Application of Defected Ground Structure in Reducing the Size of Amplifiers

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***Abstract*—This letter presents a new technique to reduce the size of microwave amplifiers using defected ground structure (DGS). The DGS on the ground plane of microstrip line provides additional effective inductive component [1], which enables a microstrip line with very high impedance to be realized [2] and shows a slow-wave characteristics [3]. The resultant electrical length of the microstrip line with DGS is longer than that of the conventional microstrip line for the same physical length. Therefore, the microstrip line with DGS can be shortened in order to maintain the same electrical length, matching, and performances of the basic (original) amplifier. In order to show that this idea is valid, two amplifiers, of which one is designed using conventional microstrip line and the other is reduced using DGS, are fabricated, measured, and compared. The measured performances of the reduced amplifier with DGS are quite similar to the ones of the basic amplifier, even though the series microstrip lines with DGS are much smaller than those of the basic amplifier by 53.8% and 55.6% at input and output matching networks, respectively.**

***Index Terms*—Defected ground structure (DGS), slow-wave effects.**

I. INTRODUCTION

IN THE design of microwave amplifiers, it is one of the most important goals to keep the size as small as possible. One general method to obtain the small size is to match the Γ_s and Γ_L to 50 Ω port via as short locus as possible on smith chart [4]. However, in the most of amplifiers using distributed elements, there must be transmission line elements with finite length in matching networks.

Recently, there has been an increasing interest in studying the microstrip line with various periodic structures including photonic bandgap (PBG) and defected ground structure (DGS) [1]–[3], [5]–[8]. Each periodic structure has its own properties and advantages. However, problems have been observed as follows; 1) [5] and [6] have a little difficulties in realizing a lot of PBG holes in dielectric or ground plane. 2) The slow-wave effect in [7] depends on the orientation and location of the microstrip line with respect to the principal axes of the periodic structure. 3) In [8], it is extremely difficult to realize the PBG cell on a thin substrate because the width of microstrip line would also be very narrow. Another significant drawback of [8] is that it is not suitable for high power applications due to its great discontinuities and very thin line within the main signal path.

DGS, which is realized by etching only a few defects on the ground plane, is also a kind of periodic structures. However, it is much easier to design and fabricate DGS, which have the similar or superior characteristics to the conventional PBGs. Furthermore, DGS has prominent advantage in extending its applicability to other microwave circuits such as filters, dividers, couplers, amplifiers, and so on [2], [3], [9], [10].

The equivalent inductive component of the microstrip line with DGS is increased by the defect, which produces slow-wave property. It is important to pay attention to this slow-wave effect because the microstrip line with DGS has longer electrical length than the conventional microstrip for the same physical length. Therefore, the length of the microstrip line can be shortened by inserting DGS in order to preserve the same electrical length. A novel method to reduce the size of microwave amplifiers using DGS will be described later.

II. SLOW-WAVE CHARACTERISTICS OF THE MICROSTRIP LINE WITH DGS

Fig. 1(a) shows a conventional microstrip line, and Fig. 1(b) shows the microstrip line with a unit dumb-bell shaped DGS pattern on the ground plane and the same length as Fig. 1(a). There exist the equivalent inductive and capacitive elements due to the inserted DGS and also resonant frequency and cutoff frequency bands due to these equivalent elements. It is easy to recognize that the transmission constants of two microstrip lines shown in Fig. 1 will not be equal. It will be shown later that the electrical length of Fig. 1(b) is longer than that of Fig. 1(a), i.e., $\theta < \theta'$. This means the slow-wave factor of Fig. 1(b) is greater than that of Fig. 1(a) for the same physical length, L.

The de-embedded planes "A" and "B" in Fig. 1 have the same length as the dimension of $W1$ (=2 mm). Fig. 2(a) shows the $S21$ phase of the conventional microstrip line with the length of 2 mm, and Fig. 2(b) shows the microstrip line with DGS at the de-embedded plane "B" up to 10 GHz. The simulation was performed using MicroWave Studio V3.0. It is definite that the electrical length, expressed by $S21$ phase, of the Fig. 1(b), is much longer than that of Fig. 1(a). Provided that the microstrip line shown in Fig. 1(a) is a part of the matching network of an amplifier, it is possible to reduce the physical length of this line by adopting DGS pattern on the ground plane while maintaining the matching and performances of amplifier.

Fig. 3 shows the slow-wave factors of the microstrip line with the DGS on the ground plane in comparison with a conven-

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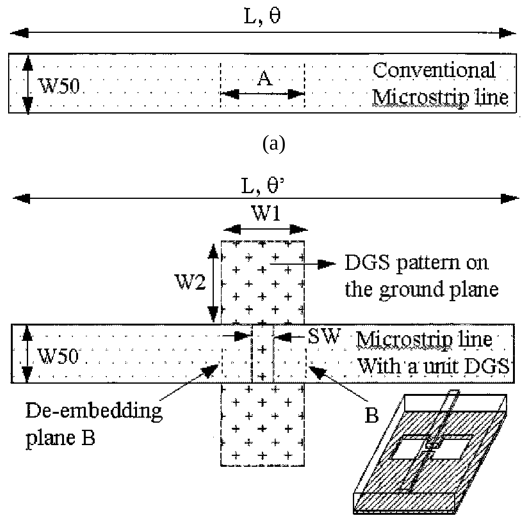
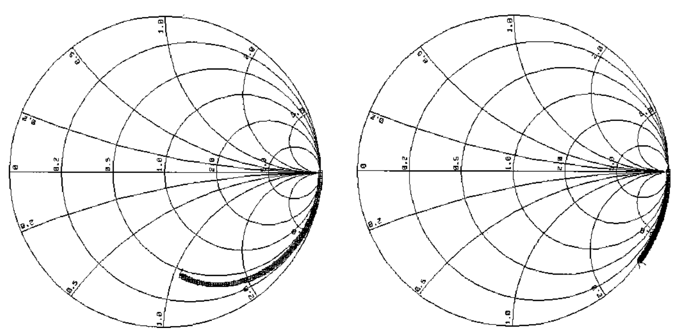


(b)

Fig. 1. (a) Conventional microstrip line; (b) microstrip line with a unit DGS pattern and the same length ($W50 = 1.4$ mm, $SW = 0.5$ mm, $W1 = W2 = 2$ mm. The substrate with 20 mils of thickness, 2.6 of dielectric constant, and 18 μm of metal thickness is adopted in this work).



(a) (b)

Fig. 2. Electrical lengths ($S21$ phases) of two microstrip lines over (a), the de-embedded plane "A" in Fig. 1(a), and (b), the de-embedded plane "B" in Fig. 1(b).

tional microstrip. Definitely, the slow-wave factor has increased in the case of Fig. 1(b). Therefore, it can be said that the shorter microstrip line with DGS can replace the longer standard microstrip line with the same electrical length kept.

III. Size Reduced Amplifier With DGS

In this section, the design and measured performances of the basic amplifier and reduced amplifier by DGS will be described. First, the basic amplifier, of which operating frequency is 2.0∼2.3 GHz, was designed and fabricated using the standard microstrip line for the comparison with the reduced amplifier. The simplified layout of the basic amplifier is shown in Fig. 4. The layouts of matching networks only are emphasized in this figure for the convenience. A general purpose HEMT device was adopted for the amplifier. Fig. 5 illustrates the measured performances of the basic amplifier. It is observed that the gain is about 15 dB over the operating frequency band.

In Fig. 4, the lengths of transmission lines, $L1'$ and $L2'$, are the targets for reducing the lengths. As has been explained above, using Figs. 1–3, $L1$ and $L2$ can be reduced by inserting

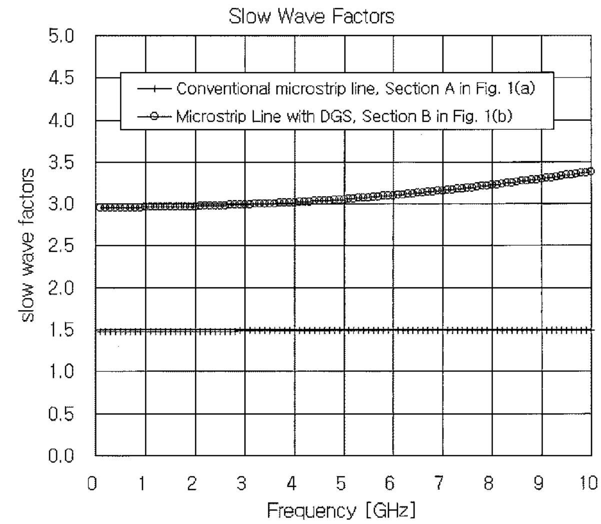


Fig. 3. Slow-wave factor of the microstrip line with DGS on the ground plane in comparison with a conventional microstrip (planes "A" and "B").

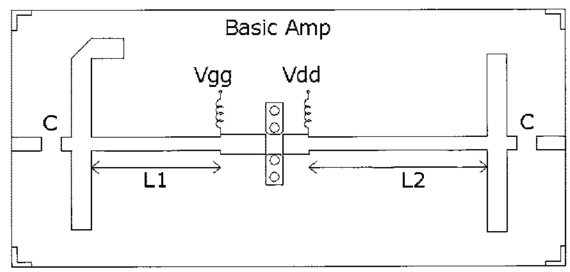


Fig. 4. Simplified layout of the basic amplifier using conventional microstrip line.

DGS. The layout of the reduced amplifier after adopting two or three DGS patterns on the ground plane is illustrated in Fig. 6. The lengths of $L1'$ and $L2'$ in the reduced amplifier are 7 mm and 10 mm, respectively, while the lengths of $L1$ and $L2$ in the basic amplifier are 13 mm and 18 mm, respectively. The ratios of the shortened lengths to the original ones are 53.8% (7 mm/13 mm) and 55.6% (10 mm/18 mm).

It should be noted that the impedance of the microstrip line with DGS does not change significantly until the loss increases severely and the cut-off characteristic becomes clear as shown in Fig. 2(b). Because the operating frequency band of the amplifier is much lower than the cut-off frequency, it is not needed to worry about the change of the impedance of the microstrip line with DGS at the desired frequency.

We measured the electrical lengths of four microstrip lines with the lengths of $L1$, $L1'$, $L2$, $L2'$ by their $S21$ phase, and verified that the electrical lengths are being maintained even after DGS patterns had been inserted.

Therefore, it can be expected that the performances of the reduced amplifier will be the same as those of the basic amplifier. Although there are minor differences, the performances shown in Fig. 7 are similar to Fig. 5 over the operating frequencies. This means the matching is still maintained after the size has been reduced. It can thus be argued that the proposed technique to reduce the size of amplifiers using DGS is very effective method without cost of the amplifier performances.

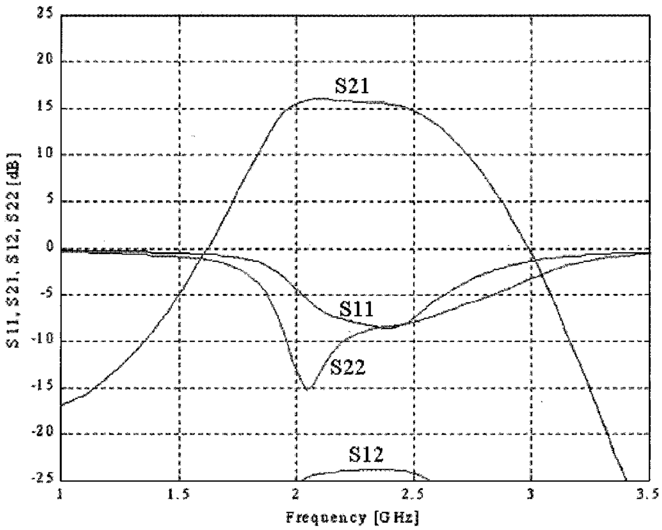


Fig. 5. Measured performances of the basic amplifier.

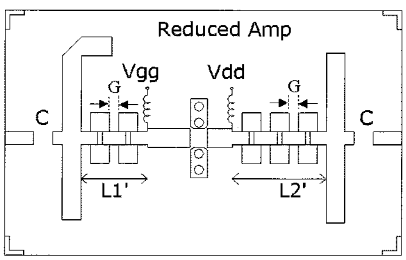


Fig. 6. Simplified layout of the reduced amplifier by DGS ($G = 1$ mm).

IV. Conclusion

A new method to reduce the size of matching networks of microwave amplifiers using the slow-wave characteristics of the microstrip with DGS has been proposed. In order to shorten the size, while keeping the same electrical length, two or three DGS patterns were adopted in matching networks. The resultant size of the microstrip line with DGS are only 54% and 56% in input and output matching networks, respectively, compared to the basic amplifier, even the amplifier performances are maintained.

The agreement between the measured performances of two amplifiers proves the slow-wave characteristics of the microstrip with DGS are very effective in reducing the size. The proposed method can be applied, even when an amplifier has been designed to have the shortest locus on smith chart. In other words, the trial for size reduction is performed again using DGS once the design is finished using smith chart. It is expected that this technique will not be limited to the amplifiers, but also can be applied to other microwave circuits.

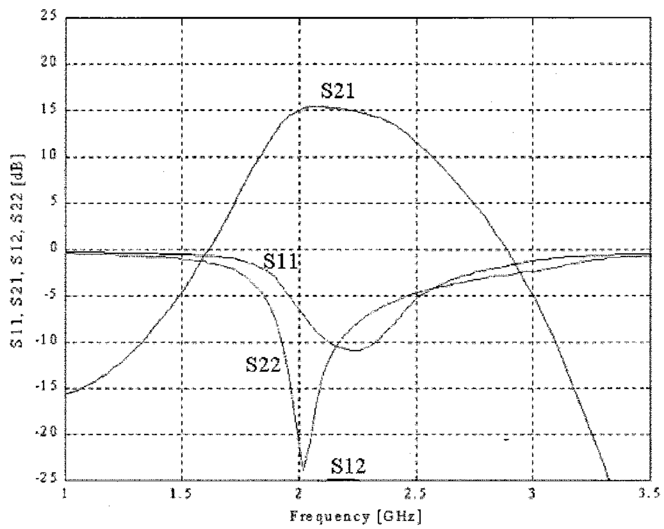


Fig. 7. Measured performances of the reduced amplifier.

We expect that the reduced amplifier will have more excellent harmonic rejection and power performances than the basic amplifier, because the equivalent inductive and capacitive elements of DGS have a resonant frequency and stop band which do not affect the matching at passband.

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