General Design Equations of *N*-Way Arbitrary Power Dividers

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Abstract---General design equation for an *N*-way power divider with arbitrary power split ratio is suggested. It consists of *N* transmission lines and *N* resistors and may be terminated in arbitrary impedances. Since a transmission line with too high characteristic impedance is difficult to realize in microstrip technology, an arbitrary design impedance *A* is introduce to control it. The *A* is arbitrary and positive value, and as many sets of design equations as possible may be produced depending design situation. Therefore, the design formulas containing *A* may be called "general design equations". To verify them, a 3-way power divider with a power split ratio of 1 : 2 : 4 has been fabricated in microstrip technology, and measured results are in good agreements with the predicted ones.

I. Introduction

The most popular *N*-way in-phase power divider was proposed by Wilkinson in 1960 [1]. He described a circularly symmetric power divider, which split a signal into *N*–equiphase, equiamplitude signals with an even or odd number of *N*. Since that time, there have been many trials for the *N*-way power dividers [2]-[5]. However, they are all for equal power dividers.

In this paper, an *N*-way power divider with arbitrary power split ratio will be introduced. It consists of *N* transmission lines with a quarter wave long and *N* resistors. If the power dividers are terminated in arbitrary impedances, any advantage to reduce the total size of integrated circuit can be expected, as asymmetric ring hybrids, asymmetric branch line hybrids and asymmetric three-port power dividers [6]-[14]. Therefore, the *N*-way power divider may be designed to have arbitrary termination impedance and perfect matchings and isolation between each output ports can be achieved. However, too high or low impedance of the transmission lines needs to be realized, which is one of realization problems.

To control it somehow, an arbitrary design impedance *A* is introduced. The *A* was suggested by Ahn and Wolff [6] for the three-port unequal power dividers and there are many sets of design equation depending on the *A*. Therefore, the design formulas containing *A* may be called general design equations. To verify the design method, a 4-way power divider with a power split ratio of 1: 2: 4: 8 has been simulated and a 3-way power divider with the ratio of 1: 2: 4 has been fabricated with microstrip technology. In this case, the characteristic impedance of the transmission lines are 85.7 Ω, 42.9 Ω and 21.4 Ω. Since the difference between 85.7 Ω and 21.4 Ω may not be ignored for equiphase outputs, two transmission lines with each 42.9 Ω are used, instead of realizing one transmission line of 21.4 Ω. The power divider has been designed at 3 GHz and measured results show good agreements with the simulated ones.

II. Analyses

An *N*-way arbitrary power divider with arbitrary power division ratio is depicted in Fig. 1 where all the transmission lines are $\lambda/4$ long. R_a, RT_1, RT_2 ...and RT_n are termination impedances, Z_1, Z_2....and Z_n characteristic impedances of the transmission lines and $P_1 : P_2 : P_3 .. : P_n$ is a power split ratio and port number is defined as shown in Fig. 1. The design formulas are

$$R_{TN} = \frac{P_{tot}}{P_N} A \qquad (1)$$

$$Z_N = \sqrt{R_a R_{TN} \left(\frac{P_{tot}}{P_N} \right)}$$

$$ZT_N = \sqrt{R_{TN} R_N}$$

where $P_{tot} = P_1 + P_2 + P_3 ..... P_N$, A is an arbitrary design impedance which can be determined by design situation [6], R_1, $R_2 \dots R_N$ are final output termination impedances and ZT_1, $ZT_2 \ldots ZT_N$ are the characteristic impedances of additional impedance transformers to transform R_{TN} into R_N.

The amount of power in dB delivered to each branch is calculated using

$$P_N = 10log_{10}\left(\frac{P_N}{P_{tot}}\right). \qquad (2)$$

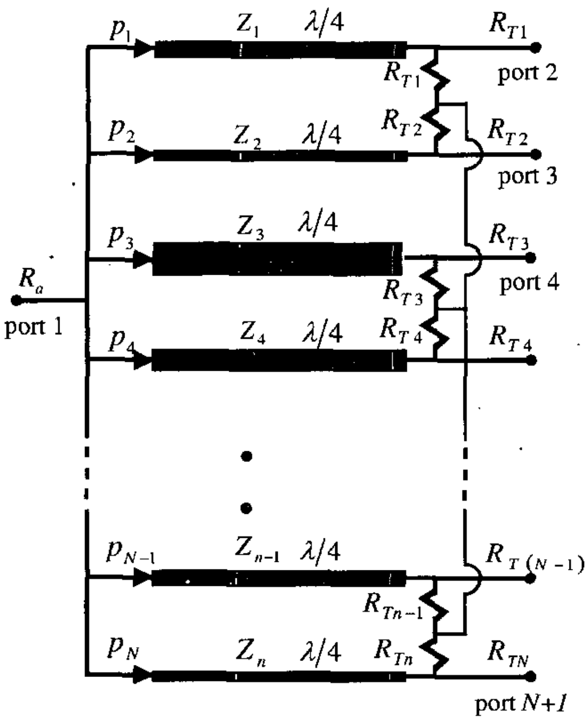

Fig. 1. N-way arbitrary power divider

Based on the design formula, a 4-way power divider has been designed at 1 GHz. Its power division ratio, $P_1 : P_2 : P_3 : P_4$ = 1: 2: 4: 8, $A = 2$ and R_a =25 Ω. In the case, Z_1 =106.6 Ω, Z_2 =53 Ω, Z_3 =26.5 Ω and Z_4 =13.2 Ω. Simulations of the power divider has been carried out under the ideal case and the results are plotted in Fig. 2 where the power division ratio shows in Fig. 2(a), the matching results in Fig. 2(b) and the isolation characteristics in Fig. 2(c).

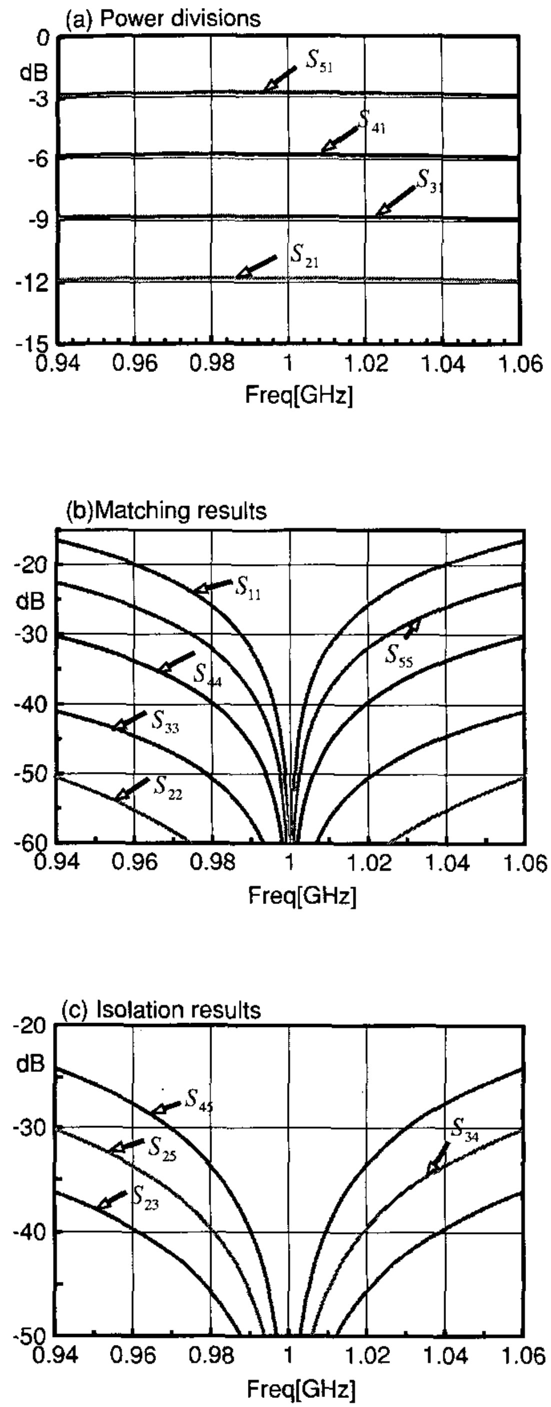

Fig. 2. Simulated results of a 4-way power divider with a power split ratio, 1 : 2 : 4 : 8.

(a) Power divisions

(b) Matchings

(c) Isolations.

Since the power divisions are in the ratio of 1: 2: 4: 8, the difference between them is 3 dB and the value of S_{51} is -2.73 dB based on (2). All the ports are perfectly matched and perfect isolations between each port can be achieved as shown in Figs. 2(b) and (c), respectively.

Table I. Design data for a 3-way power divider

$A=6$, $R_a=25\,\Omega$, $P_1:P_2:P_3=1:2:4$		
$R_{T1}=42\,\Omega$	$R_{T2}=21\,\Omega$	$R_{T3}=10.5\,\Omega$
$\varepsilon_r=2.88$, $h=508\,\mu m$		
$Z_1=85.7\,\Omega$ $w=500.4\,\mu m$ $\ell=16820.3\,\mu m$	$ZT_a=35.35\,\Omega$ $w=2178\,\mu m$ $\ell=15983\,\mu m$	
$Z_2=42.9\,\Omega$ $w=1653.5\,\mu m$ $\ell=16153.4\,\mu m$	$ZT_{T1}=45.82\,\Omega$ $w=1499.4\,\mu m$ $\ell=16213\,\mu m$	
$Z_3=21.4\,\Omega$ $w=4139\,\mu m$ $\ell=15603\,\mu m$	$ZT_{T2}=32.4\,\Omega$ $w=2441\,\mu m$ $\ell=15913\,\mu m$	

To verify the method suggested in this paper, a 3-way power divider has been fabricated with microstrip technology and designed at 3 GHz. Design data are given in Table I. As shown in the data, the power division ratio is $P_1:P_2:P_3$ = 1: 2: 4 and R_a = 25 Ω. The A is determined for the termination impedances, R_{T1}, R_{T2} and R_{T3} to have suitable values to realize, and $A=6$ in this case. The characteristic impedances of Z_1, Z_2 and Z_3 are 85.7Ω, 42.9Ω and 21.4Ω, respectively and their widths and lengths of microstrip lines on Teflon substrate ($\varepsilon_r=2.88$ and $h=508\,\mu m$) are given in Table I. However, the width of the transmission line of Z_3 is too wide and need to be realized in suitable transmission lines. Fig. 3 shows an equivalent circuit where one transmission line can be realized with two transmission lines with two times of the characteristic impedance. The ZT_a, ZT_{T1} and ZT_{T2} are characteristic impedances of the quarter wave impedance transformers to transform R_a, R_{T1} and R_{T2} into 50 Ω for the measurements. The ZT_a is that to transform R_a into 50 Ω, The ZT_{T1} is for transforming R_{T1} into 50 Ω and The ZT_{T2} is for R_{T2}.

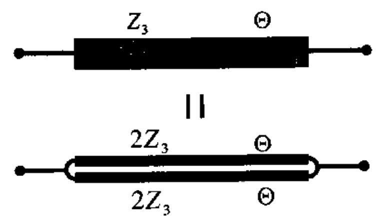

Fig. 3. An equivalent circuit to realize a transmission line with too low characteristic impedance

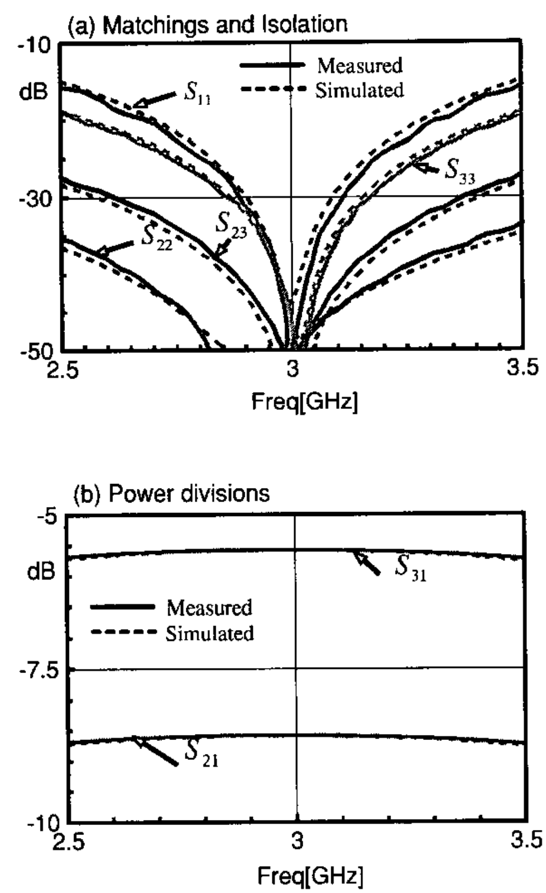

Fig. 4. Measured results of a 3-way power divider with a power split ratio, 1 : 2 : 4.

(a) Matchings and isolation

(b) Power divisions.

The port 4 terminated in R_{T3} is eliminated for easier measurements and the number of the remaining port is 3. The measured results are compared with simulated ones and the compared results are plotted in Fig. 4 where matchings and isolation results are in Fig. 4(a) and the power delivered to each port in Fig. 4(b). All the measured results are in good agreement with the simulated ones.

II. Conclusions

An *N*-way arbitrary power divider is presented. It consists of *N* transmission lines and *N* resistors and may be terminated in arbitrary impedances. Since too high characteristic impedance of microstrip line is restricted to realize, an arbitrary design impedance *A* is introduced to control it. Since the *A* is determined depending on the design situations and as many sets of design equations as possible may be produced, the design formulas may be called general design equations. Therefore, the *N*-way power dividers have advantages to reduce the total size due to arbitrary termination impedances and to realize easily without any restriction because of the *A*.

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