AN ADVANCED EQUIVALENT CIRCUIT OF SPIRAL-SHAPED DEFECTED GROUND STRUCTURE

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***Abstract* — An advanced modeling technique to achieve the equivalent circuit of spiral-shaped defected ground structures (DGS) is presented. The equivalent circuit is composed of a short-circuited stub and an inductor to express the spurious frequency as well as the resonant frequency. The elements of the equivalent circuit are extracted from the related theories on step impedance resonators (SIR) and the S-parameters calculated by electromagnetic simulation. While the existing equivalent circuit model adopts the SIR composed of transmission line elements with the same-length[1], the proposed equivalent circuit uses the SIR composed of different length of transmission line elements. It is shown that the modeled S-parameters from the proposed equivalent circuit are in excellent agreement with those obtained from the electromagnetic simulation.**

***Index Terms* — periodic structures, defected ground structures, DGS, spiral-shaped DGS**

I. INTRODUCTION

It is well known that planar transmission lines combined by periodic structures such as photonic bandgap (PBG) and defected ground structures (DGS) have larger slow-wave factor (SWF) than standard transmission lines [2-4]. In addition, spiral-shaped DGS patterns for transmission lines have been proposed in [1] and [5]. It is very interesting that “the transmission line with spiral-shaped DGS”(“Spiral-DGS line”) has higher SWF than the transmission lines with dumbbell-shape DGS as well as standard transmission lines. This means that a great potential application of Spiral-DGS is expected in the design of high frequency circuits.

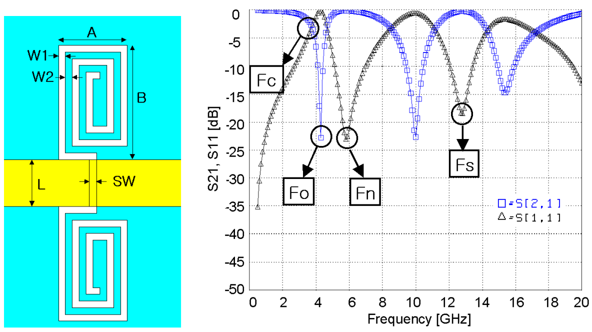
It is essential to model the exact equivalent circuit of Spiral-DGS to understand the frequency responses and to expand the usages. The equivalent circuit of Spiral-DGS has been proposed previously using the simple step impedance resonator (SIR) [1].

In this work, based on the previous work and more general theory of step impedance resonator, an advanced equivalent circuit model of Spiral-DGS is proposed. The lengths of three transmission line elements in the SIR are not fixed to be the same, but differ from each other. There are a lot of degree of freedom in the SIR, and this produces much more exact equivalent circuit than the existed method.

II. STRUCTURE OF SPIRAL DGS

Fig. 1 (a) shows the structure of a microstrip line combined by a Spiral-DGS on the ground plane, as an example. The dimensions of Spiral-DGS are designated as A, B, W1, W2, SW, and L. Here, the length of the connecting slot is fixed to be L, which corresponds to the width of 50Ω microstrip line (W50), for the convenience. L may differ from W50.

Fig. 1 (b) presents the electromagnetically (EM) calculated S-parameters for Fig. 1(a). The dielectric constant (ε_r) and thickness(H) of the selected substrate are 2.6 and 0.5mm, respectively. The dimensions of Spiral-DGS are; A=2mm, B=3.4mm, W1=W2=SW=0.2mm, L=1.4mm=W50.



(a) (b)

Fig. 1 (a) Unit Spiral-DGS on the ground plane of microstrip line (ε_r=2.6, A=2mm, B=3.4mm, W1=W2=SW=0.2mm, L=1.4mm, Substrate thickness=20mils) (b) Calculated S-parameters by EM simulation

It is shown that resonant and notch frequencies appear repeatedly. This proves intuitively that the equivalent circuit of Spiral-DGS should contain at least one distributed element rather than lumped elements only.

There are four meaningful frequencies, F_o, F_n, F_s, and F_c in Fig. 1(b). They are called conveniently in this work as the first resonant frequency, the first notch frequency, spurious frequency, and 3dB cutoff frequency, respectively.

III. THE PREVIOUS EQUIVALENT CIRCUIT [1]

Fig. 2 shows the equivalent circuit of Spiral-DGS. There is a short-circuited stub having SIR, equivalently added inductance (L_s), and resistance(R). Z_o and ϕ represent the port impedance and length of the port feeding line.

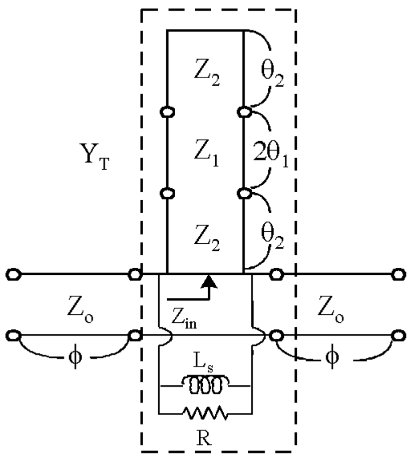


Fig. 2 Equivalent circuit using a short-circuited stub having SIR

In the previous equivalent circuit, the length of transmission line elements is fixed to be the same, i.e. $\theta_1=\theta_2=\theta$, in order to simplify the short-circuited stub. The input impedance and admittance are expressed as eqs. (1) ~ (5). Here, K is Z_2/Z_1 and positive because Z_1 and Z_2 are finite positive values.

$$Z_{in} = jZ_2 \frac{2(1+K)(1-K\cdot\tan^2\theta)\tan\theta}{K-2(1+K+K^2)\tan^2\theta + K\cdot\tan^4\theta} = jZ_2\cdot F(\omega) \quad (1)$$

$$F(\omega) = \frac{2(1+K)(1-K\cdot\tan^2\theta)\tan\theta}{K-2(1+K+K^2)\tan^2\theta + K\cdot\tan^4\theta} \quad (2)$$

$$Y_{in} = -jY_2\frac{1}{F(\omega)} \quad (3)$$

$$Y_T = Y_{in} + \frac{1}{R} - \mathrm{j}\frac{1}{\omega L_s} = G + jB_T(\omega) \quad (4)$$

$$B_T = -\frac{Y_2}{F(\omega)} - \frac{1}{\omega L_s} \quad (5)$$

Because $Z_{in}=0$ at F_n, the numerator of (1) is zero, and eq. (6) is obtained. In addition, because the denominator may be ∞ in order that $Z_{in}=0$, eq. (7) is obtained at F_s. Then, $\theta_s=\pi/2$. Now, K is calculated from eq. (8) and (9).

$$\theta_n = \tan^{-1}\frac{1}{\sqrt{K}} \quad (6)$$

$$\tan\theta_s = \infty \quad (7)$$

$$\frac{\theta_s}{\theta_n} = \frac{f_s}{f_n} = \frac{\pi/2}{\tan^{-1}(1/\sqrt{K})} \quad (8)$$

$$K = \frac{1}{\left(\tan\frac{\pi f_n}{2f_S}\right)^2} \quad (9)$$

At F_o, B_T must be 0, which produces eq. (10). Also, B_T at F_c should be equal to the susceptance value at the normalized cutoff frequency of 1-pole prototype low pass filter. This relation generates eq. (11), where g_k and Z_o are the normalized element value and port impedance level, respectively. Z_2 and L_s are calculated by equating eq. (10) and (11). Finally Z_1 is obtained from K and Z_2. The resistance(R) is calculated easily from the S-parameters at resonance.

$$-\frac{Y_2}{F(\omega_o)} - \frac{1}{\omega_o L_s} = 0 \quad (10)$$

$$-\frac{Y_2}{F(\omega_c)} - \frac{1}{\omega_c L_s} = \frac{1}{g_k Z_0} \quad (11)$$

The obtained element values are; Z_1=35.76Ω, Z_2=48.06Ω, L_S=2.0007nH, R=1,313Ω. Fig. 3 shows the characteristics of the extracted equivalent circuit.

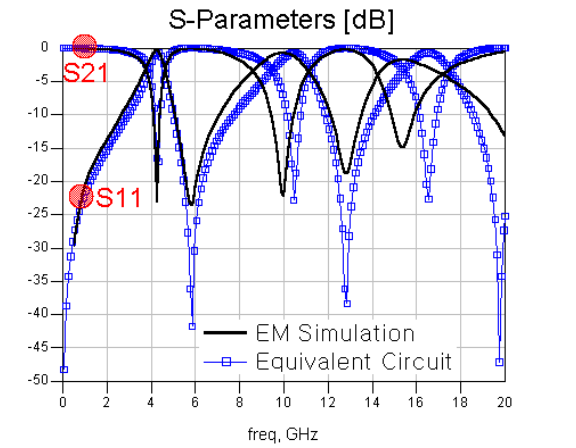


Fig. 3 Characteristics of the equivalent circuit with Fig. 1(b) overlapped.

IV. THE ADVANCED EQUIVALENT CIRCUIT

However, discrepancies are observed at the second and third resonant frequencies in Fig. 3. This is caused by the simplification of SIR, i.e. by fixing $\theta_1=\theta_2=\theta=\pi/2$(at F_s). However, in practice, there exist a great number of combinations of θ_1 and θ_2 according to K[6].

If $\theta_1\neq\theta_2$, eq. (1) does not hold any longer, and the input impedance of SIR can expressed as eq. (12). When the total length of SIR is θ_T, θ_2 is equal to $\theta_T/2-\theta_1$. Eq. (13) can be obtained using the fundamental notch condition($1=K\tan\theta_1\tan\theta_2$). Fig. 4 depicts the lots of possible combination of θ_1 and θ_T when K is the variable parameter. If K=1for the simple case, $Z_1=Z_2$ and $\theta_T=\pi$.

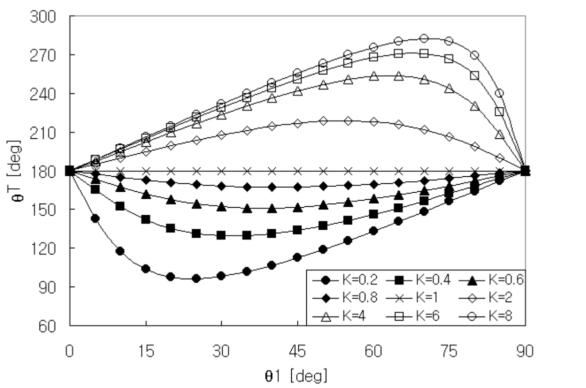


Fig. 4 Relation between θ_1 and θ_T with K as parameter

$$Z_{in}=jZ_2\frac{2(\tan\theta_1+K\tan\theta_2)(1-K\tan\theta_1\tan\theta_2)}{K(1-\tan^2\theta_1)(1-\tan^2\theta_2)-2(1+K^2)\tan\theta_1\tan\theta_2} \quad (12)$$

$$\tan\frac{\theta_T}{2}=\frac{1}{1-K}\left(\frac{K}{\tan\theta_1}+\tan\theta_1\right) \quad (13)$$

There is another condition, that is, $\tan\theta_1=-K\tan\theta_2$. Because K is positive, $\tan\theta_1$ and $\tan\theta_2$ should have the opposite sign. This restricts the possible combination of θ_1 and θ_2. Even though a great number of combination can be thought as shown in Fig. 4, only the (θ_1, θ_2) pairs which satisfy $\tan\theta_1=-K\tan\theta_2$ can be chosen. Finally the possible pairs are illustrated in Fig. 5 for various K.

Once K and the pair of θ_1 and θ_2 are determined, the remaining procedures to get Z_1, Z_2, and L_s are the same as above. As an example, when K and θ_1 are chosen to be 1.6 and 30^o, respectively, the calculated Z_1, Z_2, and L_s are 37.9 Ω, 60.7 Ω, and 2.11nH, respectively. Fig. 6 shows the S-parameters of the newly extracted equivalent circuit using the proposed method. Much better agreement than Fig. 3 is achieved. Fig. 6 proves that the exactitude of the proposed equivalent circuit has been obtained successfully..

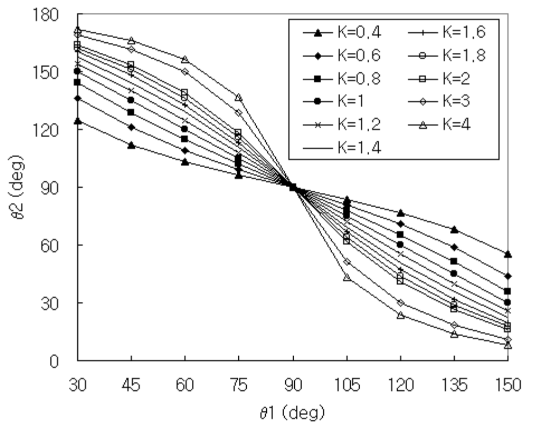


Fig. 5 Combination of θ_1 and θ_2 with K as parameter

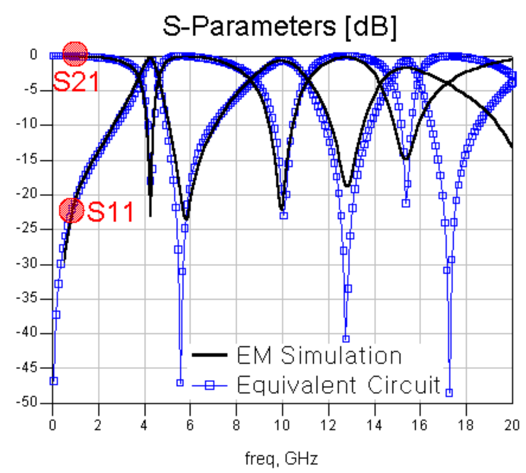


Fig. 6 Characteristics of the modified equivalent circuit with Fig. 1(b) overlapped.

V. CONCLUSION

The previous equivalent circuit for Spiral-DGS has been reviewed, and the new method to extract the improved equivalent circuit of has been proposed. Using the related equations of SIR, the lots of possible combinations of the length of transmission line element in SIR have been calculated.

Depending on the proposed method, a Spiral-DGS under the microstrip line has been model, and the electrical characteristics of the equivalent circuit were calculated on Agilent Advanced Design System (ADS), a circuit simulator. The S-parameters of the equivalent circuit excellently agree with the EM simulation up to the third resonant frequency.

The proposed method can be applied to the Spiral-DGS for CPW as well as microstrip line. Because exact equivalent circuit is available, it is expected that the application of Spiral-DGS will be expanded to the design of various high frequency circuits.

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