DESIGN OF T-SPLIT POWER DIVIDERS USING DUMBBELL SHAPED DGS

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Abstract. Power dividers and power combiners are passive microwave components for power dividing and power combining. In this paper attention has been given towards the implementation of equal power divider using conventional $50\,\Omega$ microstrip line and dumbbell shaped defected ground structures (DGS). DGS increase the effective inductance and capacitance of the line, supporting slow-wave propagation. Thus, it increases the effective line impedance of the microstrip line. Consequently, all passive and active components that are implemented using DGS have a miniaturized size compared to conventional components. In this paper one 3 dB or equal power divider has been implemented at 1.2 GHz in the first step. In the next part of the paper, one unequal power divider of dividing ratio 2:1 has been designed using DGS with microstrip line. Those dividers have wide applications in microwave circuits and feeds of array antennas.

Keywords: microstrip, defected ground structure, equal power divider, unequal power divider.

Аннотация. Предложена и исследована конструкция микрополоскового симметричного (3дБ) и несимметричного (2:1) делителя мощности. Для согласования делителей используется отверстие в подложке в форме гантели. Неоднородность увеличивает эквивалентную индуктивность и улучшает согласование.

Ключевые слова: микрополосковая линия, неоднородная подложка, симметричный делитель мощности, несимметричный делитель мощности.

I. INTRODUCTION

Power dividers are passive microwave circuits. They are often of the equal-division (3 dB) type, but unequal power division ratios are also possible [1-2]. T-split power divider is a simple three port network that can be used for power division or power combining which can be implemented in virtually any type of transmission line medium [3]. It can be made to be matched at all ports for equal-split or unequal power division ratios.

This device is also potentially lossless as no reflected power from output ports enters into it. This divider has wide applications in microwave circuits and antenna feeds, but it has a narrow bandwidth, which has the best performance at a center frequency.

Defected Ground Structure (DGS) is the etched pattern of particular shape in the ground plane of microstrip line or CPW structure. DGSs affect the parameters of circuit that can be expressed as: making interference in the fields of ground plane, increasing permittivity, increasing effective inductance and capacitance properties in transmission lines, increasing effective characteristic impedance of the transmission line, providing a bandstop characteristic and supporting slow wave propagation [4-10].

In this paper, it is proposed to improve the effective line impedance with reduction in size and dimensions of the T-split power divider by the application of DGSs. Utilizing the feature of DGS one equal or 3dB power divider has been designed at the operating frequency of 1.2 GHz. Then the output divided powers are again divided equally in different levels. In the last step one 2:1 unequal power divider has been designed using the proper DGS structure.

II.PARAMETRIC STUDY AND EFFECT ON CHARACTERESTIC IMPEDANCE OF DGS

The dumbbell shaped DGS underneath a conventional microstrip line is shown in fig 1(a). The characteristic response of DGS provides one stop band characteristic due to the introducing of some inductance and capacitance by DGS as shown in fig 1(b). The head of the dumbbell is responsible for introducing some inductance 'L', transverse slot connecting the dumbbell heads is responsible for introducing some capacitance 'C'. Thus, the DGS structure can be represented by L-C equivalent circuit as 1st order elliptical bandstop filter as shown in Fig. 1(c). Therefore, implementation of DGS with microstrip line also changes the characteristic impedance of microstrip line.
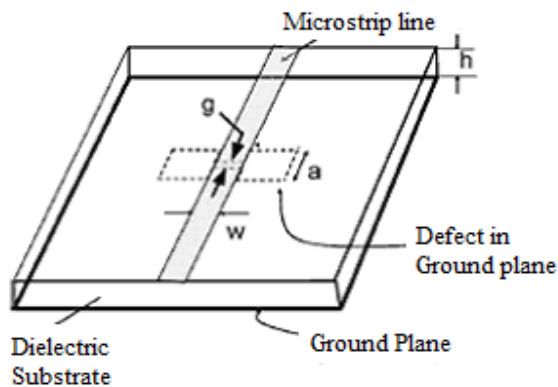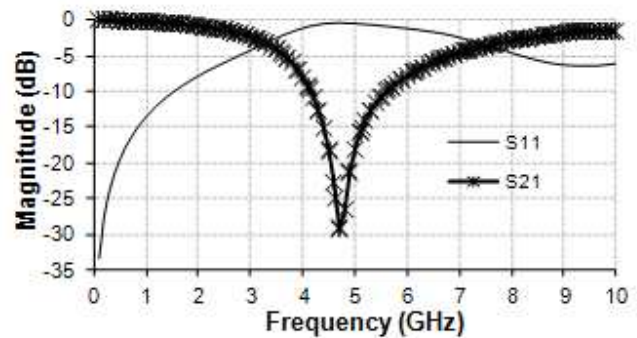

Fig. 1 (a). Dumbbell shaped DGS

Fig. 1 (b). Scattering Parameters

The structure is fabricated with FR4 substrate with dielectric constant 4.4, substrate height h = 1.58mm and negligible loss tangent.

Let, the different dimensions of the above structure are W = 3mm for $50\,\Omega$ microstrip line, DGS head length a = 5mm with width 4mm and two heads are connected by a transverse slot of length 4mm and width g = 0.4mm.
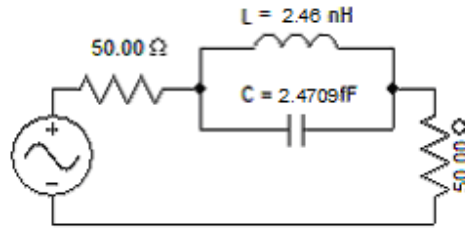
Fig. 1 (c). Equivalent Circuit

The equivalent L and C values can be obtained using the expressions as follows:

$$C = \frac{\omega_c}{2Z_0(\omega_0^{\,2} - \omega_c^{\,2})} \tag{1}$$

$$L = \frac{1}{4\pi^2 f_0^{\,2} C} \tag{2}$$

Where, f_0 and f_c are attenuation pole and attenuation zero frequencies respectively and $Z_0 = 50\,\Omega$ is the characteristic impedance of the microstrip line.

Thus, the obtained values of inductance, L=2.46 nH   and C=2.47095 fF of the taken DGS structure.

The etching of the defect on the ground plane, increases the path of the ground currents, thus increases the inductance per unit length, L. Increase in L results in the increase of the line impedance. However, the effect of C also has to be considered. The capacitance can be claimed to be decreased since the distance between the ground and the signal line has increased. In the standard microstrip line, the fields are confined between the line and the ground, at the distance ruled by the thickness of the substrate, but when the defect is placed beneath the line, the fields confined between the ground and the line are inclined, resulting in an increased distance; hence a lower capacitance. The low capacitance is another factor which increases the line impedance. So, the effect of both L and C causes the line impedance to increase.

The effective line impedance can be represented by

$$Z_{line} = \sqrt{\frac{L}{C}} \tag{3}$$

The variation of the different parameters with the variation of dumbbell head area by the variation of head length, 'a' keeping other parameters constant is shown in the following Table: 1.

Table 1. The variation of the different parameters with 'a'*(with line impedance 50 Ω)*

Length, 'a' (mm)	Inductance 'L' (nH)	Capacitance 'C' (pF)	Line impedance 'Z_{line}' (Ω)
2	1.529	2.54065	62.327
4	2.143	2.46834	72.73
5	2.46	2.47095	77.965
6	2.774	2.4295	82.094

Thus, the effect of DGS which is responsible for providing high impedance line can be explained in the above way.

The variation of inductance, capacitance and effective line impedance with the dumbbell head length 'a' as represented in table 1 are shown graphically in Fig. 2.
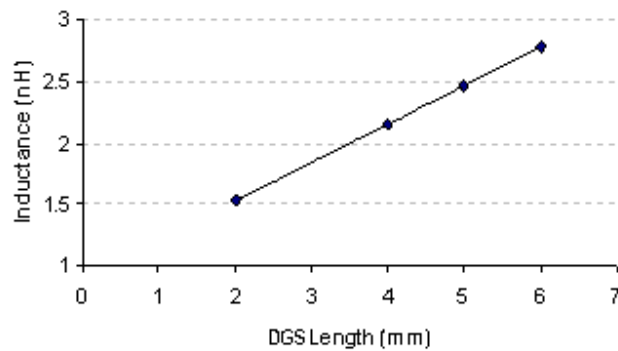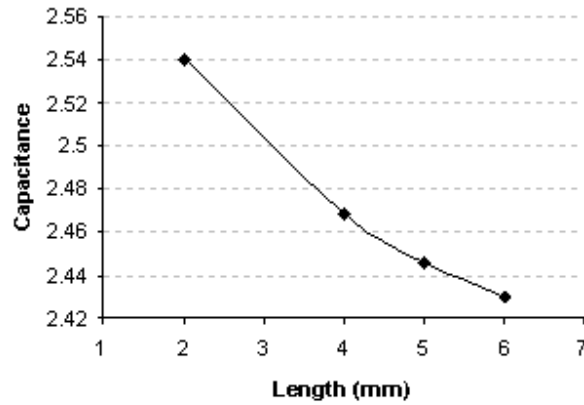

Fig. 2(a). Variation of inductance with length 'a'
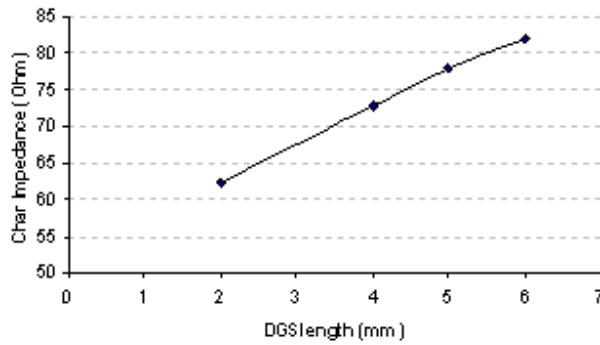
Fig. 2(b). Variation of capacitance with length 'a'

Fig. 2(c). Variation of effective line impedance with length 'a'

III. DESIGN PROCEDURE OF EQUAL SPLIT POWER DIVIDER

(a) 3-dB or Half power divider:

By definition, a 3 dB power divider is an ideally passive, lossless, and reciprocal three port device that divides power equally in magnitude with equal output phase [3]. From the general study as, one 3 dB (equal split) power divider can be made by using a $50\,\Omega$ input line and two $100\,\Omega$ output lines [3]. In this paper, the $50\,\Omega$ input line has been constructed using conventional microstrip line and two $100\,\Omega$ output lines are implemented using dumbbell shaped DGS underneath a conventional $50\,\Omega$ microstrip line.

From the analysis of the curve (Fig. 2(c)), mathematically with the help of curve fitting it can be found that the rectangular headed proposed DGS of head length, a = 9.48 mm is required to obtain the effective line impedance of $100\,\Omega$. Therefore, here one dumbbell shape DGS with two rectangular heads of length 9.48 mm and width 5mm connected with a transverse slot of length 4mm and width 0.4mm underneath a $50\,\Omega$ microstrip line is used to obtain $100\,\Omega$ output lines. Each $100\,\Omega$ line can be represented by equivalent lumped elements of inductance, L = 4.442 nH and capacitance, C = 438.8 fF.

The schematic diagram of the proposed 3dB or equal power divider is shown in the following Figure 3(a) and the characteristic response is shown in the Figure 3(b) .
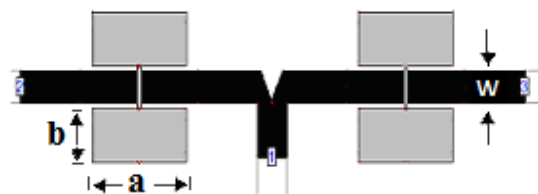

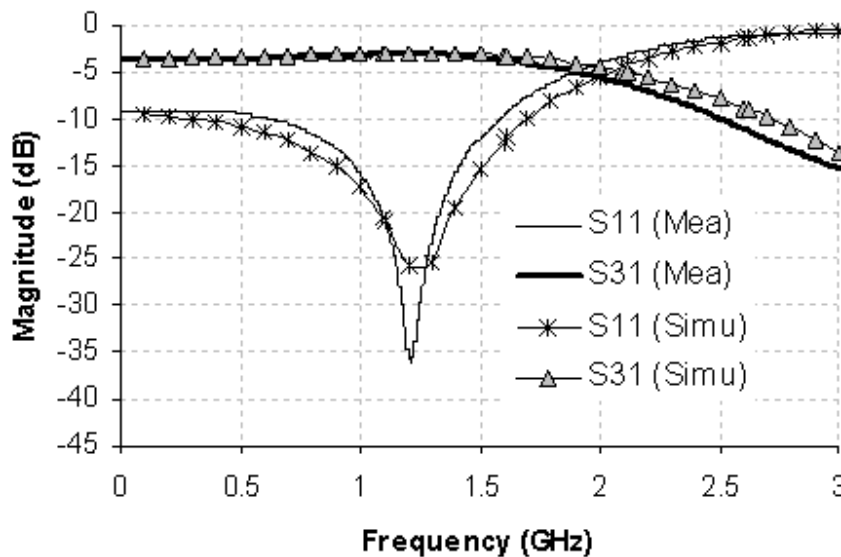Fig. 3(a). Proposed 3dB or equal power divider

Fig. 3(b). Scattering parameters

The 3dB power divider is implemented at center frequency 1.2 GHz and fabricated with FR4 substrate. The above simulated response shows that the input power (applied at port 1) is equally divided between two output ports (port 2 and port 3) and the value of output power is 3dB up to 2 GHz. The photonic view of the proposed structure is shown in the following Fig 4.

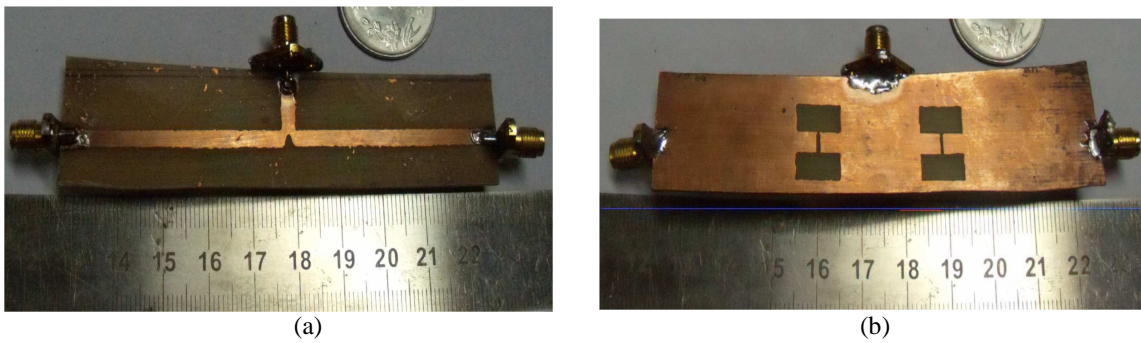(a)   (b)

Fig.4 Photonic View (a) Top plane, (b) Ground plane

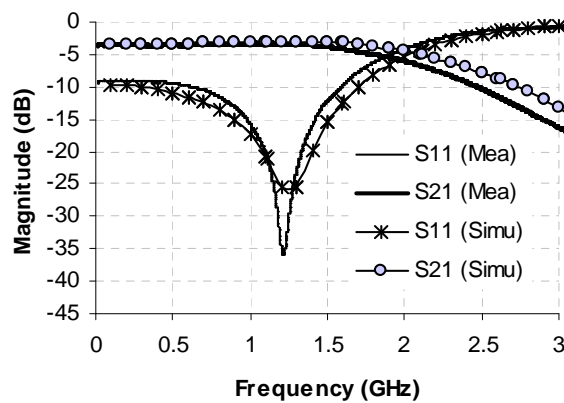The simulated and measurement responses are shown Fig. 4(c) and Fig. 4(d)

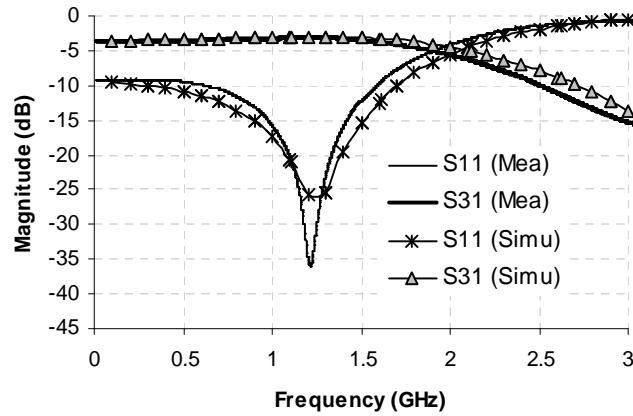Figure 4(c) S-parameters (simulated and measured) S_{11} & S_{21}

Figure 4(d) S-parameters (simulated and measured) S_{11} & S_{31}

From the above responses it has been obtained that the proposed structure provides 3dB coupling at the operating frequency 1.2 GHz and there is a good agreement between the simulated and measurement responses.

IV. DESIGN OF 2:1 POWER DIVIDER USING DGS

In this section attention has been given towards the design of one unequal power divider of dividing ratio 2:1 at the output port using the same concept of design of equal power divider.

(a) Calculation of output port impedances:

Fig. 5 shows the simple T- junction power divider structure. The T-junction power divider can be modeled as a junction of three transmission lines [3], as follows:
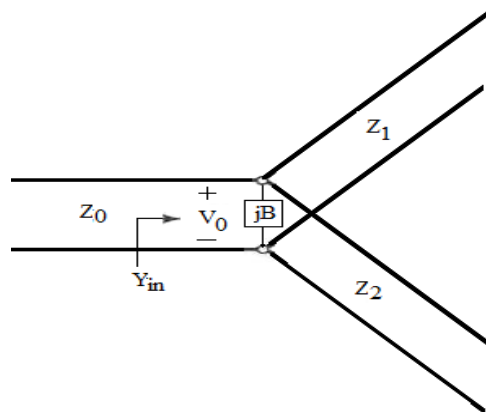

Fig 5.   Transmission line model of a lossless T-junction

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If the voltage at the junction is V_0, as shown in the Fig. 5, the output power to the matched divider is

$$P_{in} = \frac{1}{2}\frac{V_0^2}{Z_0} \qquad (4)$$

while, the output powers are

$$P_1 = \frac{1}{2}\frac{V_0^2}{Z_1} = \frac{1}{3}P_{in} \qquad (5)$$

$$P_2 = \frac{1}{2}\frac{V_0^2}{Z_2} = \frac{2}{3}P_{in} \qquad (6)$$

these results yield the characteristic impedances as

$$Z_1 = 3Z_0 = 150\Omega,$$
$$Z_2 = \frac{3Z_0}{2} = 75\Omega$$

then the input impedance to the junction is

$$Z_{in} = 75 \parallel 150 = 50\Omega$$

So, that the input is matched to the 50Ω source.

(b) Design Procedure :

75Ω line can be obtained with the help of microstrip line of width 1.4 mm and length 28mm through which two-third of the total input power will be passed.

The other output line i.e. 150Ω line can be obtained by Dumbbell shaped Diffective Ground structure (DGS) underneath 75Ω microstrip line. The variations of different parameters with the variation of the DGS head width keeping other parameters are tabulated in table 2:

Table: 2 The variation of the different parameters with 'b'*(with line impedance 75 Ω)*

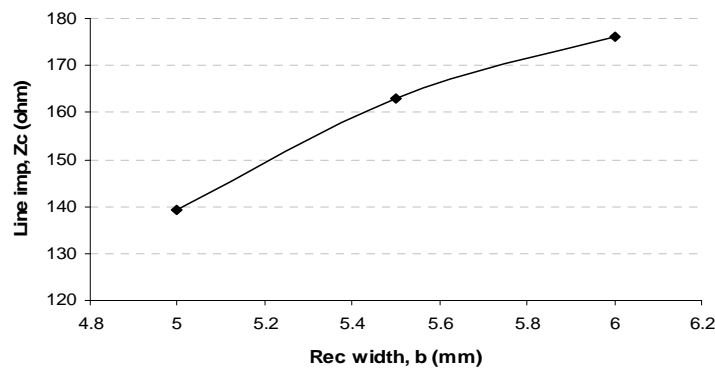| Rectangle Head width (mm)	Resonance freq, f_0 (GHz)	3dB stop band (GHz)	Inductance L(nH)	Capacitance C (fF)	Line impedance, Zc (Ω)
5.0	3.60	3.34	6.153	317.7	139.2
5.5	3.51	3.80	7.406	279.2	162.87
6.0	3.35	3.93	8.362	269.9	176

Fig. 6. Variation of effective line impedance with head width

Mathematically, with the curve fitting of the above response, it can be found that the rectangular width, 'b', and effective microstrip line impedance, 'Zc', related with each other by the following equation:

$$y = 0.0005x^2 - 0.1181x + 11.665 \tag{7}$$

Therefore, the obtained value of the rectangular width, 'b' for the $150\,\Omega$ line will be 5.2mm.

The proposed structure of the 2:1 unequal power divider is shown in the following Fig. 7(a) and the characteristic responses are shown in the Fig. 7(b). The circuit has been designed with FR4 substrate. The different dimensions are a = 10mm, b =5.2mm and two heads are connected by 4mm long, 0.4mm width transverse slot. The width of $50\,\Omega$ microstrip line is W = 3mm and that of $75\,\Omega$ microstrip line is W_1 = 1.4mm.
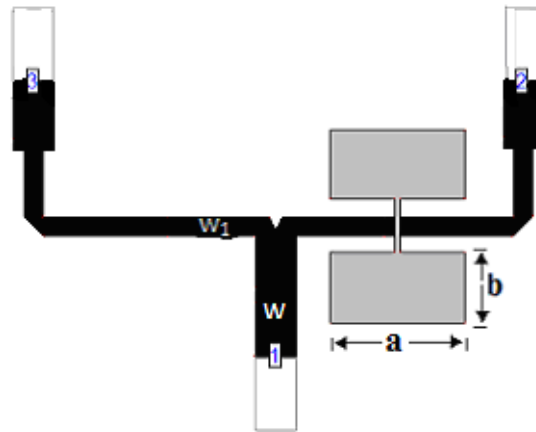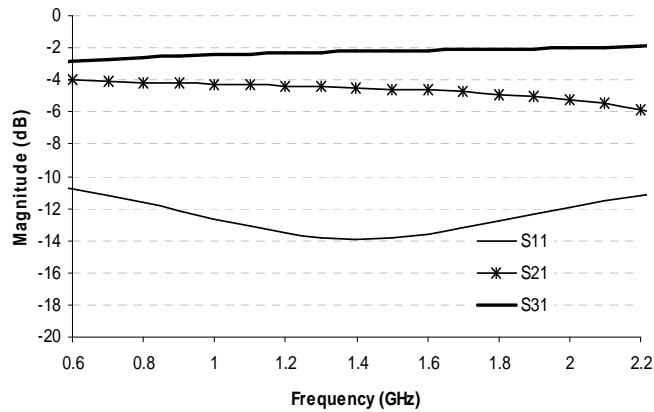
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Figure 7(a)   2:1 Power Divider using DGS

Figure 7(b)   Scattering Parameters

The above structure shows that the transmitted power at 1.2 is almost 4.1 dB and that of at port 3 is almost 2 dB i.e the input power divided in 2:1 ratio at port 2 and port 3. Thus, the proposed structure acts as a 2:1 power divider.

V. CONCLUSION

In this paper one important property of the DGS i.e. increment of the characteristic impedance of the transmission line compare to the conventional one has been used to design equal or unequal power divider. The characteristic impedance of the output line must be too high to design power divider. Design of high impedance line can

be possible utilizing very narrow width transmission line but practically fabrication of that narrow width is almost impossible. Therefore, the high impedance line can be easily achieved with conventional microstrip line along with DGS. One $100\,\Omega$ line is designed with conventional $50\,\Omega$ microstrip line which is required to design equal or 3 dB power divider. Similarly, one $150\,\Omega$ line can be achieved with $75\,\Omega$ microstrip line addition with DGS which is required for designing of unequal 2:1 power divider.

Acknowledgment

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