Unequal Power Divider Using Series RC Circuit for Improved Isolation

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Abstract— This paper presents a high dividing ratio unequal power divider with improved isolation using a series RC circuit. To improve isolation, we used an isolation component composed of a series resistor and capacitor circuit. This circuit is placed at an arbitrary position in the quarter-wave transmission line to achieve power division. In addition, to achieve a high dividing ratio, the low impedance line is composed of a capacitive loaded transmission line with slow-wave characteristics. To validate the performance of the proposed unequal power divider, we simulated and fabricated the unequal power divider for an operating frequency of 1 GHz. The experimental results are in good agreement with the simulated results.

1. INTRODUCTION

A power divider is a fundamental component in RF and microwave systems, such as in feeding networks for array antenna systems [1], power amplifiers [2], and six-port reflectometers [3]. Conventional unequal power dividers have poor isolation and output port matching conditions because the quarter-wave transmission lines used for power division are nearby. To improve performance, many papers have examined design methods, such as using multi-stage, dual band, and parallel RLC isolation networks [4], 0° phase shifting isolation stages [5], multi-section transmission line and multi-layer techniques [6], isolation networks [7], exponentially tapered lines [8], and multi-layer slotlines with BPF responses [9].

To improve the isolation performance of a conventional power divider, most design methods employ multilayer or multi-section configurations to reduce the interference between dividing transmission lines. These methods have the drawbacks of large size and complex structure. Because the quarter-wave transmission lines for power dividing must be nearby to allow the connection of the isolation component, the isolation performance degrades between output ports. In addition, because the end point of the small-size isolation component is connected to the output port, it is difficult to add connections between output ports and other circuits.

In this paper, we present an unequal power divider with improved isolation based on a series RC circuit. The series RC isolation component is placed at an arbitrary position in the quarter-wave transmission line [10]. In addition, to design an unequal power divider with a high dividing ratio, the used low impedance line is a transmission line with a shunt open stub to achieve slow-wave characteristics [11]. The proposed unequal power divider is theoretically analyzed to derive equations for output port matching and isolation. For the validation of the proposed 10 : 1 unequal power divider, we simulated and fabricated the device for an operating frequency of 1 GHz.

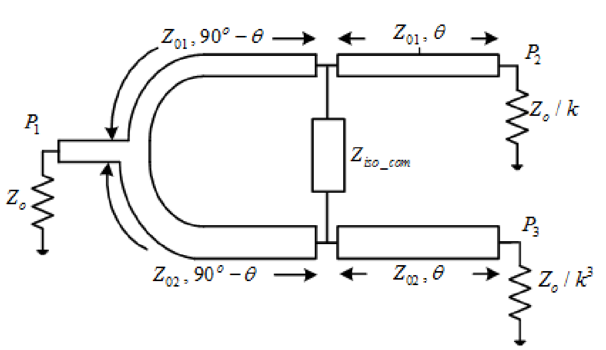

Figure 1: Configuration of the proposed unequal power divider.

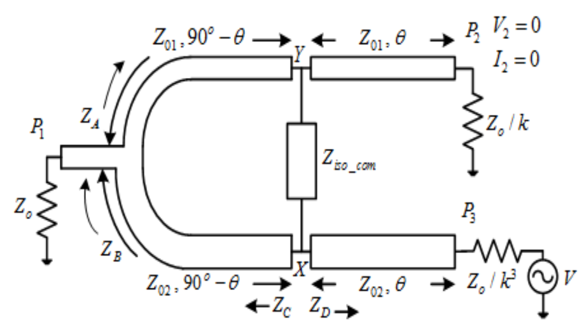

Figure 2: Equivalent circuit for matching and isolation.

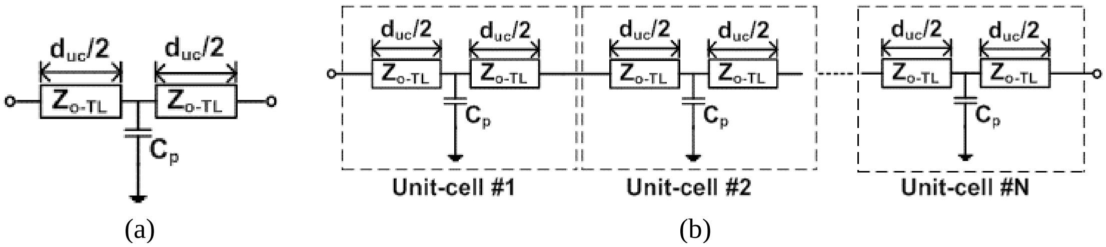

Figure 3: Transmission line with shunt open stub. (a) Equivalent circuit of unit-cell structure. (b) Cascade connection of unit-cells.

2. THEORY AND DESIGN

The configuration of the proposed unequal power divider is shown in Figure 1.

The power-dividing ratio of the divider is $k^2(= P_3/P_2)$. The isolation components are placed at an arbitrary position in the quarter-wave transmission line. When the matching condition at port 1 is satisfied, the characteristic impedances are $Z_{01} = \sqrt{(1+k^2)/k}Z_o$ and, $Z_{02} = \sqrt{(1+k^2)/k^5}Z_o$. To find the optimum position θ of the isolation component to determine the matching and isolation conditions between output ports, the source is excited at port 3 in Figure 2. If the perfect isolation condition between output ports is satisfied, the voltage and current at port 2 are zero. Therefore, point Y is essentially shorted. In this condition, the impedances $Z_A{\sim}Z_D$ in Figure 2 are given by

$$Z_A = jZ_{o1}\tan\left(90^\circ - \theta\right), \quad Z_B = \frac{Z_A \cdot Z_o}{Z_A + Z_o} \tag{1}$$

$$Z_C = Z_{o2}\frac{Z_B + jZ_{02}\tan(90^\circ - \theta)}{Z_{02} + jZ_B\tan(90^\circ - \theta)}, \quad Z_D = Z_{02}\frac{Z_o/k^3 + jZ_{02}\tan\theta}{Z_{02} + j\left(Z_o/k^3\right)\tan\theta} \tag{2}$$

To match the output port at position X, the following condition must be satisfied

$$\frac{1}{Z_C} + \frac{1}{Z_{iso\_com}} = \frac{1}{Z_D^*} \tag{3}$$

From Equations (1)$\sim$(3), the isolation component Z_{iso_com} can be defined as

$$Z_{iso\_com} = R_{iso\_com} + jX_{iso\_com} \tag{4}$$

where R_{iso_com} and X_{iso_com} are the resistance and reactance of the isolation component, respectively.

According to Equation (4), the isolation component Z_{iso_com} can be implemented using a series resistor and capacitor circuit.

To design the 10 : 1 unequal power divider, the impedance values of the transmission line are found. $Z_{01} = 93.25\,\Omega$ and $Z_{02} = 9.33\,\Omega$. In addition, the transformer impedance value of the P_3 output port is $8.89\,\Omega$. Because these impedance values are very low, corresponding structures are difficult to fabricate on a microstrip line because of their large widths. We designed the equivalent circuit of a unit-cell to overcome these problems, specifically, by using a short length transmission line with a shunt open stub, as shown in Figure 3. Because the unit-cell has slow-wave characteristics, the cascade connection transmission line of the unit-cell can be used to reduce the physical length of the transmission line and to create low impedance lines. To design a capacitive loaded transmission line (CLTL) with N unit-cells and electrical length θ_{CLTL}, we can calculate the transmission line length d_{uc} and capacitance C_p for a given transmission line ($Z_{o\text{-}TL}$ and $v_{o\text{-}TL}$) and given values ($Z_{o\text{-}CLTL}$ and $v_{o\text{-}CLTL}$) of the CLTL as follows:

$$d_{uc} = \frac{Z_{o\text{-}CLTL} \cdot \theta_{CLTL} \cdot v_{o\text{-}TL}}{2\pi \cdot f_o \cdot N \cdot Z_{o\text{-}TL}}, \quad C_p = \frac{\theta_{CLTL} \cdot \left(Z_{o\text{-}TL}^2 - Z_{o-CLTL}^2\right)}{2\pi \cdot f_o \cdot N \cdot Z_{o\text{-}TL}^2 \cdot Z_{o\text{-}CLTL}} \tag{5}$$

The capacitance C_p can be implemented using shunt open stubs

$$2\pi \cdot f_o \cdot C_p = \frac{1}{Z_{OP\text{-}ST}} \cdot \tan\left(\frac{2\pi f_o}{v_{OP\text{-}ST}} \cdot l_{OP\text{-}ST}\right) \tag{6}$$

where $Z_{OP\text{-}ST}$ and $v_{OP\text{-}ST}$ are the characteristic impedance and phase velocity of the open stub transmission lines, respectively, and $l_{OP\text{-}ST}$ is the open stub length.

3. SIMULATED AND MEASURED RESULTS

In this section, the simulated and experimental results regarding the proposed unequal power divider are described. We designed an unequal power divider with a power ratio of $k^2 = 10$, an isolation component placed at the center position $\theta = 45°$, and an operating frequency of 1 GHz. The isolation component is a series circuit composed of a 15-Ω resistor and 1.8-pF capacitor. The Teflon substrate for the proposed unequal power divider had a dielectric constant of 2.2, a thickness of 0.787 mm, and a conductor thickness of 0.035 mm. The simulation was carried out using Microwave Office, which is a software developed by National Instruments.

Figure 4 shows the variation of isolation S-parameters as the isolation component position θ changes. In addition, Figure 5 shows the variation in resistor and capacitor values as θ changes. Figure 6 shows a photograph of the fabricated 10 : 1 unequal power divider. To implement the low impedance lines, we used Equations (5), and (6) The transmission line width, length ($W_{o\text{-}TL}$, d_{uc}) and open stub width, length ($W_{OP\text{-}ST}$, $l_{OP\text{-}ST}$) of the CLTL are listed in Table 1. Figure 7 shows the S-parameter results for the proposed divider. The 50-MHz center frequency shift is caused by the fabrication inaccuracy of the microstrip line. The insertion loss of $|S_{21}|$ is 11.1 dB and $|S_{31}|$ is 1.3 dB. The return loss of $|S_{11}|$ is 17 dB, $|S_{22}|$ is 15 dB, and $|S_{33}|$ is 17 dB. In addition, the isolation of $|S_{23}|$ is 25 dB.

Table 1: CLTL microstrip line — element dimensions for low characteristic impedances.

	$W_{o\text{-}TL}$ (mm)	d_{uc} (mm)	$W_{OP\text{-}ST}$ (mm)	$l_{OP\text{-}ST}$ (mm)	N
$Z_{o\text{-}CLTL} = 9.33\,\Omega$ (Z_{02})	5.2	2.9	1.0	39	3
$Z_{o\text{-}CLTL} = 8.89\,\Omega$ (transformer)	5.2	3.2	1.0	43	5

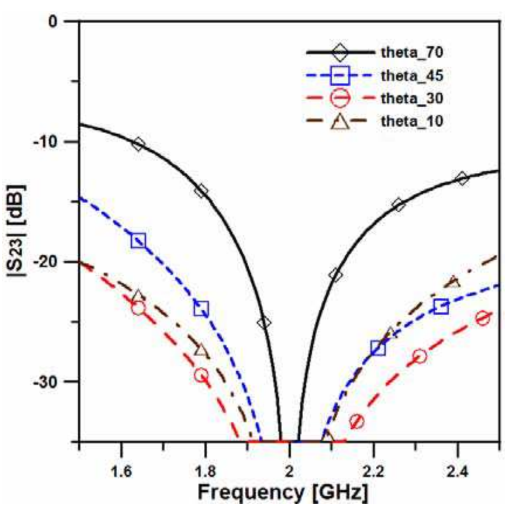

Figure 4: Simulation results for the isolation S-parameter variation of a 10 : 1 power divider versus θ.

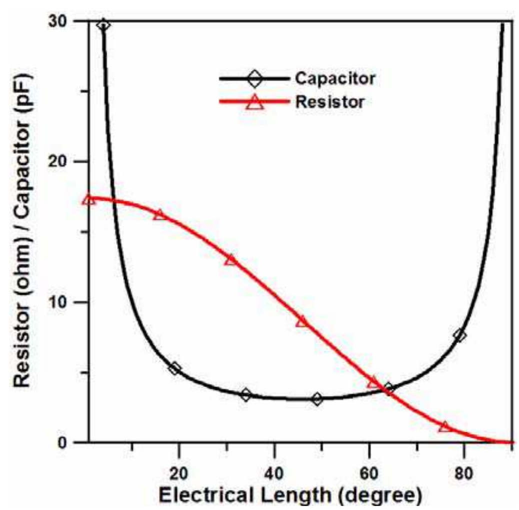

Figure 5: Variation of resistor and capacitor values versus θ.

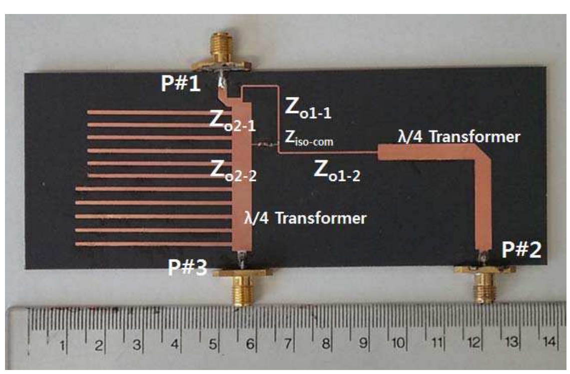

Figure 6: Photograph of fabricated 10 : 1 unequal power divider.

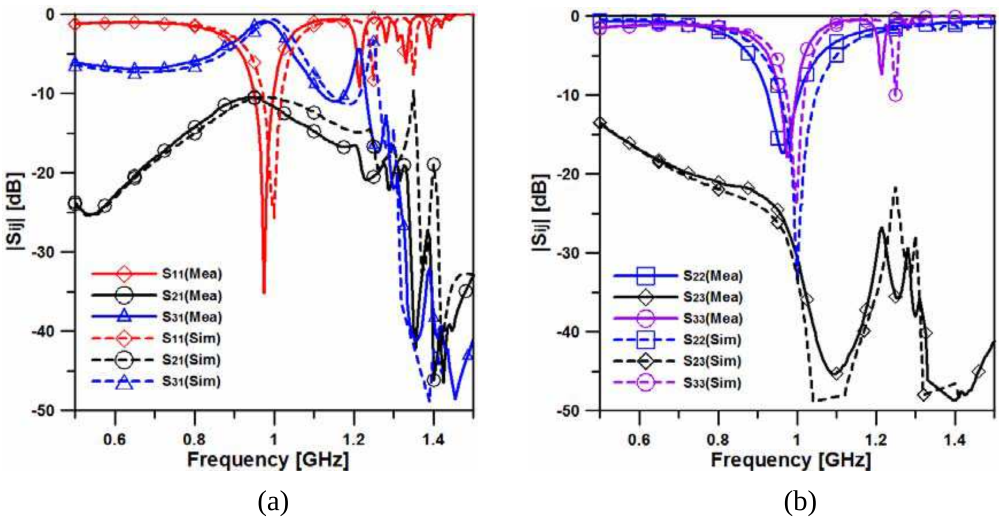

Figure 7: S-parameter results of proposed 10 : 1 unequal power divider, (a) $|S_{11}|$, $|S_{21}|$, $|S_{31}|$ and (b) $|S_{22}|$, $|S_{23}|$, $|S_{33}|$.

4. CONCLUSION

This paper presented a 10 : 1 unequal power divider with improved isolation. The series RC circuit of the isolation component is placed at the $\theta = 45^\circ$ position in the quarter-wave transmission line. Using a capacitive loaded transmission line of a small transmission line and a shunt open stub, the low impedance line of the 10 : 1 unequal power divider was realized. The proposed divider has good performance such as good port matching, low insertion loss and high isolation.

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