WHITE PAPER

Optimizing Performance and Efficiency of PAs in Wireless Base Stations: Digital pre-distortion reduces signal distortion at high power levels

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Introduction

Rapid growth in both subscribers and digital content is stressing wireless infrastructures as more data traffic demand is placed on a limited amount of the wireless spectrum. Meeting this demand has escalated procurement costs for base station systems and their operating expenses, which are driven by high energy consumption. Base station power amplifiers (PAs) – the devices that drive wireless signals outward from a base station – can account for as much as 30 percent of a base station's cost. Implementing crest factor reduction (CFR) and digital pre-distortion (DPD) techniques before wireless signals reach the base station PA can improve the quality and coverage of the base station's signal while reducing the system's procurement and operating costs.

Recent years have seen tremendous growth in wireless subscribers. Moreover, new services like music downloads and Internet access on wireless cell phones have meant more and more data transmissions over wireless infrastructures. At the same time, however, the frequency spectrum allocated for wireless communications has been essentially constant. But with more users and more traffic, the wireless spectrum has become very crowded.

This is analogous to a very crowded highway at rush hour. Think of the frequency spectrum as a highway and the data (voice call, music or Internet content) as cars. The highway width or number of lanes represents the fixed available wireless spectrum. Adding lanes to this wireless data highway is a tremendous undertaking, much like adding lanes to a real highway–land must be purchased, buildings torn down and more lanes constructed.

On a vehicular highway, the cars are all going somewhere and their drivers want to arrive on time. Each car represents part of a voice call or a music download; many cars all arriving at the right time represent a completed download or call. As more subscribers use wireless devices to access digital content, more cars are added to the highway. When too many cars clog the freeway, everything slows down. The same thing happens on wireless networks.

To solve this problem, wireless providers have switched to wireless standards that use the spectrum more efficiently. This is analogous to stacking multiple cars (with the same destination) on top of a truck and sending the truck down the highway. This allows more data to flow on the same highway without slowing down traffic. The wireless standards CDMA2000, W-CDMA, TD-SCDMA, MC-GSM, WiMAX and LTE were all deployed or defined to improve spectral efficiency. Figure 1 shows the wireless standards deployed or defined in recent years to improve spectral efficiency.

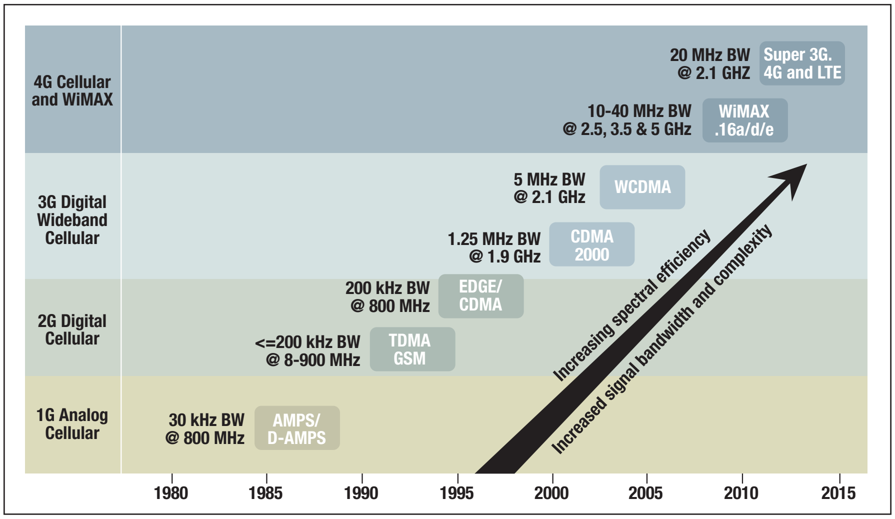

Figure 1: Evolution of wireless standards

Maintaining quality of service

These new wireless standards move greater amounts of data over a fixed frequency spectrum, but they also have a downside-they are very sensitive to distortion in the base station PA. This distortion degrades signal quality and will impair data traffic. To compensate, wireless providers must reduce the transmit power of the PA or purchase much larger PAs to cover the same area. Clearly, wireless providers must maintain coverage; consequently, they purchase larger, more expensive PAs. These larger PAs consume more electricity, increasing operating costs.

The transition to spectrally efficient wireless standards has dramatically increased the cost to deploy and operate wireless services. Solving this problem is critical if providers want to reduce the cost of their services while improving quality. Texas Instruments (TI) has developed a solution that combines adaptive digital pre-distortion (DPD) with crest factor reduction (CFR) to address these issues.

Although past techniques like RF feed-forward, RF feedback, RF/IF pre-distortion and post-distortion have improved PA performance and reduced distortion, adaptive DPD schemes have proven most cost-effective and flexible. The TI DPD/CFR solution enhances PA performance for all contemporary wireless standards and the most prevalent PA technologies, including Class A/B, Doherty and even the emerging envelope-tracking PA architectures. Figure 2 compares DPD with other approaches.

Technique	Cancellation performance	Bandwidth	Power added efficiency	Size/ complexity	Reliability
RF feedback	Good	Narrow	Medium	Medium	Medium
RF feedforward	Good	Wide	Medium	Large	Low
RF pre-distortion	Best	Medium	High	Medium	Medium
Adaptive Digital pre-distortion	Best	Wide	High	Lowest	High

Figure 2: Comparison of common techniques used to improve linearity of power amplifiers

Creeping distortion

DPD and CFR are two signal manipulation techniques that sense the input and output signal characteristics and counteract the mechanisms that allow distortion to creep into a PA's wireless output signals. This results in PAs with output performance that is virtually linear for an extended segment of their operating range. The output power to a PA does not have to be reduced to avoid distortion in the upper end of its operating range. This makes PAs more energy-efficient, which in turn lowers a base station's cooling requirements and operating expenses.

To understand how a PA works, consider Figure 3. An ideal PA would have the linear or one-to-one response shown by the blue line. In this case, raising the input power by 10 percent increases output power by 10 percent. The performance of a real-world PA follows the black curve. It conforms to the ideal PA's performance curve at low output power levels, but deviates and falls below the ideal at higher output power levels. For example, increasing the input power to a real-world PA by 10 percent might only result in a 9 percent increase in output power. Eventually, the PA's output power ceases to increase even as input power continues to rise.

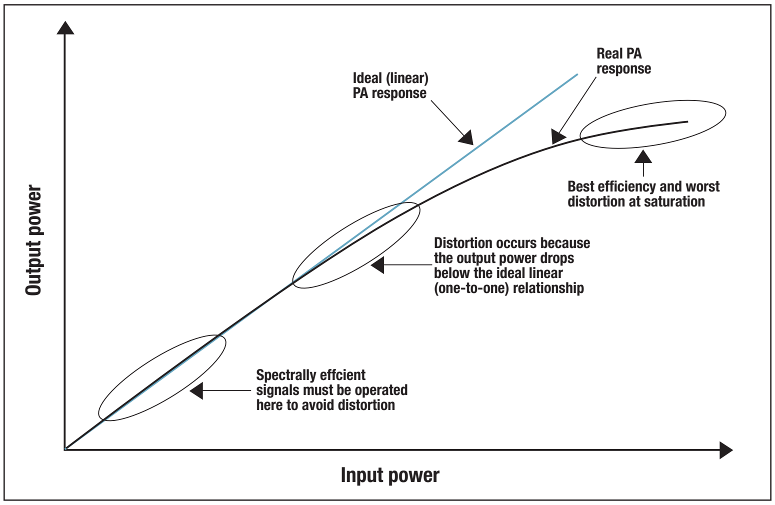

Figure 3: Input to Output characteristic of a power amplifier

To understand the importance of CFR and DPD to current and future wireless infrastructures, you need to understand three fundamental characteristics of PAs. First, the output power determines the range of the wireless signal. Greater output power provides a larger coverage area for the base station. Second, the power efficiency of a PA increases with output power and is highest near its saturation level. From these two characteristics, it is clear that it is best to operate the base station at its highest power to provide the best range and most efficient power consumption.

Historic wireless standards allowed service providers to operate base stations near the maximum output power, providing the lowest capital costs (fewer base stations to cover the same area) and lowest operating costs (lower electricity costs). The explosion in the number of wireless users and the amount of data traversing the infrastructure have changed this because of the third characteristic of PAs: distortion increases with increasing output power and becomes significant when the PA begins to deviate from the ideal (linear) curve.

This third characteristic is important because contemporary wireless standards are much more susceptible to distortion, meaning that base station PAs must be operated at levels well below saturation to ensure acceptable signal quality. At levels below saturation, a greater percentage of input energy is dissipated as heat rather than transmitted in the output signal.

This is analogous to owning a car with a large, very powerful engine but not being able to drive it at high speeds. The owner is paying for a lot of gas because of the poor gas mileage associated with the large engine but can't take advantage of the engine's power. Ideally, if the engine were very fuel-efficient, the owner could enjoy the car's power and at the same time have low gas bills. Similarly, the ideal PA would output strong signals because it would be operating at close to its saturation level; at the same time, there would be very low distortion in the signals. It would also be very energy-efficient because it would be operating at close to saturation. This is exactly what DPD and CFR do for a PA. They increase the linearity of a PA's operating output power, thus reducing its energy consumption.

Linearizing PA performance

Adaptive DPD can extend the straight-line performance of wideband radio frequency (RF) PAs much farther than is normally possible. As mentioned earlier, the output power deviates from the ideal linear performance curve when output power is increased. This is where distortion is introduced into the PA's amplified output signal, resulting in degraded signal quality and interference. DPD compares the distorted output signal of the PA to the undistorted input signal. Then, a signal that is exactly opposite to the distortion in the output signal is added to the input, effectively canceling the distortion. Because DPD extends the linear range of a PA, it is called a linearization technique (Figure 4).

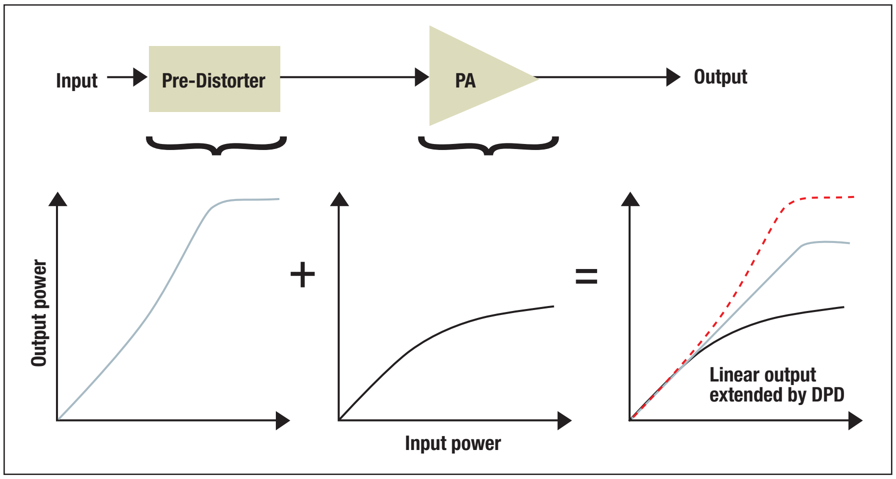

Figure 4: Pre-distortion extends the linear range of power amplifier by compensating for its non-linear behavior

Comparing output and input signals is known as feedback, and is most effectively performed digitally. Because operating conditions such as temperature may change, digital feedback provides the information needed to adapt the pre-distortion to changing conditions. A digital pre-distortion and feedback implementation is much more robust, flexible and manufacturable than an analog implementation. DPD can extend a PA's linear performance by another 2 or 3 decibels (dB), a significant increase considering the operating range of the PA.

By linearizing a PA's output performance over a greater portion of its operating range, less costly, lower rated PAs can still meet the performance requirements of the system. In addition, a PA with a more linear performance curve is more energy-efficient. This reduces electricity costs and makes the system less expensive to deploy because it dissipates less power as heat, easing cooling requirements.

CFR is another type of digital pre-distortion technique. It improves the operating output power of a PA by reducing the peak-to-average ratio (PAR) of input signals. To understand how CFR works, reconsider Figure 3 and our earlier analogy of stacking cars on top of a truck to improve the amount of data or traffic transmitted on wireless networks. Figure 3 shows that if the input power is increased enough, the output power saturates and the PA will not provide any increase in output power. This is like a tunnel that the truck must pass through. If too many cars are stacked on top of the truck, and if the stack is taller than the opening of the tunnel, the top cars will be left on the highway and slow down other traffic. Moreover, when the truck arrives at its destination, several cars will be missing. Those missing cars represent missing parts of a phone call.

Continuing the analogy, the CFR algorithm analyzes the height of each truck to determine whether it is too high to fit through the tunnel. If necessary, it shrinks each car just a bit to allow the truck to pass through the tunnel and for all of the cars to get to their destination. CFR automatically reduces signal peaks and allows it to pass through the PA without clipping or distortion.

TI's CFR algorithm is unique in that excessively high signal peaks are cancelled by adding a signal of inverse characteristics, instead of simply clipping off the input signal as it reaches a peak. Clipping the input signal is of limited benefit, as it actually introduces some distortion into the output signal instead of eliminating it.

The TI solution reduces PAR yet maintains the quality of the output signal. By reducing the PAR of the input signal, the PA's output power can be extended in a linear fashion. For example, a 3-dB reduction in PAR will allow an operating point for the PA that is 3 dB higher, thus increasing the operating efficiency of the PA. This 3-dB improvement in the PA's operating point actually represents a doubling of its output power without increasing its power consumption. Visualize a car with the power and horsepower of a V8, but the fuel economy of a much smaller four-cylinder engine.

Taken as a whole, base stations consume a tremendous amount of energy. Consequently, many wireless service providers are imposing more stringent efficiency requirements on their base stations, not only to reduce operating costs but also because of environmental concerns. With some wireless standards, TI's DPD/CFR solution can increase the operating point (output power) of the PA by 10 times while simultaneously increasing power efficiency by a factor of four. With this performance, the TI solution will have significant impact on wireless base station deployment and operating costs.

Conclusion

TI has implemented innovative adaptive DPD and CFR algorithms in a single-chip application-specific semiconductor product (ASSP) for the wireless infrastructure market. By compensating and counteracting inherent deficiencies in base station PAs, TI's GC5325 allows the base station PA to operate at a higher output power and addresses two of the most critical requirements of wireless base stations: cost and power efficiency. The GC5325 addresses all contemporary and emerging wireless standards like W-CDMA, WiMAX, LTE and MC-GSM to provide the most integrated and complete transmit processor solution available today.