Adaptive Bias LINC Architecture for Wireless Transmitters

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Abstract

In this paper, a novel adaptive bias LInear amplification with Nonlinear Components (LINC) transmitter is introduced and simulated. Where predistortion is applied to the baseband signal; thus the bias of the high efficient power amplifier (PA) is adaptively changed according to the envelop distribution of the modulated baseband signal and the PA itself. This novel transmitter can simultaneously achieve relatively high average efficiency and linearity even with a high peak-to-average (PAR) signal. A comprehensive simulation framework has been developed to validate this adaptive bias scheme with 16, 32, and 64 QAM signals, which have higher than 5 dB PAR levels.

1. Introduction

In modern digital communication systems, various modulation schemes have been applied to achieve high spectrum efficiency. These schemes include high order M-ary QAM and OFDM. However, these signals are characterized by high PAR which is manifested by a deep envelope fluctuation. This high PAR constitutes a serious nonlinear behavior problem of the PA. On the other hand, high average efficiency is needed as it would significantly influence the thermal management, reliability, and operating costs of the base stations. LINC is a very promising methodology to eliminate the need for highly linear PAs. The simplified LINC transmitter is shown in Fig.1a. The LINC principle is based on decomposing an amplitude modulated signal into two constant-envelope components using a signal component separator (SCS). The resulting two constant-envelope signals then can be amplified individually by two highly efficient non-linear amplifiers. During this amplification, these constant-envelope signals are robust against amplitude distortion. After amplification, they are properly combined to create the linearly-amplified signal. The concept of LINC was introduced by Cox [2] in 1974. After Cox, the LINC approach has been applied to a variety of communication systems. Multiple variations/ modifications [3-6] on the LINC approach have been lately proposed to improve the linearity or efficiency of the modern wireless communication systems. However, it is still difficult to simultaneously achieve high average efficiency and high linearity---especially for a high PAR signal. In this paper, a novel adaptive bias scheme will be proposed based on several innovations, including using high efficiency switching-mode power amplifiers (SMPA) --- under different bias with a constant input power, optimizing the combiner's efficiency based on known SMPA gain performance and the signal's dynamics with baseband predistortion. It is anticipated that this adaptive bias LINC could be utilized for a wide range of communication standards as well.

2. Challenges in LINC Transmitter

Generally, there are four kinds of combiners that can be used at the output combining stage. These combiners can be separated into two categories: Isolated (Wilkinson and Hybrid) and Non-isolated (Chiréix and Lossless). The isolated combiners yield perfect linearity at the output; however, their combing efficiency degrades dramatically special for a high PAR signal. Although the non-isolated combiners offer high average combining efficiency, their linearity is poor. As shown in [7], even with phase predistortion, the Chireix combiner with saturated nonlinear amplifiers to reach the objective of both high-efficiency and high-linearity amplification does not seem possible. The choice of the PAs' type and operation is very crucial for the LINC transmitter design. Since the transmitter overall efficiency is also dependent upon the specific efficiency characteristics of its individual PAs. In general, the efficiency of SMPAs (Class D, E and F) is substantially higher than the conventional linear-mode PAs. Furthermore, in the LINC transmitter, when an isolated power combiner is utilized, the PA selection is relatively unrestricted. In short, SMPAs with isolated combiners could achieve higher linearity than those with non-isolated combiners. Even

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though SMPAs with isolated combiners are recognized to have lower combining efficiency than those with non-isolated combiners, a novel adaptive bias scheme can be utilized to increase the average efficiency while sustaining a relatively high linearity.

3. Adaptive Bias LINC Transmitter Approach

In the adaptive bias LINC transmitter, the high linearity is achieved with an isolated combiner and baseband predistortion while the LINC transmitter's average overall efficiency is improved by changing the DC bias of the SMPAs with a constant input power and decreasing the decomposition angle of the signal.

As shown in Fig.1a, in regular LINC transmitter, a general band-limited signal S(t) can be written as:

$$S(t) = A(t)\cos(\omega t); \qquad A(t) = r_{\max}\cos(\phi(t)) \qquad (1)$$

Here A(t) is the signal amplitude, ω is the carrier frequency, r_{max} is maximum amplitude of A(t). This signal is split by the SCS into two signals: S_1(t) and S_2(t), with modulated phases and constant-envelope:

$$S_1(t) = 0.5\ r_{\max}\cos(\omega t - \phi(t)); \qquad S_2(t) = 0.5\ r_{\max}\cos(\omega t + \phi(t)) \qquad (2)$$

Fig.1b&c shows that the decomposition angle of a regular LINC (ϕ(t)) is larger than that of an adaptive bias LINC (g(t)) and the new decomposition angle *g*(t) is defined as:

$$\cos(g(t)) = \begin{cases} \cos(\phi(t)) & for\ \ \phi(t) < \phi_{th} \\ \alpha\cos(\phi(t)) & for\ \ \phi(t) > \phi_{th} \end{cases} \qquad \phi_{th} : threshold\ angle \qquad (3)$$

α is a bias index that will be determined in the following analysis.
For an isolated combiner:
When ϕ(t)>ϕ_{th}, the combining angle changes from ϕ(t) to *g*(t), the output signal of the isolated combiner increases: $V_{ocombiner2} = \cos(g(t))/\cos(\phi(t))\ V_{ocombiner1}$ (4)

By this way the combining efficiency of the isolated combiner increases from $\cos^2(\phi(t))$ to $\cos^2(g(t))$.
For a SMPA:
When ϕ(t)> ϕ_{th}, V_{dc1} changes to V_{dc2} (V_{dc2}<V_{dc1}), the voltage-gain of the SMPA decreases:

$$G_2 = G_1 / \alpha \qquad (5)$$

Here, G_2, G_1 are the voltage-gains under V_{dc2}, V_{dc1} respectively.
Subsequently, the output voltage of the SMPA reduces and is given by: $V_{opa2} = V_{opa1}/\alpha$ (6)

$$G_1 / G_2 = \cos(g(t)) / \cos(\phi(t)) = \alpha \qquad (7)$$

In order to linearly amplify the signal with the adaptive bias scheme, (7) should be satisfied. Ideally, α is only restricted to ($1/\cos(\phi(t)) > \alpha > 1$). However in practical designs, it is preferred to select different levels of V_{dc} and choose g(t) according to a discrete set of G_1/G_2 ratios. Therefore, the threshold angle can be selected: $\phi_{th} = \cos^{-1}(1/\alpha)$ (8)

When ϕ(t)<ϕ_{th}, an adaptive bias LINC functions as a regular LINC. However, when ϕ(t)>ϕ_{th}, predistortion is applied to the baseband signal and the bias of the SMPA is adaptive changed. The efficiency of the adaptive bias LINC transmitter is the product of the combiner's and SMPAs' efficiency given that the SCS portion only consumes a very small fraction of the DC power. To achieve a high overall efficiency, the efficiency of the SMPAs should not be significantly reduced when lowering the voltage-gain. Meanwhile, when more discrete levels of V_{dc} are applied, it is possible to produce even higher average combining efficiency, but the adaptive bias LINC transmitter will become progressively more complicated.

4. Adaptive Bias LINC Transmitter Simulation

In this study, a voltage mode class D (VMCD) PA is selected for its high efficiency performance and will be analyzed here. The schematic diagram of an ideal VMCD PA and its transient waveforms can be found in [8]. Here, a more realistic VMCD PA (shown in Fig.2a) will be used. The simulation results of this VMCD PA are shown in Fig.2b, where the drain bias voltage and the input power level have been selected to assure that the voltage-gain (V_Gain) is linearly proportional to V_{dc} with a constant input power, meanwhile the drain efficiency only has a noticeable, slight deviation. Fig.3a shows the architecture of the adaptive bias LINC transmitter. Fig.3b shows the proposed simulation framework, where ADS Ptolemy simulation incorporates Matlab and Circuit Envelope simulator. Matlab is used to generate two constant envelope baseband signals with baseband predistortion --- $s_1(t)$ & $s_2(t)$, emulating the SCS and LUT. Rather than operating on the RF signals S(t), $S_1(t)$ & $S_2(t)$ as mentioned in Fig. 1a, their baseband equivalents, s(t), s1(t) & s2(t) are used here. Within the Ptolemy environment, these two baseband signals are up-converted into RF signals --- $S_1(t)$ & $S_2(t)$, then they are imported into a sub-level simulation environment (Circuit Envelope simulator) with bias control signals. In the sub-level environment, the two RF signals are fed to VMCD PAs and summed by an isolated combiner. The bias control signals switch the drain bias of the VMCD PAs through a single pole/multi throw switch. The VMCD PAs are simulated through the Circuit Envelope simulator to predict their efficiency and their in-band & out-band nonlinearity. Afterwards, the output of the isolated combiner is exported back to the Ptolemy environment. The amplified RF signal is then down-converted into baseband, and finally, Matlab sink module is used to plot and compare the amplified baseband signal with the reference baseband signal. Here a LINC transmitter with 16QAM input signal (24.3K sym/s) is simulated as an example to demonstrate the robustness of the simulation framework and validate the adaptive bias LINC concept. The in-band and out-of-band distortion expressed in terms of EVM and ACPR (channel bandwidth: 32KHz, offset: 35KHz) are used to evaluate the linearity of the system. The input 16QAM signal with 5dB PAR uses raised cosine filter to generate I and Q signals. Fig.4 presents the normalized spectrum of reference signal and output signals of regular/adaptive bias LINC transmitter. The noise floor is slightly higher for adaptive bias transmitter compared to that of regular LINC transmitter, further simulation indicates that this is due to the abrupt drain voltage switching of the GaN VMCD PA. Table I compares the average overall efficiency between regular LINC and adaptive bias LINC transmitter using three different modulated signals (16, 32 and 64QAM). Table I shows that the adaptive bias LINC achieves over 10% higher average overall efficiency than the regular LINC, although it achieves slightly worse ACPR and EVM than regular LINC. However, in each case the adaptive bias LINC achieves ACPR>45dBc and EVM<2%. Table I also shows that with higher PAR signals, the improvement of average overall efficiency is even more pronounced. This novel adaptive LINC scheme is not limited to QAM modulation which has been validated here, but it can be applied to multi-standard transmitter by simply changing the baseband signal processing.

5. Conclusion

We have proposed a novel adaptive bias LINC transmitter. The new decomposition angle is determined not only by the signal's dynamic properties but also by the combiner's combining efficiency and the SMPA's gain/efficiency performance under different bias conditions. A comprehensive simulation framework has been used at the system level to take the switch's transient delay, the nonlinearity of the VMCD PA and the non-ideal property of the combiner into account in one simulation environment. The simulation results showed that this novel scheme can help in improving the average overall efficiency of the LINC transmitter at least 10% while sustaining a relatively high linearity.

6. Reference

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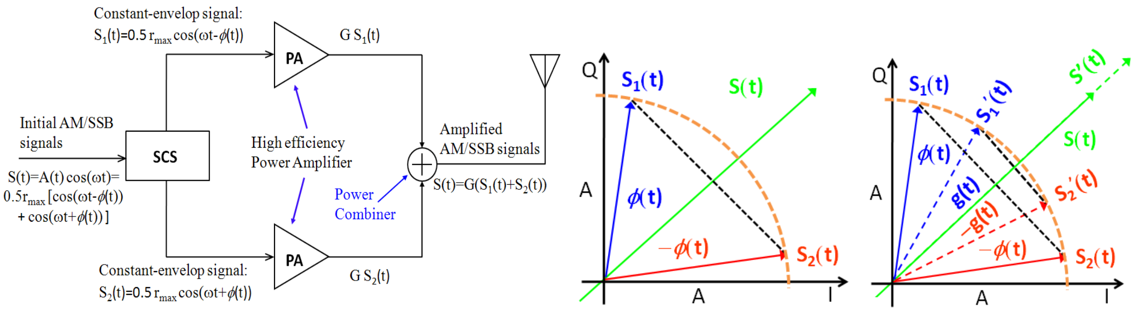
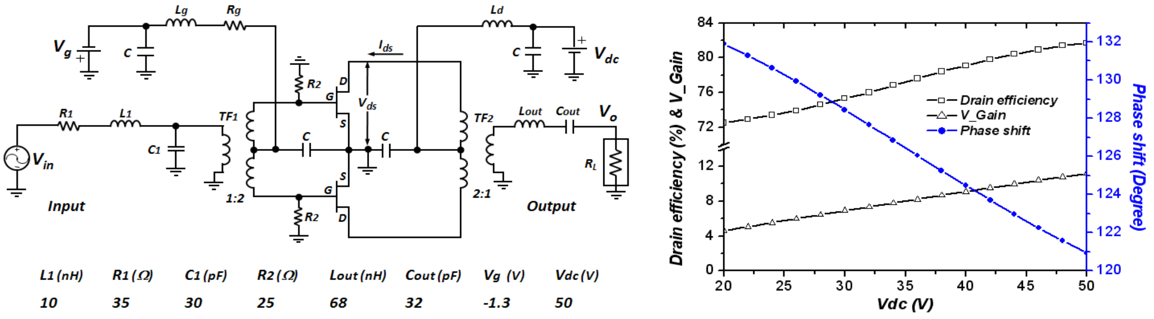


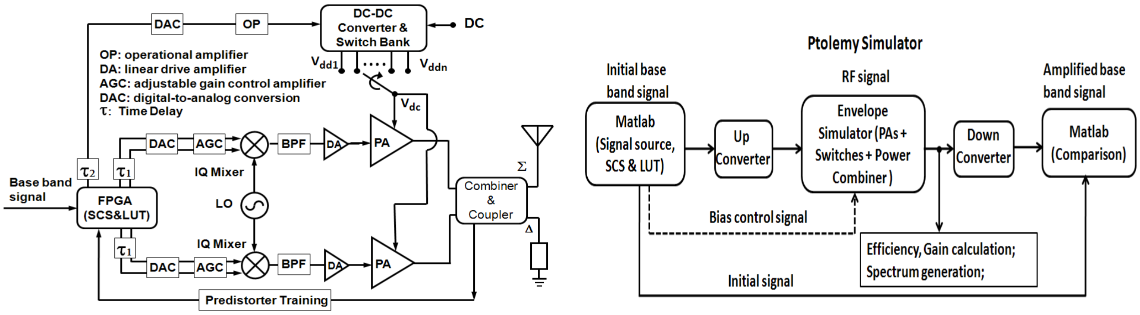
(a) (b) (c)

Fig. 1. (a) A simplified LINC transmitter schematic; (b) Regular LINC; (c) Adaptive bias LINC.



(a) (b)

Fig.2. (a) VMCD PA simulation schematic at 100 MHz using GaN HEMT (Eudyna EGN045MK); (b) Drain voltage vs. Drain efficiency, Voltage gain and Phase shift between input and output.



(a) (b)

Fig.3. (a) Adaptive bias LINC transmitter architecture; (b) Block diagram of overall system simulation.

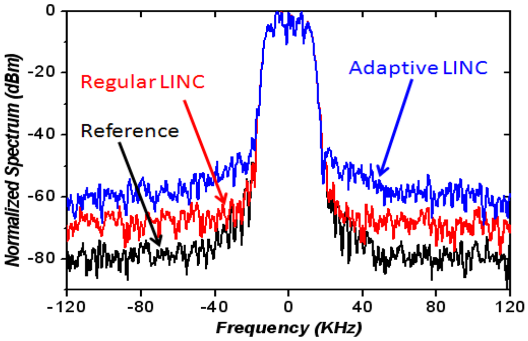


Fig.4. Simulation results for 16QAM: Normalized spectrum for reference, regular and adaptive bias LINC.

TABLE I
COMPARISON OF REGULAR LINC AND ADAPTIVE BIAS LINC

Modulated Signal	PAR (dB)	LINC Scheme	Average overall efficiency (%)	ACPR (dBc)	EVM (%)
16 QAM	5.0	Regular	43.2	55.2	0.29
		Adaptive bias	53.3	46.0	0.79
		Reference	N/A	56.2	N/A
32 QAM	5.7	Regular	39.4	53.3	0.21
		Adaptive bias	51.5	46.0	1.23
		Reference	N/A	54.2	N/A
64 QAM	6.8	Regular	34.3	55.2	0.34
		Adaptive bias	49.4	45.3	1.86
		Reference	N/A	57.2	N/A