A Novel Digital Feedback Predistortion Technique with Memory Lookup Table

Junghwan Moon[1] · Jangheon Kim[2] · Bumman Kim[1]

Abstract

We have developed a novel digital feedback predistortion(DFBPD) linearization based on RF feedback PD for the wide bandwidth modulated signals. The wideband PD operation is carried out by combining the DFBPD and memory lookup table(LUT). To experimentally demonstrate the linearization performance of the proposed PD technique for wideband signal, a class-AB amplifier using an LDMOSFET MRF6S23140 with 140-W peak envelope power is employed at 2.345 GHz. For a forward-link 2FA wideband code-division multiple-access signal with 10 MHz carrier spacing, the proposed DFBPD with memory LUT delivers the adjacent channel leakage ratio at an 10 MHz offset of -56.8 dBc, while those of the amplifier with and without DFBPD are -43.2 dBc and -41.9 dBc, respectively, at an average output power of 40 dBm. The experimental result shows that the new DFBPD with memory LUT provides a good linearization performance for the signal with wide bandwidth.

Key words : Digital Predistortion, Memory Effect, Power Amplifier, Wideband Code Division Multiple Access.

Ⅰ. Introduction

The power amplifier(PA) is an essential element in current wireless communication systems, but it is inherently nonlinear. The nonlinearity induces in-band error as well as out-of-band error distortion, leading to adjacent channel interference and degradation of bit-error rate performance. To meet the linearity requirements mandated by regulatory agencies, it is necessary to compensate the nonlinear characteristics of the PA. Traditionally, the PA was driven into the back-off power region, more than peak-to-average power ratio(PAPR), to operate within the linear portion of its operating curve. However, modern communication systems, such as wideband code-division multiple access(WCDMA), world interoperability for microwave access, etc., use the complex modulation scheme to transmit much information at one time. As a result, the signals of the systems vary rapidly and have a large PAPR. It means the PA should be backed off far from its saturation point, which results in very low efficiency operation. To improve efficiency without compromising linearity performance, it is necessary to adopt the PA linearization technique[1]~[10].

Among the linearization techniques, a digital predistortion(DPD) is one of the most promising technique. In our group, the digital feedback predistortion(DFBPD) technique for base station transmitter, based on RF feedback PD[11], has been developed[8], combining the PD and feedback technique. Fig. 1 shows the FBPD in analog

and digital domains. It has better system tolerance to error due to the feedback circuit, faster convergence, and simpler structure compared to the conventional DPD algorithm. Even though the conventional DPD uses the complex adaptation algorithm, such as recursive least square(RLS), least square(LS), etc., for extracting the PD signals[4]~[7], the DFBPD algorithm is very simple and expressed as

$$W^k\left(\left|v_m(n)\right|\right) = v_e^{k-1}(n)\Big|_{\left|v_m(n)\right|}$$
$$= v_d^{k-1}(n) - \frac{v_a^{k-1}(n)}{G_{PD}}\Bigg|_{\left|v_m(n)\right|},$$

for iteration

$$k = 1, 2, 3, \ldots, K \tag{1}$$

where $v_m(n)$ and $v_d(n)$ are the original and predistorted input signals, $v_a(n)$ is the final output signal, and G_{PD} is the overall PD system linear gain. The LUT is constructed by only this error signal $v_e(n)$ as a function of the input for the training sequence with time sample, $n=1, 2, \cdots, L$. In addition, we have experimentally demonstrated suitableness of the linearization technique for distortion without memory.

As emerging radio systems are increasingly evolving to wider bandwidth signals, we have to consider not only static nonlinearity defined by AM/AM and AM/PM, but also the memory effect to accurately extract the PD signal. To compensate the memory effect while maintaining

(a) Analog feedback predistorter
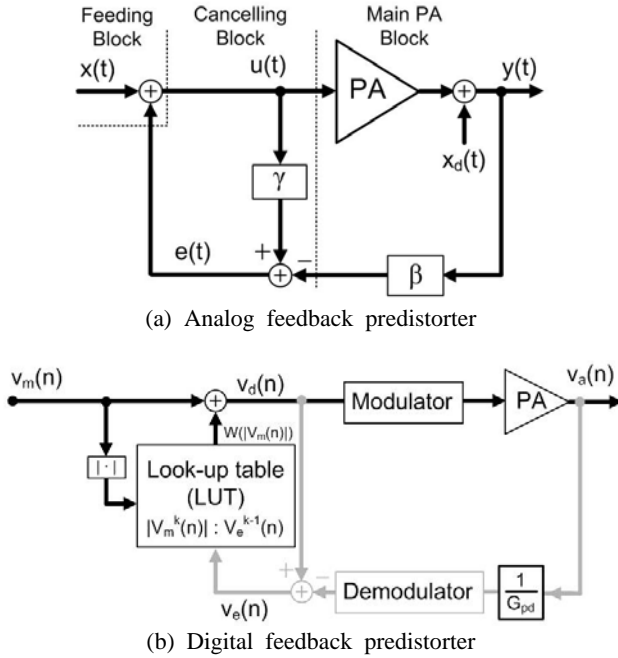

(b) Digital feedback predistorter

Fig. 1. Simplified block diagrams of the analog and digital feedback predistorter.

the advantage of the DFBPD, a dynamic nonlinear filter is added in front of the DFBPD structure[9]. Although its memoryless compensation part is based on the DFBPD algorithm, the other adaptive algorithms are also required to train the coefficients of the dynamic nonlinear filter. As a result, the algorithm needs two individual procedures to compensate both the static and dynamic nonlinearities.

In this paper, we propose a new DFBPD algorithm for a wide bandwidth signal. The wideband PD operation is carried out by inserting the memory LUT into the DFBPD structure. This technique extracts the PD signal compensating both static and dynamic nonlinear characteristics at a time by only using the DFBPD algorithm. For the experiments, a class-AB PA is fabricated at 2.345 GHz using an LDMOSFET with 140-W peak envelope power(PEP). From the experimental results, we conclude that the DFBPD with memory LUT can deliver better linearization performance than the conventional DFBPD for the wide bandwidth signal, while maintaining most of the DFBPD technique's advantages.

Ⅱ. Operation of DFBPD with Memory LUT

For a nonlinear PA with memory, the output signal is expressed as a function of the current as well as previous input signals, as follows:

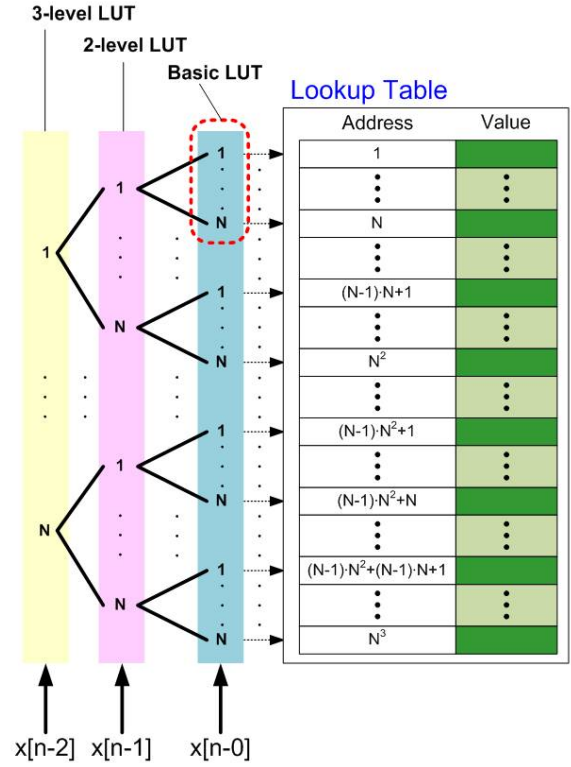$$y(n) = f\left[x(n), x(n-1), \cdots, x(n-M)\right] \tag{2}$$

Fig. 2. Simplified memory LUT.

where f is the nonlinear transfer function of the PA, M is the memory depth, and $x(n)$ and $y(n)$ represent the input and output signals, respectively. As a result, the same current inputs with different historical inputs usually lead to different outputs. To represent the above input and output relationship under the PA operation with memory effect, the nested LUT concept is proposed in [10], as shown in Fig. 2, which has a second- order memory depth(M=2). In this paper, we call this LUT the memory LUT. To find the LUT address according to the historical inputs, the LUT addressing is carried out as follows: in the case of M=2, first, an index value $I(n-2)$ depending on the previous input sample $x(n-2)$ is determined among the number of N-addressing value; the input value is quantized over N value. Subsequently, $I(n-1)$ is selected according to the sample $x(n-1)$. Through the determination of $I(n-2)$ and $I(n-1)$, one basic LUT cell is selected among the N^2-basic LUTs. Each basic LUT consists of N-elements. Finally, the index $I(n)$ determined by the input value $x(n)$ is used to extract the appropriate PD signal in the DFBPD. In short, according to the historical and current input signals, the index of the memory LUT is calculated, as follows:

$$CI(n-M, \cdots, n) = 1 + \sum_{i=0}^{M}\left[\left(I(n-i)-1\right) \cdot N^i\right] \tag{3}$$
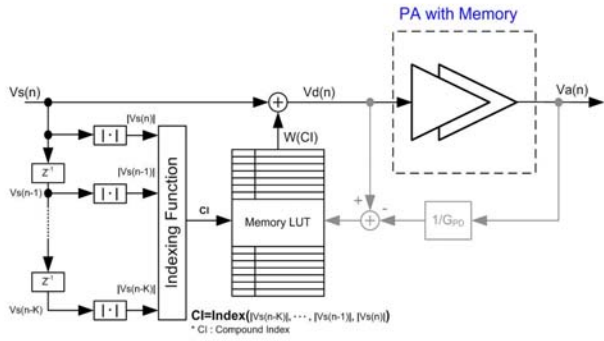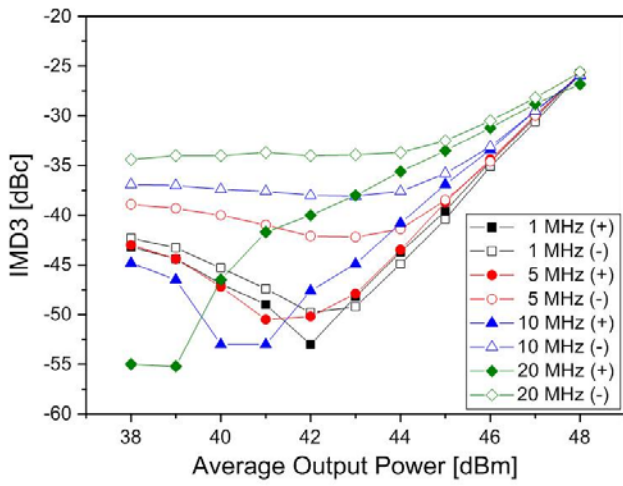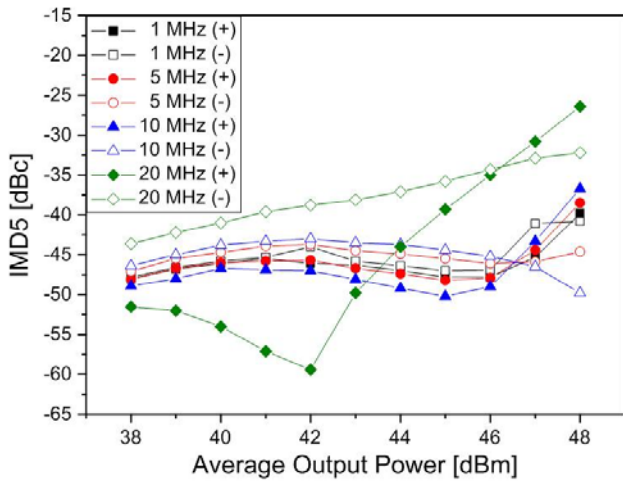
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Fig. 3. Simplified block diagram of the DFBPD with memory LUT.

(a) IMD3 characteristics

(b) IMD5 characteristics

Fig. 4. Measured IMD3 and IMD5 characteristics for two-tone signals.

Fig. 3 illustrates the simplified block diagram of the proposed DFBPD for wideband PD operation. Unlike the conventional DFBPD configuration, it uses the memory LUT to compensate both the static and dynamic non-

linearity of the PA. Each element of the memory LUT is constructed by

$$W^k(CI) = v_e^{k-1}(n)\big|_{CI}$$

$$= v_d^{k-1}(n) - \frac{v_a^{k-1}(n)}{G_{PD}}\bigg|_{CI},$$

for iteration

$$k = 1, 2, 3, \ldots, K \qquad (4)$$

As a result, the appropriate PD signal according to the historical input signals can be constructed at a time.

Ⅲ. Experimental Results

We have designed a class-AB PA using Freescale MRF-6S23140 LDMOSFET with 140-W PEP at 2.345 GHz. In the experiments, the drain and gate voltages are set to 28 V and 2.83 V(I_{DSQ}=1.24 A), respectively. Moreover, the PA has optimized the high linearity and efficiency. Before applying the proposed PD algorithm, we explore the nonlinear characteristics and memory effect using two-tone signals(up to 20 MHz tone spacing). Fig. 4 presents the third-order inter-modulation distortion (IMD3) and fifth-order inter-modulation distortion(IMD5) for the two-tone signals. The large amounts of asymmetrical characteristics of the IMD3s and IMD5s mean the PA exhibits a serious memory effect[12],[13].

To validate the proposed algorithm for the linearization of wideband signals, we have employed a forward-link WCDMA 2FA signal with 10 MHz carrier spacing (15 MHz signal bandwidth, 76.8 MSps) and 7.5 dB PAPR at the 0.01 % level of the complementary cumulative distribution function(CCDF). The Agilent ADS using a PSG and VSA connected solution is used for the linearization, as shown in Fig. 5. The proposed algorithm has two AM/AM and AM/PM memory LUTs, which are indexed by the envelope magnitude. The magnitude is quantified into 256 levels. To compensate the memory effect, the memory depth is set to K=2. Each value of the memory LUT is found by MATLAB using the DF-BPD algorithms. In the DFBPD algorithm, the PA behavioral model with both static and dynamic memory nonlinearity is required to find the values of the memory LUT entries. To model the memoryless nonlinearity and memory effect of the PA, we employ the augmented Hammerstein structure, which is a cascade of a strong nonlinear static subsystem and a dynamic weak nonlinear subsystem consisting of the linear and nonlinear filters. In the experiments, the 7th-order memoryless polynomial is used to represent the static nonlinearity, and each coefficient of the polynomial is trained using the LS adaptive algorithm. In addition, two nine- and four-
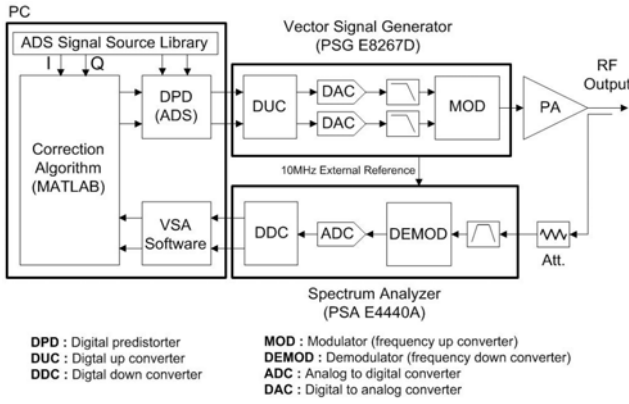
Fig. 5. Experimental setup for linearization.

(a) AM/AM characteristics

(a) AM/AM characteristics

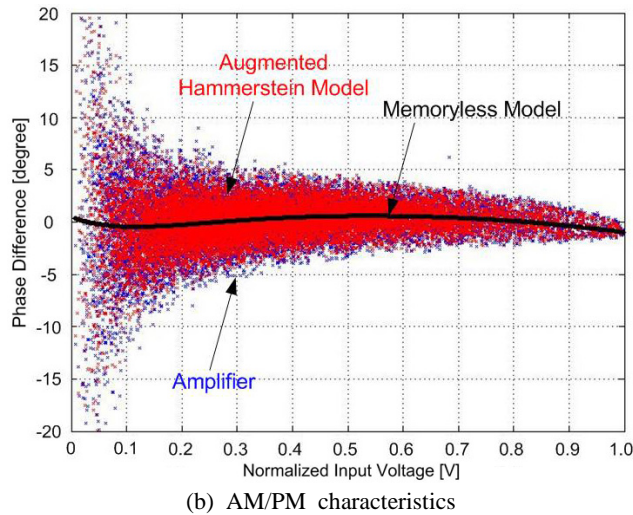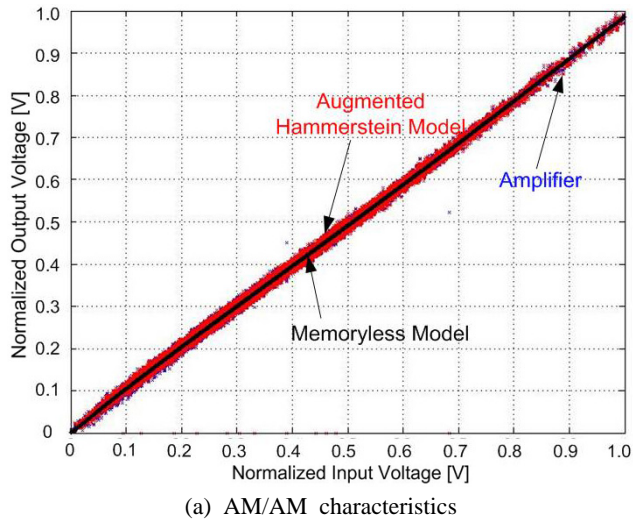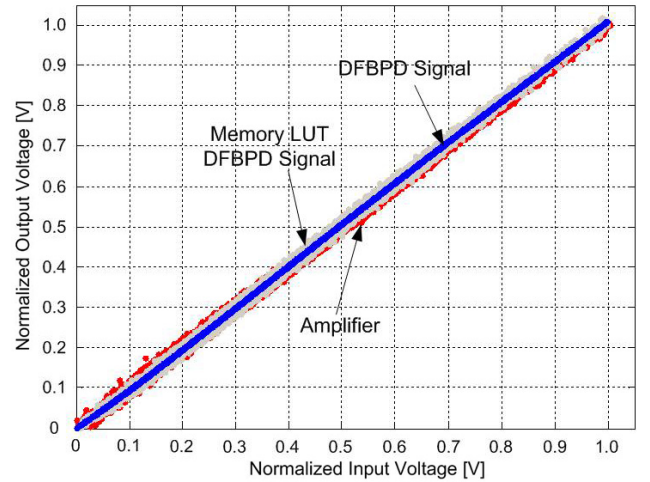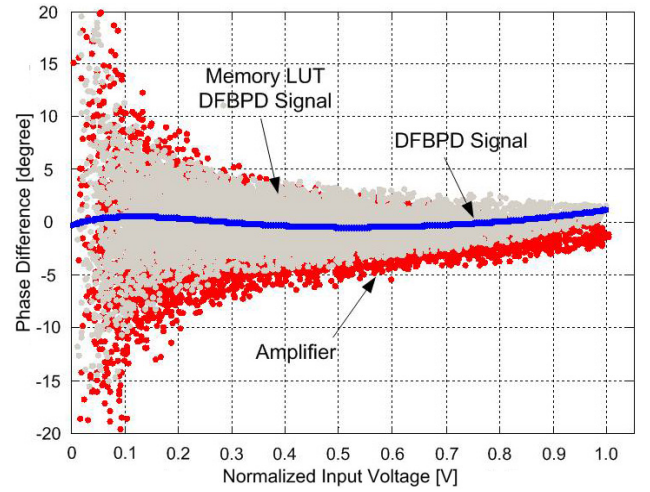(b) AM/PM characteristics

(b) AM/PM characteristics

Fig. 6. Modeled AM/AM and AM/PM characteristics of the memoryless and augmented Hammerstein model.

(b) AM/PM characteristics

Fig. 7. Measured AM/AM and AM/PM characteristics of the DFBPD and DFBPD with memory lookup table signals.

rithm. Fig. 6 illustrates the modeled AM/AM and AM/PM characteristics of the memoryless and augmented Hammerstein models. The augmented Hammerstein model provides a good agreement with the measured one. In particular, the normalized mean square error of the augmented Hammerstein is −41.2 dB, while that of the memoryless polynomial is −30.0 dB.

Fig. 7 represents the measured AM/AM and AM/PM characteristics before linearization and the corresponding PD signals generated by the DFBPD and DFBPD with memory LUT algorithms. The DFBPD provides the memoryless predistorted signal to compensate the strong nonlinear static characteristics, while the DFBPD with memory LUT generates the predistorted signal with memory to linearize the bandwidth-dependent nonlinear characteristics. Fig. 8 illustrates the measured spectra of the predistorted signals produced by the DFBPD and

tap finite impulse response(FIR) filters are employed to denote the dynamic memory effect. The FIR filters parameter identification is performed using the RLS algo-

DFBPD with memory LUT. The DFBPD provides balanced spurious emission, but the DFBPD with memory LUT generates unbalanced spurious emission, reflecting the memory effect.

Fig. 9 shows the measured AM/AM and AM/PM characteristics of the amplifier output after DFBPD and DFBPD with memory LUT linearization at an average output power of 40 dBm for WCDMA 2FA signals with 10 MHz carrier spacing. Both predistortion algorithms successfully compensate the static nonlinear characteristics. In addition, the AM/AM and AM/PM scattering characteristics caused by the memory effect are better suppressed by the DFBPD with memory LUT than the DFBPD because of the memory LUT. Fig. 10 represents the measured WCDMA 2FA spectra before and after DFBPD and DFBPD with memory LUT linearization techniques at an average output power of 40 dBm. The adjacent channel leakage ratio(ACLR) at an offset of 10 MHz for the DFBPD with memory LUT is −56.8 dBc, which is an enhancement of 14.9 dB at the same average output power. The experimental results clearly show that the DFBPD algorithm can compensate not only static, but also dynamic nonlinearity of the PA by chan-

(a) AM/AM characteristics

(b) AM/PM characteristics

Fig. 9. Measured AM/AM and AM/PM output characteristics after DFBPD and DFBPD with memory lookup table linearization.
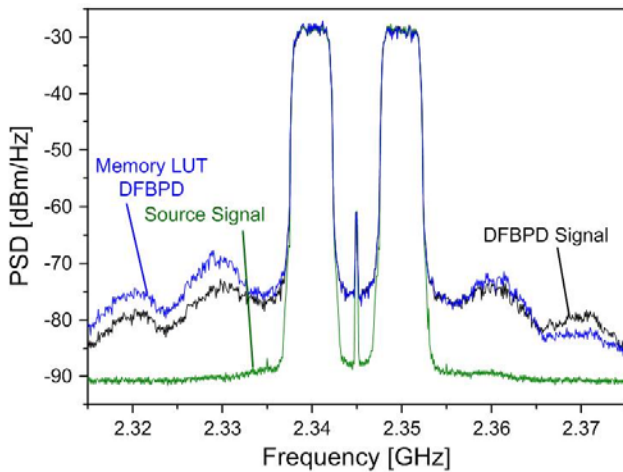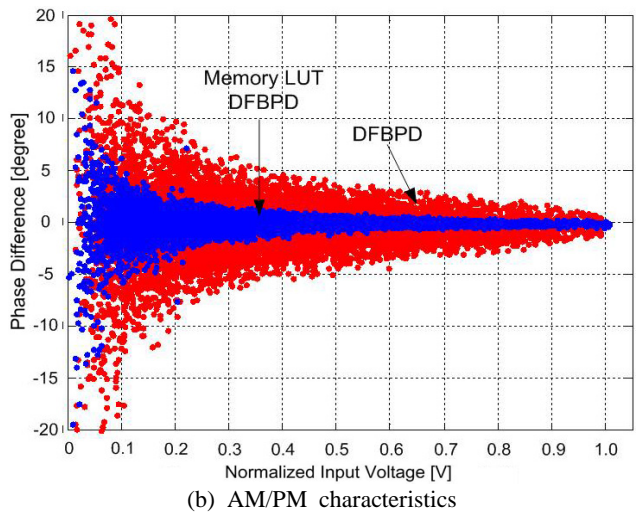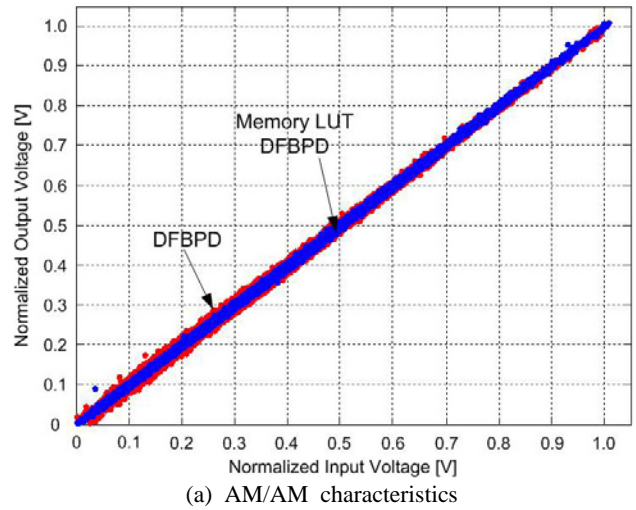

Fig. 8. Measured WCDMA 2FA spectra of the predistorted signals.

Table 1. Measured performance before and after linearization at an average output power of 40 dBm for WCDMA 2FA signal with 10 MHz carrier frequency.

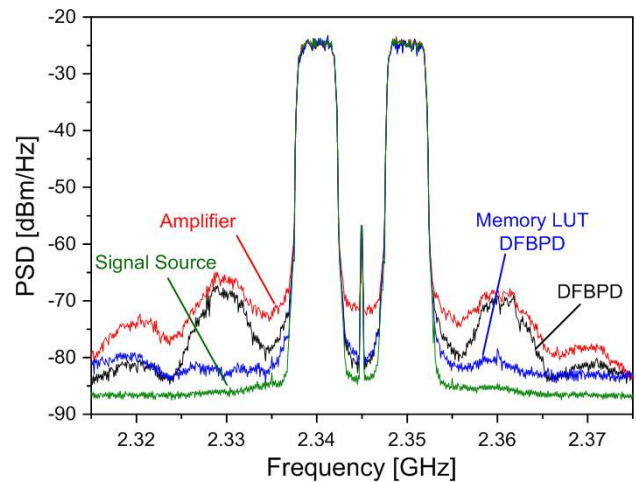|	ACLR [dBc] at +/−10 MHz
Amplifier	−43.5/−41.9
DFBPD	−45.0/−43.2
DFBPD with memory lookup table	−56.8/−57.6

Fig. 10. Measured WCDMA 2FA spectra before and after linearization.

ging the configuration of LUT. The measurement results are summarized in Table 1.

IV. Conclusions

We have presented a novel DFBPD linearization for the wide bandwidth modulated signals. The wideband PD operation is achieved by combining the DFBPD and memory LUT. For the experiments, a class-AB amplifier is designed at 2.345 GHz using an LDMOSFET with 140-W PEP. To experimentally demonstrate the capability to compensate the static and dynamic nonlinear characteristics, we have employed a forward-link WCDMA 2FA signal with 10 MHz carrier spacing(15 MHz signal bandwidth). The proposed DFBPD with memory LUT delivers the ACLR at an 10 MHz offset of -56.8 dBc, while those of the amplifiers without PD and with DFBPD are -41.9 dBc and -43.2 dBc, respectively, at an average output power of 40 dBm. From the experimental results, we conclude that the DFBPD with memory LUT can deliver better linearization performance than the conventional DFBPD for the wide bandwidth signal, while maintaining most of the DFBPD technique's advantages.

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