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Tunable Combline Bandpass Filter Using Cross-Coupled Stepped-Impedance Resonators with Enhanced Characteristics

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Abstract

This paper proposes a tunable combline bandpass filter with high selectivity, constant bandwidth, and good stopband performances. A filter with these characteristics is obtained by applying cross-coupling to the conventional combline bandpass filter using stepped-impedance resonators(SIRs). For high selectivity and constant bandwidth, cross-coupling is utilized and the SIR configuration is used for enhanced stopband performances. The proposed combline tunable bandpass filter with 5 % of fractional bandwidth at 1.6 GHz was fabricated and tested. The measured results showed 11.6 % tunability with constant bandwidth, high selectivity and enhanced stopband characteristics.

Key words : Combline Filters, Stepped-Impedance Resonator, Cross-Coupling, Microstrip Filters, Transmission Zeros, Tunable Filters.

Ⅰ. Introduction

The recent convergence of multiband communication systems into a compact mobile terminal has required tunable bandpass filters, in which the characteristics of conventional filters, such as constant bandwidth, high selectivity, and good stopband performances, must be included.

For enhanced selectivity in a tunable bandpass filter, structures using an open stub[1] or source/load-multiresonator coupling[2] were proposed. For enhanced stopband performances, a tunable filter using a lowpass type resonator was proposed[3]. Moreover, structures using stepped-impedance resonators(SIRs)[4] or coupling-controlled varactors[5] were proposed for enhanced selectivity in tunable filters. In tunable filters, all three methods can be further enhanced by combining them, but a tunable bandpass filter can be more easily enhanced by using cross-coupled SIRs. Therefore, this paper proposes a microstrip tunable combline bandpass filter using cross-coupled SIRs as shown in Fig. 1.

It is a well-known fact that bandpass filters have high selectivity and improved stopband performances in cases cross-coupled structure as well as SIRs are applied[6]~[8]. However, it is difficult to generate cross-coupling in combline tunable bandpass filters by applying the previously suggested coupling structures in [6] and [7]. This is because varactors and their bias circuits usually block the cross-coupling in their structures. As an alternative, the proposed filter in Fig. 1 applies the filter configuration in [9], in which there is no cross-coupling structure. The coupling structure of the filter configuration in [9] and the reason why transmission zeros are generated by the coupling structure, based on the Darlington procedures, is discussed in section Ⅱ-A[10]. In section II-B, the reason for being able to constantly maintain the bandwidth of the tunable filter in the proposed filter structure in Fig. 1, is explained. In section Ⅲ, simulated and experimental results of the proposed filter are shown.

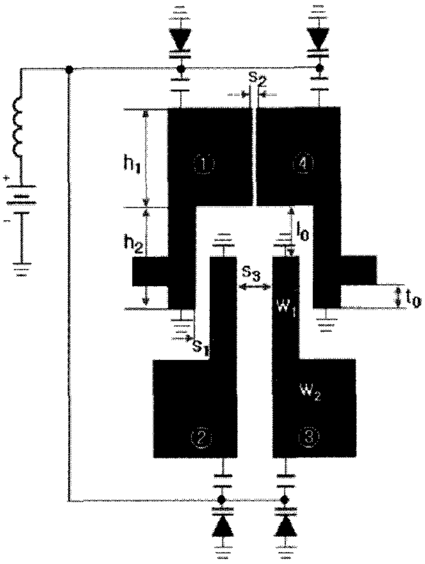

Fig. 1. Physical layout of the proposed tunable combline bandpass filter(s_1=0.975 mm, s_2=0.35 mm, s_3=1.5 mm, h_1=h_2=8 mm, l_0=1.6 mm, t_0=1.8 mm, w_1=1.25 mm, w_2=3.2 mm).

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Ⅱ. Analysis of the Proposed Filter Configuration

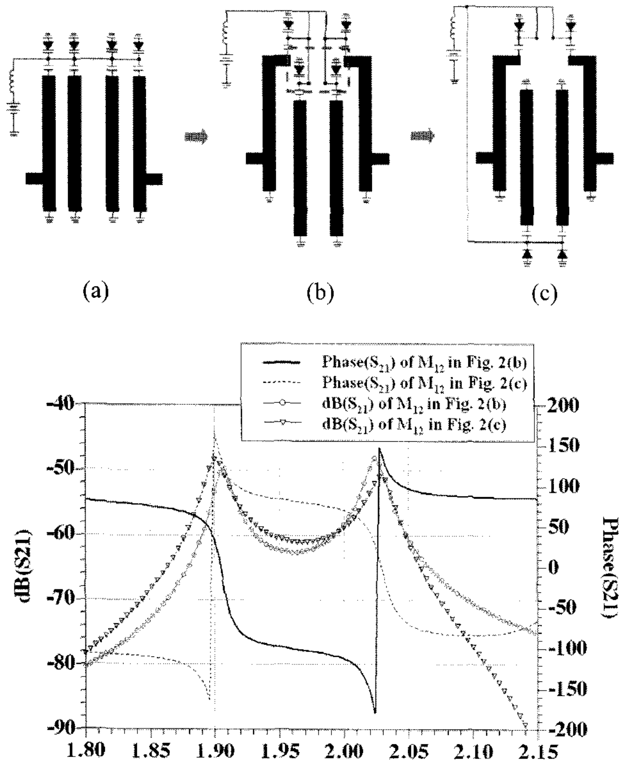
2-1 The Analysis of the Proposed Cross-Coupling Structure

As shown in Fig. 2(b), varactors and bias-lines block the cross-coupling between the 1st and 4th resonators. However, the blocks can be removed by applying the proposed structure in [9] as shown in Fig. 2(c). Fig. 2(d) shows that the sign of M_{12} in Fig. 2(b) is opposite to that in Fig. 2(c). Therefore, the coupling matrix of Fig. 2(c) is expressed as (1) in contrast to that of [6].

$$[M]=\begin{bmatrix} 0 & -|M_{12}| & 0 & -|M_{14}| \\ -|M_{12}| & 0 & |M_{23}| & 0 \\ 0 & |M_{23}| & 0 & -|M_{12}| \\ -|M_{14}| & 0 & -|M_{12}| & 0 \end{bmatrix} \tag{1}$$

The matrix of (1) shows that M_{12} and M_{14} have the same sign and M_{23} has only the opposite sign.

However, as is shown by following analysis, the matrix of Fig. 2(c) has the same transfer function as that of Fig. 2(b).


(a) (b) (c)

(d)

Fig. 2. (a) The structure of the conventional combline bandpass filter. (b) The structure applying the coupling matrix in [6] to Fig. 2(a). (c) The structure applying the filter configuration in [8] to Fig. 2(a). (d) Simulated resonant responses of M_{12} in Fig. 2(b) and Fig. 2(c).

According to [10], the poles and the residues of the even-mode admittance of the filter in Fig. 2(b) are expressed as

$$\lambda_{e1,2}=\frac{M_{23}-M_{14}\pm\sqrt{(M_{14}-M_{23})^2+4(M_{23}M_{14}+M_{12}^2)}}{2} \tag{2}$$

$$M_{12}=-\lambda_{e1}T_{e11}T_{e21}-\lambda_{e2}T_{e12}T_{e22} \tag{3}$$

$$K_{e1}=\sqrt{2}T_{e11}^2,\ K_{e2}=\sqrt{2}T_{e12}^2 \tag{4}$$

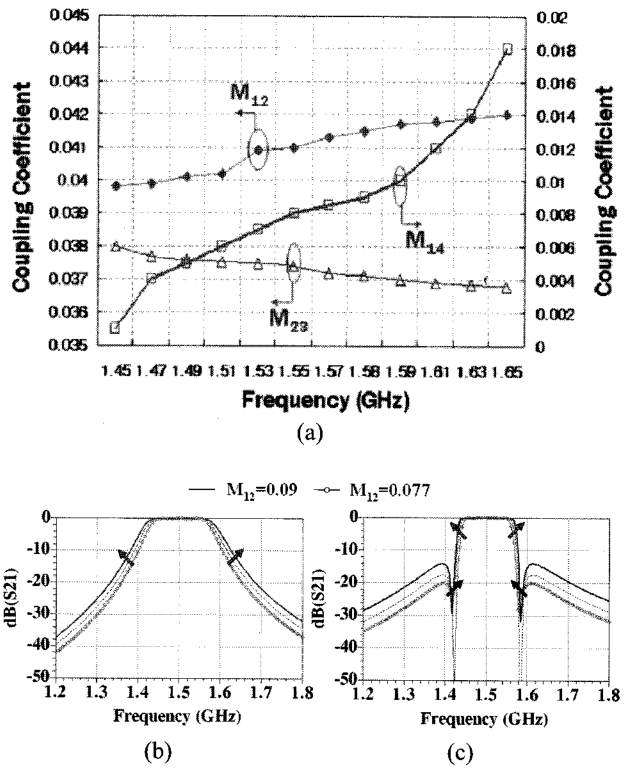
In (1), poles λ_{e1} and λ_{e2} are composed of M_{12}, M_{14}, and M_{23}. In (2), M_{12} is composed of elements of the even-mode orthogonal-transformation matrix (T_{e11}, T_{e12}, T_{e21} and T_{e22}) and $\lambda_{e1,2}$. Moreover, residues K_{e1} and K_{e2} in (3) are calculated from T_{e11} and T_{e12}. In (1), the sign of M_{12} does not affect λ_{e1} and λ_{e2}. Also, the variation of the signs of T_{e11} and T_{e12} by the sign of M_{12} does not affect K_{e1} and K_{e2} in (3). Therefore, the transfer functions in Fig. 2(b) and (c) are identical because even-mode admittance does not change by the variation of the sign of M_{12}. As a result, the filter configuration in Fig. 2(c) has the transmission zeros as the structure in [6], as well as eliminating the blockage of varactors and bias-lines.

2-2 The Cross-Coupled Method for Constant Bandwidth of Tunable Filter

For constant tunable filter bandwidth, coupling coefficient of adjacent resonators should be in an inverse proportion to frequency[4]. As shown in Fig. 3(a), M_{23} can be inversely proportional to the frequency by using the proposed method in [4]. However, for M_{12}, being in inverse proportion to the frequency is difficult, because the arrangement of the 1st and 2nd resonators is different from that in [4]. However, the bandwidth of tunable filters can be constantly maintained in the event that M_{14} are also in proportion to the frequency as shown in Fig. 3(a). When the coupling coefficient of adjacent resonators increases, the bandwidth increases 140 MHz to 188 MHz in Fig. 3(b) and 135 MHz to 152 MHz in Fig. 3(c), respectively. Because transmission zeros get nearer to the passband of the filter by the increase of the cross-coupling coefficient, the increase of bandwidth by M_{12} is suppressed. Therefore, the bandwidth of the proposed filter in Fig. 1 can be constantly maintained.

Ⅲ. Simulated and Measured Results

The proposed filter was designed with 5 % of fractional bandwidth at 1.6 GHz. The varactor used was



(a)

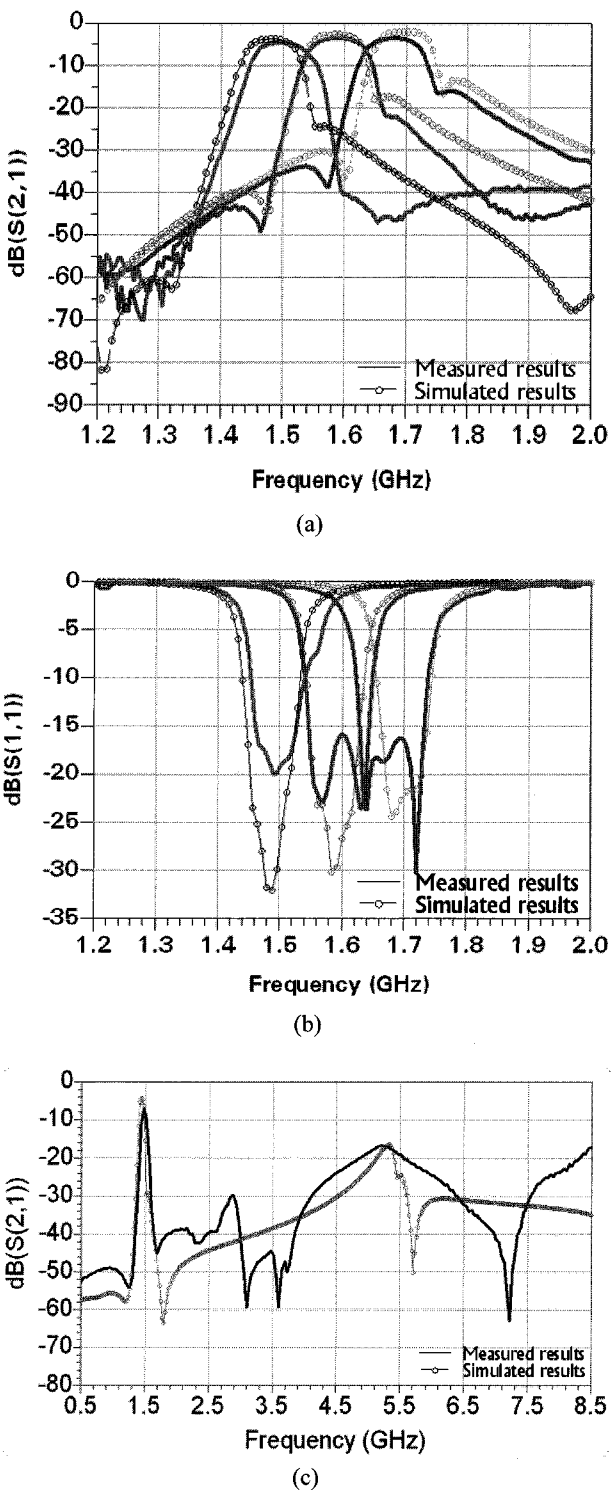
(b) (c)

Fig. 3. (a) Simulated results of coupling coefficients in the proposed filter of Fig. 1. (b) Simulated results of the filter without the cross coupling. (c) Simulated results of the filter with the cross coupling.

1SV277(Toshiba), and the substrate used in the design was RO3003(Rogers) with a 20 mil thickness. The bias voltage of the varactors was up to 5 V. As shown in Fig. 4, the measured results showed good agreement with simulated results. As shown in Fig. 4(a), the center-frequency tunable range was 1.5~1.68 GHz and the 3 dB bandwidth of the filter was 85 MHz (@ 1.5 GHz)~89 MHz(@ 1.68 GHz). As shown in Fig. 4(c), the stopband rejection was greater than 18 dB up to 8.5 GHz. The insertion and return losses were 6 dB and 15 dB, respectively. The P1 dB of the filter input was 13 dBm.

Ⅳ. Conclusion

This paper proposes a tunable combline bandpass filter using a cross-coupled stepped-impedance resonator. For enhanced selectivity, the proposed tunable filter applies the cross-coupled structure in [9]. The structure analyzed by Darlington's procedure has transmission zeros near the passband of the filter. Moreover, the bandwidth of the filter is maintained constantly by using a cross-coupled structure, because the increase of bandwidth by the coupling between adjacent resonators is suppressed by the cross-coupling. For enhanced stopband performances, the SIR configuration is used. The measured results showed very good agreement with simulated ones.



(a)

(b)

(c)

Fig. 4. (a) Simulated and measured results of S_{21} of the proposed filter. (b) Simulated and measured results of S_{11} of the proposed filter. (c) Simulated and measured results of stop-band performance of the proposed filter.

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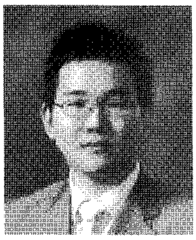

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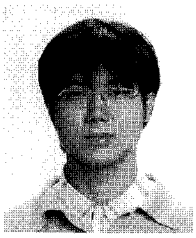

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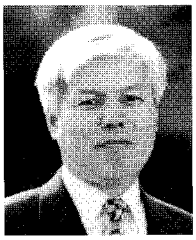

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