A New Equivalent Transmission Line Modeling of Dumbbell Type Defected Ground Structure

JONGIM PARK
Division of Information Technology Engineering, Soonchunhyang Univ.
646 Eupnae Shinchang Asan Chungnam 336-745 R.O.Korea.

KYUHO PARK
Korea Electronics Technology Institute, Telecommunication Components Research Center.
455-6 Masan Jinwi Pyeongtaek Gyeonggi 451-865 R.O.Korea.

SUNGKEUN CHANG
RRC for Wireless Communication Devices, Soonchunhyang Univ.
646 Eupnae Shinchang Asan Chungnam 336-745 R.O.Korea.

DAL AHN
Division of Information Technology Engineering, Soonchunhyang Univ.
646 Eupnae Shinchang Asan Chungnam 336-745 R.O.Korea.

Abstract: - A novel equivalent circuit modeling method for a Dumbbell Type Defected Ground Structure (DBT-DGS) unit section is proposed. The proposed equivalent circuit consists of a short stub, additional series transmission lines and a resistor. All things consider is transmission zero, to compensate a phase difference, and to show losses such as conductor, dielectric, and radiation loss for the DBT-DGS, respectively. The circuit parameters are extracted from a simple circuit analysis method. EM simulation results show good agreements with circuit simulation results in wide band and the validity of our circuit modeling for the DBT-DGS.

Key-Words: - Unit DBT-DGS, dumbbell type, equivalent circuit, short stub, electrical length, phase.

1 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 millimeter-wave frequency band applications due to their great potential capability [1-5]. In this paper, the proposed DBT-DGS is applied to practical microwave circuits by modeling of a novel equivalent circuit. DBT-DGS has a transmission line structure with etched defects of the dumbbell type on metallic ground plane. The characteristics of DBT-DGS shows a stop-band and slow-wave effect in specific frequency band [6-13]. DBT-DGS basically has a role of a typical one-pole low pass filter with notch frequency. The equivalent circuit with transmission lines is derived from the field analysis results of DBT-DGS. Based on the simple circuit analysis theory, the equivalent circuit parameters are extracted. It is possible to apply this equivalent circuit to various microwave components.

2 Dumbbell Type DGS

Fig.1 shows the unit DBT-DGS pattern for microstrip line. In order to implant a DBT-DGS pattern in substrate, DBT-DGS has to be realized by etching off the dumbbell type from the bottom ground plan.

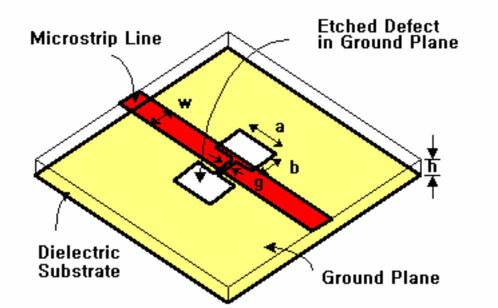


Fig.1 Unit DBT-DGS Patterns for microstrip lines (ε_r =2.2, a=b=5mm, g=0.5mm, W=2.4mm, Substrate thickness=31mil)

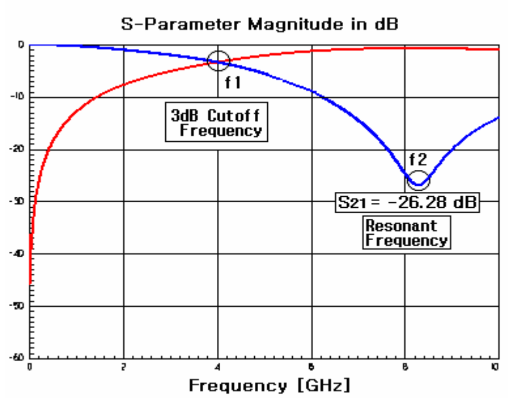


Fig.2 Characteristics of unit DBT-DGS

Fig.2 shows the characteristics of unit DBT-DGS of Fig.1. It looks like the typical characteristic of one-pole low pass filter. From this result, it is predicted that the equivalent circuit of a unit DBT-DGS is consisted of parallel L-C network, whose resonant frequency depends on the L and C values. The two square defects are the source of the equivalent inductance and the narrow connecting slot is converted to capacitance. Therefore, the resonant frequency depends on the dimensions of DBT-DGS. The equivalent circuit parameters can be extracted by using characteristics in fig.2. [4], [5].

Fig.3 shows the equivalent circuit and parameters that can be extracted by using characteristics in fig. 2.

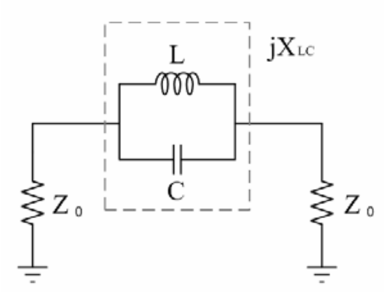


Fig.3 Equivalent circuit of the unit DBT-DGS

3 A new Equivalent Circuit Modeling of DBT-DGS

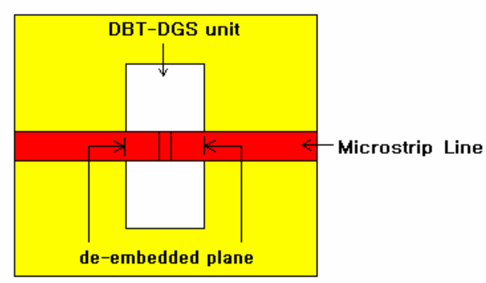


Fig.4 Plane view of unit DBT-DGS

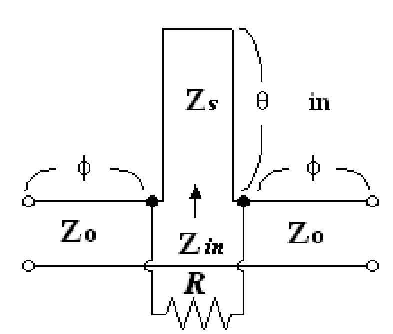
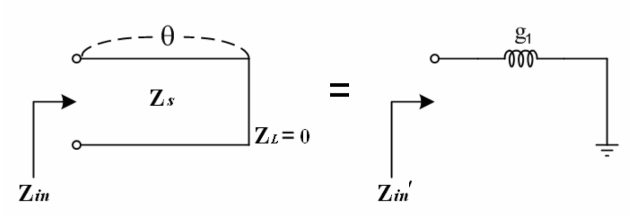


Fig.5 New equivalent circuit of unit DBT-DGS

It is necessary to extract the equivalent circuit elements through modeling process to understand the characteristics of the DBT-DGS. Fig.5 shows the proposed new equivalent circuit, which is composed of an ideal transmission line, short stub and resistance. Z_s and θ are the characteristics impedance and electrical length of the short stub, R is loss condition. ϕ denotes the electrical length to the de-embedded reference plane from the ports.



(a) (b)

Fig.6 (a) Simplified transmission line model for finding input impedance. (b) One-pole Butterworth low pass filter prototype.

Two input impedance of Fig.6 (a) and (b) are expressed as follows;

$$Z_{in} = Z_s \frac{Z_L + jZ_s \tan\theta}{Z_s + jZ_L \tan\theta} = jZ_s \tan\theta \qquad (1)$$

$$Z_{in}^{'} = \omega^{'} Z_0 g_1 \qquad (2)$$

Where $\omega^{'} = 1$ is the normalized frequency, $g_1 (= 2)$ is the prototype value of the Butterworth type LPF, and $Z_0 (= 50\Omega)$ is the scaled port impedance.

Input impedance of short stub Z_{in} has same value of $Z_{in}^{'}$ One-pole Butterworth low pass filter prototype.

$$jZ_s \tan\theta = \omega^{'} Z_0 g_1 \qquad (3)$$

The 3dB cutoff frequency and resonant frequency are designated as f_1 (3.93GHz) and f_2 (8.2GHz), in Fig.2, respectively. θ and Z_s value is decided by Eq . (4) and (5). v_p is transfer rate of transmission line

$$\theta = \frac{\pi}{2} = \frac{\omega}{v_p} \cdot l$$
$$= \frac{2\pi f}{v_p} \cdot \frac{\lambda}{4} \quad (\lambda = \frac{v_p}{f})$$
$$= \frac{2\pi f_1}{v_p} \cdot \frac{v_p}{4 \cdot f_2} \quad (v_p = 3 \times 10^8 m/s) \qquad (4)$$

$$Z_s = \frac{Z_0 g_1}{\tan\theta} \qquad (5)$$

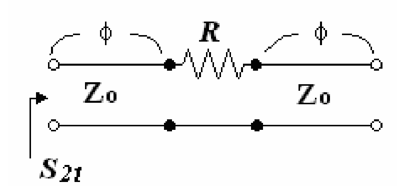


Fig.7 Equivalent circuit for finding the resistance R at resonance

The R can be a simple network theory shown at Fig.7. The magnitude of T is calculated as 0.04854 from resonant frequency in Fig.2.

$$S_{21}[dB] = 20\log|T| \qquad (6)$$

$$T = \frac{2Z_0}{2Z_0 + R} \qquad (7)$$

$$R = \frac{2Z_0(1-T)}{T} \qquad (8)$$

R is obtained using eq. (8) Electrical length ϕ is calculated easily by comparing the phase difference of two results between EM simulation and equivalent circuit, and compensating the proper additional electrical length. The equivalent circuit elements are calculated using the modeling technique as described above. The parameters are obtained as follows; $Z_s = 106.73\Omega$, $\theta = 43.13^{\circ}$, and $R = 1960\Omega$. ϕ $= 16.83^{\circ}$

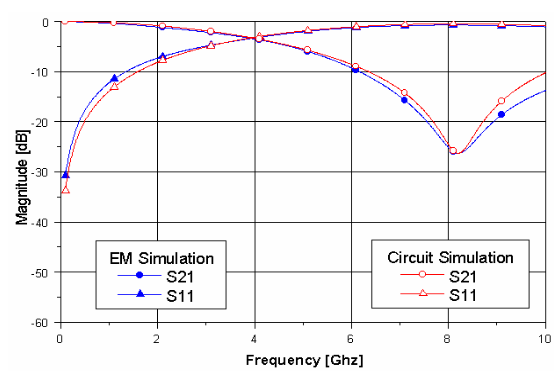


Fig.8 Comparison of the calculated characteristics of the equivalent circuit with the EM simulation results for the unit DBT-DGS show in Fig. 4

Fig.8 represents the simulated responses of equivalent circuit with the s-parameters shown in fig. 2 overlapped. The good agreement is observed as expected. The same agreement can be obtained by applying the modeling technique to the case of microstrip DBT-DGS line.

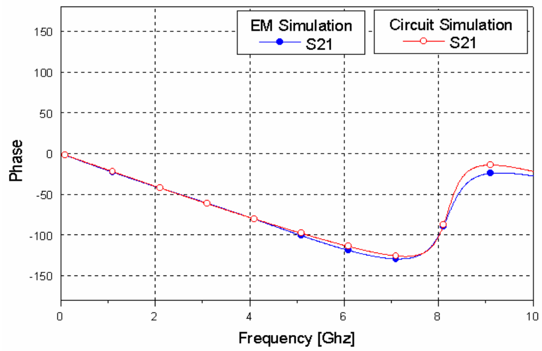


Fig.9 Comparison of the phase characteristics of the equivalent circuit with EM simulation results

Fig.9 display phase characteristics. Fig.8 and 9 represent the calculated transfer characteristics using the new equivalent circuit.

4 Conclusion

This paper has proposed a new equivalent circuit model of DBT-DGS applied to microstrip line. The equivalent circuit for DBT-DGS was derived by a 3D field analysis result and simple circuit theory. The validity of the proposed circuit has been proved by good agreement between EM and circuit simulations. Unit DBT-DGS was simple design and the slow-wave characteristics and wide band rejection, which enabled high impedance and low insertion loss. It is anticipated to develop the more accurate and various equivalent circuits to apply microwave circuit extensively. The proposed design and modeling could apply to in the input of power amplifier to remover 2nd, 3rd harmonics. If proposed design is added in ground plane of low pass filter it is possible to develop wider transmission line than conventional one and harmonic rejection can be provided. Because proposed design provides device size reduction, it is expected that DBT-DGS may be applied to with MIC, MMIC, and RFIC technologies.

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