A Wideband Analog Predistortion Power Amplifier With Multi-Branch Nonlinear Path for Memory-Effect Compensation

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***Abstract*—A wideband, multi-branch analog predistorter (MBAPD) is reported to compensate for memory effects as well as memoryless nonlinearity of the power amplifier (PA) for repeater systems with wideband modulated signals. For verification, the MBAPD with three-branch nonlinear path is implemented with a 30 W class-AB PA and tested using a two-carrier wideband code division multiple access (WCDMA) signal with 15 MHz tone spacing at 2.14 GHz. From the measured results at an average output power of 33 dBm, the proposed MBAPD shows the adjacent channel leakage ratios (ACLRs) at ± 15 MHz offset of -60.4 dBc and -60.2 dBc, which are an improvement of over 25 dB and 12 dB, compared to the PAs without APD and with conventional APD, respectively.**

***Index Terms*—Analog predistorter, delay, memory effects, power amplifier (PA), wideband.**

I. Introduction

MEMORY effects of the power amplifiers (PAs) are commonly identified as the magnitude and phase asymmetries between the lower and upper intermodulation (IM) components according to tone spacings for a two-tone signal and the unbalanced spurious emission for modulated signals [1]–[3]. Therefore, memory-effect compensation is very critical to analog and digital predistorters (APD and DPD) because memoryless linearizers can not improve the linearity of the PA with memory effects. The DPDs have provided superior linearity with different memory-effect compensation algorithms in the digital domain, but they result in a complicated algorithm and expensive solution [3], [4]. The APDs have several advantages, such as simple structure, low cost, and proper linearity improvement over feedforward or DPD techniques. Also, they are suited to repeater systems due to direct amplification of RF signals between handsets and base stations [5]–[9]. Various reported APDs with memory-effect compensation enhance linearity to some degree, but they are not effective for wideband modulated signals [7]–[9].

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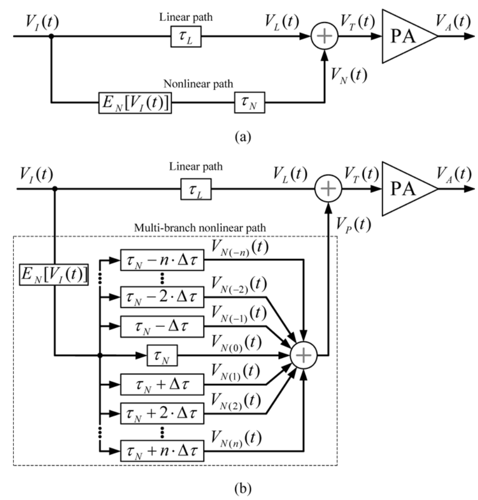


Fig. 1. Block diagrams of (a) the CAPD and (b) the proposed MBAPD.

In this letter, we propose a wideband APD with memory-effect compensation using a multi-branch, nonlinear path for repeater systems with wideband modulated signals. Additional nonlinear paths are used to compensate for memory effects as well as memoryless nonlinearity of the PA. For the experimental validation, the APD with three-branch nonlinear path has been implemented with a 30 W class-AB PA and tested with a two-carrier wideband code division multiple access (WCDMA) signal with 15 MHz tone spacing at 2.14 GHz. The measured results show the notable linearity improvement over a wide range of output power levels.

II. Wideband Multi-Branch Analog Predistorter

For the conventional APD (CAPD) to significantly improve the linearity, the PA should be carefully designed to show less memory effects, but memory effect reduction is very difficult for wideband signals. Fig. 1(a) shows the block diagram of the CAPD. In the nonlinear path of the CAPD, a diode-based error generator produces the symmetrical memoryless distortion signal, which is at the same time controlled by the vector modulator [5], [6]. However, since the PA shows the asymmetry between the lower and upper bands due to memory effects for wideband signals, it is very difficult for the CAPD to significantly cancel the distortion components of the PA. Therefore, the APD with memory-effect compensation should apply to the PA showing memory effects.

By adding additional nonlinear paths to the CAPD, we have developed the multi-branch APD (MBAPD) with various delay differences ($\Delta\tau$) to compensate for memory effects as well as memoryless nonlinearity of the PA as shown in Fig. 1(b), which improves the linearity. The linear path is comprised of the main delay line (τ_L). The multi-branch nonlinear path has a nonlinear function of $E_N(\cdot)$ and various delay lines with different $\Delta\tau$ connected in parallel, which is the memory-effect compensation part of the MBAPD. The τ_L is delay-matched with the main delay in the nonlinear path (τ_N).

The $E_N(\cdot)$ transforms the wideband input signal of $V_I(t)$ into memoryless nonlinear signal of $E_N[V_I(t)]$, which passes through nonlinear paths with various delays. The total predistorted signal of $V_P(t)$ contains the instantaneous, high-order, and past input signals. Finally, these signals are used to compensate for memory effects as well as memoryless nonlinear characteristics of the PA. The total output signals of the MBAPD of $V_T(t)$ can be expressed as

$$\begin{aligned} V_T(t) &= V_L(t) + V_P(t) \\ &= V_I(t-\tau_L) + \sum_{m=-n}^{n} V_{N(m)}(t) \\ &= V_I(t-\tau_L) + \sum_{m=-n}^{n} E_N[V_I(t-\tau_N - m\cdot\Delta\tau)] \quad (1) \end{aligned}$$

where $V_L(t)$ and $V_N(t)$ are the modulated signal after the linear path and each predistorted signal after different delay lines in the nonlinear path, respectively. Although the $E_N(\cdot)$ in the nonlinear path produces the memoryless signal of $E_N[V_I(t)]$, the MBAPD with various $\Delta\tau$ compensates for memory effects as well as memoryless nonlinear characteristics of the PA since the $E_N[V_I(t)]$ is transformed by various $\Delta\tau$ and summed into the $V_P(t)$ with memory characteristics. Therefore, the linearity at the PA output of $V_{\mathrm{A}}(t)$ can be improved by controlling $\Delta\tau$ and the number of additional nonlinear paths of n according to signal bandwidth of modulated signal and memory-effect quantity of the PA [10].

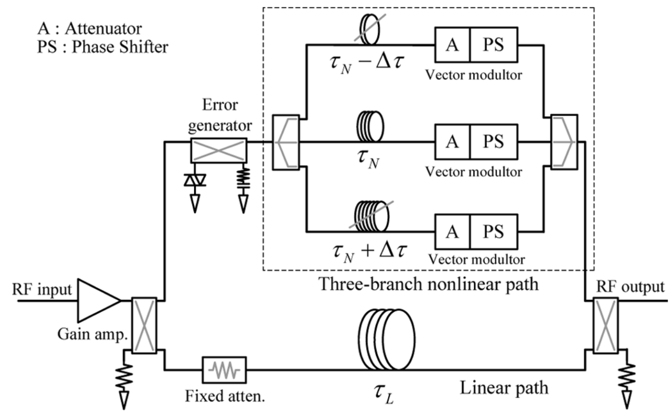
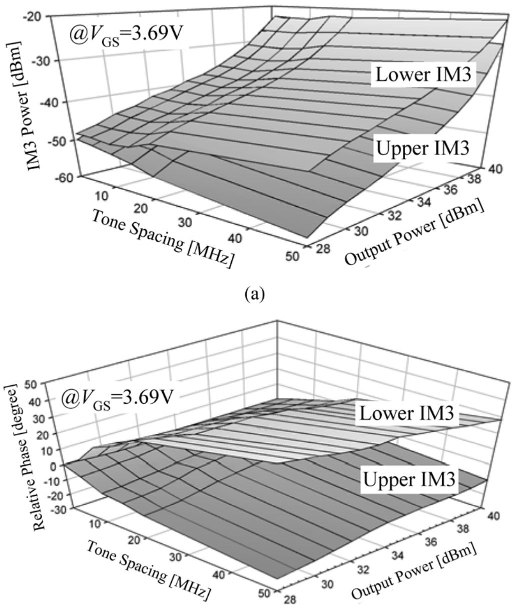


Fig. 2. Schematic of the proposed MBAPD with three-branch nonlinear path.



(a)

(b)

Fig. 3. Measured (a) magnitude and (b) phase distortions of the implemented PA according to tone spacings and output power levels for a two-tone signal.

III. Implementation and Experimental Results

Fig. 2 shows the MBAPD with three-branch nonlinear path. The two additional, nonlinear paths have a shorter and longer delay than the τ_N and are used to compensate for memory effects of the PA. In this experiment, the τ_N and τ_L are 1.8 ns and 5.4 ns, respectively. The optimum $\Delta\tau$ of 2 ns is determined experimentally based on [10].

The PA has been implemented using Freescale MRF21030 LDMOSFET with 30 W PEP in the class-AB operation at a V_{DD} of 28 V and a V_{GS} of 3.69 V ($I_{DQ} = 180$ mA). The implemented PA has a $P_{1\ \mathrm{dB}}$ of 43.2 dBm. To reduce memory effects, the drain bias circuit incorporates a $\lambda/4$ bias line with a 3 mm line width and several decoupling capacitors. Fig. 3 depicts the measured magnitudes and phase distortions of the IM3 according to tone spacings and output power levels after reducing memory effects of the PA. The magnitude and phase differences between the lower and upper IM3s at low power levels are larger as the tone spacings are increased due to memory effects. However, the linearity of the implemented PA can be improved with the MBAPD with proper memory-effect compensation because the IM3s are monotonous without any abrupt changes.

Fig. 4 shows the measured power spectral densities (PSDs) of predistorted signals generated by the CAPD and the MBAPD for a two-carrier WCDMA signal with 15 MHz tone spacing. As shown in Fig. 3, the PA shows higher spurious emission in the lower band than in the upper band. Therefore, the MBAPD can compensate for memory effects of the PA with help of asymmetrical predistorted signals generated by the fine adjustment of three vector modulators, compared to symmetrical signals of the CAPD. Fig. 5 shows the measured PSDs before and after linearization at a P_{out} of 33 dBm, which is a 10.2 dB back-off output power. The CAPD shows the limited ACLR improvement due to memory effects. However, the MBAPD achieves the significant ACLR improvement by compensating for memory effects. From summarized results in Table I, the ACLR at a 15 MHz offset for the MBAPD is -60.4 dBc, which is an improvement of around 25.3 dB and 12.5 dB compared to the

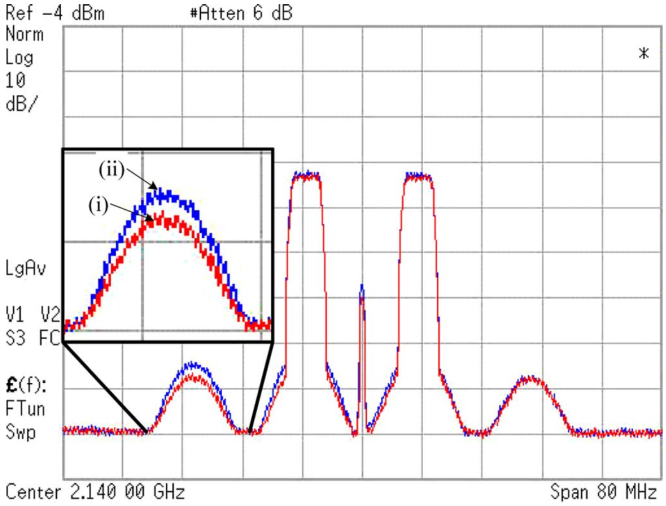


Fig. 4. Measured PSDs of predistorted signals. (i) The CAPD and (ii) The MBAPD.

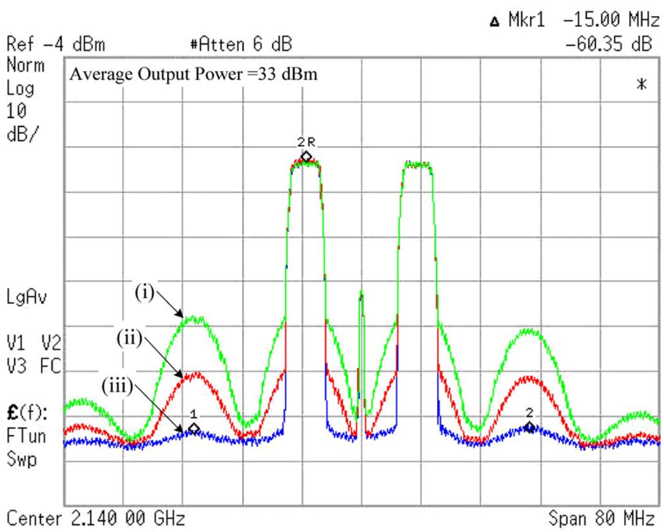


Fig. 5. Measured PSDs. (i) Without APD, (ii) With CAPD, and (iii) With MBAPD.

PAs without APD and with CAPD, respectively. Fig. 6 proves that the MBAPD significantly improves the ACLR over a wide output range. At an ACLR of -45 dBc, the MBAPD delivers higher output power and drain efficiency over 3 dB and 9.9%, respectively, compared to those of the CAPD.

IV. Conclusion

We have proposed a wideband MBAPD to compensate for memory effects as well as memoryless nonlinearity of the PA for wideband modulated signals. For verification, the MBAPD with three-branch nonlinear path was implemented with a 30-W class-AB PA and tested using a two-carrier WCDMA signal with 15-MHz tone spacing at 2.14 GHz. From the measured results at an average output power of 33 dBm, the proposed MBAPD shows the ACLR improvement of over 25 dB and 12 dB, compared to the PAs without APD and with CAPD, respectively. Therefore, the proposed MBAPD can be a useful linearization solution for multi-carrier repeater systems with wideband modulated signals.

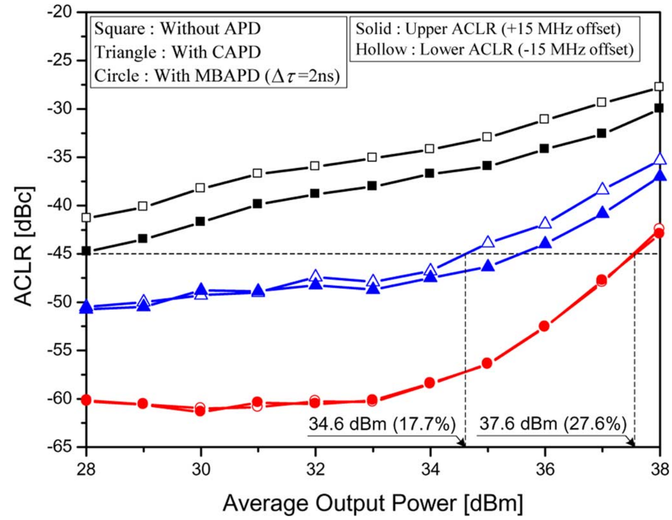


Fig. 6. Measured ACLRs for various conditions according to output power levels for a two-carrier WCDMA signal.

TABLE I
Measured ACLRs at an Output Power of 33 dBm for a Two-Carrier WCDMA Signal With 15-MHz Tone Spacing

Contents	ACLR [dBc]	
	-15-MHz offset	+15-MHz offset
PA	-35.1	-38.1
CAPD + PA	-47.9	-48.7
MBAPD + PA	-60.4	-60.2

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