Design of Wideband Multi-way Power Divider with the Modified Impedance Transformer

C. W. Tang and W. M. Chuang
Center for Telecommunication Research, Advanced Institute of Manufacturing with High-Tech Innovations
Department of Cmmunications Engineering, National Chung Cheng University, Taiwan

Abstract— An easy method for designing the multi-way wideband power divider has been proposed. In order to obtain a wide operational frequency, the corrected coefficients for the wideband impedance transformer are adopted. A wideband four-way power divider has been developed as a design example. Well-matched results of simulation and measurement can validate the proposed approach.

1. INTRODUCTION

In current wireless communication, the need for wide bandwidth is growing rapidly. Power dividers are important components in microwave applications. In addition, the multi-way power divider is a key component for phase-array antennas, power amplifiers, and multi-port circuits. Wilkinson power dividers are generally adopted for two-way power division [1]. Consequently, the multi-way power divider can be realized by interconnecting two-way Wilkinson power dividers. A general method of designing the multi-way power divider is utilizing the binominal response on the multi-stage transmission lines. However, the available bandwidth of the multi-way power divider remains limited. The multi-way power dividers with interconnection have been studied in [2–4]. In [4], a calculated method for designing the multi-way power divider with interconnecting two-way power dividers is achieved. Unfortunately, the interconnection between two-way power dividers may restrict the optimal design.

In order to obtain a wideband multi-way power divider, the corrected coefficients are adopted for the multi-stage transmission lines shown in Figure 1. With the assistance the corrected coefficients, the design of power dividers with required input reflection level can be simplified. Moreover, both even- and odd-mode analysis are provided to obtain the optimal isolation resistor values.

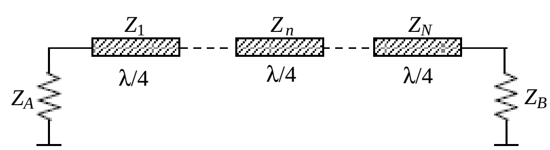


Figure 1: Diagram of the multi-stage transmission lines.

2. DESIGN FORMULAS OF THE MODIFIED IMPEDANCE TRANSFORMER

In order to obtain a wide operating bandwidth, the general binominal response utilize upon the multi-stage transmission lines can be modified by multiple the correct coefficients K_n. Consequently, the characteristic impedances Z_n can be modified by integrating the corrected coefficients K_n with transmission lines at each stage as

$$Z_n = \begin{cases} \dfrac{Z_A \cdot R^{2^{-N} \cdot \sum_{k=0}^{n-1} C_k^N}}{K_n}, & \text{for } n < \frac{N+1}{2} \\ Z_A \cdot R^{2^{-N} \cdot \sum_{k=0}^{n-1} C_k^N}, & \text{for } n = \frac{N+1}{2} \\ Z_A \cdot R^{2^{-N} \cdot \sum_{k=0}^{n-1} C_k^N} \cdot K_n, & \text{for } n > \frac{N+1}{2} \end{cases} \tag{1}$$

$$K_n = K_{N-n+1} \tag{2}$$

where $R = Z_B/Z_A$.

As for the two-stage transmission lines, Figure 2(a) shows the simulated results of $|S_{11}|$ with various corrected coefficient K_1. It is indicated that the smaller the corrected coefficient is, the

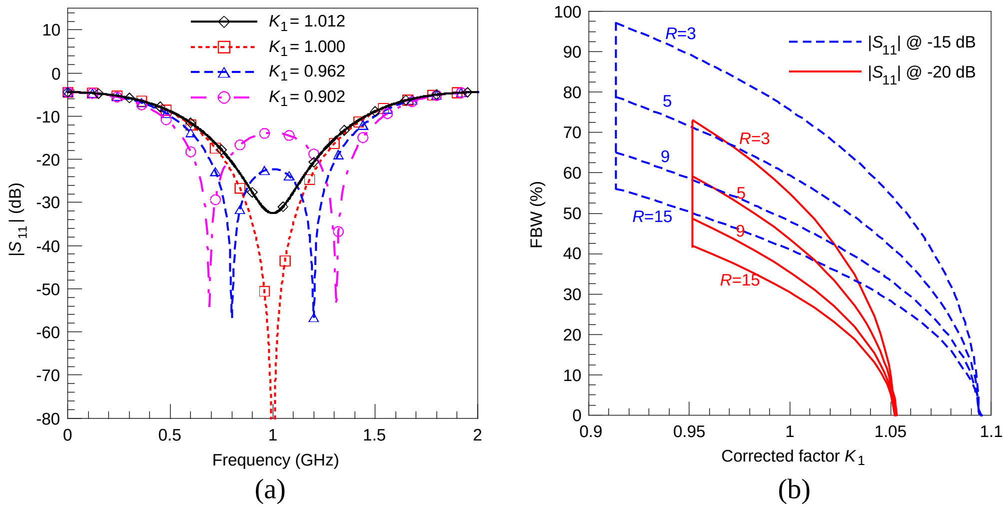


Figure 2: Simulated results of the two-stage transmission lines multiple the correct coefficient K_1. (a) $|S_{11}|$. (b) Relation between FBW and corrected coefficient K_1.

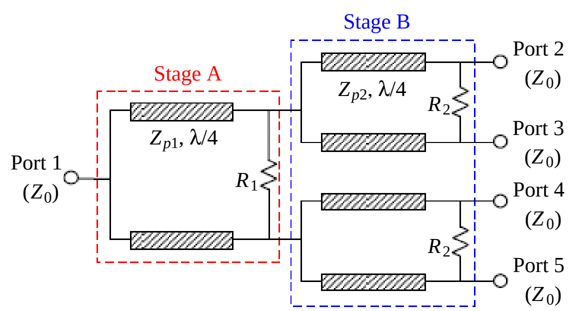


Figure 3: Structure of the exemplary four-way power divider.

larger the available fractional bandwidth (FBW), and the $|S_{11}|$ are. Moreover, there is a wider operating bandwidth with $K_1 < 1$ than that with the binomial response, $K_1 = 1$. Figure 2(b) also shows the similar tendency that the larger the impedance ratio R is, the smaller the FBW is.

3. DESIGN EXAMPLE OF THE WIDEBAND FOUR-WAY MICROSTRIP POWER DIVIDER

By interconnecting three two-way power dividers, a four-way power divider is realized with the two-stage structure, as shown in Figure 3. In Figure 3, port 1 is the input port while ports 2–5 are four output ports. The two-way power divider, indicated as Stage A in Figure 3, is composed of a resistor R_1 and two quarter-wavelength transmission lines with characteristic impedance Z_{p1}. Other two power dividers indicated as Stage B, are composed of two resistors R_2 and four quarter-wavelength transmission lines with characteristic impedances Z_{p2}. The four-way power divider is developed at 1 GHz as the central frequency and with FBW of 61.4% when the insertion loss is 20-dB. In addition, this power divider is fabricated on FR4 substrates, whose dielectric constant, loss tangent, and layer thickness are 4.4, 0.018, and 1.6 mm, respectively.

3.1. Even-mode Analysis

The even-mode equivalent circuit of the power divider shown in Figure 3 can be expressed as Figure 4(a). Moreover, in Figure 4(b), resistors R_1 and R_2 are removed from the even-mode equivalent circuit since they do not have effects on signals from input and output ports. Therefore, the two-stage transmission lines can be utilized to obtain the impedances Z_{p1} and Z_{p2} as

$$Z_{p2} = Z_1 \tag{3}$$
$$Z_{p1} = Z_2/2 \tag{4}$$

3.2. Odd-mode Analysis

The odd-mode equivalent circuit of the power divider shown in Figure 3 can be expressed as Figure 5(a). Moreover, Figure 5(b) is the odd-mode equivalent circuits of both Figures 4(a) and 5(a). In addition, Figure 5(c) is the even-mode equivalent circuit of Figure 5(a). Under the matching condition, resistors R_2 and R_1 can be derived from Figures 5(b) and 5(c), respectively, as

$$R_2 = 2Z_0 \tag{5}$$

$$R_1 = Z_{p2}^2/Z_0 \tag{6}$$

With 4 for the impedance ration R in Figure 4(b) and two-stage transmission lines adopted for the circuit, 0.962 should be selected for corrected coefficient K_1 according to Figure 2(b), where FBW is 61.4% with 20-dB for insertion loss. Consequently, from (1) to (4), the impedances Z_{p1} and Z_{p2} can be obtained as $68.02\,\Omega$ and $73.5\,\Omega$, respectively. Moreover, from (6) and (5), resistors R_1 and R_2 will be $108.05\,\Omega$ and $100\,\Omega$, respectively. In this paper, the resistor R_1 is modified as $107\,\Omega$ for real fabrication, which causes return loss degradation of 0.5 dB at four output ports. Figure 6(a) shows the theoretically modified responses. It is indicated that the bandwidth of $|S_{11}|$ at -20 dB is wider with the modified power divider proposed in this paper than the traditional Wilkinson power divider.

These theoretical parameters can be transformed into the physical dimensions shown in Table 1 with the aid of the electromagnetic (EM) simulator IE3D. Figures 6(a) and 6(b) show the layout and photograph of the fabricated four-way power divider. The total area of this prototype is $63.3 \times 74.57\,\mathrm{mm}^2$. Figure 6(a) compares the simulated and measured results of the fabricated power divider with -20-dB for $|S_{11}|$. Moreover, Figure 6(a) also presents measured insertion

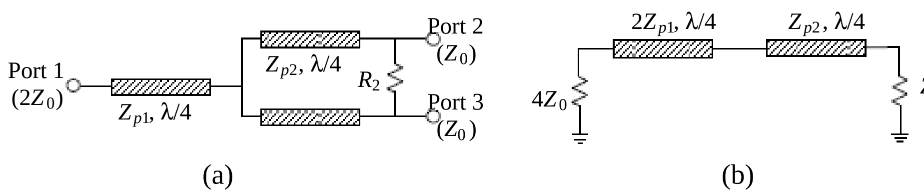


Figure 4: Half circuit of the four-way power divider with even-mode excitation. (a) Even mode of Figure 3. (b) Even mode of Figure 4(a).

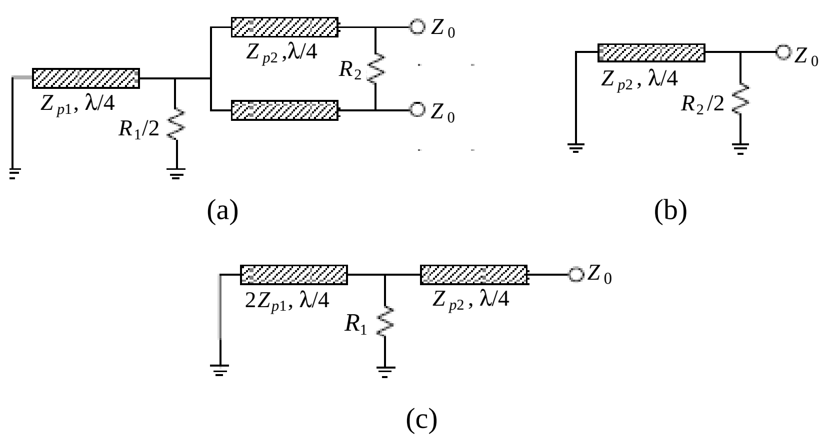
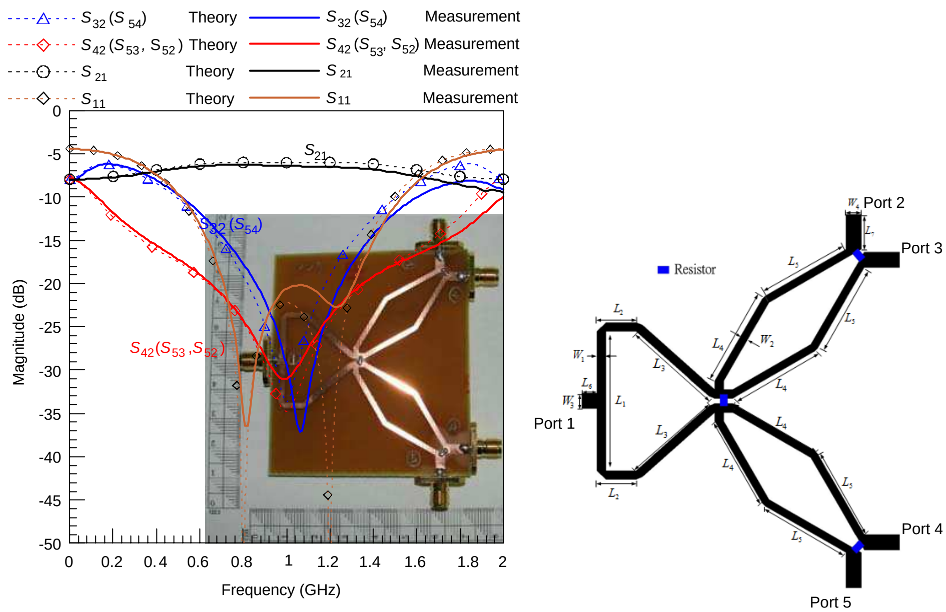


Figure 5: Half circuit of the four-way power divider with odd-mode excitation. (a) Odd mode of Figure 3. (b) Odd mode of Figure 4(a). (c) Even mode of Figure 5(a).

Table 1: Dimensions of the fabricated four-way power divider.

W_1	W_2	W_3	W_4	L_1	L_2
1.78	1.51	3.06	3.06	27.8	6.0
L_3	L_4	L_5	L_6	L_7	Unit: mm
19.35	20.0	18.65	3.0	7.0	



(a) (b)

Figure 6: Proposed wideband four-way power divider. (a) Photograph and comparisons of theoretical/measured return loss, insertion loss, and isolation. (b) Layout.

loss and isolation, and the measured insertion loss is around 0.5 dB. The well matched result of simulation and measurement validates the design for a simple and wideband power divider.

4. CONCLUSION

In this paper, the corrected coefficients for the wideband impedance transformer has been proposed and adopted on the design of wideband multi-way power divider. The even- and odd-mode analyses have been presented and optimal values of isolation resistors have been obtained. Moreover, design principles and example are provided and simulated. Furthermore, a prototype of the wideband four-way power divider is designed, fabricated, and measured. With the proposed structure, performance of S_{11} can be predicated in advance. Well-matched results of simulation and measurement validate the proposed approach.

ACKNOWLEDGMENT

This work was supported in part by the National Science Council, Taiwan, under Grant NSC 102-2221-E-194-013-MY2 and Ministry of Education, Taiwan, Republic of China.

REFERENCES

1. Wilkinson, E. J., "An N-way hybrid power divider," *IEEE Trans. Microw. Theory Techn.*, Vol. 8, No. 1, 116–118, 1960.
2. Cohn, S. B., "A class of broadband three-port TEM mode hybrids," *IEEE Trans. Microw. Theory Techn.*, Vol. 16, No. 2, 110–115, 1968.
3. Yee, H. Y., F.-C. Chang, and N. F. Audeh, "N-way TEM-mode broadband power dividers," *IEEE Trans. Microw. Theory Techn.*, Vol. 18, No. 10, 682–688, 1970.
4. Zhou, J., K. A. Morris, and M. J. Lancaster, "General design of multi-way multi-section power dividers by interconnecting two-way dividers," *IEEE Trans. Microw. Theory Techn.*, Vol. 55, No. 10, 2208–2215, 2007.