Digitally Assisted Load Modulated Balanced Amplifier for 200W Cellular Infrastructure Applications


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Abstract—The paper demonstrates, for the first time, a high power (200W) load modulated balanced amplifier (LMBA) targeting 5G cellular infrastructure applications. Both amplitude and phase of the injected signal applied to the control power amplifier (CPA) are configured using a dynamic phase shaping function along with a pre-distortion digital front-end. Digital baseband processing provides flexibility in varying both amplitude and phase of the injected signal to the CPA which improves efficiency and overall linearity of the LMBA. Under real-time modulated signal excitation, excellent linearity is achieved using a segmented digital predistortion (DPD) approach applied to the balanced power amplifier (BPA) branch and a power-dependent phasing function applied to the CPA branch. The LMBA prototype implementation is carried out using NXP’s 100 W gallium nitride (GaN) on silicon carbide (SiC) pre-match device in the balanced branch. Measured results achieve peak output power of 53 dBm (200 W) with 44% linearized efficiency at 8 dB back-off and corrected ACPR of -52 dBc across LTE Band-41 (~2.6 GHz).

Keywords—Balanced amplifier, load modulated, gallium nitride (GaN), high power, power amplifiers, LMBA, segmented DPD.

I. INTRODUCTION

Modern wireless systems rely on advanced communication standards using modulated signals characterized by high spectral efficiency in order to optimize the usage of the scarce spectrum resources. These signals with high peak-to-average power ratio (PAPR) require the power amplifier (PA) to operate at high back-off levels (typically 8 dB or more). Thus, the PA architectures must be simultaneously efficient at output back-off (OBO) and achieve the required peak power level. Architectures such as Doherty, which rely on dynamic load modulation [1] are popular in today’s cellular infrastructure transmitters. More recently, Load Modulated Balanced Amplifiers (LMBAs) have been suggested as a potential candidate for efficiency enhancement over wide OBO ranges [2]-[5]. In a LMA amplifier, a control signal is injected through the isolated port of a balanced power amplifier (BPA) wherein the amplitude and phase variation of the injected signal can actively synthesize load impedances of RF amplifiers at different power levels. The control signal is often injected using an external control PA (CPA). The objective of the CPA is to perform the load modulation from optimum efficiency, at output back-off, to optimum linearity at peak power. To accomplish this, the phase of the CPA is fixed at a constant value and the control signal amplitude is varied to load modulate the BPAs.

Previous works have largely focused on the principle of applying constant phase of the CPA and typically limited to lower power levels (e.g. small cell base station applications [2-4]). Furthermore, LMA inherently shows non-linear gain compression characteristics [4], limiting its application under modulated signal environment where quality of service is an important figure of merit. In [3], the authors discuss design and characterization of a load modulated balanced amplifier and report results with a conventional DPD linearization technique.

Fig. 1. (a) Digitally assisted Load Modulated Balanced Architecture (LMBA) with balance amplifier (BPA), control PA (CPA) and digital front-end comprising of dynamic phasing function and pre-distorter; (b) Combined efficiency and gain as function of output power back-off with dynamic phase variation

This work presents a digitally assisted LMA architecture for macro cell application with peak power higher than 200 W. The LMA consists of dual inputs with full control over amplitude and phase of the control signal in digital domain. The proposed architecture utilizes dynamic phase shaping in the CPA path as a function of input drive level for maximizing efficiency enhancement at OBO. Besides, a segmented digital-predistortion (DPD) approach is utilized for the first time to the best of authors’ knowledge only to the
BPA branch which corrects for the linearity requirements with wideband modulated signals. While previous publications incorporate predistorter for both BPA and CPA [2-4], this work confirms that there is minimal impact when the CPA input is predistorted. Consequently, limiting the predistorter only at BPA input and keeping the CPA path simple, improves overall system efficiency and lowers the digital system cost and power. Overall, the proposed digitally assisted LMBA utilizes: (i) digitally engineered phase shaping function applied to the CPA input for optimum trade-off between AM-AM flatness, peak power, and combined drain efficiency, and (ii) segmented DPD technique for improved linearization of the LMBA which typically exhibits higher compression characteristics.

II. DIGITALLY ASSISTED LMBA

A. Digitally Assisted LMBA Architecture

The architecture of digitally assisted LMBA is shown in Fig.1 (a). The dual input digital front-end consists of a predistorter in the BPA path and a power phasing function in CPA branch to provide higher back off efficiency enhancement. Like previous works [2-4], the amplitude variation of CPA (from off to on) load modulates BPA i.e. from high to low output loading.

In the CPA path, the proposed architecture exploits the dynamic phase shaping extracted from continuous wave (CW) characterization and is applied to the CPA input modulated signal. On the other hand, improved linearizability of LMBA is achieved by applying pre-distorted signal only to BPA input.

Due to higher compression characteristics exhibited by LMBA together with strong memory effects typically observed in GaN transistors, segmented DPD approach [5] significantly boosts DPD performance. The operation of a typical LMBA can be subdivided into three regions based on the dynamic range: (i) a low power region where only the Balanced PA is operating, and (ii) a medium power region where CPA begins to load modulate the BPA, (iii) a higher power region where both BPA and CPA are fully active and operating at high power levels.

The results presented in this paper are based on a DPD scheme with 3 segments with 130 polynomial DPD coefficients in total. The first segment of DPD is of a simpler nature used to model the lower range, while the model complexity increases gradually moving to second and third segment of the DPD covering upper range of LMBA operation. In this work, segmented DPD is based on a generalized memory polynomial (GMP) scheme [6].

III. LMBA IMPLEMENTATION AND MEASUREMENTS

A. 200W LMBA Architecture Implementation

The high power LMBA architecture is implemented for 200 W peak power using NXP’s 100 W GaN on SiC HEMT on each branch of a BPA in an NI780 ceramic package. While the CPA uses the same GaN die, it is being down-sized by lowering the drain voltage. Each GaN transistor in BPA is biased at Vdd=48 V and Idq(total) ~300 mA while the CPA was biased at Vdd=28 V and Idq~150 mA. Each GaN transistor incorporates an input low-pass T-match for the fundamental frequency. In addition, to boost PA back-off efficiency, input also includes a second harmonic short implemented through on-chip L-C resonance circuit on each gate pad of unit cell. The BPA and CPA are combined using a 2-section branch line coupler designed on Rogers 4350B 20 mil thick substrate (Er~3.6) with the ports matched to Z0~25 Ω. The 2-section branch line coupler measured performance is shown in Fig.2(a)-(c). At 2.6 GHz, the coupling is ~3 dB with return loss better than -40 dB and relative phase difference of 90° between BPA combining ports.

NXP’s Digital Front-End system which has 2 synchronous TX channels and 1 RX channel with DPD rate ~307.2 MSPS has been implemented to independently control BPA and CPA. With the ability to process the baseband IQ data, the system is capable of shaping input signal for optimum amplitude and phase relationship between CPA and BPA inputs. However, this work has explored the impact of phase shaping on overall LMBA performance.
B. Measurement Results

The measurement setup of the digitally assisted LMBA is shown in Fig. 3(a). The digital pre-distorter and dynamic phase function features are implemented in the baseband domain and up converted. Two 40W LDMOS drivers with 30 dB gain operating at >10dB OBO are implemented to drive BPA and CPA, separately. A linear input amplitude relation versus drive level is maintained between CPA and BPA where $P_{in(CPA)}^2/P_{in(BPA)} = 2.5$ dB. CW measurements for gain and efficiency with different CPA phase conditions are shown in Fig. 3(b) and (c). The efficiency versus output power is plotted as a function of input phase variation in Fig.3(b,c). The efficiency is computed by measuring the power at the coupler’s output port and the dc consumption of both the BPA’s and CPA’s branches. CW characterization hence enables the extraction of a “dynamic phase profile” optimally trading off back-off efficiency with DPD friendly LMBA linearity. The back-off efficiency shows considerable enhancement over the balanced amplifier baseline. With a measured peak power of 53 dBm under CW excitation, at 6 dB OBO i.e. Pout~47 dBm, the architecture demonstrates 62% efficiency and 48% efficiency at 8 dB OBO. The gain variation across different phases is shown in Fig. 3(c) where the peak efficiency trace results in high AM/AM compression across output power. On the contrary, using static one carrier (1C) LTE20 FDD (Frequency Division Duplex) modulated signal with PAPR ~10.3dB, Fig. 4 depicts the LMBA trends in raw linearity and combined drain efficiency as a function of static over dynamic range phase relationship between CPA and BPA.

Based on the outcome of efficiency and linearity trade-offs measured using CW and modulated signal, input power dependent phase shaping function versus drive is extracted which in this case is a tanh function as shown in Fig.2(d). The selection of dynamic phase control is established such that at peak power LMBA provides best linearity while at back-off (~8 dB OBO) the phase is applied for maximum efficiency enhancement.

For DPD based linearizability assessment of the LMBA demonstrator under modulated stimulus, a static 1C-LTE20 FDD signal exhibiting a PAPR~7dB is selected. As a baseline experiment, Fig 3(e) top plot shows uncorrected and corrected DPD spectrum of non-LMBA (BPA only) which achieves 32.4% linearized drain efficiency. Fig.3(e) bottom plot illustrates LMBA performance (both BPA and CPA included) with ACPR correction of -52 dBc at average output power of 45.4 dBm and combined linearized drain efficiency (BPA+CPA) of 44% with total coefficients limited to 76 only. Corresponding AM-AM and AM-PM behavior of uncorrected (GREEN), predistorted (BLUE) and corrected (MAGENTA) are depicted in Fig.3(d). In this regard, LMBA outperforms typical balanced amplifier performance with 12% boost in back-off efficiency.
IV. CONCLUSION

High power 200W digitally assisted GaN based LMBA is presented in this paper. A digital front-end with dynamic phase shaping in control PA branch and pre-distorter in BPA branch is reported for the first time which implements segmented DPD approach. The presented digitally assisted LMBA demonstrates peak output power of 53 dBm (200W) with 44% linearized efficiency at 8 dB back-off and corrected ACPR of -52 dBc across Band-41.

REFERENCES