Experimental Investigation on Efficiency and Linearity of Microwave Doherty Amplifier

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Abstract — **We have investigated the microwave Doherty amplifier, testing for efficiency and linearity. For the experiment, a 1.4GHz Doherty amplifier has been implemented using a silicon LDMOSFET. The Doherty amplifier-I(a combination of a class B carrier amplifier and a class C peaking amplifier) and the Doherty amplifier-II(a combination of a class AB carrier amplifier and a class C peaking amplifier) have been compared with class B and AB amplifiers, respectively, using single-tone, two-tone, and forward-link CDMA signals. It demonstrated the superior performance of Doherty amplifiers. The results provide a topology selection guide of the CDMA base station power amplifier to achieve both linearity and efficiency enhancements.**

I. Introduction

The microwave Doherty amplifier was first proposed to improve efficiency using the technique of load-line modulation of a carrier amplifier through a peaking amplifier attached to a quarter-wave line [1],[2]. Because of the quarter-wave line and input splitter circuits, MMIC implementation of the Doherty amplifier has been reported only at a very high frequency(over a few tens of GHz) [3]-[5]. MIC implementation of the microwave Doherty amplifier is suitable at a lower frequency, such as the base station amplifier at a few GHz. It can deliver higher efficiency without losing linearity or even with improved linearity. As the power level of the amplifier increases and the size becomes compact, the high efficiency becomes an important figure of merit for the amplifiers of the CDMA base stations due to thermal heating problems.

In this paper, we designed a 1.4GHz microwave Doherty amplifier, and compared the efficiency and linearity for the two modes of operation: the Doherty amplifier-I(combination of class B carrier amplifier and class C peaking amplifier) and -II(combination of class AB carrier amplifier and class C peaking amplifier). They are compared with conventional class B and class AB for various signals(one-tone, two-tone, and forward-link CDMA signals). The efficiency and linearity improvements are simultaneously achieved in the Doherty amplifiers for the CDMA signal with high peak to average ratio(11dB). The circuit description and experimental results are presented in this paper.

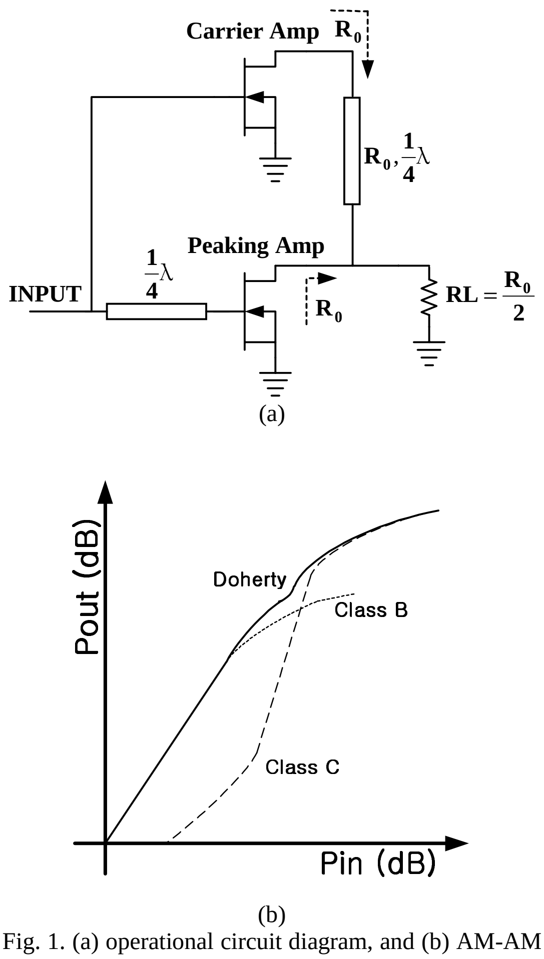

Fig. 1. (a) operational circuit diagram, and (b) AM-AM characteristics of the conventional Doherty amplifier

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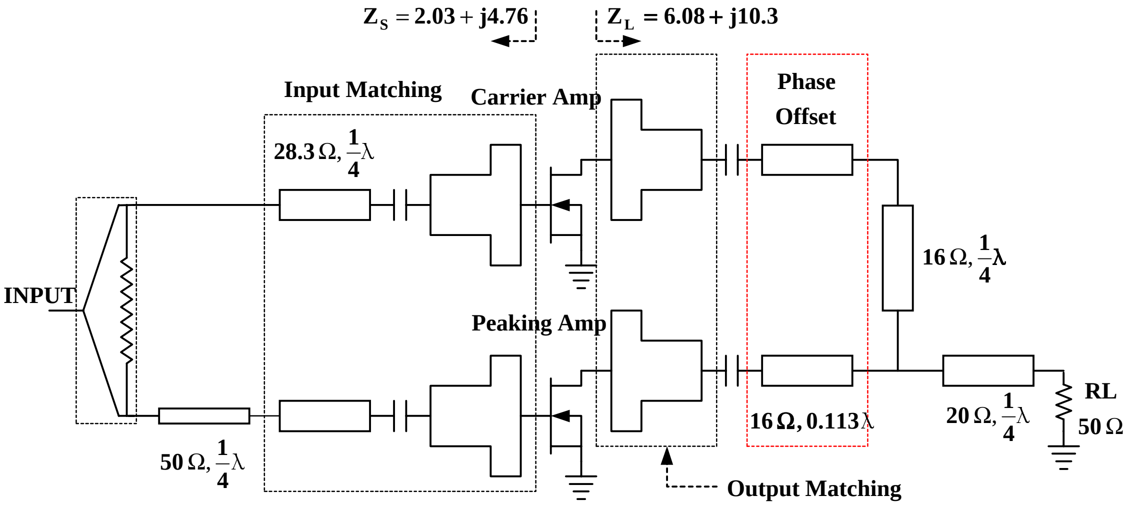


Fig. 2. Circuit diagram of 1.4GHz Doherty amplifier using silicon LDMOSFET

II. Circuit Description

Basic operation of the Doherty amplifier has been well described in previous papers [1]-[5]. Fig. 1 shows the schematic diagram(Fig. 1(a)) and output versus input power(AM-AM) characteristics(Fig. 1(b)) of the conventional Doherty amplifier. The Doherty amplifier has three operation modes: low, medium, and high input power drive modes. For the low input power drive mode, the characteristic load impedance of the carrier amplifier is doubled to **2Ro** by a quarter-wave impedance transformer, because the peaking amplifier is open-circuited. Efficiency is increased due to the high load resistance in very low input drive level. For the high input power drive mode, the load impedance of the carrier amplifier becomes **Ro**, because of turn-on of the peaking amplifier. For the medium input power drive mode, the load impedance of the carrier amplifier varies from **2Ro** to **Ro** according to the input drive level.

Generally, the carrier amplifier and peaking amplifier have different operation modes. AM-AM characteristics of the Doherty amplifier using parallel combination of class B and class C amplifiers is shown in Fig. 1(b). The AM-AM characteristics can be linearized by compensating the saturation response of the class B carrier amplifier by turning on the class C peaking amplifier. Hence, the linearization is possible at a high power drive level for the Doherty amplifier. However, a procedure to improve linearity must not generate the higher order IM terms(IM5, IM7,…) from the signal clipping at the output of the peaking amplifier.

Fig. 2 shows the circuit diagram of the implemented Doherty amplifier in this experiment. The same devices(Ericsson's PTF10107, 5W PEP silicon LDMOSFET) are used for both carrier and peaking amplifiers. The input and output of the amplifier are matched to 16Ω using micro-strip open stubs to have source impedance(ZS) of 2.03+j4.76 and load impedance(ZL) of 6.08+j10.03. The 16Ω quarter-wave line is used for Doherty operation and 20Ω quarter-wave transformer is used for transforming 8Ω to 50Ω. Input signal is split by Wilkinson divider and 50Ω quarter-wave line is inserted at the input stage of peaking amplifier to match phase delay between the two paths.

Additional 16Ω lines(0.113λ, 40.68°) are inserted at the output stages of both amplifiers as a tuning component to achieve optimized performance. For active load modulation, the additional phase offset tuning is necessary because the imaginary part of the output impedances are different for the different load impedances. Hence, the microstrip matching circuit is optimized at the high power level and the additional element contributes to the matching at low power level. Without the added element, the amplifier may not show a proper Doherty operation.

III. Experimental Results

Performance comparisons between the Doherty-I and class B amplifier and between the Doherty-II and class AB amplifiers are performed. Fig. 3 shows PAE (power-added efficiency) of

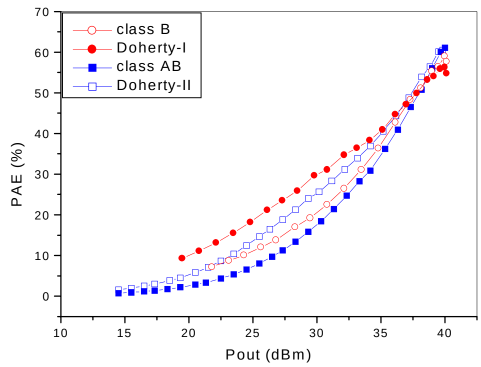
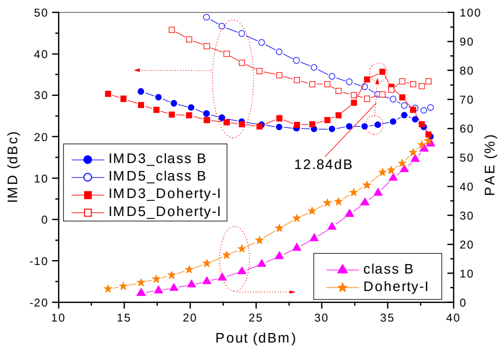
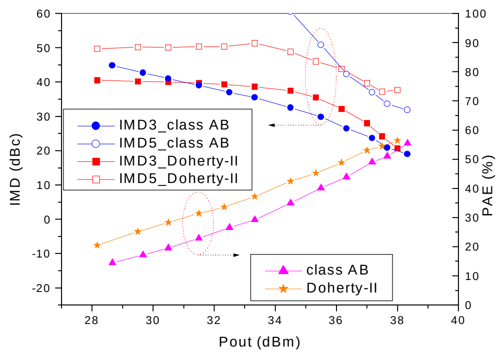


Fig. 3. Power added efficiency of the Doherty-I, Doherty-II, class B, and class AB amplifiers versus output power at 1.4GHz with one-tone(CW) input



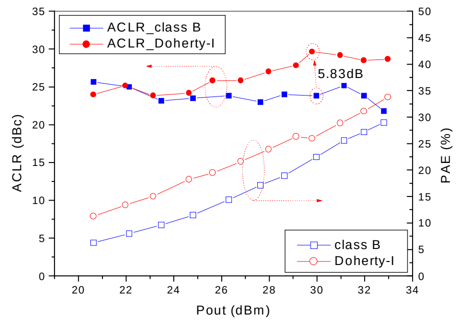
(a)



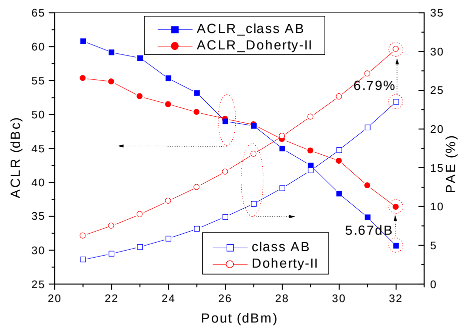
(b)

Fig. 4. (a) IMD3, IMD5, and PAE of the Doherty-I and class B amplifiers, and (b) of the Doherty-II and class AB amplifiers versus average output power: two-tone test results(1.4GHz and 1.401GHz, 1MHz spacing)

the Doherty-I, Doherty-II, class B, and class AB amplifiers versus output power, when 1.4GHz CW signal is applied. PAEs of the Doherty amplifiers-I and –II are improved throughout the wide output power range compared to the class B



(a)



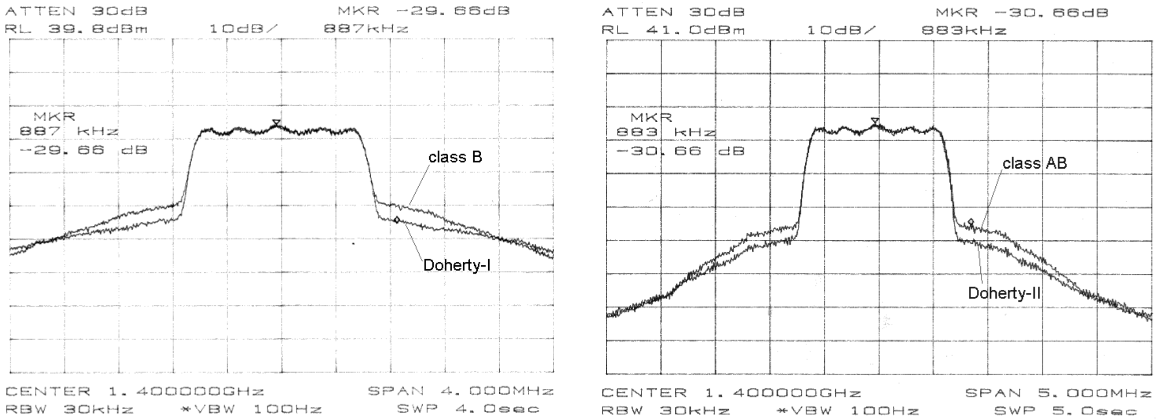
(b)

Fig. 5. (a) ACLR at 885KHz offset and PAE of the Doherty-I and class B amplifiers, and (b) of the Doherty-II and class AB amplifiers versus average output power: CDMA signal(forward-link, chip rate of 1.2288Mcps, and peak-to-average ratio of 11dB)

and class AB amplifiers, respectively.

The two-tone(1.4GHz and 1.401GHz, 1MHz spacing) characteristics are compared in Fig. 4. IMD3, IMD5, and PAE of the Doherty-I and class B amplifiers(Fig. 4(a)) and of the Doherty-II and class AB amplifiers(Fig. 4(b)) versus average output power are compared. The Doherty amplifier-I has clearly better efficiency and an improved IMD3, with as much as a 12.84dB improvement at an output power of 33dBm. IMD5 is worse at a low power level but it becomes better at a high power level(more than 33dBm), in comparison with the class B amplifier(see Fig. 4(a)). The Doherty amplifier-II also shows better efficiency but has worse IMD3 and IMD5 at a low power level, which improves at a high power level in comparison with the class AB amplifier(see Fig. 4(b)).

CDMA test results are shown in Fig. 5. ACLR's at 885KHz offset and PAE's of the Doherty-I and class B amplifiers(Fig. 5(a)), and of the Doherty-II and class AB amplifiers(Fig. 5(b)) versus average output power are compared using CDMA signal (forward - link, chip rate of



(a) (b)

Fig. 6. (a) output CDMA spectra of the Doherty-I and class B amplifiers: average output power of 30dBm, and (b) of the Doherty-II and class AB amplifiers: average output power of 32dBm

1.2288Mcps, and peak-to-average ratio of 11dB). The Doherty amplifier-I shows a significantly improved efficiency and the ACLR is improved by 5.83dB at output power 30dBm(see Fig. 5(a)). The Doherty amplifier-II also has an improved efficiency by 6.79% with an improved ACLR by 5.67dB at output power 32dBm(see Fig. 5(b)).

Output CDMA spectra of the Doherty-I and class B amplifier at output power 30dBm are shown in Fig. 6(a), and Doherty-II and class AB amplifier at output power 32dBm are shown in Fig. 6(b). They clearly show improved linearity. This improved linearity and efficiency at a high power level can be expected since the AM-AM modulation is compensated for the high power level by the peaking amplifier.

IV. Conclusions

We presented a comparative investigation of the microwave Doherty amplifier with various input signals. A 1.4GHz microwave Doherty amplifier using a high power silicon LDMOSFET has been implemented for the experiments. Both Doherty amplifiers delivered improved efficiency and linearity simultaneously for the CDMA signal in comparison with conventional class B or AB amplifiers. These results will provide a good topology selection guide of the CDMA(including W-CDMA and CDMA-2000) base station power amplifier design to achieve both linearity and efficiency enhancements or help to design a high efficiency power amplifier with improved linearity.

Acknowledgement

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