The Equivalent Circuit Modeling of Defected Ground Structure with Spiral Shape

Chul-Soo Kim, Jong-Sik Lim*, Sangwook Nam*, Kwang-Yong Kang, Jong-Im Park**, Geun-Young Kim*** and Dal Ahn**

Telecommunication Basic Research Lab., ETRI, R.O.Korea
*School of Electrical Eng., Seoul National Univ., R.O.Korea
**Division of Information Technology Eng., Soonchunhyang Univ., R.O.Korea
***School of Information and Communication, Tamna univ., R.O.Korea
E-mail : dahn@ramrec.sch.ac.kr

Abstract **We proposed the newl y etched DGS(Defected Ground Structure) with a spiral shape in metallic ground plane and the equivalent circuit modeling applied to a spiral DGS for the microstrip line. The proposed spiral DGS can provide steep rejection characteristics with the one and only spiral. The equivalent circuit for the spiral DGS is derived by means of three-dimensional field analysis methods. To represent spurious resonance, the equivalent circuit of a spiral DGS is consisted of an inductor and a shorted stub with step impedance. The circuit parameters are extracted from a simple circuit analysis method. Experimental results show excellent agreements with circuit simulation results in wide band and the validity of our circuit modeling for the spiral DGS.**

I. INTRODUCTION

Recently, several researches on the defected ground structure (DGS) and photonic band gap (PBG) structure have been reported with various configurations in microwave and millimeterwave frequency band applications.[1]-[7] A defected ground structure(DGS) for the microstrip line has etched-defects in a metallic ground plane like photonic bandgap (PBG) structures. Since an etched-defect of the ground plane disturbs the shielded current distribution in the ground plane. The DGS with periodic or non-periodic shape provides rejection band in some frequency range due to increasing the effective inductance of a transmission line. This disturbance can change characteristics of a transmission line such as line capacitance and inductance.[3][6] This band rejection characteristic of DGS is available to a power amplifier module, and filters, etc.[3]-[5] Increased effective inductance with DGS can provide wider width of transmission line than that of a conventional line. This characteristic can apply to power dividers and branch line coupler.[6][7] These device applications require various modeling methods to obtain equivalent circuits and parameters for the DGS.

In this paper, we proposed a newly etched DGS unit with a spiral shape in ground plane as shown in Fig. 1, and presented a equivalent circuit of the spiral DGS for a microstrip line. The equivalent circuits of the new spiral DGS are derived by using the field analysis method and are consisted of an inductor and a shorted stub with step impedance in order to represent periodic attenuation poles and zeros. The inductor as a lumped element can control the distance between pole and zero in frequency. The equivalent circuit parameters for the spiral DGS unit are extracted on the basis of a circuit analysis theory. The measured results show the excellent agreement with field simulation results of equivalent circuit in wide band and the validity of the modeling method for the spiral DGS. It is possible for the newly proposed spiral DGS unit to apply to various microwave components.

II. CONFIGURATION AND EQUIVALENT CIRCUIT OF A SPIRAL DGS UNIT

Fig. 1 illustrates a schematic diagram of the microstrip transmission line with the proposed DGS unit, which is etched on metallic ground plane with spiral shape. The line width is chosen for the characteristic impedance(Zo) of 50ohm like a conventional microstrip line. Each dimensions shown in Fig. 1 are a = b = 5 mm, g = 0.4 mm, and w = 2.4 mm, respectively. The substrate for simulations and measurements was a RT/Duroid 5880 with thickness of 31 mil and a dielectric constant (ε_r) of 2.2.

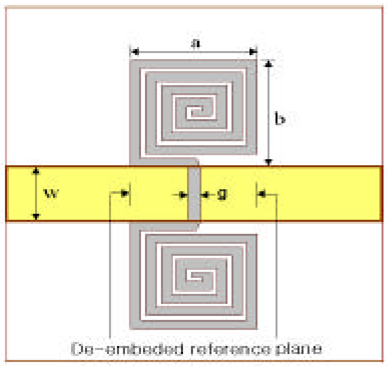

Fig. 1. The proposed spiral DGS unit

The spiral DGS unit without periodic arrangement was simulated by Ansoft-HFSS V.8.0. The simulation results are shown in Fig. 2.

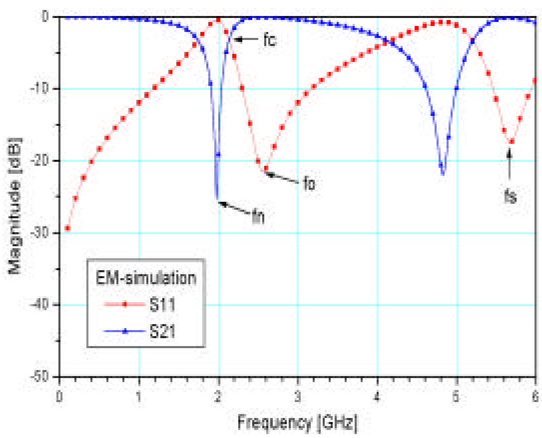

Fig. 2. EM-simulation results of the proposed spiral DGS unit

As shown in Fig. 2, it is reveals that the adoption of a spiral DGS unit increases the effective series inductance of the microstrip line.[3] Since lumped elements can't represent the spurious resonance. The new equivalent circuit for a spiral DGS unit is induced in order to illustrate the periodic resonance as shown in Fig. 3. The proposed equivalent circuit is consisted of a shorted stub with step impedance and an inductor. Then, the shorted stub with step impedance shows a spurious resonance and the lumped element inductor reveals the cross coupling between the etched defect line in ground plane. The electrical length ϕ with characteristic impedance(Z_0) denotes electrical length related to the de-embedded reference plane. Parameters of equivalent circuit can be extracted from the EM-simulation results and circuit theory.

Eq. (1) represents the input impedance toward the shorted stub with step impedance.[8]

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

where, K is an impedance ratio of Z_2/Z_1.

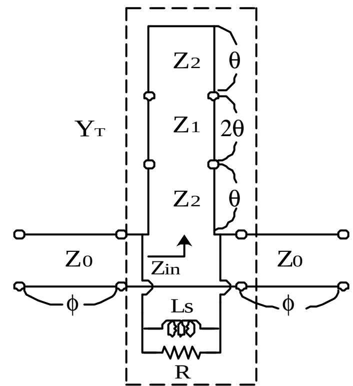

Fig. 3. The equivalent circuit of a spiral DGS unit

Therefore, the total admittance(Y_T) of equivalent circuit with dashed line is given by eq. (2).

$$Y_T = Y_{in} + G - j\frac{1}{\omega L_s} = G + jB_T(\omega) \qquad (2)$$

The resonance condition can be obtained from the following relation :

$$Z_{in} = 0 \qquad (3)$$

Using the fundamental frequency f_0 and corresponding length θ_0, the resonance condition is given as eq. (4) also.

$$\theta_0 = \tan^{-1}\frac{1}{\sqrt{K}} \qquad (4)$$

Taking the first spurious resonance(f_s) and corresponding θ_0, we can derive the following relation from eq. (1) and (2).

$$\tan\theta_s = \infty \qquad (5)$$

then,

$$\frac{\theta_s}{\theta_0} = \frac{f_S}{f_0} = \frac{\pi}{2\tan^{-1}(1/\sqrt{K})} \qquad (6)$$

The spurious resonance f_s for the spiral DGS unit can be controlled by the impedance ratio K related to a shorted step impedance stub.[8] From eq. (6), one can obtain the impedance ratio(K) as follows ;

$$K = \left(\tan\frac{\pi f_0}{2f_S}\right)^{-2} \qquad (7)$$

At notch frequency (f_n) and 3 dB cutoff frequency(f_c), the susceptance (B_T : from eq.(2)) should be equal to a zero and the susceptance(right term of eq.(9)) of the prototype low-pass filter with one-pole, respectively. Then, one can obtain following relations.

$$\frac{Y_2}{F(w_n)} + \frac{1}{w_n L_s} = 0 \tag{8}$$

$$\frac{Y_2}{F(w_c)} + \frac{1}{w_c L_s} = \frac{-1}{g_k Z_0} \tag{9}$$

where g_k denotes the prototype value of Butterworth-type low-pass filter, and Z_0 means the scaled impedance level of the in/out terminated ports.

We can derived parameters of equivalent circuit from eq. (8) and (9) as follows ;

$$Z_2 = -g_k Z_0 \left[\frac{1}{F(w_c)} - \frac{1}{F(w_n)} \cdot \frac{w_n}{w_c} \right] \tag{10}$$

$$L_s = -Z_2 \frac{F(w_n)}{w_n} \tag{11}$$

$$Z_1 = Z_2 / K \tag{12}$$

From a phase simulation near the notch frequency, register (R) of equivalent circuits can be obtained by the approximation equation (13) ;

$$R = \frac{\Delta a(w)}{\Delta B_T(w)} \tag{13}$$

where, $\alpha(\omega)$ denotes the phase of S21 in EM-simulation.

The electrical length (ϕ) of equivalent circuits can be determined from the phase difference between EM-simulation and circuit simulation results for the spiral DGS unit. From the above all equations, various para-meters of equivalent circuit are calculated as follows.

Impedance : $Z_1 = 44$[ohm], $Z_2 = 59.735$[ohm]
Electrical Length : $\theta = 40.637$ [degree] at f_0
$\phi = 9.57$ [degree] at f_c
Inductance : $L_s = 4.306$nH
Resistance : R = 1375.69[ohm]

Fig. 4 shows the comparison obtained by simulation results and measurement with extracted elements. The comparison of phase characteristics for the proposed spiral DGS unit is shown in Fig. 5. The measurement and field calculation are carried out under an absorbing boundary condition. From the above comparison, the experimental and EM-simulated results show an excellent agreement with equivalent circuit simulation results in wide band. Therefore, the proposed equivalent circuit modeling is valid and useful.

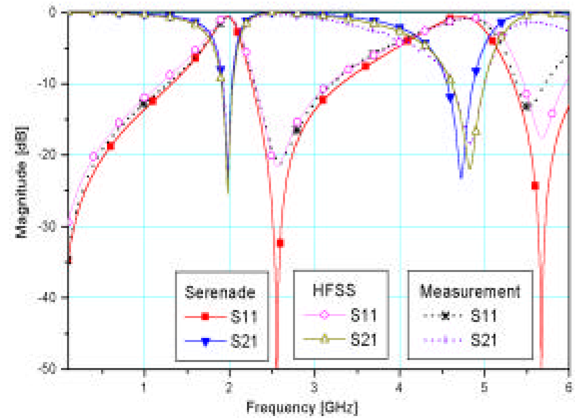

Fig. 4. The comparison results of a spiral DGS unit

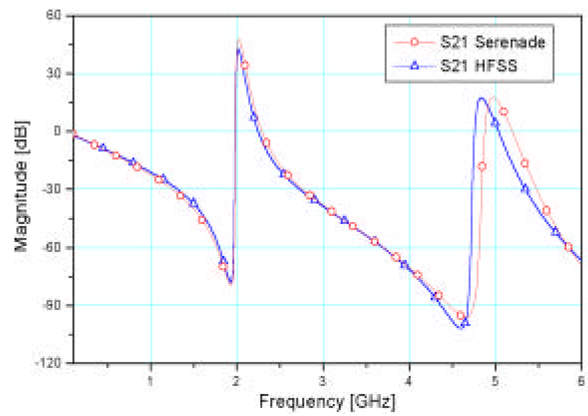

Fig. 5. The comparison of phase characteristics

III. PERIODIC ARRAY OF SPIRAL DGS UNIT

Fig. 7 shows simulation and measurement results of the spiral DGS cascaded with two unit sections as shown in Fig. 6. The distance (d) shown in Fig. 6 is 5 mm, and the others are same like Fig. 1.

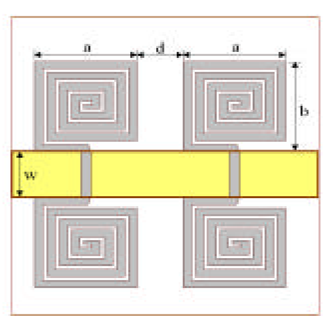

Fig. 6. The configuration of the spiral DGS with two unit sections

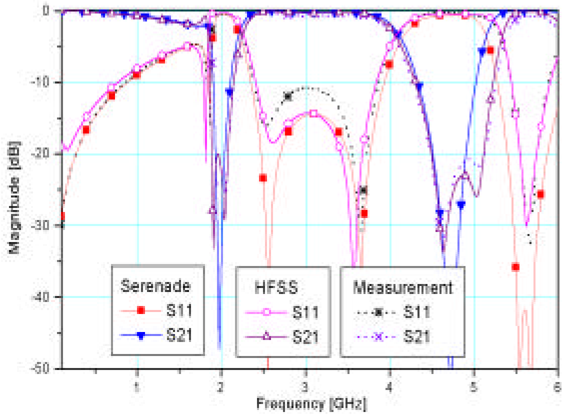

Fig. 7. Characteristics of spiral DGS with two unit sections

Fig. 8 shows the comparison of simulation results for the spiral DGS array with four unit sections. Although spiral DGS units are cascaded, the EM-simulation shows the good agreement with circuit simulation up to 6 GHz. The measured results of same version agree with the circuit simulation well (not shown in Fig. 8). Fig. 9 shows the photograph of the fabricated spiral DGS.

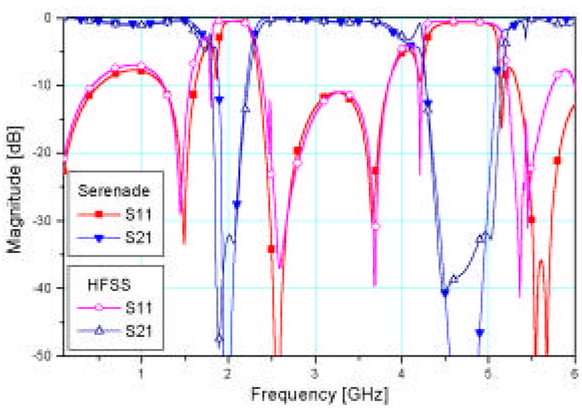

Fig. 8. Characteristics of spiral DGS with four unit sections

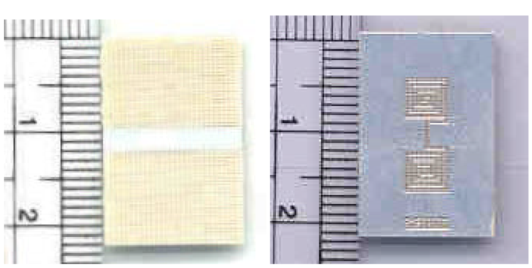
(a) Top view (b) Bottom view

Fig. 9. The photograph of a spiral DGS unit

IV. CONCLUSIONS

We proposed the new spiral DGS etched in metallic ground plane and the equivalent circuit modeling applied to microstrip line. The proposed spiral DGS unit (including periodic DGS) can provide narrow stopband and steep rejection characteristics. The equivalent circuit for the spiral DGS is derived by means of 3D field analysis methods and circuit theory. The proposed equivalent circuit has a shorted stub with step impedance to represent a spurious resonance. The experimental results show the excellent agreement with simulation results of equivalent circuit in wide band and the validity of the modeling method for the spiral DGS. We expect that this newly proposed spiral DGS and circuit modeling can be applied to various microwave components.

REFERENCES

[1] Y. Qian and T. Itoh, "Planar periodic structures for microwave and millimeter wave circuit applications," *IEEE MTT-s Dig.*, pp.1533-1536, June 1999.

[2] F. R. Yang, Y. Qian, and T. Itoh, "A novel uniplanar compact PBG structure for filter and mixer applications," *IEEE MTT-s Dig.*, pp.919-922, June 1999.

[3] D. Ahn, J. S. Park, C. S. Kim, J. Kim, Y. Qian, and T. Itoh, "A design of the low-pass filter using the novel microstrip defected ground structure", *IEEE Trans. on MT Ts.*, vol.49, no.1, pp.86-93, Jan. 2001.

[4] J. S. Yun, G. Y. Kim, J. S. Park, D. Ahn, K. Y. Kang, and J. B. Lim "A design of the novel coupled line bandpass filter using defected ground structure," *IEEE MTT-S*, vol.1, pp.327-330, June 2000.

[5] J. S. Lim, H. S. Kim, J. S. Park, D. Ahn, and S. Nam, "A power amplifier with efficiency improved using defected ground structure," *IEEE Microwave and Wireless Components Lett.*, vol.11, no.4, pp.170-172, March 2001.

[6] J. S. Lim, S. W. Lee, C. S. Kim, J. S. Park, D. Ahn, and S. Nam, "A 4:1 unequal wilkinson power divider," *IEEE Microwave and Wireless Components Letters*, vol.11, no.3, March 2001.

[7] J. S. Lim, C. S. Kim, J. S. Park, D. Ahn and S. Nam, "Design of 10dB 90° branch line coupler using microstrip line with defected ground structure," *IEE Electronics Lett.*, vol.36, no.21, pp.1784-1785, Oct. 2000.

[8] M. Makimoto, and S. Yamshita, "Bandpass filters using parallel coupled stripline stepped impedance resonators," *IEEE Trans. on Microwave Theory Tech.*, vol. MTT-28, no. 12, pp.1413-1417, Dec. 1980.