Proceedings of the International MultiConference of Engineers and Computer Scientists 2010 Vol II,
IMECS 2010, March 17 - 19, 2010, Hong Kong

Equivalent Circuit Model of the Slotted Ground Structures (SGSs) Underneath the Microstrip Line

Hung-Wei Wu and Cheng-Yuan Hung

***Abstract*—In this paper, the equivalent circuit model of the slotted ground structures (SGSs) underneath the microstrip line is presented. The slotted ground structures are etched off on the ground plane to provide the stopband over the desired frequency range. The frequency response of the stopband can be determined by the dimensions of SGSs. The interaction between the SGSs can equivalent to a parallel T-network circuit and the elements can be derived from the simple formulas. Current distribution on the ground plane shows the interactions of electromagnetic waves propagation around the SGSs at 3.75 and 4.32 GHz. Measured results of the SGS are in good agreement with the EM and circuit simulation.**

***Index Terms*—slotted ground structure (SGS), circuit model, microstrip line, current distribution, stopband.**

I. Introduction

Photonic bandgap (PBG) structures with periodic arrays are etched on the ground plane have been proven to provide the high rejection in desired frequency range [1-3]. However, there are five parameters need to concern such as filling factor, cell distance, cell shape, cell position and number of cells, when designing the PBG structures. Defected ground structures (DGSs) with semi-lumped characteristics are widely used in the filtering devices [4]. The DGSs exhibit the behavior of multi PBG structures and/or a wide stopband in performance, which are used to suppress the spurious response of the passive devices with harmonics [4]-[9]. Due to their filtering and slow-wave effects, the slotted ground structures (SGSs) attract a growing interest among the various types of the DGS [7], [8].

To evaluate the frequency response of the SGSs, the full-wave electromagnetic (EM) simulation is used to tuning the dimensions of the SGSs. However, it costs a lot of time for achieving the optimum design. The optimization based on an equivalent circuit model of the device is required. The equivalent circuit models for the DGSs were reported in [9]-[12]. T. Itoh *et al.* proposed an ideal transmission line characterized by its impedance and electrical length for the slot and an ideal transformer to model coupling to the slot [9]. However, it is well known that typical microstrip line has losses; the microstrip line should be carefully considered in the equivalent circuit model. H. W. Wu *et al.* proposed an effective equivalent circuit model of the circular SGS under the microstrip line. The equivalent circuit model consists of lumped elements which can be demonstrated a transformer between the SGS and the microstrip line [11]. Although the equivalent circuit model has been demonstrated between the microstrip line and the single SGS, the interactions on the ground plane between the periodic SGSs should be further demonstrated. J. S. Hong *et al.* proposed the T-network with a lowpass circuit to represent the interaction between the two SGS cells [12]. However, the T-network with the lowpass circuit can not describe the interactions between the SGSs.

In this paper, we propose the equivalent circuit model of the slotted ground structures (SGSs) underneath the microstrip line. The single SGS can be modeled by parallel *RLC* circuit and the extraction of the equivalent elements can be derived from the simple formulas. The interaction between the two SGSs can be further proven by the parallel T-network circuit combined with lowpass- and highpass circuit. The modeling method of the SGSs underneath the microstrip line is described as follows.

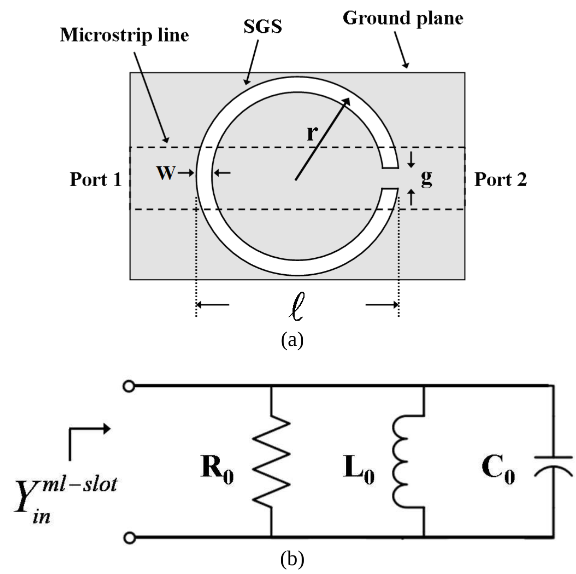

Fig. 1. (a) Top view and (b) the equivalent circuit model of the single slotted ground structure. (The gray is the metallic conductor and the white is the etched ground plane)

Manuscript received December 22, 2009. This work was supported by the National Science Council of Taiwan, under Grant NSC 98-2218-E-168-003.

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ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

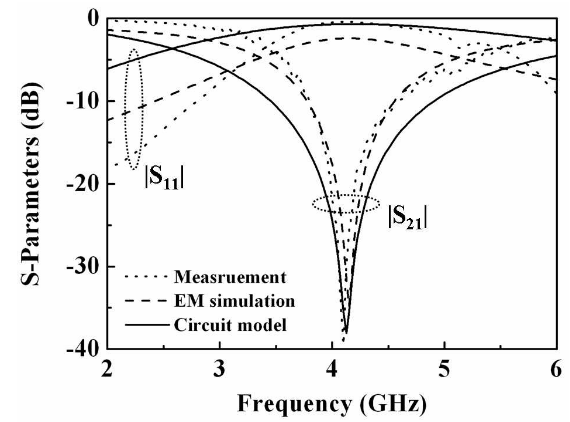


Fig. 2. Frequency responses of circuit simulation, EM simulation and measurement for the single slotted ground structure. (r_{ext} = 5.2 mm, g = 2 mm and w = 0.6 mm in Fig. 1(a))

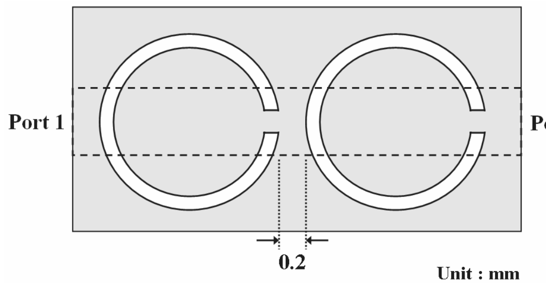


Fig. 3. Top view of the two slotted ground structures underneath the microstrip line. (Dimensions of the two SGSs are the same with Fig. 1(a))

II. Circuit Model Of The Single SGS

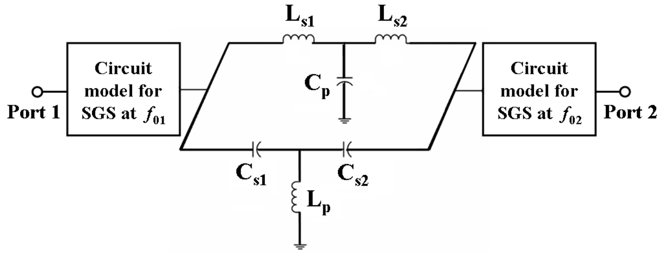
Fig. 1(a) shows the typical planar microstrip with single slotted ground structure (SGS). A 50 Ω microstrip line with single SGS etched on the ground plane is designed on a Duroid 5880 substrate having thickness of 0.787 mm and dielectric constant ε_r of 2.2. The circuit model of the microstrip line with single SGS is shown in Fig. 1(b) [11]. The performance of single SGS acts like the bandstop filter, the parallel *RLC* circuit is suitable. R_0, L_0 and C_0 are given by

$$R_0 = 1/\mathrm{Re}[Y_{in}^{ml-slot}] \quad (1a)$$

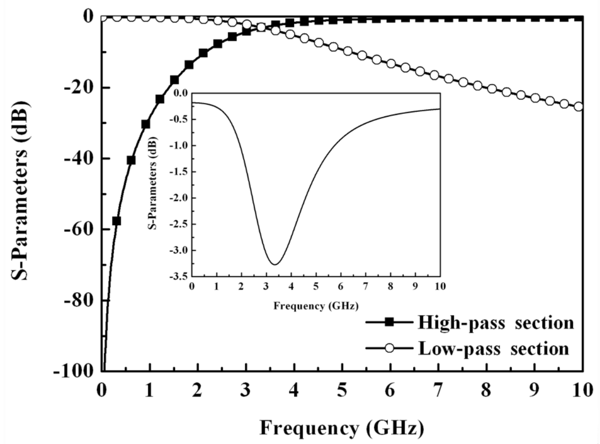
$$C_0 = \mathrm{Im}[Y_{in}^{ml-slot}]/2\pi f_0 (f_0/f_c - f_c/f_0) \quad (1b)$$

$$L_0 = 1/4\pi^2 f_0^2 C_0 \quad (1c)$$

where f_0 is the attenuation pole frequency and f_c is the cutoff frequencies of the single SGS, and $Y_{in}^{ml-slot}$ is the input admittance of microstrip line to SGS. The SGS having parameters of r_{ext} = 5.2 mm, g = 2 mm, and the SGS width of 0.6 mm has an attenuation around 4 GHz, which can be simulated first by using a full-wave EM simulation IE3D [13]. The attenuation level (-37 dB) of the stopband is observed. The circuit parameters extracted from the measured S-parameters and based on the eq. (1) are R_0 = 3.6921 KΩ, L_0 = 3.3379 nH and C_0 = 0.4299 pF. Fig. 2 shows the frequency responses of circuit simulation, EM simulation and measurement. The attenuation level (-39 dB) of the stopband by using the circuit simulation agrees with those of EM simulation and measurement due to the extraction of the equivalent resistance.



(a)



(b)

Fig. 4. (a) Equivalent circuit model and (b) frequency response of the interaction for the slotted ground structures.

III. Interaction Between The Two SGSs

Fig. 3 shows the top view of the two SGSs underneath the microstrip line. The two-pole stopband (expressed as f_{01} and f_{02}) produced by the two SGSs and the interactions appeared between the two SGSs, which can be applied on the spurious suppression for the filters. Fig. 4(a) shows the equivalent circuit model of the interactions between the two SGSs. The interactions can be modeled by using the parallel T-network circuit which is combined with the lowpass- and the highpass circuit. The equivalent parameters of the parallel T-network are derived as follows [14]

$$L_{si} = \mathrm{Im}[Z_{ii} - Z_{12}]/2\pi f_c \text{ , i = 1 or 2 at } f_{01} \quad (2a)$$

$$C_{si} = -1/2\pi f_c \cdot \mathrm{Im}[Z_{ii} - Z_{12}], \text{ i = 1 or 2 at } f_{02} \quad (2b)$$

$$C_p = -1/2\pi f_c \cdot \mathrm{Im}[Z_{12}] \quad (2c)$$

$$L_p = \mathrm{Im}[Z_{12}]/2\pi f_c \quad (2d)$$

where Z_{ii} and Z_{12} can be derived by matching Z-parameters of the two-port T-network [15]. Fig. 4(b) shows the frequency response of the interactions between the SGSs. The equivalent circuit model can effectively demonstrate the bandwidth of the stopband by parallel T-network circuit. Fig. 5 shows the current distribution of the two SGSs on the ground plane at 3.75 GHz and 4.32 GHz, respectively. The interactions between the two SGSs are obviously appeared and the current distribution is almost concentrated on the area between the two SGSs at 3.75 GHz and 4.32 GHz, corresponding to the frequency response the 2-pole stopband. Fig. 6 shows the frequency responses of circuit simulation, EM simulation and measurement for the two slotted ground structures. It is found the f_{01} = 3.75 GHz and f_{02} =

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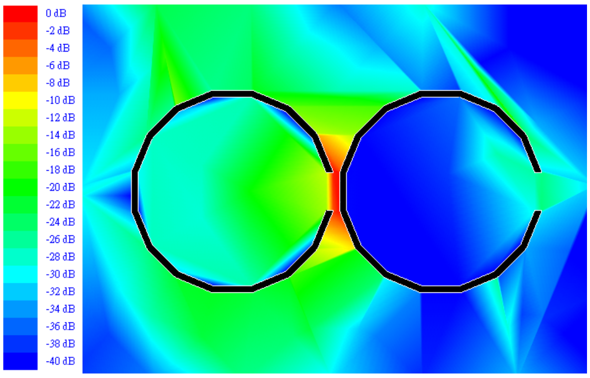
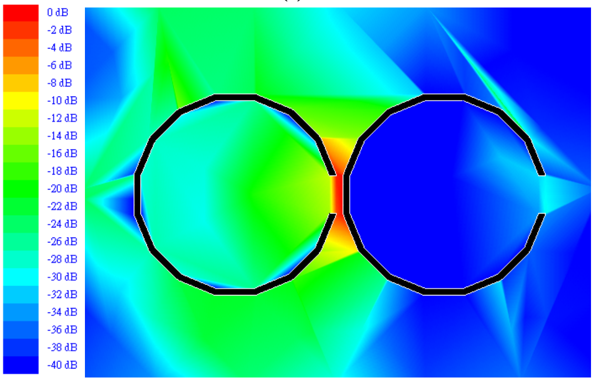
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)



(a)



(b)

Fig. 5. Current distribution of the two slotted ground structures on the ground plane at (a) 3.75 GHz and (b) 4.32 GHz.

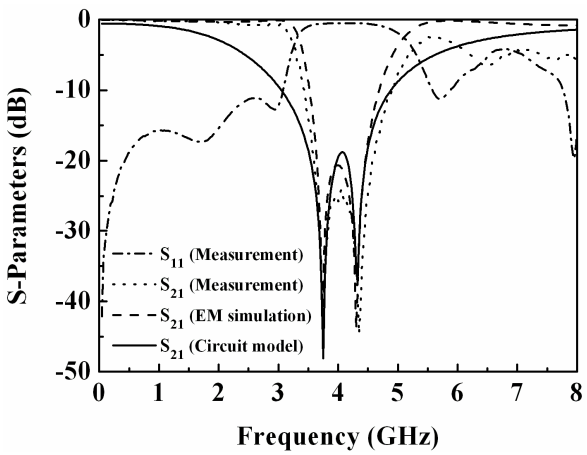


Fig. 6. Frequency responses of circuit simulation, EM simulation and measurement for the two slotted ground structures.

4.32 GHz, respectively and the attenuation level of the transition is around –20dB. The parameters in the resonant tank are R_0 = 5.917 KΩ, L_0 = 0.916 nH, and C_0 = 2 pF at f_{01} and are R_0 = 7 KΩ, L_0 = 0.729 nH, and C_0 = 1.889 pF at f_{02}. The circuit parameters of the interactions are extracted from measurement: L_{s1} = 3.5213 nH, L_{s2} = -3.2015 nH, C_p = -0.6492 pF, C_{s1} = -0.6461 pF, C_{s2} = 0.7092 pF and L_p = 3.5022 nH, respectively. The negative values for the extracted parameters L_{s2}, C_p, and C_{s1} are allowed for the typical circuit modeling. The interactive energy stored in the etched slot and metallic gap for SGS is similar to the lumped-element inverter with negative values [16].

IV. CONCLUSION

In this paper, the equivalent circuit model of the slotted ground structures (SGSs) underneath the microstrip line has been presented. The single SGS can be modeled by parallel *RLC* circuit and the extraction of the equivalent elements can be derived from the simple formulas. The interaction between the two SGSs can be further proven by the parallel T-network circuit combined with lowpass- and highpass circuit. Current distribution on the ground plane shows the interactions of electromagnetic waves propagation around the SGSs at 3.75 and 4.32 GHz. Measured results of the SGSs are in good agreement with EM and circuit simulation.

REFERENCES

[1] K. K. M. Cheng, "Design of dual-mode ring resonators with transmission zeros," *Electron Lett*., vol. 33, no. 16, pp. 1392-1393, July. 1997.

[2] C. H. Chang, H. S. Wu, H. J. Yang and C. K. C. Tzuang, "Coalesced single-input single-output dual-band filter," in *IEEE MTT-S Int. Dig.*, pp. 511-514, June 2003.

[3] Y. Qian, V. Radisic, and T. Itoh, "Simulation and experiment of photonic bandgap structures for microstrip circuits," in *Proc. 1997 Asia-Pacific Microwave Conf*., pp. 585–588.

[4] 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. Microw. Theory Tech.,* vol. 49, no. 1, pp. 86–93, Jan. 2001.

[5] R. Y. Yang, M. H. Weng, H. W. Wu, H. D. Hsueh and M. P. Houng, "Dual-mode ring bandpass filter using defected ground structure with a wider stopband," *IEICE Trans. Electron. Lett*., vol. E87-C, no. 12, pp. 2150-2157, Dec. 2004.

[6] M. H. Weng, H. W. Wu, R. Y. Yang, and M. P. Houng, "High spurious suppression of the dual-mode patch bandpass filter using defected ground structure," *IEICE Trans. Electron. Lett.*, vol. E87-C, pp. 1738-1740, Oct. 2004.

[7] A. B. A. Rahman, A. K. Verma, A. Boutejdar, and A. S. Omar, "Control of bandstop response of Hi-Lo microstrip low-pass filter using slot in ground plane," *IEEE Trans. Microw. Theory Tech*., vol. 52, no. 3, pp. 1008–1013, Mar. 2004.

[8] J. S. Lim, C. S. Kim, Y. T. Lee, D. Ahn, and S. Nam, "A spiral-shaped defected ground structure for coplanar waveguide," *IEEE Microw. Wireless Compon. Lett*., vol. 12, no. 9, pp. 330–332, Sep 2002.

[9] C. C. Chang, C. Caloz, and T. Itoh, "Analysis of compact slot resonator in the ground plane for microstrip structures," in *Proc. 2001 Asia-Pacific Microwave Conf*., pp. 1100–1103.

[10] C. Caloz, H. Okabe, T. Iwai, and T. Itoh, "A simple and accurate model for microstrip structures with slotted ground plane," *IEEE Microw. Wireless Compon. Lett*., vol. 14, no. 4, pp. 133–135, Apr. 2004.

[11] H. W. Wu, Y. K. Su, M. H. Weng, R. Y. Yang and C. S. Ye, "An effective equivalent circuit model of slotted ground structures under a microstrip line," *Microw. Opt. Technol. Lett.*, vol. 50, no. 10, pp. 2651-2653, Oct. 2008.

[12] J. S. Hong and B. M. Karyamapudi, "A general circuit model for defected ground structures in planar transmission lines," *IEEE Microw. Wireless Compon. Lett*., vol. 15, no. 10, pp. 706–708, Oct. 2005.

[13] *IE3D Simulator*, Zeland Software, Inc., 2002.

[14] H. W. Wu, M. H. Weng, Y. K. Su, R. Y. Yang and C. Y Hung, "An accurate equivalent circuit for etched resonator with effective negative permittivity," *Microw. Opt. Technol. Lett.*, vol. 49, no. 1, pp. 231-234, Jan. 2007.

[15] K. C. Gupta, R. Garg, I. Bahl, and P. Bhartia, *Microstrip Lines and Slotlines,* 2nd ed, Norwell, MA: Artech House, 1996.

[16] J. S. Hong and M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*. New York: Wiley, 2001.