A 4 : 1 Unequal Wilkinson Power Divider

Jong-Sik Lim, Sung-Won Lee, Chul-Soo Kim, Jun-Seok Park, Dal Ahn, and Sangwook Nam

***Abstract*—This letter presents the design and measured performances of a microstrip 4 : 1 unequal Wilkinson power divider. The divider is designed using the conventional Wilkinson topology with the defected ground structure (DGS). The DGS on the ground plane provides an additional effective inductive component to the microstrip line. This enables the microstrip line to be realized with very high impedance of over 150 Ω. By employing the DGS to the unequal Wilkinson topology, 4 : 1 power dividing ratio can be obtained easily without any problem in realization, while it has been impractical to fabricate a 4 : 1 divider using the conventional microstrip line because of very thin conductor width and extremely low aspect ratio (W/H). As an example, a 4 : 1 divider has been designed and measured at 1.5 GHz in order to show the validity of the proposed DGS and unequal divider. The measured performances of the 4 : 1 unequal power divider well agree with the exactly same dividing ratio as that expected.**

***Index Terms*—4 : 1 power, defected ground structure, DGS, unequal power divider, Wilkinson power divider.**

I. Introduction

POWER dividers and combiners are used extensively in RF/microwave power amplifiers, linearizers, and many kinds of test equipment. Among all sorts of divider, the Wilkinson topology shows the basic concept of N-way power dividing by its simple structure [1]. The 2-way equal dividing is a typical application of the Wilkinson structure, because it is very simple to design, realize, and test. On the contrary to this simplicity of the 1 : 1 divider, the unequal Wilkinson divider has been used with strict restrictions in design and fabrication because it requires a microstrip line with very high impedance, i.e., extremely low aspect ratio (W/H) or very thin conductor width. For example, a 4 : 1 Wilkinson divider requires 158 Ω microstrip line. In practice, the characteristic impedance of a realizable microstrip has its limitation at around $120 \sim 130$ Ω, although it depends on the dielectric constant (ε_r) and the thickness of the substrate (H). It is almost impractical to realize a 158 Ω line using the conventional microstrip structure.

To overcome this limitation in realizable characteristic impedance, a much wider conductor for the microstrip line is required for the same characteristic impedance. Recently, it has been reported that the microstrip line with Defected Ground Structure (DGS) patterns in the ground plane has the stop band characteristics due to the equivalent effective inductance of the DGS [2]–[4]. One remarkable advantage of using the DGS under the microstrip line is that it is possible to increase the characteristic impedance by this additional effective inductance generated by the DGS. This inductance enables the characteristic impedance of the microstrip line to be much higher than that of a conventional microstrip without the DGS for the same conductor width.

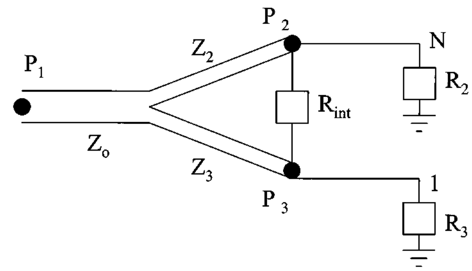

Fig. 1. Conventional N : 1 unequal Wilkinson power divider. Characteristic impedance and resistor values are shown in Table I.

TABLE I
CHARACTERISTIC IMPEDANCE AND RESISTOR VALUES OF N : 1 UNEQUAL WILKINSON POWER DIVIDER SHOWN IN FIG. 1

N	Z_2 [Ω]	Z_3 [Ω]	R_{int}[Ω]	R_2 [Ω]	R_3 [Ω]
2	51.5	103.0	106.1	35.4	70.7
3	43.9	131.6	115.5	28.9	86.6
4	39.5	158.1	125.0	25.0	100.0

In this letter, a design and measured performances of a 4 : 1 unequal Wilkinson power divider are presented. This divider has a 158 Ω microstrip line with reasonable width for easy fabrication. The 158 Ω microstrip line with the DGS has a much wider conductor width than that of the conventional microstrip line by 238% and a reduced length of $\lambda/4$ by 83%. The 4 : 1 divider has been fabricated using the general MIC technology and measured at 1.5 GHz. The measured performances, which are in very good agreement with the predicted ones exactly, will be shown in the following sections.

II. Design of a 4 : 1 Unequal Wilkinson Power Divider

Fig. 1 shows the conventional N : 1 unequal Wilkinson power divider [5], and Fig. 2 the proposed 4 : 1 Wilkinson divider which has a 158 Ω microstrip line with the DGS. All characteristic impedances of the microstrip section and resistor values are listed in Table I. It is relatively easy to realize the unequal divider for $N = 2$. However it becomes impractical

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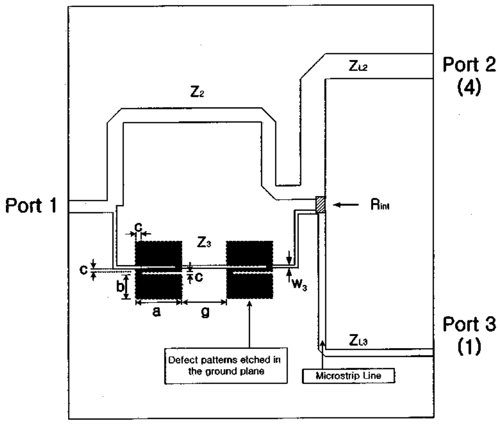


Fig. 2. The proposed 4 : 1 unequal Wilkinson power divider which has a 158 Ω microstrip line with the DGS. The two identical DGS patterns are etched in the bottom plane, i.e., the ground plane. The DGS dimensions are $a = b = g = 6$ mm and $c = 0.4$ mm. Z_{L2} and Z_{L3} are the $\lambda/4$ transformers between R_2, R_3, and Z_o.

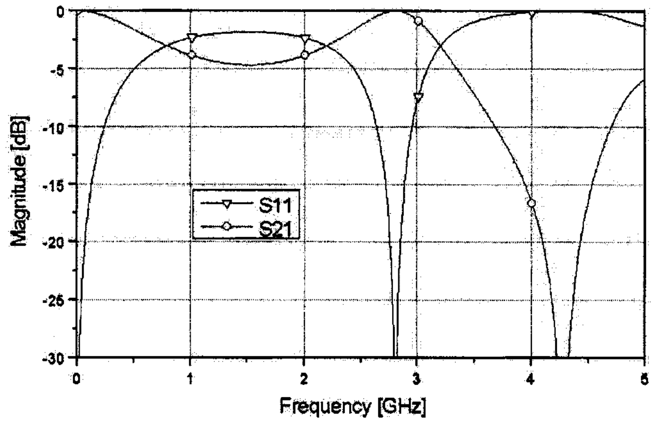


Fig. 3. Characteristics of the microstrip line with the DGS whose impedance is Z_3.

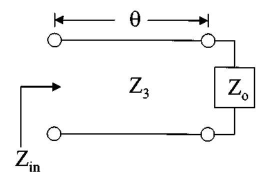


Fig. 4. Simplified model for the microstrip line with the DGS. Z_o (50 Ω) is the system characteristic impedance for the calculation of Z_3 and measurement. Here, Z_o is attached as a load to calculate Z_3.

to fabricate from $N = 3$ because Z_3 must be a very high impedance value. The impedance values of over 158 Ω for $N = 4, 5, \ldots$ are extremely undesirable.

Recently, it has been reported that microstrip lines with the DGS on the ground plane have increased effective inductance [2]–[4], which plays a great role in increasing the characteristic impedance of the microstrip line. We realized the 158 Ω microstrip line with the DGS and fabricated a 4 : 1 divider using it in order to show that the DGS can be applied in realizing very high impedance microstrip lines. The 4 : 1 Wilkinson divider was fabricated easily using this high impednace line.

We analyzed the microstrip line with the DGS using an electromagnetic simulator for finding the impedance value (Z_3). Z_3 is determined from Fig. 3, the simple transmission line theory depicted in Fig. 4, and (1)–(3). Fig. 3 shows the simulated characteristics of the lower path with the DGS shown in Fig. 2. This transmission line with the DGS can be simplified like Fig. 4. Here, Z_o, i.e., 50 Ω, is the system characteristic impedance for the calculation of Z_3 and measurement. It is attached to the line with the DGS as a load to calculate Z_3. When $\theta = \pi/2$ at center frequency, the magnitude of the reflection coefficient (Γ) is maximum. From the S_{11} at 1.5 GHz shown in Fig. 3 and (1), Γ can be calculated easily. Following (2) and (3) produce the Z_3, i.e., the impedance of microstrip line with the DGS. The calculated Z_3 was 158 Ω finally.

$$S_{11}\ [\text{dB}] = 20 \log |\Gamma| \tag{1}$$

$$Z_{\text{in}} = Z_o \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{2}$$

$$Z_3 = \sqrt{Z_{\text{in}} Z_o} = Z_o \sqrt{\frac{1 + |\Gamma|}{1 - |\Gamma|}}. \tag{3}$$

Two microstrip lines with 158 Ω of characteristic impedance were compared by their conductor width and length of $\lambda/4$. One is the proposed microstrip line with DGS and the other is conventional one. The substrate used is RT/Duroid 5880 with 2.2 of the dielectric constant and 31 mils of the thickness. At 1.5 GHz, the conductor width of 158 Ω (W_3 in Fig. 2) is 0.4 mm and the length of $\lambda/4$ is 32.3 mm for the line with the DGS, while they are 0.17 mm and 38.83 mm for the conventional microstrip line. There are large differences between the two widths (0.4 mm/0.17 mm $=$ 235%) and the two lengths of $\lambda/4$ (32.3 mm/38.83 mm $=$ 83%). The enlarged width and reduced length of the microstrip line mitigate the limit of low aspect ratio (W/H) for 158 Ω and give the smaller circuit.

III. Measured Performances and Discussions

Fig. 5 shows the photograph of the fabricated 4 : 1 Wilkinson divider which has the 158 Ω microstrip line with the DGS. The termination resistors, R_2 and R_3, are replaced by Z_{L2} and Z_{L3}, $\lambda/4$ transformers between R_2, R_3, and Z_o, for the practical measurement system. Fig. 6 shows the ideal performances calculated by a circuit simulator and the measured ones of the 4 : 1 Wilkinson divider. The measured power dividing ratio is exactly 4 to 1 at port 2 and port 3 over 1.2 to 1.8 GHz with excellent matching and isolation. To our knowledge, this is the first implementation of such kind of 4 : 1 unequal Wilkinson divider using MIC fabrication technology.

Another important issue of the proposed divider is the power handling capability. In order to increase the operating power, the conductor width of microstrip line should be as wide as possible. For the same characteristic impedance, microstrip lines with the DGS have much wider conductor than conventional ones. Therefore, the DGS can be a good choice for the case of handling high power.

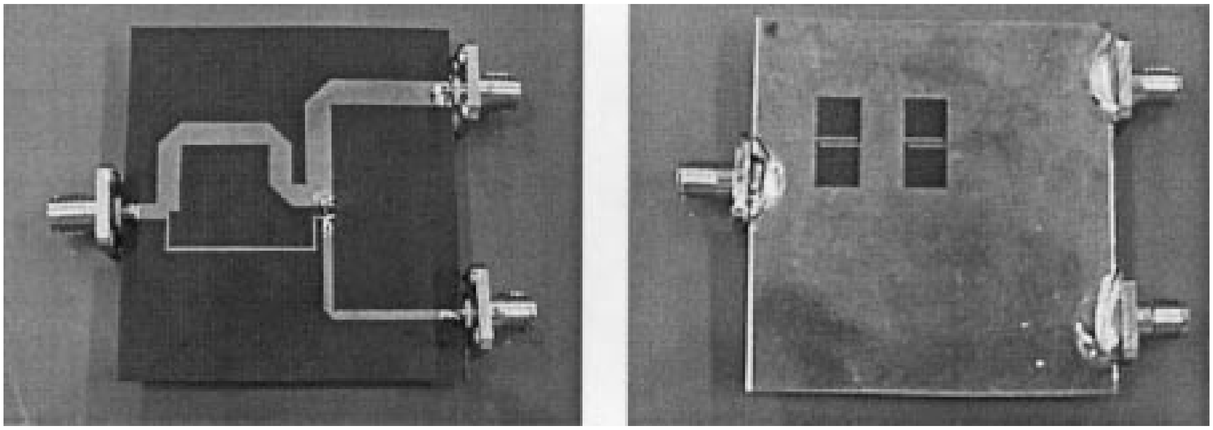
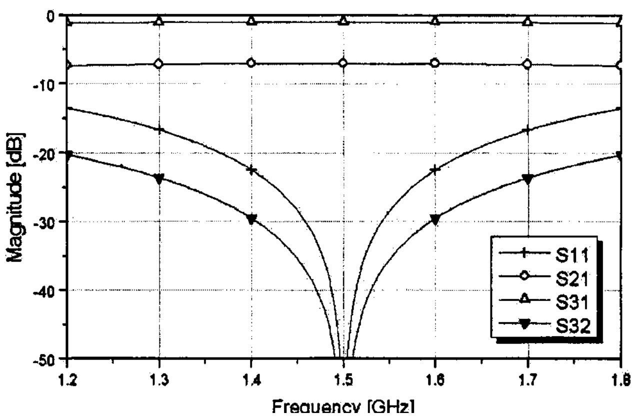
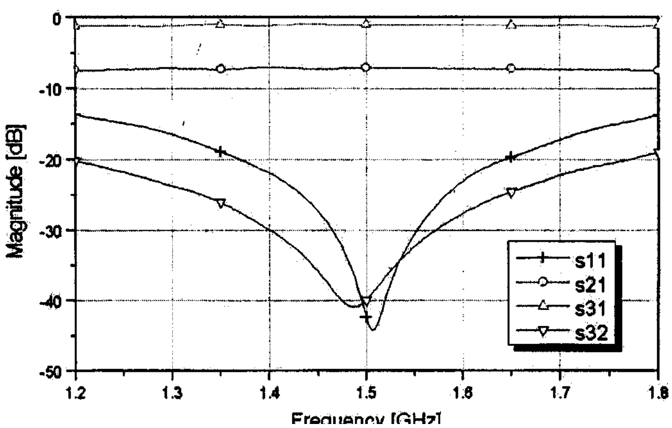


Fig. 5. Photograph of the fabricated 4 : 1 unequal Wilkinson power divider.



(a)



(b)

Fig. 6. Performances of 4 : 1 power divider: (a) Ideal performances and (b) measured performances of the fabricated divider.

IV. Conclusion

We proposed a 4 : 1 unequal Wilkinson power divider using a microstrip with the DGS on the ground plane. Due to the increased effective inductance of the DGS, the aspect ratio of the 158 Ω microstrip line has been increased to 235% and the length of $\lambda/4$ has been reduced to 83%. The fabricated conductor width of the 158 Ω microstrip line were 0.4 mm, while 0.17 mm for the conventional one. The enlarged conductor width and reduced length has a great advantage in design and realization such a high impedance line and smaller circuit. The fabricated 4 : 1 divider showed excellent matching and isolation, and exact dividing ratios of -1 dB and -7 dB at port 2 and port 3 without additional losses induced by the DGS over $1.2 \sim 1.8$ GHz.

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