

## ***Linearization Techniques for Power Amplifiers***

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Power amplifier linearization is, in essence, the use of electronic correction to eliminate distortion in amplifiers so that designers can use very efficient operating modes such as Class A/B, Class B, or even higher modes. In other words, linearization allows the use of an inexpensive, efficient amplifier instead of a large, inefficient one. The wide variety of air interface standards, frequency bands, and government emissions regulations have resulted in a wide range of linearization techniques, including:

- In-line pre-distortion
- Analog pre-distortion
- Digital pre-distortion
- Feedforward
- Cross-cancellation
- Envelope Elimination & Restoration

Each of these techniques has proven to be useful for specific applications, based on the wide variety of requirements for peak power, bandwidth, linearity, and efficiency. This paper will examine the unique advantages of each approach. In addition, this paper will discuss the trends in wireless base station system architecture which are driving PA designers to develop new linearization systems.

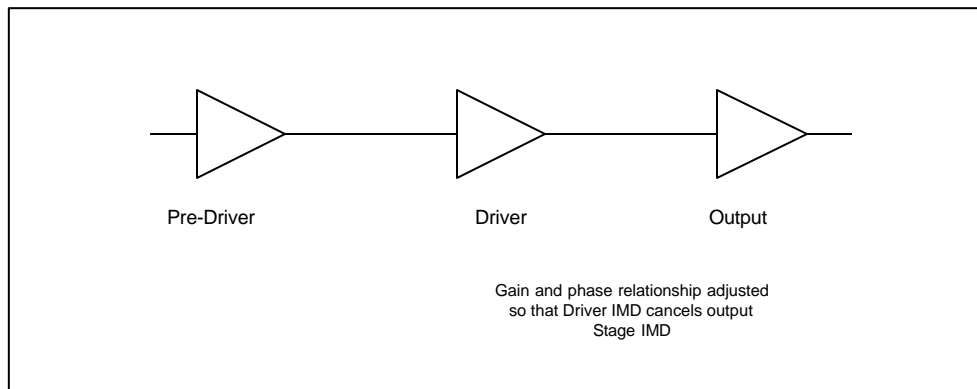
	<b>Correction</b>	<b>Bandwidth</b>	<b>Efficiency</b>	<b>Flexibility</b>	<b>Cost</b>
In-line Pre-D	<b>2-3 dB</b>	<b>15-25 MHz</b>	<b>5-8%</b>	<b>Low</b>	<b>Very low</b>
Diode-based Analog Pre-D	<b>3-5 dB</b>	<b>15-25 MHz</b>	<b>5-8%</b>	<b>Low</b>	<b>Low</b>
Cross- cancellation	<b>15-20 dB</b>	<b>10-20 MHz</b>	<b>10-12%</b>	<b>Medium</b>	<b>Medium</b>
Feed-forward	<b>30 dB</b>	<b>25-60 MHz</b>	<b>6-10%</b>	<b>Medium</b>	<b>High</b>
Digital Pre-D	<b>15-20 dB</b>	<b>15-20 MHz</b>	<b>12-14%</b>	<b>High</b>	<b>Medium</b>
Envelope Elimination & Restoration	<b>20-25 dB</b>	<b>15-20 MHz</b>	<b>20%+</b>	<b>Medium</b>	<b>Medium</b>

**Linearization Techniques for Mobile Wireless Applications**

***Simple Analog Techniques:***

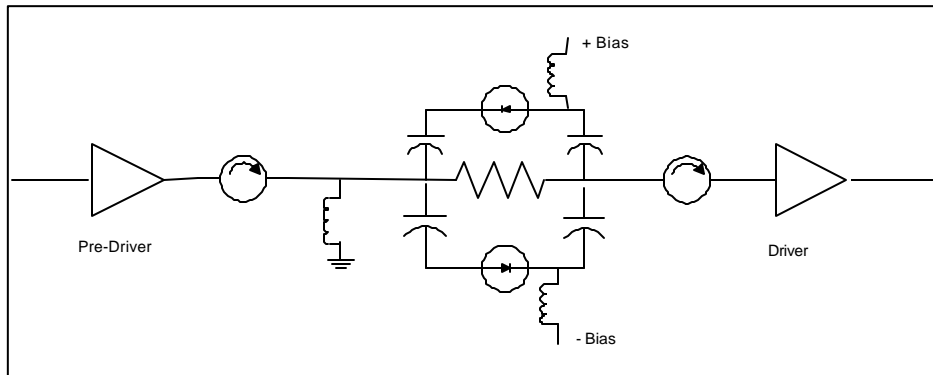
One of the least expensive ways to boost the linearity and efficiency of an amplifier is to apply some simple circuit tricks to the input of the amplifier, in order to compensate for distortion at the output stage. These techniques normally yield limited benefit in terms of linearization or efficiency improvement for a given design, but for many applications a minor improvement is adequate to meet the requirement.

In-line pre-distortion involves the use of driver amplification stages in order to compensate for the distortion of the output stage. Essentially, in this approach the designer seeks a balance between the amplitude of the intermodulation products from the driver and the output stages. Then the designer can situate the transistors themselves on a physical layout such that the intermodulation products combine out of phase.



**In-line Pre-distortion Block Diagram**

Other forms of analog pre-distortion can involve diodes or small transistor elements, which are driven at high RF power levels in order to intentionally create distortion. The resulting intermodulation distortion is then applied to the input of the intended amplifier chain in order to result in the canceling of intermodulation in subsequent stages. The simple block diagram shown will address AM/AM distortion through the use of a resistive element and diodes appropriately biased to control the level of distortion. A reactive element can be inserted in an additional network to address AM/PM characteristics.



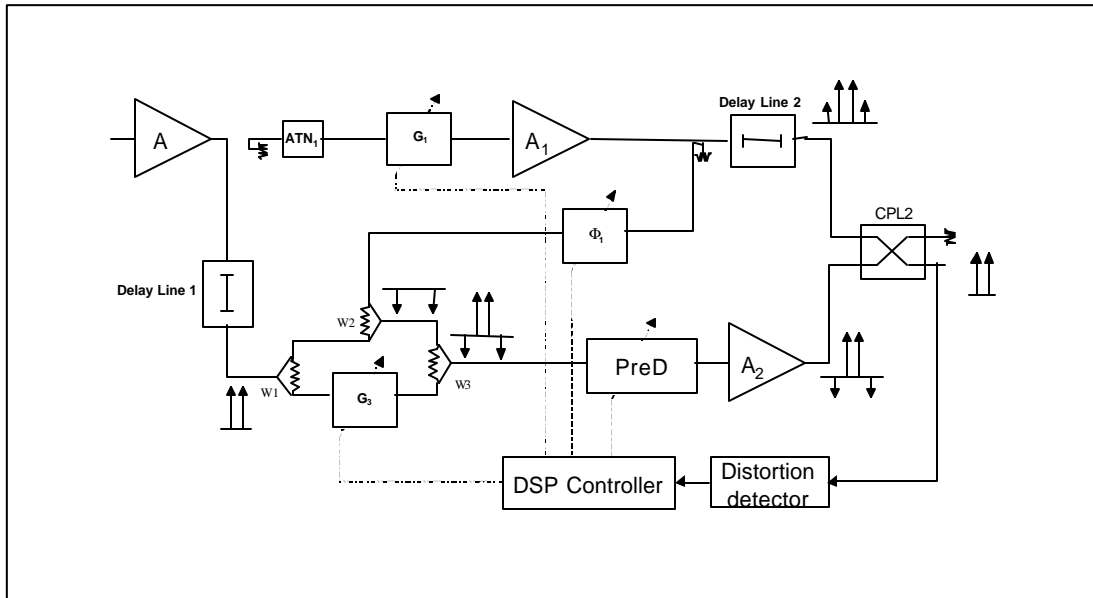
### **Diode-Biased Analog Pre-Distortion Block Diagram**

Note: Other analog pre-distortion techniques have been used in which more complex circuits correct more than the 3-5 dB level. These circuits are beyond the scope of this overview.

#### ***Cross-cancellation:***

One way to achieve higher levels of performance in analog “pre-distortion” is to use two very similar amplifier elements in order to correct each other. In this way, the thermal profile and electrical characteristics of the two elements can more exactly compensate for each other. In addition, the use of adaptive correction loops adds precision and eliminates the impact of variations in performance between the two amplifier elements.

In the cross-cancellation technique, the output of one amplifier is used to predict the distortion of the second identical amplifier. Through a cancellation of the carrier signal followed by manipulation of the phase relationship of intermodulation signals, the cross-cancellation technique can result in highly effective elimination of overall intermodulation distortion at the output hybrid combiner.

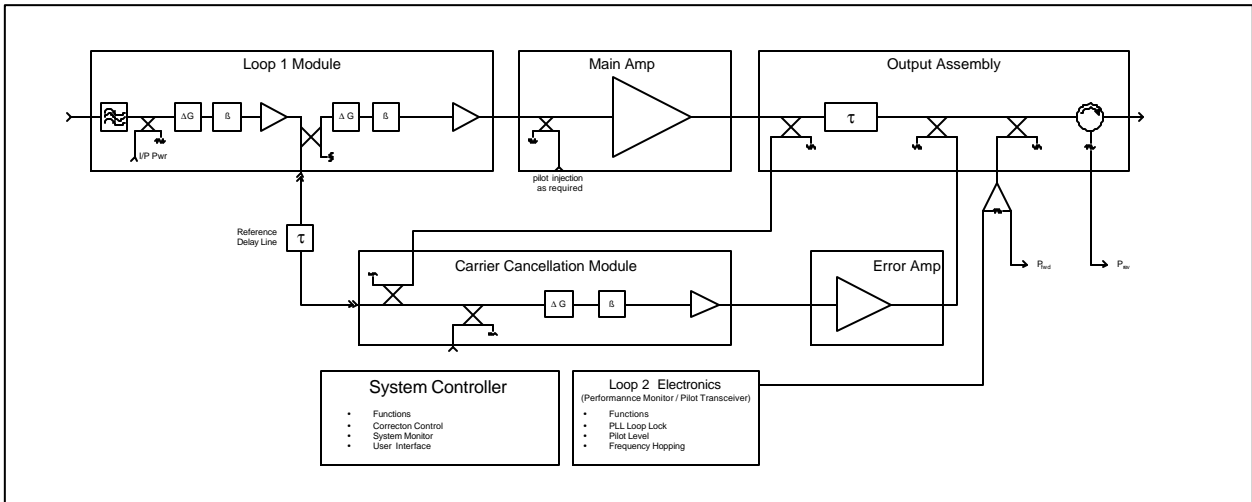


**Cross-Cancellation Block Diagram**

***Feed-forward:***

One of the most common techniques in the industry today involves the use of feed-forward correction. Feed-forward offers both breadth and depth, in that the linearity of an amplifier can be increased by approximately 30 dB, over an instantaneous signal bandwidth ranging up to 60 MHz or more.

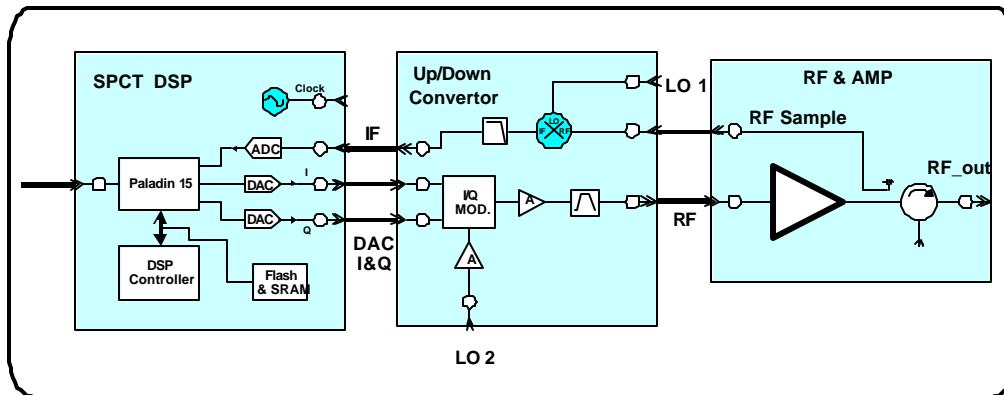
The feed-forward amplifier has been widely used primarily due to the versatility of the design. In this approach, the main amplifier carries the load for output power amplification, and the error signal extracted from the output can be very effectively separated through carrier cancellation (see the block diagram) and re-injected via the error amplifier. Careful control of the phase relationship of the error signal to the main path will result in excellent linearization. The drawbacks of this approach include the cost of the error amplifier and the delay line that becomes necessary in order to maintain the required time relationship between main path and error path.



**Feed-Forward Block Diagram**

**Digital Pre-distortion:**

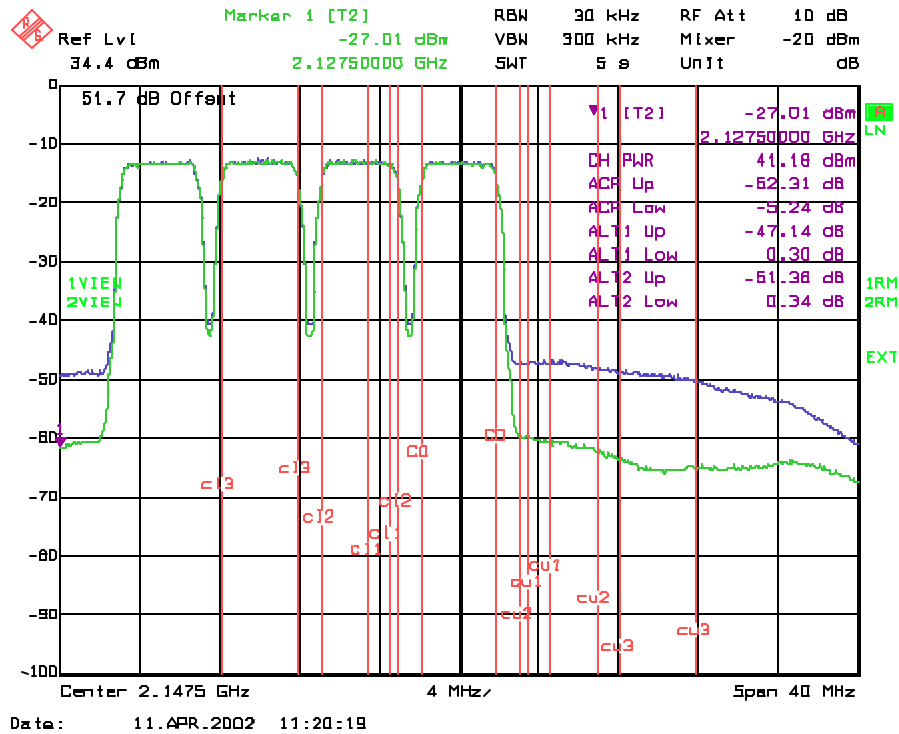
Digitally-based linearization techniques can increase the linearity and efficiency benefits associated with pre-distortion due to the flexible nature of digital adaptation loops. Recent advances in the state of the art for digital and mixed-signal circuits have allowed this technique to become useful in mobile wireless infrastructure systems.



**Digital Pre-distortion Block Diagram**

One realization of digital pre-distortion involves the use of a high speed DSP processor to minimize the distortion created by a conventional power module. The input signal is a composite complex baseband signal; this signal will be pre-distorted by the

DSP processor using information collected by the system controller, which compares the reference input signal with the sample signal from the output of the power amplifier. The pre-distorted baseband digital signal will be converted to analog, upconverted to RF frequency, then amplified by the power module. The adaptation portion is completed by taking a portion of the amplified signal, downconverting to IF frequency, re-sampling and re-digitizing then back to the DSP for optimization.



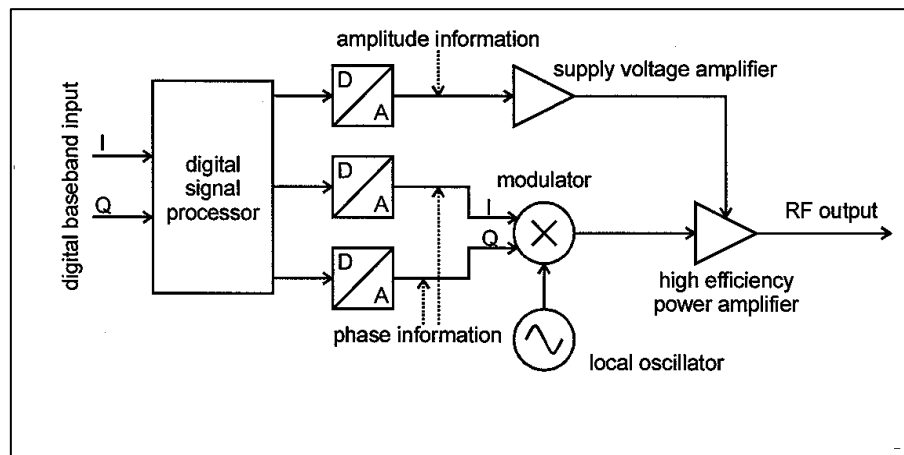
**Digital Pre-distorter performance for four W-CDMA signals  
(50W output power, 17% power module efficiency)**

### ***Envelope Elimination & Restoration:***

One technique under investigation for mobile wireless systems involves the separation of amplitude and phase information in the signal, in order to use very highly efficient amplifier modes. This technology has been applied successfully in some narrowband applications such as handset power amplifiers, and development is continuing to extend the bandwidth for infrastructure applications. Essentially, the concept in envelope elimination and restoration (EE&R) involves the use of a “high class” amplifier, operated in Class D or even Class F mode for the constant-envelope or phase component of the signal. Then, the bursty amplitude component of the signal is

directly applied to the output amplifier as direct modulation. The use of DSP signal processing is applied to the design in order to compensate for non-linear effects in the separate amplifier chains and in the direct modulation at the output.

As mentioned previously, the EE&R technique is under investigation for mobile wireless systems. While narrowband results have been demonstrated with extremely high efficiency results, the commercial application of this technology depends on the viability of wideband operation in the modulator.



**Envelope Elimination and Restoration Block Diagram**

**Conclusion:**

Practical designers in the real world use an infinite variety of techniques from each of these categories, in order to come up with useful amplifier products. In particular, the mobile wireless communications community and has used a wide variety of the techniques described here, due to the high power and high linearity required in mobile networks. In the future, we can expect that increasing cost pressure from consumers and the need for high-speed data transmission will place additional focus on the use of innovative linearization techniques. After all, the purpose for linearization is to reduce cost, increase efficiency, and improve linearity. All of these considerations will be come more important as high-speed data transmission takes a central role in everyday communications.