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UNIT LENGTH PARAMETERS, TRANSITION SHARPNESS AND LEVEL OF RADIATION IN DEFECTED MICROSTRIP STRUCTURE (DMS) AND DEFECTED GROUND STRUCTURE (DGS) INTERCONNECTIONS

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Abstract—In this paper, some important concepts about the defected microstrip structure (DMS) and defected ground structure (DGS) interconnections are introduced.

In concept number one, three different types of interconnections are analyzed for determining the unit length and frequency dependent characteristics, based on the perturbed direct and return current paths and electromagnetic (EM) simulations. Therefore, the proposed interconnections with non-uniform circuit and ground planes (DMS and DGS) can be modeled using the uniform circuit and ground planes with frequency dependent unit length parameters. This concept can be used for designing the microwave circuits loaded with DMS or DGS. Results show that the unit length parameters are the same at high frequencies but different at low frequencies due to the different current distributions and consequently different geometry shapes.

In concept number two, the level of radiation in these interconnections due to the area of defects is determined and compared. The very large radiation, due to large etched area on ground plane, is a deficiency of DGS interconnections. Using the DMS version, the harmful radiation can be decreased effectively.

In concept number three, the level of transition from passband to stopband is calculated and compared. Sharper transition can better

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suppress the band spurious signals. Finally, all performances are tabulated and compared.

1. INTRODUCTION

In recent years, there has been a growing interest in the study of microstrip interconnections with various periodic structures that prohibit wave propagation in certain frequency bands, including photonic band gap (PBG), electromagnetic band gap (EBG) and defected ground structures (DGSs) [1–3]. In a DMS [4–8], similar to a T-shaped cell, there is no etching in ground plane such as DGS. DMS is made by etching a uniform or non-uniform slit on the signal strip and etching the very small slits perpendicular to the main slit. This defect causes a band stop in the frequency response.

This paper shows that DMS interconnection provides good cutoff frequency characteristics due to the more effective inductance with respect to DGS.

In this paper, several structures are compared. 1) DMS interconnection, 2) DGS interconnection so that each of the etched rectangular head in DGS is similar to the etched area of the T-shaped head in DMS, and 3) DGS with an etched squared head with the same resonance in DMS. These interconnections have been simulated and analyzed in order to obtain the quantity of unit length parameters. These parameters are determined by the EM simulation results for interconnections in which the currents on the circuit or ground planes have been perturbed by defects.

The radiation from the defects of interconnection is a harmful phenomenon for measurements or integration of components. Compared to DGS, the DMS has less radiated EMI ground noise. EMI is directly dependent on the etched surface area of defect. Hence, DMS strategy is very suitable for applications of global wireless communication and sensitive military systems.

In a filter, the sharpness level of transition from passband to stopband is an important technical specification for more dumping in-band spurious signals. This specification in connection with DMS and DGS interconnections is determined and compared.

This paper is organized as follows. Section 2 introduces three kinds of DGS and DMS interconnections. Section 3 deals with the frequency response of these interconnections. Unit length parameters are extracted in Section 4. Investigation and comparison of radiation levels of proposed interconnections are discussed in Sections 5 and 6, respectively followed by conclusion in Section 7.

2. DMS AND DGS INTERCONNECTIONS

DGS interconnection, with periodic or non-periodic structure, provides some rejection frequency band due to increased effective inductance of a transmission line. This characteristic of DGS interconnection is available to many circuits such as power amplifier module, planar antennas, power divider, and filters, etc. When DGS interconnection is used to design microwave circuits the problems of EMC should be considered because no image current is created on circuit plane, and then the leakage through the ground plane will occur. Using DMS interconnection, the defect is etched on the conductor line, and there is no leakage through the ground plane. In this case, the image current is created on the ground plane.

The DMS interconnection increases the electric length and associated inductance. As can be seen in this paper, compared to DGS if DMS is used as a filter, the harmful radiation can be decreased with lower etched area of defect. This structure can be integrated more easily with other microwave circuits. Also filter and antenna dimensions can be effectively reduced by using DMS. The DMS interconnection disturbs the current distribution only across the strip, thereby giving a modified microstrip line with certain stop band and slow-wave characteristics. In a microstrip patch antenna design using DGS, the performance of radiation pattern is degraded because of additional radiation from ground plane.

Figure 1(a) shows a schematic of DMS and DGS interconnections and related parameters. The area head of rectangular pattern in DGS interconnection is equal to the area head of the T-shaped cell in DMS interconnection. The proposed structures are designed on a substrate with relative permittivity $\varepsilon_r = 2.33$ and thickness $h = 0.787\,\mathrm{mm}$.

Figures 1(b), 1(c) and 1(d) show 3D view of the proposed DMS and DGS interconnections, which are located on the microstrip line and ground plane. The line widths are chosen to have 50 Ohm microstrip lines. In order to obtain good insight into the line parameters due to the shape of the cells, the narrow gap g, which determines the gap capacitance, was kept equal to 0.2 mm for all cases.

At high frequencies the radiation from the defect area of a microstrip filter using DGS is a source of catastrophic errors in measurement procedures with respect to the simulation results. Thus, reduction of this area using DMS is a properly desired achievement. This paper shows the etched area can be decreased using DMS without any major change in the performance of DGS interconnection.

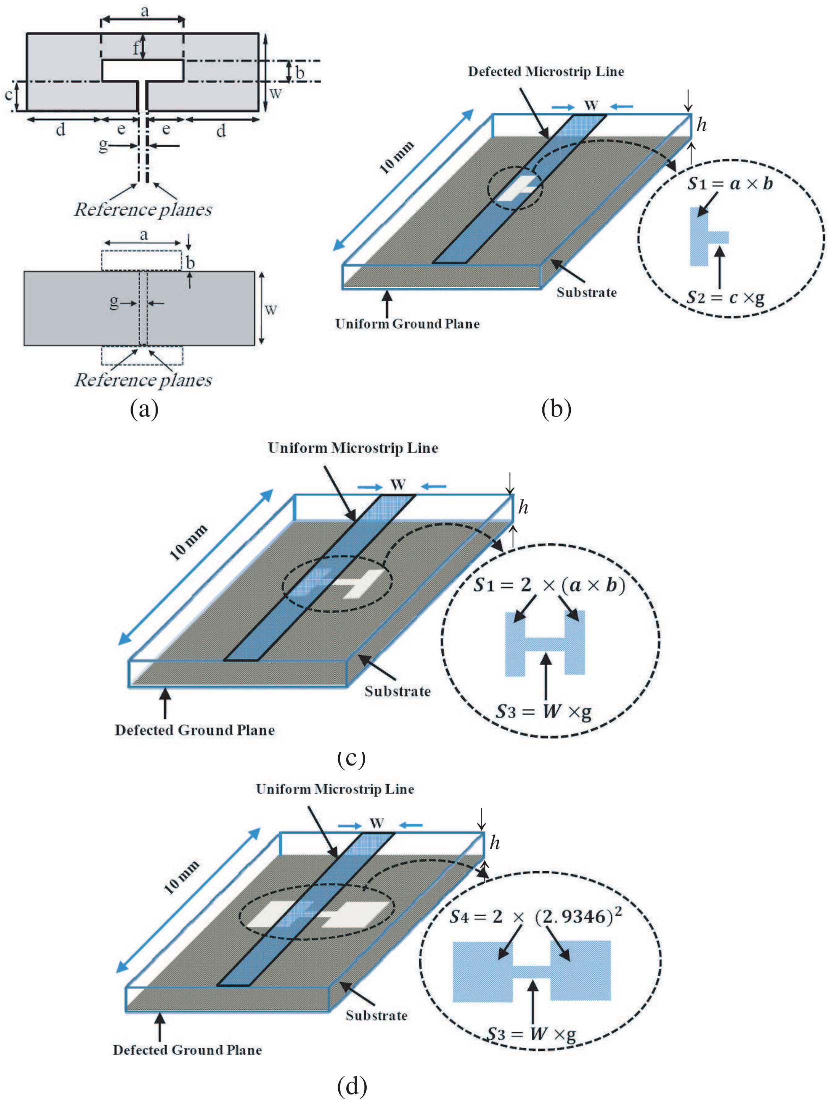


Figure 1. (a) Unit cell DMS and DGS parameters with $a = 6.2\,\mathrm{mm}$, $b = 0.5728\,\mathrm{mm}$, $c = 1.3572\,\mathrm{mm}$, $d = 1.9\,\mathrm{mm}$, $e = 3\,\mathrm{mm}$, $f = 0.4\,\mathrm{mm}$ and $g = 0.2\,\mathrm{mm}$, and (b), (c) and (d) 3D view of the DMS and DGS interconnections with the almost same resonant frequencies.

3. FREQUENCY RESPONSES OF DMS AND DGS INTERCONNECTIONS

The simulation results for DMS (Fig. 1(b)) and DGS (Fig. 1(c)) interconnections is shown in Fig. 2. As can be seen in Fig. 2, it is easy to conclude that employing the same etched area of heads in both DMS and DGS interconnections makes almost the same resonant frequency. However, the etched area in DGS interconnection is twice of the DMS interconnection. A slight difference in resonant frequency is due to a little more gap length in DGS interconnection (because $W > c$). Using the squared head DGS interconnection with the same DMS resonant frequency causes the sides of the squared head reaching 2.9346 mm (Fig. 1(d)), so that the etched area in squared head DGS interconnection is more than 4.8 times of the etched area in DMS interconnection. Using the large etched areas in the squared head DGS creates high radiation due to the great current loops. In this case, large squared head DGS acts as an efficient loop antenna. Hence, with employing DMS interconnection, the harmful radiation becomes minimized. The comparison of squared head DGS and its DMS version is shown in Fig. 3.

4. EXTRACTION OF UNIT LENGTH PARAMETERS OF DMS AND DGS INTERCONNECTIONS

DMS and DGS perturb the direct and return current paths and then change the unit length parameters of interconnection. Based on EM simulation results, the inductance and capacitance line parameters of the DMS/DGS interconnection is established and these parameters are extracted using circuit theory. The S-parameters can be obtained from HFSS simulation to derive the L and C per unit length parameters of

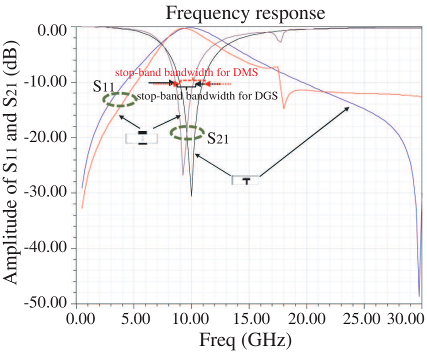


Figure 2. Comparison of amplitude frequency responses of DMS and DGS interconnections as shown in Figs. 1(b) and 1(c).

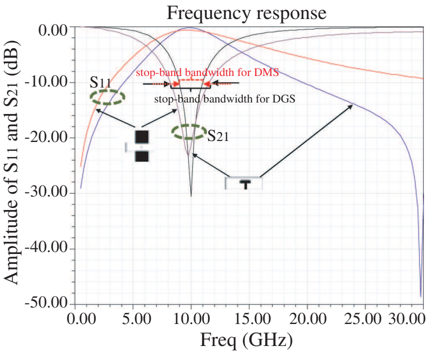


Figure 3. Comparison of amplitude frequency responses of DMS and DGS interconnections as shown in Figs. 1(b) and 1(d).

the line. The S-parameters is given by:

$$[S(f)] = \begin{bmatrix} S_{11}(f) & S_{12}(f) \\ S_{21}(f) & S_{22}(f) \end{bmatrix} \tag{1}$$

The relations among the S-parameters, Z_{11}, Y_{11} and the propagation constant for the lossless line are given by:

$$\begin{aligned} Z_{11}(f) &= \frac{Z_p \cdot ((1+S_{11}(f)) \cdot (1-S_{22}(f)) + S_{12}(f) \cdot S_{21}(f))}{(1-S_{11}(f)) \cdot (1-S_{22}(f)) - S_{12}(f)S_{21}(f)} \\ &= -j \cdot Z_0 \cot(\beta(f) \cdot l) \end{aligned} \tag{2}$$

$$\begin{aligned} Y_{11}(f) &= \frac{Y_p \cdot ((1-S_{11}(f)) \cdot (1+S_{22}(f)) + S_{12}(f) \cdot S_{21}(f))}{(1+S_{11}(f)) \cdot (1+S_{22}(f)) - S_{12}(f)S_{21}(f)} \\ &= -j \cdot Y_0 \cot(\beta(f) \cdot l) \end{aligned} \tag{3}$$

where Z_p is the port impedance of 50 Ohm, and Y_p is the corresponding admittance. β, l, Z_0 and Y_0 are propagation constant, length, characteristic impedance and admittance of interconnection, respectively. Then:

$$Z_0(f) = \sqrt{\left|\frac{Z_{11}}{Y_{11}}\right|} \tag{4}$$

and

$$\beta(f) = \cot^{-1}\left(\sqrt{|Z_{11} \cdot Y_{11}|}\right)/l \tag{5}$$

The relation between inductance and capacitance for circuit line is given by:

$$L(f) \cdot C(f) = \mu \cdot \varepsilon \tag{6}$$

and

$$Z_0(f) = \sqrt{\frac{L(f)}{C(f)}} = \frac{1}{C(f)\upsilon} \tag{7}$$

therefore, the unit length inductance and capacitance of interconnection are given by:

$$L(f) = \frac{1}{\upsilon^2 C(f)} = \frac{\frac{1}{C(f)\upsilon} \cdot \frac{2\pi f}{\upsilon}}{2\pi f} = \frac{Z_0(f) \cdot \beta(f)}{\omega(f)} \tag{8}$$

and

$$C(f) = \frac{1}{\upsilon^2 L(f)} \tag{9}$$

where

$$\upsilon = \frac{1}{\sqrt{\mu \cdot \varepsilon}} \tag{10}$$

Simulations were performed for investigation per unit length inductance and capacitance of these three interconnections.

At dc, the current is distributed uniformly throughout the conductor. However, as the frequency rises, there will be a tendency for the current to concentrate at the surface of the conductor. It is assumed that the current decreases exponentially inside the conductor (skin effect) and that the current is the same at the top and bottom of the conductor.

As a result, the outer portions of the conductor contribute less than the inner parts to the overall inductance (current has more difficulty passing through the inner parts due to skin effect).

Thus, if the current is concentrating on the surface, the inductance will decrease. Thus, with an increase of frequency, the inductance decreases.

As can be seen in Fig. 4, with increasing frequency, the per unit length inductance is decreased. The current distribution is supposed to be a vector quantity and a function of frequency. Hence, the inductance of the transmission line decreases to a limited extent with an increase in frequency. At low frequencies the slight difference in inductance of these interconnections is more due to the different current distributions and consequently different geometry shapes. At high frequencies the behavior of line inductance is almost the same, and DMS and DGS have the same effect on the unit length inductance.

Figure 5 shows the unit length capacitance of these interconnections. The results indicate almost no difference in capacitance values of

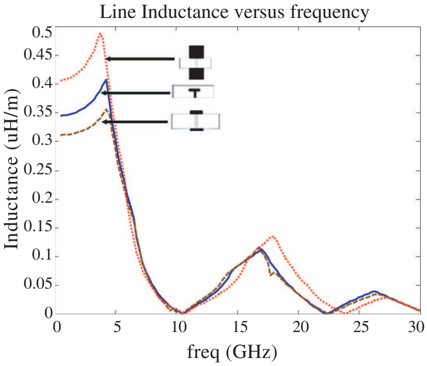


Figure 4. Comparison of unit length inductance for three proposed interconnections as shown in Figs. 1(b), 1(c) and 1(d).

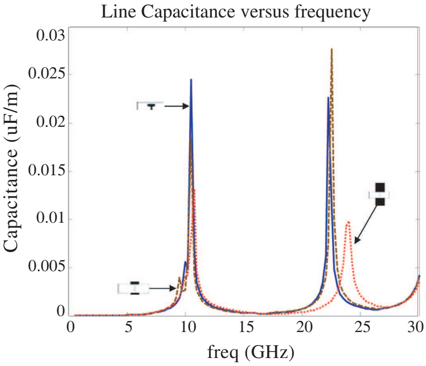


Figure 5. Comparison of unit length capacitance for three proposed interconnections as shown in Figs. 1(b), 1(c) and 1(d).

three interconnections. This matter is clearly shown that DMS interconnection with smaller etched area has the same DGS interconnection performance with larger etched area, which causes more harmful radiation and loss.

5. INVESTIGATION OF LEVEL OF RADIATION IN DMS AND DGS INTERCONNECTIONS

The lowest impedance in signal return path is in a plane directly under the signal trace. Defects on ground and circuit planes divert the circuit and ground current flow, thereby producing high impedance (Inductance) and voltage drops that are the cause of increased radiations. In addition, ground plane defect will significantly increase the crosstalk between parallel interconnections that cross over them.

In order to evaluate the E-field discontinuity and intensity of current distributions around the defects, the performance of DMS and DGS interconnections are obtained using EM simulations.

From Fig. 6, it can be observed that the defects on circuit and ground planes cause discontinuities in direct or return current path and then increase transmission loss and harmful radiation at high frequencies. Defect on ground plane causes more severe degradation in the transmission line performance. Since there is no image currents in the circuit plane for large current loops in DGS interconnection, the radiated power in DGS becomes maximized. So, in the DMS, the EMC problem can be better solved than the DGS. As can be seen in Fig. 6, using the larger DGS, the return path of the current is fully disturbed.

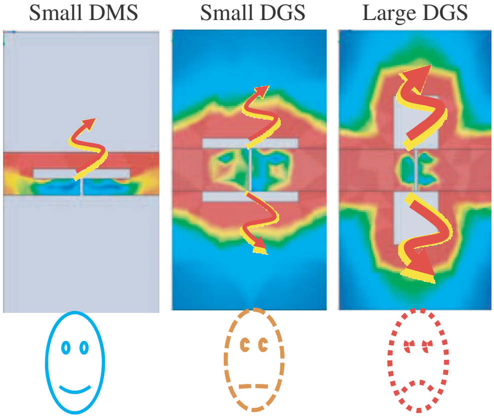


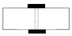
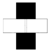
Figure 6. Current distributions and level of radiations of DGS and DMS interconnections.

6. COMPARISON OF THE PERFORMANCE IN DMS AND DGS INTERCONNECTIONS

Comparison of performance of these interconnections with respect to various parameters could be useful for the selection of type of defects in any application. The sharpness factor f_0/f_c determines the sharpness level of transition from passband to stopband regions, where f_c and f_0 are cut off and resonance frequencies, respectively. The sharpest transition is ideally obtained for $f_0/f_c = 1$. The Larger value of f_0/f_c-ratio means that the sharpness of the transition from passband to stopband is poorer. Smaller sharpness factor is better for an effective filtering. The sharpness factor in DGS interconnection (Fig. 1(c)) is slightly better than DMS interconnection, but only at the price of reduced stop-band bandwidth. Also the stop-band bandwidth in another DGS interconnection (Fig. 1(d)) is better than DMS interconnection, but only at the price of degradation in sharpness factor and very high harmful radiation because of larger etched area.

High radiation due to large area defect on ground plane is a deficiency of DGS interconnections and causes very high EMI noise. However, in DMS interconnections the radiation can be found, but this effect is low to moderate level because of its smaller etched area with respect to DGS interconnections. The level of radiation in squared head DGS is 2.85 dB more than DMS. The summary comparison between these interconnections is shown in Table 1.

Table 1. Several characteristics of proposed interconnections.

Parameters Circuits	Sharpness factor	stop-band bandwidth (GHz)	Total area of defect (mm^2)	Harmful raadiation qualitatively	Harmful radiation Based on peak E-field (dB) (quantitatively)
	1.3	2	3.72	Low to moderate	7.39
	1.2	1.6	7.56	High	8.57
	1.6	3.25	17.68	Very high	10.24

7. CONCLUSION

In this paper, unit length parameters are extracted using EM and circuit modeling approaches. These parameters can be used for any microstrip circuit loaded with DMS or DGS interconnections.

Also, impact of various defects on interconnection performances was presented in this paper. In order to reduce the ground plane split discontinuities, harmful radiation and transmission loss usage of DMS interconnection were proposed. Hence, a great performance without missing major quality of performance was obtained using DMS strategy. Thus, a design procedure with minimum radiation in a certain resonant frequency for a DGS interconnection can be started firstly by designing its equal DMS type.

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