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A Wideband and High Rejection Multimode Bandpass Filter Using Stub Perturbation

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***Abstract*—A novel multimode bandpass filter with high and wide rejection band is proposed by using an open stub. The open-stub has two functions in the filter: 1) perturbation for the multimode operation and 2) zero point generation at the stopband for the stopband control. With proper input/output coupling, additional two poles, i.e., four poles, can be generated for the proposed filter structure. The design is then verified by experiment. The single structure four-mode filter has low insertion loss, good stopband performance, and compact size and linear phase.**

***Index Terms*—Filter, linear phase filter, microstrip, multimode resonator, network model, zero point.**

I. INTRODUCTION

MICROWAVE filters with high-performance and compact size are highly demanded in many communication systems [1], [2]. The microstrip (MS) planar filters are still drawing much attention, due to the advantages of low cost and easy fabrication [1]–[10]. Resonators, as the fundamental elements in a filter, usually determine the size of the filter. Reducing resonator size is an effective approach to miniaturize filter size. There are two basic ways to reduce the resonator size: the first way is to reduce the size of the resonator by modifying its' physical structures. It can be seen that the hairpin filters [3], [4] make progress in size reduction from parallel-coupling structures to U-shape resonators. Further progress in size reduction is made by the miniaturized hairpin resonator filters [5], [6], where the separate electric and magnetic coupling paths (SEMCP) are introduced in the folded quarter-wavelength resonator to shrink the size and to generate additional zero point. The other way for the filter size reduction is to modify the traditional resonator to generate additional modes, causing the resonator to have multiple resonate frequencies and thus one physical resonator can be treated as multiple electrical resonators. Examples can be seen from the dual-mode ring resonator [7], [8], dual-mode rectangular patch [9], dual-mode triangular patch [10] and dual-modes circular patch. Recently, a five-pole filter was built based on a single triple-mode stepped-impedance resonator (SIR) [11] for ultra-wide bandwidth application (UWB). A novel compact multimode UWB filter configuration with additional zero points in stopband is implemented in [12]. In [13], the triple open stubs in shunt to a SIR are used to build UWB filter. The electromagnetic bandgap (EBG) embedded multimode resonator is used for UWB filter [14]. The triple SIRs loaded resonator is used to build the filter with improved upper stopband [15] and out-of-phase transmission line cancellation is used to generate a notch band in the UWB frequency band.

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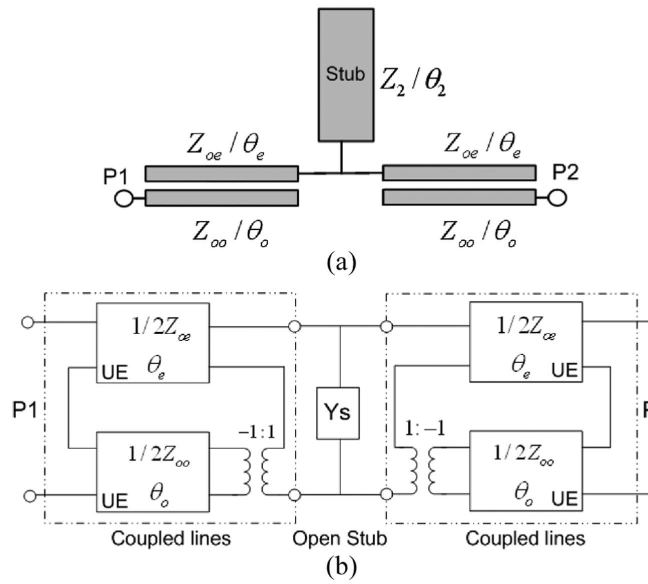

Fig. 1. Proposed multimode filter and its network model: (a) transmission line model of the proposed multimode filter and (b) the network model of (a).

In this letter, instead of using SIR [11], [13], triple open stubs shunted to SIR [13]–[15], and EBG-embedded resonator [14], a novel filter configuration as shown in Fig. 1(a) composed of single stub and two sections of coupled transmission lines is introduced for multimode filter design. The dual functions, i.e., multimode perturbation and zero point (ZP) generation, of the open stub loaded on the uniform half-wavelength resonator are analyzed and demonstrated for the first time. The proposed four-mode filter achieves good rejection in the frequency range about twice of the fundamental frequency band. The operation mechanism of the proposed filter is verified by the simulation and experiment.

II. CHARACTERISTICS OF STUB PERTURBATION

Fig. 1(a) shows the proposed filter configuration. An open stub with impedance of Z_2 and electric length of θ_2 connects with two section coupled transmission lines at the left-hand and right hand sides. The coupled transmission lines provide the even-mode impedance and electric length of Z_{oe} and θ_e and also the odd-mode impedance and the electric length of Z_{oo} and θ_o respectively. The structure in Fig. 1(a) can be represented by using the equivalent circuit network shown in Fig. 1(b) with unit element (UE) of the network [2]. As shown in Fig. 1(b), the coupled transmission lines are represented by the UEs and the $-1{:}1$ transformer [16].The shunt stub can be represented by the admittance of Y_s connected in shunt in the middle of the equivalent networks of the two section of coupled transmission lines. The transmission characteristics of the network in Fig. 1(b) are calculated by doing the matrix conversion from ABCD matrix to the S-matrix. The ABCD matrix can be obtained by cascading the ABCD matrixes of the coupled transmission lines and the stub as shown in the following:

$$\begin{bmatrix} A_t & B_t \\ C_t & D_t \end{bmatrix}_t = \begin{bmatrix} A_c & B_c \\ C_c & D_c \end{bmatrix}_c \times \begin{bmatrix} 1 & 0 \\ Y_s & 1 \end{bmatrix}_s \times \begin{bmatrix} A_c & B_c \\ C_c & D_c \end{bmatrix}_c \quad (1)$$

where

$$A_c = \frac{Z_{oe}\cot\theta_e + Z_{oo}\cot\theta_o}{Z_{oe}\csc\theta_e - Z_{oo}\csc\theta_o} = D_c \quad (2)$$

$$B_c = \frac{j}{2}\frac{Z_{oe}^2 + Z_{oo}^2 - 2Z_{oe}Z_{oo}(\cot\theta_e\cot\theta_o + \csc\theta_e\csc\theta_o)}{Z_{oe}\csc\theta_e - Z_{oo}\csc\theta_o} \quad (3)$$

$$C_c = \frac{2j}{Z_{oe}\csc\theta_e - Z_{oo}\csc\theta_o} = D_c \quad (4)$$

$$Y_s = j/Z_2\tan\theta_2. \quad (5)$$

To demonstrate the operation of the proposed structure, the microstrip lines and RT/Duroid 4003 dielectric substrate with $\varepsilon_r = 3.38$ and thickness of 20 mil are used. Three cases will be compared and studied in this letter. Case (a) is the structure in Fig. 1(a) without the perturbation stub, which is actually an edge coupled half-wavelength resonator with two open ends. The coupled lines with $Z_{oo} = 107\ \Omega$ and $\theta_{\mathrm{o}} = 91.4^\circ$ and $Z_{oe} = 95.5$ and $\theta_{\mathrm{e}} = 87.4$ at 5.4 GHz are chosen respectively. Case (b) is the structure of case a) with stub. As shown in Fig. 1(a), the stub has characteristic impedance of 40Ω and electric length of 53.3° at 5.4 GHz. Case (c) is open stub shunt between two 50Ω I/O ports. To study the resonator characteristics, loose couplings, i.e., large coupling gap, of the coupled lines are set to minimize the affects due I/O feeder lines. The results of the three cases (a), (b), and (c) corresponding to frequency response curves (a), (b), and (c) in Fig. 2 respectively are compared. Curve (a) in Fig. 2 shows the typical response of the traditional half-wavelength resonator (i.e., the structure of Case (a) with loose coupling). The second harmonic of PP1 appears about twice of the fundamental frequency PP1, which make the stopband of the half-wavelength resonator become narrow. Curve (b) in Fig. 2 shows two resonant frequencies PP1 and PP2, which are close to each other due to the perturbation of the stub. An additional ZP generated in the stopband results in the stopband having a higher rejection and wider bandwidth than that for the case (a). The generation of the ZP is due to the resonance of the stub (refer to the overlapped ZPs of curves (b) and (c) in Fig. 2). From an investigation among the above three cases, it is concluded that the stub has the following two functions: 1) it causes the half-wavelength resonator to operate as dual-mode resonator through the perturbation at the center of the resonator. 2) it is able to achieve the high rejection and wide bandwidth in stopband through the ZP generation of the stub itself.

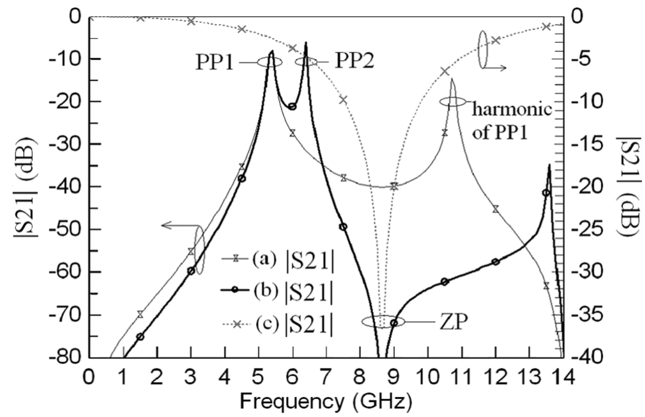

Fig. 2. Frequency responses of case (a) (filter in Fig. 1(a) without open stub), case (b) (filter in Fig. 1(b) with open stub), and case (c) (open stub).

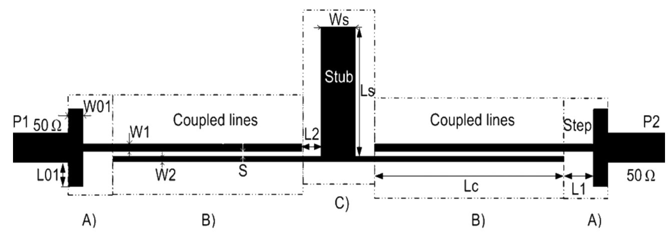

Fig. 3. Configuration of the proposed four-mode BPF.

III. Four Mode Filter Design

The investigation in Section II shows the operation principle of the proposed multimode filter structure. To achieve good passband return loss and stopband rejection, the structure in Fig. 1(a) is modified to the filter structure in Fig. 3. The structure is symmetrical along the open stub in C) portion. The portion A) is mainly used to adjust the I/O matching. The portion C) is to generate the multiple operation modes and adjust the ZP in the stopband to control the stopband performance. The coupled lines in portion B) are to control the filter bandwidth as well as the modes. A design example of the configuration in Fig. 3 with main dimensions: $W1 = 11$ mil, $W2 = 8$ mil, $W01 = 31$ mil, $L01 = 36.4$ mil, $Lc = 347.4$ mil, $Ws = 62.2$ mil, and $Ls = 195.2$ mil was made. The coupling gap S of coupled lines affects both the passband bandwidth and the operation modes. Fig. 4 shows the comparison of the filter with different coupling gaps of $S = 63$ mil, $S = 7$ mil and $S = 4$ mil. It can be seen that for the weak coupling condition (i.e., S is large), there are only two resonating poles, (i.e., PP1 and PP2). When the coupling is strong (i.e., S is small), it is interesting to note that four poles are generated in the passband, i.e., additional two poles PP3 and PP4 are generated. The decrease of the gap S increases bandwidth of the filter. The ZP in stopband is mainly determined by the C) portion of Fig. 3. The increase the length of stub decreases the bandwidth of the filter and shifts the ZP close to the passband.

IV. Results and Discussions

The planar $4 \sim 6.5$ GHz filter ($S = 7$ mil) is designed and fabricated using the Ro4003 materials. Multimode filter is measured with HP8722ES vector network analyzer together with 3.5 mm connector calibration kits. The universal substrate test

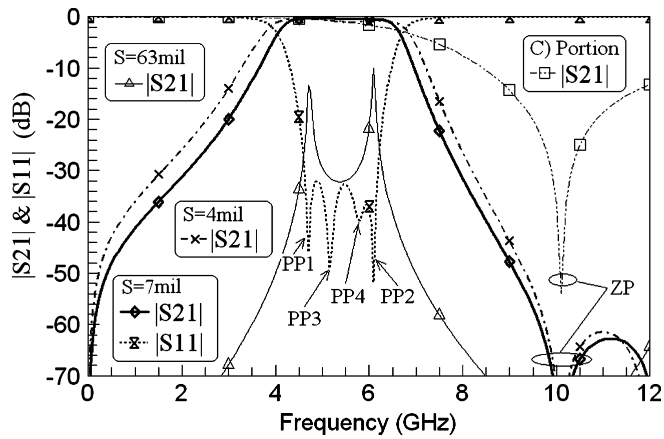

Fig. 4. Characteristics of the proposed filter with different coupling gap S note: curve of C) portion is the response of structure C) in Fig. 3.

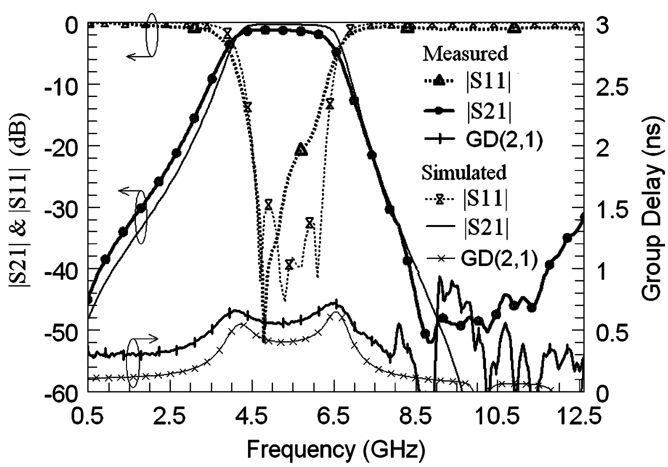

Fig. 5. Comparison the theory and experiment results of the proposed filter.

fixtures WK-3001-B from Microwave Inter-continental Inc. are used for I/O port connections for measurement. The simulated results and the measured results are compared in Fig. 5. The measured 3-dB bandwidth is from 4 to 6.3 GHz (the fractional bandwidth is 45%) which is narrower than that of simulated results (4 $\sim$ 6.6 GHz) using circuit simulator in ADS2005A. Both simulated results and measured results of the multimode filter shows a good return loss (more than 20 dB) in passband and rejection in the stopband (from 8.4 to 11.7 GHz, the rejection is more than 40 dB). From 8 to 12.6 GHz, which is the second harmonic range of the traditional half-wavelength resonator, the rejection is more than 30 dB. The measured minimum insertion loss, including the SMA connector losses of test fixture in I/O ports, is only 1.2 dB. The simulated and measured results of the group delay for the multimode filter are compared in Fig. 5. The group delay variation of 0.2 ns in the passband range is small enough for high linearity system applications. The difference between the simulated and measured group delays is due to the additional phase delay of the test fixture which is not considered during the simulation and not de-embedded in the measurement. The length of the four-mode filter is close to that of the traditional half-wavelength resonator at the center operating frequency. The board size of the four-mode bandpass filter (BPF) is 1200 mil times 450 mil ($0.5\lambda0 \times 0.18\lambda0$, $\lambda0$ is the free space wavelength at center operating frequency).

V. Conclusion

In this letter, a novel multimode filter structure by using stub perturbation is proposed and investigated. The stub is used to achieve multimode operation and additional zero point simultaneously. The measured results of the proposed filter demonstrates not only a wide passband bandwidth, low insertion loss and compact size through multimode operation but also a wide stopband and high stopband rejection through the intrinsic zero point generation of the open stub. The filter has a linear phase response. These characteristics are challenge to be achieved simultaneously using the traditional filter configurations.

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