A Novel Wideband Bandpass Filter Using A Cross-Shaped Multiple-Mode Resonator

M. H. Ren, D. Chen, and C. H. Cheng

***Abstract*—A novel wideband bandpass filter (BPF) using a cross-shaped microstrip multiple-mode resonator (MMR) is presented in the letter. The MMR is composed of a section of open-ended microstrip-line and a pair of short-ended stubs. Its three resonant modes are used to construct the passband of the proposed BPF. And two coplanar waveguides are used as the input/output transmission-lines to improve the coupling between the MMR and input/output transmission-lines. The filter has been investigated numerically and experimentally. Both simulated and measured results show that the filter has a good performance, including controllable bandwidth from 66% to 114%, low insertion loss (lower than 0.78 dB), and a small group delay variation.**

***Index Terms*—Bandpass filter (BPF), cross-shaped resonator, multiple-mode resonator (MMR).**

I. INTRODUCTION

MICROWAVE wideband bandpass filters (BPFs) have been extensively investigated as a key block of wideband wireless communication systems. Recently, planar microwave wideband BPFs have been receiving much attention due to the advantages such as small size, low cost, and easy fabrication, and several schemes have been developed. In [1], a microstrip wideband BPF with a fractional bandwidth from 40% to 70% based on conventional parallel-coupling mechanism was reported, in which a symmetric three-line microstrip structure is used to increase the coupling between parallel microstrip lines because a tighter coupling is needed to realize such a wide passband. In [2], a microstrip ring resonator with two tuning stubs was proposed. Using the resonator, a BPF with a bandwidth of about 49% may be constructed. In [3], an ultra-wideband (UWB) BPF with a bandwidth of over 100% constructed on coplanar-waveguide (CPW) was reported, in which the ultra-wide passband is realized by combining a low-pass filter and a high-pass filter. In [4], a kind of microstrip wideband BPF using a cross-shaped multiple-mode resonator (MMR) was proposed, in which a wide passband of over 20% may be realized by using three resonant modes of the MMR. The BPF has a relatively simple structure, but it exhibits a high performance. For this reason, the scheme was applied to the design of UWB BPFs by the authors again [5], [6].

In this letter, we present a wideband BPF using a novel microstrip cross-shaped MMR. The novel MMR is composed of a section of open-ended microstrip-line and a pair of short-ended stubs with the same dimensions. The cross-shaped MMR in [4] is composed of a section of open-ended microstrip-line and two open-ended stubs. The difference between the two MMRs is that the two open-ended stubs are replaced by two short-ended stubs. The difference in the two structures results in the change of their resonant modes. In the novel MMR, much larger frequency gaps between three resonant modes used for the passband of the BPF may be achieved. Therefore, the BPF using the novel MMR has a wider passband, and the bandwidth of its passband may be controlled over the range from 66% to 110%, even though only three resonant modes of the MMR are used in the passband of the BPF similarly to the BPF in [4]. Two CPWs are used as the input/output transmission-lines of the novel MMR to improve the coupling between the MMR and input/output transmission-lines. The BPF exhibits a good performance including compact size, a low insertion loss, controllable bandwidth and a small group delay variation. Details of the filter design are presented and measured results are given to demonstrate the performance of the proposed BPF.

II. DESIGN OF THE PROPOSED WIDEBAND BPF

Fig. 1 illustrates the proposed wideband BPF using a microstrip cross-shaped MMR. The MMR is composed of a section of open-ended microstrip-line and a pair of short-ended stubs with the same dimensions. The short-ended stubs are symmetrically connected to the open-ended microstrip-line section at its central point. The MMR is constructed on a substrate with a relative permittivity ε_r and a thickness h. The MMR is arranged symmetrically about the input/output CPW which is constructed on the conductor ground of the MMR. The dimensions of the MMR are L_1, W_1, L_2, and W_2, respectively. The dimensions of the input/output CPW are W_c and S_c, respectively, and the gap between the input and output CPWs is D.

Three resonant modes of the MMR are used to construct the passband of the BPF as shown in Fig. 2. One is the dominant mode of the half-wavelength resonator composed of the open-ended microstrip-line and the two short-ended stubs. Two other modes are the dominant mode of the quarter-wavelength resonator composed of a half of the open-ended microstrip-line and a short-ended stub, and its second-order mode, respectively. The resonant frequency of the half-wavelength resonator is mainly determined by the parameter L_1, but it will vary with the parameter L_2. The resonant frequencies of the quarter-wavelength resonator are determined by the parameter $L_1/2 + L_2$. For the design of the BPF in Fig. 1, we found a simple scheme in which the length L_2 of the short-ended stubs may be taken as λ_g/4 at the central frequency of the BPF first, and the parameter L_1 may be taken as about λ_g/2, where λ_g is the waveguide wavelength of the electromagnetic wave on the microstrip-line. In this case, the resonant frequency of the half-wavelength resonator is at

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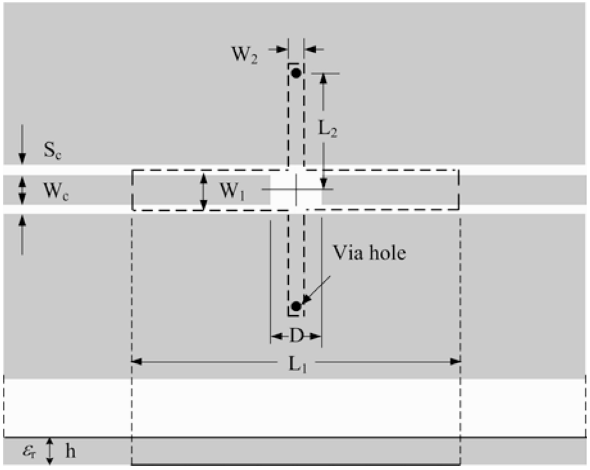

Fig. 1. Proposed wideband BPF using a cross-shaped MMR.

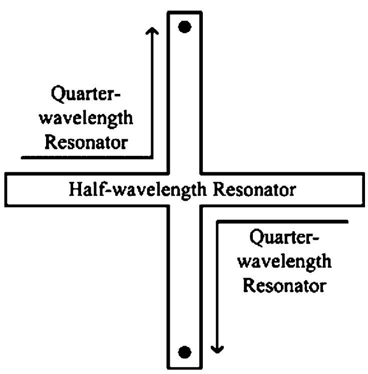

Fig. 2. Resonant modes of the cross-shaped MMR.

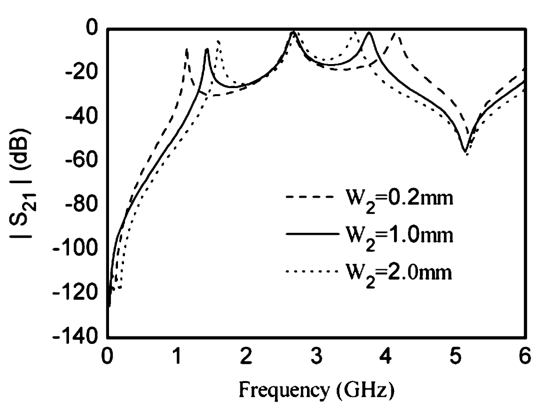

Fig. 3. Variation of the resonant frequencies of the three modes.

the central frequency of the BPF. Then the bandwidth of the BPF may be controlled by adjusting the width of the short-ended stubs as its length is kept unchanged.

Simulation for the BPF design is carried out on IE3D, a commercial electromagnetic simulator. In simulation, the BPF is constructed on a substrate with a relative permittivity $\varepsilon_r = 10.2$ and a thickness $h = 0.635$ mm. The characteristic impedance of the input/output CPW is taken to be 50 Ω. Fig. 3 shows the variation of the resonant frequencies of the three modes mentioned above as the width of the short-ended stubs is changed and all the other parameters are fixed, in which $W_c = 2.0$ mm,

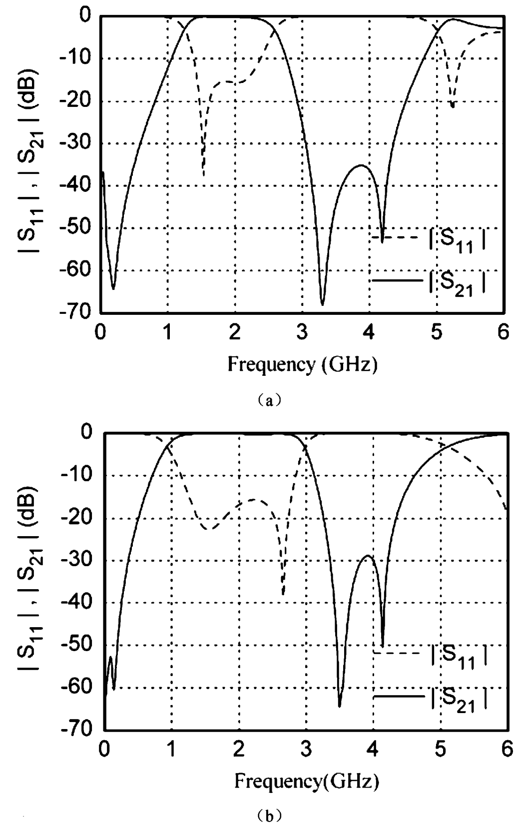

Fig. 4. Simulated performances of the BPFs with different bandwidth.

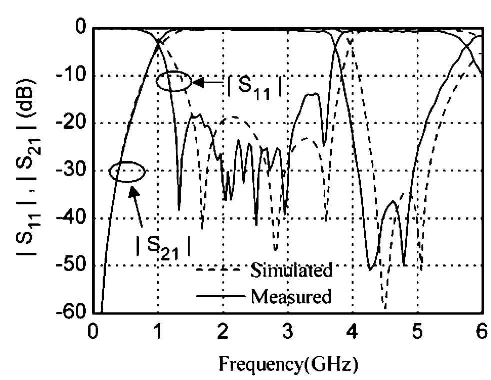

Fig. 5. Simulated and measured performance of the wideband BPF.

$S_c = 0.5$ mm, $L_1 = 24.8$ mm, $W_1 = 2.0$ mm, $L_2 = 13.0$ mm, $D = 25.6$ mm, respectively. In the figure it may be seen that the two resonant frequencies of the quarter-wavelength resonator can be controlled effectively by adjusting the width of the short-ended stubs. At the same time, the resonant frequency of the half-wavelength resonator is kept unchanged almost. It means that the bandwidth of the BPF can be controlled by designing the width of the short-ended stubs properly.

Based on the result, the wideband BPFs with different bandwidths may be designed by using the simple principle described above. Besides, a proper coupling between the MMR and the input/output CPWs and a good impedance matching at both the input and the output of the filter may be achieved by adjusting the dimensions of the CPWs and the gap between the

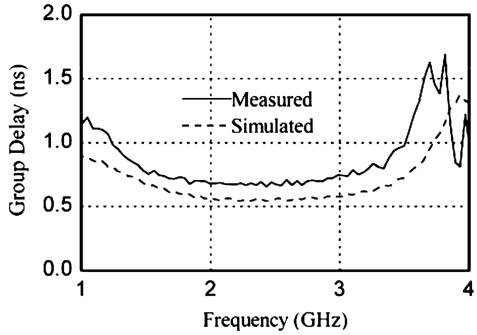

Fig. 6. Simulated and measured group delay of the wideband BPF.

input and the output CPWs. Fig. 4 shows the simulated performance of two BPFs with different bandwidths. In Fig. 4(a), the short-ended stubs of the MMR are designed to be much wider than the open-ended microstrip-line, therefore the bandwidth of the BPF is about 66% only. The parameters of the BPF are $W_c = 1.4$ mm, $S_c = 0.4$ mm, $L_1 = 34.0$ mm, $W_1 = 1.0$ mm, $L_2 =$15.2 mm, $W_2 = 4.0$ mm, $D = 5.0$ mm, respectively. In Fig. 4(b), the short-ended stubs of the MMR are designed to be thinner than the open-ended microstrip-line, in this case, the bandwidth of the BPF is about 100%. The parameters of the BPF are $W_c = 2.0$ mm, $S_c = 0.5$ mm, $L_1 = 34.0$ mm, $W_1 = 2.0$ mm, $L_2 =$15.2 mm, $W_2 = 1.5$ mm, $D = 7.0$ mm, respectively. It may be also seen that the two BPFs have a high out-of-band rejection level.

Fig. 5 shows the performance of a practical BPF constructed on a substrate with a relative permittivity $\varepsilon_r = 10.2$ and a thickness $h = 0.635$ mm. It was fabricated with a wet etching process and measured on a Network Analyzer HP 8720. In measurement, the BPF is connected with two SMA connectors. The dimensions of the BPF are $W_c = 2.0$ mm, $S_c = 0.5$ mm, $L_1 =$ 24.8 mm, $W_1 = 2.0$ mm, $L_2 =$13.0 mm, $W_2 = 1.0$ mm, $D =$ 3.6 mm, respectively. For comparison, simulated performance of the BPF is given in the figure too. It may be seen that the measured results agree well with the simulated results. Measured data show that its passband is from 1.02 to 3.71 GHz, which indicates its relevant fractional bandwidth is about 114%. The maximum insertion loss is 0.43 dB from 1.24 to 2.55 GHz, and it is 0.78 dB from 2.55 to 3.59 GHz. The minimum insertion loss in-band is 0.29 dB. The return loss $|S_{11}|$ is lower than -13 dB within its passband. Meanwhile, the BPF has a high out-of-band rejection level which is below -20.0 dB over the frequency range 3.99–5.14 GHz, and there exist two transmission zeroes outside its passband. Fig. 6 shows measured group delay of the BPF. The measured group delay varies between 0.67 and 1.63 ns with a maximum variation of 0.96 ns over its whole passband.

III. CONCLUSION

A novel microstrip cross-shaped MMR is presented. The MMR is composed of a section of open-ended microstrip-line and a pair of short-ended stubs. Its three resonant modes may be used to construct the passband of a wideband BPF with a relevant fractional bandwidth from 66% to 114%. The design of the wideband BPFs using the MMR is discussed and a simple design scheme is presented. A practical BPF with CPW input/output using the MMR is given to demonstrate its performance. Both measured and simulated results show that the BPF has a good performance including a low insertion loss, a small group delay variation, and a high out-of-band rejection level. The BPFs may be applied in the design of microwave circuits with a wide operation frequency band and UWB communication systems.

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