Linearity-Optimized 3.5 GHz GaN HEMT Doherty Amplifier

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Abstract: This paper reports the linearity optimization of GaN HEMT Doherty amplifier for 3.5 GHz WiMAX applications. For the linearity optimization of the Doherty amplifier, not only gate biases but also shunt capacitors in output matching circuits of the carrier and peaking cells are controlled. For experimental verifications, a Doherty amplifier is designed and implemented using Cree CGH40010 with 10-W peak envelope power (PEP) and tested using a 1-carrier WCDMA and WiMAX signals. The Doherty amplifier is optimized for a WiMAX signal at an output power of 33 dBm, which is a 9.5-dB back-off power from the saturation power of 42.5 dBm. From the measured results, the relative constellation error (RCE) is –34.2 dB with the drain efficiency of 27.8%, compared to the class-AB power amplifier with the RCE and drain efficiency of -24.3 dB and 16.3 %.

1. Introduction

The Doherty amplifiers have received attention as a promising candidate to improve efficiency. Therefore, it is well-known that the Doherty amplifier shows high efficiency at a large back-off region, but poor linearity compared to the class-AB power amplifier. Analog or digital predistortion and feedforward linearization techniques have been used to improve the linearity of the Doherty amplifier [1]-[3]. Analog predistortion techniques have simple circuitry and low cost, but show limited performance. Digital preditortion and feedfoward techniques provide excellent linearity improvement, but have bulky size and complex circuitry. Furthermore, feedforward methods decrease the high efficiency of the Doherty amplifier owing to their inherent poor efficiency. Recently, in order to improve the linearity of the Doherty amplifier without extra linearization techniques, the *N*-way configuration, uneven power drive, adaptive bias control, and so on have been applied to the Doherty amplifier. However, their performances have not been enough satisfy linearity specifications [4], [5].

In this paper, we report a highly linear GaN HEMT Doherty amplifier for 3.5 GHz WiMAX Applications. To improve linearity without extra linearization techniques, the optimization of the gate biases and the output matching circuits with shunt capacitors of the carrier and peaking amplifiers are optimized. For experimental verification, a Doherty amplifier is designed and implemented using Cree CGH40010 GaN HEMT with 10-W peak envelope power (PEP) and tested the 1-carrier WCDMA and WiMAX signals. The measured results show a highly linear GaN HEMT Doherty amplifier for 3.5 GHz WiMAX applications.

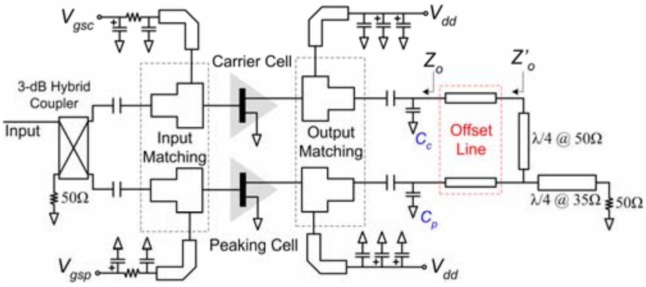


Fig. 1. The schematic of a 2-way Doherty amplifier.

2. Linearity-Optimized Doherty Amplifier

Derivative superposition has emerged as a useful circuit-level linearization technique, being conceptually simple, not requiring a significant increase in circuit complexity or precise circuit tuning, and achieving good performance [6], [7]. Thus, because a derivative-superposition amplifier is constructed by placing a number of devices in parallel and may consist of two or more devices, this technique can easily apply to the Doherty configurations, which possibly have different gate biases [8].

Figure 1 shows the schematic diagram of a 2-way Doherty amplifier, which consists of a carrier cell and a peaking cell. Two cells are simply modeled by voltage-controlled current sources, where each current source is represented by a Taylor-series expansion to the third-order, as shown below [9].

$$\begin{aligned} I_D(v_{GS}) &= \frac{\partial I_D}{\partial v_{GS}} v_{GS} + \frac{1}{2}\frac{\partial^2 I_D}{\partial v_{GS}^2} v_{GS}^2 + \frac{1}{6}\frac{\partial^3 I_D}{\partial v_{GS}^3} v_{GS}^3 + \cdots \\ &= G_m v_{GS} + G_{m2} v_{GS}^2 + G_{m3} v_{GS}^3 + \cdots \end{aligned} \tag{1}$$

where G_m is the transfer function derivative. The carrier and peaking cells are at different bias conditions, so the coefficients in the Taylor-series polynomials will be different for each cell. Here, we apply a two-tone input signal to the carrier and peaking cells of the Doherty amplifier.

$$v_{GS} = V_S(\cos\omega_1 t + \cos\omega_2 t) \tag{2}$$

where V_s is magnitude of the input signal. The upper-band third-order intermodulation (IM3) components of the carrier and peaking cells at the output of the Doherty amplifier can be expressed, respectively, as below.

$$I_{D.c}(2\omega_2 - \omega_1) = \frac{3}{4} \cdot G_{m3.c} \cdot V_s^3 \cdot e^{j\phi_c} \tag{3}$$

$$I_{D.p}(2\omega_2 - \omega_1) = \frac{3}{4} \cdot G_{m3.p} \cdot V_s^3 \cdot e^{j\phi_p} \tag{4}$$

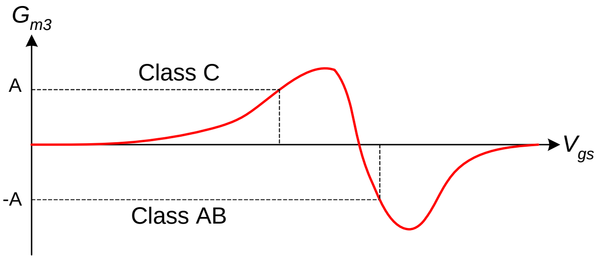


Fig. 2. G_{m3} of the GaN HEMT according to gate bias voltage.

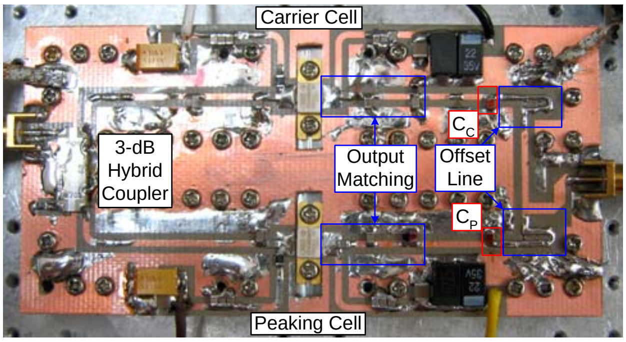


Fig. 3. Photograph of the fabricated 3.5-GHz GaN HEMT Doherty amplifier.

where ϕ_c and ϕ_p are phases of the carrier and peaking cell, respectively, which depend on the gate bias voltage. From the G_{m3} of GaN HEMT according to gate bias voltage in Fig. 2 [9], two equations of (3) and (4) can be used to cancel of the IM3 at the output of the Doherty amplifier by using the derivative superposition. For the perfect IM3 cancellation, a peaking cell should be biased to class-C mode with the G_{m3} of A when a carrier cell is biased to class-AB mode with the G_{m3} of $-A$. It is worth noting that the cancellation of the IM3 can be obtained when two cells are biased on opposite sides of the IM3 null.

3. Implementation and Experimental Results

The Doherty amplifier has been implemented using Cree CGH40010 GaN HEMT with 10-W PEP and RF35 (H=0.5 mm, ε_r=3.5) circuit board at the WiMAX band of 3.5 GHz. The input and output matching circuits of each cell have been individually adjusted to achieve good performance. In the process of determining the optimum length of the offset line, the output impedance of $Z_o=11.3+j*7.6\Omega$ has been transformed to $Z'_o=267\Omega$ by the 0.225λ (81°) length of the 50Ω offset line. To reduce memory effects, the drain bias circuit incorporates a λ/4 bias line and several tantalum decoupling capacitors. The gate bias voltages of the carrier and peaking cells were a class-AB bias of -2.14V and a class-C bias of -5V, respectively, with the drain bias voltage of 28V. The shunt capacitors in output matching circuits of the carrier and peaking cells were the C_c of 0.3 pF and C_p of 0.5 pF, respectively. Figure 3 shows the photograph of the fabricated 3.5 GHz GaN HEMT Doherty amplifier.

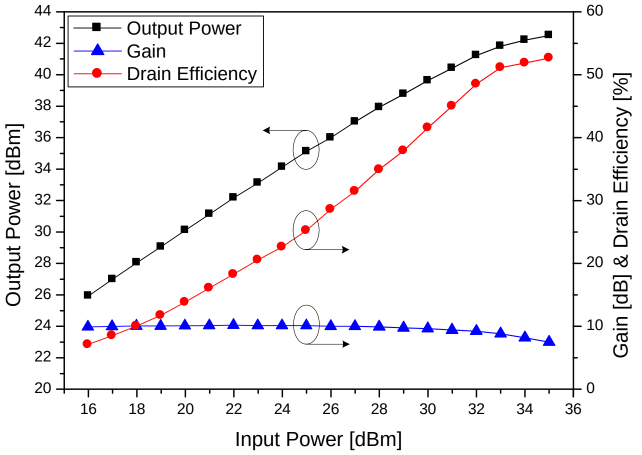


Fig. 4. Measured output power, gain, and drain efficiency characteristics according to input power levels for a continuous wave of 3.5 GHz.

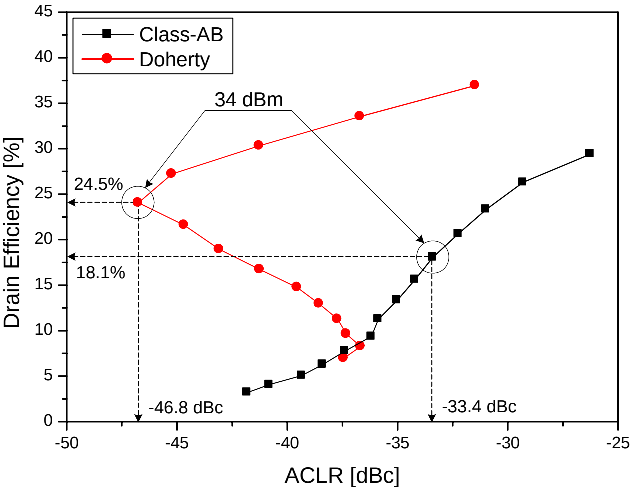


Fig. 5. Measured drain efficiency according to ACLR for a 1-carrier WCDMA signal.

Figure 4 shows the measured output power, gain, and drain efficiency characteristics according to input power levels for a continuous wave of 3.5 GHz. The implemented GaN HEMT Doherty amplifier can deliver the peak drain efficiency of 52.6% at an output power of 42.5 dBm.

For a 1-carrier WCDMA signal, the Doherty amplifier was optimized at an output power of 34 dBm by adjusting two gate biases and shunt capacitors. The gate bias voltage of the peaking cell was adjusted to -5.84V. The C_c and C_p were 0.9 pF and 0.7 pF, respectively. For more accurate comparison, the class-AB power amplifier was also fabricated, which had the class-AB bias with a quiescent current of 450mA and drain bias voltage of 28V. Figure 5 shows the measured drain efficiency according to adjacent channel leakage ratio (ACLR) characteristics for a 1-carrier WCDMA signal. The ACLR has been measured at ±2.5-MHz offset in the symmetrical state between the lower and upper bands. At an average output power of 34 dBm, an ACLR of -46.8 dBc is achieved, which is 13.4-dB improvement compared to the class-AB power amplifier with an ACLR of -33.4 dBc. Figure 6 shows the measured

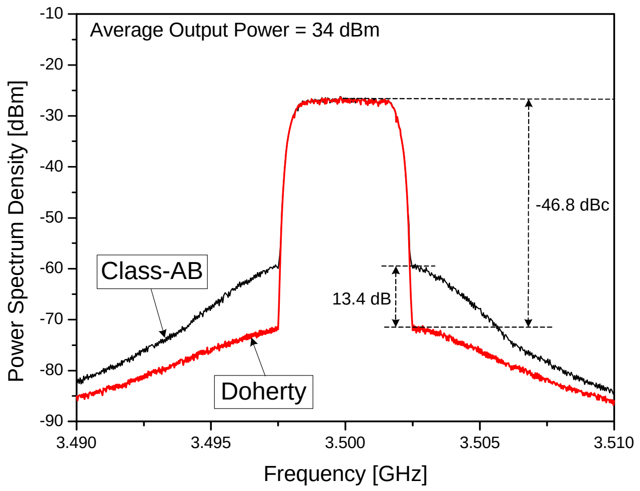


Fig. 6. Measured power spectrum densities at an average output power of 34 dBm for a 1-carrier WCDMA signal.

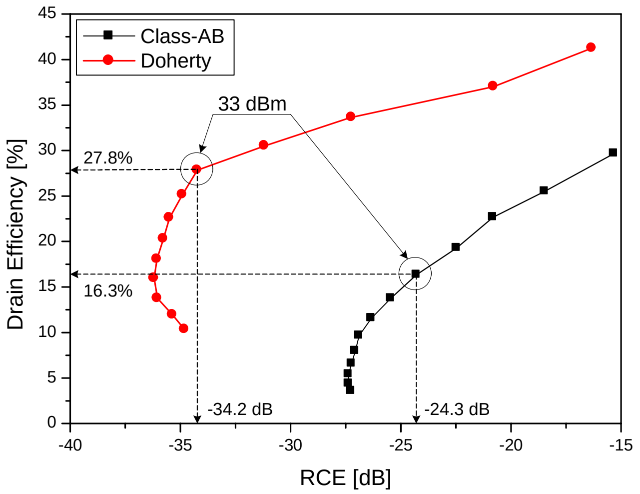
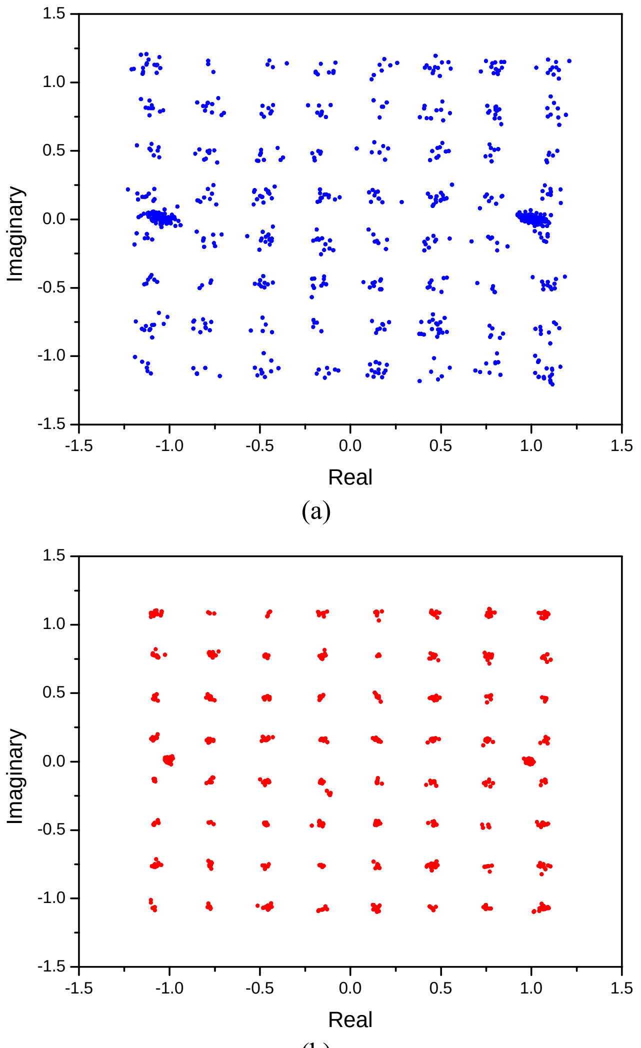


Fig. 7. Measured drain efficiency according to RCE for a WiMAX signal.

power spectrum densities for a 1-carrier WCDMA signal. The drain efficiency of 24.5% for the Doherty amplifier is obtained at an average output power of 34 dBm. Over a wide output power range, the drain efficiency of the Doherty amplifier is enhanced over 6.4% compared to that of the class-AB power amplifier.

For the WiMAX signal, the relative constellation error (RCE) instead of an ACLR should be measured. The ACLR is the out-of-error and can be improved by the G_{m3} cancellation. However, the RCE shows the amount of in-band-error like the error vector magnitude (EVM) [10]. The IEEE 802.16-2004 with 28 MHz signal bandwidth, the burst type of 64-QAM-3/4, and the PAPR of 9.47 dB was used as the WiMAX signal. The Doherty amplifier was re-optimized at an output power of 33 dBm for the WiMAX signal with the gate bias voltages of -2.17V and -7.31V. The additional C_c and C_p of 0.3 pF and 0.5 pF were inserted into the output matching circuit of the carrier and peaking cells, respectively. Figure 7 depicts the measured drain efficiency according to RCE characteristics for the WiMAX signal. At an output power of 33 dBm, the RCE of -34.2 dB is obtained, compared to the class-AB power amplifier with the RCE of -24.3 dB. For the Doherty amplifier, the drain efficiency is over 10% higher than that of the class-AB power amplifier.



(a)

(b)

Fig. 8. Measured constellation diagrams for a WiMAX signal. (a) Class-AB power amplifier. (b) Dohety amplifier.

Figure 8 shows the measured constellation diagram for a WiMAX signal. The constellation diagram of the Doherty amplifier is clearer than that of the class-AB power amplifier, which means that the Doherty amplifier has more linear amplification characteristics.

4. Conclusions

In this paper, we have proposed a linearity-optimized GaN HEMT Doherty amplifier for 3.5 GHz WiMAX applications. To improve linearity without extra linearization techniques, the optimization of the gate biases of the carrier and peaking cells and output matching circuits with shunt capacitors was used. For experimental verification, a Doherty amplifier was designed and implemented using Cree CGH40010 GaN HEMT with 10-W PEP and tested using the 1-carrier WCDMA and

WiMAX signals. The measured results for a WCDMA signal showed that the Doherty amplifier optimized at an output power of 34 dBm can deliver an ACLR of -46.8 dBc at ±2.5-MHz offset with the PAE of 24.5 %. For a WiMAX signal of IEEE 802.16-2004 with 28-MHz signal bandwidth and 64-QAM-3/4 bust type, the Doherty amplifier deliver the RCE of -34.2 dB with the drain efficiency of 27.8%, compared to the class-AB power amplifier with the RCE of -24.3 dB and the drain efficiency of 16.3%. From the measured results, it is worth noting that the linearity-optimized GaN HEMT Doherty amplifier can be a promising solution for the 3.5 GHz WiMAX applications.

Acknowledgement

This work was in part supported by the BK21 program and the National Center for Nanomaterials Technology (NCNT).

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