# A Technique for Reducing the Size of Amplifiers Using Defected Ground Structure

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*Abstract* — **This paper presents a method to reduce the size of amplifiers using defected ground structure (DGS). DGS on the ground plane of transmission line such as microstrip and coplanar waveguide provides a slow–wave characteristics caused by its equivalent inductive and capacitive components [1,2]. Due to this slow-wave effect, the electrical lengths of the microstrip lines, which are combined by DGS in matching networks, are longer than the original ones. Therefore, the physical length of microstrip line can be shortened by inserting DGS in order to keep the original electrical length and matching the same. The resultant length of the microstrip lines with DGS are only 54% and 56% of the original lines in input and output matching networks, respectively. Additionally, because the microstrip lines with DGS have rejection characteristics slightly at harmonic band, while standard transmission lines have a very wide passband only, the magnitude of the second harmonic is less than that of the original amplifier. The technique for size reduction of amplifier using DGS is also applied to a coplanar waveguide (CPW) amplifier. The resultant lengths of CPW lines combined by DGS in matching networks are only 50% of the original lengths. It is shown that the measured performances of original amplifier and size-reduced amplifier are same for both microstrip and CPW amplifiers.**

## I. INTRODUCTION

In the design of microwave amplifiers using MIC and MMIC technology, it is one of the important goals to reduce the size as small as possible. One general method to reduce the size of amplifiers is to match the matching points ($\Gamma_S$ and $\Gamma_L$) to 50-$\Omega$ port via as short locus as possible on smith chart [3]. However, basically, the required performances should be prior to the size. Therefore, sometimes, it is inevitable to keep the quite large size in order to achieve the desirable performances of amplifiers. In any cases whether it is designed to have the minimal locus on smith chart or not, in the most of amplifiers using distributed elements, there must be transmission line elements with finite length in matching networks.

In general, once a design of matching networks is completed, the size of amplifier is fixed. However, if there exist a method to reduce this fixed size while keeping the performance same, it is much desirable to adopt this method because the size reduction is one of important goals as described above.

Recently, there has been an increasing interest in studying the microstrip line with various periodic structures such as photonic bandgap (PBG) and defected ground structure (DGS) [1,2,4-7]. DGS, which is realized by etching only a few defects on the ground plane under the microstrip line, is also a kind of periodic structures. The structure of DGS is very simple, so it is much easier to design and fabricate DGS, which have the similar or superior characteristics to the conventional PBG. Furthermore, DGS has prominent advantage in extending its applicability to other microwave circuits such as filters, dividers, couplers, amplifiers, and so on [2,8-10].

The equivalent inductive component of “the microstrip line with DGS” (“DGS line”) increases by the defect and produces the increased effective dielectric constant equivalently, that is, slow-wave property. Due to this slow-wave effect, DGS line has longer electrical length than the standard microstrip for the same physical length. Therefore, the length of the microstrip lines in matching networks can be reduced by inserting DGS on the ground plane in order to maintain the same electrical length and matching characteristics. Hence the size of amplifier can be shortened by inserting DGS onto ground plane under matching networks without any critical degradation in the performances of the original amplifier.

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

Fig. 1 shows a standard microstrip line and a microstrip line with a unit dumb-bell shaped DGS pattern on the ground plane. There exist the equivalent inductive and capacitive elements caused by DGS. These L-C components produce a resonant frequency and cutoff frequency band. It is easy to recognize that the transmission constants of two microstrip lines will not be equal. It is going to be shown 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, 2mm, as the dimension of W1. Fig. 2 shows the simulated S21 phase of the standard microstrip line with the length of 2mm, and DGS line at the de-embedded plane “B”. The simulation was performed using MicroWave Studio V3.0. It is definite that the electrical length, indicated by S21 phase, of the Fig. 1(b) is much longer than that of Fig. 1(a). Provided that the

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standard 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 by combining DGS on the ground plane to maintain the original electrical length and amplifier performances.

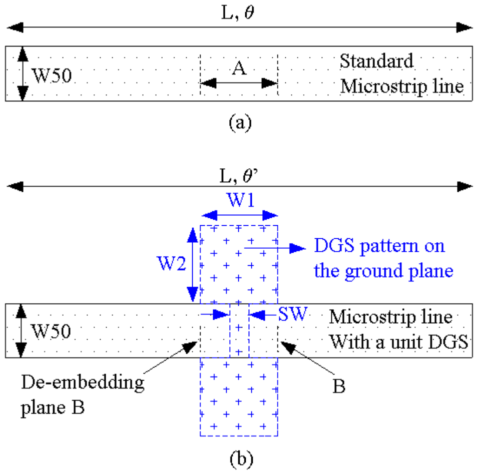


Fig. 1. (a) A standard microstrip line (b) A microstrip line with a unit DGS pattern (W50=1.4mm, SW=0.5mm, W1=W2=2mm. Substrate thickness=0.5mm, $\varepsilon_r$=2.6).

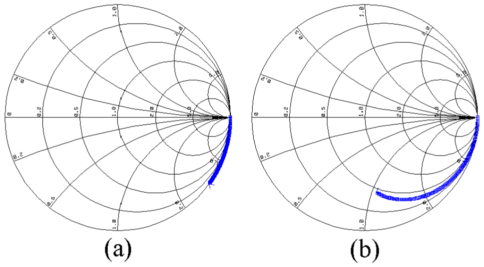


Fig. 2. Electrical lengths (S21 phases) of two microstrip lines up to 10GHz over (a) the de-embedded plane "A" in Fig. 1 (a) and (b) the de-embedded plane "B" in Fig. 1 (b).

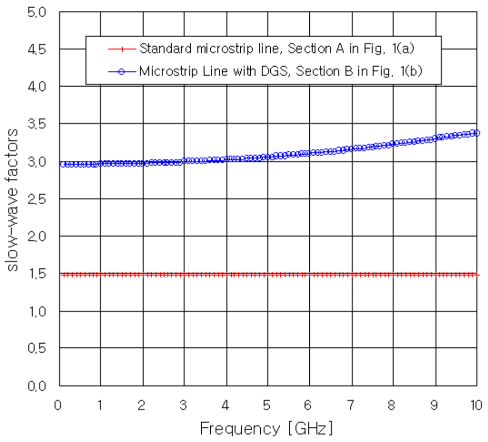


Fig. 3. Slow-wave factors of two microstrip lines. (At the de-embedded plane "A" and "B").

Fig. 3 shows the slow-wave factors of DGS line in comparison with a standard microstrip at planes "A" and "B". Definitely the slow-wave factor has increased by DGS. It can be said that the shorter microstrip line with DGS can replace the original standard microstrip line with the same electrical length kept.

## III. SIZE REDUCTION OF AMPLIFIERS USING DGS

First of all, the "original amplifier", of which operating frequency is 2.0~2.3GHz, has been designed using the standard microstrip line and measured in order to be compared to the "reduced amplifier". The layout shown in Fig. 4 has been simplified in order that the size reduction of matching networks is emphasized for the convenience of comparison.

In Fig. 4(a), the lengths of microstrip lines, L1 and L2, are the targets for reducing. L1 and L2 can be shortened by inserting DGS so that the electrical lengths are kept to be the same. The layout of the reduced amplifier is illustrated in Fig. 4(b). The lengths of L1' and L2' are 7mm and 10mm, respectively, while the original lengths of L1 and L2 are 13mm and 18mm, respectively. The ratios of the reduced lengths to the original ones are only 53.8% (7mm/13mm) and 55.6% (10mm/18mm).

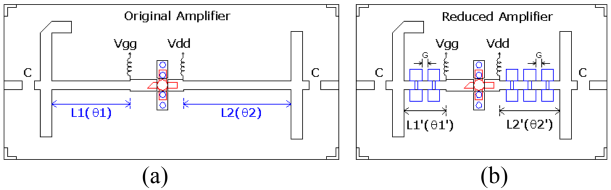


Fig. 4. Layout of the (a) original and (b) reduced amplifier using microstrip (G=1mm).

## IV. MEASURED PERFORMANCES

Four microstrip line sections in matching networks, L1, L2, L1', and L2', were measured so that their electrical lengths, θ1, θ1', θ2, and θ2', to be compared by S21 phases. Fig. 5 shows the ratios, i.e. θ1/θ1' and θ2/θ2'. The ratios are very close to the ideal value "1". It should be noted that this agreement guarantees the matching of the amplifier is maintained even though the microstrip lines in matching networks have been shortened by DGS. So, it can be expected that the performances of the reduced amplifier will be the same as those of the original amplifier.

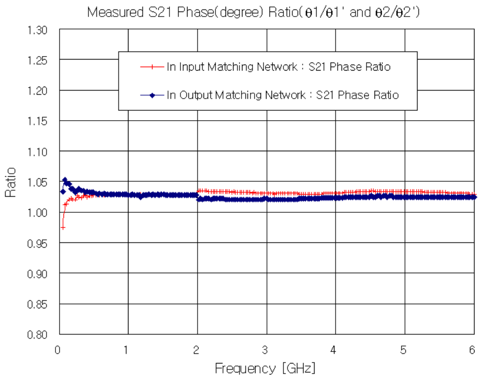
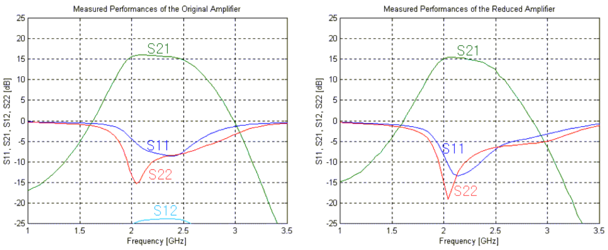


Fig. 5. Ratio of the measured S21 phases, θ1/θ1' and θ2/θ2'.

Fig. 6 illustrates the measured S-parameters of the original and reduced amplifier. Although there are some minor differences, the measured performances are quite similar to each other. This means the matching is still maintained after reducing L1 and L2. It can thus be argued that this new method using DGS in reducing the size of amplifiers is very effective method without cost of amplifier performances.



(a) (b)

Fig. 6. Measured performances of the (a) original and (b) reduced amplifier.

Fig. 7 tells us that the magnitude of the second harmonic, expressed by the second harmonic rejection from the fundamental (Fo-2Fo), of the reduced amplifier is less than that of the original amplifier. This difference is caused by the cut-off characteristics of the DGS line due to the equivalent L-C components of DGS at harmonic frequency band. Even though the rejection is not strong at the second harmonic frequency, however, there is no such cut-off at high frequency in standard microstrip line because of its simply broad passband.

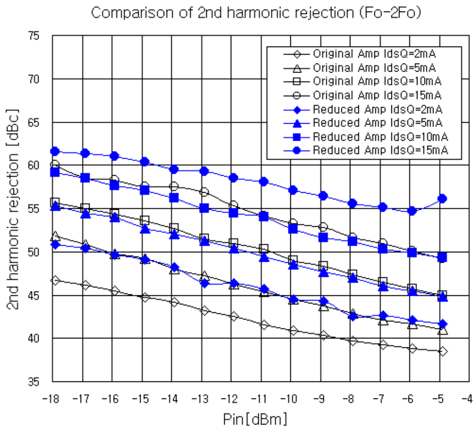
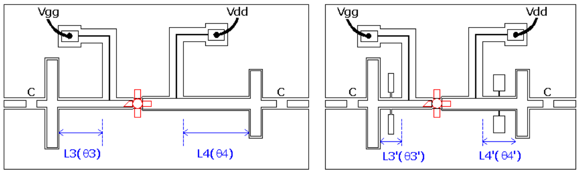


Fig. 7. Comparison of the second harmonic components, which is expressed by the second harmonic rejection from the fundamental (Fo-2Fo).

## V. SIZE REDUCTION IN CPW AMPLIFIERS

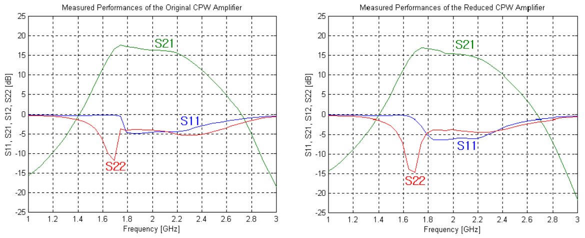
The method to reduce the size of amplifiers using DGS can be applied to CPW amplifiers, too. It is possible to design a DGS on the ground plane of CPW, which is called DGSCPW. The expected characteristics of DGSCPW is similar to that of a microstrip lines with DGS. The phenomenon of the slow-wave effect and the principle of the shortening the size of matching networks are exactly same as in the microstrip amplifier.



(a) (b)

Fig. 8. Layout of the (a) original and (b) reduced CPW amplifiers

Fig. 8 shows two CPW amplifiers, so called "original amplifier" and "reduced amplifier" again. The size reduction method using DGS can be applied to the original amplifier in order that θ3≈θ3' and θ4≈θ4' in matching networks. The resultant L3' and L4' are 4mm and 6mm, while L3 and L4 are 8mm and 12mm, respectively. The measured performances of two amplifiers, shown in Fig. 9, prove that the proposed method is quite acceptable again in CPW amplifiers.



(a) (b)

Fig. 9. Measured performances of the (a) original and (b) reduced CPW amplifiers

## VI. CONCLUSION

A new method to reduce the size of amplifiers using DGS has been proposed. Due to the slow-wave effects of the microstrip and CPW lines with DGS on the ground plane, the physical size of the original amplifiers could be reduced while the original performances are being kept. The resultant lengths of the transmission lines with DGS are around half of the original lengths in input and output matching networks.

The magnitude of the second harmonic was measured for the investigation of the possible application in high power amplifiers, although the amplifier device was not a high power device of watt-level. The obtained second harmonics of the reduced amplifier were lower than that of the original amplifier under various bias conditions.

The good agreement between the measured performances of the original and reduced amplifiers proves the slow-wave effects of the microstrip and CPW lines with DGS are very effective in reducing the size. Even when an original amplifier has been designed to have very small size, the proposed method can be applied. This means that the try for size reduction is applied again using DGS. Additionally, because the equivalent L-C elements of DGS form the cutoff characteristics at harmonic frequency band and do not affect the matching at fundamental, the power performances are expected to be improved by DGS.

## ACKNOWLEDGEMENT

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