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Technique for Parameter Enhancement in Microwave Circuits

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Abstract – *Microwave circuits play an important role in wireless communication systems. This paper proposes an efficient technique to design a Destructive/Defected Ground Structure (DGS) based microwave circuits. A dumbbell shaped DGS is used to design a microwave circuits. Here, first a Chebyshev type bandpass filter is designed and then a DGS is inserted. Several simulations and comparisons showed the validity of the proposed equivalent circuit model and modeling method. Also, a microwave directional coupler is designed and then a dumbbell shaped slotted ground plane is used under the coupled region to minimize the requirement for a narrow slot between the coupled line. The designed microwave coupler has a broadband performance and relaxed coupled-line spacing. Simulation result for an optimized DGS based coupler is demonstrated. Finally, a DGS based Phase shifter is designed. These phase shifter gives good characteristic results in terms of insertion loss, return loss and phase shift. Simulation results are well in agreement with theoretical one.*

Key Words: Wireless communication, WiMAX, bandpass filter, directional coupler, phase shifter, parallel-coupled microwave.

1. Introduction

Modern microwave engineering is an exciting and dynamic field due to the explosion in demand for many new microwave-based applications that affect the daily life of nearly every person on the planet. Modern microwave engineering involves predominantly devices and circuit's analysis and design in contrast to the electromagnetic field theory orientation years ago. Thus, the design and development of new microwave devices and systems that serve the new generations of applications is a necessity. With the fast developments in systems that use microwave frequency bands, such as mobile telecomm, wireless medical monitoring & imaging, global positioning, satellites for data transmission, TV broadcasting, weather forecasting and remote sensing, wireless internet, healthcare (diagnosis and treatment), and even in computer engineering with bus systems working in the GHz bands, microwave engineering has been going through a period of resurgence over the last two decades. It has also undergone a radical transformation in recent years.

Compact sizes, low cost and high performance often meet the stringent requirements of modern microwave communication systems. Some new technologies such as(LTCC) Low-temperature co-fire ceramic technology,(LTCF) Low-temperature co-fire ferrite and structures such as Photonic band gap (PBG), DGS, (SIW) Substrate integrate wave-guide has been evolved to enhance the whole quality of system. Yablonovitch and John proposed PBG in 1987 [1][2] which implodes and utilizes metallic ground plane that breaks traditional microwave circuit design to surface components and distributions of the medium circuit plane. PBG is a periodic structure known for providing rejection of certain frequency band but, it's difficult to use it for the design of the microwave or millimeter-wave components. Similarly, another technique called ground plane aperture (GPA) incorporates microstrip line with a centered slot at the ground plane and it has attractive applications in 3 dB edge coupler for tight coupling and band pass filters for spurious band suppression and enhanced coupling [3][4].

With the introduction of GPA below the strip, line properties can be changed as characteristic impedance varies with the width of the GPA. Several compact and high performance components have been reported earlier, Electromagnetic band gap (EBG) or alternatively called photonic band gap (PBG) structures have periodic structure. Recently, there has been an increasing interest in microwave and millimetre wave Applications of PBG circuits. Various shapes of DGS structures have been appeared. Since DGS cells have inherently resonant property, many of them have applied to filter circuits.

The aim of this project is to design and analyse the Band pass filter, Direction coupler and Phase shifter using Defeated Ground Structure to get maximum return loss and minimum insertion loss with reduced ripples in pass region also reduce mutual coupling between two microstrips and to get required phase shift.

2. Defected Ground Structure

DGS is an etched periodic or non-periodic cascaded configuration defect in ground of a planar transmission line (e.g., microstrip, coplanar and conductor backed coplanar wave guide) which disturbs the shield current distribution in the ground plane cause of the defect in the ground. This disturbance will change characteristics of a transmission line such as line capacitance and inductance. In a word, any defect etched in the ground plane of the microstrip can give rise to increasing effective capacitance and inductance [14].

2.1 Basic Structure of DGS

The dumbbell DGS are composed of two *a* × *b* rectangular defected areas, *g* × *w* gaps and a narrow connecting slot wide etched areas in backside metallic ground plane as shown in Fig. 1. This is the first DGS.

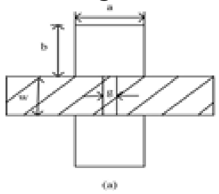


Fig. - 1: The first Dumbbell DGS unit [10].

2.1 DGS Unit

There have been two research aspects for adequately utilizing the unique performance of DGS: DGS unit and periodic DGS. In Fig. 4.2, it is shown that a variety of attached area shapes including spiral head, arrowhead-slot and "H" shape slots and so on. There also have been more complex DGSs so as to improve the circuit performance shown in Fig. 2, such as: a square open-loop with a slot in middle section, open-loop dumbbell and interdigital DGS.

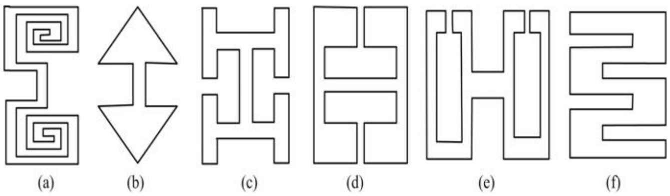


Fig. – 2: Various DGSs: (a) spiral head, (b) arrowhead-slot, (c) "H" shape slots, (d) a square open-loop with a slot in middle section, (e) open-loop dumbbell and (f) interdigital DGS [10].

DGS has more advantages than PBG as follows:

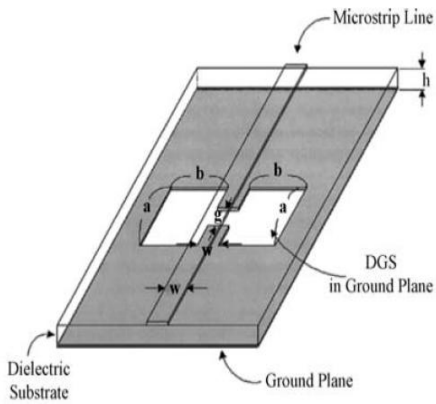
(1) The circuit area becomes relatively small without periodic structures because only a few DGS elements have the similar typical properties as the periodic structure like the stop-band characteristic.
(2) The simulated *S*-parameters for dumbbell DGS unit can be matched to the one-pole Butterworth-type low-pass response. For the DGS unit, DGS pattern is simply fabricated and its equivalent circuit is easily extracted.
(3) DGS needs less circuit sizes for only a unit or a few periodic structures showing slow-wave effect.
(4) Compared with PBG, DGS is more easily to be designed and implemented and has higher precision with regular defect structures. Therefore, it is very extensive to extend its practical application to microwave circuits [10].

Fig. 3 (a) shows the DGS microstrip with unit defect, which is etched off on ground plane and Fig. 3 (b) shows the newly proposed equivalent circuit [11].

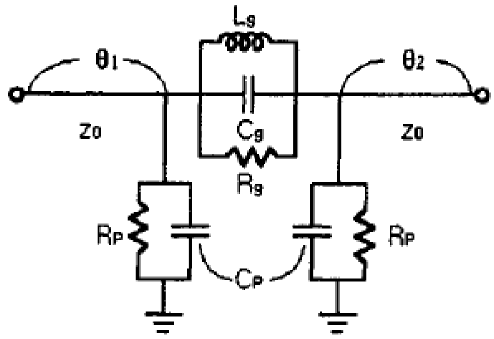
3. Implementation of DGS Based Bandpass Filter

3.1 Bandpass Filter without DGS

In this the band pass filter for wireless communication is proposed. In this work a way is given to design and fabricate bandpass filter for the WiMAX application for the frequency range from 5GHz to 7GHz with parallel-coupled micro strips which used the composite resonators and stepped impedance resonators for filter realization.



(a)



(b)

Fig. - 3: (a) 3-Dimensional view of the DGS unit section (b) Its equivalent circuit

The bandpass filter is designed for width *W*=25 mil, length *L*=250 mil and space *S*=25 mil. The schematic of the filter is shown in Fig. 4 (a). The schematic also shows all the specifications of the filter.

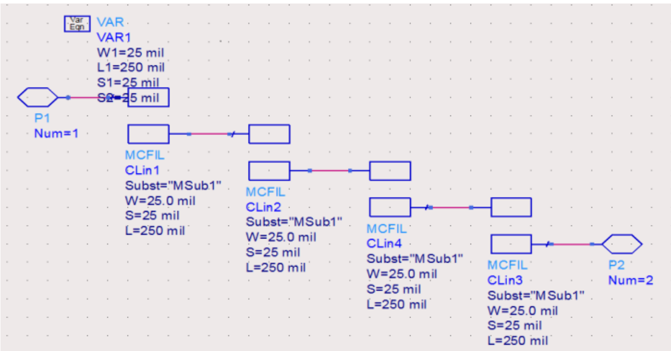


Fig. – 4: (a) Schematic of bandpass filter

The designed filter has the layout as shown in fig. 4 (b). In a practical implementation, the specification for losses in pass region can normally be higher than zero. Chebyshev approach exploits this not so strictly given specification values. It can be 0.01 dB, or 0.1dB.

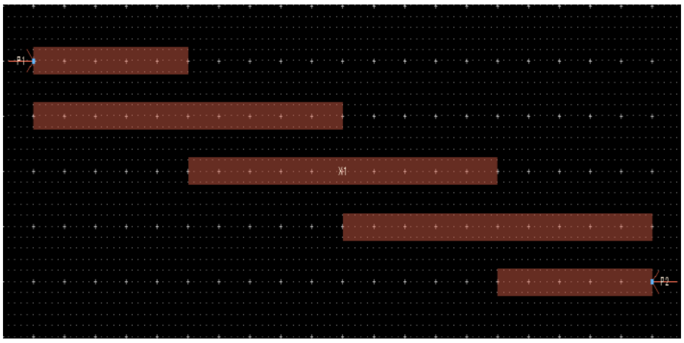


Fig. – 4: (b) Layout of band pass filter

Fig. 4 (c) shows the simulation results of the given bandpass filter without DGS

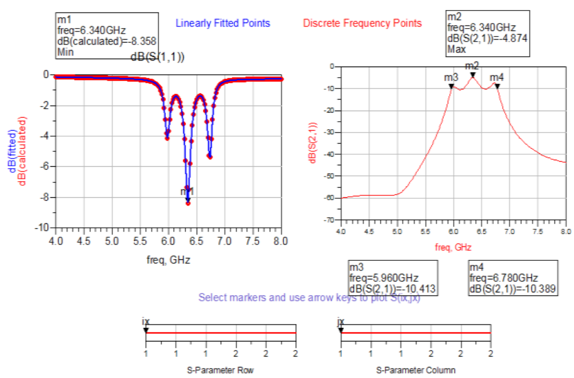


Fig. -4: (c) the simulation result of bandpass filter without DGS

Therefore from Fig. 4 (c) the return loss at 6.340 GHz is given as -8.358dB marked as M1 and the insertion loss is -4.874 dB at frequency 6.340 GHz marked as M2. The bandwidth of the filter between 5.960 GHz and 6.780 GHz is 820 MHz

3.2 DGS based Bandpass Filter

Now the bandpass filter with defeated ground structure for better performance and simulation result. The band pass filter with dumbbell shape DGS is proposed to remove the ripples in pass band region.

3.2.1 Bandpass filter with two dumbbell shaped DGS

The two dumbbell shape DGS are placed near the feed point as shown in the layout which is shown in Fig. 5. (a).

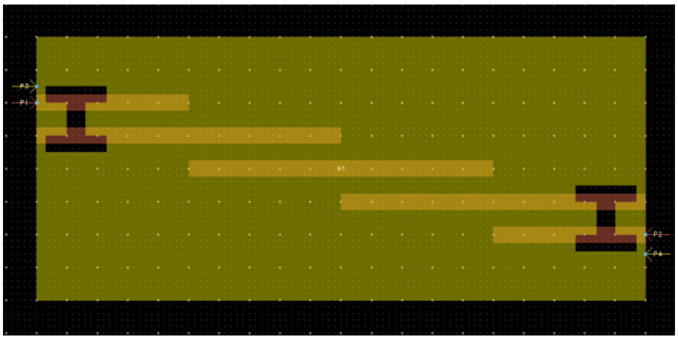


Fig. -5: (a) Band pass filter with two dumbbell shaped DGS

The simulation result of two dumbbell shape DGS band pass filter is shown in fig. 5 (b). Therefore, from Fig. 5 (b) the return loss at 6.680 GHz is given as -22.461 dB which is shown by pin M1 and the insertion loss is -2.22dB at frequency 6.680 GHz which is shown by pin M2. The band width of this bandpass filter is 1.06 GHz which is calculated using M3 and M4.

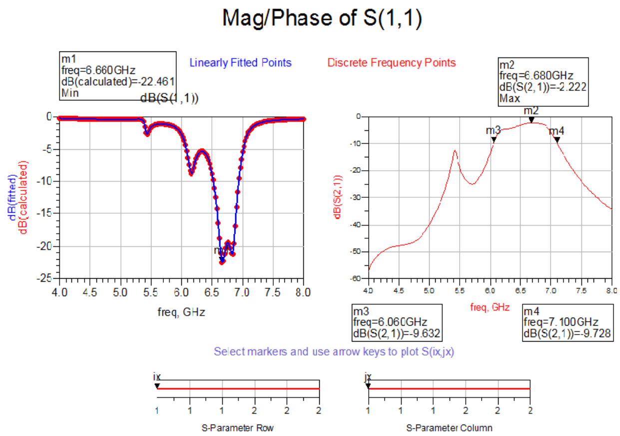


Fig. - 5: (b) The simulation result of band pass filter with two DGS

3.2.2 Bandpass filter with four dumbbell shaped DGS

Furthermore the number of dumbbell shape DGS are increased to get the better result. The schematic of this proposed filter with four dumbbell shaped DGS is as shown in Fig. 6 (a).

The simulation result of two dumbbell shape DGS band pass filter is shown in Fig. 6 (b).

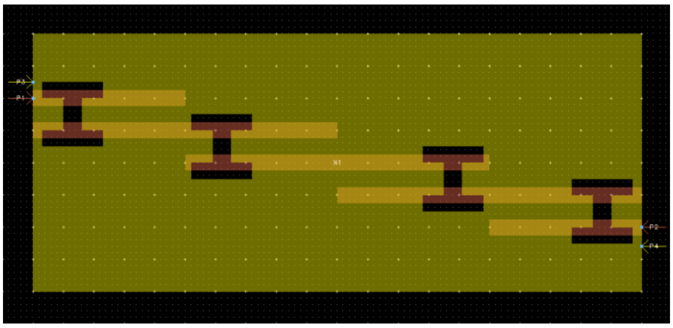


Fig. – 6: (a) Band pass filter with four dumbbell shape DGS

Therefore from Fig. 6 (b) the return loss at 5.860GHz is given as -24.722dB which is shown by pin M1 and the insertion loss is -3.024dB at frequency 5.280GHz which is shown by pin M2. The band width of this bandpass filter is 2.08GHz which is calculated using M3 and M4.

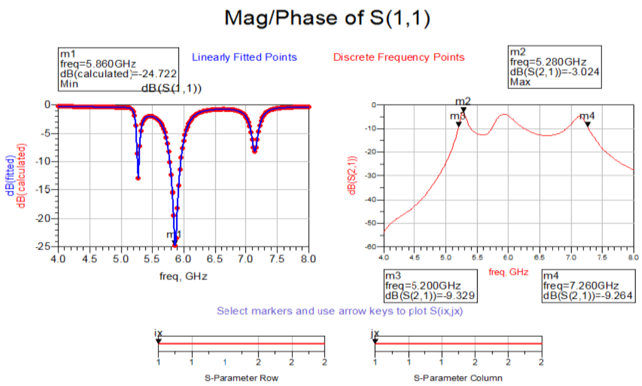


Fig. - 6: (b) the simulation result of bandpass filter with four dumbbell shape DGS.

3.3 OBSERVATION TABLE

Table-I: Various Parameters of Bandpass filter

FILTER	RETURN LOSS	INSERTION LOSS	BANDWIDTH
BANDPASS FILTER WITHOUT DGS	-8.358dB at 6.340GHz	-4.874dB at 6.340GHz	820MHz
BANDPASS FILTER WITH TWO DGS	- 22.461dB at 6.680GHz	-2.222dB at 6.680GHz	1.06GHz
BANDPASS FILTER WITH FOUR DGS	-24.722dB at 5.860GHz	-3.024dB at 5.280GHz	2.08GHz

4. DGS BASED MICROSTRIP COUPLER

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 Fig. 7.

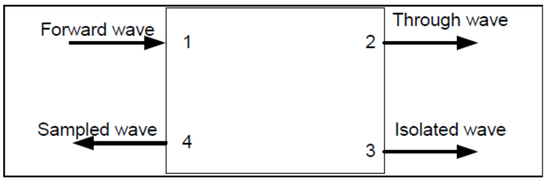


Fig. -7: Directional coupler model

As seen in the fig. 7, the coupler is a four-port 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:

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

Where *k* is the coupling factor (a linear value).

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 Fig. 8.

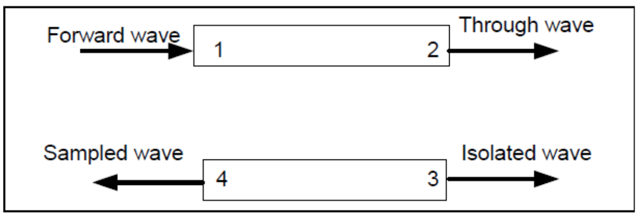


Fig. -7: Coupled lines based directional coupler.

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 (S_{31}/S_{41}) 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 (S_{21}) or 10 log ($1 - k^2$).
- Return Loss: 20 log (S_{11}).
- Coupling: 20 log (S_{31}) or 20 log (k).
- Directivity: 20 log (S_{31}) – 20 log (S_{41}).

4.1 10 dB Directional Coupler Design

The fig. 8 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".

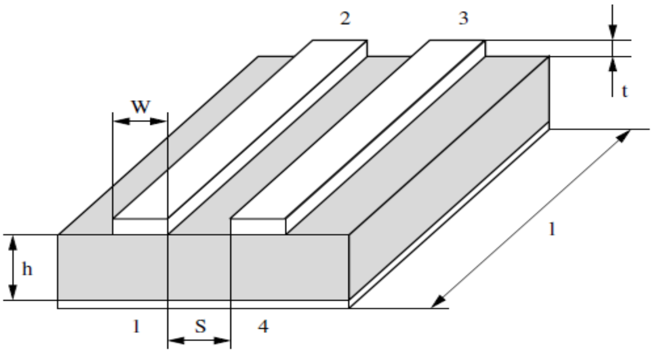


Fig. -8: Microstrip directional coupler

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.

$$S_{21} = \sqrt{1 - C^2}$$

$$S_{41} = C \qquad 2$$

$$S_{31} = 0$$

$$S_{11} = S_{22} = S_{33} = S_{44} = 0$$

For both ideal - forward and backward - couplers the ref lection 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.

4.1.1 10 dB directional coupler with infinite ground

Fig. 9 (a) shows coupling strips design in ADS software. Coupling strips are of dimension W = 520 µm = 0.520 mm, L = 14.93mm and spacing between coupling strips are S = 199 µm = 0.199mm. There are total 4 ports in coupling strips, port 1, port 2, port 3 and port 4 respectively. Substrate used for this design is Fr_4 with dielectric constant ε_r = 4.4 and height of substrate used is 1.6 mm.

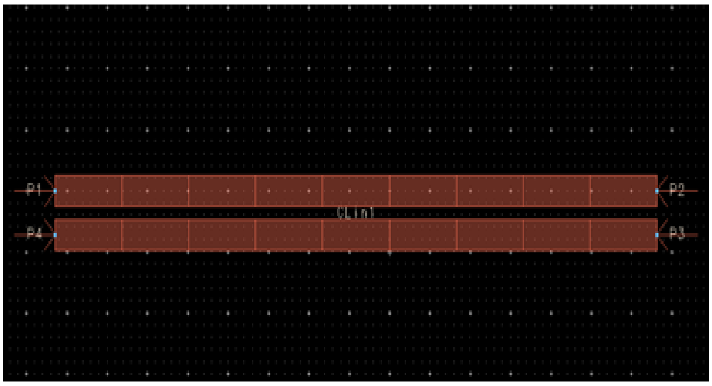


Fig. -9: (a) 10 dB directional coupler with infinite ground

Fig. 9 (b) shows simulated output of 10d directional coupler strips. Here coupling loss between two strips is -9.407dB.

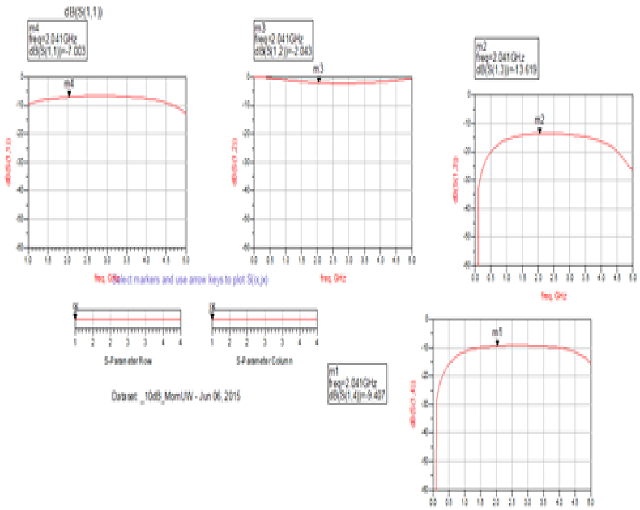


Fig. -9: (b) the simulated result of 10 dB directional coupler with infinite ground

4.1.2 10 dB directional coupler with finite ground

Now the 10dB directional coupler is then designed with same dimensions and finite ground is applied under the structure which is shown in Fig. 10 (a) and then simulated for the frequency range of 1GHz to 5 GHz

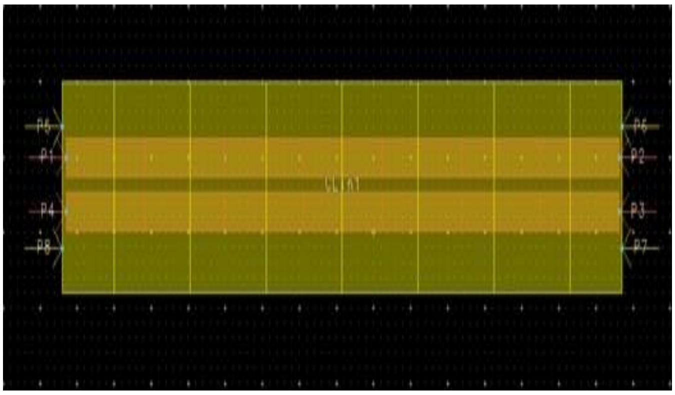


Fig. -10: (a) 10dB directional coupler with finite ground

The simulated result for observed for 10dB directional coupler with finite ground as -8.904 dB coupling loss as shown in Fig 10 (b).

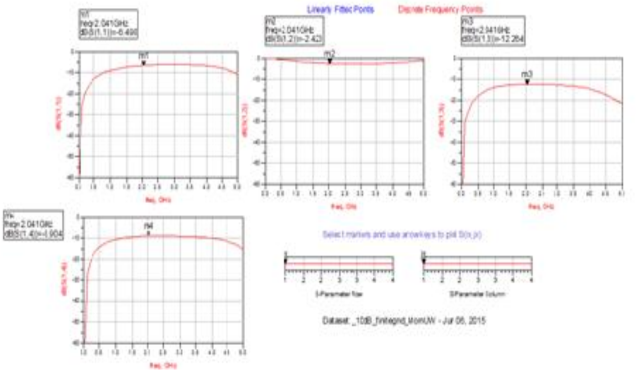


Fig. -10: (b) the simulated result of 10 dB coupling loss with finite ground

4.1.3 10 dB directional coupler with finite ground and one dumbbell shaped DGS

Now one dumbbell shaped DGS is used with the same 10dB directional coupler with finite ground using same dimensions for the frequency range of 1GHz to 5Ghz. Fig. 11 (a) shows the 10dB directional coupler with finite ground and one dumbbell shaped DGS

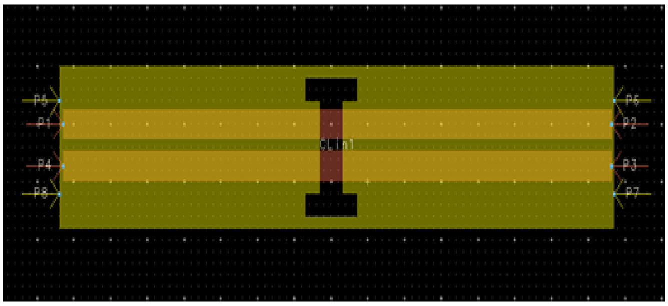


Fig. -11: (a) 10dB directional coupler with finite ground and one dumbbell shaped DGS

The simulated result for observed for 10dB directional coupler with finite ground as -8.704 dB coupling loss as shown in Fig 11 (b).

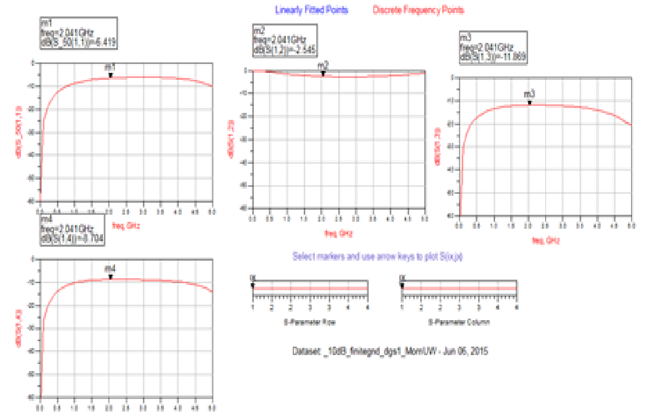


Fig. -11: (b) the simulated result of 10dB directional coupler with finite ground and one dumbbell shaped DGS

4.1.3 10 dB directional coupler with finite ground and five dumbbell shaped DGS

Furthermore the numbers of DGS slots in the 10dB directional coupler with same dimension are increased up to five as shown in Fig. 12 (a).

The simulation result of this directional coupler with 5 dumbbell shaped DGS for S14 as -9.407 dB coupling loss is shown in Fig. 12 (b) 10dB directional coupler with finite ground and five dumbbell shaped DGS

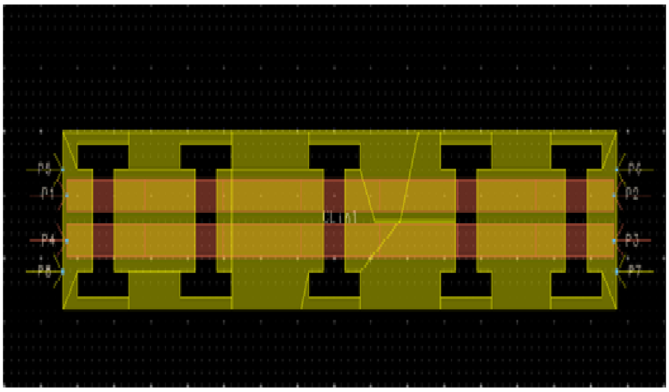


Fig. -12: (a) 10dB directional coupler with finite ground and five dumbbell shaped DGS

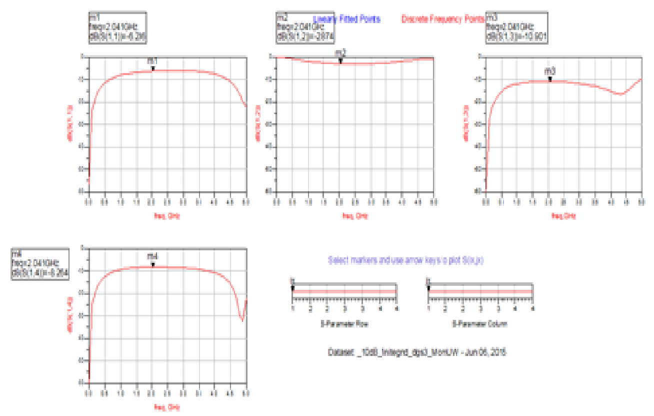


Fig. -12: (b) 10dB directional coupler with finite ground and five dumbbell shaped DGS

4.2 Results and Discussion of Directional Coupler

Table-II: *S* Parameters for Directional coupler:

	Infinite Gnd S = 0.199 mm	Finite Gnd	SF= 0.243 mm	DGS1	S1= 0.265 mm	DGS3	S3= 0.328 mm
S11 (dB) Return Loss	**-7.003**	-6.498	-6.197	-6.419	-5.990	-6.236	-5.503
S12 (dB) Through	**-2.043**	-2.423	-2.415	-2.545	-2.537	-2.874	-2.878
S13 (dB) Isolation	**-13.619**	-12.26	-12.44	-11.86	-12.11	-10.90	-11.29
S14 (dB) Coupled	**-9.407**	-8.904	**9.402**	-8.704	**-9.403**	-8.264	**-9.407**

5. DGS BASED PHASE SHIFTER

Phase Shifters are devices, in which the phase of an electromagnetic wave of a given frequency can be shifted when propagating through a transmission line. In many fields of electronics, it is often necessary to change the phase of signals. RF and microwave Phase Shifters have many applications in various equipment's such as phase discriminators, beam forming networks, power dividers, linearization of power amplifiers, and phase array antennas.

Microstrip phase shifter is designed with frequency f=2.4 GHz, phase shift of 90° and 180°, FR4 is used as a substrate with dielectric constant as 4.4, tan delta as 0.02 and height of the substrate as 1.6mm.

5.1 Phase shifter on Infinite Ground Plane

Here phase shifter is implemented on infinite ground and simulated. Fig. 13 (a, b) and Fig. 14 (a, b) shows the simple and modified phase shifter with its simulated results

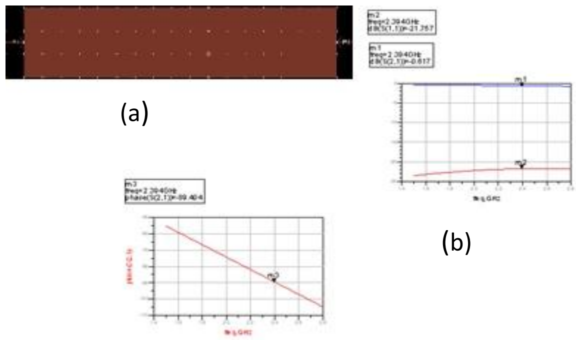


Fig. -13: (a) Phase shifter on infinite ground plane (b) the simulated result of phase shifter on infinite ground plane

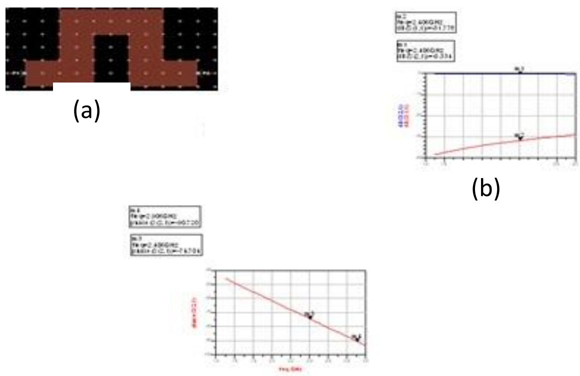


Fig. -14: (a) Modified Phase shifter on infinite ground plane (b) the simulated result of modified phase shifter on infinite ground plane

5.2 Phase shifter on Finite Ground Plane

Now the finite ground is placed on both simple and modified phase shifter. Fig. 15(a, b) and Fig. 16 (a, b) shows the modified phase shifter with its simulated results.

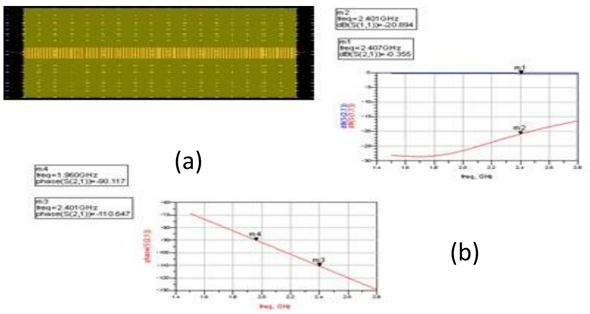


Fig. -15: (a) Phase shifter on finite ground plane (b) the simulated result of phase shifter on finite ground plane

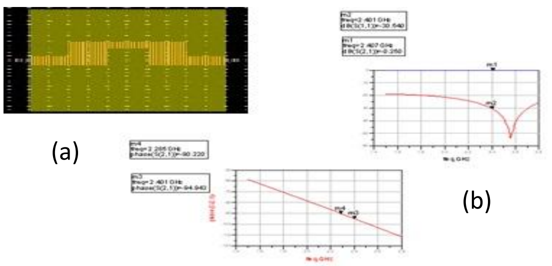


Fig. -16: (a) Modified Phase shifter on finite ground plane (b) the simulated result of modified phase shifter on finite ground plane

5.3. OBSERVATION TABLE

Table-III shows the combine results of Fig. 13 to Fig. 16. From the observation table it is observed that the phase response of phase shifter is improved by adding finite ground on the phase shifter. The shape of the phase shifter also affects the output of phase shifter.

Table – III: Infinite and Finite Ground plane phase shifters

Figure No.	Ground Plane	Shapes	Return Loss	Insertion Loss	Phase shift	Frequency at which 90 degree achieved
Fig – 13	Infinite	Straight line	-21.57	-0.3	89.9	2.4 GHz
Fig – 14	Infinite	Modified shape	-31.29	-0.3	-91.2	2.9 GHz
Fig – 15	Finite	Straight line	-20.8	-0.3	-110	1.9 GHz
Fig – 16	Finite	Modified	-30.5	-0.2	94	2.28 GHz

5.3 PHASE SHIFTER WITH DUMBBELL SHAPED DEFECTED GROUND STRUCTURE

Now most widely used dumbbell shaped DGS is applied on the phase shifter with finite ground in single layer and three layer then the result is observed. It was found that dumbbell shape in three layer provided greater phase shift resulting in more compactness as compared to dumbbell shape in single layer.

5.3.1 Phase shifter with single layer DGS

Here first single layer DGS is applied on the finite ground which is shown in Fig. 17 (a) and then simulated as shown in Fig. 17 (b).

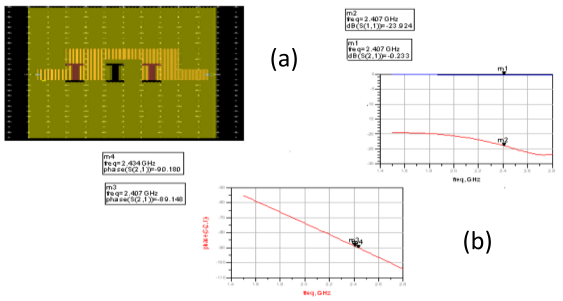


Fig. -17: (a) Modified shape Phase shifter with single layer dumbbell shape DGS on finite ground plane, (b) Simulated result

5.3.2 Phase shifter with three layer DGS

It observed that dumbbell shape in three layer provided greater phase shift resulting in more compactness as compared to dumbbell shape in single layer. Phase shifter with finite ground with three layer DGS and its simulated result is shown in fig. 18 (a) and fig. 18 (b).

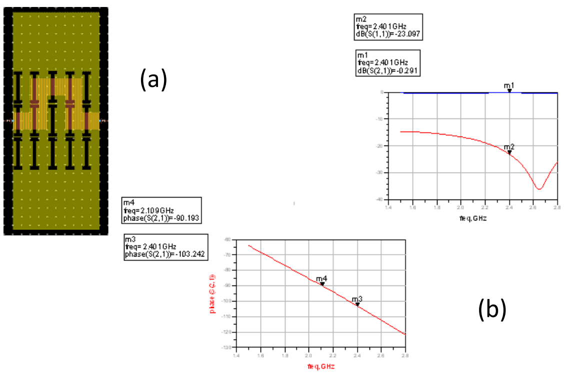


Fig. -18: (a) Modified shape Phase shifter with three layer dumbbell shape DGS on finite ground plane, (b) Simulated result.

5.4. OBSERVATION TABLE

Now the results of phase shifter with single layer DGS and three layer DGS is compared with modified phase shifter with no DGS which is shown in Table IV.

Table- IV: comparison between Phase shifter with DGS and without DGS

Figure No.	Shapes	Return Loss	Insertion Loss	Phase shift at 2.4GHz	Frequency at which 90 degree phase achieved
Fig – 17	Dumbbell in single layer	-23.9	-0.2	90	2.43 GHz
Fig – 18	Dumbbell in three layer	-23.09	-0.2	-103.2	2.1 GHz
Fig- 16	Modified shape without DGS	-30.5	-0.2	94	2.28 GHz

6. CONCLUSIONS

Designing of bandpass filter with Butterworth approach in combination with concentrated components, i.e. inductors and capacitors and its computational verification in form of parallel coupled microstrip lines with the program Sonnet give very good filter characteristics for frequency range of 4.8 GHz to 6.8 GHz. At the center frequency the insertion loss and reflection factor has the values about -2 dB and better than -15 dB, respectively. The measurement gives also very good filter characteristics at the frequency of 4.8 GHz to 6.8 GHz. This larger loss originates likely from losses of the coaxial connectors and their poor contacts to the microstrip line.

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. The designed coupler has a compact size with a dimension of 14.93 mm X 1.368 mm.

The proposed phase shifter was fabricated on FR4 substrate and is suitable for small size wireless devices. For complete product demonstration 90° and 180° phase shifter were fabricated. 180° phase shifter was design using modified shape. 90° phase shifter with and without DGS were compared and optimization in terms of return loss, insertion loss and phase shift achieved were shown. The simulation results are in best agreement with the theoretical ones. From the simulation result it was found that the microwave phase shifter with alphanumeric shape DGS offers 30% size reduction. The new shape proposed offers 30-40% size reduction. Depending upon the application requirement, the corresponding DGS in the phase shifter can be chosen.

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