

Simulation and Experimental Studies of a New Defected Ground Structure for Microstrip Lines at Ka-band

Rajendra Prasad Dixit^{1*}, Rajesh Roy², Abhimanyue Kumar Kush³, Kiran Sharma⁴

^{1,2,3}Defence Electronics Applications Laboratory, Dehradun, India

⁴Department of Physics

Graphic Era (Deemed to be University), Dehradun, India

*Corresponding author: rajendraprasaddixit@gmail.com

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Abstract

Simulation and experimental results of a new type of Defected Ground Structure (DGS) for microstrip line at Ka-band have been discussed. The proposed modified square slot DGS exhibits single stop band in frequency range from 26 GHz to 40 GHz. There are many published works on DGS up to K-band but DGS performance in Ka-band has to be explored. Thus, stop band effect of a new DGS has been studied for microstrip line at Ka-band. Variation in DGS dimensions changes the stop band characteristics. The simulated results have been validated with the measured data. Resonant frequency of stop band of the DGS can be varied from 28.2 GHz to 35.4 GHz.

Keywords- Defected Ground Structure (DGS); Microstrip Circuits; Ka-band.

1. Introduction

Research in photonic band gap was started for optical applications. Photonic Band Gap (PBG) structures have periods that provide rejection of some frequency bands. This effect is called band gap or stop band effect (Radisic et al., 1998; Maystre, 1994; Qian et al., 1997). But, designing of PBG circuit based microwave or Millimeter Wave (MMW) circuits is very difficult because it is cumbersome to find its equivalent circuit and parameters. DGS also provides the band gap or stop band effect at microwave and MMW frequencies in a different manner that of a PBG (Kim et al., 2000). Due to ease of finding equivalent circuit and parameters of DGS, they are useful in design of microwave or MMW components. Thus, new theories are explored to use DGS for designing these components.

In DGS, the conducting ground layer beneath the substrate of a planer microwave and MMW circuits (in microstrip, stripline, CPW configuration) is having different regular defects structures to improve the performance of the microwave and MMW circuits. In a basic element structure of DGS, a resonant gap or slot in the conducting ground layer of planar line is placed deliberately. The placement of defect is directly under the line and it is so aligned that efficient coupling to the line can be obtained. When different defects in conducting ground plane are created in different transmission media, new characteristics are introduced in these media.

The Figure 1 shows the new resonant structures, used in this study, which is different from the DGS structure proposed by Chul-Soo Kim et al. (Kim et al., 2000). In the structure, the outer square side is ‘a’ and the inner square side is ‘b’. The path between outer and inner square, (a-b) has been used as DGS unit. Stop band characteristics of the DGS show its properties when the defects are placed beneath the microstrip line.

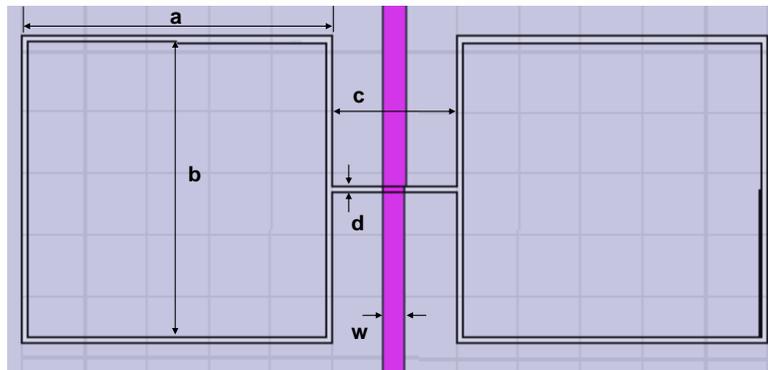


Figure 1. Proposed DGS unit

Now-a-days microwave and MMW components with DGS have gained much popularity and are used for various applications. Effect of DGS on gain, bandwidth, resonant frequency and size reduction of square patch antenna has been explored (Chakraborty et al., 2013). A lot of work has been published on DGS up to K-band (Kim et al., 2000; Hong and Karyamapudi, 2005; Biswas and Guha, 2013; Chakraborty et al., 2013; Liu et al., 2005; Ahn et al., 2001; Fan and Yan, 2010), but DGS performance in Ka-band has to be explored. Thus, stop band effect of the new DGS has been discussed for microstrip line at Ka-band. The DGS unit has been simulated with different dimensions to show the variation in stop band characteristics. The results have been compared with the measured data.

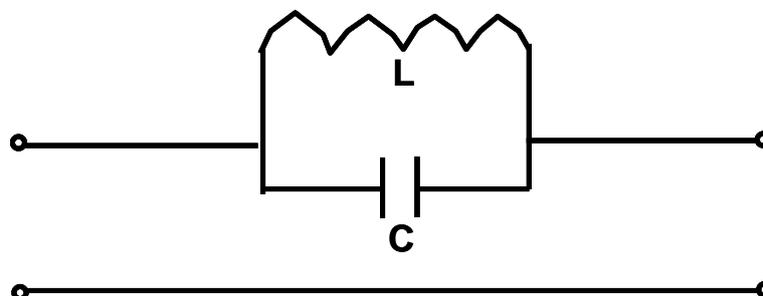


Figure 2. The equivalent circuit of the DGS unit

2. DGS Design

Periodic or non-periodic etched slots or defects in the conductive ground layer of a planar transmission line create a disturbance in the shield current distribution in the ground (Liu et al., 2005; Ahn et al., 2001). A DGS is basically a resonant trap. Defect dimensions determine the resonance properties of the structure. In absence of any defect, stop band effect vanishes.

When the new square slot DGS is created in ground plane, propagation of electromagnetic fields is disturbed showing anomalous dispersion around the resonance of DGS. The etched slot created disturbance changes the distributed inductance and capacitance properties of the microstrip line. Thus an inductance-capacitance equivalent circuit of transmission line could represent the DGS unit circuit. A series-connected parallel LC resonance circuit, shown in Figure 2, represents the frequency characteristic of the DGS unit. The equivalent capacitance, C and inductance, L of the DGS can be calculated as follows:

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

$$L = \frac{1}{4(\pi f_0)^2 C} \quad (2)$$

Where, ω_0 = angular resonance frequency, ω_c = 3-dB cut-off frequency, and Z_0 = characteristic impedance of the transmission line (Fan and Yan, 2010).

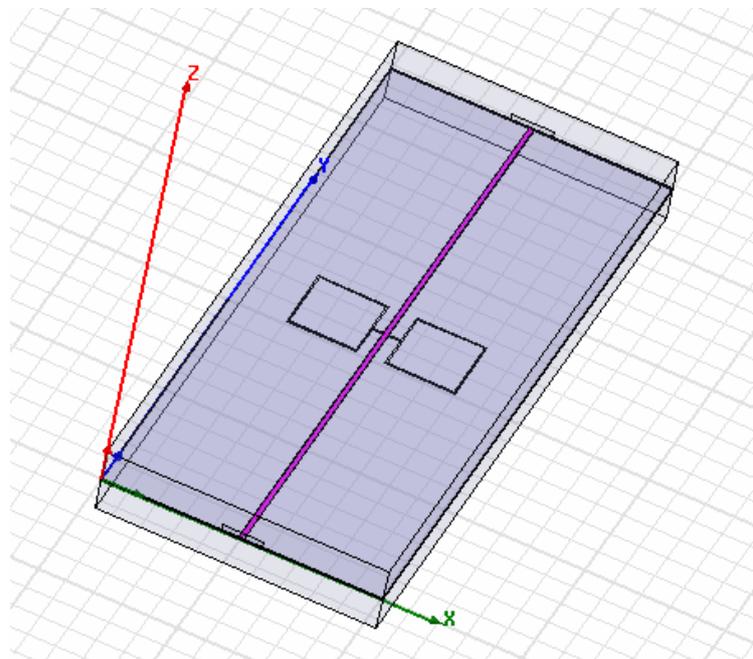


Figure 3. 3-D View of the DGS unit (etched in the conducting ground layer of a microstrip line)

3. Method

For this study, a microstrip line was chosen. The proposed DGS, Figure 1, is located on the conducting ground layer. The Figure 3 shows the 3-D view of the simulated microstrip line with the DGS. The line width of microstrip line is chosen for the characteristic impedance of 50 ohm at Ka-band (26 GHz to 40 GHz) on a 0.127 mm thick RT/ Duroid substrate with a relative dielectric constant of 2.2. The DGS gap length, c and the distance, d are 2 mm and 0.1 mm, respectively for all cases. The simulation and experimental studies were done for the DGS dimensions, a= 3 mm, b= 2.8 mm; a= 5 mm, b= 4.8 mm; and a= 6 mm, b= 5.8 mm,

respectively. Simulation was done in 3-D High Frequency Structure Simulator (HFSS) and Agilent Technologies Advanced Design System (ADS). The circuit was fabricated using wet chemical etching process and SMA 2.9 connectors were used. Measurement was taken using Rohde and Schwarz Vector Network Analyzer ZVK.

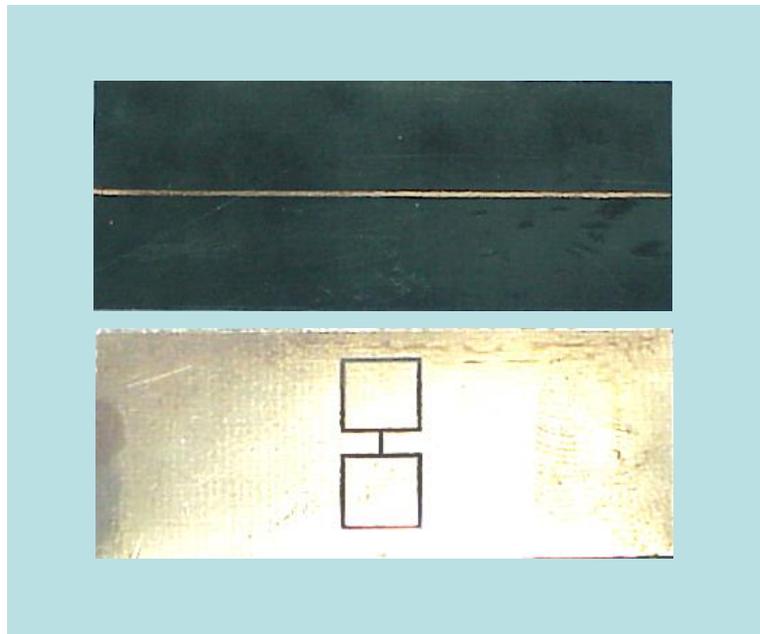


Figure 4. Fabricated 50 Ω microstrip line and the DGS unit (The DGS gap length, c and the distance, d are 2 mm and 0.1 mm. The DGS dimensions are, $a= 6$ mm, $b= 5.8$ mm.)

4. Result and Discussion

The fabricated 50 Ω microstrip line and proposed DGS unit have been shown in the Figure 4. The DGS gap length, c and the distance, d are 2 mm and 0.1 mm. The DGS dimensions are, $a= 6$ mm, $b=5.8$ mm. The Figure 5 shows the comparison of the simulated S-parameter of the proposed single DGS unit and equivalent series-connected parallel LC resonance circuit. S-parameter of the DGS unit has been simulated using HFSS when DGS gap length, $c= 2$ mm, the distance, $d= 0.1$ mm, dimensions, $a= 3$ mm, $b= 2.8$ mm. Equivalent LC parameters has been obtained from the above results using Equations (1) and (2) and series-connected parallel LC resonance circuit simulation has been done in ADS. It is clear from the figure that the resonate frequency and cut-off frequency are in good agreement. The Figure 6 shows the simulated frequency response of a single DGS unit using HFSS when DGS gap length, c and the distance, d are 2 mm and 0.1 mm, respectively for all cases. The simulation studies have been done for the DGS dimensions, $a= 3$ mm, $b=2.8$ mm; $a= 5$ mm, $b=4.8$ mm; and $a= 6$ mm, $b= 5.8$ mm, respectively. From simulated S-parameters and Equations (1) and (2), the equivalent LC parameters are obtained and tabulated in Table 1. The results show that the effective inductance decreases and the resonant frequency shifts from 28.2 GHz to 35.4 GHz.

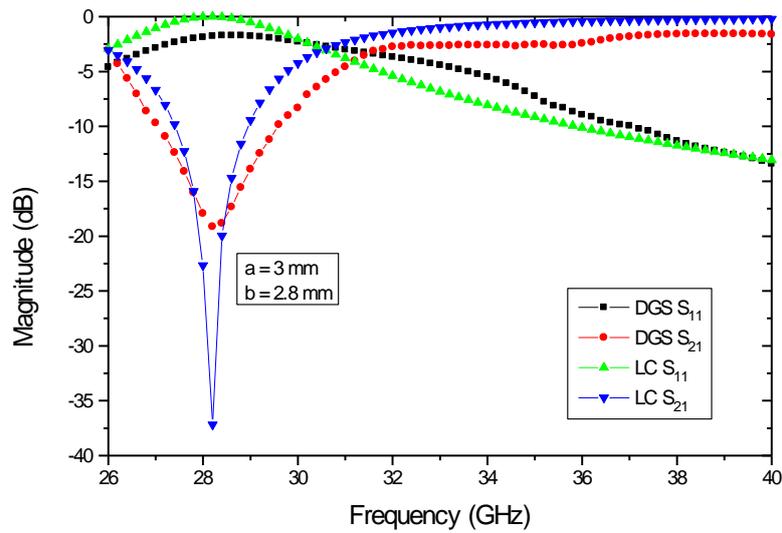


Figure 5. Comparison of the simulated S-parameters of the DGS unit and equivalent series-connected parallel LC resonance circuit (The DGS gap length, c and the distance, d are 2 mm and 0.1 mm. The DGS dimensions are, $a=3$ mm, $b=2.8$ mm.)

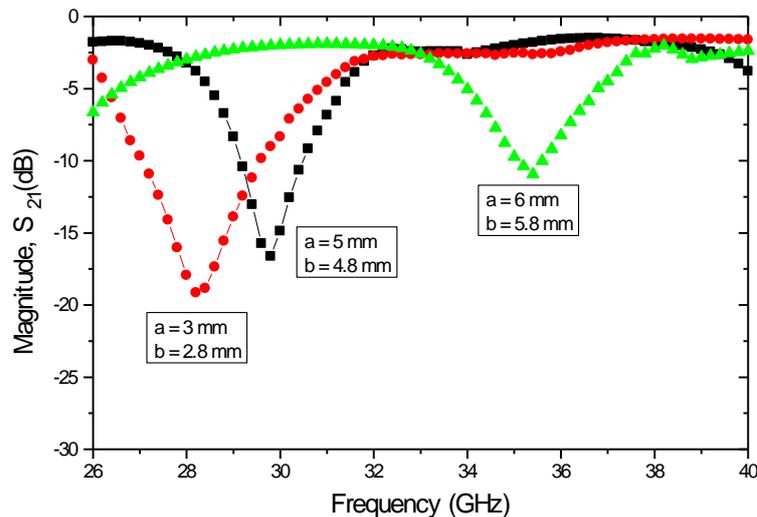


Figure 6. Simulated S_{21} parameters (The DGS gap length, c and the distance, d are 2 mm and 0.1 mm, for all cases. DGS dimensions are, $a=3$ mm, $b=2.8$ mm; $a=5$ mm, $b=4.8$ mm; and $a=6$ mm, $b=5.8$ mm.)

Table 1. Obtained inductance, capacitance, cutoff frequency and attenuation pole location of DGS unit

Parameters	DGS dimension (when DGS gap length, c and the distance, d are 2 mm & 0.1 mm, respectively for all cases)		
	$a=3$ mm, $b=2.8$ mm	$a=5$ mm, $b=4.8$ mm	$a=6$ mm, $b=5.8$ mm
Inductance (nH)	0.092	0.07	0.058
Capacitance (pF)	0.347	0.405	0.35
Cutoff Frequency (GHz)	26.0	27.9	33.2
Attenuation Pole Location (GHz)	28.2	29.8	35.4

Measured S_{21} (for the DGS dimensions, $a=3\text{ mm}$, $b=2.8\text{ mm}$ when DGS gap length, c and the distance, d are 2 mm and 0.1 mm , respectively) has been shown in the Figure 7. A close agreement between simulated and measured data is revealed from the figure. In figure, there is a shift in resonant frequency from 28.2 GHz to near 27 GHz . It due to the variation in fabrication parameters as these parameters are very stringent at Ka-band. Attenuation in pass band attributes to radiation losses. From the above results, it can be concluded that the shift of the stop band frequencies is due to change in dimensions of DGS. The frequency response of the DGS can be helpful to add additional rejection at the edges of pass band of a filter. The structure response may also be helpful to suppress out of band harmonic frequency, image frequency or any frequency band where the filter structure has poor rejection. The proposed DGS resonators will be helpful in removing higher order responses in different microwave components like directional couplers, power combiner, dividers.

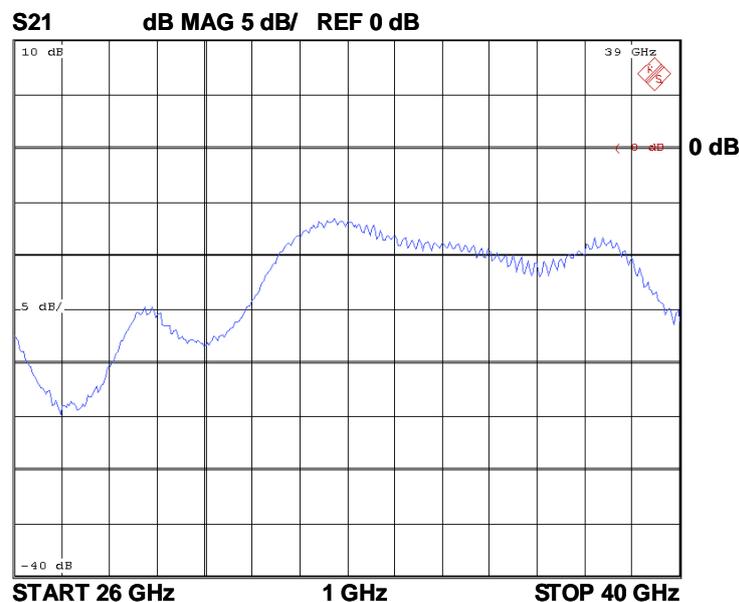


Figure 7. Measured S_{21} for the DGS unit (The DGS gap length, c and the distance, d are 2 mm and 0.1 mm . The DGS dimensions are, $a=3\text{ mm}$, $b=2.8\text{ mm}$.)

5. Conclusion

Simulation and measured results of a new DGS on microstrip line at Ka-band have been explored. The new DGS at Ka-band has been discussed and its brief design procedure has been also described. From the above results, it can be concluded that the shift of the stop band frequencies from 28.8 GHz to 35.4 GHz is due to changing dimensions of DGS. At Ka-band tolerance to the different dimension are very stringent. The DGS stop band characteristics may be useful for the suppression of unwanted signals. The simulation results and measured data describe the DGS characteristics.

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