A Novel Microstrip Transversal Bandpass Filter with Simultaneous Size Reduction and Spurious Responses Suppression

Wai-Wa Choi[1], Kam-Weng Tam[1] and R. P. Martins[1, 2]
[1]Wireless Communication Laboratory
Faculty of Science and Technology, University of Macau, Macao, China, Email: welsyc@umac.mo
[2]On leave from Instituto Superior Técnico, Technical University of Lisbon, Portugal

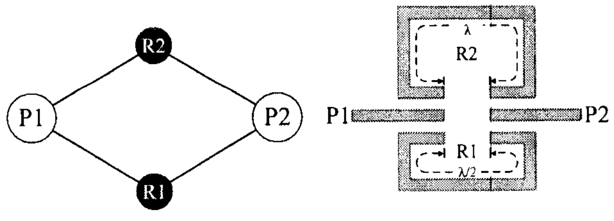
Abstract - **A novel miniaturized microstrip transversal bandpass filter with simultaneous size reduction and spurious responses suppression is proposed. In this new filter structure, the stepped-impedance resonator technique is used to not only shorten the resonator size but also suppress its spurious responses. A prototype transversal bandpass filter centered at 2 GHz with 5% FBW is designed and experimentally characterized. This new filter achieves 15% size diminution when compared with the conventional structure. In addition, spurious responses at 3 GHz and 5 GHz are suppressed by 30 dB and 18 dB respectively.**

Key Words - **Spurious Responses Suppression, Stepped-Impedance, Size Reduction, Transversal Filter.**

I. INTRODUCTION

The microstrip cross-coupled bandpass filter permits the development of compact filter with narrowband and high-Q for modern telecommunication systems. A number of bandpass structures and their associated coupling schemes have been previously proposed [1]-[5]. Amongst them, the transversal filter with its coupling scheme, presented in Fig. 1(a) has recently been investigated and a transmission zero can be easily introduced in the passband proximity to improve the filter selectivity [5]. The conventional microstrip transversal bandpass filter uses two resonators R1 and R2 that are implemented by open-loop resonators with full-wavelength and half-wavelength respectively, as seen in Fig. 1(b). The signal from port P1; splits as well as transverses into these two resonators' paths; and then these two split signals will be recombined into port P2. A transmission zero is generated due to the signal phase cancellation of the above split signals. To minimize the size, quarter-wavelength short resonator is proposed to replace the above lengthy full-wavelength open-loop resonator even the use of via is a laggard [5]. In addition, this filter suffers from the problem of spurious responses located near the fundamental frequency f_0. Due to the full-wavelength resonator periodicity, unwanted spurious will be located at harmonic frequencies of f_0 for example. This indeed degrades the stopband rejection and becomes an intrinsic performance limitation associated with the wide stopband applications.

In order to achieve simultaneous size minimization and spurious response suppression, a novel microwave transversal bandpass filter based on the stepped-impedance resonator is proposed and compared with the conventional structure. A simple stepped-impedance resonator (SIR) technique is applied to shorten the one wavelength open-loop resonator of the conventional transversal filter and the spurious response is distanced due to the impedance change of the resonator in order to achieve wider stop band. Besides this introductory section, the SIR will be introduced and simple design guidelines for size minimization will be given in section II and the performance of spurious response suppression will also be discussed. In section III, a proposed microstrip transversal bandpass filter prototype centered at 2 GHz with 5% fractional bandwidth is designed and implemented. The corresponding measurement results are presented and discussed. Finally, the conclusions will be drawn in section IV.



(a) (b)

Fig. 1 The conventional microwave transversal bandpass filter (a) coupling scheme and (b) microstrip implementation

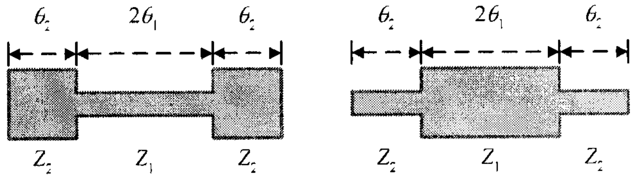
---

This work has been financially supported by the University of Macau under the Research Grant Ref. No. RG009/04-05S/C62/MR/FST.

II. MICROSTRIP TRANSVERSAL BANDPASS FILTER USING STEPPED-IMPEDANCE RESONATOR

A. Size Minimization For Microstrip Transversal Bandpass Filter

As illustrated in [5], the quarter-wavelength short resonator is used to replace the full-wavelength resonator of Fig. 1(b) but the via is a problem. In order to realize simultaneous size reduction and via free implementation, the stepped-impedance resonator is used. For the SIR structure as shown in Fig. 2 [6], three transmission line segments are arranged symmetrically where both ends have identical characteristic impedance and electrical length Z_2 and θ_2 respectively. The characteristic impedance of the middle section is Z_1 and its electrical length is θ_1. The impedance ratio R and normalized resonator length L expressed in (1) and (2) are also defined to characterize the SIR. Assuming that the step discontinuity is minor for the SIR, it is shown that the spurious resonance frequency of the resonator can be controlled by the impedance ratio R. The normalized resonator length can be shorten when R is less than 1. The design of the SIR can be based on (3) where Y_i is the admittance of the resonator.



(a) (b)

Fig. 2 Conventional half-wavelength SIR structure. (a) $R < 1$ and (b) $R > 1$

$$R = \frac{Z_2}{Z_1} \tag{1}$$

$$L = \frac{2(\theta_1 + \theta_2)}{\pi} \tag{2}$$

$$Y_i = jY_2 \frac{2(R\tan\theta_1 + \tan\theta_2)(R - \tan\theta_1 \cdot \tan\theta_2)}{R(1-\tan^2\theta_1)(1-\tan^2\theta_2) - 2(1+R^2)\tan\theta_1 \cdot \tan\theta_2} \tag{3}$$

Thus, similar to [6], the SIR can be designed to minimize the microwave resonator at resonance frequency f_0 with control of spurious responses.

B. Spurious Response Suppression For Microstrip Transversal Bandpass Filter

Shown in Fig. 3 is the microstrip transversal filter when the SIR is used in the upper full-wavelength open-loop resonator. In the proposed design, half-wavelength open-loop resonator is kept in the lower resonator as in the conventional ones which determines the center frequency f_0 of the filter. For the upper open-loop resonator, two half-wavelength stepped-impedance resonators with $R < 1$ are designed to offer 180° phase shift to the lower signal path cancellation. As an example, a SIR bandpass filter centered at 2 GHz has been designed on the substrate with relative dielectric constant 3.38; substrate height 1.524 mm and impedance ratio $R = 0.55$. The dimensions of the filter are optimized and listed in Table I. The simulation results for the proposed filter plotted against the transfer characteristic of a conventional transversal bandpass filter with similar specification are shown in Fig. 4 and Fig. 5 [7].

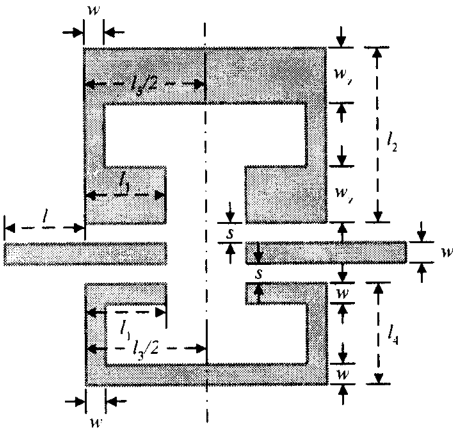


Fig. 3 Proposed microstrip stepped-impedance resonator transversal bandpass filter

TABLE I
Dimensions of the proposed stepped-impedance transversal filter in mm

w	1.7
w_z	4.7
l_1	10.90
l_2	23.36
l_3	23.90
l_4	5.30
l	3
S	0.2

In Fig. 4, it shows that both filters obtain the similar passband transfer characteristic @ 2 GHz with BW close to 100 MHz (5% FBW). A transmission zero is located at 1.95 GHz with 1.1 dB low passband insertion loss and 22 dB good matching. Fig. 5 shows the wideband frequency responses of the filters. As observed, the conventional microstrip transversal filter suffers from the 1st and 2nd spurious responses @ 3 GHz and 5 GHz respectively. By using stepped-impedance resonators, 31 dB and 18 dB spurious responses suppressions are observed at 3 GHz and 5 GHz respectively. Simultaneously, the filter size is also reduced by 15% according to the used impedance ratio.

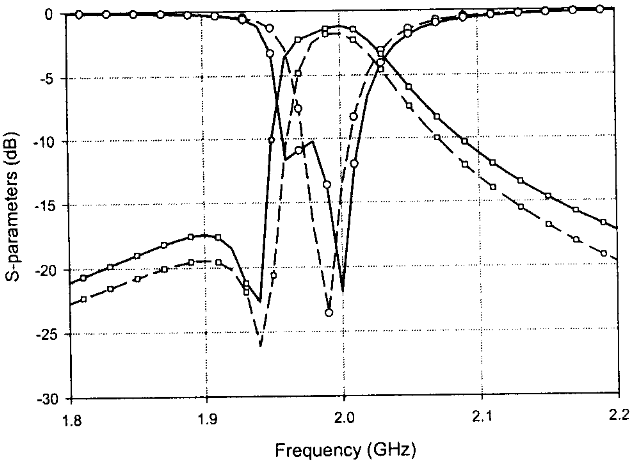


Fig. 4 Simulated in-band $|S_{11}|$ (O) and $|S_{21}|$ (☐) of the conventional (---) and proposed (—) microstrip transversal bandpass filter

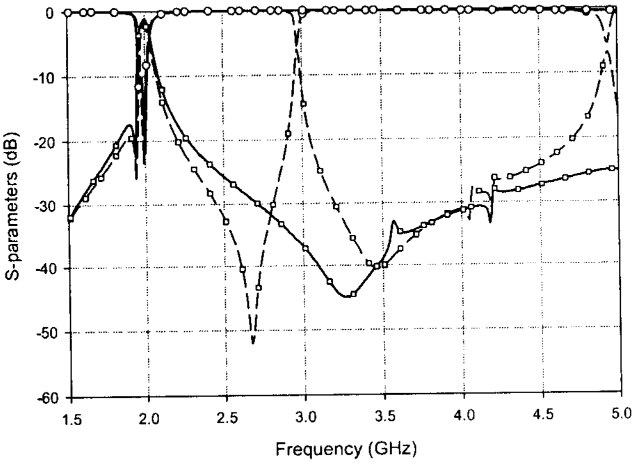


Fig. 5 Simulated wide-band $|S_{11}|$ (O) and $|S_{21}|$ (☐) of the conventional (---) and proposed (—) microstrip transversal bandpass filter

To investigate the spurious response suppression performance due to the used SIR as above, the proposed filter structure is simulated with impedance ratios *R* from 1 to 0.5 [7], and the results are summarized in Fig. 6. It is observed that the normalized spurious responses frequencies can be distanced to the higher frequency. The normalized ratio of the 1st spurious frequency to fundamental frequency is increased from 1.48 to 1.80 whilst 2nd spurious ratio ranges from 2.45 to 2.94.

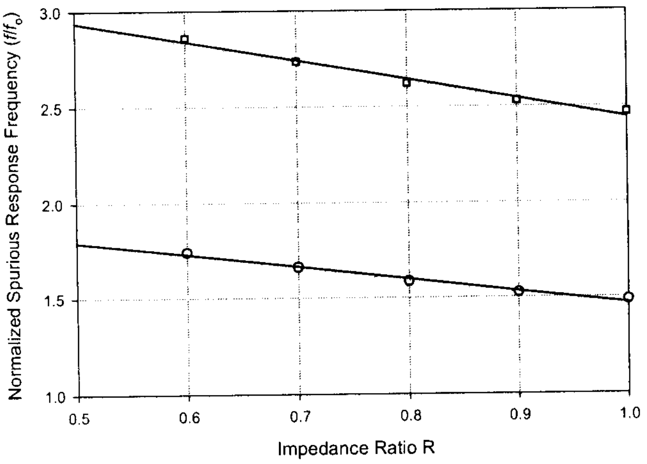


Fig. 6 Simulated 1st (O) and 2nd (☐) normalized spurious responses frequency against different impedance ratio *R*

III. MEASUREMENT RESULTS

In order to verify the proposed method, the conventional and proposed prototype filters centered @ 2 GHz with 5% FBW are designed and implemented using the RO4003 substrate with relative dielectric constant 3.38 and substrate thickness 1.524 mm. Both filters' measurements have been recorded in Fig. 7 and Fig. 8 showing a good agreement with the simulation results. In Fig. 7, it illustrated that these two filters report similar in-band characteristics. Both filters demonstrate that only 50 MHz frequency shift is observed at the frequency which is located at 1.95 GHz. Transmission zero due to the signal phase cancellation is reported at 1.9 GHz. Around 1.9 dB passband insertion loss as well as 24 dB matching are also measured at the center frequency.

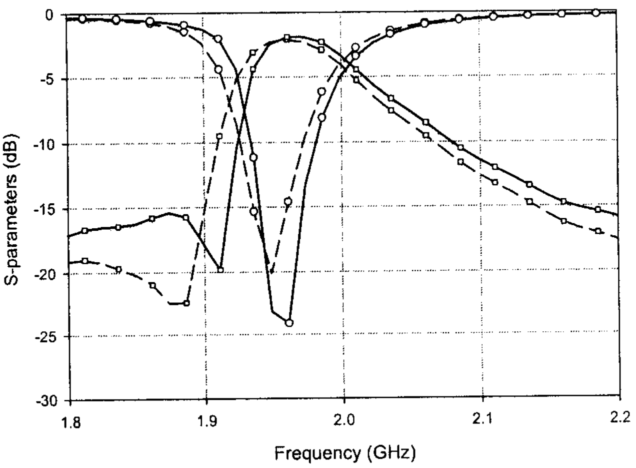


Fig. 7 (a) Measured in-band $|S_{11}|$ (O) and $|S_{21}|$ (□) of the conventional (---) and proposed (—) microstrip transversal bandpass filter

The stopband performance of the proposed filter outweighs the conventional structure by more than 30 dB and 18 dB suppressions at 3 GHz and 5 GHz as shown in Fig. 8. This yields spurious free stopband with around 30 dB rejection till 5 GHz. The proposed SIR transversal filter photo is shown in Fig. 9. This filter area is about 30 × 30.76 mm^2 and this yields about 15% size reduction when compared with that of the conventional ones.

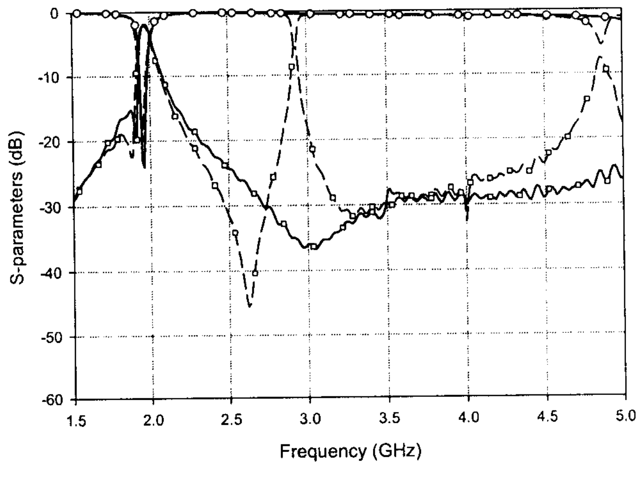


Fig. 8 Measured wide-band $|S_{11}|$ (O) and $|S_{21}|$ (□) of the conventional (---) and proposed (—) microstrip transversal bandpass filter

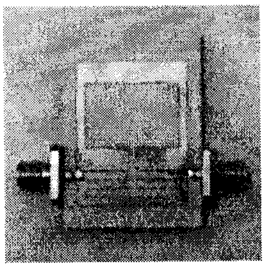


Fig. 9 Photo of the stepped-impedance transversal filter

IV. CONCLUSIONS

A novel miniaturized microstrip transversal bandpass filter with simultaneous size reduction and spurious responses suppression is proposed. By using the stepped-impedance resonator, the proposed filter was designed and fabricated with 15% size reduction compared to the conventional structure. Experimental results show that this SIR transversal filter structure not only preserves the basic passband characteristic but also offers 30 dB and 18 dB spurious responses suppressions to realize a wide stopband till 5 GHz.

ACKNOWLEDGMENT

The authors would like to thank the measurement support of Prof. K. W. Leung at Wireless Communications Research Centre of City University of Hong Kong.

REFERENCES

[1] J. S. Hong and M. J. Lancaster, "Cross-coupled microstrip hairpin-resonator filters," *IEEE Trans. Microwave Theory Tech.*, vol. 46, no. 1, pp. 118-122, January 1998.

[2] C. C. Yu and K. Chang, "Novel compact elliptic-function narrow-band bandpass filters using microstrip open-loop resonators with coupled and crossing lines," *IEEE Trans. Microwave Theory Tech.*, vol. 46, no. 7, pp. 952-958, July 1998.

[3] J. S. Hong and M. J. Lancaster, "Design of highly selective microstrip bandpass filters with a single pair of attenuation poles at finite frequencies," *IEEE Trans. Microwave Theory Tech.*, vol. 48, pp. 1098-1107, July 2000.

[4] U. Rosenberg and S. Amari, "Novel coupling schemes for microwave resonator filters," *IEEE Trans. Microwave Theory Tech.*, vol. 50, no. 12, pp. 2896-2902, December 2002.

[5] D. C. Rebenaque, F. Q. Pereira, J. P. García, A. A. Melcón and M. Guglielmi, "Two compact configurations for implementing transmission zeros in microstrip filters," *IEEE Microwave and Wireless Compon. Lett.*, vol. 14, no. 10, pp. 475-477, October 2004.

[6] M. Makimoto and S. Yamashita, "Bandpass filters using parallel coupled stripline stepped impedance resonators," *IEEE Trans. Microwave Theory Tech.*, vol 28, no. 12, pp. 1413-1417, December 1980.

[7] *IE3D*, Zeland Software Inc., Fremont, CA, March 2002.