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A Design of Unequal Termination Impedance Power Divider with Filtering and Out-of-band Suppression Characteristics

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***Abstract*—This paper presents a design of unequal termination impedance 3-dB power divider with filtering and out-of-band suppression characteristics. Two transmission poles are appeared in the passband by controlling characteristic impedance of shunt half-wavelength transmission line. For an experimental validation, the proposed 3-dB power divider with an impedance transforming ratio of 3 is designed at the center frequency (f_0) of 2.6 GHz. From measurements, the magnitude of S_{21} and S_{31} are determined to be -3.8 dB and -3.6 dB at f_0. The amplitude division within -3.9 dB is obtained on the bandwidth of 480 MHz (2.4-2.88 GHz). The input and output return losses are higher than 15.58 dB for the same bandwidth. Moreover, the isolation between output ports is higher than 11.4 dB from DC to 7.4 GHz.**

Keywords—coupled line, impedance transformer, out-of-band suppression, power divider.

I. Introduction

Power dividers have widely used for various microwave systems such as antenna feeding elements, power amplifiers, and mixers [1]-[6]. Since the conventional power dividers are based on λ/4 transmission line (TL), it has a limitation for circuit realization with a high impedance transforming ratio (*r*). In [1], the modified constant conductance-type transmission-line impedance transformers was investigated for power dividers. The circuit size could be reduced by using a stepped-impedance modified T-type network, but authors did not consider the out-of-band suppression characteristic.

In recent years, the power dividers integrated with bandpass filters have been considered in modern communication systems [2], [3]. In [2], the power divider was designed by integrating fourth-order bandpass filters at input and output ports, which provides four transmission poles in the passband and good out-of-band suppression. However, the insertion loss is increased as a number of resonators increases. Similarly, a filtering power divider was designed by integrating π-type impedance matching network, which has a large circuit size [3]. In [4], five resonators were used to designed power divider with a filtering response and out-of-band suppression characteristic. However, the circuit is seem complexity to design and analysis due to many resonators. Furthermore, most of the filtering response power dividers were designed with equal termination port impedances. If the bandpass filtering power divider can be realized with unequal termination impedances, the additional matching circuit can be avoided [5] to match with the connected other circuits. And the insertion loss also can be reduced, which is a critical design issue in case of high power amplifier design.

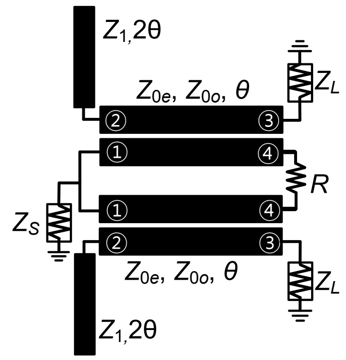
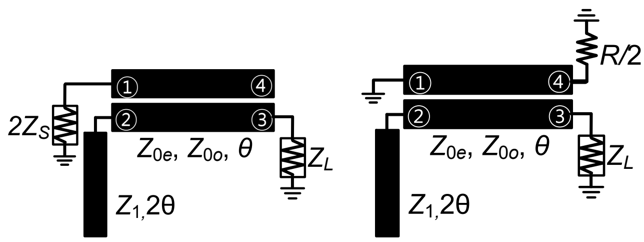


Fig. 1. Proposed structure of unequal termination impedance power divider.



(a) (b)

Fig. 2. (a) even- and (b) odd-mode decompositions of the proposed power divider.

In this paper, an unequal termination impedance 3-dB power divider with the bandpass filtering characteristic is

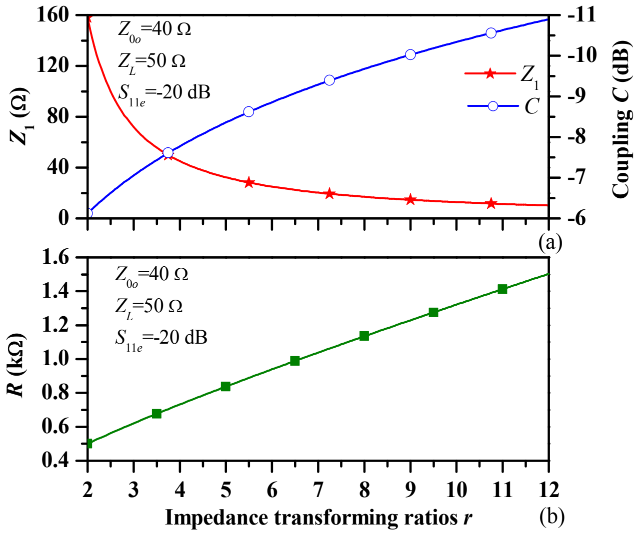


Fig. 3. (a) Z_1 and coupling coefficient and (b) isolation resistance (R) of coupled line according to impedance transforming ratio.

analyzed and designed. To verify the design equations, the proposed power divider is design at the center frequency (f_0) of 2.6 GHz. The proposed power divider can provide two transmission poles in the passband and a wide out-of-band suppression characteristic.

II. Design Equations

Fig. 1 shows the proposed structure of unequal termination impedance 3-dB power divider where input port (port 1) and output ports (port 3s) are terminated with Z_s and Z_L, respectively. The proposed circuit consists of two pair coupled lines with shunt open stub TLs of Z_1 at port 2 and an isolation resistor (R) connected at port 4. The electrical length of coupled line and shunt TL are quarter wavelength (λ/4) and half wavelength (λ/2) at the f_0, respectively. The S-parameters of the equal-split (3-dB) power divider can be expressed in terms of equivalent even- and odd-mode S-parameters [6] as shown in (1).

$$S_{11} = S_{11e} \tag{1a}$$

$$S_{21} = S_{31} = S_{12} = S_{13} = S_{21e}/\sqrt{2} \tag{1b}$$

$$S_{22} = S_{33} = \left(S_{22e} + S_{22o}\right)/2 \tag{1c}$$

$$S_{23} = S_{32} = \left(S_{22e} - S_{22o}\right)/2 \tag{1d}$$

Since the proposed circuit is a symmetrical 3-ports network, even- and odd-mode analysis can be applied to find S-parameters. Fig. 2(a) and 2(b) show equivalent circuits of even- and odd-mode excitations, respectively. At the even-mode, the termination impedance of Z_L is transformed to $2Z_S$ for 3-dB power divider. Moreover, the R does not affect to the connected circuit as shown in Fig. 2(a). The unequal termination impedance S-parameters can be derived [7] from the Z-parameters of coupled line and shunt TL as (2).

TABLE I

Calculated Values of Proposed Power Divider

Z_L=50 Ω, Z_{0o}=40 Ω, S_{11}=-20 dB at f_0		
r=3		
Z_{0e} (Ω)	Z_1(Ω)	R (Ω)
103.83	71.91	620.6

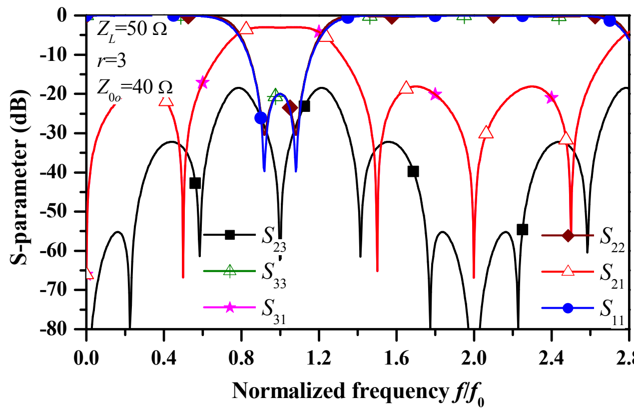


Fig. 4. Frequency response of the unequal termination impedance 3-dB power divider with r=3.

$$S_{11e} = \frac{\left(Z_{11} - 2Z_S\right)\left(Z_{22} + Z_L\right) - Z_{12}Z_{21}}{\left(Z_{11} + 2Z_S\right)\left(Z_{22} + Z_L\right) - Z_{12}Z_{21}} \tag{2a}$$

$$S_{21e} = 2Z_{21}\sqrt{2Z_S Z_L}\Big/\left[\left(Z_{11} + 2Z_S\right)\left(Z_{22} + Z_L\right) - Z_{12}Z_{21}\right] \tag{2b}$$

where

$$Z_{11} = j\cot\theta\left[\left(Z_m^2\cot\theta\right)\Big/\left(2Z_1\cot 2\theta + Z_p\cot\theta\right) - Z_p\right]\Big/2 \tag{3a}$$

$$Z_{22} = jZ_p\left[\left(Z_p\csc^2\theta\right)\Big/\left(2Z_1\cot 2\theta + Z_p\cot\theta\right) - \cot\theta\right]\Big/2 \tag{3b}$$

$$Z_{21} = Z_{12} = jZ_m\csc\theta\left[\left(Z_p\cot\theta\right)\Big/\left(2Z_1\cot 2\theta + Z_p\cot\theta\right) - 1\right]\Big/2 \tag{3c}$$

$$\theta = \pi f/2f_0 \tag{3d}$$

$$Z_p = Z_{0e} + Z_{0o} \tag{3e}$$

$$Z_m = Z_{0e} - Z_{0o} \tag{3f}$$

$$Z_L = 2rZ_S. \tag{3g}$$

where Z_{0e} and Z_{0o} are even- and odd-mode impedances of coupled line. At the f_0, Z_{0e} with specified values of S_{11e}, Z_S, and r can be found as (4).

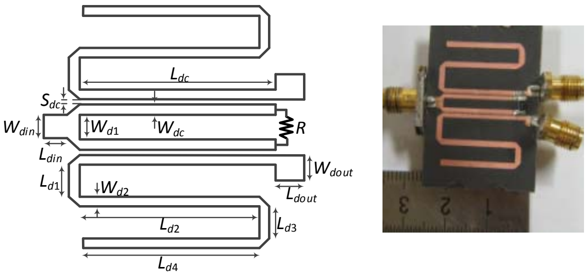
$$Z_{0e} = 4Z_S\sqrt{r\left(1 + S_{11e}\big|_{f_0}\right)\Big/\left(1 - S_{11e}\big|_{f_0}\right)} + Z_{0o} \tag{4}$$

Since the coupling coefficient of coupled line is defined as

$$C = \frac{Z_{0e} - Z_{0o}}{Z_{0e} + Z_{0o}} \tag{5}$$

TABLE II
PHYSICAL DIMENSION OF THE PROPOSED POWER DIVIDER

W_{dc}=1 mm	L_{din}=3 mm	L_{d2}=17 mm	L_{dout}=3 mm
S_{dc}=0.2 mm	W_{d1}=2.2 mm	L_{d3}=3.4 mm	R=0.91 kΩ
L_{dc}=19 mm	L_{d1}=5 mm	L_{d4}=17 mm	
W_{din}=2.4 mm	W_{d2}=1.3 mm	W_{dout}=2.4 mm	



(a) (b)

Fig. 5. Power divider: (a) layout and (b) photograph of the fabricated circuit.

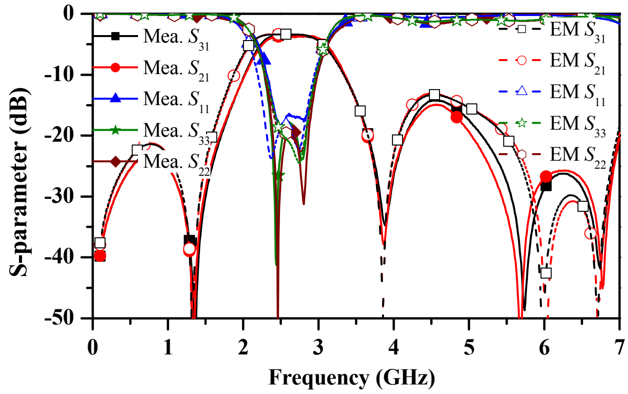


Fig. 6. Scattering parameter of EM and measurement results.

Characteristic impedance Z_1 of open stub TL can be calculated from (2a) as (6).

$$Z_1 = (Z_{0e} + Z_{0o})/(r-1) \quad (6)$$

where r should be higher than 1. From (2b), the normalized transmission zero frequencies can be obtained as (7).

$$f_{zt}/f_0 = (2n-1)/2 \quad (7a)$$

$$f_{zc}/f_0 = 2n \quad (7b)$$

where n, f_{zt}, and f_{zc} are integer and the transmission zero frequencies generated by the TL and coupled line, respectively.

At the odd-mode excitation, the Z_S is short-circuited and resistor R is divided into half as shown in Fig. 2(b). The odd-mode reflection coefficient S_{22o} can be derived from the basic circuit theory by applying S_{23} = 0 for the perfect isolation. Then R can be found as (8).

$$R = Z_p^2/4Z_S \quad (8)$$

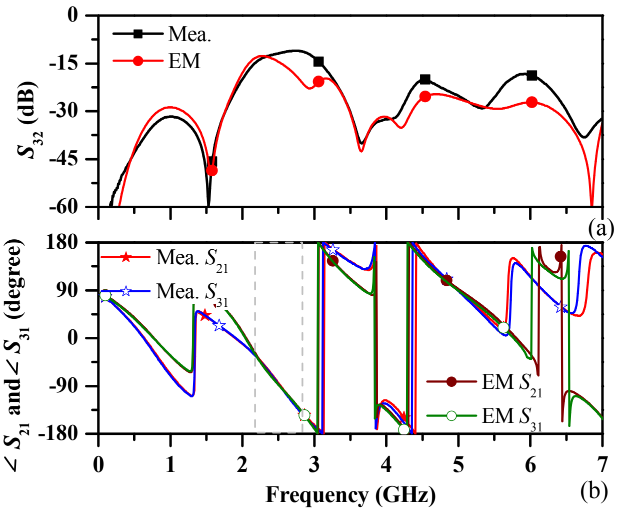


Fig. 7. EM simulation and measurement of: (a) S_{32} and (b) phase S_{21} and S_{31}.

For illustrating the relation between C, Z_1, and R according to Z_{0o}, the design graphs are plotted in Fig. 3 in condition of Z_{0o} = 40 Ω, Z_L = 50 Ω, and S_{11e} = -20 dB. As seen from this figure, a higher r requires a loose coupling C. By choosing Z_{0o}=40 Ω, the maximum C is required -6.12 dB to design power divider with r = 2. Moreover, from (6) the Z_1 is inverse proportional to r. Therefore, the traded off among r, C, and Z_1 are required to design the proposed power divider. Moreover, the R is increased almost linearly with increasing r. Fig. 4 shows the simulated frequency characteristics of the 3-dB power divider with Z_L = 50 Ω, r = 3 and S_{11e} = -20 dB at the f_0. The calculated elements values are shown in Table I. As shown in this figure, the power division between output ports are same and all ports are matched with a return loss of 20 dB at f_0. Moreover, the proposed power divider provides almost infinite isolation characteristic between output ports. Two transmission zeros are obtained due to λ/2 open stub TL.

III. SIMULATION AND MEASUREMENT

To validate the proposed 3-dB power divider, an r = 3 (50-to-8.33 Ω) for S_{11e} = -20 dB at f_0 = 2.6 GHz was designed, simulated, and measured. The calculated values are shown in Table I. The odd-mode impedance (Z_{0o}) of coupled line can be chosen by designer for easily fabrication. The circuit is fabricated on substrate with ε_r = 2.2 and h = 31 mils.

Fig. 5 shows the layout and photograph of the fabricated power divider. The physical dimension of the designed power divider is shown in Table II. The total size of proposed circuit is 25 × 35 mm^2. The simulated and measured characteristic of the power divider circuit are shown in Fig. 6. The measured input and output return losses are given as S_{11} = 16.4 dB, S_{22} = 19.2 dB, and S_{33} = 17.75 dB at the f_0, respectively. The measured input and output return loss are higher than 15.58 dB within the operating band of 2.4-2.88 GHz. And the measured insertion losses (S_{21} and S_{31}) at the f_0 are 3.8 dB and 3.6 dB, respectively, showing a good agreement with the simulation results. Within frequency range of 2.4 - 2.88 GHz, the measured insertion loss is better than 3.9 dB. The transmission zeros are located at 1.35 GHz, 3.9 GHz, 5.68 GHz, and 6.75 GHz which provide high selectivity and wide out-of-band suppression characteristics. The out-of-band suppression characteristics at lower side of operating band is more than 20 dB from DC to 1.7 GHz. Similarly, out-of-band suppression is higher than 15 dB from 3.5 GHz to 7 GHz. Fig. 7(a) and 7(b) show the simulated and measured isolation and phase characteristics, respectively. As seen in this figure, the isolation between output ports is given as 11.4 dB at the f_0 and better than -11 dB from DC to 7 GHz. The different between analysis and measured results may be due to the unexpected parasitic elements of the bending transmission lines. The phases of S_{21} and S_{31} are the same from 2.2 GHz to 3 GHz.

IV. Conclusion

In this paper, a design of unequal termination impedance 3-dB power divider with filtering and out-of-band suppression characteristics is presented. The proposed circuit can block DC current and pass RF signal through circuit. Both the simulation and measurement results are provided to validate the proposed circuits. The proposed circuits are simple to design and fabricate and are also expected to be applicable in various RF circuits and system that require frequency selective performance.

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