrated in Fig. 4(a). Corresponding coupling matrix M can be synthesized with one transmission zero at the upper stopband by [22] and the synthesized S-parameters are shown in Fig. 4(b).

$$M = \begin{bmatrix} 0 & 0.2774 & 0.7719 & 0.7204 & 0 \\ 0.2774 & -1.2204 & 0 & 0 & 0.2774 \\ 0.7719 & 0 & -0.7819 & 0 & -0.7719 \\ 0.7204 & 0 & 0 & 1.5330 & 0.7204 \\ 0 & 0.2774 & -0.7719 & 0.7204 & 0 \end{bmatrix} \tag{4}$$

Depending on the above analyses, a UWB filter is design, simulated, and fabricated. Fig. 5 shows the simulated and measured frequency responses of the filter with passband from 3.1-10.7 GHz. As can be seen from the figure, there is a good agreement between the predicted and measured results. Two transmission zeros at 11.2 and 13.4 GHz are observed in the upper stopband. The transmission zero at 11.2 GHz is inherent in the filter topology and the transmission zero at 13.4 GHz is generated by the loaded stubs at half wavelength.
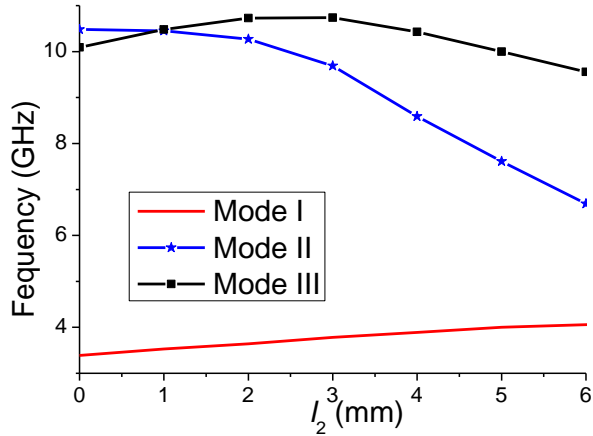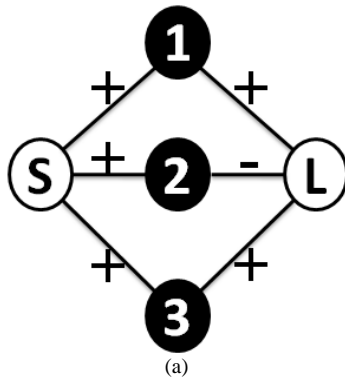

Fig.3. The relationship between the resonant frequencies of the first three excited modes and the stub length l_2.
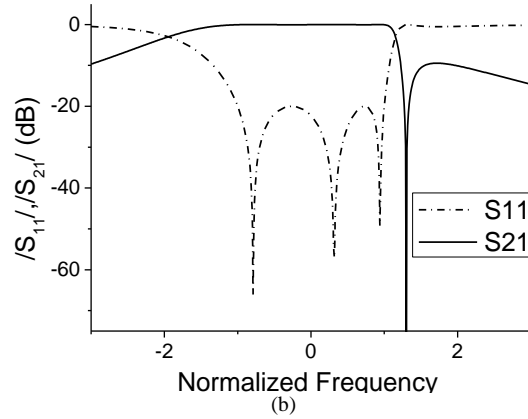

(a)

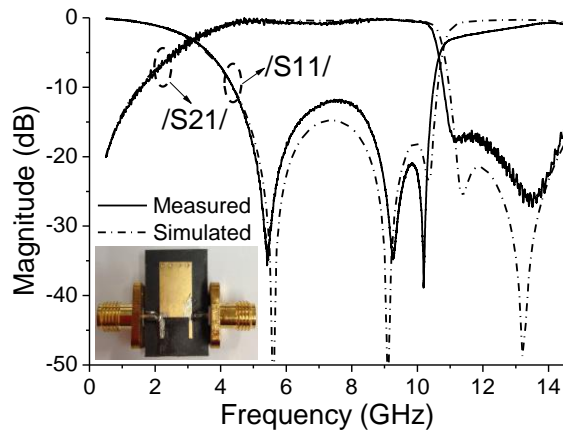Fig.4. (a) Topology and (b) Synthesized S-parameters of the proposed triple-mode filter.

Fig.5. Measured and simulated responses of the UWB filter.

3. Uwb Filter with a Tunable Notched Band

As shown in Fig.1 (b), the proposed UWB BPF with a tunable notched band can be realized by connecting a loaded stub-capacitor to the triple-mode HMSIW resonator. The notched frequency f_N can be obtained by

$$Y_{inN} = Y_N \frac{j2\pi f_N C_t + jY_N \tan \theta_N}{Y_N - 2\pi f_N C_t \tan \theta_N} = \infty \tag{5}$$

That is

$$f_N = \frac{Y_N}{2\pi C_t \tan \theta_N} \tag{6}$$

where Y_{inN} is input impedance of the loaded stub-capacitor, C_t is the capacitance of the loaded varactor, and Y_N and θ_N is the impedance and electric length of the loaded stub, respectively.

For facilitating the DC bias circuit, the two loaded stubs are turned to the upper side of the HMSIW resonator. The dimensions for the proposed UWB filter in Fig. 1(b) are designed as follows: w_{1n}=6.1 mm, l_{1n}=10 mm, w_{2n}=0.8 mm, l_{2n}=4.5 mm, and l_n=0.9 mm. A MA46H120 varactor is used in the prototype circuit. The varactor capacitance is 200 and 1200 fF at 10 and 0V reverse bias, respectively. The DC bias is fed to the varactor through the DC block capacitors C_b and the resistors R_b are utilized as RF blockage elements. Fig. 6 shows the simulated and measured S_{21} of the tunable filter. When the bias voltage V_c varies from 0 to 10.0 V, the notched frequency is tuned from 3.7 to 7.7 GHz. The return loss is better than 13 dB within the tuning range. Photograph of the fabricated BPF is presented in Fig. 7 with a circuit size (including the bias circuit and input/out output ports) of 12.1mm*14.7mm, i.e., 0.46 λ_g*0.38 λ_g, where λ_g is the guided wavelength of 50-Ω microstrip line at the central frequency of 6.85 GHz. Comparisons with other reported UWB BPFs with notched band are listed in Table1, which shows that the proposed UWB filter has a notched band with wide tuning range, easy fabrication and a compact size.

Table 1. Comparison with the reported UWB BPFs with notched band

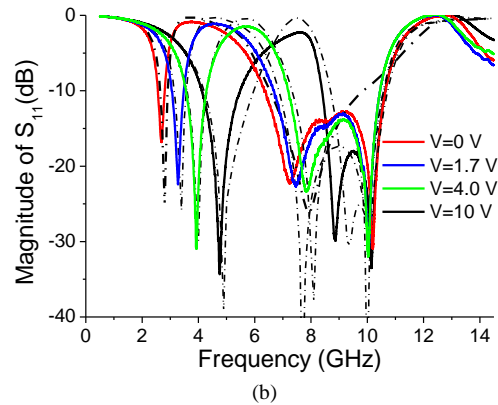| Ref.	Size	Notch frequency (GHz)	Technology	Tunablity
[12]	$0.66\lambda_g$ *$0.36\lambda_g$	7	PCB	No
[13]	$0.30\lambda_g$ *$0.17\lambda_g$	5.8	PCB	No
[14]	$1.68\lambda_g$ *$0.5\lambda_g$	8.07	PCB	No
[15]	$1.10\lambda_g$ *$0.63\lambda_g$	5.85/8.05	PCB	No
[16]	$0.63\lambda_g$ *$0.13\lambda_g$	5.59	PCB	No
[17]	$1.03\lambda_g$ *$0.57\lambda_g$	5.41	PCB	No
[18]	4.8mm*2.9mm	3.5-6.5	IPD	Yes
[19]	10mm*2.5mm	6.3-7.7	MEMS	Yes
[19]	10mm*2.5mm	5.5-6.45/7.8-8.8	MEMS	Yes
[20]	20mm*40mm	3.65-4.35	PCB	Yes
[21]	$1.1\lambda_g$ *$0.63\lambda_g$	5.45-6.07	PCB	Yes
This work	**$0.46\lambda_g$ *$0.38\lambda_g$**	**3.7-7.7**	**PCB**	**Yes**
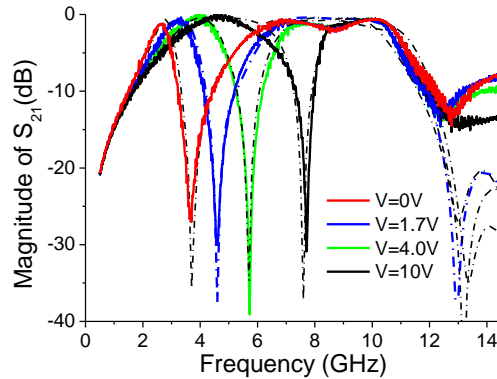
(a)

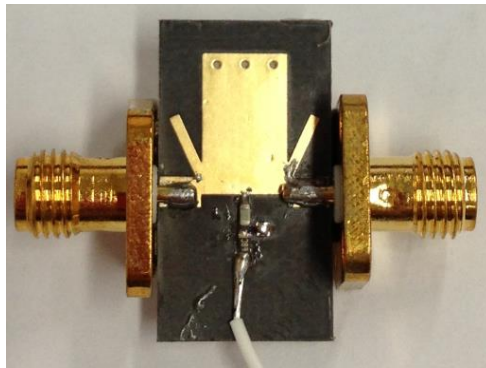Fig.6. Measured and simulated responses of the UWB filter with a tunable notched band .(a) S21; (b) S11.

Fig.7. Photograph of fabricated UWB filter with tunable notch.

4. Conclusions

A novel UWB filter with a tunable notched band is presented in this letter based on triple-mode HMSIW resonator. The triple-mode characteristic of the proposed resonator is analyzed. By altering the lengths of the loaded-stubs, the frequencies of the three modes can be allocated evenly in the UWB band. Also, two transmission zeros are produced at the upper stopband to improve attenuation of the passband edges. Simultaneously, a notched band with wide tuning range (3.7 GHz-7.7 GHz) can be realized by employing a varactor diode. Good agreement between the simulation and the measurement results demonstrates the validity of the design.

Acknowledgements

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