Doherty Amplifier with DSP Control to Improve Performance in CDMA Operation

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***Abstract* — A power amplifier for CDMA applications which consists of a Doherty amplifier and a digital signal processing (DSP) controller is presented. DSP is used to dynamically adjust the gate bias of the auxiliary (peaking) amplifier at the rate of the signal envelope to obtain gain flatness (i.e. AM-AM distortion correction). Furthermore, DSP is used as a digital predistortor to improve the overall linearity by adjusting the phase at baseband (i.e. AM-PM distortion correction). The 840MHz Doherty amplifier is realized with two commercially available MESFETs in a hybrid circuit, and the DSP is implemented externally with a board controlled by a personal computer. It is shown that by utilizing these DSP techniques, the overall linearity and efficiency characteristics of the Doherty amplifier can be significantly improved.**

I. Introduction

The Doherty amplifier has gained renewed interest recently since it is able to achieve high efficiency over a wide range of output power [1-3]. This feature is highly advantageous in mobile phone applications, since the output power requirements vary over a range of greater than 20dB. However, a common problem with the Doherty amplifier is nonconstant gain and phase behavior as a function of power, which is detrimental to ACPR.

An invaluable technique to improve the performance of the power amplifiers is to incorporate digital signal processing (DSP). DSP has been widely applied to base station amplifiers to significantly improve linearity [4]. In most instances, DSP is used as means of providing digital predistortion at the baseband. Alternatively, DSP can be used to monitor and control other aspects of the amplifier such as the amplifier power supply voltage [5]. In this paper, we show that the use of DSP for gate bias control combined with digital predistortion is highly beneficial in correcting the gain and phase characteristics of the Doherty amplifier and thereby improving linearity.

II. Amplifier Circuit Design

The Doherty amplifier (Fig. 1) consists of main and auxiliary amplifiers with an impedance inverter (usually

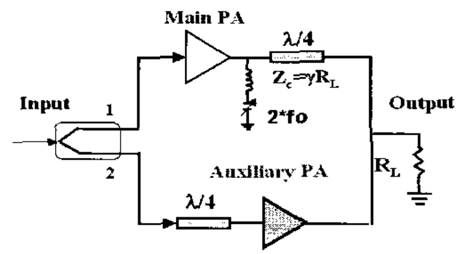

Fig. 1: Doherty amplifier topology

implemented as a quarter-wave transformer) connecting the outputs. At low power, the main amplifier is the only device operating, and the auxiliary amplifier, biased Class C, turns on when the main amplifier becomes saturated. The role of the auxiliary amplifier is to supply an appropriate amount of current to decrease the effective load seen at the output of the main amplifier. By doing so, the main amplifier is able to deliver current to the load while remaining in saturation. A significant consequence of this is that the efficiency of the total amplifier system remains high while the main amplifier operates in saturation. This desirable characteristic is evident in the efficiency measurements of a GaAs MESFET-based Doherty amplifier in Fig. 2. The device used for the main amplifier is an MwT-971 and for the auxiliary amplifier is

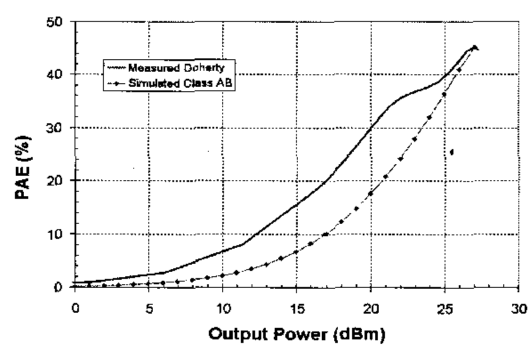

Fig 2.Measured single-tone PAE of a MESFET-based Doherty amplifier and simulated PAE class AB amplifier with similar output power and quiescent bias.

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an Infineon CLY-5. For comparison with the experimental results, Figure 2 also shows simulated PAE of a class AB amplifier constructed with an MwT-971 FET with similar output power and quiescent bias. High PAE (>35%) is obtained over an approximately 6dB wide region for the Doherty amplifier, and a significant efficiency improvement is obtained over a wide power range. A harmonic trap at the output of the main amplifier is implemented to enhance performance of the Doherty amplifier, by means of series LC circuit to ground tuned to short the second harmonic of both main and auxiliary amplifiers.

The load-pulling effect caused by the auxiliary amplifier is typically non-ideal. It is difficult to accurately match the gain saturation characteristics of the main amplifier with the turn-on characteristics of the auxiliary amplifier as the power level is increased. As a consequence, both gain and phase deviate significantly in the high power region when the auxiliary amplifier is turned on, as seen in the measured gain and phase characteristics of Fig. 3. Correspondingly the ACPR behavior of the amplifier with CDMA signals is unsatisfactory.

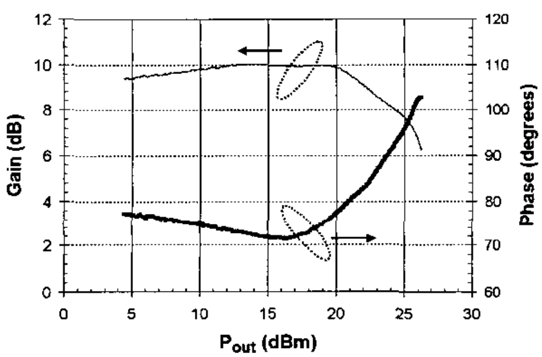

Fig 3. Measured gain and phase vs. output power with single-tone input

III. DSP CONTROL STRATEGY

DSP can be used to obtain significant improvement in amplifier performance. With the Doherty amplifier, DSP can be used to dynamically change a variety of parameters according to the signal input. DSP control over the Doherty amplifier with the system shown in Fig. 4 was studied. Baseband signal is generated in the form of I & Q, and then up-converted to RF. After being amplified by a pre-amplifier, the signal is split by a 1:2 ratio Wilkinson power divider into the main and auxiliary amplifier paths. DSP generates another voltage signal V_{gg2}, which is applied to the gate bias of the auxiliary amplifier.

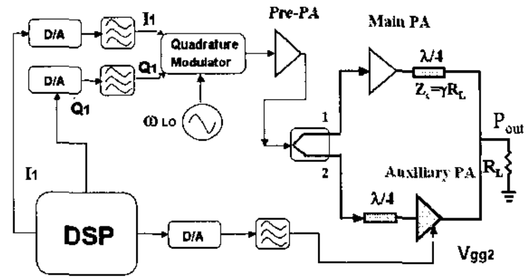

Fig 4: System implementation of the DSP with the Doherty amplifier.

This system is used for both gate bias control of the auxiliary amplifier and baseband phase predistortion. These two DSP applications will solve the problem of compressed gain and nonconstant phase of the Doherty amplifier, respectively. By doing so, relatively flat gain and phase can be achieved, resulting in improved linearity.

A. Gain Correction with Dynamic Gate Bias

The gate bias of the auxiliary amplifier (V_{gg2}) plays an important role in the performance of the Doherty amplifier. The efficiency characteristics can be tailored by adjusting the value of the gate bias, where lower gate bias (i.e. lower drain current) results in higher efficiencies in the high power region. This effect is illustrated in simulation results of drain efficiency shown of Fig. 5. From an efficiency point of view, a lower gate voltage is desired. However, the consequence of not supplying enough current from the auxiliary amplifier (i.e. lowering the gate voltage) is a decrease in the overall gain. DSP control can alleviate this problem by dynamically changing the bias voltage of the auxiliary amplifier according to the instantaneous envelope of the input signal in order to make gain flat. This will improve the linearity as well as provide

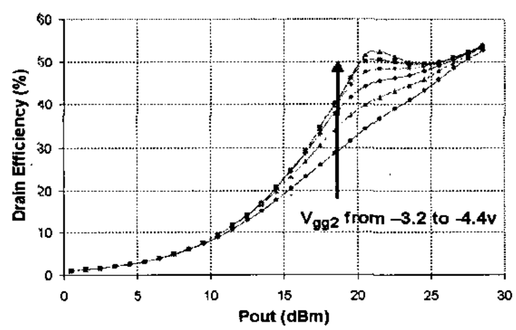

Fig 5: Simulated change of the drain efficiency of the Doherty amplifier.

the optimum dynamic bias for efficiency in the high power region.

The dynamic gate bias control strategy requires detailed thorough characterization of the gain vs. power characteristics over a wide range of gate voltages. This is accomplished by performing a single tone power sweep with an Agilent 8753ES vector network analyzer. By recording the bias voltages and building an interpolated table in Matlab, the optimum V_{gg2} values which maintain constant gain and maximize efficiency can be calculated for each instantaneous signal power. V_{gg2} is outputted to the gate bias network of the auxiliary amplifier at the same delay as the RF input signal of the auxiliary amplifier. This synchronization is assured by adjusting the length of the signal path. Additionally, the design of the gate bias network is critical since it has to accommodate a dynamic bias signal at the rate of the CDMA envelope frequency. Fig 6 shows a representative time domain measurement of the dynamic gate bias voltage and the CDMA envelope waveform, demonstrating the synchronization between the two signals.

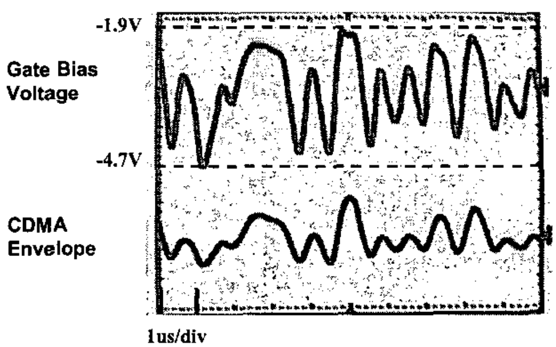

Fig 6: Measured control bias voltage and CDMA envelope

B. Phase Correction with Baseband Predistortion

AM-PM distortion was also found to play an important role in influencing the ACPR, particularly in the region when the auxiliary amplifier is turned on. This is evident in the phase vs. power curve in Fig. 3 where the phase varies as much as 30°. Digital predistortion of the phase at baseband can be applied to the input signal to further improve the linearity of the Doherty amplifier.

Phase data from the same measurements made for the gain characterization was analyzed for the phase predistortion strategy. Fig. 7 shows AM-PM distortion curves measured at various values of V_{gg2}. From the table of gate bias voltages calculated for gain compensation, a list of phase values interpolated from the data in Fig. 7 that correspond to the respective gate biases is created as a function of output power. Such a plot is shown in Fig. 8.

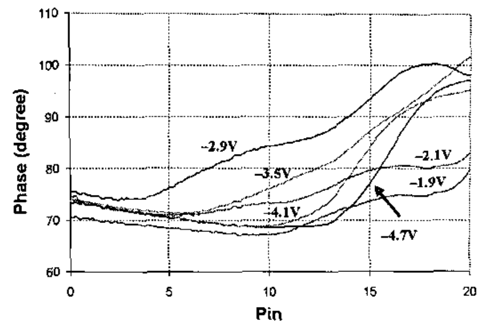

Fig 7: Output Phase vs. input power with different bias V_{gg2} of the auxiliary amplifier

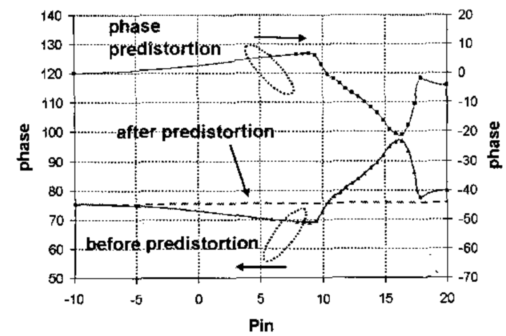

Fig 8: AM-PM distortion of DSP controlled Doherty amplifier and the predistorted phase

Then, the "mirror image" of this data is calculated for the phase predistortion data, normalized, and programmed into the DSP controller. This phase predistortion data is also shown in Fig. 8.

It should be noted that the conventional approach of gain predistortion at baseband gives very little benefit in improving the ACPR in the system described in Fig. 4, since it is ultimately the gate bias of the auxiliary amplifier that limits the overall gain of the Doherty amplifier. Even if the power at the input is increased (assuming gain compression compensation), this will further force the main amplifier into saturation and gain will be reduced. In order to effectively apply gain predistortion to the Doherty amplifier, separate input paths for the main and auxiliary amplifiers have to be supplied so that the input drive levels can be independently adjusted. Therefore, for the DSP linearization strategy described in this paper, gain distortion is corrected first by the dynamic gate biasing of the auxiliary amplifier (as described in the previous subsection), and subsequently, the phase is corrected by predistortion of the phase at baseband based on the dynamic gate bias voltage values from gain correction.

IV. EXPERIMENTAL RESULTS

To demonstrate the effectiveness of the DSP control strategy to improve linearity and efficiency, the same Doherty amplifier described previously was used in the system in Fig. 4. Fig 9. shows a comparison of ACPR between the original and the DSP-controlled amplifier. The effectiveness of the DSP is very clear, where ACPR1 specification is met at a higher power level. DSP-control also improves the PAE in the high power region as seen in Fig. 10. This is because the dynamic bias control compensates the gain, allowing higher output power and thereby increasing PAE.

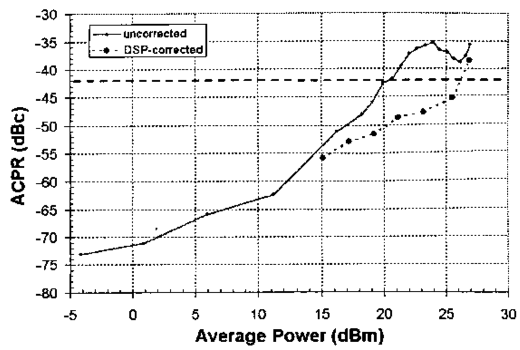

Fig 9: ACPR1 (885kHz offset at the right shoulder) vs. CDMA average output power of uncorrected and DSP-corrected amplifier.

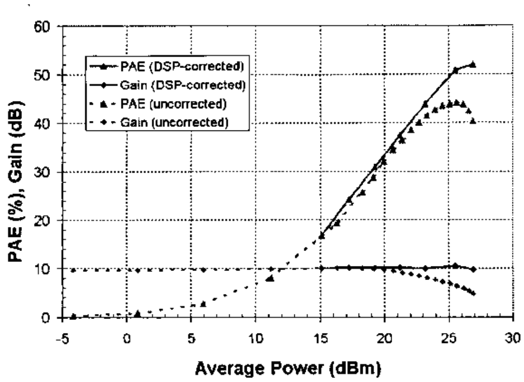

Fig 10: PAE and Gain vs. CDMA average output power of uncorrected and DSP-corrected amplifier.

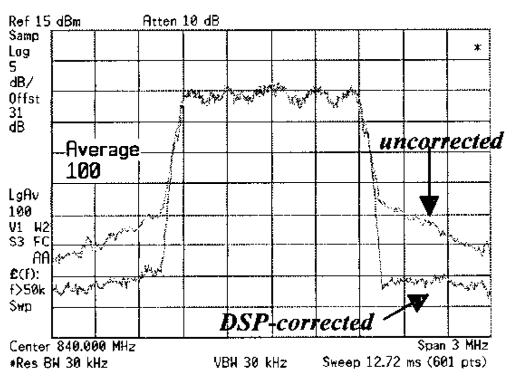

Fig 11: ACPR improvement in CDMA spectrum at 23dBm average power.

Fig. 11 shows a spectrum of a CDMA signal at 23dBm average power with and without DSP-control. There is more than 10dB improvement of ACPR (right shoulder) by utilizing the proposed DSP techniques.

V. CONCLUSION

DSP techniques were applied to the Doherty amplifier in CDMA operation to improve both the linearity and efficiency. AM-AM distortion was corrected by dynamically adjusting the bias of the auxiliary amplifier at the rate of the signal envelope. AM-PM distortion was improved by adjusting the phase of the signal at the baseband frequency. This work demonstrates the importance of synergistically combining DSP with power amplifiers to improve system performance.

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