Highly miniaturised Wilkinson power divider employing π-type multiple coupled microstrip line structure

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Using a π-type multiple coupled microstrip line structure, a highly miniaturised Wilkinson power divider is fabricated. The line length of the power divider was reduced to about $\lambda/44$, and its size was 37% of a conventional Wilkinson power divider. The novel power divider showed good RF performances in S/C band.

Introduction: In RFIC devices such as PA and mixer [1], a combiner/divider is required for its operation. A Wilkinson power divider is one of the passive components widely used for power splitting/combining. However, a conventional Wilkinson power divider employs a quarter-wavelength line, which highly increases circuit size and manufacturing cost.

In this work, to realise a miniaturised Wilkinson power divider, we propose a π-type multiple coupled microstrip line structure (MCMLS). Concretely, the Wilkinson power divider was highly miniaturised by substituting a quarter-wavelength line for π-type MCMLS. In the π-type MCMLS, the characteristic impedance of the line does not increase rapidly, though the line is shortened by shunt capacitors, which facilitated the fabrication of the miniaturised RF passive components.

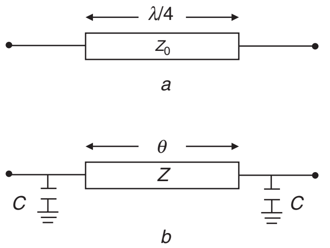

Fig. 1 *Quarter-wavelength line, and conventional π-type single microstrip line structure (SMLS) equivalent to quarter-wavelength line*

a Quarter-wavelength line
b Conventional π-type SMLS equivalent to quarter-wavelength line

Novel microstrip line employing π-type MCMLS: Figs. 1*a* and *b* show a quarter-wavelength line and conventional π-type single microstrip line structure (SMLS) equivalent to the quarter-wavelength line, respectively. Equations (1)–(3) should be satisfied in order that the conventional π-type SMLS may be equivalent with the quarter-wavelength line [2].

$$\omega C = \frac{\cos\theta}{Z} \tag{1}$$

$$Z = \frac{Z_0}{\sin\theta} \tag{2}$$

$$Z = \frac{Z_0}{\sqrt{1-(\omega C Z_0)^2}} \tag{3}$$

From (1) and (2) we can see that as the line length of the π-type SMLS of Fig. 1*b* becomes shorter, the shunt capacitor C and characteristic impedance Z become larger in a range of $0 \le \theta \le \pi/2$, which makes it impossible to physically realise a microstrip line shorter than $\lambda/10$ by using the π-type SMLS [2]; e.g. if the line length of the π-type SMLS becomes less than $\lambda/10$, the characteristic impedance Z becomes higher than 100 Ω. However, the microstrip line, the characteristic impedance of which is higher than 100 Ω, cannot be realised on semiconducting or dielectric substrate owing to its very thin line width [3]. Note that (3) indicates that a reduction of shunt capacitor C results in a decrease of the characteristic impedance Z. Therefore, to solve the above problem for the conventional π-type SMLS, a novel structure with a reduced shunt capacitor should be employed. For this reason, we propose a π-type MCMLS in this work, which is shown in Fig. 2. The advantage of a π-type MCMLS is as follows. As shown in Fig. 2, for the π-type MCMLS, coupling capacitance C_p exists between lines, and a part of coupling capacitance C_p serves as the shunt capacitor like C of the π-type SMLS of Fig. 1*b*, because a part of C_p is connected to the grounded line. Therefore, a part of coupling capacitance C_p contributes to a reduction of line length like shunt capacitor C of the π-type SMLS shown in Fig. 1*b*, and the total shunt capacitor contributing to a reduction of line length for the π-type MCMLS is a summation of real shunt capacitor C_1 and a part of coupling capacitance C_p; i.e. the total shunt capacitor contributing to a reduction of line length for π-type MCMLS can be expressed as $C_1 + \alpha C_p$, where α is a coefficient indicating a portion serving as the shunt capacitor. For this reason, real shunt capacitor C_1 of the π-type MCMLS shows a lower value than C of the π-type SMLS, because αC_p serves as the shunt capacitor. Therefore, from (3), we can see that the characteristic impedance Z_1 of the π-type MCMLS becomes lower than Z of the π-type SMLS owing to its comparatively lower shunt capacitance C_1, which facilitates the fabrication of miniaturised passive components on semiconducting or dielectric substrate. For example, in case that the quarter-wave line of Fig. 1*a* is transformed to a π-type circuit with a length $\lambda/44$, the characteristic impedance Z of the π-type SMLS is increased to 200 Ω, while the characteristic impedance Z_1 of the π-type MCMLS becomes 60 Ω, which can be realised on semiconducting or dielectric substrate. In this work, we developed a highly miniaturised Wilkinson power divider using the π-type MCMLS.

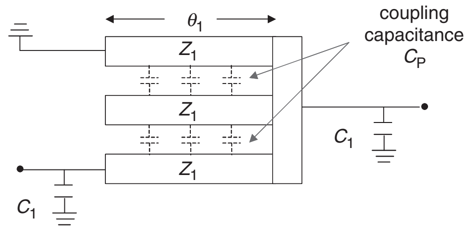

Fig. 2 *π-type multiple coupled microstrip line structure (MCMLS)*

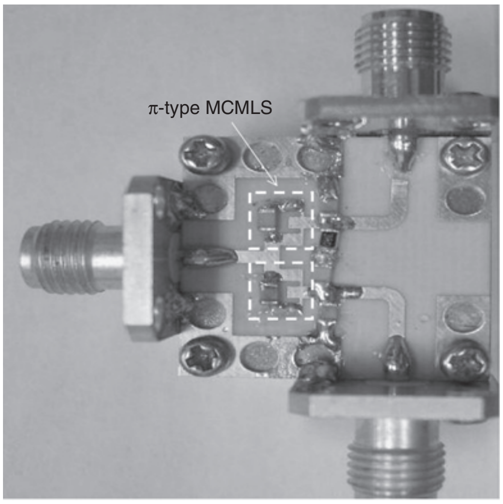

Fig. 3 *Photograph of highly miniaturised Wilkinson power divider employing π-type MCMLS*

Highly miniaturised Wilkinson power divider employing π-type MCMLS: Fig. 3 shows a photograph of the highly miniaturised Wilkinson power divider employing the π-type MCMLS, which was fabricated on teflon substrate. The line width and spacing between lines are 1 and 0.4 mm, respectively, and the resistance and shunt capacitor are 3.04 Ω and 1.83 pF, respectively. As shown in Fig. 3, the Wilkinson power divider was highly miniaturised by substituting a quarter-wavelength line for the π-type MCMLS. The size of the novel and conventional Wilkinson power divider on teflon substrate are summarised in Table 1. As shown in the Table, the shunt capacitance of the π-type MCMLS and π-type SMLS is 0.5 and 1 pF, respectively. The line length was highly reduced to $\lambda/44$ using the π-type MCMLS, and the circuit size of the power divider employing the π-type MCMLS are 37 and 53% of the conventional one employing a quarter-wave line and a π-type SMLS, respectively. Figs. 4 and 5 exhibit power and phase division characteristics for the miniaturised Wilkinson power divider employing the π-type MCMLS. From 3 to 5.5 GHz, we can observe equal power and phase characteristics. Concretely, we can observe power division higher than −5.5 dB, and isolation better than −9 dB.

Table 1: Circuit size of novel and conventional Wilkinson power divider

	Power divider size	Line length	Shunt C
π-type MCMLS	17 mm^2	1 mm	0.5 pF
π-type SMLS	32 mm^2	8.2 mm	1 pF
Quarter-wave line	45 mm^2	11.3 mm	

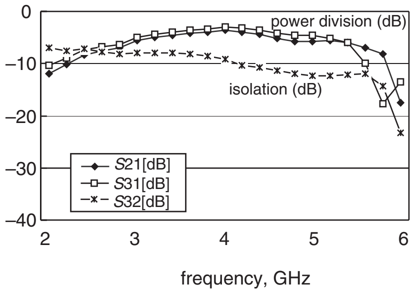

Fig. 4 *Power division and isolation characteristics for miniaturised Wilkinson power divider employing π-type MCMLS*

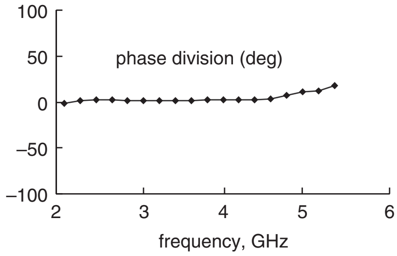

Fig. 5 *Phase division characteristics for miniaturised Wilkinson power divider employing π-type MCMLS*

Conclusion: We propose a π-type MCMLS, which facilitated development of miniaturised passive components on dielectric substrate. Using the π-type MCMLS, we fabricated a highly miniaturised Wilkinson power divider on teflon substrate. The line length of the Wilkinson power divider was reduced to $\lambda/44$, and its size was 37 and 53% of the conventional one employing a quarter-wave line and a π-type SMLS, respectively. The Wilkinson power divider exhibited good RF performances in the S/C band.

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