Bias-Switching Quasi-Doherty-Type Amplifier for CDMA Handset Applications

Seongjun Bae, Junghyun Kim, *Inho Nam, Youngwoo Kwon

School of Electrical Engineering, Seoul National University
San 56-1 Shinlim-dong, Kwanak-ku, Seoul, 151-742, Korea
*WAVICS Co., Ltd. F11 Telson Venture Tower, 943-3,
Dokok-dong, Kangnam-ku, Seoul, Korea
e-mail : ykwon@snu.ac.kr

Abstract — A new approach of "quasi-Doherty" type amplifier based on bias switching has been developed for CDMA handset applications. By dividing the mode of operation according to the output power requirement, the efficiency was optimized in the low-power region while the linearity was improved in the high-power region. In this way, the proposed bias-switching Doherty amplifier could meet the stringent ACPR specification of the CDMA systems over the entire power region while improving the low-power efficiencies. Biasing to the peak amplifier has been switched according the mode of operation for this purpose. Prototype 0.5-W power amplifier module has been designed and fabricated to demonstrate the concept. In the low power mode, PAE of 17 % and ACPR of -51.8 dBc were achieved at output power of 16 dBm. In high power mode, PAE of 32 % and ACPR of -50 dBc were achieved at output power of 25 dBm.

I. INTRODUCTION

Modern mobile communication systems impose stringent requirements on the power amplifiers regarding the efficiency and the linearity. Simultaneous requirement of high efficiency and ultimate linearity makes the power amplifier design even more difficult since strong compensating effects exist between the two. One simple method to achieve compromised results is to adopt class-AB biasing schemes. However, simple class-AB biasing scheme has its own limits in terms of ultimate performance.

For CDMA systems, linearity (ACPR : Adjacent Channel Power Ratio) is a parameter that needs to be satisfied over the entire power range, which makes the efficiency of the CDMA PA's much lower than the GSM counterparts. The efficiency at low-power region is of supreme interest for battery lifetime. This is due to the fact that for typical urban environment, the handset is mostly operated with the output power range below 10 dBm. For extended battery lifetime, the current CDMA handset system allows multiple modes of operation for power amplifiers depending on the TX power requirement. Bias switching is generally used for this purpose. For example, the bias to the class-AB amplifier is switched to low current, when the amplifier is in the low power mode. In this way, the current consumption is reduced, resulting in enhanced efficiencies. The linearity is compromised by down biasing, but for low-power mode of operation, the amplifier can still meet the ACPR specifications.

Doherty-type amplifiers promise enhanced efficiencies at backed-off power levels [1]-[5]. Monolithic Doherty-type amplifiers have been successfully implemented up to K-band [2][3]. Significant efficiency enhancement has been experimentally demonstrated at backed-off power levels using this approach. However, the measured results on the linearity of the Doherty-type amplifier have been various [1][3]. As will be shown later, "true-Doherty" amplifier cannot meet the CDMA linearity requirement over the entire output power range.

In this paper, we introduce a bias switching technique to Doherty-type amplifiers so that they can satisfy the

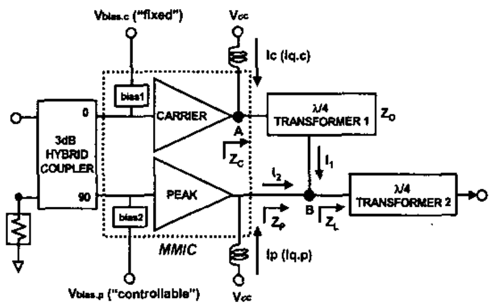

Fig. 1. Simplified diagram of the proposed amplifier

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linearity requirement over the entire power range. This technique was applied to the power amplifiers of CDMA handset applications, and resulted in enhanced efficiencies in the low-power region while meeting the linearity specifications in the high-power region.

II. CIRCUIT DESCRIPTION

The circuit schematic of the Doherty-type amplifier is shown in Fig. 1. It is composed of carrier amplifier, peak amplifier, quarter-wavelength impedance transformers, and quadrature 3-dB hybrid coupler. For the true Doherty mode of operation, a carrier amplifier is operated in class AB while a peak amplifier is biased at class C [6].

To obtain optimized efficiency over a power range wider than 3 dB, 'extended' Doherty-type approach has been employed in this work [5]. Device size ratio of 1 to 4 was chosen between the carrier and peak amplifiers. The power range of efficiency enhancement can in this way be extended to about 14 dB back-off. Based on this concept, a 0.5W Doherty-type amplifier has been designed and fabricated for Korean PCS frequency band (center frequency=1.765GHz).

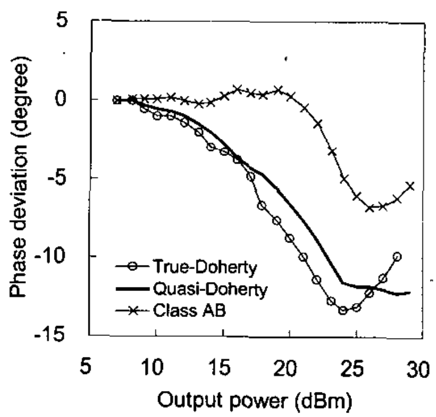

Fig. 2. Measured Phase deviation

In order to evaluate the linearity of the Doherty-type amplifiers, AM-AM and AM-PM characteristics have been measured and compared with those of conventional Class-AB amplifier. Fig. 2 shows the measured power-dependent AM-PM characteristics. As the power range enters saturation region (output power > 20 dBm), rapid change of phase with power is observed in true Doherty mode, which is believed to be the major cause of linearity degradation. This problem has to be cured for the amplifier to meet the stringent ACPR requirement of the CDMA system. Distortion in the AM-PM characteristics could be reduced by increasing the bias to the peak amplifier. It was originally biased at class-C (Ic=10 mA) for true Doherty-type of operation. When the bias current was increased to 30 mA, no pronounced valley pattern could be observed in the AM-PM characteristics (see solid curve in Fig. 2). The enhanced linearity is expected at the cost of the efficiency in this "quasi-Doherty" type of operation.

It is also worthwhile to note that AM-PM characteristic of the "quasi-Doherty" amplifier is no better than the "true-Doherty" mode in low power region. This is an important observation since it tells us that bias increase is not needed in the low power region. Therefore, the linearity and efficiency of the amplifier can be optimized simultaneously if the bias switching is applied near 20 dBm. Low bias current below 20 dBm allows the amplifier to operate in "true-Doherty" mode, resulting in optimum efficiency. On the other hand, increased bias current above 20 dBm guarantees the linearity at high power region.

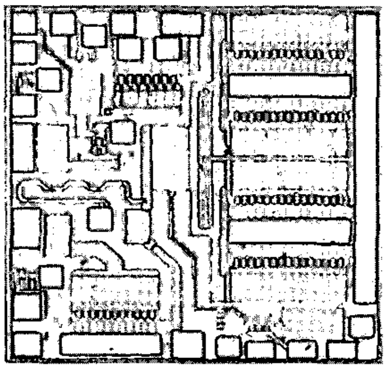

Fig. 3. Photography of MMIC

III. FABRICATION AND MEASUREMENTS

To demonstrate the proposed concept, a power amplifier module consisting of the aforementioned 0.5-W Doherty MMIC amplifier and the external output matching circuits has been fabricated. The MMIC chip was fabricated using a commercial 2 μm InGaP HBT foundry process. Both the carrier and peak amplifier were composed of 2-stage amplifier. A photograph of the fabricated MMIC is shown in Fig. 3. The chip size is 1.2

mm × 1.3 mm. External components including a quadrature 3-dB hybrid coupler terminated with 50 Ω resistor, and λ/4 transformers were realized on printed

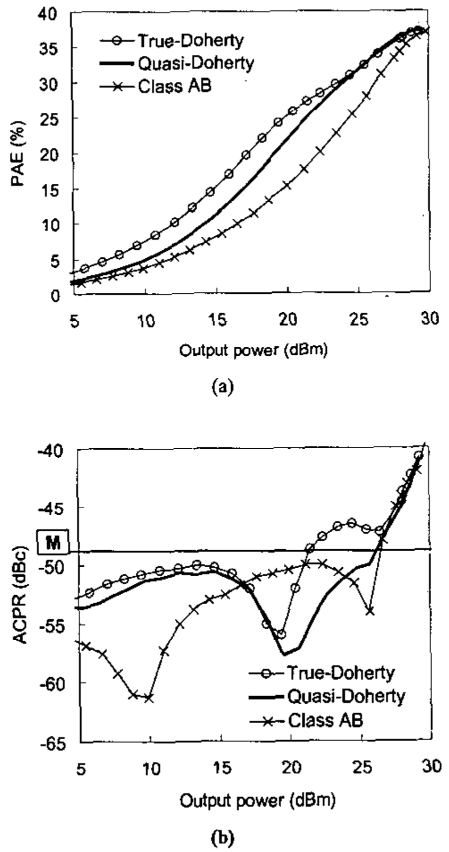

Fig. 4. Measured (a)PAE, and (b)ACPR

circuit board. As a reference, conventional class-AB amplifier has also been designed and fabricated using the same transistors.

Power measurements were performed at room temperature at a collector supply voltage of 3.4 V. First, the performance of "true-Doherty", "quasi-Doherty" and conventional class-AB amplifier has been compared without bias switching. For "quasi-Doherty" mode of operation, a fixed bias current of 30 mA was applied to peak amplifier while a lower bias current is applied to "true-Doherty" amplifier. Fig. 4 compares power-

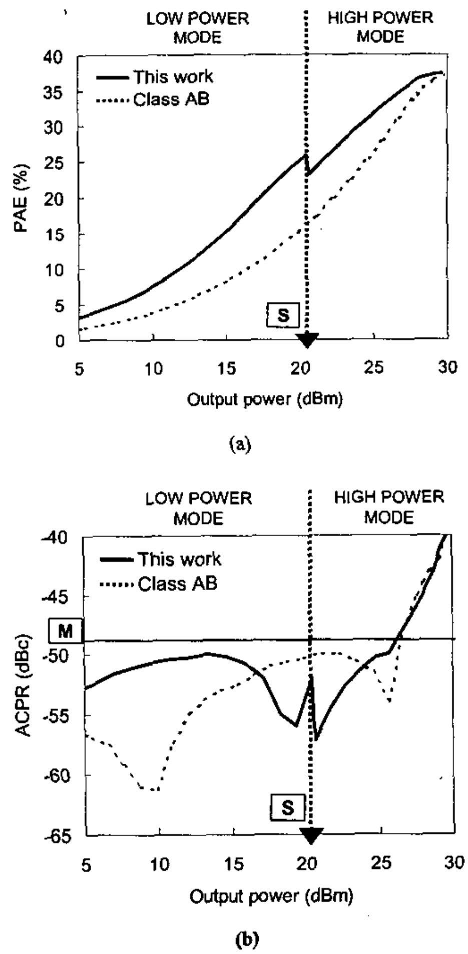

Fig. 5. Measured (a)PAE, and (b)ACPR of the proposed amplifier

dependent PAE's and ACPR's of the amplifiers. The measurements were performed using an IS-95 reverse channel CDMA modulated signals.

As expected from the AM-PM characteristic in Fig. 2, the linearity of Doherty type amplifier is inferior to that of class AB amplifier. When the ACPR criteria of –49 dBc (specified as M in Fig. 4) is used, "true-Doherty" amplifier cannot be operated above 20.5 dBm. On the other hand, "quasi-Doherty" amplifier meets the linearity specifications all the way up to 26 dBm.

In terms of efficiency, "true-Doherty" amplifier shows considerable advantage over conventional class-AB amplifier at backed-off power levels. However, the difference in the efficiency between "true" and "quasi" Doherty amplifier above 20 dBm is insignificant due to self-biasing effects at high power levels.

Fig. 4 (b) also shows little ACPR difference below 20 dBm between the "true" and "quasi" Doherty amplifiers as expected from the AM-PM characteristics. This confirms that bias switching can be effectively applied around 20 dBm to optimize the efficiency below 20 dBm and the linearity above.

Using the control signal that is already available from the baseband controller of the CDMA handsets, the amplifier can be operated, depending on the TX power requirement, in two different modes – low-power mode and high-power mode. Fig. 5 shows the PAE and ACPR when the bias switching is applied at 20 dBm (specified as S in Fig. 5). Thus, the amplifier operates in "true-Doherty" mode below 20 dBm, and "quasi-Doherty" mode above 20 dBm. Fig. 5 (b) clearly shows that the bias-switching Doherty amplifier meets the ACPR specifications over the entire power range up to 26 dBm. In addition, compared with class-AB case, significant efficiency enhancement can be achieved over the whole power range. In the low-power mode, PAE of 17 % and ACPR of –51.8 dBc were achieved at an output power of 16 dBm. In the high-power mode, PAE of 32 % and ACPR of –50 dBc were achieved at the output power of 25 dBm. The performances of conventional Doherty-type amplifier, the proposed bias switching Doherty-type amplifier, and class-AB amplifier are summarized in Table. I.

Table I

Three kinds of amplifier performance summary

MODE / TYPE	LOW POWER MODE	HIGH POWER MODE	
		PAE @Pout = 25dBm	ACPR @Pout = 25dBm
Conventional Doherty Amplifier	Iq = 20 mA (Iq.c = Iq.p = 10 mA) PAE = 17 % @Pout = 16dBm ACPR = -51.8 dBc @Pout = 16dBm	32 %	-46.5 dBc
Proposed Doherty type Amplifier using peak bias modulation (This work)		32 %	-50 dBc
Conventional Class AB Amplifier	Iq = 70 mA PAE = 9 % @Pout = 16dBm ACPR = -52 dBc @Pout = 16dBm	27 %	-52.5 dBc

IV. Conclusions

A new bias-switching quasi-Doherty amplifier has been developed for CDMA handset applications. By employing bias switching scheme available from the current handsets, the proposed Doherty amplifier could be operated in two different modes – "true-Doherty" mode in the low power region and "quasi-Doherty" in the high power region. In this way, the efficiency could be optimized in the low power, while the high-power linearity could be improved to meet the stringent ACPR requirement of the CDMA handset systems. When applied to the CDMA handsets, significant extension of battery lifetime is expected.

Acknowledgement

The authors would like to thank B. K. Choi for technical assistance during testing and measurement.

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