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A High-Performance Dual-Mode Filtering Power Divider with Simple Layout

Gang Zhang, Xuedao Wang, Jia-Sheng Hong, *Fellow, IEEE*, and Yang Zhao

***Abstract*— This letter presents a simple microstrip dual-mode filtering power divider (FPD) with sharp frequency selectivity and good in-band isolation. A new topology is proposed to integrate only a single resonator and a resistor to realize the dual functions of the power division and filtering. In order to further improve its frequency selectivity and obtain wide upper stopband, three open-ended stubs are integrated into the input and outputs of the FPD, respectively. The presented FPD stands out from those in the literature, by both improved performance and simple design layout. For validation, a prototype FPD operating at 2.2 GHz with 3-dB fractional bandwidth (FBW) of 18.2% is designed and fabricated. Experimental results agree well with the simulated ones. Results indicate that the new FPD exhibits better than 32 dB in-band isolation along with 24 dB harmonic suppression up to 6.28 GHz (2.85 f_0).**

***Index Terms* — Filtering power divider, dual-mode resonator, good isolation.**

I. INTRODUCTION

POWER dividers (PDs) and bandpass filters (BPFs) are the essential passive components in modern wireless communication systems. Conventionally, these two devices occupy an excessive area in RF front-end system. To tackle this problem, one effective approach is to integrated the PD and an BPF into a single component, namely, filtering power divider (FPD) to realize the both functions of specified power division/combination and frequency selectivity simultaneously. In recent years, much effort has been made on the exploration of the high performance FPDs in [1]-[5].

Typically, one FPD is presented in [1] by replacing quarter-wavelength transformers in the conventional Wilkinson PD with two filtering structures. However, the designed circuit exhibits poor insertion loss and isolation between the output ports. In order to achieve good in-band isolation and wide stopband, the folded quarter-wavelength resonators are applied in a mixed coupling scheme [2]. Unfortunately, the coupling is not easily controlled. In [3], a coupled-line type filtering power divider is proposed with two-pole bandpass response. Nevertheless, it needs to make extra efforts to improve the frequency selectivity. In addition, a dual-mode FPD utilizing a pair of E-shaped resonators in asymmetric coupling structure is presented in [4] to achieve improved performance. However, the design configuration is not flexible. Apart from these designs listed above, FPDs utilizing substrate integrated waveguide resonant cavity [5] have also been reported so far. It should be mentioned that, all the aforementioned FPD designs require two-way double resonators for its filtering response and power division at the same time, always resulting in a relative large layout and complex design. To the best of our knowledge, there are few reports on the design of microstrip FPD based on only a single open-type resonator.

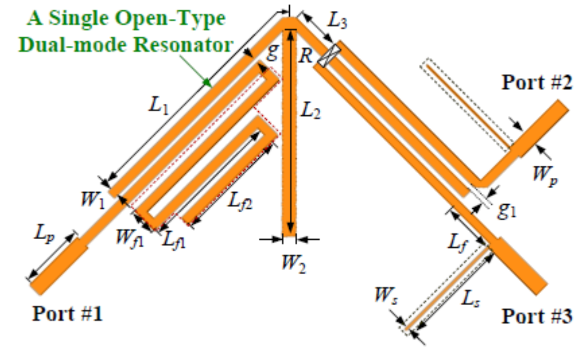

Fig. 1. Layout of the proposed dual-mode FPD.

This letter is aimed to present a new and simple design for dual-mode FPD, which utilizes only a single open-type T-shaped resonator and a resistor achieving sharp frequency selectivity and high in-band isolation. The resistor is added between the two output lines to get good isolation performance of the FPD. In addition, three open-ended stubs are integrated into the input and outputs to generate multiple transmission zeros, improving the frequency selectivity and harmonic suppression. For demonstration, a prototype dual-mode FPD is implemented. Both simulated and measured results are in good agreement, which validates the design concept.

II. ANALYSIS AND DESIGN

A. Configuration of the proposed FPD

Fig.1 shows the configuration of the proposed dual-mode FPD, which consists of only a single T-shaped resonator, one isolating resistor, one stub attached microstrip input line (Port #1) as well as two stub-loaded output coupled lines (Port #2, 3). As observed, the couplings between output lines and the resonator exhibit the same amplitude and in-phase property since the two output lines are symmetrically located at both sides of the right arm of the resonator. Meanwhile, the resistor is introduced between the two output lines to enhance the port-to-port isolation. Detailed analysis is given as follows.

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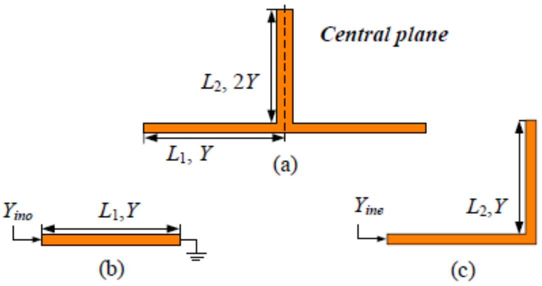


Fig. 2. (a) T-shaped dual-mode resonator, (b) equivalent circuit model of odd-mode bisection, (c) equivalent circuit model of even-mode bisection.

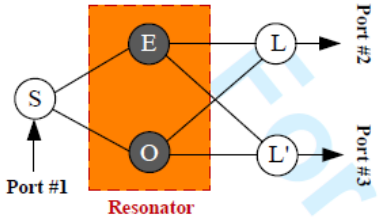


Fig. 3. Coupling scheme of the proposed FPD without *R* and integrated stubs.

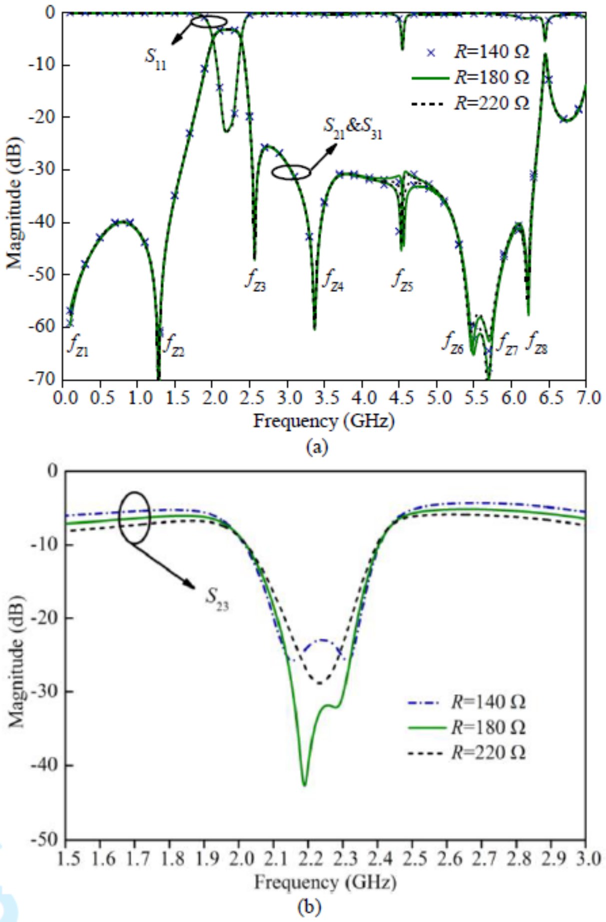
B. *Analysis and design of the proposed FPD*

In this work, the T-shaped dual-mode resonator as described in Fig. 2(a) is adopted to obtain the desired frequency response. As the resonator is symmetrical with respect to its central plane, the odd- and even-mode analysis method can be utilized to analyze its resonance property [6]. Fig. 2(b)-(c) depict the equivalent circuit models of its half symmetrical bisections. Accordingly, the working frequencies of the resonator can be solved as,

$$f_{odd}=c\big/(4L_1\sqrt{\varepsilon_e})\quad f_{even}=c\big/[2(L_1+L_2)\sqrt{\varepsilon_e}]\tag{1}$$

where c is the light speed in free space, and ε_e denotes the effective dielectric constant of the substrate. In this design, the substrate is selected as Rogers RO4003C, with a relative dielectric constant of 3.38, thickness of 0.508 mm, and loss tangent of 0.0027.

Fig. 3 gives the corresponding coupling scheme of the FPD, where E and O represent the even and odd modes of the resonator which compose the dual-mode filtering response. Intuitively, the input signal excited at Port #1 firstly propagates along the input transmission line, then will be coupled to the dual-mode resonator, and finally equally split and coupled to the two output lines at output ports, i.e., Port #2 and Port #3, respectively. Thus, the coupling coefficients in Fig. 3 satisfy the relationship of $M_{EL}=M_{EL'}$ and $M_{OL}=M_{OL'}$. It is mentioned that the isolation resistor (*R*) has not yet been considered in Fig. 3 since it hardly affects the dual-mode filtering power division responses due to its symmetry property [2]. As the coupling strength is altered, the filtering responses will be changed. Therefore, once the filtering response is specified, the port-to-port isolation will be mainly fulfilled by changing the resistance of the *R*.



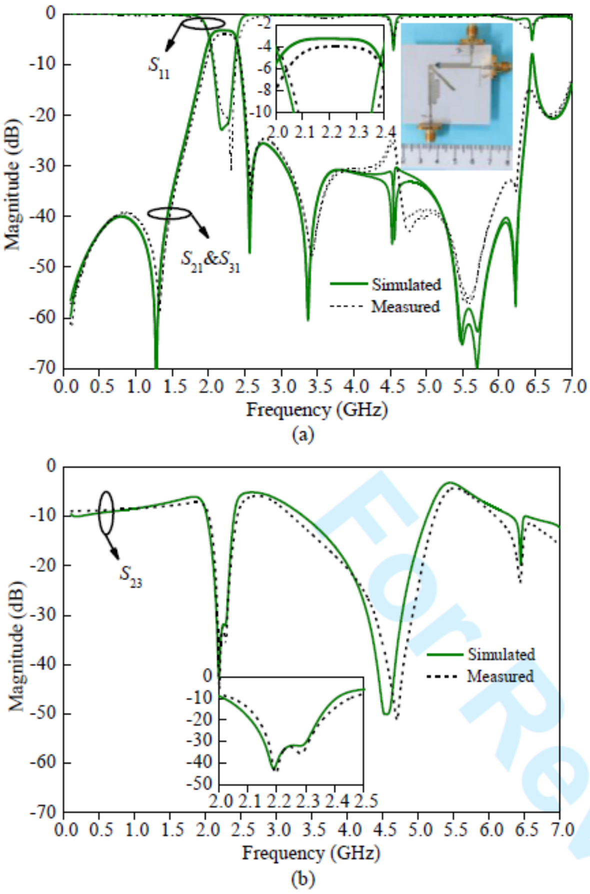
(a)

(b)

Fig. 4. Simulated *S*-parameters with varied *R* at central frequency f_0=2.2 GHz. (a) Magnitudes of S_{11}, S_{21}, and S_{31}, (b) magnitudes of S_{23}.

Herein, a prototype FPD with the center frequency of f_0=2.2 GHz and desired 3-dB fractional bandwidth (FBW) of 18.5% is designed for an example. The design procedure is summarized as the following steps. Firstly, according to (1), calculate the parameters (L_1=22.6 mm and L_2 =17.6 mm) of the T-shaped resonator with the derived frequencies f_{odd}= 2.08 GHz and f_{even}=2.34 GHz from a targeted coupling matrix [7]. Secondly, based on the required external *Q*-factors to even- and odd-modes (Q_{exe}=30.1 and Q_{exo}=11.2) from the matrix, determine the values of the width (W_1=0.6 mm) and gap (g=0.2 mm g_1=0.3 mm) through extracting the two group delays, i.e., $\tau_{S11}(f_{even})$ and $\tau_{S11}(f_{odd})$. The third step is to select the total length (44.4 mm) of the attached open stub as shown in red dashed-line section in Fig. 1, according to the desired introduced additional transmission zero (TZ) at 1.28 GHz for frequency selectivity. Meanwhile, determine the parameters (L_s=10.7 mm and W_s=0.1 mm) of the open loaded stub in black dashed section of Fig. 1 for harmonic suppression at 4.5 GHz. Subsequently, fine tuning is performed to obtain optimal performance. Finally, by changing the resistance, the value of *R* (180 Ω) is determined for ideal port-to-port isolation.

Fig. 4 plots the simulated optimal scattering parameters under different values of the *R*. It is observed that various resistances result in different isolation while hardly change the filtering performance. As seen from the Fig.4 (a), there are



(a)

(b)

Fig. 5. Measured and simulated results of the FPD. (a) Magnitudes of S_{11}, S_{21}, and S_{31}, (b) magnitudes of S_{23}.

eight TZs introduced in this FPD. The first, sixth, and seventh TZs are the inherent TZs of the input and output coupled lines [8]. The second, fourth and eighth TZs are generated due to the attached open-ended stub at input line, which are derived in [9]. The third TZ is introduced by the resonance of the stub loaded at the central plane of the resonator for even mode [10]. The fifth TZ is created from a pair of loaded open-ended stubs at output feed lines for unwanted harmonic suppression.

III. RESULTS AND DISCUSSION

To validate the proposal, the prototype filtering power divider is implemented. The layout parameters in Fig. 1 are finally determined as (Units: mm): L_1=22.3, W_1=0.6, L_2=18.4, W_2=1.2, L_3=3.7, L_f=4.8, L_{f1}=13, W_{f1}=2.1, L_{f2}=10.2, L_s=10.4, W_s=0.1, L_p=6, W_p=1.18, g=0.2, g_1=0.3. The photograph of the fabricated FPD is shown in the insert plot of Fig. 5. The simulation was accomplished by the EM simulator HFSS while the measurement was carried out on the Agilent N5244A network analyzer. Fig. 5 plots the simulated and measured results. As shown in the figure, the measured center frequency is 2.2 GHz, with the 3-dB fractional bandwidth of 18.2%. Two transmission poles inside the passband can be clearly observed. Within this operating band, the measured minimum insertion loss (IL) is 0.95 while the return loss is better than 19.5 dB. The in-band isolation between output ports is higher than 32 dB. Besides, eight TZs are created as expected, which helps a lot to achieve sharp frequency selectivity and good harmonic suppression with more than 24 dB rejection level from DC to 6.28 GHz (2.85f_0). Table I compares the performances of the proposed FPD with other reported ones. It indicates that the presented work exhibits not only high performance, i.e., large fractional bandwidth, sharp frequency selectivity and attractive in-band isolation but also a very simple topology against others.

TABLE I
COMPARISONS WITH OTHER PREVIOUS WORKS

Refs.	Topology	3-dB FBW	D (λg^2)	Num. of TZs	IL (dB)	In-band Iso. (dB)
[2]	Tw Double Rs	6.5%	0.02	4	3.96	>20
[3]	Tw Double Rs	10.0%	0.05	0	4.20	>17
[4]	Tw Double Rs	13.3%	0.16	6	3.97	>22
This work	**Cs Single R**	**18.2%**	**0.14**	**8**	**3.95**	**>32**

Refs.: References. R: Resonator. Tw: Two-way. Cs:Co-shared. D:dimension. Num.:Number. IL: insertion loss. Iso.:Isolation.

IV. CONCLUSION

This letter has presented a microstrip dual-mode filtering power divider (FPD) utilizing a simple open-type resonator. A new topology has been proposed to realize the power splitting and filtering functions. The analysis and design procedure have been described. An example of a filtering power divider has been implemented to demonstrate the design concept. The experimental results indicate that the proposed FPD exhibits not only sharp frequency selectivity and wide upper stopband, but also excellent in-band isolation performance. These above properties makes the proposed FPD attractive for applications in wireless communication systems.

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