The Design of a Compact, Wide Spurious-Suppression Bandwidth Bandpass Filter Using Stepped Impedance Resonators

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***Abstract* — We propose an analytical design for a microstrip broadband spurious-suppression filter. The proposed design uses every section of the transmission lines as both a coupling and a spurious suppression element, which creates a very compact, planar filter. While a traditional filter length is greater than the multiple of the quarter wavelength at the center passband frequency ($\lambda_g/4$), the proposed filter length is less than (order n^{th}+1)·$\lambda_g/8$. The filter's spurious response and physical dimension are controlled by the step impedance ratio (R) between two transmission line sections as a $\lambda_g/4$ resonator. The experimental result shows that, with R of 0.2, the out-of-band attenuation is greater than 40 dB; and the first spurious mode is shifted to more than 5 times the fundamental frequency. Moreover, it is the most compact planar filter design to date. The results also indicate a low in-band insertion loss.**

I. Introduction

Microwave filters are important components in most microwave applications. By carefully defining the signal band, filters limit the system noise and reduce the potential effect of out-of-band interference. Microwave filter design techniques have been subjects of active interest for several decades. Current filter applications present stringent requirements for size, cost, and ease of fabrication. Moreover, in many applications the out-of-band interference must be minimized [1]-[4]. Despite several techniques proposed to extend out-of-band rejection bandwidth, their designs require large area, large step in conductor width, or multiple layers.

Sanada *et al* [5] proposed the quarter-wave-length Step Impedance Resonator (SIR) filter design that SIRs are arranged in-line on a substrate. This arrangement relies on capacitive and inductive coupling at resonator ends; therefore the total filter size is long. Moreover, the capacitive coupling at the open-end section limits the maximum filter's bandwidth. Makimoto [4] proposed a coaxial $\lambda_g/4$ SIR cavity filter which can be designed analytically. However, using this technique, the filter is non-planar and can not be directly applied to the microstrip $\lambda_g/4$ SIR filter due to the complex coupling between each SIR. In addition, the microstrip line version was designed based on experiment which is conducted to determine the physical spacing between each SIR for a given SIR's coupling ratio. This paper proposes a microstrip $\lambda_g/4$ SIR filter design technique that simplifies the filter design procedure, while maintaining very compact, low-cost, and high spurious suppression response.

II. Quarter-wave SIR Filter Spurious Characteristics

The $\lambda_g/4$ SIR has a superior spurious response than other types of SIR. Its size is smaller and excites fewer spurious frequency modes. Fig. 1 shows a $\lambda_g/4$ SIR. According to Fig. 1, the input admittance at the open end side can be derived as follows:

$$Y_{in} = j \cdot Y_2 \frac{\tan(\theta_1)\tan(\theta_2) - R}{\tan(\theta_1) + R\tan(\theta_2)} \tag{1}$$

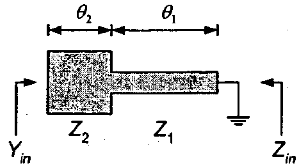


Fig. 1 Microstrip line SIR structure.

Where:

- θ_1 : an electrical length of the transmission line Z_1,
- θ_2 : an electrical length of the transmission line Z_2,
- Y_{in} : input admittance from the open end of the resonator,
- Z_{in} : input impedance from the grounded end,
- R : the stepped impedance ratio Z_2/Z_1.

The resonance condition is when Y_{in} equals to 0, as shown in (2).

$$R = \frac{Z_2}{Z_1} = \tan(\theta_1)\tan(\theta_2) \tag{2}$$

Since there is only one resonance conditions in (1) when the nominator of (1) equals 0, the number of spurious frequencies is minimized and shifted away from the fundamental frequency. From (2), it is found that the second resonance (or the first spurious) frequency is maximized when $\theta_1=\theta_2=\theta_0$ for all R that are greater than 0. Given this condition, all spurious frequencies can be expressed in terms of the fundamental frequency. The first four spurious modes are plotted as a function of R in Fig. 2.

From Fig. 2, spurious frequencies become higher as R becomes smaller. Moreover, R's relation to θ_0 results in reduction in SIR size with decreasing impedance ratio.

IV. Filter Design Procedures

To construct a $\lambda_g/4$ microstrip SIR filter, SIRs are parallel coupled as shown in Fig. 3. There are two canonical coupled line circuits on the SIR. The open end and the short-circuit end coupling sections are used one after another as shown in Fig 4 and Fig. 5 respectively. The couplers can be modeled as admittance and impedance invertors [6].

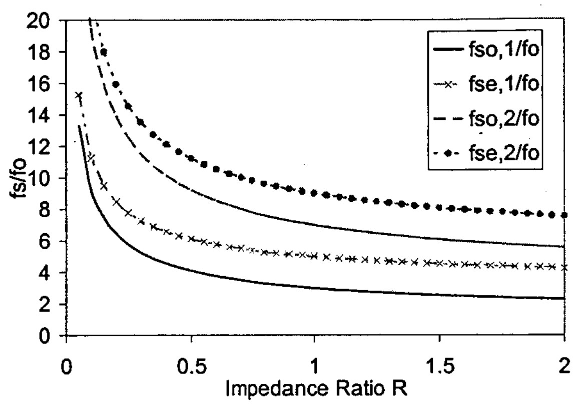


Fig. 2. Spurious resonance frequencies of the proposed SIR when $\theta_1=\theta_2=\theta_0$.

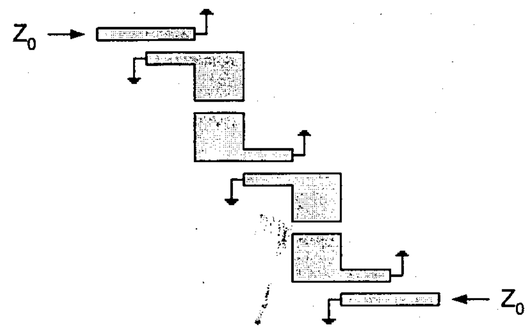


Fig. 3. The proposed parallel-coupled line $\lambda_g/4$ SIR band-pass filter structure with a single R value.

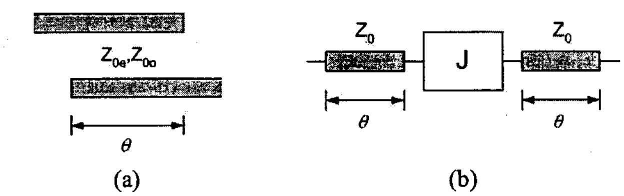


Fig. 4. The coupled line filter (a) and its equivalent circuit (b) with open-end termination.

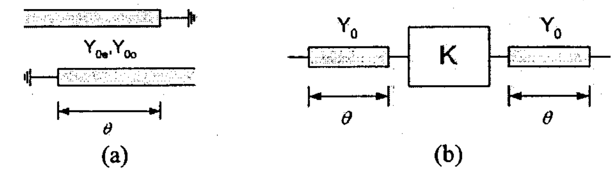


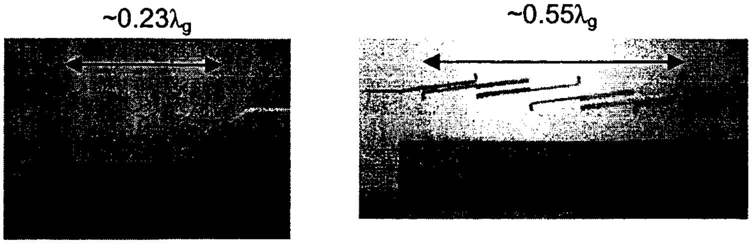
Fig. 5. The coupled line filter (a) and its equivalent circuit (b) with open-end termination.

In the design of N-stage band-pass filter, all SIRs have the same R in all stages as shown in Fig. 3. Since most applications require same impedance termination at the input and output, this type of filter is restricted to an even order filter response. The tapping technique at the end ports [2] can be used to realize any order of filter response, and to create nulls in the spurious band. This is beyond the scope of this paper and is considered a future extension.

V. Hardware Implementation and Experimental Results

Two bandpass filters are fabricated to demonstrate the proposed technique. The filters shown in Fig. 6 are prototype designs for passive radiometry systems. One (Type-I) has a step impedance ratio of 0.2 and the other (Type-II) has a step impedance ratio of 0.75. A 25-mil thick Roger's Duriod 6010 substrate with the dielectric constant of 10.2 is used. R is adjusted based on 50 Ohm characteristic impedance at the input/output terminal.

From Fig. 7 and 8, the average in-band insertion loss is 4.2 dB for R=0.2, and 3.0dB for R=0.75, respectively. The insertion loss of the bandpass filter with R=0.2 is lower than that with R=0.75 due to lower SIR's Q and higher coupling loss with R=0.2 than that with R=0.75. The stop-band attenuation is more than 40 dB up to $5f_0$ for R=0.2 and up to $3.4f_0$ for R=0.75. Total Type–I filter electrical length is $0.33\lambda_g$. It is approximately $0.23\lambda_g$ long from input to output port, the smallest 4^{th} order planar filter to date.



(a) (b)

Fig. 6. $\lambda_g/4$ SIR 4[th] order bandpass filters (a) Type I, R=0.2 (b) Type II, R=0.75

The spurious frequency matches with the calculated frequency with a few percent of error for the first few modes when R=0.75, and becomes less accurate at high frequency. This is due to parasitics of vias and open sections. Not only vias, open and step discontinuities cause in-band microstrip line length adjustment, but also variation over the broad frequency range. They also cause an unequal θ_1 and θ_2, which shift the spurious frequencies from their optimum frequency condition where $\theta_1=\theta_2=\theta_0$. In addition to the existing spurs, they can be excited due to a step in conductor width. A step in conductor width causes gradual change in discontinuity parasitics at the transition frequency of traveling wave mode in the microstrip line, which excites spurious frequency resonant modes [7]. This becomes a concern in a filter with small R since the first spurious mode can be dominated by the spur caused by this factor.

VI. Conclusion

We propose a new microstrip filter design technique that simplifies and provides analytical guidance for suppression filter design. Using only a single technique, the spurious rejection bandwidth extends significantly. Moreover, the resultant microstrip coupled resonator filter footprint is the smallest planar filter to date.

References

[1] C. Quendo, E. Rius, C. Person, and M Ney, "Integration of Optimized Low-Pass Filters in a Bandpass Filter for Out-of-Band Improvement," *IEEE Trans. Microwave Theory & Tech.*, Vol. 49, No. 12, 2001, pp.2376-2383.

[2] J. Kuo, E. Shih, "Microstrip Stepped Impedance Resonator Bandpass Filter with an Extended Optimal Rejection Bandwidth," *IEEE Trans. Microwave Theory & Tech.*, Vol. 51, No. 5, 2003, pp. 1554-1558.

[3] M. Makimoto and S. Yamashita, "Bandpass Filters Using Parallel Coupled Stripline Stepped Impedance Resonators," *IEEE Trans. Microwave Theory & Tech.*, Vol. 28, No. 12, 1980, pp. 1413-1417.

[4] M. Makimoto, and S. Yamashita, *Microwave Resonators and Filters for Wireless Communications: Theory, Design and Application*, Springer-Verlag Berlin Heidelberg, New York, 2001.

[5] A. Sanada, H. Takehara, and I. Awai, " λg/4 Stepped-Impedance Resonator Bandpass Filters Fabricated on Coplanar Waveguide," *IEEE MTT-S Digest*, pp. 385-388, 2002.

[6] G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Network, and Coupling Structures*, Norwood, MA: Artech House, 1980.

[7] R. K. Hoffmann, *Handbook of Microwave Integrated Circuits, Norwood*, MA: Artech House, 1987, Chapter 10, pp.272-282.

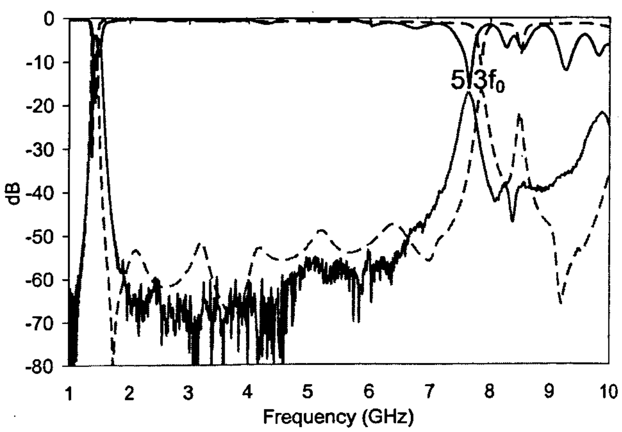


Fig. 7. EM Simulated (dash line) and Measured (solid line) S_{21} and S_{11}(in dB) of the Type-I (R=0.2) filter response

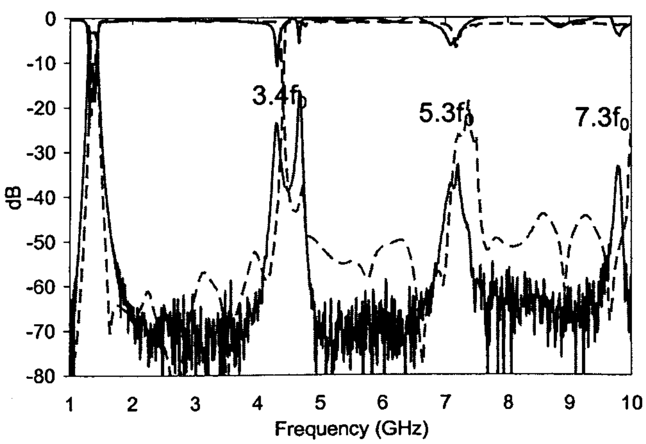


Fig. 8. EM Simulated (dash line) and Measured (solid line) S_{21} and S_{11} (in dB) of the Type-II (R=0.75) filter response