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A SIMPLIFIED EQUIVALENT CIRCUIT MODEL FOR DEFECTED GROUND STRUCTURES IN PLANAR TRANSMISSION LINES

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Abstract—In this paper, an equivalent circuit model for special type of planer transmission lines with defected ground structures (DGS) is presented. This structure has multi stop bands in its frequency behaviour. The proposed circuit is very simple compared to the previously published works. It is considered as simplified form of the model found in [8]. Using sensitivity analysis on model [8], some circuit parameters can be omitted without significant influence on the response of the model. The modified model is easily extracted from the full-wave EM simulations. An excellent agreement is obtained between S-parameters of the simplified equivalent circuit and their counterpart of full wave EM simulators.

1. INTRODUCTION

A numerous RF circuits relay on DGS planer transmission lines such as filters, power dividers, matching circuits for amplifiers [1–4]. Simulation time for such circuits is very high using full wave EM simulators. Equivalent circuit models are very important to decrease the simulation time and consequently the time needed for design process. Two transmission zeroes behaviour is modeled with equivalent circuits [5–8]. Distributed elements as well as lumped components are utilized in [5–7]. Consequently, values of the effective dielectric constant and characteristic impedance of the slot are needed. These values are difficult to be extracted in case of complex shapes slots.

The need for information concerning slot is alleviated in [8]. Where, equivalent circuit from lumped components is used and verified. Two parallel L-C resonant circuits to model the transmission zeros and

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another one to model the interaction region between the two resonance frequencies are utilized to form an equivalent circuit model. However, some negative values are usually extracted for the interaction region circuit model.

In this paper, sensitivity analysis is performed on the extracted models of the examples found in [8]. This analysis reveals that the S-parameters behaviour has very low sensitivity with respect to circuit model parameters of the interaction region. Consequently, dropping this part from the circuit has little and neglected influence on the behaviour of the model. Therefore, a simple circuit with lower number of parameters is obtained. The developed circuit has only the two parallel L-C that model the resonance frequencies. This paper is organized as follows. Section 2 is focused on the sensitivity analysis on the examples of [8]. The validation of the modified model is presented in Section 3. Finally, the conclusion is drawn in Section 4.

2. SENSITIVITY ANALYSIS

The sensitivity analysis measures how much the behavior of a model is sensitive to the variation of one of its parameters. The equivalent circuit model under sensitivity study is presented in [8], as shown in Fig. 1. The circuit is the model for the DGS planer circuit that has two zeros transmission, f_{01} and f_{02}, in its behavior. The values of the parameters of the equivalent circuit are extracted using (1) and (2) [8].

$$C_k = \frac{1}{Z_0}\frac{1}{4\pi\Delta f_{3\,\mathrm{dB}-k}} \quad L_k = \frac{1}{(\omega_{0k})^2 C_k} \quad \text{for} \quad k = 1, 2 \tag{1}$$

where, $\Delta f_{3\,\mathrm{dB}-k}$ is the 3-dB bandwidth at f_{0k}, ω_0 the radian frequency at f_{0k}, and Z_0 the characteristic impedance of the line.

$$Ci = -\frac{1}{2\pi f_T X_{21}} \quad L_{ik} = \frac{X_{kk} - X_{21}}{2\pi f_T} + \frac{L_k}{\left(\frac{f_T}{f_{0k}}\right)^2 - 1} \quad \text{for} \quad k = 1, 2 \tag{2}$$

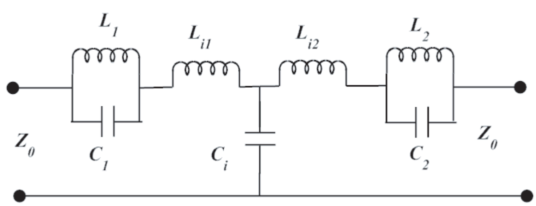

Figure 1. Equivalent circuit of DGS planer transmission lines [8].

where, f_T is transmission pole frequency between the two zeroes frequencies and X_{kk} the imaginary parts of Z-parameters at f_T.

The sensitivity, χ_{ij-k} of the model behavior, S_{ij}-parameters, with respect to model parameters, p_k, is mathematically expressed as in (3).

$$\chi_{ij-k} \triangleq \frac{\partial S_{ij}}{\partial p_k} \frac{p_k}{S_{ij}} \tag{3}$$

The relative sensitivity gives the percentage error in S_{ij} for 1% error in p_k.

Two cases that have been addressed in [8] are compared by carrying out the sensitivity analysis. The first one is concerning CPW DGS while the other covers microstrip DGS. Sensitivity analysis tool in ADS is used as a software package in our work.

2.1. Example One

The CPW DGS under study is shown in Fig. 2. The dielectric substrate has thickness of 1.27 mm and relative dielectric constant of 10.8. The characteristic impedance of the line is 50 Ω. The extracted parameters values, using (1) and (2), are $C_1 = 0.897\,\text{pF}$, $L_1 = 1.23\,\text{nH}$, $C_2 = 1.63\,\text{pF}$, $L_2 = 0.221\,\text{nH}$, $C_i = 0.033\,\text{pF}$, $L_{i1} = 0.995\,\text{nH}$ and $L_{i2} = -0.919\,\text{nH}$.

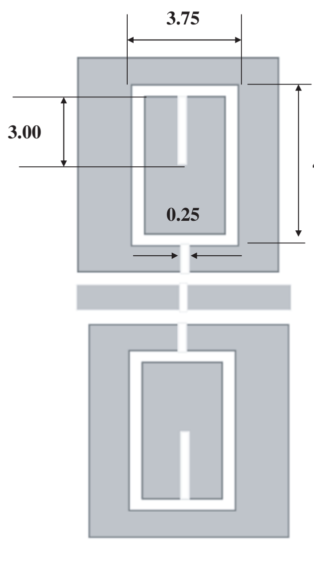

Figure 2. Schematic of CPW circuit used in example one. All dimensions in mm.

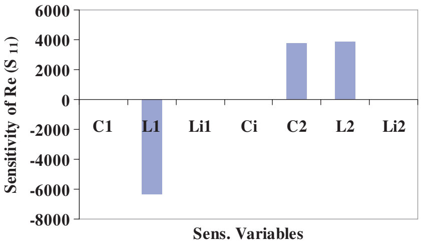

Figure 3. Sensitivity of Re (S_{11}) w.r.t model parameters.

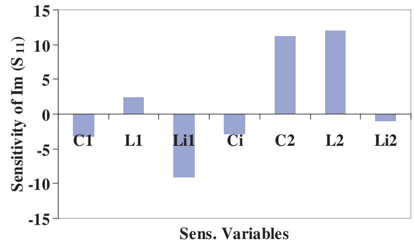

Figure 4. Sensitivity of Im (S_{11}) w.r.t model parameters.

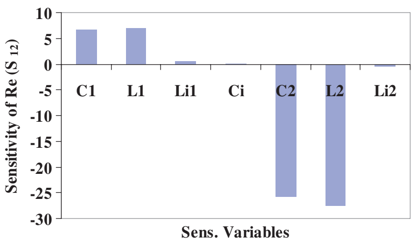

Figure 5. Sensitivity of Re (S_{12}) w.r.t model parameters.

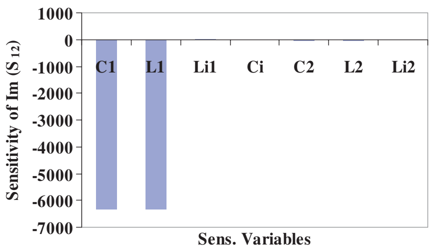

Figure 6. Sensitivity of Im (S_{12}) w.r.t model parameters

The sensitivity analysis is performed on the extracted equivalent circuit. Figs. 3–6 depict the sensitivity of the real and imaginary parts of the S-parameters due to the circuit model parameters. S-parameters, especially Re (S_{11}) and Im (S_{12}), are very sensitive to C_1, L_1, C_2 and L_2 parameters. Therefore, removing L_{i1}, L_{i2} and C_i does not affect the behaviour of the model. Comparison among the complete model, the model without L_{i1}, L_{i2} and C_i parameters, and full wave EM simulator will be presented in the next section.

2.2. Example Two

In this example, DGS microstrip, shown in Fig. 7, is investigated. The utilized substrate is the one used in the previous example.

The characteristic impedance of the line is $50\,\Omega$. The extracted parameters values, using (1) and (2), are $C_1 = 1.349\,\text{pF}$, $L_1 = 0.4184\,\text{nH}$, $C_2 = 1.02\,\text{pF}$, $L_2 = 0.082\,\text{nH}$, $C_i = 0.028\,\text{pF}$, $L_{i1} = -0.749\,\text{nH}$ and $L_{i2} = 0.5745\,\text{nH}$.

As shown in the Figs. 8–11, S-parameters are sensitive to C_1, L_1, C_2 and L_2, especially Re (S_{11}) and Im (S_{12}). Consequently, removing L_{i1}, L_{i2} and C_i does not influence the behaviour of the model.

Comparison among the complete model, the model without L_{i1}, L_{i2} and C_i parameters, and full wave EM simulator will be addressed in the next section.

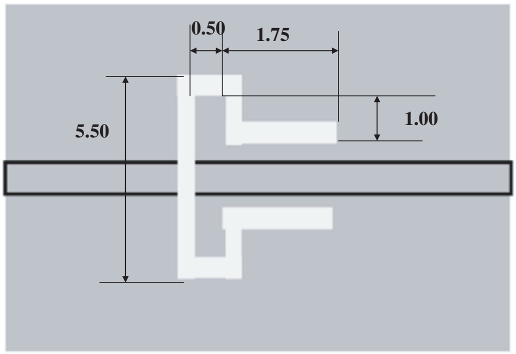

Figure 7. Layout of DGS microstrip circuit used in example two. All dimensions in mm.

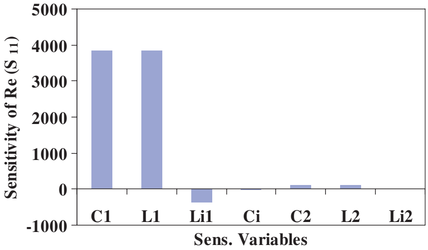

Figure 8. Sensitivity of Re (S_{11}) w.r.t model parameters.

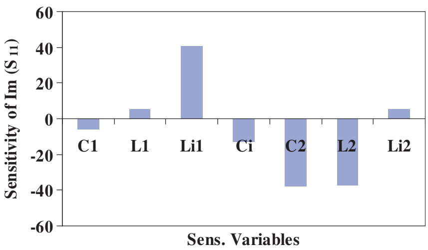

Figure 9. Sensitivity of Im (S_{11}) w.r.t model parameters.

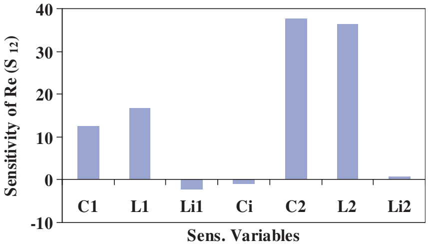

Figure 10. Sensitivity of Re (S_{12}) w.r.t model parameters.

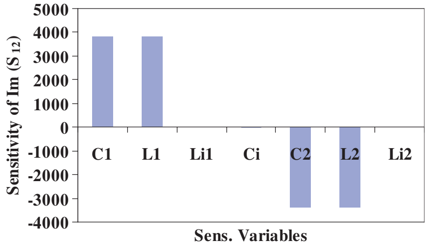

Figure 11. Sensitivity of Im (S_{12}) w.r.t model parameters.

3. VALIDATION OF THE MODIFIED MODEL

As discussed in the previous section, the model of the planer circuit with two resonance frequencies can be modeled with two parallel L-C circuit, as depicted in Fig. 12. The two examples under study are verified in the following subsections.

3.1. Example One

Comparisons among the magnitudes and phases of S-parameters of the modified model, the model with interaction representation, and EM simulation are shown in Fig. 13 for the magnitudes and Fig. 14 for phases. Excellent agreement among S-parameters of the modified model, model of [8], and EM simulator is noticed.

3.2. Example two

Concerning the second validation case, comparison among S-parameters of the modified model, the model with interaction

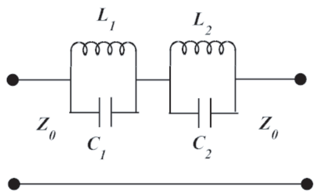

Figure 12. The simplified equivalent circuit model.

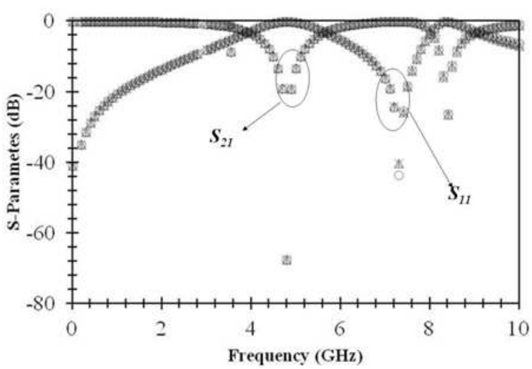

Figure 13. S-parameters of simplified circuit (Δ), complete circuit (*) and EM simulator ($\circ$) for 1st example.

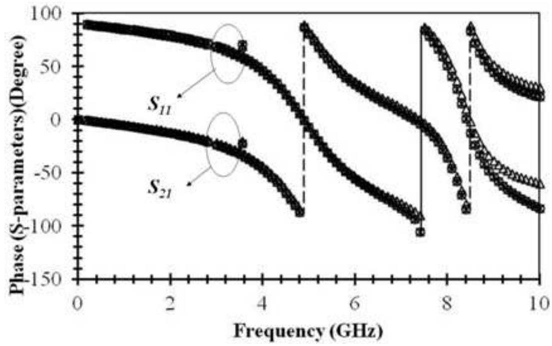

Figure 14. Phase of S-parameters of simplified circuit (Δ), complete circuit (*) and EM simulator ($\circ$) for 1st example.

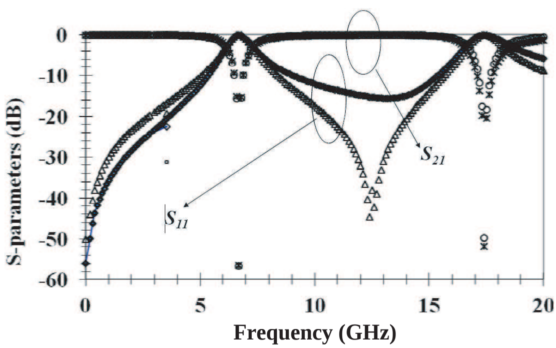

Figure 15. Magnitude of S-parameters of simplified circuit (Δ), complete circuit (*) and EM simulator ($\circ$) for 2nd example.

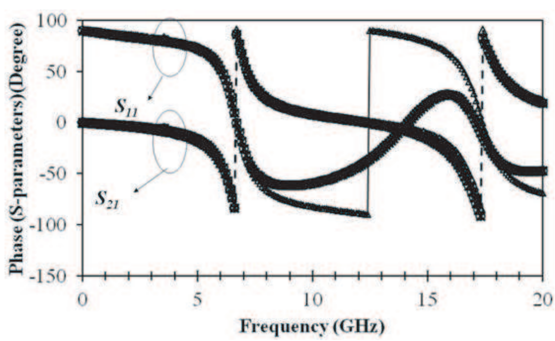

Figure 16. Phase of S-parameters of simplified circuit (Δ), complete circuit (*) and EM simulator ($\circ$) for 2nd example.

representation, and EM simulation are shown in Figs. 15 and 16 for magnitudes and phases respectively. Excellent agreement is obtained for both of magnitude and phase of S_{21}. Noticeable disagreement for S_{11} is observed between the two resonances. However, this disagreement can be disregarded since it is under -15 dB level, a very low value.

3.3. Example 3.3

Seeking for more validation of the proposed model, more complicated circuit is simulated using this model. The circuit under study is composed of cascaded three unit cells, as shown in Fig. 17 and simulated as in the previous two examples, EM simulation and circuit simulation using complete equivalent circuit and proposed modified version. The values of the equivalent circuit parameters for the individual unit are $C_1 = 2.059$ pF, $L_1 = 0.8746$ nH, $C_2 = 1.457$ pF, $L_2 = 0.2303$ nH, $C_i = 0.0385$ pF, $L_{i1} = -1.009$ nH and $L_{i2} = 1.093$ nH.

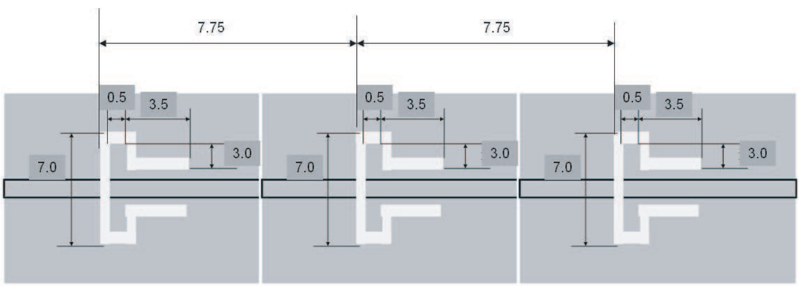

Figure 17. Layout of cascaded three unit cells in CPW technology.

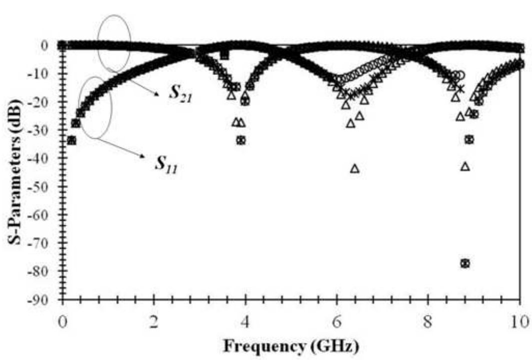

Figure 18. Magnitude of S-parameters of simplified circuit (Δ), complete circuit (*) and EM simulator ($\circ$) for 3rd example.

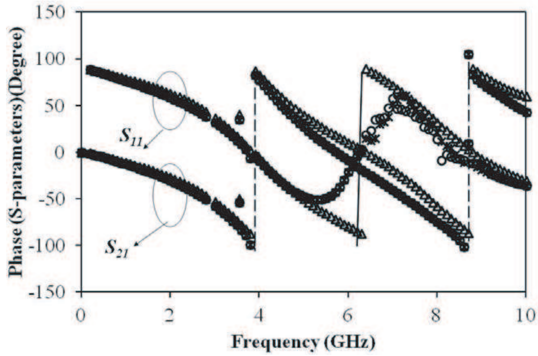

Figure 19. Phase of S-parameters of simplified circuit (Δ), complete circuit (*) and EM simulator ($\circ$) for 3rd example.

As depicted in Figs. 18 and 19, in general, the magnitude and phases of S-parameters of modified circuit are in perfect match with the corresponding parameters of complete circuit and EM simulation, especially for S_{21}. However, in the frequency band ranging from 5.8 GHz to 6.8 GHz, a little mismatch in magnitude and phase of S_{11} parameter among the three simulations is observed. This disagreement can be neglected since it appears in the low levels of S_{11}, under -15 dB.

4. CONCLUSION

In this paper, sensitivity analysis is utilized to simplify the equivalent circuit model of a DGS planer structure that has two resonance frequencies. The analysis demonstrates that the model of the interaction region between the two resonances has little impact on the behavior of the model. Consequently, the updated model is composed of two cascaded parallel L-C circuits. Each circuit models one resonance frequency. The simplified model has been verified with the original model as well as EM simulations of the planer circuit.

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