A Novel Power Amplifier Linearization Method for Handset Applications

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Abstract - A new circuit concept to improve the maximum linear output power of a Universal Mobile Telecommunication System (UMTS) power amplifier (PA) is introduced in this paper. The proposed circuit consists of an analog pre-distorter (APD) integrated at the input of a class B amplifier. The proposed APD extends the maximum linear output power of the PA to 28dBm with corresponding power added efficiency (PAE) of 52.3%. Simulation result shows that at 1.95GHz, PA has a worst case adjacent channel leakage ratio (ACLR) of -36dBc at output power of 28dBm. With a respective input and output return losses of -27.6dB and -13.2dB, the PA's power gain is simulated to be 33.3dB while exhibiting an unconditional stability characteristic from DC to 3GHz. The monolithic microwave integrated circuit (MMIC) power amplifier (PA) is designed in 2μm InGaP/GaAs process. The proposed APD technique serves to be a good solution to improve the maximum linear output power of the UMTS PA without sacrificing other critical performance metrics.

Keywords: Power amplifier, Analog Predistorter, Power added efficiency, Hetero junction bipolar transistor, Universal mobile telecommunication system, Adjacent channel leakage ratio

Introduction

Recently, there is an explosive growth in the number of UMTS standard users. This is due to the excitement in the high data rate usage around the globe. Therefore, handset designers, particularly power amplifier (PA) designers confront stiff challenges in improving the maximum linear output power so that linear transmission still occurs in remote areas. This transmission also needs to be efficient in order to prevent rapid energy drainage of the battery.

Several methods have been reported recently to improve the maximum linear output power of the PA. The most prominent technique among them is the pre-distortion technique. In this method, the input RF signal to the PA is distorted prior amplification by changing its non-linear transfer function's magnitude and phase to have an opposite responses to the phase and magnitude of the non-linear components generated by the PA. The Digital Predistortion Technique (DPD) is the upcoming pre-distortion method used to linearize the PA [1]-[3]. In this method, these non-linear responses are generated with the aid of a DSP processor. The complexity in integration, resulting in larger chip size and dual fabrication process are among the visible disadvantages of DPD. On the other hand, APD offers a simple solution of integrating additional active devices, usually within the same process at the input of the power amplifier [4]-[9]. Alternatively, passive elements are utilized as a predistorter, to linearize a non-linear class-E PA [10].

In this paper, a new APD technique is introduced to improve the maximum linear output power of a UMTS PA. In order to meet the stringent ACLR specification for UMTS, an analog pre-distorter block is integrated at the input of the main amplifier, realizing a single chip solution which reduces the cost and space required on the phone board.

Design Methodology

In order to achieve an IMD3 cancellation, the third order components generated at the output of the APD need to have an opposite response respective to the third order components generated by the class-B main amplifier. In practice, this can be achieved if an opposite AM-AM and AM-PM responses are generated between the APD and main amplifier [11].

Figure 1 illustrates the schematic of the proposed PA. A dual stage output matching network consists of L3, C8, TL3 and C9 is proposed to transform the 50 ohm load to the output impedance of the main amplifier. L3 represents bond wires, whereas TL3 denotes a transmission line.

In HBT, spectral re-growth is mainly contributed by its base-collector parasitic capacitance Cbc [12]. Therefore, in this work we propose to utilize the base collector diode at the input of the driver, as an integral part of the circuit which generates an opposite phase (AM-PM) response. The reverse bias capacitance Cbc-reversebias and forward bias capacitance Cbc-forwardbias are expressed as follows [13]:

$$C_{bc-reversebias} = \frac{C_{bc0}}{\left(1 + \frac{V_{CB}}{\varphi_0}\right)^{n_c}}$$

Where Cbco is the collector-base capacitance when VCB=0, φo is the collector base junction built in voltage and nc is the grading coefficient of the collector base junction. In order to generate an opposite output phase response, the collector-base junction is forward biased. The forward biased collector base capacitance is expressed by:

$$C_{bc-forwardbias} = \frac{C_{bc0}}{\left(1 - \frac{V_{CB}}{\varphi_0}\right)^{n_c}}$$

Based on (1) and (2) the positive and negative phase insight in effect to VCB cancels off the Cbc-reversebias with a single forward biased base collector diode integration, Cbc-forwardbias. However, with the aid of two base collector diodes (Cbc-forwardbias > Cbc-reversebias) and L3, an opposite phase response (AM - PM) is observed at the output of the APD. The simulated AM-PM responses of the devices at location A and C is illustrated in Figure 2.The APD's phase expansion and main amplifier's phase compression cancels out each other contributing to the improvement of the IMD3 performance.

On the other hand, generation of an opposite AM-AM response is accomplished through the T section intermediate matching network, consists of C4, L2 and C5. The Smith plot of Figure 3 illustrates the location of the output impedance of the APD denoted at point A. Point B describes the input impedance of the main amplifier. Based on the profile of Figure 4, matching towards point A which observes a gain expansion compensates the gain compression of the main amplifier.

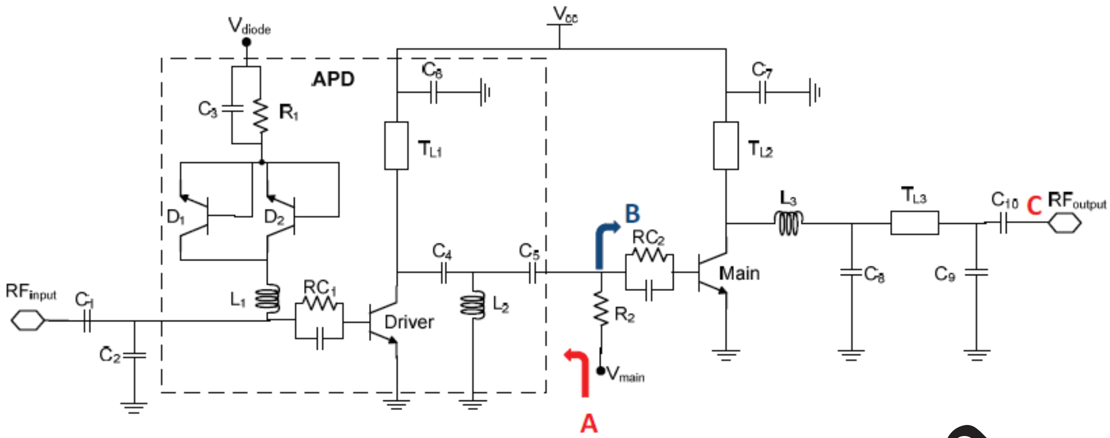

Figure 1. Schematic diagram of the UMTS PA with built in APD. "A" denotes the output of the APD, "C" is the output of the class-B main amplifier. "B" is the input of the main amplifier.

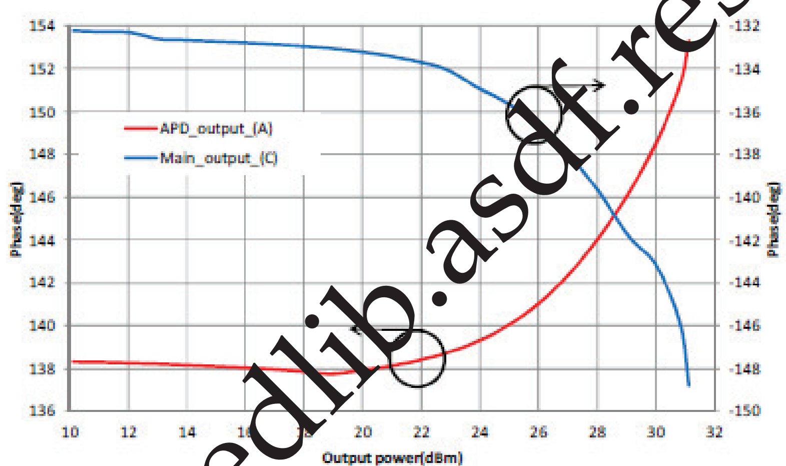

Figure 2. Simulated AM-PM response at location A and C respectively.

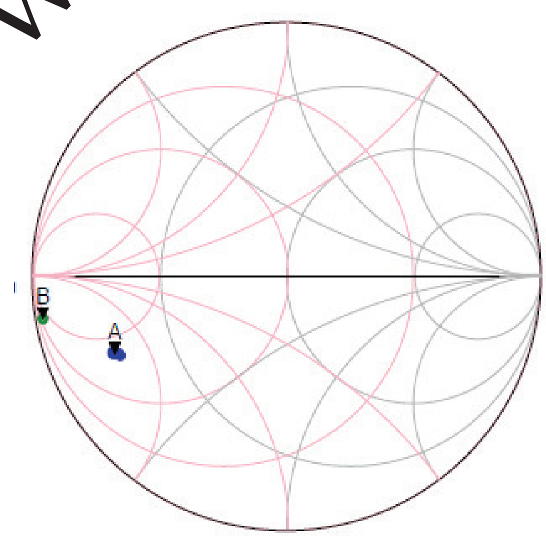

Figure 3. Location of the impedance point of the APD (A) and main amplifier (B).

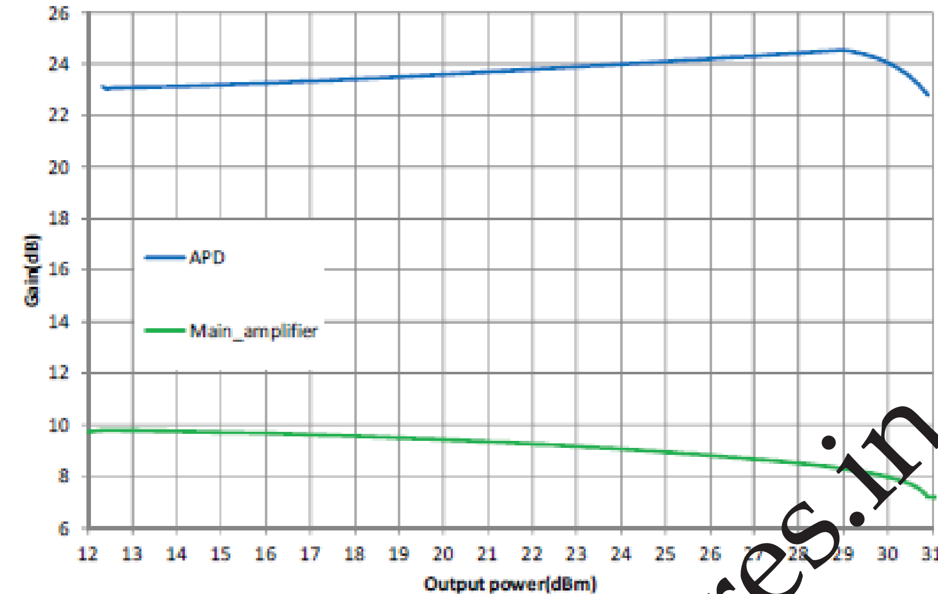

Figure 4. AM-AM profile of the APD and the main amplifier.

Simulation Results

The S-parameters of the proposed UMTS PA with supply headroom of 3.3V are shown in Figure 5. The S11 and S22 are well matched at 1.95GHz, with a corresponding gain S21 of 33.3dB. A low S11 indicates that the APD does not generate a severe input mismatch loss at the fundamental frequency.

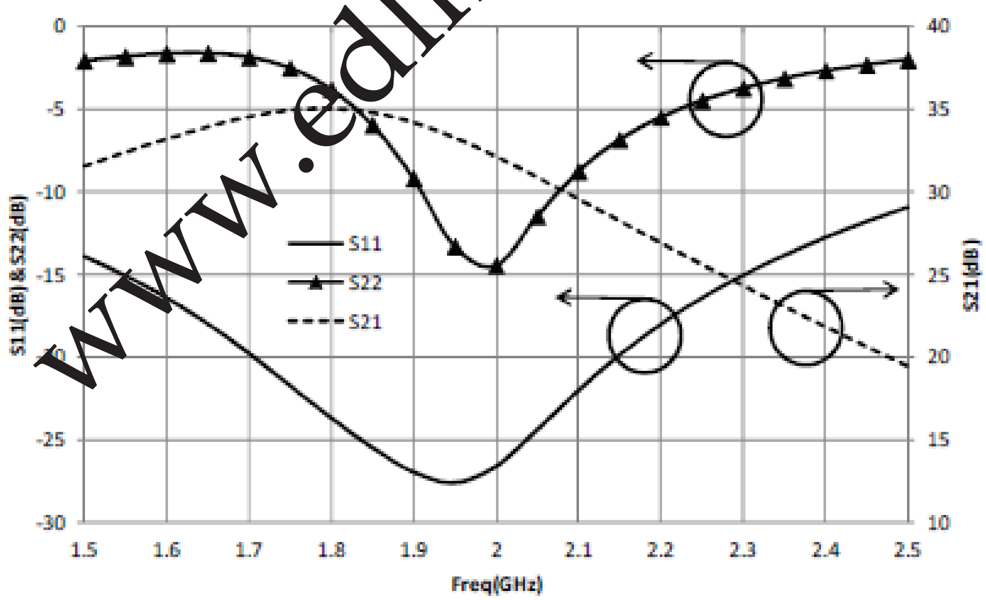

Figure 5. Measured and simulated parameters of the PA with a supply voltage of 3.3V.

With more than 30dB of power gain, the PA is still unconditionally stable. The K-factor plot is illustrated in Figure 6. From DC to 3GHz, K-Factor is observed to be more than 1.

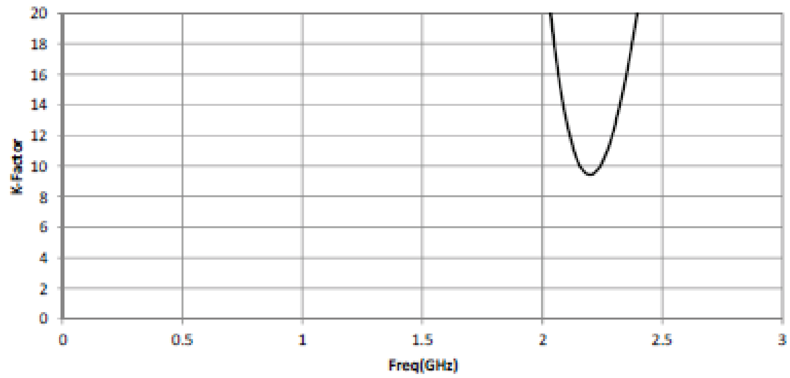

Figure 6. PA has K-Factor >1 from DC up to 3GHz.

The power gain across output power plot of the PA is shown in Figure 7, which measures up to maximum output power of 30.5dBm, or 1.1W. The 1dB compression point of the PA is observed to be 29.5dBm.

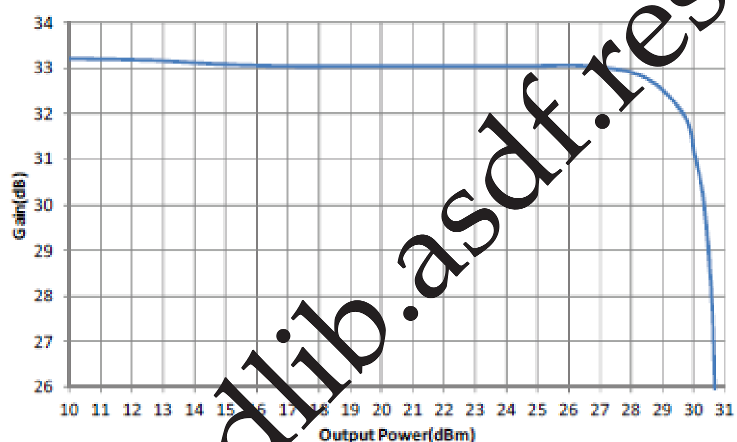

Figure 7. Gain vs output power plot of the PA.

The resulting ACLR and PAE plot is shown in Figure 8. With a supply voltage of 3.3V, PA is capable to deliver PAE of 52.3% at output power of 28dBm, with a corresponding ACLR of -36dBc. The regulated specification for ACLR is -33dBc, as per stated in the 3GPP specifications.

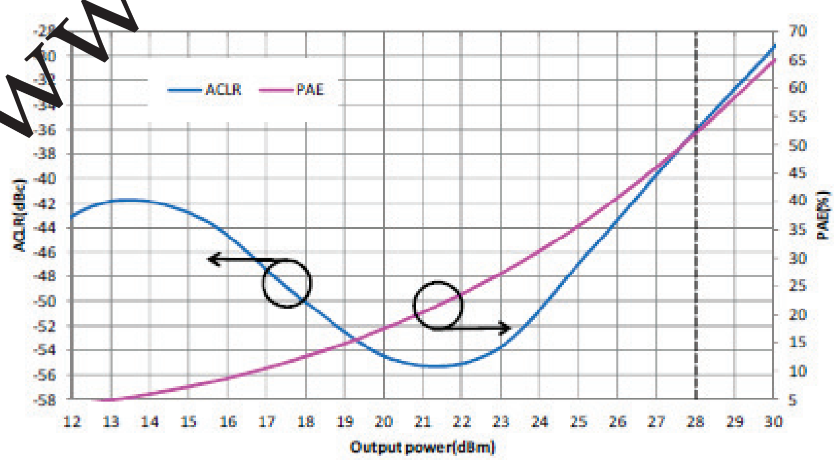

Figure 8. ACLR and PAE performances of the linearized PA at 1.95GHz.

In Figure 9, the contribution of the proposed linearization technique is apparent. The ACLR improves 14dB at output power of 28dBm.

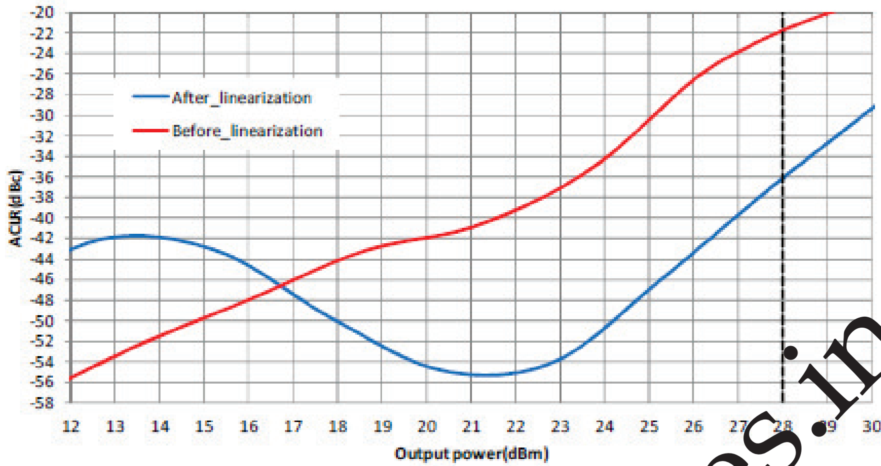

Figure 9. ACLR plot before and after linearization.

In Figure 10, the ACLR spectrum at the maximum linear output power of 28dBm before and after linearization is illustrated.

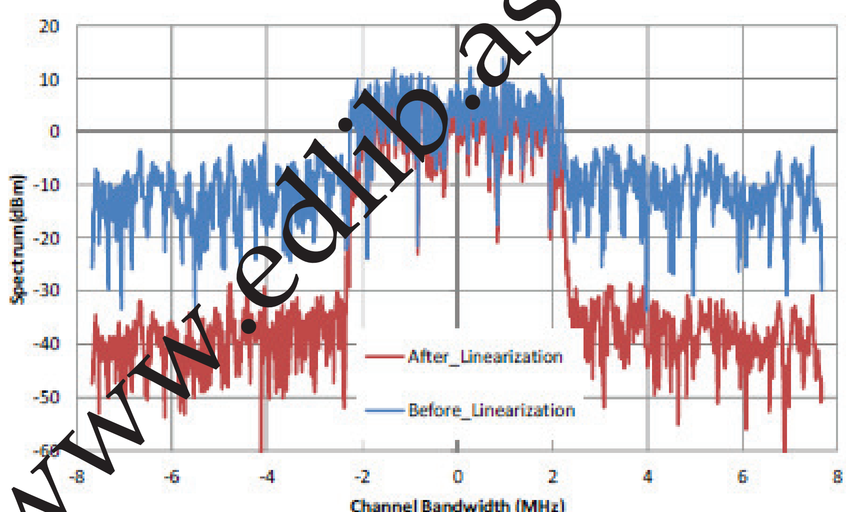

Figure 10. Spectrum plot at 28dBm before and after linearization.

Conclusion

A novel linearizer topology to improve the maximum linear output power of a UMTS PA is introduced. The integrated analog predistorter (APD) which provides a significant improvement in the ACLR does not jeopardize the input return loss, gain and stability of the PA, which are critical in constructing a reliable transmitter. At output power of 28dBm, PA delivers 52.3% PAE, meeting the ACLR specifications for UMTS. The single chip solution saves the design cost too. These results highlight the potential application of the proposed PA in a handset transmitter system, which favors a low voltage operation, thus prolonging the battery life.

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