A New Estimation Method of Power Amplifier's Amplitude and Phase Errors for Adaptive Linearizer using Analog Circuitry

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Many linearization techniques for RF power amplifier (PA) need an adaptive control system for tracking drifts of the amplifier's characteristics and maintaining the performance. To do so, the output distortion or error levels should be monitored constantly. In this paper, we present a new method for estimating the PA's amplitude and phase errors. The proposed method estimates the amplitude and the phase errors separately. Then these two errors are summed for the estimation of the total error. For feasibility of the system, the error surface is measured applying the embodied estimator to a postdistortion linearizer and compared with the third-order intermodulation distortion (IMD_3) improvements obtained in the same control range.

INTRODUCTION

For more efficient use of the spectral resource, linear modulation schemes, such as quadrature phase-shift keying (QPSK), M-ary quadrature amplitude modulation (QAM), are adopted as standards in modern digital mobile communication systems. However, their fluctuating envelopes demand highly linear RF power amplifiers (PAs) to not generate intermodulation distortion in adjacent channels. For the above reason, many linearization techniques and their derivations have been developed to improve the linearity of the RF PA [1]-[2]. Unfortunately, the PA's characteristics drift with environmental changes (e.g., junction temperature, input power, supply voltage, device aging, etc.) and the linearizers need to be controlled according to these variations in an adaptive manner for maintaining the linearity improvements [3].

In an adaptive control system, the precise estimation of the intermodulation distortion (IMD) or error levels at the PA's output is one of the important factors that determine the performance. Several estimation methods have been devised for this purpose and these can be divided in two groups. The one is the error power detection and the other is the correlation detection [4]. However, the power detection demonstrates poor performance, because of the limited detector's dynamic range and the correlation method usually needs complex and expensive digital signal processors (DSP) [5].

In this paper, a new estimation technique of the PA's amplitude and phase errors is presented. The amplitude and phase errors are estimated separately and summed for the total error. This estimator is totally implemented using analog circuits and applied to a postdistortion linearizer [6]. For validation of the proposed method, the output error is estimated varying the control parameters in the postdistortion linearizer and compared with the IMD_3 improvement surface in the same control range.

SYSTEM DESCRIPTION

Fig. 1 illustrates the block diagram of the proposed error estimator. This system is comprised of two parts: the amplitude and the phase error estimation circuits. As widely known, the amplitude error can be obtained from the difference between the input and output envelope squares [7], and is given by

$$e_{am}(t) = \mathrm{E}\{|V_i(t)|^2 - |V_c(t)|^2\} \qquad (1)$$

where $V_i(t)$ and $V_c(t)$ are the input and output complex envelopes of the linearization system, respectively. Before the evaluation of Eq. (1), the output signal is properly scaled to account for the feedback path gain and a delay line is also inserted in the input path to compensate the delay mismatch. Fig. 2 shows the detailed block diagram of the automatic gain control (AGC) and averaging circuit in Fig. 1.

To estimate the phase error, a 90° hybrid coupler is used for converting the PM distortion to an equivalent AM signal. As shown in [8], the difference of the envelope squares between two output signals from the coupler is expressed by

$$|V_1(t)|^2 - |V_2(t)|^2 = 4|V_i(t)|\,|V_c(t)| \sin \phi \qquad (2)$$

where $V_1(t)$ and $V_2(t)$ are the two complex envelopes from the coupler and ϕ is the phase difference of the input and output signals:

$$\phi = \angle V_c(t) - \angle V_i(t).$$

Thus the phase error can be approximated by

$$e_{pm}(t) \approx 16\,|V_i(t)|^2\,|V_c(t)|^2\,\phi^2, \text{ for small } \phi. \qquad (3)$$

Finally, the amplitude and phase error are summed to form the total error

$$e(t) = e_{am}(t) + e_{pm}(t). \qquad (4)$$

To verify the feasibility of the proposed estimator, we need to vary the output error of the PA. Therefore, we use the postdistortion linearizer, because it can control the upper and lower IMD levels independently [6]; this estimator however can be applied to other linearization systems, such as predistortion, feedforward, etc.

IMPLEMENTATION AND RESULTS

In this paper, the error estimator has been fully realized using commercially available integrated circuits (ICs), such as operational amplifier (Op-Amps), multipliers, etc. The components were carefully selected considering to the bandwidth of the input signal. The DC offsets of the devices were also optimized for a better performance. Fig. 3 shows the photograph of the manufactured printed circuit board (PCB).

We first measured the upper and lower IMD_3 improvements (Fig. 4) varying the complex gain of the third-order error signal generator (ESG_3) in the postdistortion system, in which a 5 W Class A amplifier at cellular band was used for linearization. Then, the output error levels were estimated in the same control range. As shown in Fig. 5, the amplitude and phase error form the orthogonal V-shaped surfaces. In the total error contour, there exists a unique global minimum point, at which the upper and lower IMD_3 improvements are maximized. Therefore, a simple gradient search algorithm will be sufficient to control the linearizer 's parameters.

CONCLUSION

A new estimation method of the PA's output complex error has been presented. In the proposed technique, the total error is estimated from the variances of the two time-domain difference signals caused by the PA's AM-AM and AM-PM nonlinearities. The entire system has been realized using commercial analog ICs, such as Op-Amps, multipliers, and further simplification will be possible by integrating the majority of ICs in a single chip.

We have also demonstrated the feasibility of the proposed method measuring the error surface at the output of the postdistortion linearizer. The implemented estimator however is applicable to other linearization systems, such as predistortion, feedforward, with minor change in the circuit configuration. The upper and lower IMD_3 improvements were maximized at the unique minimum point in the measured error surface; the controllability is therefore guaranteed.

ACKNOWLEDGEMENT

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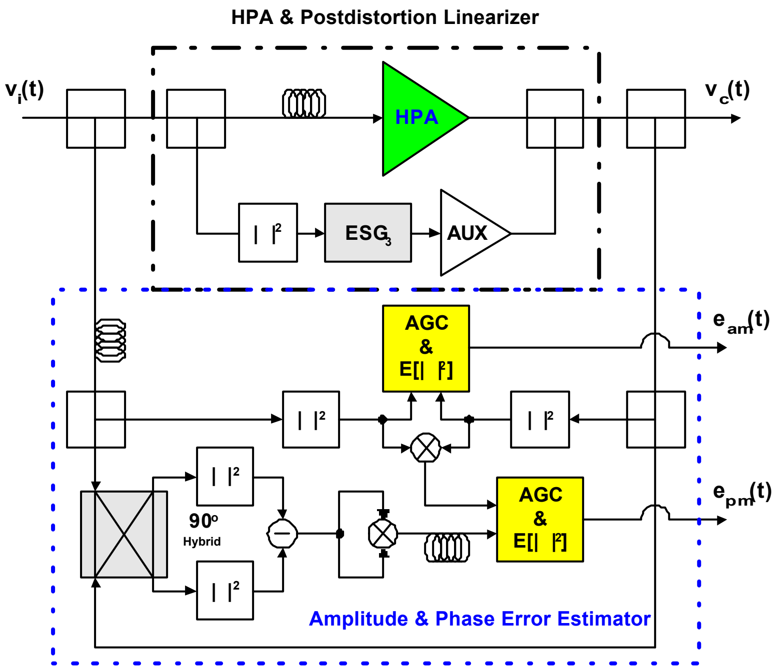


Figure 1: Block diagram of the proposed estimator

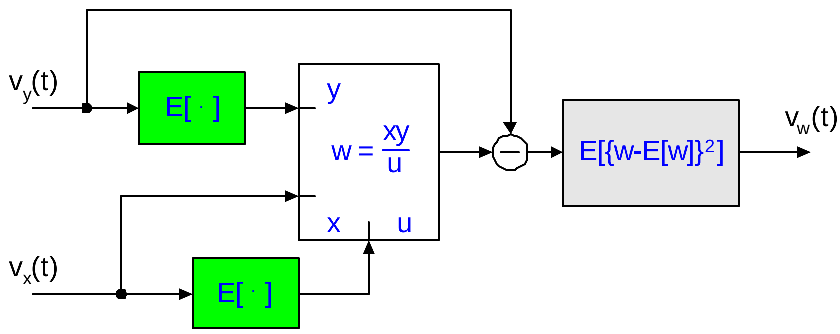


Figure 2: Block diagram of the AGC and averaging circuit

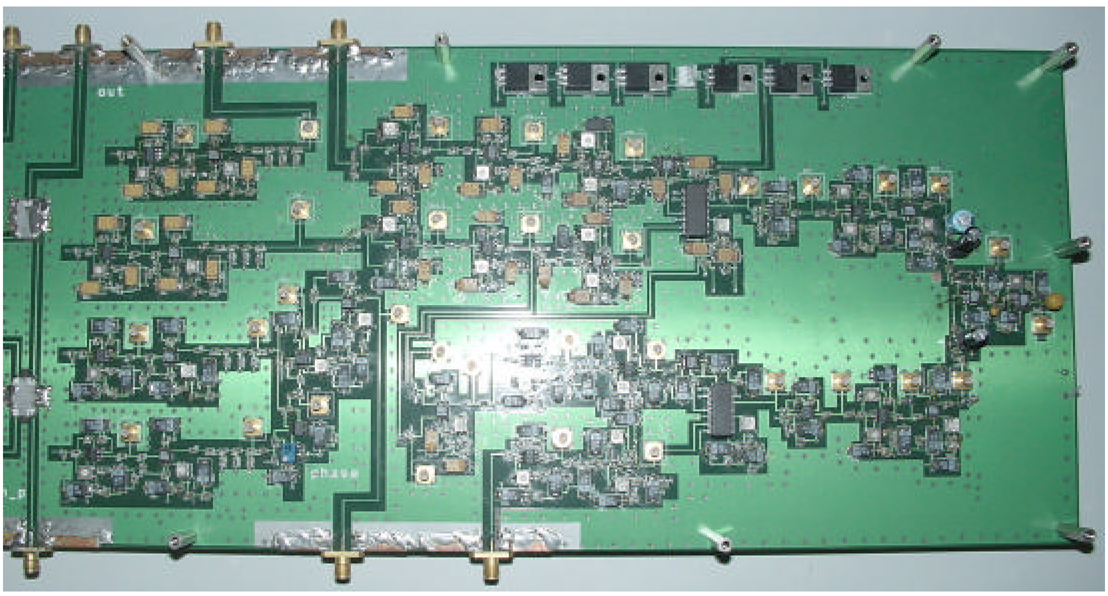
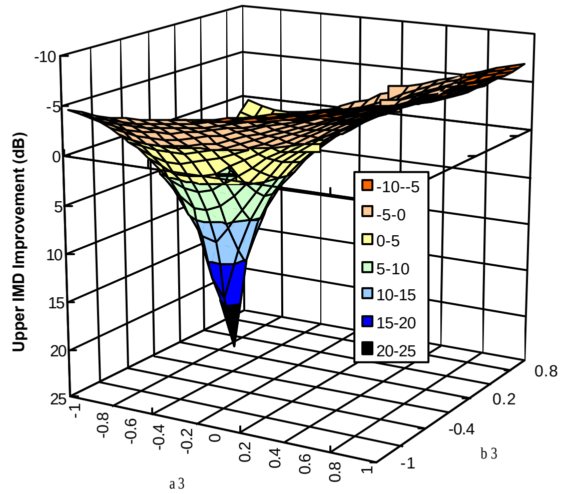
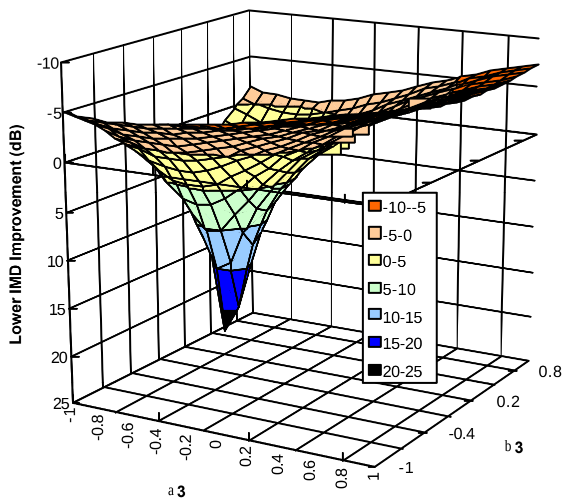


Figure 3: Photograph of the implemented system

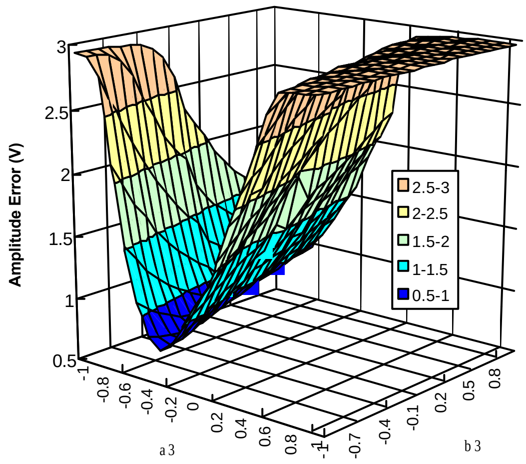


(a)

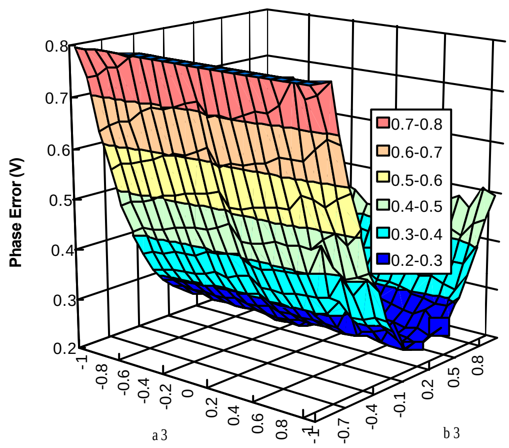


(b)

Figure 4: IMD_3 improvement surfaces using ESG_3(a) upper IMD_3 (b) lower IMD_3



(a)



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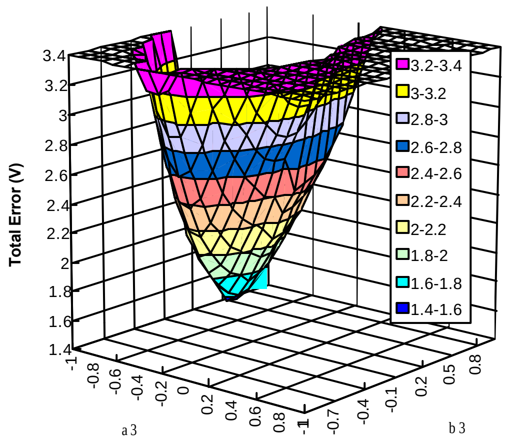

(c)

Fig. 4. Measured error surface according to the variation of the ESG_3's complex gain: (a) amplitude (b) phase (c) total error surface