Compact Wilkinson power divider using two-section asymmetrical T-structures

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A compact planar Wilkinson power divider is proposed using two-section asymmetrical T-structures to achieve a significant size reduction and retain a mimic return-loss bandwidth as compared with the conventional one. The asymmetrical T-structure is realised by two series high-impedance lines with unequal electrical lengths and a shunt low-impedance line. The two-section configuration has the advantage of decreasing the shunt stub size, and then achieving an optimally miniaturised circuit layout. The developed power divider has a 66.5% 15 dB return loss bandwidth and only occupies a 12.7% circuit size of the conventional one. The measured results of the developed power divider are in a good agreement with simulated results.

Introduction: The Wilkinson power divider is one of the essential components in various microwave circuits and systems owing to its advantages of simplicity, impedance matching at all ports, and great isolation between outputs. However, since a Wilkinson power divider mainly consists of two quarter-wave transmission lines (TLs) [1], it occupies a large circuit size for low-frequency applications and inevitably increases the manufacturing cost. In recent years, many researches have proposed a variety of techniques [2–6] to miniaturise the circuit size of the Wilkinson power divider. Although these approaches can provide about 60–80% circuit size reductions, they suffer from the serious return-loss bandwidth degradation as compared with the conventional structure [1]. Table 1 summarises the performance comparisons of the published Wilkinson power dividers and this work. To simultaneously consider the factors of the circuit size reduction and the return loss bandwidth, the size-bandwidth product is newly defined in this Letter and then calculated in Table 1 for performance evaluation.

Table 1: Performance comparisons of published Wilkinson power dividers and this work

Ref.		[2]	[3]	[4]	[5]	[6]	This work
Frequency (GHz)		2.02–3.3	0.625–1.06	0.71–1.04	1.28–1.56	0.817–1.014	0.652–1.3
FBW (%)		48	51.6	37.8	19.7	21.5	66.4
Return loss (dB)		>15	>15	>15	>15	>15	>15
Isolation (dB)		>12	>11.5	>13.6	>15	–	>12
Insertionloss (dB)	$\vert S_{21}\vert$	3.35	–	3.26	–	3.39	3.168
	$\vert S_{31}\vert$	3.39	–	3.17	–	3.41	3.197
Relative circuit size (%)		36.5	34	14.7	39	25.7	12.7
Product*		30.5	34.06	32.2	12	15.97	57.96

*Product = {1-relative circuit size(%)}·{15 dB return loss bandwidth (%)}

In this Letter, the two-section asymmetrical T-structures are employed to replace the quarter-wave TLs of the conventional Wilkinson power divider as shown in Fig. 1*a*. Namely, each section of the asymmetrical T-structure should provide a 45° phase angle. The design formulas of the 45° single-section asymmetrical T-structure are modified from the formulas in [7]. As two high-impedance TLs of the single-section T-structure are folded as shown in Fig. 1*b*, one can optimally arrange the T-structures to miniaturise the Wilkinson power divider circuit layout as shown in Fig. 2.

Circuit design: To design a two-section asymmetrical T-structure, a quarter-wavelength TL with the characteristic impedance of Z_0 is first equally divided into two sections of the 45° TLs and then the high- and low-impedance (HLI) section [7] can be synthesised to replace each section of the TL. Each HLI section can be evolved into an asymmetrical T-structure shown in Fig. 1*a*, which is composed of two series-connected high-impedance lines with unequal lengths, namely $\theta_1 \neq \theta_3$, and a shunt low-impedance stub with the impedance Z_2 and electrical length θ_2 to replace each section of the TL. To synthesise a 45° HLI with a impedance of 70.7 Ω, the relationship between the electrical length and impedance in [7] should be re-derived as

$$q_b = \tan^{-1}\left\{\frac{-Z_b[Z_o^2 + 2\cot(q_b)Z_oZ_a + Z_a^2]}{\cot(q_b)Z_a(Z_o^2+Z_b^2)+Z_o(Z_a^2+Z_b^2)}\right\} \quad (1)$$

where, Z_a, Z_b, θ_a, and θ_b are the characteristic impedances and the electrical lengths of the HLI section, respectively. As the impedances of the HLI structure are selected as $Z_a = 95\ \Omega$ and $Z_b = 51\ \Omega$, one can determine the electric lengths as $\theta_a = 22.4°$ and $\theta_b = 20.2°$ based on the design equation (1). Here, the low-impedance Z_b of the HLI structure can be further equivalent to a symmetrical T -structure by the formulas in [7]. Therefore, the circuit parameters of the asymmetrical T-structure shown in Fig. 1*b* can be determined.

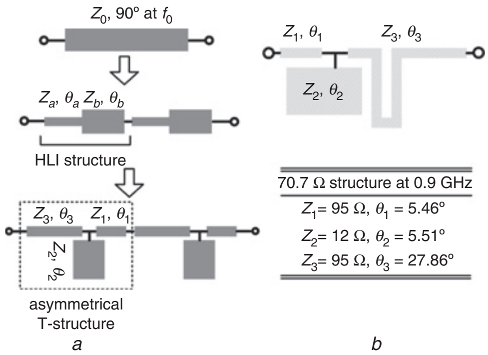

Fig. 1 *Circuit schematics of asymmetrical T-structures and developed compact power divider*

a Conventional MS and its two-section asymmetrical T-structure
b Single-section asymmetrical T-structure and its circuit parameters designed

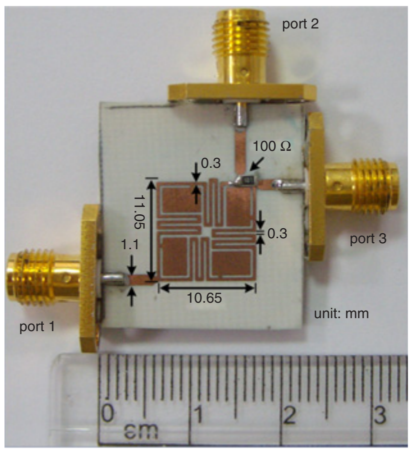

Fig. 2 *Circuit photograph of developed power divider*

Results: Shown in Fig. 2 is the circuit photograph of the proposed power divider using two-section asymmetrical T-structures. Herein, this divider has a circuit size of 11.05 × 10.65 mm, which is 12.7% of the conventional coupler. The measured results of the developed power divider were carried out by an Agilent E5071C four-port vector network analyser as shown in Fig. 3. Here, the circuit simulation results are realised by the ideal transmission lines in Agilent ADS using the circuit parameters listed in Fig. 1*b*. The measured $|S_{11}|$ is better than −15 dB from 0.652 to 1.3 GHz with a 66.4% fractional bandwidth, while the isolation $|S_{32}|$ is greater than 12 dB over at the same frequency range. Compared with the published power dividers in Table 1, the proposed power divider has the best size-bandwidth product value, namely 57.96%. The measured transmission coefficients, $|S_{21}|$ and $|S_{31}|$, at 0.9 GHz are −3.168 and −3.197 dB, respectively. It reveals that except for the conductor and dielectric losses, the miniaturised technique proposed in this Letter does not lead to unreasonable insertion loss.

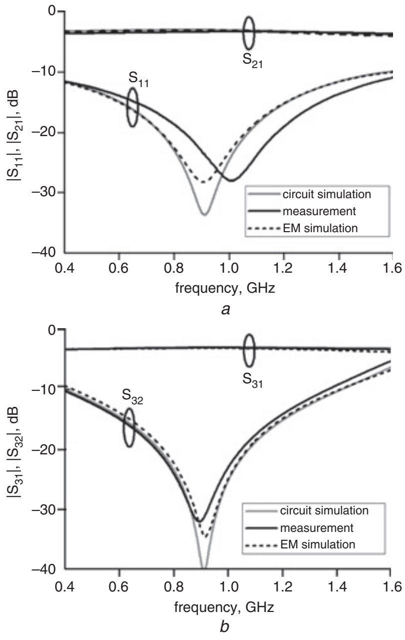

Fig. 3 *Measured and simulated results*

a S_{11} and S_{21}

b S_{31} and S_{32}

Conclusion: A compact Wilkinson power divider has been successfully designed and experimentally verified using two-section asymmetrical T-structures to retain a mimic return-loss bandwidth as that of the conventional one. As illustrated in Table 1, the developed power divider achieves a significant size reduction 87.3%, and has a better size-bandwidth product, about 57.96%, than those of published power dividers

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One or more of the Figures in this Letter are available in colour online.

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