Peaking 증폭기의 최적화 바이어스를 이용한 비대칭 3-way 도허티 증폭기의 선형성 향상 연구

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Linearity improvement of uneven 3-way Doherty amplifier using unequal biases of peaking amplifiers

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Abstract

We have demonstrated that the linearity of the uneven 3-way Doherty amplifier can be improved effectively using the uneven power drive and unequal biases of the peaking amplifiers. We have built the amplifier using Freescale LDMOSFET MRF6P21190 with 190 watts power for WCDMA application. For the forward-link 4-carrier WCDMA signal, the adjacent channel leakage ratio(ACLR) performances at 5 MHz and 10 MHz offsets are -51.2 dBc and -52.4 dBc, respectively, at an average power of 45 dBm and drain efficiency of 11.45 %. These results show clearly that the proposed amplifier is very attractive to a repeater system application.

I. Introduction

In the design of modern power amplifiers, the linearity, along with the efficiency enhancement techniques, play an important role to enhance the performance. The amplification of the signal, such as CDMA, WCDMA and OFDM with a high PAR, requires a highly linear amplification to the intact communication quality [2].

Numerous Linearization techniques are available such as feedforward, feedback and predistortion linearizer. However, these techniques cause the additional expenses of complicated circuits, poor efficiency, large size and cost. Therefore, we have proposed an amplifier that has excellent linearity performance and easy to implement without any additional circuits.

Doherty amplifier has been originally proposed to improve the efficiency, but it can also improve the linearity simultaneously. The uneven 2-way Doherty amplifier can deliver a highly enhanced efficiency with some linearity improvement. Therefore, the amplifier needs more linearizing circuit, such as analog pre-distorter or digital pre-distorter, to satisfy the specification of a repeater system. As a result, the total efficiency is reduced and the circuit is complex. We have been proposed the uneven 3-way Doherty amplifier using the unequal biases of the two peaking amplifiers, which can improve the linearity significantly without additional circuits, while maintain a similar efficiency to a class AB amplifier. The cancellation of the high order intermodulations of the carrier and peaking amplifiers can improve the linearity.

II. Uneven 3-way Doherty Amplifier

The basic operation mechanism of the Doherty amplifier is a load modulation at low power levels by the peaking amplifiers [3]. Fig. 1 shows an operational diagram of the 3-way Doherty amplifier to explain the load modulation mechanism.

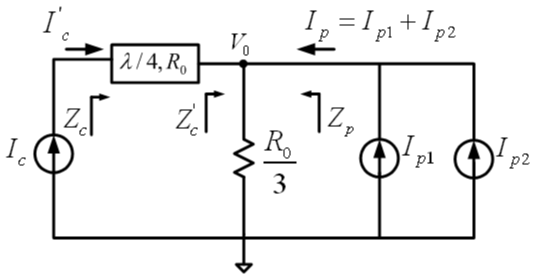

Fig. 1. Load modulation of the 3-way Doherty amplifier.

At a low power region, if the I_p becomes zero, the transformed impedance Z_c viewed from the current source I_c becomes $3R_0$. If the I_p becomes two times of I_c, at a high power region, Z_c becomes R_0. Therefore, the peak efficiency can be achieved at the peak and -9.5 dB back-off output power [4].

In the conventional implementation of the 3-way Doherty amplifier, the improper load modulation restrict the Doherty operation. The one reason is that the current source I_p is not fully open when the peaking amplifier is off and the other is that Z'_c is not resistive impedance only. Also, unequal bias levels of the carrier and peaking amplifiers result in much lower current of the peaking amplifiers than that of the carrier amplifier at the full power level. We have been solved these limitations by the offset lines, bias control and unequal power drive in previous works [3], [4], [5].

The generation of nonlinear output current can be expressed in Taylor series below.

$$I_{out} = gm_1 \cdot v_i + gm_2 \cdot v_i^2 + gm_3 \cdot v_i^3 + \cdots + gm_5 \cdot v_i^5 + \cdots$$

As shown, the IM_3 and IM_5 currents are primary generated by the $gm_3 \cdot v_i^3$ and $gm_5 \cdot v_i^5$ [7]. Fig. 2 shows that the IM_3 and IM_5 currents generated by the carrier amplifier can be cancelled by those of the two peaking amplifiers with properly selected gate biases. In case of the uneven 2-way Doherty amplifier, we can achieve perfect IM_3 cancellation, but not in IM_5. In case of the proposed uneven 3-way Doherty amplifier, the biases of the two peaking amplifiers can be controlled individually, so as to get the cancellations of not only IM_3 but also IM_5. Therefore, the proposed uneven 3-way Doherty amplifier using the unequal peaking biases can be considerably more linear without *3rd* and *5th* order IMDs.

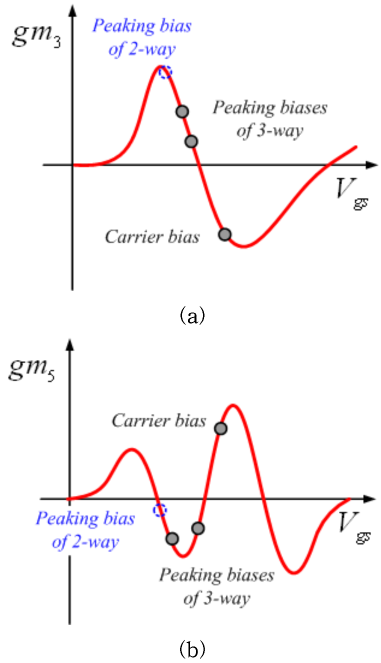

Fig. 2. Normalized *gm* curves of the FETs and biases. (a) Normalized gm_3 curve (b) Normalized gm_5 curve

However, the two peaking amplifiers of the proposed amplifier have higher biases than that of the uneven 2-way Doherty amplifier because each of the two peaking amplifiers should generate small IM_3 currents to cancel the IM_3 of the carrier amplifier. And the efficiency has been reduced, similar to class AB amplifier and lower than that of the uneven 2-way Doherty amplifier.

III. Implementation

The proposed amplifier has been designed and implemented at 2.14 GHz using three 190 watts PEP MRF6P21190 LDMOSFETs, which is the push-pull configuration of two 95 watts FET devices. As shown in Fig. 3, two cells of the uneven 3-way Doherty amplifiers are combined with balanced combiner to get more output power. At the input stage, 3 dB hybrid couplers has been used for the input power divider and 90° phase difference between carrier and peaking amplifiers. The pi-attenuators have been utilized for the uneven power drive, in front of carrier amplifiers. For the purpose of perfect load modulation, the optimized power dividing ratio has been 5 : 9 : 9 for the carrier and two peaking amplifiers, respectively, and the same 0.24 λ offset lines have been implemented.

While the bias of carrier amplifier is fixed at class AB, two biases of the peaking amplifiers have been individually adjusted to cancel both the IM_3 and IM_5 currents of the carrier amplifier, properly. Finally, the output matching networks have been optimized to get the best linearity at 45 dBm(30 watts) average output power for the 4-carrier forward-link WCDMA signal.

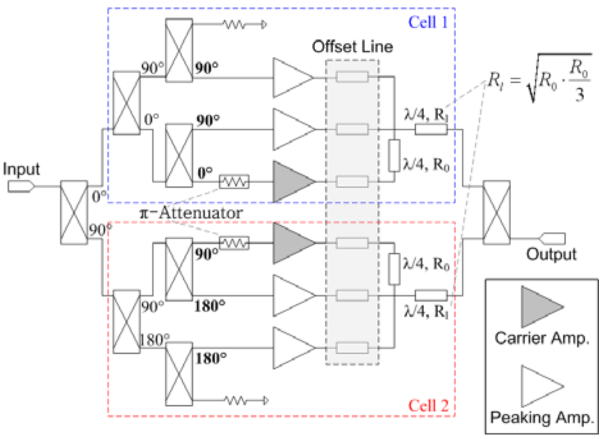

Fig. 3. Block diagram of uneven 3-way Doherty PA.

Ⅳ. Experimental Results

For the verification, we have experimented with two-tone and 4-carrier forward-link WCDMA signals. The performance of the uneven 3-way Doherty amplifier using the unequal peaking biases has been compared with class AB amplifier and the uneven 2-way Doherty amplifier, which are implemented with identical devices and have been optimized at the same backed-off output power. The quiescent current of the carrier amplifier is 1.6 A and those of two peaking amplifiers are 0.46 A and 0.38 A, respectively.

Fig. 4 shows the IM cancellation results of the uneven 3-way Doherty using the unequal peaking biases, considerably improved linearity compared with the class AB amplifier. At around 47 dBm average output power, it shows -8 dB ~ -10 dB lower IMD_3 for an 1 MHz spacing two-tone signal. Due to the influence of memory effects, upper and lower IMD_3 characters are asymmetrical for the 20 MHz tone-spacing signal, but it shows the linearity is improved by at least -6 dB. The performance of IMD_5 has been remarkably improved, around -10 dB at a large output power level and for the various tone-spacing signals. These results verify the proposed amplifier can perfectly cancel IM_3 and IM_5, together.

For the forward-link 4-carrier WCDMA signal, as shown at Fig. 5, ACLR performances at 5 MHz and 10 MHz offsets are -51.2 dBc and -52.4 dBc at an average output power of 45 dBm. Table 1 shows the compared performances of the three type of implementations at the same backed-off(-12.5 dB) output power. The proposed amplifier has -8 dB and -2 dB lower ACLR at 10 MHz offset compared with the class AB amplifier and the uneven 2-way Doherty amplifier, respectively. The drain efficiency of 11.45 % at 45 dBm output power, shown in Fig. 6, is comparable with that of class AB amplifier.

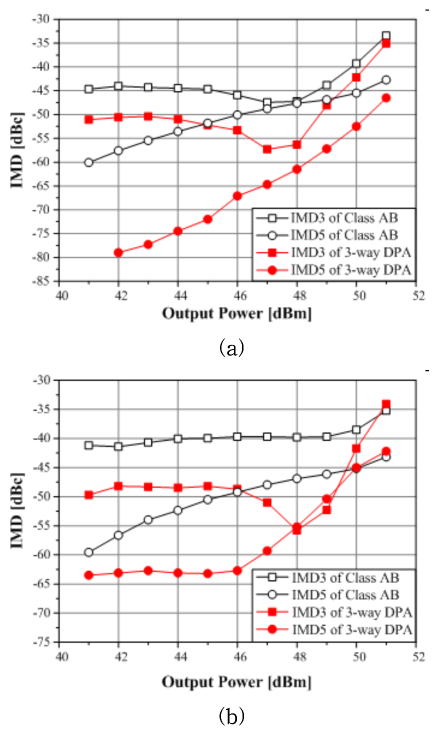

Fig. 4. Measured IMD_3 and IMD_5 performances for two-tone signal. (a) 1MHz spacing (b) 20 MHz spacing

V. Conclusions

We have proposed an uneven 3-way Doherty amplifier using the unequal peaking biases. The proposed amplifier shows much better linearity performance than uneven 2-way Doherty amplifier with the comparable drain efficiency of class AB amplifier. For the forward-link 4-carrier WCDMA signal, ACLR performances at 5 MHz and 10 MHz offsets are -51.2 dBc and -52.4 dBc, respectively, and the drain efficiency is 11.45 %, at an average output power of 45 dBm. These results clearly show that the proposed amplifier is a very attractive candidate for HPA of a repeater system application.

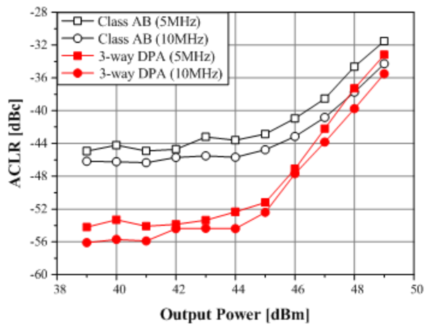

Fig. 5. Measured ACLR performance for WCDMA 4FA signal.

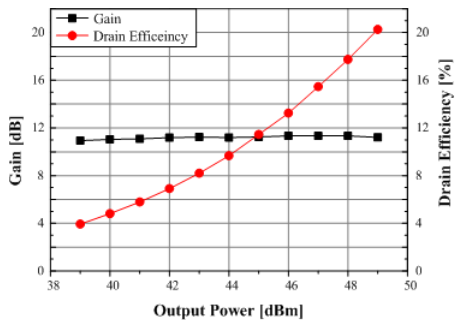

Fig. 6. Measured power gain and drain efficiency performance for WCDMA 4FA signal.

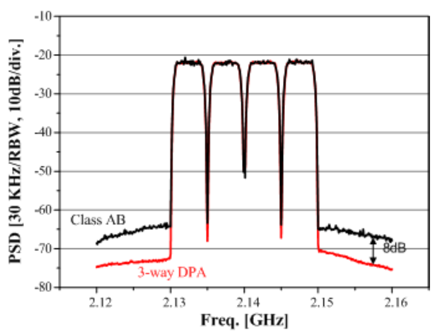

Fig. 7. Power spectral density for WCDMA 4FA signal at 45 dBm average output power(-12.5 dB back-off power).

		Class AB	2-way Doherty	3-way Doherty
Output power [power backoff]		*42 dBm [12.5 dB]*	*43 dBm [12.5 dB]*	***45 dBm [12.5 dB]***
ACLR	5 MHz offset	*-42.9 dBc*	*-48.8 dBc*	***-51.2 dBc***
	10MHz offset	*-44.7 dBc*	*-50.7 dBc*	***-52.4 dBc***
Drain Efficiency		*12.33 %*	*19.03 %*	***11.45 %***

Table 1. Compared performance for WCDMA 4FA signal.

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