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A Novel Equivalent Circuit and Modeling Method for Defected Ground Structure and Its Application to Optimization of a DGS Lowpass Filter

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Abstract **— In this paper, a novel equivalent circuit and modeling method for a defected ground structure is proposed to design the optimized DGS lowpass filter circuit. The equivalent circuit presented in this paper has parallel capacitance to explain the fringing fields due to the defects on the metallic ground plane. Several comparisons between the EM-simulations on the DGS circuits and circuit simulations on its equivalent circuits are demonstrated to show the validity of the proposed equivalent circuit model. Optimization for the DGS circuit is carried out by using the proposed equivalent circuit. Simulation and measurement on the fabricated DGS lowpass filter show the optimized passband and stopband performances.**

I. INTRODUCTION

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, we newly proposed more accurate equivalent circuit model than the reported equivalent circuit of DGS. Furthermore, the extraction method of equivalent circuit parameters has been also derived DGS circuits shows the validity of the proposed equivalent circuit model and modeling method. Also, by employing the proposed equivalent circuit of DGS, a harmonic rejection lowpass filter is optimized. Simulation and measured result for an optimized lowpass filter at 4GHz cutoff frequency will be demonstrated.

II. MODELING METHOD

Fig.1 (a) shows the DGS microstrip with unit defect, which is etched off on ground plane, and Fig.1 (b) shows the newly proposed equivalent circuit.

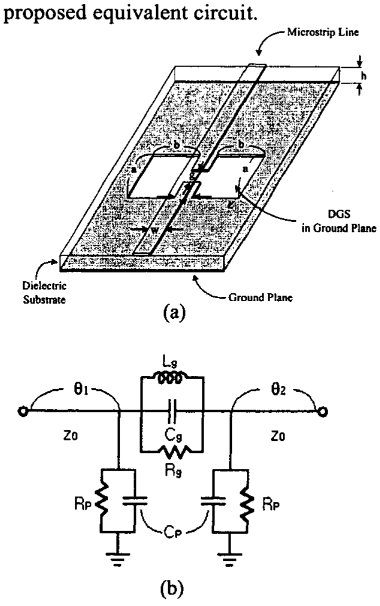

Fig. 1. (a) 3-Dimensional view of the DGS unit section. (b) The newly proposed equivalent circuit.

The proposed equivalent circuit includes the parallel capacitance that is due to the relatively large fringing field

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Since the parallel capacitance might cause changing the characteristic impedance level and electrical length of the DGS unit section, it should be considered as a part of equivalent circuit for more accurate modeling procedure. In order to derive the equivalent circuit parameters, the S-parameters of unit DGS cell at the reference plane should be calculated by EM-simulation. [5]–[8] Once the S-parameters are calculated, by using the relation between the S-parameter and ABCD-parameter the equivalent circuit parameter can be extracted.

$$A=\frac{(1+S_{11})*(1-S_{22})+S_{12}S_{21}}{2S_{21}}=1+\frac{Y_b}{Y_a} \quad (1)$$

$$B=\frac{(1+S_{11})*(1+S_{22})-S_{12}S_{21}}{2S_{21}}=\frac{1}{Y_a} \quad (2)$$

$$C=\frac{1}{Z_o}\frac{(1-S_{11})*(1-S_{22})-S_{12}S_{21}}{2S_{21}}=2Y_b+\frac{Y_b^2}{Y_a} \quad (3)$$

$$D=\frac{(1-S_{11})*(1+S_{22})+S_{12}S_{21}}{2S_{21}}=1+\frac{Y_b}{Y_a} \quad (4)$$

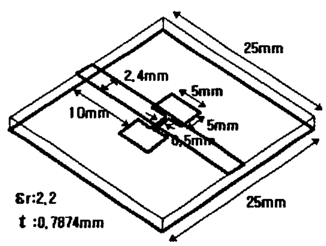
The resulting equivalent circuit parameters are given by

$$Y_a=\frac{1}{B}=\frac{1}{R_g}+jB_r \quad (5)$$

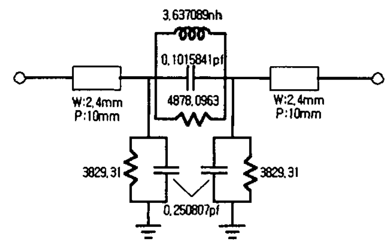
$$Y_b=\frac{A-1}{B}=\frac{-1\pm\sqrt{1+BC}}{B}=\frac{D-1}{B}=\frac{1}{R_p}+jB_p \quad (6)$$

$$C_g=\frac{B_r}{\omega_2\cdot(\frac{\omega_1}{\omega_2}-\frac{\omega_2}{\omega_1})},\ L_g=\frac{1}{\omega_2{}^2C_g},\ C_p=\frac{B_p}{\omega_1} \quad (7)$$

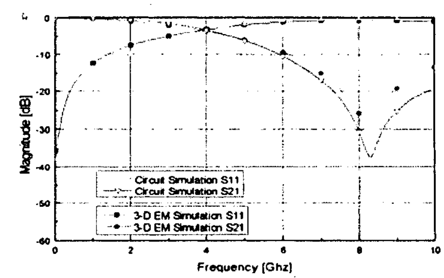
Fig.2 shows the example for the extraction of the equivalent circuit parameter. The substrate for simulation was an RT/Duroid 5880 with 31-mil thick and a dielectric constant ε_r of 2.2.



(a)



(b)



(c)

Fig. 2. A DGS modeling example. (a) Unit DGS cell for modeling. (b) Extracted equivalent circuit. (c) Comparison between the EM-simulations on unit DGS cell and circuit simulations on its equivalent circuits.

To show the effectiveness of the proposed equivalent circuit and modeling method, we simulated the 4-section DGS circuit, which is cascaded by 50Ω microstrip lines with 5mm length. Fig.3 shows the simulation.

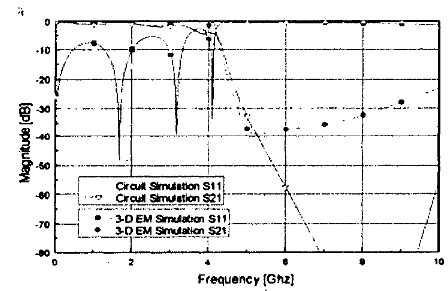


Fig. 3. Comparison between the EM-simulation on the four-section DGS circuit and circuit simulation on its equivalent circuit.

III. Optimization and Design DGS Cells

By employing the proposed equivalent circuit, we have optimized the 3-section DGS lowpass filter to have an optimum performance in passband and stopband simultaneously. Fig.4 shows the optimized DGS lowpass filter.

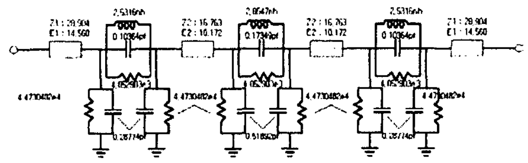
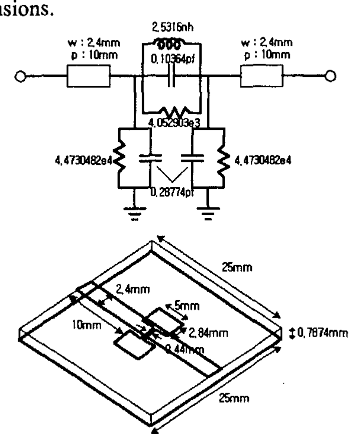
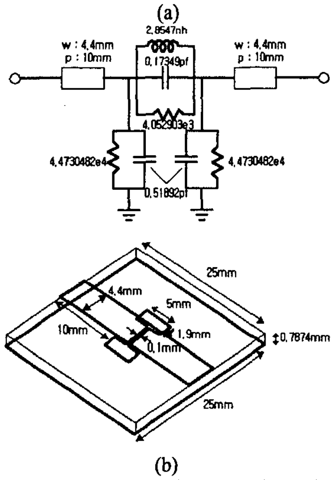


Fig. 4. Schematic of the optimized lowpass filter with 3-section DGS equivalent circuits.

In order to implement the optimized DGS lowpass filter from the equivalent circuit shown in Fig.4, equivalent circuits should be realized with unit DGS cells. Fig.5 shows the equivalent circuits composed of the optimized DGS lowpass filter and corresponding its physical DGS cell dimensions.



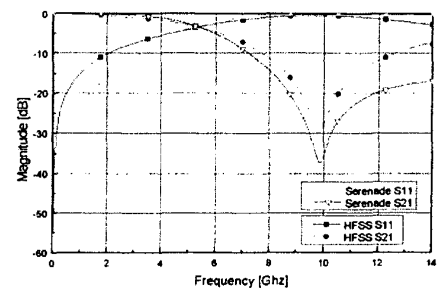
(a)



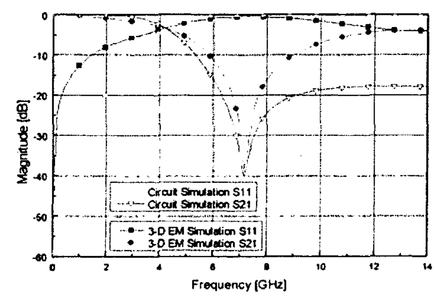
(b)

Fig. 5. Unit DGS cells and its equivalent circuits of the optimized 3-section DGS lowpass filter.

The substrate for implementation of unit DGS cells was an RT/Duroid 5880 with 31-mil thick and a dielectric constant ε_r of 2.2. Comparisons of simulations to investigate how well matched between the equivalent circuits and implemented DGS cells are shown in Fig. 6.



(a)



(b)

Fig. 6. Comparisons between the EM-simulations on implemented unit DGS cells and circuit simulations on its equivalent circuits.

IV. Simulation and Measurement

We have implemented the optimized 3-section DGS lowpass filter by using the unit DGS cells shown in Fig.5. Fig.7 shows a layout of the implemented 3-section DGS lowpass filter. The overall length included the 50Ω-microstrip feeding lines is 52mm. Simulations on the optimized lowpass filter are shown in Fig.8. As shown in Fig.8, both circuit- and EM-simulations on the optimized DGS lowpass filter demonstrate the optimum performances in passband and stopband. Return losses are less than –20dB up to 4GHz and second harmonic rejections are greater than 40dBc in both simulations. Fig.9 shows the measurement on the fabricated 3-section DGS lowpass filter. Measurement shows good agreement with simulations on the optimized 3-section DGS lowpass filter. Also, photographs of the fabricated DGS lowpass filter are shown in Fig.10.

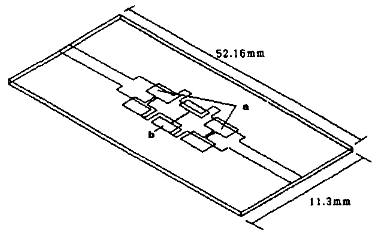


Fig. 7. Layout of the optimized 3-section DGS lowpass filter.

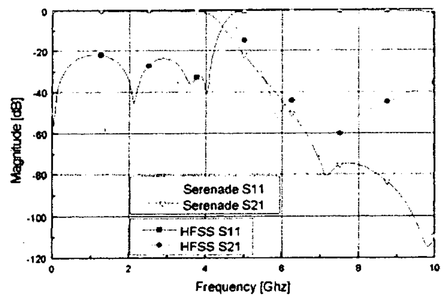


Fig. 8. Simulations on the optimized lowpass filter with 3-section DGS equivalent circuits.

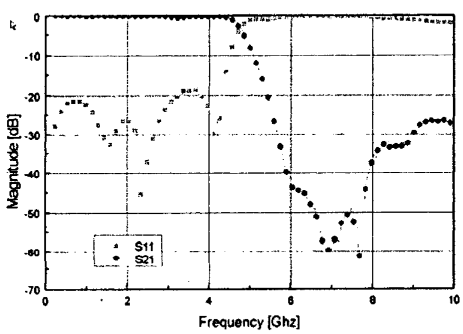
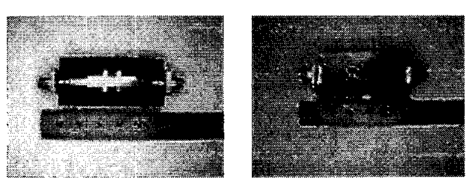


Fig. 9. Measurements on the Optimized lowpass filter with 3-section DGS equivalent circuits.



(a) (b)

Fig. 10. Photos of the fabricated 3-section DGS lowpass filter.

V. CONCLUSION

In this paper, more accurate equivalent circuit model than the reported equivalent circuit of DGS has been proposed. By using parametric relations, the equivalent circuit parameter extraction method for the unit DGS cell has been also derived. By demonstrating several simulations and comparisons on DGS circuits, we have shown that the proposed equivalent circuit model and modeling method is very useful and effective to adapt to DGS applications. Furthermore, we have designed a harmonic rejection DGS lowpass filter by optimization procedure on the proposed equivalent circuit of DGS. Both simulations and measurement on the optimized DGS lowpass filter have demonstrated the optimum performances in passband and stopband.

ACKNOWLEDGEMENT

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