Design of New Attenuator Structure with Quad Spiral sHaped Defected Ground Structure

Yongwoo Jeong*, Young-Joo Song**, Hyung-Sik Park**, Dal Ahn***

Abstract We suggest new attenuator design and formula using quad spiral shaped defected ground structure (DGS). Series resistors and quarter wavelength transmission line that has a role of inverter have been synthesized for attenuator design and novel attenuator structure using quad spiral shaped DGS is fabricated, the measurements show good agreement with theoretical anticipations. The suggested attenuator could remove peak of insertion loss graph through various attenuation method. The various attenuations are obtained by attached pin-diodes, 10-15dB attenuation leveling is realized for validity of suggested design.

Key Words : Quad spiral shaped defected ground structure, attenuator, pin-diode.

1. Introduction

The attenuator has been used for controlling the signal level and system power budget in communication system[1-4]. The conventional attenuator structure can be extracted by using T and Pi type resistor circuit model[5]. According to these structures, attenuator has flat attenuation level over all frequency range. These attenuators have been modified for system requirement and used for controlling signal levels with various elements like pin-diodes. When unexpected signal level occurs, it needs to control peak signal level in specified band width. The suggested attenuator is designated to produce downward curved insertion loss graph and could be used to flat upward, peak insertion loss curve to satisfy the system requirements. If there is the unexpected, inevitable upward curved insertion loss, it could be removed and flatten as well. This paper suggests that novel attenuator design can be realized with quad spiral shaped defected ground structure. Quad spiral structure is modified version of spiral defected ground structure(DGS), has four spiral shaped defected pattern on the ground plane and

results device size reduction in comparison with previous DGS. It is used for this design concept, modified to be a base station as a role of an attenuator. The proposed attenuator is supposed to be able to control insertion loss level in specified frequency range by amplitude equalization, so it is employing quarter wavelength impedance transformer. And it is suitable as an add-on circuit for controlling unwanted insertion loss peak in specific frequency bandwidth, for it doesnt give whole system any return lose when attenuation occurs. Circuit analysis and EM simulation are acquired; it shows good agreement between simulation and measurement.

2. Design theory of attenuator

The attenuator circuit that has been usually used in modern systems can theoretically be presented as shown Fig. 1[5].

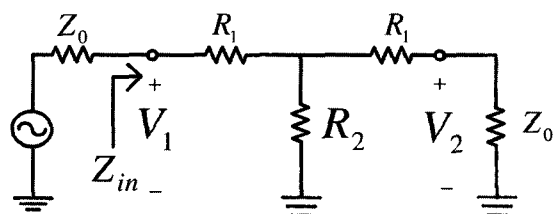This combination of three resistors can be analyzed as ABCD parameter like eq.(1)

Fig. 1. T-type attenuator circuit

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$$\begin{bmatrix} A = 1 + \dfrac{R_1}{R_3} & B = R_1 + R_2\dfrac{R_3}{R_1 R_3} \\ C = \dfrac{1}{R_3} & D = \dfrac{R_2}{R_3} + 1 \end{bmatrix} \quad (1)$$

These values of resistors can be derived from analysis of the co-relation between voltages and impedances.

$$Z_m = \frac{V_1}{I_1} = \frac{A V_2 + B(-I_2)}{C V_2 + D(-I_2)} = \frac{A Z_{out} + B}{C Z_{out} + D} \quad (2)$$

Substitute each parameter of eq. (1) into eq. (2)

$$R_1 R_2 + R_2 R_3 + R_1 R_3 + R_1 R_3 + (R_1 + R_3) Z_{out}$$
$$- (R_2 + R_3) Z_m - Z_{out} Z_{in} = 0 \quad (3)$$

The solving sequence from eq. (1) to eq. (3) can be used for case of

$$R_1 R_2 + R_2 R_3 + R_1 R_3 - (R_1 + R_3) Z_{out}$$
$$+ (R_2 + R_3) Z_m - Z_{out} Z_{in} = 0 \quad (4)$$

Transform S-parameter to ABCD parameter to obtain the attenuated insertion loss level.

$$S_{21} = \left. \frac{b_2}{a_1} \right|_{a_2 = 0} \rightarrow \frac{2}{A + B/Z_0 + C Z_0 + D} \quad (5)$$

$$A + B/Z_0 + C Z_0 + D = 2/S_{21} \quad (6)$$

Now we can derive all variables as below;

$$R_3 + R_1 + (R_1 R_2 + R_2 R_3 + R_1 R_3)\frac{Z_{in}}{Z_{out}^2}$$
$$+ \frac{Z_{out}^2}{Z_{in}} + R_2 + R_3 - 2 R_3 \frac{1}{S_{21}} = 0 \quad (7)$$

$$\therefore R_1 = R_2 = \frac{1 + (1/S_{21})^2 - 2/S_{21}}{(1/S_{21})^2 - 1} \times Z_m \quad (8)$$

$$\therefore R_3 = \frac{2 Z_{in} S_{21}}{1 - (S_{21})^2} \quad (9)$$

But this combination of lumped resistors can not be a sort of microwave device controller by itself, so that it has to be analyzed, transformed to the distributed circuit. Despite of the disability for systematic perspective by itself, eq. (7)~eq. (9) could be useful

in the proper distributed circuit is provided. Fig. 1 can be transformed by using the quarter-wavelength impedance transformer that is in T-type attenuator equivalent circuit with resistors in Fig. 2. The parameters in Fig. 2 can be derived from the imped-ance matching condition.

The parameters of Fig. 2 are given by following relations;

$$Z_{in1} = \frac{Z_a^2}{R_1 + Z_0} \quad (10)$$

$$Z_{in2} = \frac{Z_a^2}{R_a + Z_{in1}} \quad (11)$$

$$\quad (12)$$

In eq. (10)~(12), Z_a means quarter-wavelength impedance transformer that has a role of inverter can be · replaced with transmission line without any unwanted flaws, and R_a can be obtained by condi-tion $Z_{in} = Z_{in2}$

3. Quad spiral shaped defected ground structure

Here we want to introduce defected ground struc-ture that has been called as 'DGS'. DGS has origi-nally dumbbell shaped, defected slot on the ground and the increased effective inductance in the trans-mission line in comparison with conventional trans-mission line. Unit quad spiral shaped DGS has four spiral shaped slot patterns on the ground. It surely can be simplified to parallel RLC resonator and transmission line by using phase compensation between 3D FEM and RLC circuit simulation [6]. We can employ the resonance characteristic of quad spiral shaped DGS for application of attenuator.

Fig. 3 shows the plane & three dimensional views of designed quad spiral shaped DGS, has been fabricated in Duroid substrate (a = 8.5 mm, b = 5.3 mm, c = 12.98 mm,
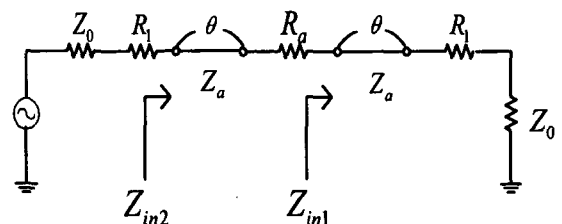

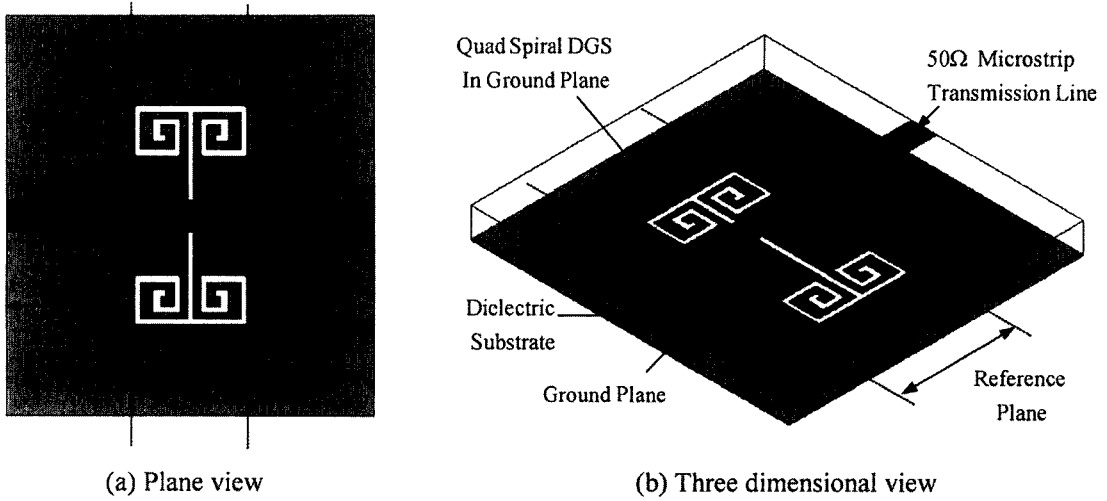Fig. 2. New structure attenuator using the quarter-wave length impedance transformer.

(a) Plane view   (b) Three dimensional view

Fig. 3. The plane view of unit quad spiral shaped defected ground structure

d = 3.805 mm, g = 0.5 mm, w = 2.31 mm). The reference planes represent the analysis point of this model, for the inside area of this model is a main core. The equivalent circuit of this quad spiral shaped DGS can be simplified as shown in Fig. 4. This simplify of equivalent circuit is targeted to under 3GHz, uses the frequency variables like resonant point, 3dB cut-off point and phase compensations. The aspect of de-embed quad spiral shaped DGS, which is showed as the reference planes section in Fig. 4, is an open circuit at the resonance frequency and it can be used as a series connection of resistor between port 1 and 2 of the DGS [6]. This connection can realize a series resistor connection in Fig. 2 at resonance condition. Also the electrical length of the equivalent circuit in quad spiral DGS is generally a positive value, can be used to reduce the quarter-wavelength transmission line [6]. This simplified equivalent circuit shows good agreement
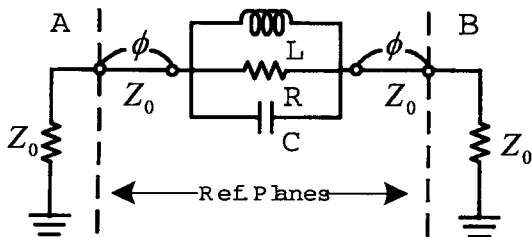

Fig. 4. Simplified equivalent circuit
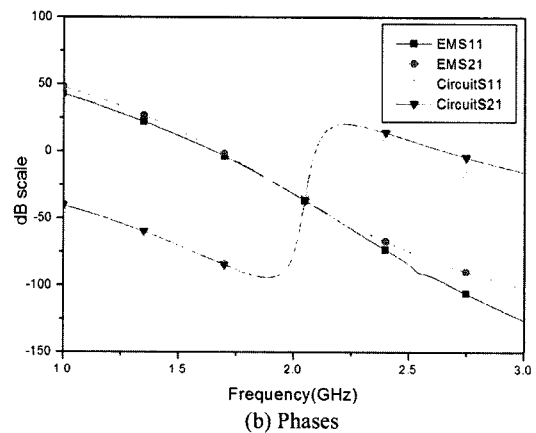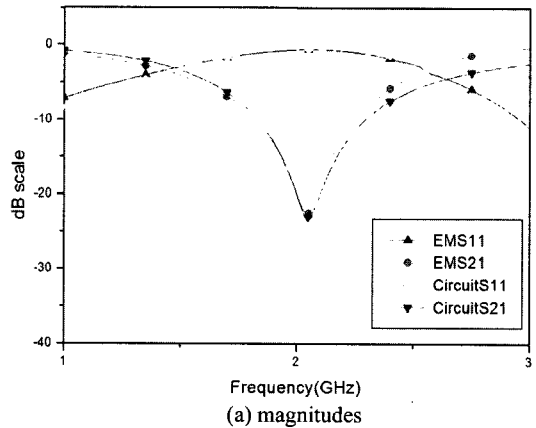

(a) magnitudes

(b) Phases

Fig. 5. Characteristics of EM and circuit simulations of quad spiral shaped DGS equivalent circuit

between EM and circuit simulation in Fig. 5 as well.

This structure allows us to develop multi-section quad spiral shaped DGS, anticipate that gaps between each unit quad spiral shaped DGS could be realized as quarter-wave length impedance transformer Z_a which is shown in Fig. 2. The 3 dimensional view of multi-section quad spiral shaped DGS is shown in Fig. 6 that could be the base part of attenuator, if lumped resistors were attached on the each section of quad shaped DGS. Basic dimensions in Fig. 6 are same to ones of unit quad spiral DGS.

4. Fabrications and experiments

An attenuator in this paper has been built on the basic quad spiral shaped DGS, shows the possibility of attenuating insertion loss level even if normal chip resistors were attached on this structure without DC bias. We fabricated 3 section quad spiral shaped DGS in order to prove the validity of attenuator structure through this prototype model.

A 6dB fixed attenuator was realized in this fabricated model, each chip resistor value on the ground plane can be derived from eq. (1)~eq. (9) as well. Fabrication was performed in Duroid substrate ($\varepsilon_r = 2.33$, substrate height = 31mil). This structure is supposed to have a downward curved insertion loss graph so that it has a role of an attenuator of flatting upward curved insertion loss graph. The measurement of characteristic is shown in Fig. 8, agrees with circuit simulation. Return loss property was shifted down from resonance anticipation, for this prototype has not basically considered of return loss accuracy, but of downward curved insertion loss feature to prove its possibility of attenuation.
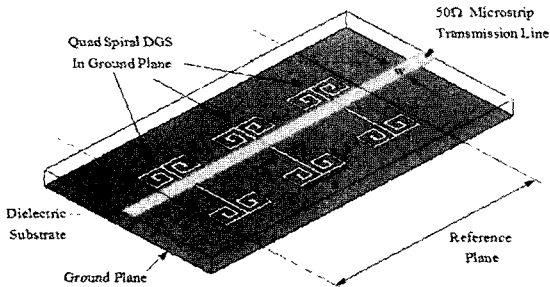

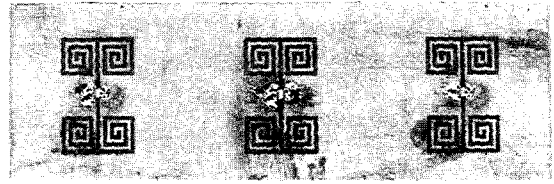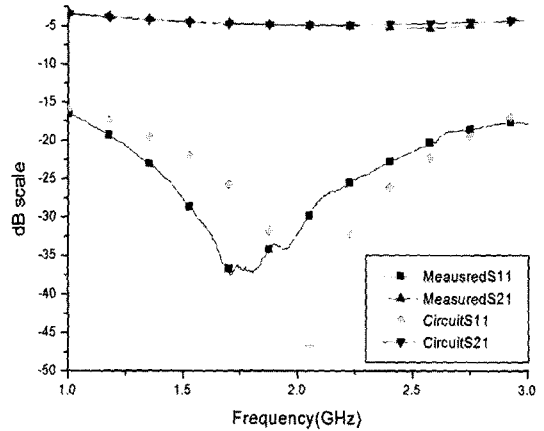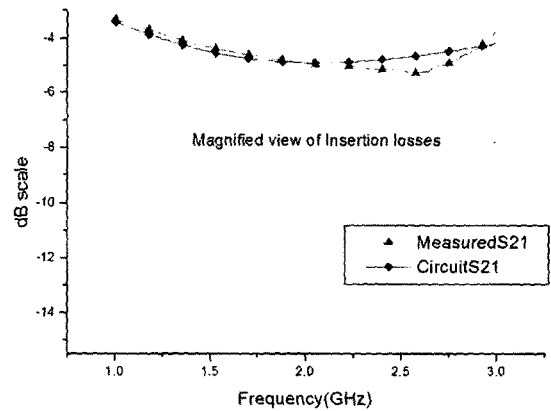Fig. 6. Multi-section quad spiral shaped DGS

Fig. 7. Ground plane view of attenuator prototype model

(a) Measurements & circuit simulation

(b) Magnified view of insertion losses

Fig. 8. Fabricated prototype attenuator

Lack of DC bias, this prototype can not produce the variable attenuation. Based on this prototype, 10~15dB variable attenuator has been designed on the quad spiral shaped DGS by using same substrate on same dimensions. Given by equation from eq. (1) to eq. (9) with condition of $Z_a = 50$ ohm, the circuit values R_1 and R_a can be obtained for variable attenuation, respectively. DC bias input circuit has to be on the ground plane to avoid attaching any lumped

elements on the signal plane, for element on the signal plane may cause bad effect on return loss. And if DC bias feeding line is over the pattern, it causes radiation error. There are radiation flows over ground plane like antenna beam; if any materials that can be represented perfectly conducting surface is placed in radiation flows, it causes radiation fails and frequency shifting. Fig. 9 shows the bottom view of DC bias lines that cause radiation failure.

So we re-designed model to reduce radiation fails, made it have etched DC feeding line on the ground plane. And this feeding line is separated from ground plane to avoid any harmful feedback of DC currents to the analyzer. Fig. 10 shows advanced model that is lack of radiation failure.

There is transmission line has 50 ohm characteristic in 1.8GHz center frequency on signal plane without any lumped elements. DC voltage dividing circuit is implanted on the ground to control input voltage ratio sensitively. The voltage ratio setting of this circuit may be changed whenever DC generator spec is different. Fig. 11 shows the magnified view

(a) A: DC voltage dividing circuit

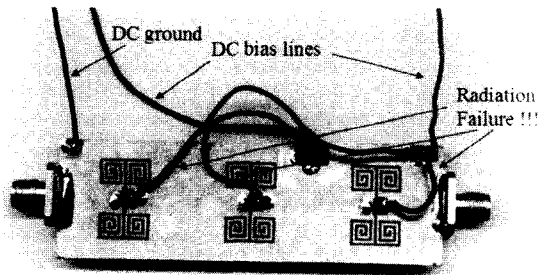(b) B: Pin diode circuit

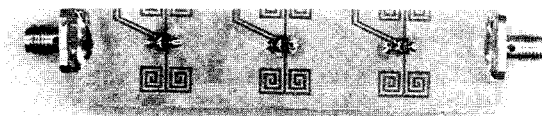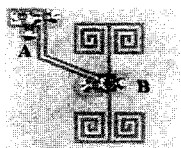Fig. 11. Detail views of points A, B of Fig. 10

Fig. 9. Fabricate model that has radiation failure

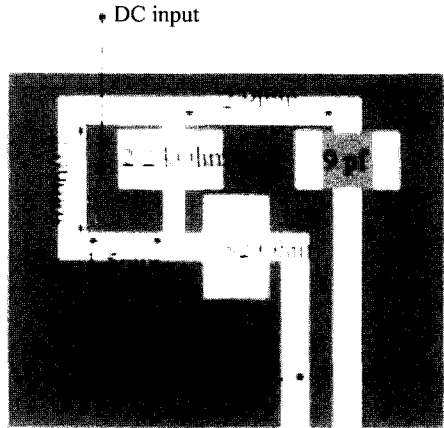(a) Fabricated attenuator using quad spiral shaped DGS.
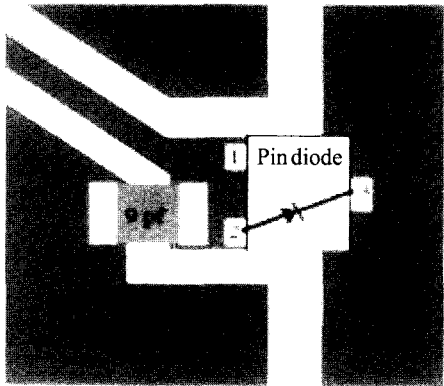

(b) Magnified view of unit

Fig. 10. The bottom view of advanced attenuator

of DC voltage dividing circuit and pin diode in detail.

Pin diode on the ground is Agilent Technologies HSMS-8101 single model. Within the range of its break down voltage, it is controlled to make the variable attenuation. If any unexpected insertion loss peak is observed, system manager can add this attenuator into system as add-on circuit, which has downward curved insertion loss property, to remove the peak point. Even though this circuit is sort of attenuator, it does not give any effect on the other frequency range, but on specific problematic bandwidth, for it is using quarter-wave length impedance transformer. Fig. 12 shows unique feature of this novel attenuator in variable attenuations.
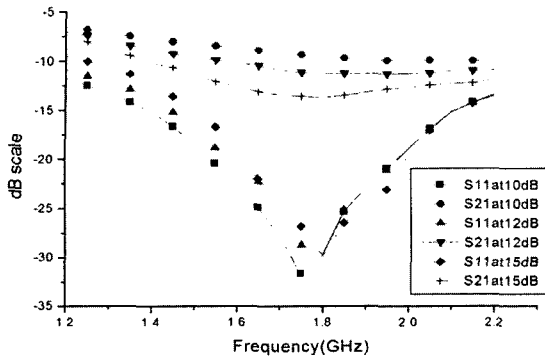
Fig. 12. Variable attenuation measurements

5. Conclusion

The new structure of attenuator using quad spiral shaped DGS has been proposed and fabricated. For the synthesis of attenuator, 3-section quad spiral shaped DGS patterns are used, and lumped elements are attached on the ground plane for operation of attenuation. We suggest that this structure has no lumped elements on the signal plane, so that good return loss can be provided and there is no need to attach DC blocking capacitor on the signal plane. And insertion loss feature of this structure shows downward curved shape that may be used to remove unwanted insertion loss peak as an add-on circuit in system and only give effects on problematic band-width, because of its quarter-wave length impedance

transformer. Furthermore pin diodes have been applied to this structure and variable attenuation is realized in 10~15dB scale.

References

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