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DGS based Low Profile Micro Strip Coupler

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***Abstract*— This paper proposes an efficient technique to design a destructive ground structure (DGS) based low profile micro strip coupler. A dumbbell shaped DGS is used to design a microstrip coupler. Here, a micro strip directional coupler is designed first and then a dumbbell shaped slotted ground plane is used underneath the coupled region in order to relax the requirement for a narrow slot between the coupled lines. The designed micro strip coupler has a broadband performance and relaxed coupled-line spacing. Simulation results for an optimized DGS based coupler are demonstrated. The simulated and measured results show that the designed coupler exhibits a coupling of 10 ± 1 dB across the band 0.5 GHz to 4.5 GHz, when the spacing between the coupled lines is 0.328 mm. Without the slot in the ground plane, the spacing should be less than 0.199 mm to achieve the same value of coupling across that band. The designed coupler has a compact size with a dimension of 14.93 mm X 1.368 mm. The simulation results agree with the theoretical ones.**

***Keywords*— Microstip Coupler, 10 dB Coupler, destructive ground structure Introduction**

I. INTRODUCTION

Couplers are widely used in microwave circuit design. A very commonly used basic element in microwave system is the directional coupler. Its basic function is to sample the forward and reverse travelling waves through a transmission line or a waveguide. The common use of this element is to measure the power level of a transmitted or received signal. The model of a directional coupler is shown in Figure 1.

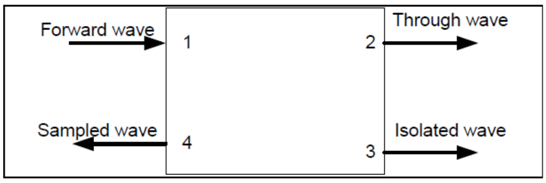


Fig.1: Directional coupler model

As seen in the figure, the coupler is a four-ports device. The forward travelling wave goes into port 1 and exit from port 2. A small fraction of it goes out through port 4. In a perfect coupler, no signal appears in port 4. Since the coupler is a lossless passive element, the sum of the signals power at ports 1 and 2 equals to the input signal power. The reverse travelling wave goes into port 2 and out of port 1. A small fraction of it goes out through port 3. In a perfect coupler, no signal appears in port 4. The directional coupler S-parameters matrix is:

$$S = \begin{pmatrix} 0 & 0 & -j\sqrt{1-k^2} & k \\ 0 & 0 & k & -j\sqrt{1-k^2} \\ -j\sqrt{1-k^2} & k & 0 & 0 \\ k & -j\sqrt{1-k^2} & 0 & 0 \end{pmatrix}$$

where k is the coupling factor (a linear value). (1)

One popular realization technique of the directional coupler is the coupled lines directional coupler; two quarter wavelength lines are placed close to each other. The wave travelling through one line is coupled to the other line. Such a coupler is shown in Figure 2.

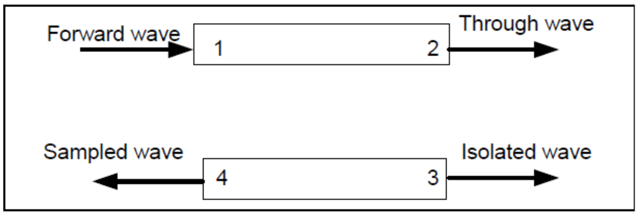


Fig.2: Coupled lines based directional coupler.

Since there is no ideal coupler available, some of the forward travelling wave is coupled into port 3. This mean that we may think that there is a reverse travelling wave when there isn’t. This is very critical in application where the directional coupler is used to measure the return loss of the device. By calculating 20 log(S31/S41) we can find the return loss of the device connected to port 2. If out coupler has no perfect directivity then out measurement is not accurate. There are few simple parameters to describe the functionality of a coupler:

- Insertion Loss: 20 log(S21) or 10 log(1 − k2).
- Return Loss: 20 log(S11).
- Coupling: 20 log(S31) or 20 log(k).
- Directivity: 20 log(S31) − 20 log(S41).

Recently, there has been an increasing interest in studying the microstrip line with various periodic structures including photonic bandgap (PBG) and defected ground structure (DGS) [1]-[8]. Each .periodic structure has its own properties and advantages. DGS, which is realized by etching only a few defects on the ground plane under the microstrip line, is also a kind of periodic structures [4]. Most of PBG applications are limited to providing deep and wide stopband performance for circuits. [1]-[2] Meanwhile, DGS has prominent advantage in extension its applicability to other microwave circuits such as filters, dividers, couplers, amplifiers, and so on. [3]-[8] PBG has been also used in filter designs to improve stopband performance by rejecting the higher order passbands, due to its inherent stopband behavior. Specially, both PBGs and DGS have been very effectively used to terminate the harmonics for power amplifiers. However, it is very difficult for implementing the PBGs or DGS circuits for the purposed of the harmonic termination to satisfy simultaneously the excellent passband and stopband characteristics [3].

In this paper a microstrip directional coupler is designed first and then a dumbbell shaped slotted ground plane is used underneath the coupled region in order to relax the requirement for a narrow slot between the coupled lines. The designed microstrip coupler has a broadband performance and relaxed coupled-line spacing. Simulation results for an optimized DGS based coupler are demonstrated.

I. *Basic Element of DGS*

DGS is realized by etching a defect in the ground plane of planar circuits, which disturbs the shield current distribution in the ground plane and change the characteristics of a transmission line such as line capacitance and inductance. The DGS applied to microstrip line creates a resonance in the circuit with the resonant frequency controllable by changing the shape and the size of the slot. The combination of DGS elements and microstrip line yields sharp resonances at microwave frequencies which can be controlled by changing shape and size of DGS circuitry [9].

To fulfill the different requirements, a variety of DGS shapes have evolve over times including dumbbell, periodic, fractal, circular, spiral, L and H shaped structures [10], [11]. The basic element of DGS is shown in Fig.3 which is a resonant gap or slot in the ground surface placed directly under the transmission line and aligned for efficient coupling to the line. Consequently DGS is able to provide a wide band-stop characteristics in some frequency bands with only one or small number of unit cells. Defected Ground Structures as the name implies, refers to some compact geometries commonly known as a “unit cell” etched out as a single defect or in periodic configuration with small period number on the ground plane of a microwave printed circuit board (M-PCB) to attribute a feature of stopping wave propagation through the substrate over a frequency range.

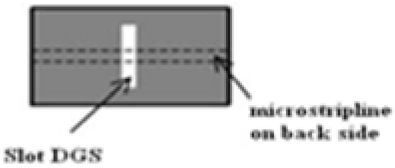


Fig.3: Basic element of DGS.

The DGS slots are resonant in nature. They have different shapes and sizes with different frequency responses and equivalent circuit parameters. The presence of a DGS under a printed transmission line actually perturbs the current distribution in the ground plane and thus modifies the equivalent line parameters over the defected region. Thus, it influences the guided wave characteristics and is found to exhibit (i) Band-gap properties as revealed due to electromagnetic band-gap (EBG) structures and (ii) a slow wave effect, which helps in miniaturizing the printed circuits.

II. PROPOSED DGS BASED COUPLER

10dB Directional Coupler Design:

The below pictures shows two parallel conductor strips on a dielectric substrate with a backplane metallization. Both the conductor strips have the width W, the height t and the length l. There is a finite gap S between the conductors. The substrates height is denoted by h. With the gap between the conductor strips small enough a capacitive as well as inductive coupling occurs. Such a microstrip structure is called “microstrip coupled lines".

There are two types of directional couplers: backward (coupling from port 1 to port 4) and forward (coupling from port 1 to port 3) couplers. The S-parameters of an ideal directional backward coupler are as follows - with C denoting the coupling coefficient.

$$S_{21} = \sqrt{1 - C^2}$$
$$S_{41} = C$$
$$S_{31} = 0$$
$$S_{11} = S_{22} = S_{33} = S_{44} = 0$$

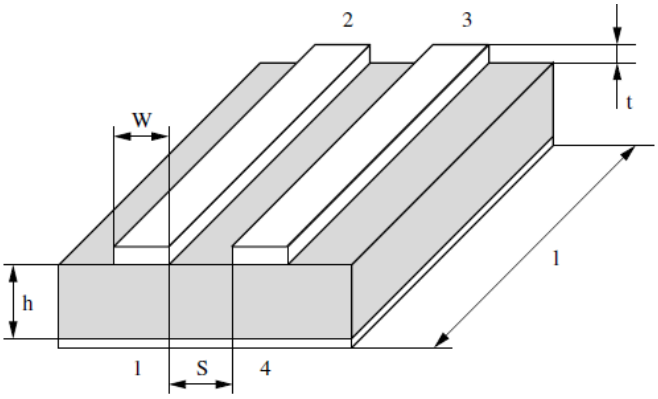


Fig.4: Micro strip directional coupler

In a three conductor system - as the microstrip coupled lines are - there are two types of modes: even and odd. Thus such a system is described by odd and even characteristic impedances ($Z_{L,o}$ and $Z_{L,e}$) and odd and even effective dielectric constants ("εr,eff,o and "εr,eff,e). The characteristic equations for an ideal backward coupler are

$$\varepsilon_{r,eff,e} = \varepsilon_{r,eff,o}$$
$$Z_{L,e} \neq Z_{L,o}$$

and those for an ideal forward coupler are

$$\varepsilon_{r,eff,e} \neq \varepsilon_{r,eff,o}$$
$$Z_{L,e} = Z_{L,o}$$

The S-parameters of the ideal directional forward coupler are as follows.

$$S_{21} = \sqrt{1 - C^2}$$
$$S_{31} = C$$
$$S_{41} = 0$$
$$S_{11} = S_{22} = S_{33} = S_{44} = 0$$

For both ideal - forward and backward - couplers the reflection coefficients are zero. Port 1 is called the injection port. Port 2 is the transmission port. In a backward coupler port 4 is the coupled port and port 3 is called the isolated port. In a forward coupler it's the other way around.

Design equations

In microwave circuits, backward line couplers are most wide spread. The basic design equations can be written as

$$C = \frac{Z_{L,e} - Z_{L,o}}{Z_{L,e} + Z_{L,o}}$$
$$\beta \cdot l = \frac{\pi}{2}$$
$$Z_L^2 = Z_{L,o} \cdot Z_{L,e}$$
$$Z_{L,e} = Z_L \cdot \sqrt{\frac{1+C}{1-C}}$$
$$Z_{L,o} = Z_L \cdot \sqrt{\frac{1-C}{1+C}}$$

with

$$\beta \cdot l = \frac{\pi}{2}$$
$$\leadsto l = \frac{\pi}{2 \cdot \beta} = \frac{\pi \cdot c}{2 \cdot \omega} = \frac{c}{4 \cdot f} = \frac{\lambda}{4}$$

the length *l* of such a coupler is defined by a quarter wavelength. Both the characteristic impedances can be computed by the reference impedance Z_L, i.e. 50 Ω, and the coupling coefficient *C*.

Applying the design equations for reference impedance Z_L = 50 Ω and the coupling coefficient

C as 10 dB at 2 GHz, linearizing the coupling coefficient,

$$C_{dB} = -10\text{dB}$$
$$\leadsto C = 10^{C_{dB}/20} = 10^{-0.5} \approx 0.316$$

Thus, the even and odd impedances are

$$Z_{L,e} = Z_L \cdot \sqrt{\frac{1+C}{1-C}} \approx 69.4\Omega$$
$$Z_{L,o} = Z_L \cdot \sqrt{\frac{1-C}{1+C}} \approx 36.0\Omega$$

Using Z_{oe} ($Z_{L,e}$) and Z_{oo} ($Z_{L,o}$) if we consider *Zoe* and *Zoo* for single line as Z_{ose} and Z_{oso};

$$Z_{ose} = \frac{Z_{oe}}{2} \quad \text{and} \quad Z_{oso} = \frac{Z_{oo}}{2}$$

Now what we should find $(w/h)_{se}$ and $(w/h)_{so}$ from Z_{ose} and Z_{oso}. To do that let us use single line equations:

$$\frac{W}{h} = \begin{cases} \dfrac{8e^A}{e^{2A} - 2} & \text{for W/h} < 2 \\ \dfrac{2}{\pi}\left[B - 1 - \ln(2B-1) + \dfrac{\varepsilon_{r-1}}{2\varepsilon_r}\left\{\ln(B-1) + 0.39 - \dfrac{0.61}{\varepsilon_r}\right\}\right] & \text{for W/h} > 2 \end{cases}$$

where $$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

At that point, we are able to find (w/h)se and (w/h)so by applying Zose and Zoso (as Zo) to the single line microstrip equations. Now we can come to a point where we reach the w/h and s/h for the desired coupled microstrip line using a family of approximate equations as following:

$$\frac{s}{h}=\frac{2}{\pi}\cosh^{-1}\left[\frac{\cosh\{(\pi/2)(w/h)_{se}\}+\cosh\{(\pi/2)(w/h)_{so}\}-2}{\cosh\{(\pi/2)(w/h)_{so}\}-\cosh\{(\pi/2)(w/h)_{se}\}}\right]$$

$$\left(\frac{w}{h}\right)_{se}=\frac{2}{\pi}\cosh^{-1}\left(\frac{2d-g+1}{g+1}\right)$$

$$\left(\frac{w}{h}\right)_{so}=\frac{2}{\pi}\cosh^{-1}\left(\frac{2d-g-1}{g-1}\right)+\frac{4}{\pi(1+\varepsilon_r/2)}\cosh^{-1}\left(1+2\frac{w/h}{s/h}\right)\qquad \varepsilon_r\le 6$$

$$\left(\frac{w}{h}\right)_{so}=\frac{2}{\pi}\cosh^{-1}\left(\frac{2d-g-1}{g-1}\right)+\frac{1}{\pi}\cosh^{-1}\left(1+2\frac{w/h}{s/h}\right)\qquad \varepsilon_r\ge 6$$

$$g=\cosh\left(\frac{\pi s}{2h}\right)\qquad d=\cosh\left(\pi\frac{w}{h}+\frac{\pi}{2}\frac{s}{h}\right)$$

As a result, we began from parameters *C*, *Zo* and ε_r and at the end find w/h and s/h.

$\lambda=\upsilon_p/f$ and $\upsilon_p=c/\sqrt{\varepsilon_{eff}}$, here c is the speed of light, $3.10^8\,m/s$

The selection of microstrip with $\varepsilon_r = 4.3$, $\mu_r = 1$, $h = 1.55$ mm, t = 7 µm leads to the design of 10 dB microstrip coupler with

$$W = 520\mu\text{m}$$
$$S = 199\mu\text{m}$$
$$L = 14.93\text{mm}$$

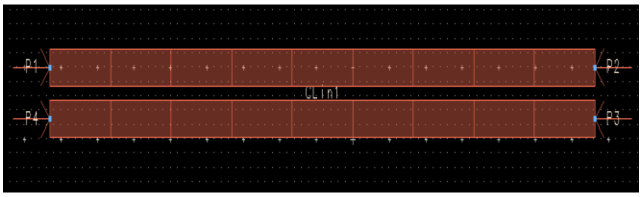


Fig.5: 10dB directional coupler with infinite ground

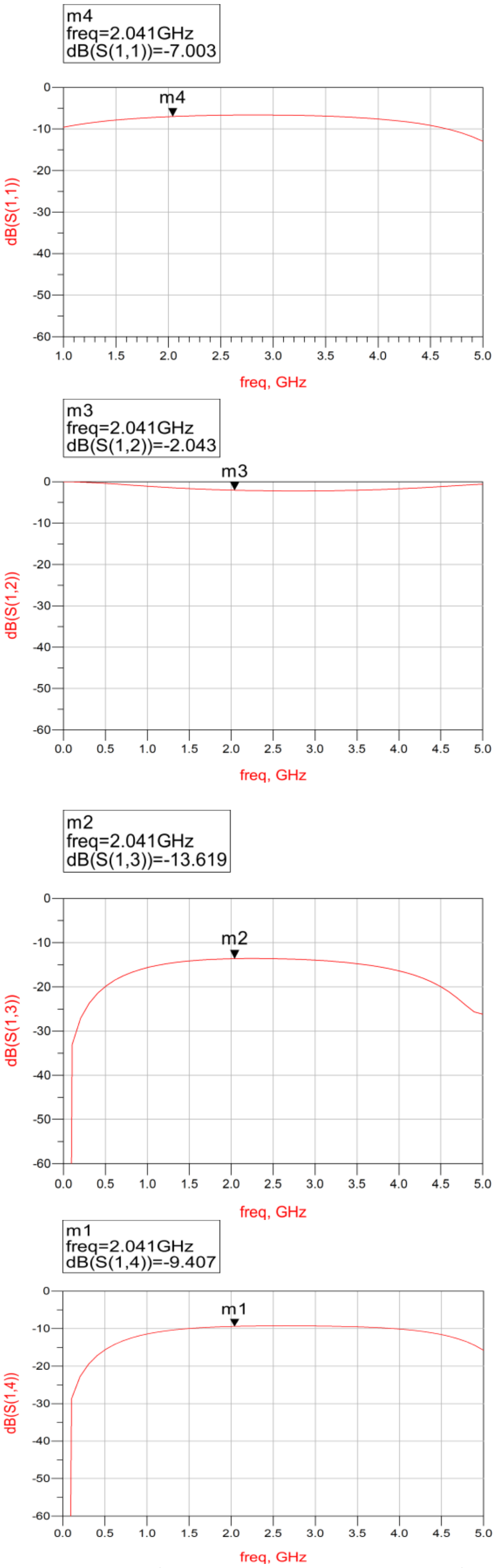


Fig.6: Parameters of 10dB directional coupler designed in fig.5

The 10dB directional coupler then designed with same dimensions with one dumbbell shape DGS slot as shown if fig.7(a) and then simulated for the frequency range of 1GHz to 5 GHz, The results observed for S14 as -8.704.

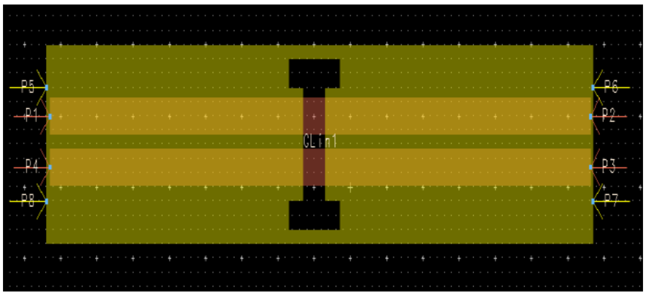


Fig.7(a): 10dB directional coupler with one dumbbell shape DGS slot

To improve the results further the number of DGS slots are increased to three and placed as shown in fig.7(b).The simulation results observed for this directional coupler as S14 to be -8.516.

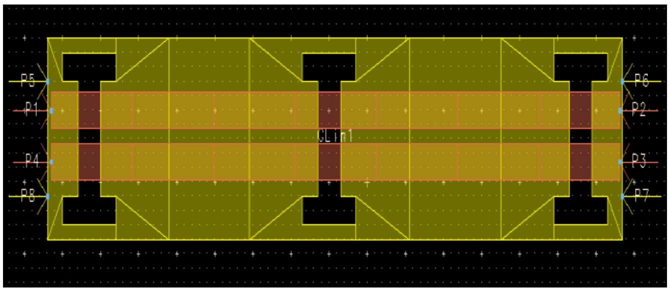


Fig.7(b): 10dB directional coupler with three dumbbell shape DGS slots

Furthermore the numbers of DGS slots in the 10dB directional coupler are increased up to five as shown in fig.7(c). The simulation result of this directional coupler for S14 as -8.264.

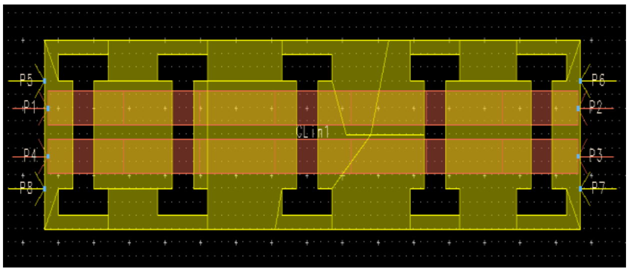


Fig. 7(c): 10dB directional coupler with five dumbbell shape DGS slots

The simulation results of the directional coupler designed as in fig.7(c) are shown in fig.10

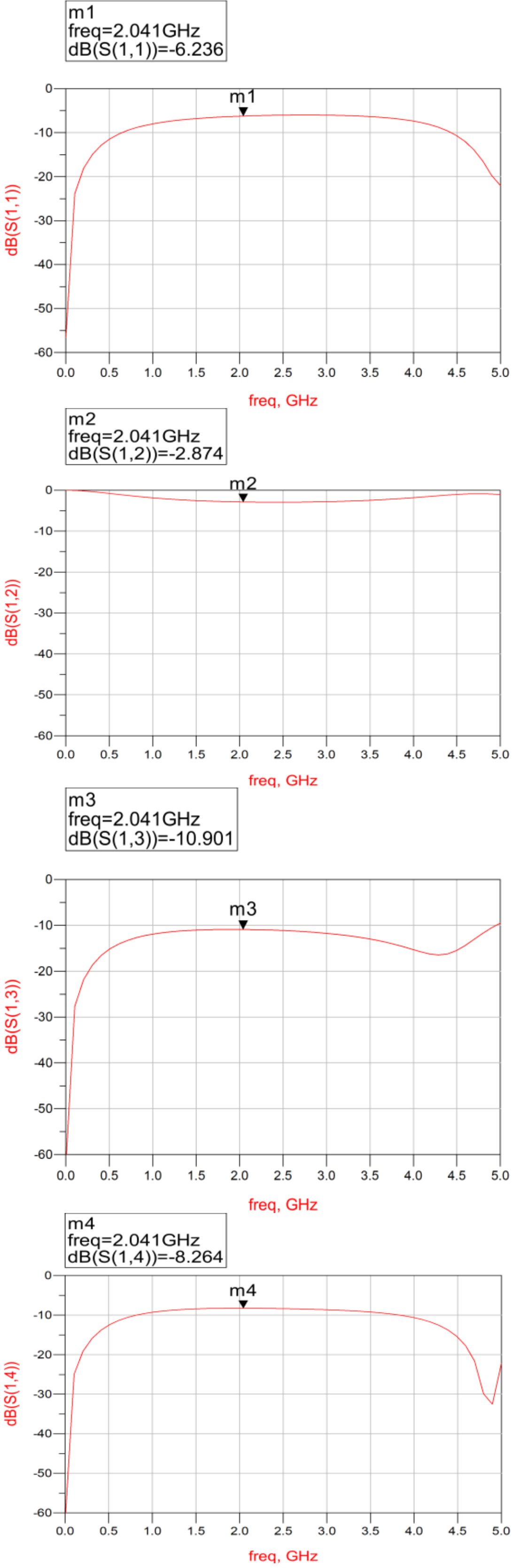


Fig.8: parameters of directional coupler designed in fig.7(c)

From the above results it is clear that to get the same coupling as with infinite ground can be achieved by relaxing the gap spacing, so the gap spacing for the 10dB directional coupler increased to 0.328mm as shown in fig.9. The simulation results for the same are shown in fig.10.

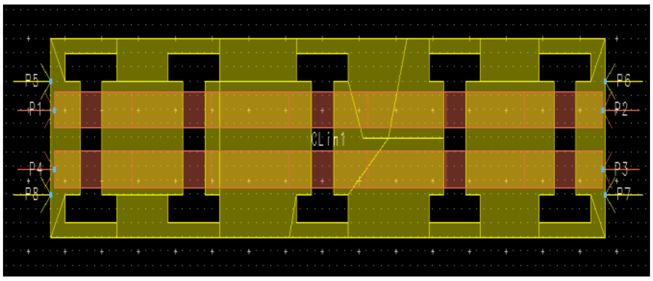
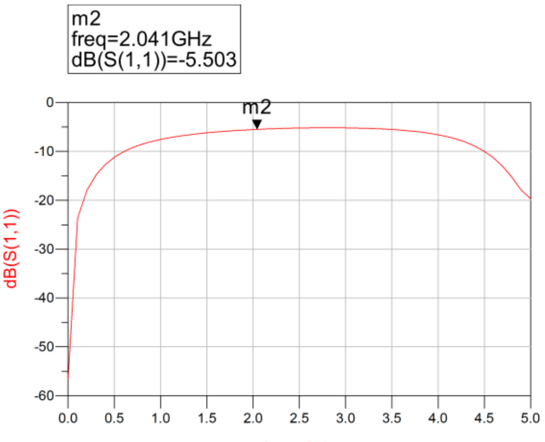
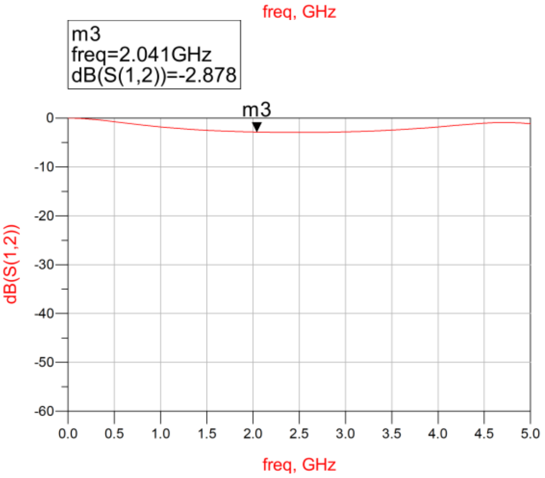
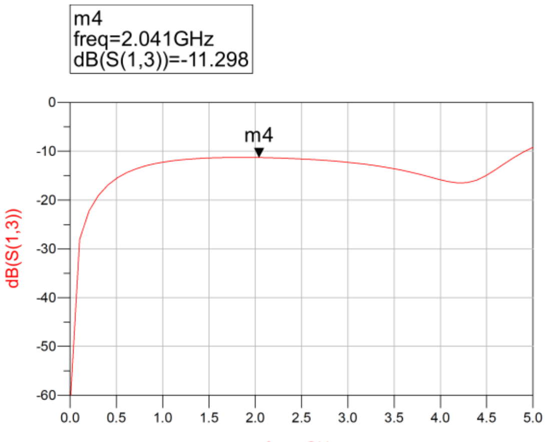


Fig.9: 10 dB directional coupler with increased gap spacing







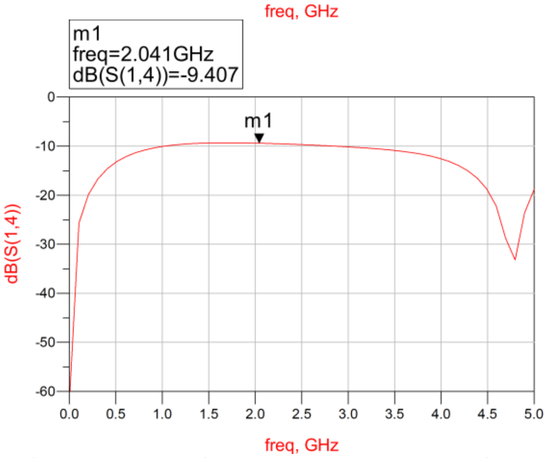


fig.10: parameters of directional coupler designed in fig.9

III. RESULTS AND DISCUSSION

The coupler given in Figs. 5, 7, and 9 are simulated on Agilent's ADS2011.05. The simulation results of the coupler are shown in Figs. 6, 8, and 10, respectively. The proposed DGS based coupler with five dumbbell shape DGS shown in Fig.7(c) is simulated for the frequency range from 1 GHz to 5 GHz and the simulation results are as shown in Fig.8. Table I shows that he increase in number of slots, requires much more relaxation in spacing to achieve the same coefficient of coupling as that of with infinite ground.

Coupler Specifications: 10 dB Coupler at 2 GHz (2.041 GHz)

Design Specifications:
W = 520 µm = 0.520 mm
S = 199 µm = 0.199 mm
L = 14.93 mm

SF= Spacing in case of finite ground

IV. CONCLUSIONS

An efficient technique to design a destructive ground structure (DGS) based microstrip directional coupler is proposed. A dumbbell shaped DGS is used to design a microstrip coupler. Due to the use of DGS, the spacing between two coupled lines can be relaxed minimizing the crosstalk. The designed microstrip coupler has a broadband performance and relaxed coupled-line spacing. Simulation results for an optimized DGS based coupler are demonstrated. The simulated and measured results show that the designed coupler exhibits a coupling of 10 ± 1 dB across the band 0.5 GHz to 4.5 GHz, when the spacing between the coupled lines is 0.328 mm. Without the slot in the ground plane, the spacing should be less than 0.199 mm to achieve the same value of coupling across that band.

	Infinite Gnd S = 0.199 mm	Finite Gnd	SF= 0.243 mm	DGS1	S1= 0.265 mm
S11 (dB) Return Loss	**-7.003**	-6.498	-6.197	-6.419	-5.990
S12 (dB) Through	**-2.043**	-2.423	-2.415	-2.545	-2.537
S13 (dB) Isolation	**-13.619**	-12.264	-12.441	-11.869	-12.116
S14 (dB) Coupled	**-9.407**	-8.904	**-9.402**	-8.704	**-9.403**

	DGS2	S2 = 0.289 mm	DGS3	S3 0.328 mm
S11 (dB) Return Loss	-6.339	-5.786	-6.236	-5.503
S12 (dB) Through	-2.682	-2.676	-2.874	-2.878
S13 (dB) Isolation	-11.431	-11.741	-10.901	-11.298
S14 (dB) Coupled	-8.516	**-9.403**	-8.264	**-9.407**

The designed coupler has a compact size with a dimension of 14.93 mm X 1.368 mm. The simulation results are in best agreement with the theoretical ones.

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