A New Method to Suppress Harmonics Using $\lambda/4$ Bias Line Combined by Defected Ground Structure in Power Amplifiers

Yong-Chae Jeong, *Member, IEEE*, Si-Gyun Jeong, *Student Member, IEEE*, Jong-Sik Lim, *Member, IEEE*, and Sangwook Nam, *Member, IEEE*

***Abstract*—A new $\lambda/4$ bias line combined by a dumb-bell shaped defected ground structure (DGS) is proposed to suppress harmonics in power amplifiers. The proposed DGS bias line maintains the required high impedance even after DGS is inserted, while the width and length of the $\lambda/4$ bias line are broader and shorter than those of conventional bias lines. When the DGS bias line is used in power amplifiers, the third harmonic components as well as the second harmonic are reduced, because of the increased slow-wave effect over wide harmonic band. It is shown that the reduction of the third harmonic component, the improvement of 1 dB compression point, and power added efficiency are 26.5 dB, 0.45 dB, and 9.1%, respectively.**

***Index Terms*—Defected ground structure (DGS), harmonic suppression, power amplifiers.**

I. Introduction

RECENTLY, extensive researches on photonic band gap (PBG) structures have been conducted for microwave circuit applications [1], [2]. The applications of PBG for power amplifier, filter, and mixer have been reported. Defected ground structure (DGS), which is realized by etching a few dumb-bell shaped patterns on the ground plane of microstrip line, has been proposed [3]. Several applications using DGS to design a coupler, filter, and power amplifier have been already presented [4]–[6]. It is expected that DGS can be applied effectively in microwave circuits in many ways to utilize its advantages over the conventional PBGs.

Small signal amplifiers in UHF band usually adopt chip inductors as RF choke for bias. Additionally, $\lambda/4$ high impedance transmission lines terminated with chip capacitor or radial stub are also used as bias line. To minimize the interference between bias line and signal transmission line, the difference between the characteristic impedances of bias line and signal line should be as large as possible.

However, in high power amplifiers, because transistors consume much current, the width of bias line, the lower the characteristic impedance. So, it is much more difficult to achieve the isolation between bias circuit and signal path in high power amplifiers than small signal amplifiers. Additionally, when a capacitive-terminated $\lambda/4$ bias line is connected to the signal line, even harmonic components are blocked, while odd harmonic components pass the signal line. This has been one of serious problems, too. In addition, the proper harmonics termination is required to increase the efficiency.

We propose a new $\lambda/4$ bias line combined by DGS for high power amplifiers. The proposed bias line maintains the required high characteristic impedance sufficiently. The width and length of the proposed DGS bias line are much broader and shorter than those of conventional $\lambda/4$ high impedance bias line. It will be described that the third harmonic component as well as the second harmonic component are surely suppressed when the proposed DGS bias line is applied to power amplifiers.

II. Design of $\lambda/4$ High Impedance Bias Line Using DGS

The DGS pattern under the microstrip line produces the additional equivalent inductance and increased characteristic impedance. In conventional microstrip lines, the line width is getting extremely narrow as the required line impedance increases more and more. However, in the microstrip line with DGS, because the additional inductance results in the highly increased characteristic impedance, the line width is broader than that of the standard microstrip line for the same characteristic impedance. The broadened width of the microstrip line can be understood as the increased equivalent capacitance, which plays a great role in raising the phase constant and slow-wave effects. Therefore, it can be summarized that DGS leads to the reduction of circuit sizes.

Fig. 1(a) and (b) shows the layouts of a conventional microstrip line and a microstrip line with DGS. The measured S_{21} and group delay (GD) are shown in Fig. 1(c). The substrate is RT/duroid 5880 with the dielectric constant of 2.2 and thickness of 31 mils. The width of DGS microstrip line is much broader than that of the conventional 50 Ω microstrip line. The measured results show that there is no transmission problem in DGS microstrip line under 4 GHz. If the $\lambda/4$ DGS bias line, which has broader width and shorter length than conventional bias line, holds high impedance value and rejects the second and third harmonics, the power amplifier would be more stable and efficient.

Fig. 2 shows the layout of the proposed capacitive-terminated $\lambda/4$ DGS bias line connected on the 50 Ω microstrip line. The characteristic impedance of DGS bias line is 120 Ω, and the width and length at the operating frequency of power amplifier,

Manuscript received July 30, 2002; revised November 28, 2002. The review of this letter was arranged by Associate Editor Dr. Arvind Sharma.

Y.-C. Jeong and S.-G. Jeong are with the Division of Information and Electronic Engineering, Chonbuk National University, Chonju 561-756, Korea (e-mail: ycjeong@moak.chonbuk.ac.kr).

J.-S. Lim and S. Nam are with the School of Electrical Engineering and Computer Science, Seoul National University, Seoul, Korea.

Digital Object Identifier 10.1109/LMWC.2003.814111

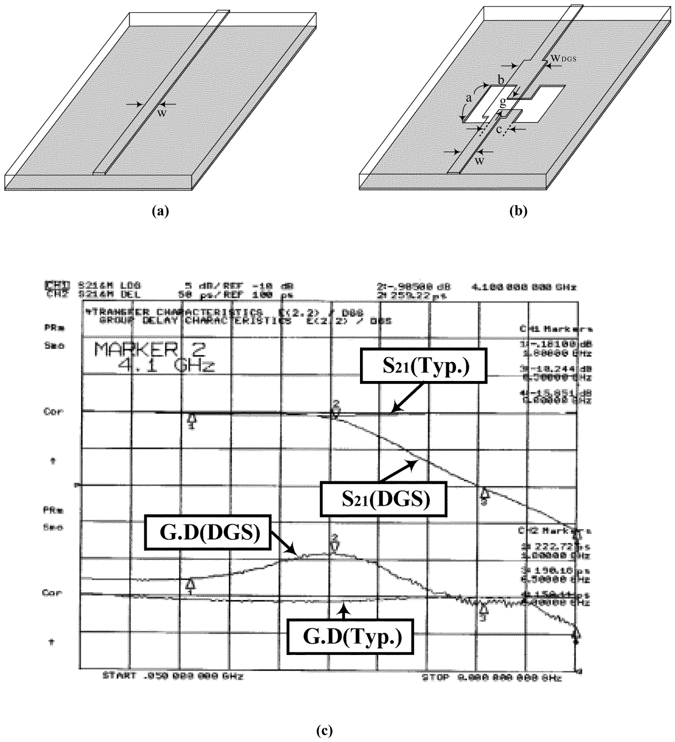


Fig. 1. (a) Layout of a conventional microstrip line ($w = 2.38$, Unit = mm), (b) layout of a 50 Ω DGS microstrip line ($a = 6$, $b = 1$, $g = 0.5$, $c = w_{DGS} = 4.7$), and (c) measured transfer characteristics and group delay.

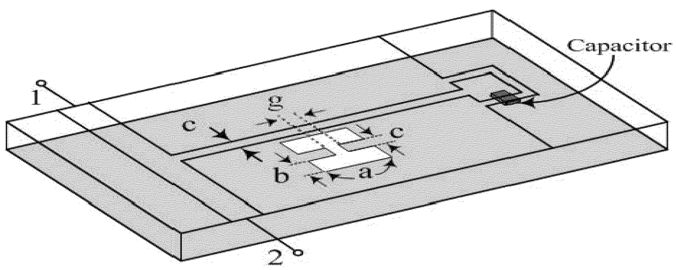


Fig. 2. Layout of $\lambda/4$ DGS bias line connected to the $50\,\Omega$ microstrip line ($a = 6, b = 3, g = 0.5, c = 1.23$ mm).

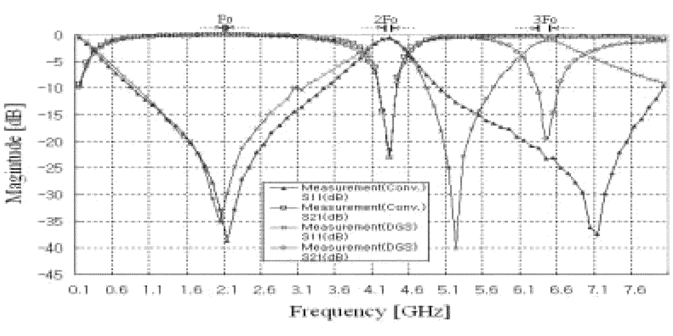


Fig. 3. The simulated and measured S-parameters result of the conventional $\lambda/4$ bias microstrip line connected to signal line.

2.14 GHz, are 1.23 mm and 23.8 mm. It should be noted that the width and length of the conventional 120 Ω $\lambda/4$ bias line are 0.41 mm and 25.1 mm, respectively. So, the width is broader by three times and the length is shorter.

Figs. 3 and 4 show the measured S-parameters of the conventional $\lambda/4$ DGS bias microstrip line and $\lambda/4$ DGS bias line

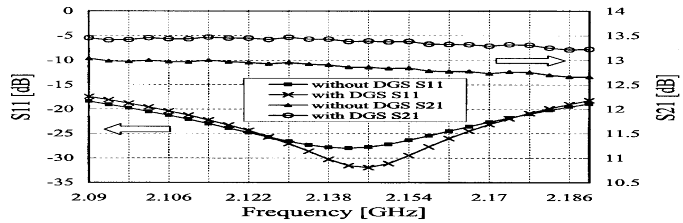


Fig. 4. The simulated and measured S-parameters result of the $\lambda/4$ DGS bias line connected to signal line.

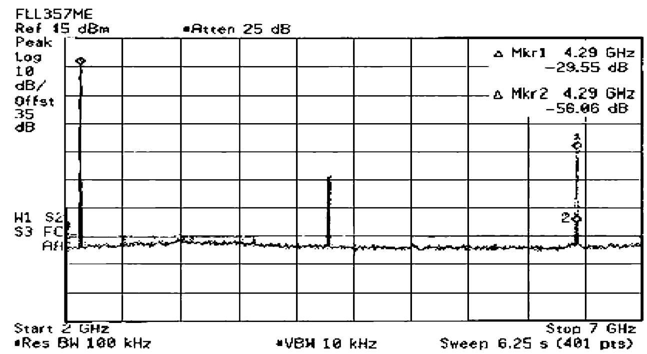


Fig. 5. Measured harmonic suppressions to fundamental power of the two PAs ($@Po = 35$ dBm).

that are connected to the 50 Ω microstrip line. The results show a good agreement in the characteristics at the fundamental and second harmonic frequencies. But the characteristics at the third harmonic frequency are quite different. It is definitely observed that the third harmonic component cannot pass the microstrip line having the $\lambda/4$ DGS bias line.

III. Amplifier Design and Measured Results

To show the validity of the proposed $\lambda/4$ DGS bias line, two power amplifiers for IMT-2000 base-station transmitters have been fabricated at 2.11~2.17 GHz using FLL357ME power device. The recommended bias conditions for class AB operation are; $V_{ds} = 10$ V and $I_{ds} = 0.6 I_{dss}$. Using load-pull method, the input and output matching conditions are obtained. A conventional $\lambda/4$ bias line has been adopted in the first power amplifier ("conventional PA"), while the proposed DGS $\lambda/4$ bias line was applied to the second power amplifier ("DGS PA"). The measured gain, return loss, and 1 dB compression point (P_{1dB}) of the conventional PA are 12.8 ± 0.1 dB, −21 dB, and 35.33 dBm, and those of the DGS PA are 13.35 ± 0.07dB, −21 dB, and 35.78 dBm, respectively.

Fig. 5 shows the second and third harmonic suppressions to the fundamental power of two PAs. In the conventional PA, the second and third harmonic suppressions are 39.21 dBc and 29.55 dBc, while those of DGS PA are 40.07 dBc and 56.06 dBc, respectively. It is noticeable that the third harmonic component level of DGS PA is quite smaller than that of the conventional PA. This means that DGS bias line terminates the third harmonic component properly. It is understood that these improvements are caused by the suppression of harmonics by DGS bias line. Fig. 6 shows harmonic suppression to fundamental of PAs according to operating frequencies. While the second harmonic

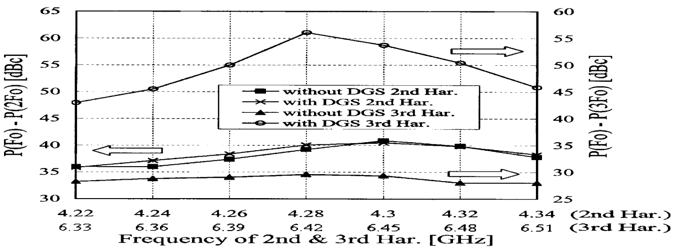


Fig. 6. Measured harmonic suppressions to fundamental component of conventional PA and DGS PA.

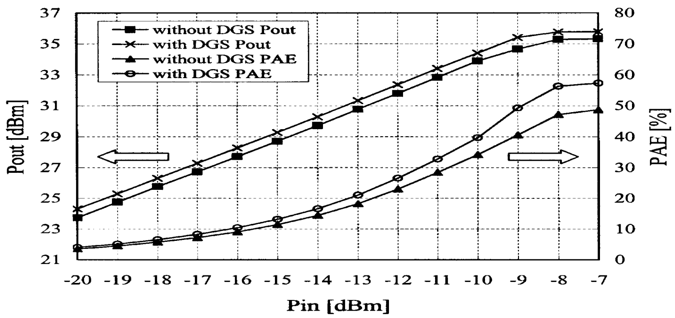
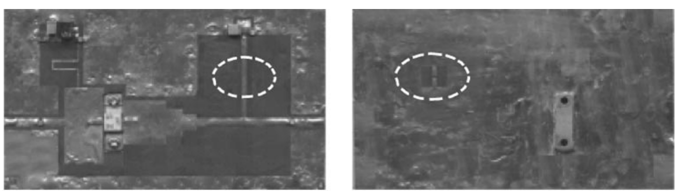


Fig. 7. Measured $P_{in} - P_{out}$ characteristics and measured PAE between the conventional PA and DGS PA.



(a) (b)

Fig. 8. Photographs of the fabricated amplifier with $\lambda/4$ DGS bias line. (a) Top view and (b) bottom view.

suppressions to fundamental of PAs higher than that of the conventional PA by 15–26 dB.

Fig. 7 shows the measured improvements of DGS PA in output power ($P_{\rm out}$), P_{1dB}, and PAE. The obtained improvements are summarized as follow; 0.45~0.76 dB in $P_{\rm out}$, 0.45dB of P_{1dB}, 0.5~9.14% of PAE. The improvement is caused by less current consumption and improved $P_{\rm out}$ of DGS PA. Because desirable improvements have been obtained, the proposed DGS bias line is a good choice for power amplifiers. Fig. 8 shows the photographs of the fabricated DGS PA having the proposed $\lambda/4$ DGS bias line.

IV. Conclusion

We have proposed a $\lambda/4$ DGS microstrip bias line to improve the performances of power amplifiers. DGS microstrip line offers broader width and shorter length than the conventional microstrip line having the same characteristic impedance. Additionally, it also offers the increased slow-wave effect over wide harmonic frequency band. When the DGS microstrip line is applied to $\lambda/4$ bias line, it provides the required high impedance and rejects the third harmonic as well as the second harmonic component.

The proposed $\lambda/4$ DGS bias line has been adopted in a power amplifier that operates for the IMT-2000 base-station transmitter. The measured third harmonic component signal of the DGS PA was lower than that of the conventional PA by at least 15 dB. The obtained improvement of P_{1dB} and PAE were 0.45 dB and 9.1%. It is expected that DGS PAs have lower IMD_3 and IMD_5 because of its suppressed harmonics. The further research is going to be performed.

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