Linear Power Amplifier based on 3-Way Doherty Amplifier with Predistorter

Bumjae Shin, Jeonghyeon Cha, Jangheon Kim, Y.Y. Woo, Jaehyok Yi, and Bumman Kim

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING AND MICROWAVE APPLICATION RESEARCH CENTER, POHANG UNIVERSITY OF SCIENCE AND TECHNOLOGY, KYOUNGBUK, 790-784, REPUBLIC OF KOREA

Abstract **This paper presents a 3-way Doherty amplifier with predistorter(PD) for a repeater application. It is implemented using three 60 watts PEP silicon LDMOSFETs and tested using two-tone and one- and two-carrier down-link WCDMA signals. For the two-carrier down-link WCDMA signal, the amplifier provides -49.1 dBc adjacent-channel-leakage-ratio(ACLR) and 10.3 % power-added efficiency(PAE) at an output power 40 dBm which is an improvement of 8.5 dBc in linearity and 2 % in efficiency compard to a similar class-AB amplifier.**

Ⅰ. Introduction

Linearity is the most important figure of merit for the power amplifiers of CDMA applications, such as IS95, CDMA 2000, WCDMA , and so on. There are many linearity boosting techniques, for example, feedforward, feedback, predistortion technique [1]. Among them, the feedforward technique is still considered to be the most popular and the best performing method. However, it also has many drawbacks, such as complexity, poor efficiency, and large size, which result in cost problems. Recently, digital PD amplifier becomes a very important technique. On the other hand, an analog predistortion technique is a low-cost solution for the moderate performance improvement. It is also a low-power consumption and simple circuit configuration over the feedforward or digital PD [2]. Therefore, for a repeater system which has less stringent linearity requirement and a small power handling than a base station system, the feedforward is not certainly necessary.

Microwave Doherty amplifier has been originally proposed to improve the efficiency, but it has been reported that the efficiency and linearity can be improved simultaneously [3]. To enhance the performances, a new load line topology using offset line has been implemented and a linearity enhancement technique has been incorporated by canceling the intermodulations from the carrier and peaking amplifiers [3]. For a microwave N-way Doherty amplifiers with one carrier amplifier and N-1 peaking amplifiers, it has been reported that 2-way Doherty amplifier can deliver a highly enhanced efficiency with some linearity improvement, but 3-way or 4-way Doherty amplifiers improve much more linearity significantly [4]. 3-way Doherty amplifier has a similar efficiency to 3-way class-AB amplifier, but with significantly improved linearity. Moreover, these Doherty amplifiers are very simple and easy to add other linearization techniques, such as predistortion technique.

In this paper, we have introduced a microwave 3-way Doherty amplifier with predistorter targeted for a cheap repeater system with 10 watts average power and about -50 dBc ACLR as well as a respectable efficiency. For the amplifier, the dominant harmonic is IMD_3 because IMD_3 and IMD_5 components have been cancelled out simultaneously in the Doherty operation. Therefore, we could adopt a simple 3rd order predistorter. The amplifier has been tested using one- and two-carrier down-link WCDMA signals having 8.6 dB peak-to-average ratio at 0.1 % CCDF and two-tone signals with 5 MHz or 10 MHz spacing. The measured results have been compared with class-AB biased amplifiers as their counterparts.

Ⅱ. Design and Implementation

A. 3-way Doherty amplifier

The basic operation principle of the Doherty amplifier has been well described in the literature [1]. The core principle of operation is a load modulation at low power levels by a peaking amplifier. Fig. 1 shows an operational diagram to explain the load modulation mechanism of the 3-way Doherty amplifier.

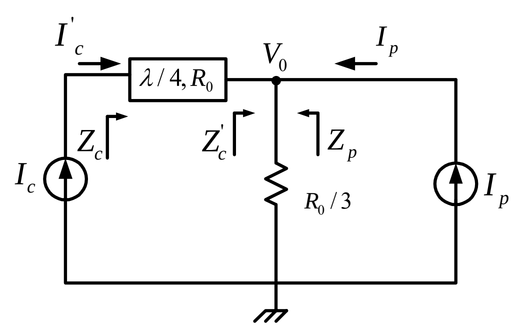


Fig. 1. Operational diagram of the 3-way Doherty amplifier

In the figure, I_c and I_p represent the carrier amplifier and the peaking amplifiers, respectively. From the figure, equation (1) is acquired. In this equation, if the I_p becomes zero, the transformed impedance Z_c viewed from the current source I_c becomes $3R_0$ and if the I_p becomes two times of I_c, Z_c becomes R_0.

$$Z_c' = \frac{V_0}{I_c'} = \frac{R_0}{3}\left(\frac{I_c' + I_p}{I_c'}\right), 0 \le I_p \le 2I_c' \qquad (1)$$
$$Z_c = \frac{R_0^{\ 2}}{Z_c'} = \frac{3R_0}{1 + I_p / I_c'} = \frac{3R_0}{1+\alpha}, 0 \le \alpha \le 2$$

Therefore, for the 3-way Doherty amplifier, the load impedance can be modulated from R_0 to $3R_0$ according to the value of I_p. But, in the actual implementation of the 3-way Doherty amplifier, the load modulation does not occur properly because of the power matching circuits at the amplifiers. Moreover, the impedance viewed from the the common load to the current source I_p is not open at a low power level where the peaking amplifier is off. It has been reported that these problems can be solved by the phase offset lines [3].

On the other hand, the nonlinear output current of the active devices can be expressed using Taylor series expansion by

$$I_{out} = gm_1 \cdot v_i + gm_2 \cdot v_i^2 + gm_3 \cdot v_i^3 + \cdots \qquad (2)$$

,where v_i is an input voltage and gm_n's are the Nth-order exapansion coefficients of the nonlinear transconductance. The third-order intermodulation distortion(IMD_3) current is mainly generated by the $gm_3 \cdot v_i^3$ of (2). The IMD_3 currents generated by the carrier and peaking amplifiers can be cancelled by selecting proper gate biases for the two amplifiers [4]. Fig. 2 presents the large-signal third-order transconductance coefficient (gm_3) curve through the gate bias level for general FETs [5].

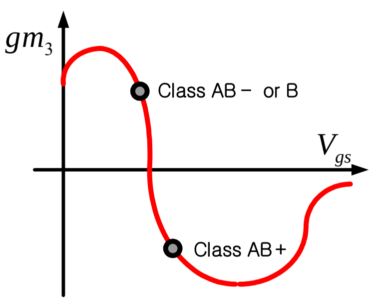


Fig. 2. Large signal gm_3 v.s. gate bias curve of general FETs

For the 3-way Doherty amplifier, which has two peaking amplifiers, the bias of the carrier amplifier is fixed at class-AB or class-A mode and the biases of the peaking amplifiers are adjusted to have perfect IMD_3 cancellation. Generally, the biases of the peaking amplifiers are a deep class-AB mode. For the 3-way Doherty amplifier, the bias point of the peaking amplifier for perfect IMD_3 cancellation is higher than that of 2-way case because of two peaking amplifiers used to cancel the IMD_3 of the carrier amplifier. Therefore, the peaking amplifiers of the 3-way Doherty amplifier can be operated more linearly without excessively generating higher order terms and the three amplifiers can be more linear.

In this paper, a 2.14 GHz 3-way Doherty amplifier has been implemented using three Motorola's MRF21060 (60 watts PEP) LDMOSFETs. The inputs have been matched to R_0=50 Ω from their source impedances of Z_s=3.547-j3.377 Ω. But their load impedances are matched a little differently from 50 Ω for the optimized performance. The 50 Ω loads are matched to $Z_{L,C}$=2.841-j1.445 Ω and $Z_{L,P}$=2.602-j1.930 Ω, the carrier and peaking amplifiers, respectively. Fig. 3 shows a photograph of the implemented 3-way Doherty amplifier.

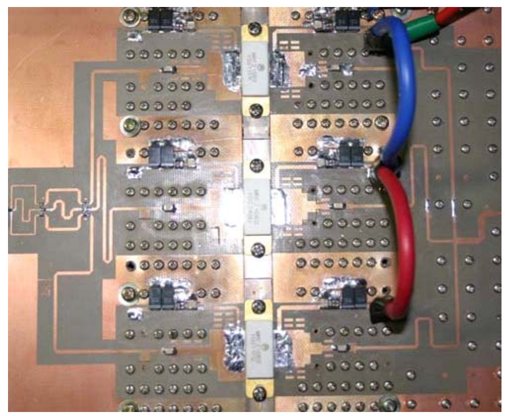


Fig. 3. Photograph of the implemented 3-way Doherty amplifier

From fig. 3, it is seen that the output matchings of the carrier and peaking amplifiers are somewhat different to improve the linearity maximally. The design process including the offset lines is presented in our previous works [3], [4]. In this experiment, the offset lines of 50 Ω with 0.012λ length are used for both the carrier and peaking amplifiers.

B. Predistorter

As shown in the experimental results of the following section, the amplifier performance is slightly off the target, so we have employed a predistorter. Fig. 4 represents the schematic diagram of the implemented predistorter. There are two paths in the predistorter. The upper path represents the fundamental component path and the lower path represents the IM_3 component path. The IM_3 generator consists of 90° hybrid, Schottky diodes, and series RC passive network with a short microstrip delay line. The input signal applied to the IM_3 generator is split into 0° and -90° ports of the 3dB hybrid coupler. The Schottky diodes at 0° port generate IM_3 term and then reflect the IM_3 and fundamental terms into the IN and ISO ports. At the -90° port, the incident signal is also reflected into

IN and ISO ports by the passive network reflector. The reflected fundamental terms of 0° and -90° ports are cancelled out at the ISO port. Accordingly, the IM_3 terms can be made on the lower path. The implemented predistoerter generates the IMD_3 with a 2dBc/dBm slope according to the output power [2].

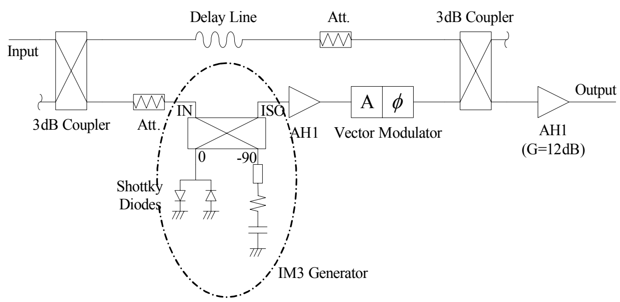
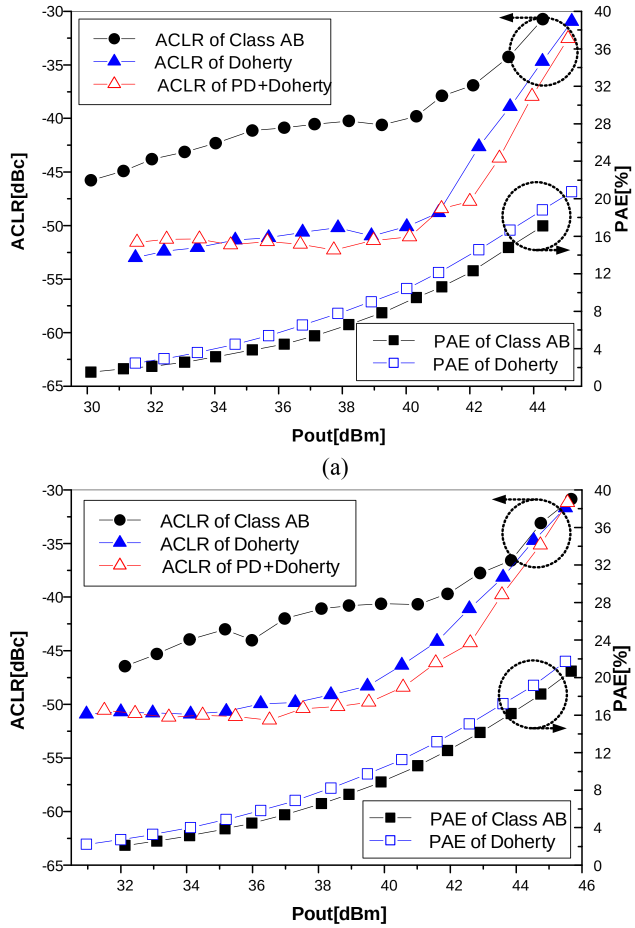


Fig. 4. Schematic diagram of the implemented predistorter

Ⅲ. Experimental Results

The performance of the 3-way Doherty amplifier with predistorter has been compared with that of a comparable class-AB amplifier using two-tone signals(5 MHz, 10 MHZ spacing) and one-carrier down-link WCDMA signal and two-carrier with 10 MHz spacing. In this experiments, the quiescent drain currents of the carrier and peaking amplifiers are set to 700 mA at V_{DD}=28 V for the class-AB case. For the 3-way Doherty amplifier, the quiescent drain current $I_{D,C}$ of the carrier amplifier is set to 820 mA at V_{DD}=28 V but those ($I_{D,P}$) of the peaking amplifiers are set to 270 mA at V_{DD}=28 V respectively.

Fig. 5 shows the measured ACLRs and PAEs of the class-AB, 3-way Doherty, and 3-way Doherty with predistorter. Fig. 5(a) is for one-carrier WCDMA signal and 5(b) is for two-carrier WCDMA signal with 10 MHz spacing. For the one-carrier WCDMA signal, the ACLRs of the 3-way Doherty and the 3-way Doherty with predistorter are improved by about 10 dB at an output power 40 dBm and the PAEs are improved slightly by about 2 % at the same output power. For the two-carrier WCDMA signal, ACLRs of the 3-way Doherty and the 3-way Doherty with predistorter are improved by 6.8 dB and 8.5 dB at an output power 40 dBm, respectively and the improvement of the PAEs is similar to the one-carrier case. Test results for one- and two-carrier down-link WCDMA signals have been summarized in Table Ⅰ and Ⅱ. As seen by Tables, the ACLR and PAE are more improved by combining the 3-way Doherty amplifier with the predistorter.



(b)

Fig. 5. Measured ACLRs and PAEs of the class AB, the 3-way Doherty, and the 3-way Doherty with PD. (a) one-carrier down-link WCDMA signal (b) two-carrier down-link WCDMA signal

Table Ⅰ. Measured performances of the class AB, the 3-way Doherty, and the 3-way Doherty with PD at an output power 40 dBm. (a) one-carrier down-link WCDMA signal (b) two-carrier down-link WCDMA signal

(a)

	ACLR[dBc]	PAE[%]
Class AB	-40	8.2
Doherty	-50.1	10.4
Doherty with PD	-51	10.4

(b)

	ACLR[dBc]	PAE[%]
Class AB	-40.6	8.2
Doherty	-47.4	10.3
Doherty with PD	-49.1	10.3

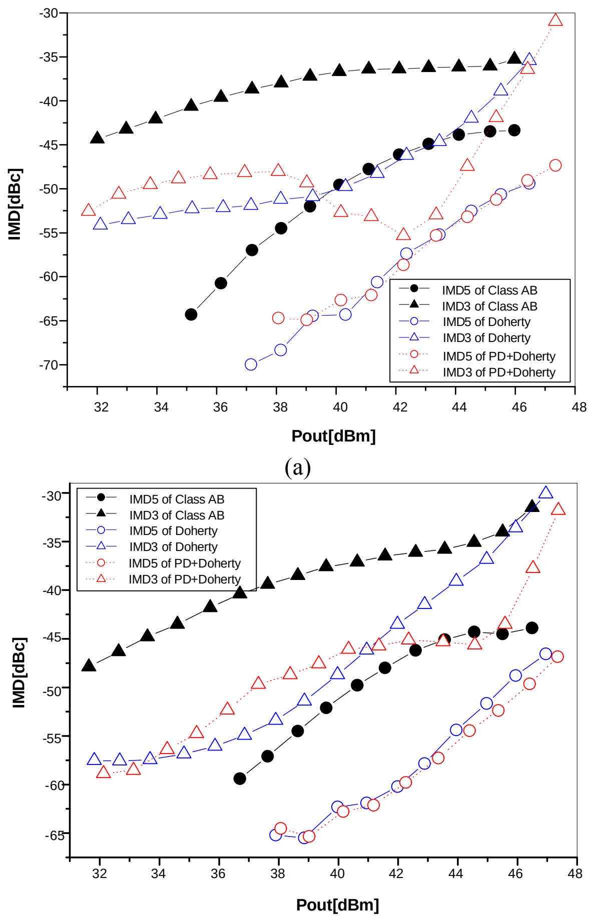
Table Ⅱ. Measured performances with -45 dBc ACLR. (a) one-carrier down-link WCDMA signal (b) two-carrier down-link WCDMA signal

(a)

	P_{out} [dBm]	PAE[%]
Doherty	41.8	13.6
Doherty with PD	42.6	15.3

(b)

(b)	P_{out} [dBm]	PAE[%]
Doherty	41.2	12.2
Doherty with PD	42.2	14.2



(a)

(b)

Fig. 6. Measured IMD_3s and IMD_5s of the class AB, the 3-way Doherty, and the 3-way Doherty with predistorter. (a) 5 MHz spacing (b) 10 MHz spacing

Fig. 6 explains the linearity boosting mechanism of the 3-way Doherty amplifier and the 3-way Doherty amplifier with predistorter. For the 3-way Doherty amplifier, IMD_3 and IMD_5 have been improved simultaneously compared to the class-AB case. On the other hand, for the 3-way Doherty amplifier with predistorter, IMD_3 has been further improved at high power levels than the 3-way Doherty amplifier. Fig. 7 shows the power spectra of the class AB and the 3-way Doherty with predistorter at an output power 40 dBm.

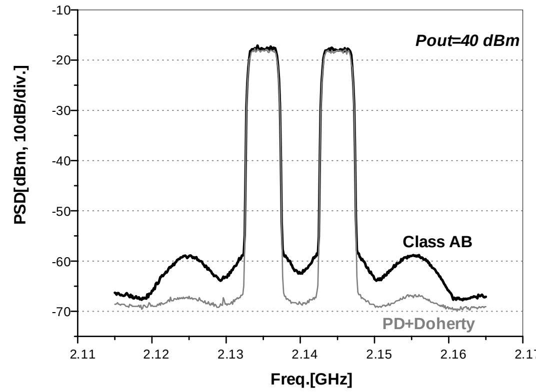


Fig. 7. Power spectral densities at an output power 40 dBm for a two-carrier down-link WCDMA signal

Ⅳ. Conclusions

For a repeater system application, a 3-way Doherty with predistorter has been proposed. For one- and two-carrier down-link WCDMA signals, the proposed one has ACLR of -51 dBc, -49.1 dBc and PAE of 10.4 %, 10.3 % respectively at output power 40 dBm, which are improvement of 11 dBc, 8.5 dBc in linearity and about 2.2 %, 2.1 % in PAE, respectively, compared to the class-AB case at the same output power. The experimental results show that the 3-way Doherty amplifier with predistorter is a good alternative for a cheap repeater system that requires less stringent linearity requirement and small power handling than a base station system.

References

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