Overview of the Linearization Techniques to mitigate the nonlinear effects of Power Amplifier

Rajbir Kaur[1,a]and M.S. Patterh[1,b]

[1a] Assistant Professor and[1b]Professor, Punjabi University, Patiala
E-mail: [1]rajbir277@yahoo.co.in

Abstract. The methods to enhance the performance of communication systems is on the rise. New innovations are required to achieve improved performance. As radio frequency (RF) power amplifier (PA) is one of the important block of communication system, so any improvement in the PA performance will definitely contribute to increase the overall communication system performance. PA is a non-linear device. To increase its performance, one has to linearize its response. For this various linearized techniques are available. So this paper gives an overview of the linearized techniques, which can be used to increase the PA performance by mitigating the non-linear effects. A comparative performance analysis of the linearized techniques have been done in this paper to find out the most suitable technique for wireless communication.

Keywords: Power amplifier, linearization, predistortion, feedforward techniques and feedback techniques.

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1. Introduction

With increase of spectral efficiency in mobile communications linearity of PA become a critical design issue especially with non-constant envelop. Linearization enables the PA to generate more output power and to operate at a higher efficiency level for the given input. Linearization is a systematic procedure that can be used to reduce the amplifier distortion, and there are many ways of amplifier linearizing. Normally, extra components are added to amplifier as a linearizer. A wide range of linearization techniques are available to the modern power amplifier communication system designer. In this paper common and mostly applied linearization methods in wireless communication systems are discussed. These techniques can be roughly classified into three groups:
Feedback techniques, Feedforward techniques and Predistortion techniques.

2. Feedback techniques

In Feedback linearization the idea is to force the PA output to follow its input. Thereare different types of feedback linearization topologies classified mainly as RF feedbackand modulation feedback, which can be divided again into two types, polar and Cartesianfeedback. In modulation feedback the modulation components I&Q of PA input and output are compared whereas in RF feedback the RF signals are compared. Feedback systems can be implemented at RF,intermediate frequency (IF) or baseband frequencies. Figure 1 illustrates the use of negative feedback around a PA with the effect of distortion, which is noise signal b (t). If G is the gain of the amplifier and K is the feedback attenuation, then output signal will be obtained as: $Z(t) = G*(s(t)+b(t))$, Feedback signal

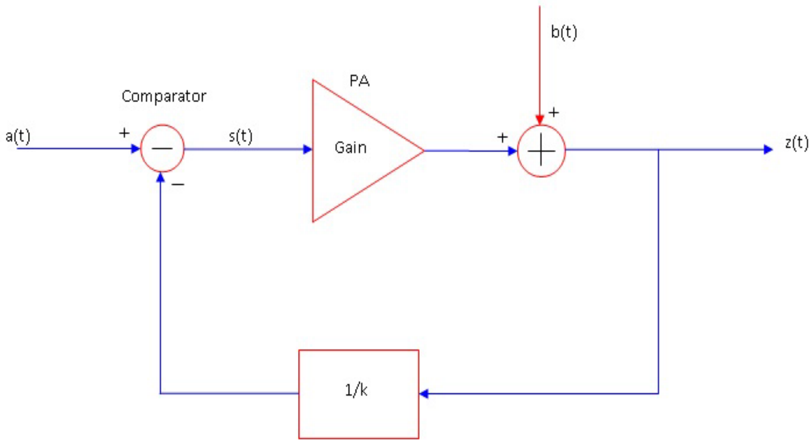

Fig. 1. Simple feedback system to linearize power amplifier

$F(t)=\frac{Z(t)}{K}$, Error signal, $s(t)=a(t)-F(t)$, therefore $z(t) = \frac{K(G*(a(t)+b(t)))}{(G+K)}$.If the amplifier gain is much greater than the feedback ratio that is G>>K, then K + G approximates to G. So $z(t) = \frac{K\times a(t) + (K\times b(t))}{G}$ .Therefore, the distortion produced by the main amplifier is reduced by a factor K/G. The disadvantage of this approach is that the improvement in distortion performance is at the expense of the gain of the power amplifier [1] and also feedback needs more bandwidth than signal.

2.1.1. Simple Envelope Feedback

Simple envelope feedback has matched envelope detectors coupled to the PA's input and output ports as shown in figure 2. A differential amplifier forms amplitude error correcting amplifier based on the detected envelope signals. The resulting error is used to control the gain of the amplifier [2]. This technique has been widely employed to improve the IMD performance of VHF and UHF solid state power amplifier in the communication industry.

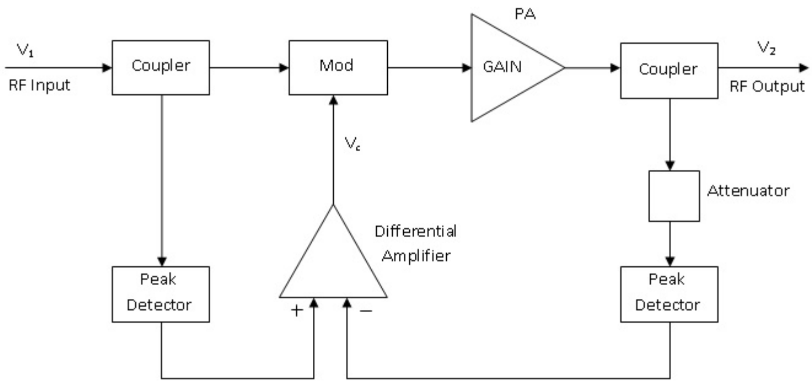

Fig.2. Envelop feedback linearization technique

The main drawback of this technique is that although this technique performs simple amplitude correction, but it starts generating IMD products when the envelope operates in the compression region of the amplifier. The delays in the detection and signal processing can cause phase differences between AM and PM processes. The envelope correction does not provide correction over the operating bandwidth for satellite application.

2.1.2. Cartesian loop feedback linearization

The band width widening problem of polar loop is solved by Cartesian loop linearization technique. Figure 3 shows the Cartesian loop linearization technique. The input signal is separated into I and Q and fed to differential amplifier, where input signals are subtracted from the feedback signal. The error signal is up converted to RF signal using a local oscillator and then combined to produce the complex RF signal, which is amplified by the PA. The output of the PA is sampled using a directional coupler and down converted and separated into I and Q using the same local oscillator used in up conversion process. A phase adjuster is required to ensure that the up and down conversion processes are correctly synchronized. [5]. One of the main drawbacks of this technique is a limited bandwidth due to delay around the loop. Due to the addition of the feedback demodulators and error amplifiers, the PAE of this system is generally not improved unless the additional components can be implemented in an IC with low power dissipation and a high efficiency power amplifier is used. Due to additional delay in IF this circuit is implemented in RF and narrow band systems. Due to stability problems it is not suitable for wide band systems.

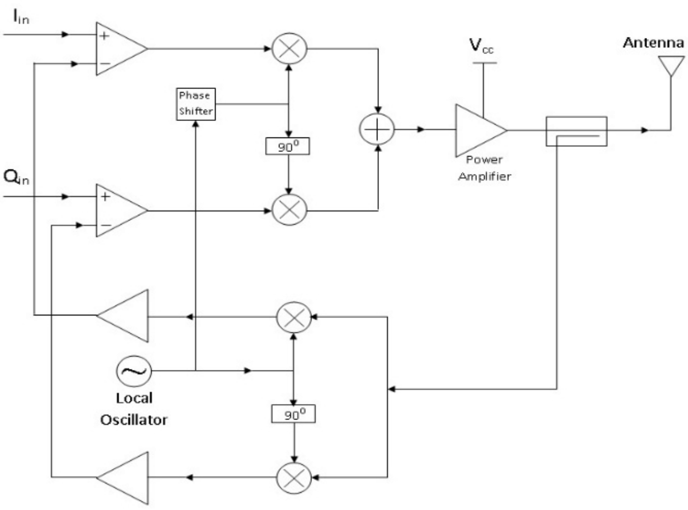

Fig. 3. Cartesian loop linearization technique

3.Feedforward Linear Power Amplifiers

This technique consist of two loops one is carrier cancellation loop (Main loop) and other one is error loop. The main loop couples and attenuates the output signal of the PA. RF signal is first applied to the main signal path to obtain the required power attenuation and phase shifting. Then RF signal is amplified by the main amplifier. The main loop is adjusted to cancel the carrier signal and introduce a sample of the distortion to the error amplifier.Figure 4 illustrate the feed forward linearization scheme. The fixed attenuator minimize the output of coupler and make it equal to input signal. The delay (τ) is used to adjust the phase between the input signal and the output signal of PA and sub tractor is used to subtract the two signals, so carrier signal will be eliminated. Error loop amplifies the distortion and adjust the phase. The output of the error loop V_D is applied to the output sub tractor to cancel the distortion. Because of non-linear characteristics of power amplifier $V_s = V_{in}A_{vc} + V_d$. The main power amplifier is attenuated by a circuit with transfer function $\frac{1}{A_{vc}}$. The output signal from attenuator is subtracted from the original signal V_{in} to generate an error signal. $V_e = V_a - V_{in}, V_e = \frac{V_d}{A_{vc}}$. This error signal is amplified by the error power amplifier and subtracted from the original power amplifier output signal to obtain output without distortion. $V_{eo} = V_e A_{vc} = \frac{V_d}{A_{vc}} \times A_{vc} = V_d, V_{out} = V_{in}A_{vc}$.

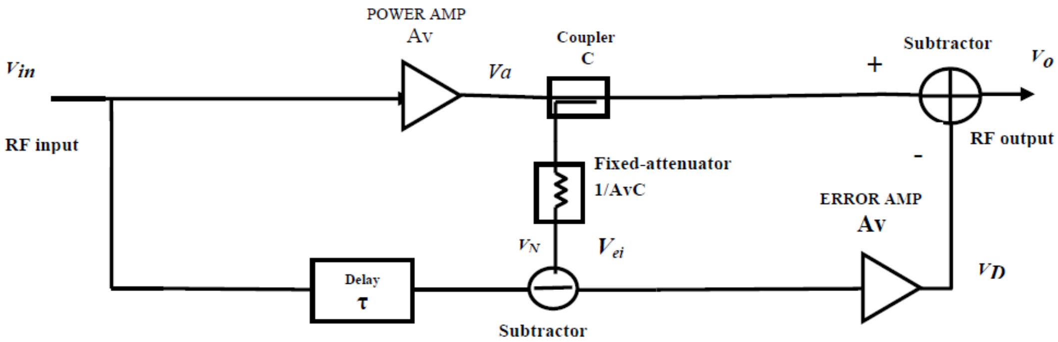

Fig.4. Feedforward linearizer technique

Hence distortion signal V_d is cancelled out for perfect amplitude and phase matching at each sub tractor. This system suppress the noise added to the signal in the main power amplifier [6]. Advantage of Feed forward linearization is that it provides high linearity improvement i.e. carrier to intermodulation ratio (C/I) is more than 50 dBc and it can deal with large bandwidth signals. Disadvantages of this technique are: Efficiency is dependent on insertion loss in the couplers, loss in delay lines, [7],Circuit is complex , sensitive to changes in amplifier characteristics, components tolerances and instantaneous power fluctuations, large physical size, poor efficiency because an auxiliary error power amplifier is needed and high cost.

4.Analog Predistortion

Analog predistortion is realized by creating the required AM/AM and AM/PM nonlinearities canceling the effects of PA using analog components. It can be implemented at RF, IF or baseband. The advantages of analog predistortion are its relatively simple circuitry, low cost, low power consumption, wideband signal handling capability and integrity. However, these systems can have in general just a moderate linearization performance and they introduce insertion loss. Moreover if they are implemented adaptively, then system complexity may increase significantly. There are various ways to implement analog predistortion. A reliable Analog predistortion system must have a kind of adaptation adjusting the predistorter according to the environmental conditions. High linearity systems based on RF predistortion are extremely difficult to achieve and are not widely available. In analog predistortion the gain and phase flatness of the predistorter and of the PA limit the operating bandwidth, and the memory effects in both of them limit the linearization performance. RF predistorter operate just in front of the power amplifier at high efficiency.

5.Digital Pre-distortion

Digital Pre-distortion is a popular technique to compensate for PA nonlinearity. It has the advantage of unconditional stability. The bandwidth is limited by the gain and phase flatness of the pre-distorter. In digital pre-distortion the inverse of the PAs response function(H), is first identified and then used for pre-distorting the signal before it is fed to the PA in such a way that the output signal of the PA is similar to the desired output, according to given linearization criteria. The output of the digital pre-distortion algorithm $y(t) = H^{-1}\{x_d(t)\}$ is fed to the PA so that the overall output can calculated as $x(t) = H\{y(t)\} = H\{H^{-1}[x_d(t)]\}$, If the inverse function (H-1), is close to the inverse to the real function of the PA, the output of the PA, x (t), will be close to the desired signal, xd(t).

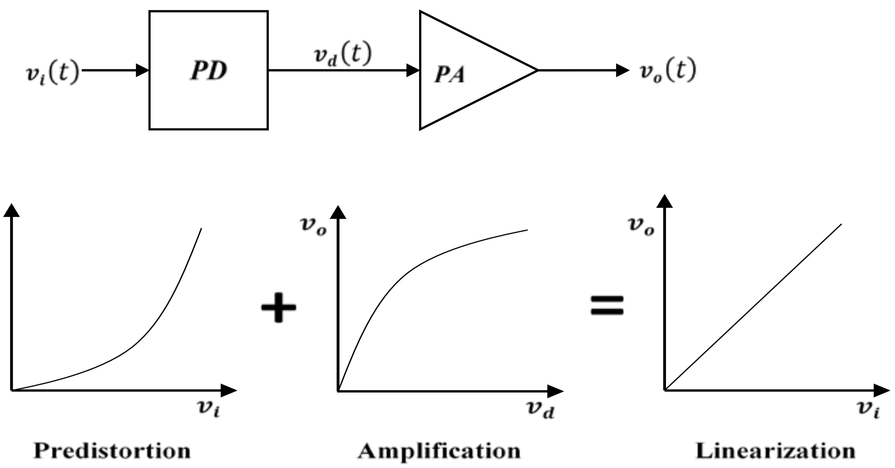

Fig.5.Conceptual block diagram of digital pre-distortion technique
Fig. 6. Power amplifier and predistorter

Digital predistorters have memory structures that are capable of linearizing power amplifiers with memory effects. The predistorter is situated in front of the non-linear power amplifier in order to generate the reverse characteristics transfer function of the amplifier by multiplying the input signal with the predistorter gain [8].This predistortion transfer function is passed through the power amplifier to compensate the non-linearity generated by the amplifier.Depending on the location of the predistorter in the transmitter,it can be divided into base band,IF and RF predistorter. The predistortion system performs four tasks. First one is Modelling of the power amplifier. Second one is Adaptive identification of the PA model parameters [9-10]. Third one is Design of the pre-distortion filter. Fourth one is realization of the Pre-distortion unit. A DPD model is a system that describe the behavior of composite systems such as mixed signal devices such as DACs, ADCs, analog circuitry such as I-Q modulators, filters, Pre-amplifiers and power amplifiers. After modeling an adaptation algorithm is applied for estimation of model parameters. The predistortion can be categorized in three parts according to the frequency at which it is implemented; RF predistortion, IF Predistortion and Baseband Predistortion. The advantages of the RF/IF predistortion is the simplicity of implementation, using few components with low cost, no stability problems compared to feedback linearization technique, usable in microwave frequencies, wide linearization bandwidth. The disadvantages are that it has modest linearity improvement, high order distortion cannot be get rid of and if the transfer characteristics change, the circuit has to be fabricated again. In adaptive predistortion, the current condition information of the amplifier is always used with the input while adjusting.In non-adaptive predistortion the amplifier characteristics do not change quicklyonce it is adapted.

Table 1: Comparison of different linearization techniques

Technique	Band width	%age efficiency	complexity	Flexibility	Cost	Correction
Feedback linearization techniques	Narrow 15 to 20 MHz	5 to 7%	low	low	low	4 to 5dB
Feedforward linearization techniques	Wide 25 to 65 MHz	6 to 10%	Medium	Medium	High	30 dB
In-Line Predistortion techniques	Narrow 15 to 25 MHz	5 to 8%	low	Very low	low	2 to 3dB
Analog Predistortion linearization techniques	Narrow 15 to 20 MHz	5 to 8%	High	Low	Low	3 to 5 dB
Digital Predistortion techniques	Narrow 15 to 20 MHz	12 to 15%	High	High	High	15 to 20dB

6.CONCLUSION

Efficient and linear power amplification has become an important consideration for portable wireless applications.This need for efficient linearized amplifiers has prompted the re-investigation and interest of various linearization schemes. Feedback, Feedforward, Analog predistortion and Digital predistortion are linearization strategies which begin with a nonlinear yet efficient power amplifier and linearize it to an acceptable level of adjacent channel interference.Among all the linearization techniques discussed in this paper, adaptive digital predistortion method is the most promising techniques suitable for application in wireless communication. The amount of mathematical operations in the adaptation unit is quite high compared to the predistorter in the forward path but since the adaptation unit does not need to operate continuously, so power consumption can be kept reasonably low. It also has the advantage of high degree of linearization, high flexibility, high integrability, no stability problem.

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