

# A Vertically Periodic Defected Ground Structure and Its Application in Reducing the Size of Microwave Circuits

Jong-Sik Lim, *Member, IEEE*, Young-Taek Lee, *Student Member, IEEE*, Chul-Soo Kim, *Member, IEEE*, Dal Ahn, *Member, IEEE*, and Sangwook Nam, *Member, IEEE*

**Abstract**—The microstrip and coplanar waveguide transmission lines combined by a vertically periodic defected ground structure (VPDGS) are proposed. The slow-wave effect, equivalent circuit, and the performances are shown. As an application example, VPDGS is adopted in the matching networks of an amplifier for size-reduction. Two series microstrip lines in input and output matching networks of the amplifier are reduced to 38.5% and 44.4% of the original lengths, respectively, due to the increased slow-wave effects, while the amplifier performances are preserved.

**Index Terms**—Defected ground structure (DGS), periodic structure, vertically periodic defected ground structure (VPDGS).

## I. INTRODUCTION

WAVE propagation in periodic structures has been studied in the area of applied physics for a long time [1]. Recently, periodic structures such as photonic bandgap (PBG) and defected ground structure (DGS) for planar transmission lines have drawn a wide interest because of their extensive applicability in antennas and microwave circuits [2]–[6]. Transmission lines having a periodic structure have a finite pass and rejection band like low-pass filters. The increased slow-wave effect and the additional equivalent components are important properties of periodic structures. The transmission lines with very high impedance can be realized and the circuit sizes are reduced using these properties [7]–[9].

The prominent feature of the proposed structure is that it is possible to organize the periodicity along the vertical direction as well as the horizontal direction. It is named as vertically periodic defected ground structure (VPDGS). On the other hand, the conventional PBG and DGS for planar transmission lines have the only horizontally periodic (HP) structure, i.e., serially cascading structure along the transmission direction.

Vertically periodic (VP) structures produce much higher slow-wave factor (SWF) than HP structures. The increased SWF means the longer electrical length for the same physical

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J.-S. Lim, Y.-T. Lee, and S. Nam are with the School of Electrical Engineering and Computer Science, Applied Electromagnetics Laboratory, Institute of New Media and Communications, Seoul National University, Seoul, Korea (e-mail: jslim@inmac3.snu.ac.kr).

C.-S. Kim is with the Telecommunications Basic Research Laboratory, Electronics and Telecommunications Research Institute, Daejeon, Korea.

D. Ahn is with the Division of Information Technology Engineering, Soon Chun Hyang University, Chungnam, Korea.

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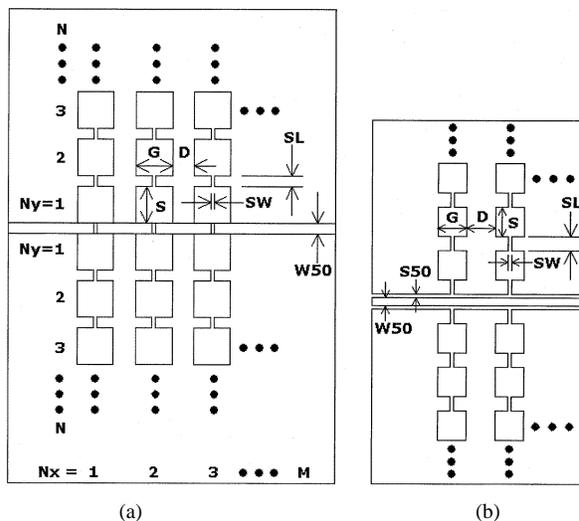


Fig. 1. Transmission lines with the proposed VPDGS. (Unit: mm) (a) Microstrip [ $\epsilon_r = 4.6$ . Thickness ( $H$ ) = 0.75,  $W_{50} = 1.4$ ,  $G = S = 5$ ,  $D = 3$ ,  $SW = 0.5$ ,  $SL = 1.5$ ]. (b) CPW ( $\epsilon_r = 10.2$ .  $H = 0.64$ ,  $W_{50} = 1.2$ ,  $S_{50} = 0.42$ ,  $G = S = D = 4$ ,  $SW = 0.5$ ,  $SL = 2$ ).

length. It has been known that the size of the transmission line can be shortened by the periodic structures because of the increased SWF [7]–[10].

The size of microwave circuits can be reduced remarkably if VPDGS is adopted. As an application example, we designed a size-reduced amplifier by inserting VPDGS into the matching networks. To our knowledge, this is the first periodic structure referred to as “vertically” and realized on planar substrates, although a widely-spread periodic structure all over the ground plane has been proposed [10].

## II. STRUCTURE AND MODELING

Fig. 1(a) and (b) show the generalized structure of the proposed VPDGS on the ground planes of the microstrip and coplanar waveguide (CPW) lines.  $N_x$  and  $N_y$  mean the number of periodic defects along the horizontal and vertical direction, respectively. VPDGS is the extended DGS along the vertical direction from the basic dumb-bell shape structure, which was presented in [3] for the first time. The unit DGS element in [3] is expressed by  $(N_x, N_y) = (1, 1)$ .

The predicted characteristics of the CPW line combined by (1, 2) VPDGS, for instance, is shown in Fig. 2(a). The electromagnetic (EM) simulation was performed on the Microwave

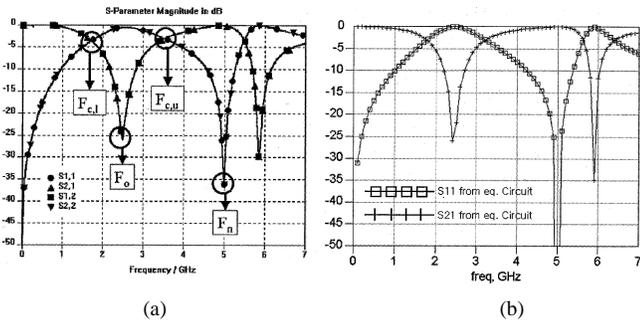


Fig. 2. Characteristics of a CPW line combined by (2, 1) VPDGS. (a) Predicted performances by EM simulation. (b) Predicted results from the equivalent circuit.

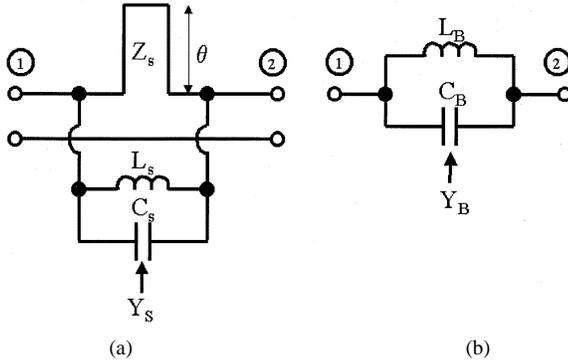


Fig. 3. (a) Equivalent circuit of the CPW line having (2, 1) VPDGS. (b) One-pole butterworth prototype band rejection filter.

Studio V3.0. The first resonant, notch, and upper and lower 3-dB cutoff frequencies, are designated as  $F_o$ ,  $F_n$ ,  $F_{c,u}$ , and  $F_{c,l}$ , respectively. The equivalent circuit is composed of a short stub, inductor, and capacitor as depicted in Fig. 3(a). The circuit elements are determined using the prototype of a band rejection filter shown in Fig. 3(b) and the following three properties: 1)  $Y_s = 0$  at the resonant frequency. 2)  $Z_s = 0$  and  $\theta = \pi$  at the notch frequency. 3)  $Y_s = Y_B$  at the 3-dB cutoff frequencies. The resultant  $Z_s$ ,  $L_s$ , and  $C_s$  are  $95 \Omega$ ,  $8.5 \text{ nH}$ , and  $0.54 \text{ pF}$ , respectively. Fig. 2(b) shows the simulated response on Agilent Advanced Design System, which is so similar to Fig. 2(a).

### III. SLOW-WAVE FACTORS AND LINE CHARACTERISTICS

The SWF of a planar transmission line can be defined as the ratio of  $\beta$  to  $\kappa_o$ , where  $\beta$  and  $\kappa_o$  are the propagation constants of the dielectric material and free space, respectively. The SWF of the transmission lines with the proposed VPDGS are expected to be greater than those of the standard transmission lines for the same physical length. Fig. 4 shows the ratios between the SWFs of the transmission lines with the VPDGS and those of the standard transmission line up to their first resonant frequencies. It is observed that the SWF grows rapidly by increasing the number  $N_y$  for the fixed  $N_x$ , although the frequency dispersion is also proportional to  $N_x$  and  $N_y$ . However, the dispersion, impedance variation, and loss problems are getting serious only at high-frequency region around the resonance or higher. Hence, those problems at the desired application frequency can

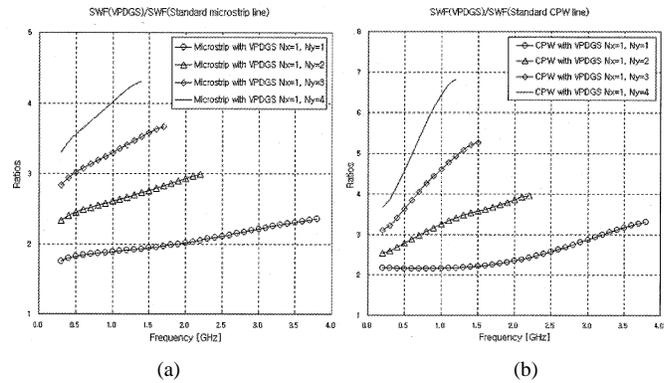


Fig. 4. Ratios between the SWFs of the transmission lines with the VPDGS and those of the standard transmissions. (a) Microstrip. (b) CPW.

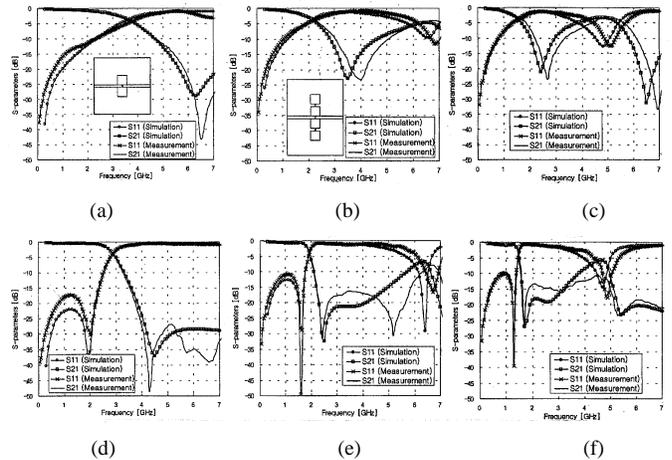


Fig. 5. Measured  $S$ -parameters of the microstrip lines with various matrices of VPDGS. (a) (1, 1), (b) (1, 2), (c) (1, 3), (d) (2, 1), (e) (2, 2), and (f) (2, 3).

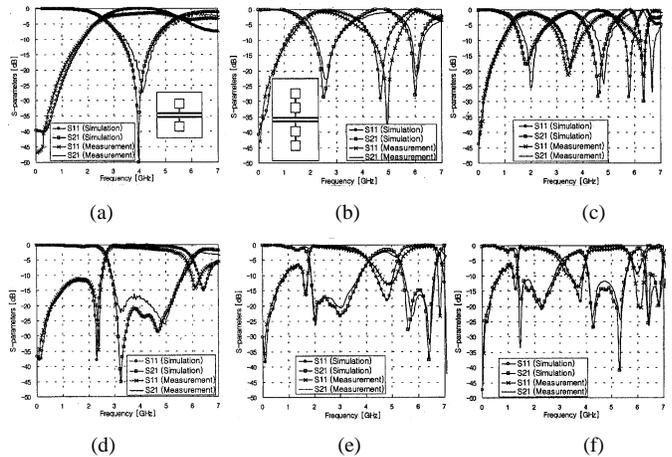


Fig. 6. Measured  $S$ -parameters of the CPW lines with various matrices of VPDGS. (a) (1, 1), (b) (1, 2), (c) (1, 3), (d) (2, 1), (e) (2, 2), and (f) (2, 3).

be avoided by selecting proper substrate and dimensions because the resonant frequency depends on the dielectric material and the dimensions of VPDGS.

Several matrices of VPDGS were realized using the dimensions shown in Fig. 1. The predicted and measured  $S$ -parameters are shown in Figs. 5 and 6. The periodic pass and stop band, and steep cutoff rejections are observed in the performances, which are in good agreement with each other.

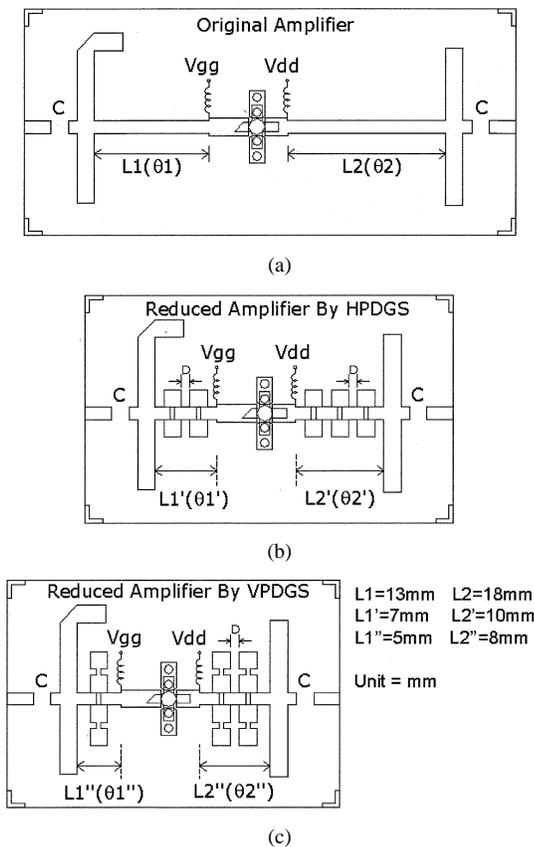


Fig. 7. Simplified layouts of (a) the original amplifier, (b) the reduced amplifier by HPDGS proposed in [9], and (c) the reduced amplifier by VPDGS. ( $\epsilon_r = 2.6$ ,  $H = 0.5$ ,  $W50 = 1.4$ ,  $SW = 0.5$ ,  $G = S = 2$ ,  $SL = W50/2$ , and  $D = 1$ ).

#### IV. APPLICATION TO REDUCE THE SIZE OF AMPLIFIERS

If a standard series transmission line is a part of matching networks of an amplifier, it can be reduced by VPDGS because of the increased SWFs [8], [9]. In this section, the size-reduction of amplifier using VPDGS is discussed. To begin with, an amplifier called the “original amplifier” has been designed using standard microstrip line and measured in order to be compared to the “reduced amplifier.” The lengths of L1 and L2 in Fig. 7(a) are to be reduced. Although L1 and L2 can be lessened using the conventional HPDGS ( $N_y = 1$ ), as illustrated in Fig. 7(b) [9], they are reduced to have much shorter lengths by using (1,2) and (2,2) VPDGS. The obtained L1'' and L2'' are only 5 mm and 8 mm, while L1 and L2 are 13 mm and 18 mm, and L1' and L2' are 10 mm and 13 mm, respectively.

It should be mentioned that the dispersion problem produced by VPDGS is not serious here, because the resonant frequencies of the microstrip lines with the unit HPDGS and VPDGS shown in Fig. 7(b) and (c) are much higher than the application frequency, i.e., the desired frequency band of the amplifiers.

Fig. 8 shows the measured  $S$ -parameters of the original and reduced amplifiers. The measured performances of the reduced amplifiers are quite similar to those of the original amplifier, even though some minor differences are observed. It should be noted that any critical degradation in the measured perfor-

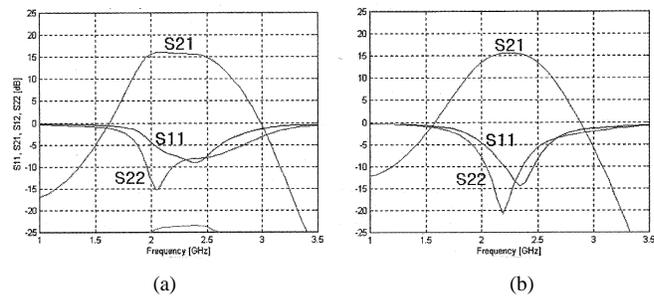


Fig. 8. Measured Performances of (a) the original amplifier and (b) the reduced amplifier by VPDGS.

manances is not observed. The obtained agreement proves that the matching of the reduced amplifier is being preserved even after L1 and L2 have been reduced significantly by VPDGS.

#### V. CONCLUSION

A vertically periodic DGS for microstrip and CPW lines, its equivalent circuit, and the increased SWF have been discussed. In order to show that the increased SWF can be applied in reducing the size of microwave circuits, an amplifier has been reduced using VPDGS. Due to the increased electrical length by VPDGS, the physical size of the original amplifier was reduced without critical cost of performances. The resultant lengths of the microstrip lines with VPDGS were only 38.5% and 44.4% of the original ones in input and output matching networks. The good agreement in the measured performances proves the increased slow-wave effects by VPDGS are very useful in reducing the size of microwave circuits.

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