A Microwave Doherty Amplifier Employing Envelope Tracking Technique for High Efficiency and Linearity

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***Abstract*—In this letter, we have demonstrated a microwave Doherty amplifier employing input signal envelope tracking technique. In the amplifier, gate bias of peaking amplifier is controlled according to the magnitude of the envelope. A 2.14-GHz Doherty amplifier has been implemented using 4-W PEP LDMOSFETs and an adaptive controlled gate bias circuit has been constructed and the control shape is optimized experimentally. The performance of the microwave Doherty amplifier has been compared with those of class AB amplifier using one-tone, two-tone, and forward-link wideband code-division multiple access (WCDMA) signals. For a forward-link WCDMA signal, the measured power added efficiency (PAE) of the microwave Doherty amplifier is 39.4% at −30 dBc adjacent channel leakage ratio (ACLR), while that of the comparable class AB amplifier is 24.2% at the same ACLR level.**

***Index Terms*—Adjacent channel leakage ratio (ACLR), envelope tracking, microwave Doherty amplifier, power added efficiency (PAE), wideband code-division multiple access (WCDMA).**

I. Introduction

FOR THE POWER amplifiers of code-division multiple access (CDMA) base stations, linearity is the most important figure of merit. To meet the stringent requirements for linearity, the power amplifiers usually operate at class A or AB mode and is backed-off of output power to accommodate a high peak-to-average power ratio. However, there is tradeoff between linearity and efficiency, and the amplifiers with a high linearity have low efficiency. As the power level of amplifier increases and the size becomes more compact, the lower efficiency causes severe thermal problems. Hence, the efficiency of the high power amplifier has become an important issue. The Doherty amplifier is a promising solution for high efficiency with good linearity. Also, it has a very simple circuit structure and is easy to implement [1]–[5].

The previously reported microwave Doherty amplifiers without envelop tracking circuits deliver more output power compared with their counterparts of class AB amplifiers at the same linearity [4], [5]. However, the drain current of the peaking amplifier is slightly lower than that of the carrier amplifier at a high power level because of the fixed lower bias of the peaking amplifier. Thus, the load impedance of this microwave Doherty amplifier cannot be fully modulated to the value for a high power match. As a result, the carrier and peaking amplifiers cannot generate their respective full powers. The reduced output powers directly affects the improvement of efficiency as well as cost.

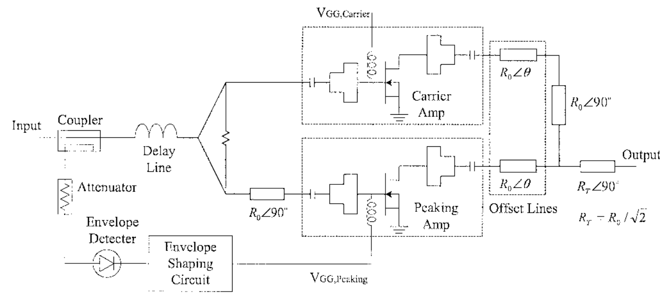

Fig. 1. Structure of a microwave Doherty amplifier employing envelope tracking technique.

To solve the problem, we propose a new microwave Doherty amplifier employing an envelope tracking technique. In the proposed Doherty amplifier, gate voltage of the peaking amplifier is controlled according to the input signal envelope to maximize efficiency with the desired linearity. For verification, a microwave Doherty amplifier is implemented and tested using one-tone, two-tones, and forward-link wideband code-division multiple access (WCDMA) signals. The Doherty amplifier is compared with the class AB amplifier, and the tested results show superior performances with the Doherty amplifier.

II. Implementation of the Proposed Doherty Amplifier

In the previous section, we proposed a new microwave Doherty amplifier. Fig. 1 shows a block diagram of the proposed Doherty amplifier. The Doherty amplifier consists of two-part circuits; a fully matched microwave Doherty amplifier and an adaptive gate bias control circuits for the peaking amplifier using an envelope tracking technique. Because of the adaptive gate bias control circuits, the Doherty amplifier can be fully modulated. Furthermore, linearity as well as efficiency can be improved by optimizing the shape of gate voltage of the peaking amplifier. The mechanism for the improvement of linearity has been explained in our earlier works [4], [5].

We have designed the microwave Doherty amplifier with a target of maximizing the power added efficiency (PAE) at

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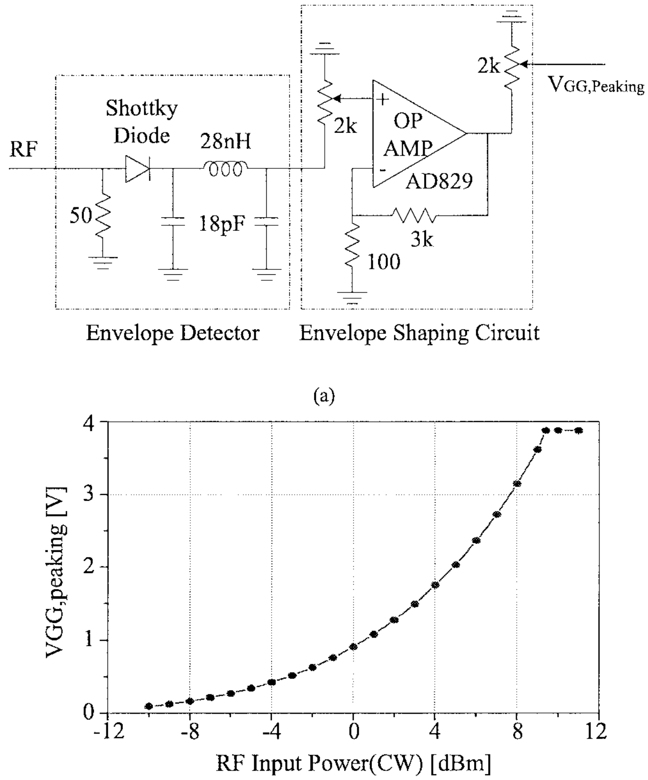


(b)

Fig. 2. (a) Optimized envelope detector and shaping circuits. (b) Gate control voltage for the peaking amplifier generated by circuit (a).

-30 dBc adjacent channel leakage ratio (ACLR). Our target of the -30 dBc has been generally used for the base station power amplifiers using a feed-forward linearization technique.

The carrier and peaking amplifiers have been implemented using Motorola's MRF281SR1 (4-W PEP) LDMOSFETs and RF35 ($h = 0.5$ mm, $\epsilon_r = 3.5$) circuit board, power-matched to $R_0 = 50\ \Omega$ at 2.14 GHz. The matched source and load impedances for the amplifiers are $Z_S = 3.1 - j3.5\ \Omega$ and $Z_L = 11.36 + j7.94\ \Omega$, respectively. And the process of determining proper lengths of offset lines has been presented in our earlier works. In this experiment, the 0.535λ lengths of offset lines have been used for both the carrier and peaking amplifiers. The output impedance transformed by the line becomes 344 Ω, which is high enough to block the output power leakage to the peaking amplifier at a low power operation.

To determine the optimum shape of gate control voltage according to the input signal envelope, we have constructed the envelope detector and shaping circuits shown in Fig. 2(a), and then experimentally optimized the values of the components to achieve the maximum PAE with -30 dBc ACLR at 2.5 MHz offset for a forward-link WCDMA signal. We have a 10 dB directional coupler, a 10 dB attenuator, a Shottky diode power detector, and a low pass filter to obtain the appropriate envelope signal level. For the envelope shaping circuit, we employed two variable resistors and a AD829 OP AMP with 600 MHz gain bandwidth product. The optimized values of components are shown in Fig. 2(a). Fig. 2(b) shows the shape of gate control voltage for the peaking amplifier. Finally, a coaxial delay line with about 24 ns time delay has been used for the delay match, but it can be replaced by a delay filter with low loss and low cost.

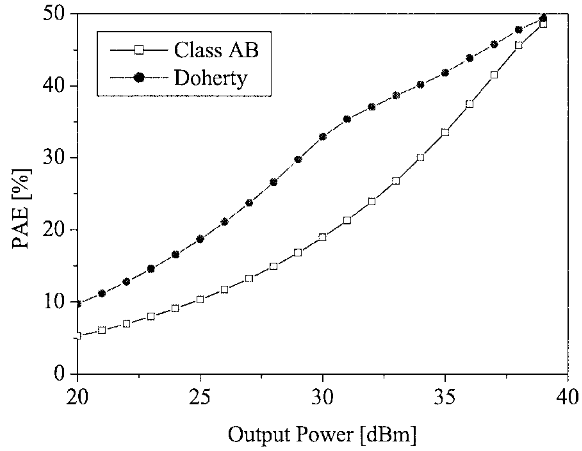


Fig. 3. PAEs of the Doherty and class AB amplifiers, when a 2.14 GHz CW signal is applied.

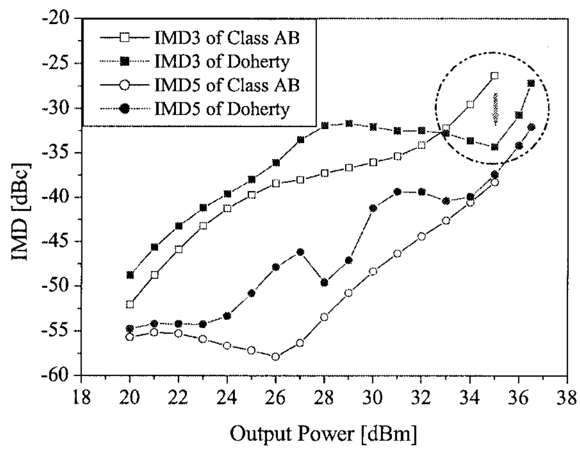


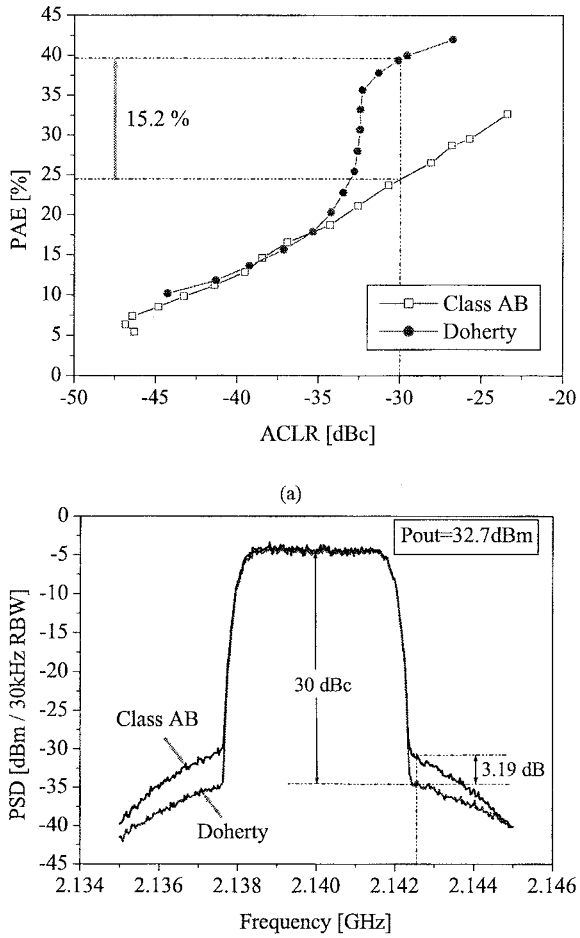
Fig. 4. Two-tone characteristics of the Doherty and class AB amplifiers.

III. Experimental Results

The performance of the proposed Doherty amplifier has been compared with that of a comparable class AB amplifier using one-tone, two-tone, and forward-link WCDMA signals. The class AB amplifier can be achieved with just AB biasing both the carrier and peaking amplifiers. In these experiments, quiescent drain currents of the carrier and peaking amplifiers have been set to 20 mA at $V_{DD} = 26$ V for the class AB amplifier. In the case of the Doherty amplifier, on the other hand, the bias point of the carrier amplifier has been kept at the value but that of the peaking amplifier has been controlled by the shape determined in Section II.

Fig. 3 shows the PAEs versus the output power of the Doherty and class AB amplifiers, when a 2.14 GHz CW signal is applied. The PAE of the Doherty amplifier has been improved significantly throughout the wide power range compared to the class AB amplifier.

To compare the linearity of the two amplifiers, we have performed a two-tone (with 2.14 GHz center frequency and 1 MHz tone spacing) test and the results are represented in Fig. 4. IMD3 and IMD5 of the amplifiers versus average output power have



(a)

(b)

Fig. 5. (a) PAEs versus ACLR and (b) power spectral densities at 32.7 dBm output power for a forward-link WCDMA signal.

been compared. The Doherty amplifier has clearly better linearity at high output power level due to IMD3 cancellation. At a low power level, however, both IMD3 and IMD5 have been higher. This degradation of IMD3 and IMD5 at a low power level is not a problem because our target has been focused on ACLR level of -30 dBcs for all output power level and the amplifier is optimized for it.

Finally, the test results for a forward-link WCDMA signal have been represented in Fig. 5. Fig. 5(a) shows the measured PAEs versus ACLRs of the Doherty and class AB amplifiers. At an -30 dBc ACLR, the PAE has been improved to 39.4%, which represents a 15.2% improvement. Fig. 5(b) shows the power spectral densities at 32.7 dBm. Due to the improved ACLR characteristics (3.19 dB) of the Doherty amplifier, the output power is increased by 1.5 dB compared to the class AB amplifier at the -30 dBc ACLR.

IV. Conclusions

For base station power amplifiers, a new microwave Doherty amplifier has been proposed. In the proposed Doherty amplifier, the gate voltage of the peaking amplifier is controlled according to the input signal envelope. The most important advantage of the Doherty amplifier relative to the earlier version of the microwave Doherty amplifier is that the peaking amplifier generates full power at a high input power level and a full load modulation can be achieved. Thus, a reduction of output power at a high power level can be prevented. For the experimental verification, a 2.14 GHz Doherty amplifier employing envelope tracking technique has been implemented using Motorola's MRF281SR1 (4-W PEP) LDMOSFETs and tested using one-tone, two-tone, and forward-link WCDMA signals. For a forward-link WCDMA signal, the implemented Doherty amplifier has PAE of 39.4% and ACLR of -30 dBc (at 2.5 MHz offset) at 32.7 dBm average output power, which is an improvement of 15.2% in efficiency and 1.5 dB of output power relative to those of the class AB amplifier at the same ACLR level. From the experimental results, the microwave Doherty amplifier proposed in this paper is expected to be useful to the base station power amplifier that requires high efficiency as well as good linearity.

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