Design of a 180-Degree Hybrid with Chebyshev Filtering Response Using Coupled Resonators

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***Abstract* — A novel 180° hybrid with third-order Chebyshev filtering response is proposed in this paper. The coupling coefficients and the external quality factors can be synthesized from the theory of coupled resonator filter. The proposed idea is verified with experimental results, with good agreement between simulation and measurement. Comparing to the conventional rat-race coupler, 80% size reduction and filtering function with high frequency selectivity has been exhibited in the proposed structure.**

***Index Terms* — bandpass filter, Chebyshev response, circuit synthesis method, size reduction, 180° hybrid.**

I. Introduction

The 180° hybrid is known as one of the core components in many RF modules such as balanced amplifier, balanced mixer, and antenna feeding network [1]. It is regarded as an in-phase or out-of-phase power divider/combiner. The 180° hybrid can be fabricated in several forms, among which the rat-race coupler is most popularly used. However, the conventional rat-race coupler composed of one 3λ/4- and three λ/4-line sections occupies large circuit size [2]. On the other hand, in order to ensure frequency selectivity, additional bandpass filters are often required, resulting in an even larger size.

To overcome this problem, the concept of combining a 180° hybrid and a bandpass filter into a single device is proposed [4]-[6]. In [4] and [5], the couplings between resonators substitute for the quarter-wavelength lines of a 180° hybrid. A 180° hybrid with bandpass response can then be transformed into a coupled-resonator network. Furthermore, the circuit size will be more compact if miniaturized resonators are used. In [6], in order to achieve a high selectivity, each resonator of the coupling structure in [4] and [5] is replaced by a dual-mode stub-loaded resonator.

In this paper, the purposes of transforming a 180° hybrid with bandpass response into a coupled-resonator network will be extended for the desired filtering shape and frequency selectivity. The proposed new coupling structure of a 180° hybrid with a third-order Chebyshev filtering response as well as the synthesis of its coupling coefficients and external quality factors will be described in section II. The implementation of the structure with both simulated and measured results will be demonstrated in section III. A few concluding remarks will also be given in the last section.

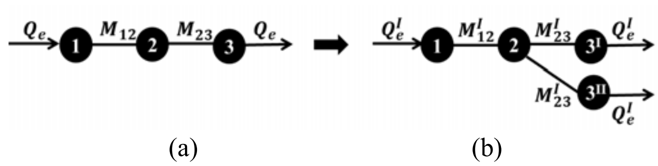
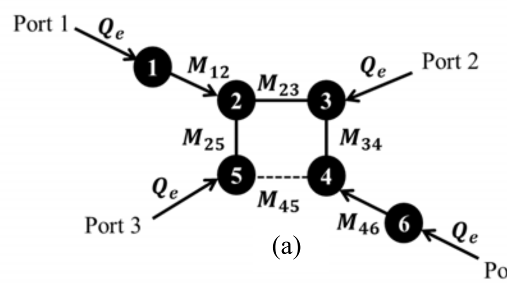


Fig. 1. (a) Coupling structure of a third-order Chebyshev filter. (b) Dividing the coupling after the second resonator.



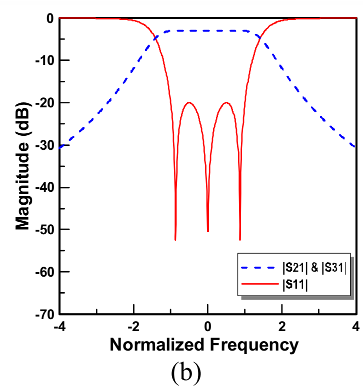


Fig. 2. (a) Coupling structure and (b) normalized frequency response of a 3 dB 180° hybrid with third-order Chebyshev filtering response (Port 4 is isolated).

II. Synthesis of Coupling Structure

As depicted in Fig. 1, the idea is to divide coupling path after the second resonator of a third-order Chebyshev filter. Considering the equal-split (3 dB) case, the resonators 3^{I} and 3^{II} in Fig. 1(b) are identical. In order to satisfy the return loss

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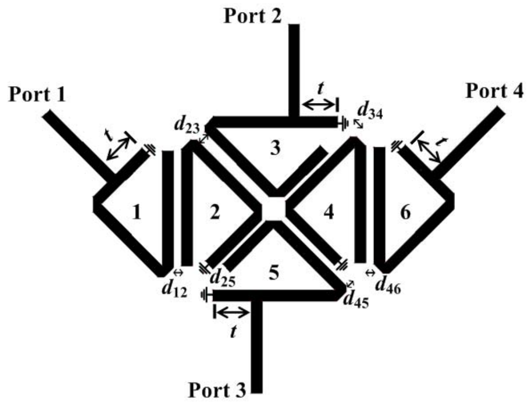


Fig. 3. Schematic layout of the proposed 180° filtering hybrid.

of third-order Chebyshev response, the structure in Fig. 1 can be analyzed using the coupled resonator theory in [3]. The relationships of the associated parameters between Fig. 1(a) and (b) can then be derived as follows,

$$\begin{aligned} M_{12}^{I} &= M_{12}, \\ M_{23}^{I} &= \frac{1}{\sqrt{2}} M_{23}, \\ Q_e^{I} &= Q_e. \end{aligned} \tag{1}$$

where the coupling coefficients and external quality factors of the filter in Fig. 1(a) can be calculated by [3].

By extending the concept of transforming a 180° hybrid into a coupled-resonator network investigated in [4]-[6], the coupling structure of 3 dB 180° hybrid with third-order Chebyshev filtering response can be proposed in Fig. 2(a). With the coupling coefficients and external quality factors calculated by (1) the normalized frequency response of this structure is shown in Fig. 2(b). It is worth mentioning that the coupling between resonators 4 and 5, M_{45} should be out of phase with other couplings, M_{12}, M_{23}, M_{25}, M_{34}, and M_{46}.

III. Experimental Verification

To verify the aforementioned idea, the proposed 180° hybrid with third-order Chebyshev filtering response is designed with a fractional bandwidth (FBW) 3.5% at a center frequency f_c = 1.5 GHz. A third-order Chebyshev lowpass prototype with a passband ripple of 0.04 dB is chosen. The corresponding coupling coefficients and external quality factors can then be found as $M_{12} = M_{46} = 0.036$, $M_{23} = M_{25} = M_{34} = -M_{45} = 0.026$ and $Q_e = 24.33$.

Figure 3 is the schematic layout for the proposed 180° filtering hybrid realization by quarter-wavelength microstrip resonators. All coupling coefficients are achieved by mixed coupling. By properly arranging the resonators, the coupling M_{45} can be out of phase with the others [3]. Note that the resonators are folded for further reducing the circuit size.

The circuit is designed and fabricated on a Rogers RO4003 substrate with a relative dielectric constant of 3.38, a thickness of 0.508 mm, and a loss tangent of 0.002. Full-wave simulator

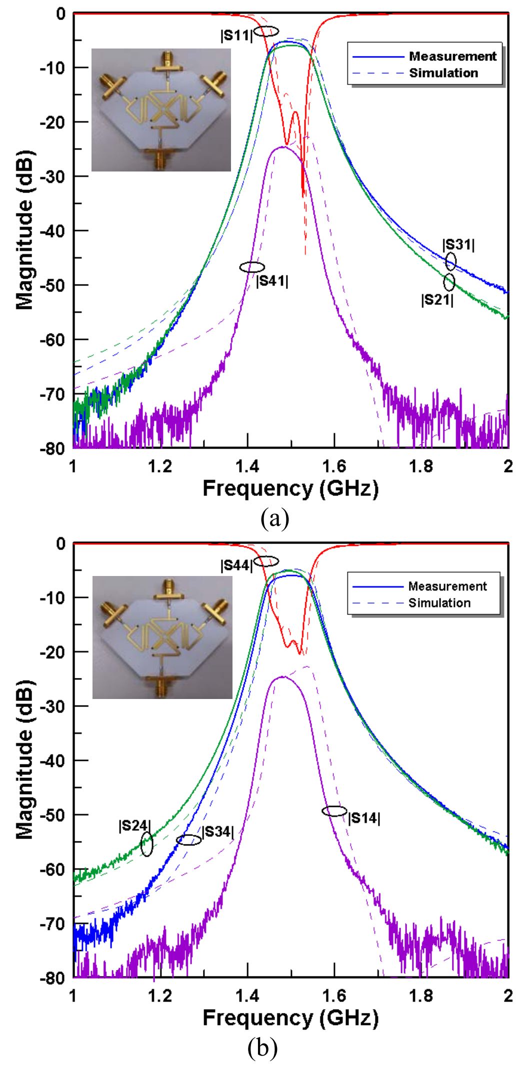
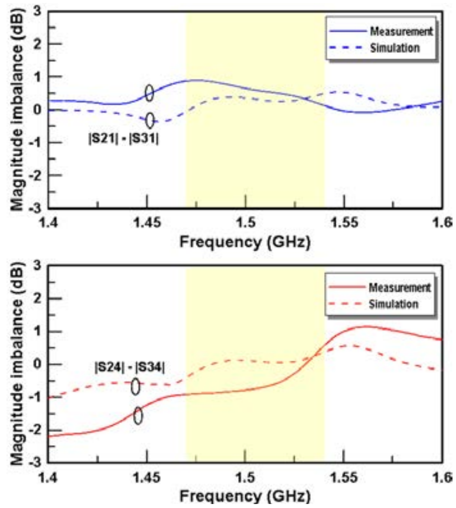


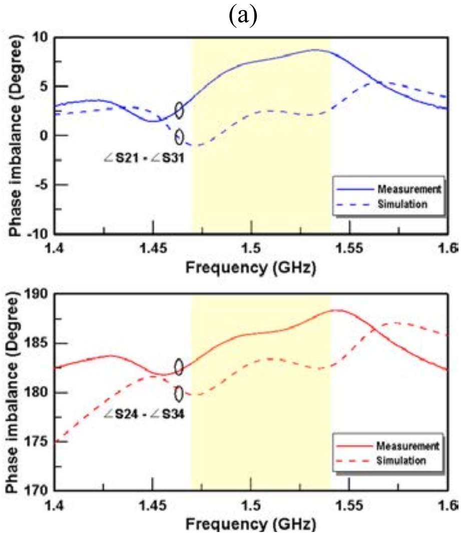
Fig. 4. Simulated and measured results of the proposed filtering 180° hybrid. (a) Port 1 (sum port) and (b) Port 4 (difference port) S-parameters.

IE3D has been used to extract the coupling coefficients and external quality factors by controlling the distance d between adjacent resonators and the tapped position t of the feeding lines, respectively. Realizable geometric parameters have been obtained as $d_{12} = d_{46} = 0.67$ mm, $d_{23} = 0.93$ mm, $d_{25} = 0.13$ mm, $d_{34} = 0.19$ mm, $d_{45} = 0.39$ mm, and $t = 4.1$ mm. In addition, the circuit size is 38.2 mm × 19.6 mm, i.e. 0.29 × 0.15 λ_g^2, where λ_g is the guided wavelength on the substrate at the center frequency of the passband. Compared to the conventional rat-race coupler, the proposed one can achieve 80% size reduction.

The proposed 180° hybrid with a third-order Chebyshev filtering response is measured on an Agilent N5222A network analyzer. Figures 4 and 5 show the simulated and measured results. The photograph of the fabricated 180° hybrid is also shown in the inset of Fig. 4. In Figs. 4(a) and (b), the measured return loss $|S_{11}|$ and $|S_{44}|$ are better than 15 dB in the



(a)



(b)

Fig. 5. Simulated and measured results of the proposed filtering 180° hybrid. (a) magnitude and (b) phase imbalance.

frequency range from 1.47 to 1.54 GHz. At the center frequency f_c = 1.5 GHz, the measured insertion losses $|S_{21}|$, $|S_{31}|$, $|S_{24}|$, and $|S_{34}|$ are 2.9, 2.3, 2.1, and 2.9 dB, respectively, in addition to the intrinsic 3 dB insertion loss of the 180° hybrid. This is mainly attributed to the insertion loss of the coupled-resonator configuration for the bandpass response. Also, the measured isolation ($|S_{41}|$ and $|S_{14}|$) are about 25 dB.

The simulated and measured magnitude- and phase-imbalance are shown in Figs. 5 (a) and (b), respectively. When considering a wave incident at sum port (port1), the measured magnitude imbalance is between 0.14 to 0.90 dB and the phase imbalance is from 3.79° to 8.71°. For a wave incident at difference port (port4), the measured magnitude imbalance is between -0.91 to 0.56 dB and the phase imbalance is from 182.99° to 188.27°.

Figure 6 shows the insertion loss of the proposed hybrid and Chebyshev responses of different orders using the same lossy resonators with unloaded quality factors Q_u = 150. It is worth

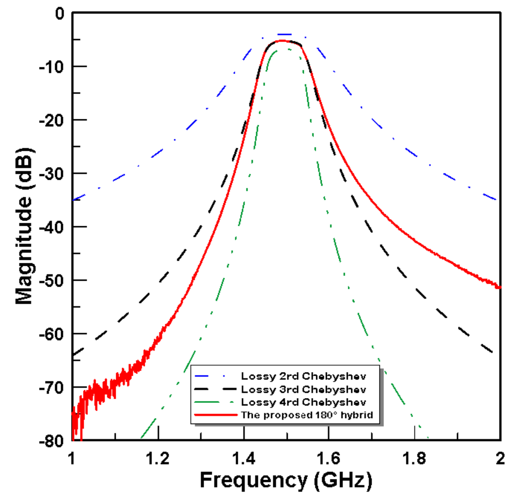


Fig. 6. Comparison of different order Chebyshev responses.

noting that the proposed one can be concluded a third-order Chebyshev response.

IV. Conclusion

In this paper, a novel and simple method using coupled-resonator configuration to design a 180° hybrid with a third-order Chebyshev filtering response has been presented. Good agreement is achieved between simulation and measurement. The proposed 180° hybrid exhibits third-order Chebyshev response (high selectivity), 80% size reduction, low phase imbalance (3.79° ~ 8.71°), and magnitude imbalance (0.14 ~ 0.9 dB). Also, the experimental results verify the feasibility of the proposed idea.

Acknowledgement

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