Linearity vs. Efficiency for Infrastructure Applications

Linearity vs. Efficiency in RF Amplifiers

To save operation expense costs, high-power RF transmitters should ideally be as energy-efficient as possible since electrical power usage is one of the highest monthly operating costs for carriers. However, making an RF power amplifier more efficient often means driving it to a point near (or beyond) its point of saturation, which unfortunately, means the modulated waveforms are being distorted. In modern, spectrally-efficient digital modulation schemes, the data is densely encoded. Both amplitude modulation (mainly Quadrature-Amplitude Modulation, or QAM) and phase modulation require a highly linear (i.e., low bit-error rate) communication channel in order to be able to reproduce the high-definition content at the receiving end. To improve amplifier linearity, one would typically "back-off" on the amplifier drive level, which (unfortunately) lowers efficiency. Therefore, improving amplifier linearity often hinders efficiency and vice versa.

To improve efficiency without sacrificing linearity, transmitter hardware designers have recently employed two methods:

- Doherty Amplifier Circuit Topology
- Envelope-Tracking Power Supply

To improve amplifier linearity, RF designers have used complex fully adaptive techniques such as:

- Digital Predistortion (DPD)

To improve RF amplifier linearity and efficiency together, a powerful "analog predistortion" technique is now available (and relatively easy to implement) from Richardson RFPD:

- Adaptive RF Power Amplifier Linearizer (RFPAL) Technology

The Doherty Amplifier can be used to improve efficiency

The RF power amplifiers are typically the most power-consuming block in high-power RF transmitter systems. Today, spectrum is extremely expensive, and the new LTE standard demands transmission of maximum amount of modulation (i.e. data) with minimum spectrum usage. As mentioned above, this in turn requires sophisticated modulation techniques, leading to wideband, high-dynamic-range signals that require extremely linear amplification to minimize overall distortion. Although linear amplification is achievable, it almost always comes at the expense of efficiency. Telecom applications use non-constant envelope modulation techniques with a high peak to average ratio (PAR). Linearity being one of the critical issues, the RF power amplifiers may be forced to operate at a significant power back-off (driven far below saturation), to allow headroom for the high PAR signal. Selecting a highly linear, high-efficiency RF power amplifier topology can be part of a good solution.

An established amplifier topology which improves the drain efficiency of a linear power amplifier (such as Class A or AB) for a wider range of output power is the RF Doherty Amplifier. This circuit topology consists of two amplifiers in parallel in such a way that the combination enhances the power added efficiency (PAE) of the main amplifier at around 6 - 10 dB back-off from the maximum output power. Overall drain efficiency can be increased by up to as much as 15 percentage points.

Linearity vs. Efficiency for Infrastructure Applications (cont.)

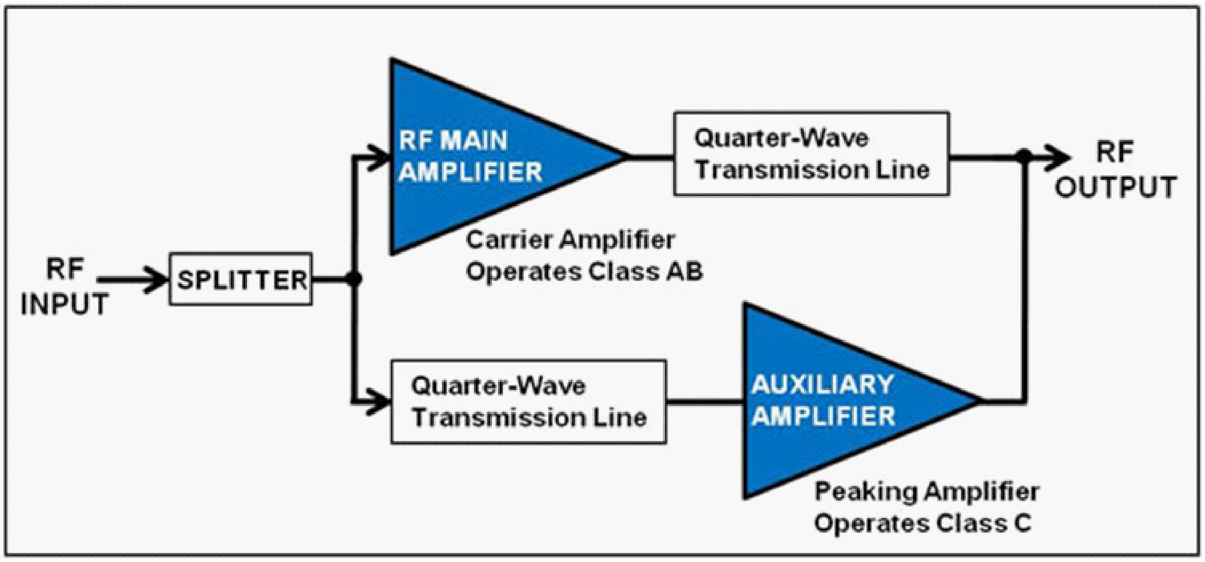

Figure 1: A Doherty RF Amplifier achieves better efficiency by using an auxiliary amplifier to vary the load impedance on the primary amplifier. This circuit topology allows the primary amplifier to continue to output a larger RF signal, dissipating less power in the amplifier. If the auxiliary amp lowers the load impedance on the primary amplifier, the primary amplifier delivers more power, yet stays linear (i.e., out of saturation).

Envelope-Tracking Power Supply techniques will improve RF amplifier efficiency

The actual amount of RF signal power being transmitted varies according to the information being transmitted at that moment. The envelope-tracking technique then is based on modulating the supply voltage of the final RF power amplifier stage in-sync with the transmitted RF power demanded at any given point. The amount of supply power available to the PA, at any given moment, is tracking the envelope of the modulation power density. This ensures that the output device remains in its most efficient operating region. The modulation of the supply voltage is performed by a power modulator device, which replaces the normal DC-DC converter providing the supply voltage.

Using envelope-tracking systems for power amplifiers, the PA efficiency can be improved tremendously. With a standard W-CDMA signal, average efficiency can be improved from the 20-30% range to the 40-45% range.

Linearity vs. Efficiency for Infrastructure Applications (cont.)

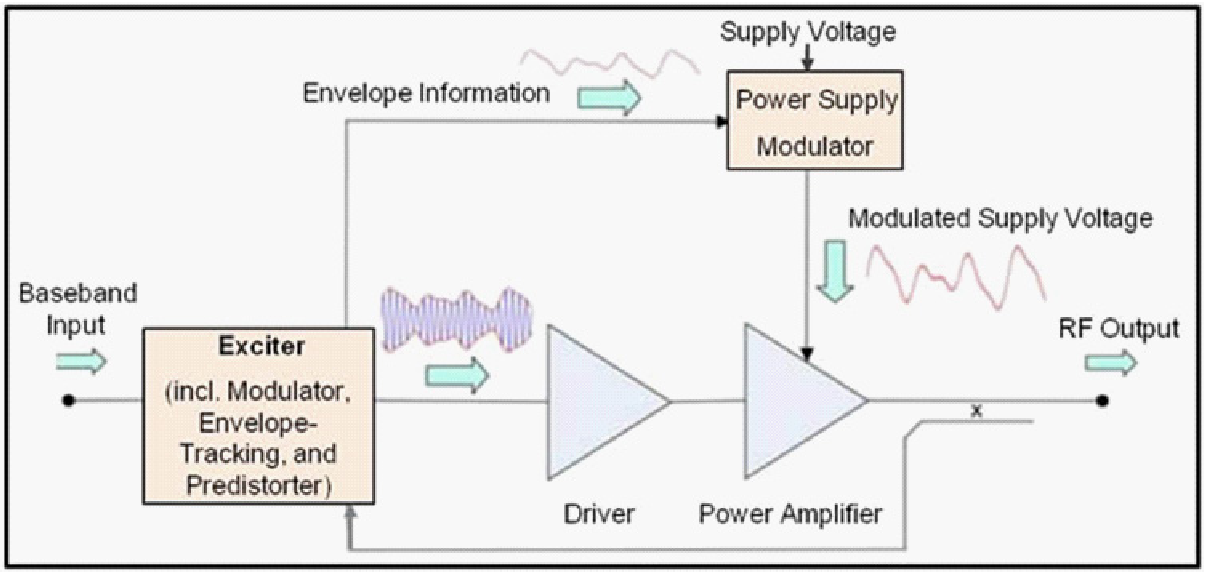

Figure 2: Envelope-Tracking achieves much greater efficiency by making sure that supply power to the PA tracks the "amplitude envelope" of the composite signal to be transmitted. The modulated supply voltage would then be highest during periods of peak modulation and lowest during periods of minute modulation.

Other challenges in designing highly linear RF amplifiers

Other impediments make designing a linear, high-power RF power amplifier even more difficult. For example, the electrical and thermal operation of the amplifier can cause "memory effects" which in turn introduce time-dependent or data-dependent nonlinearities. Electrical memory effects are analogous to the memory effects that one could observe in tube-based guitar amplifiers. The audio amps often had poorly designed power supply systems, which were basically open-loop linear supplies comprised of a large capacitor connected across a tube-rectified line voltage. A high volume power chord would heavily drive the amplifier's output stage and pull down the power supply voltage as the capacitor drained. The line voltage restored the capacitor after the heavy load, but it took 10s of milliseconds to do so. The sag in the power supply voltage changed the biasing of the output tubes in the guitar amplifier, creating a distinct "data-dependent" nonlinearity. The degree of nonlinearity depended on the previous audio signal. RF power amplifiers are subject to the same type of phenomenon. The data sequence (of the densely encoded image or voice) can include symbols that cause relatively heavy driving of the RF amplifier. This situation affects the power supply and biasing of the transistor amplifier, creating a data-dependent nonlinearity that changes with the modulation density on the RF carrier.

Besides these electrical memory effects, amplifier designers must also handle thermal memory effects. Hot and cold transistors have different transfer functions, introducing a time-dependent nonlinearity into the system. If the environment is hot or the data stream heats up the output stage, then the transistor exhibits different nonlinearity from that which it would exhibit at a cool temperature.

Linearity vs. Efficiency for Infrastructure Applications (cont.)

Designing for linearity with efficiency (adding adaptive predistortion)

As previously discussed, RF transmitter designers cannot just simply underdrive the PA across a smaller output range and suffer with the efficiency hit. RF amplifier engineers should investigate adding adaptive predistortion circuitry to gain additional linearity, while preserving efficiency. Indeed, modern RF designers have employed various digital and analog predistortion techniques and have achieved great success in meeting the modern spectral mask requirements of today's UHF digital transmission standards.

The basic method of adaptive predistortion technology is to monitor the RF signal as it exits the high-power amplifier and attenuate that signal to then be used as "feedback." You then compare the non-linearities present in the fed-back RF signal to the original modulation (before amplification) and adapt/apply an algorithm (based on a dynamic, closed-loop finite impulse response model of the non-linear process) to pre-correct the signal before it goes through the amplifier chain (i.e. pre-adjust and/or pre-compensate the signal) in order to produce a much more linear output signal. To describe just one of the possible pre-corrections in fundamental terms: If a pure sine wave signal was being clipped (i.e., peaks flattened) by an amplifier, and you "knew it ahead of time" (by monitoring the amplifier output), you could dynamically alter the signal by sharpening the peaks of waveform (i.e., predistorting it) so that when the predistorted signal is passed through that same amplifier, it would emerge as the desired pure sine wave signal. Predistortion then uses algorithms that accurately "predict" the nonlinearities of the PA to adjust the input signal so that it will end up linear once it passes through the PA.

Because a predistortion system can also use complex algorithms to predict the thermal-memory and electrical-memory effects, this type of approach will also preserve linearity in the face of these two problems. Note that the inherent linearity of the components in the RF-signal path is still relevant. There is a limit to the corrections that one can apply in the digital domain. The closer the signal path is to ideal, the easier job a digital-system designer will have creating an algorithm which provides an accurately predistorted signal.

Implementing adaptive predistortion schemes: Digital vs. Analog

In "all-digital" predistortion schemes, the digital signal representations which are used to perform the complex quadrature amplitude/phase modulation are also applied to a separate digital algorithm to predistort the modulator output and thus pre-compensating for the deterministic nonlinearity of a given transmitter system. The extra circuitry needed for adaptive Digital Predistortion (DPD) is extensive. The RF feedback must also be digitized, using an A/D conversion process, so that it can be used in the same digital algorithm within a digital signal processor. The overall DPD system then can be expensive, use a fair amount of printed circuit board real estate, and require a fair amount of power (while losing some of the efficiency gain in the process). From an engineering development standpoint, DPD can be complex as well, requiring many man-hours to invent, test and implement the software/firmware for the project.

A newer, combined analog and digital RF predistortion scheme (called "adaptive analog RF predistortion") now exists. The circuit actually samples the already modulated RF signal from the driver stage, using a directional coupler, and keeps that driver signal in the analog domain.

See more details regarding Scintera's adaptive RFPAL technology and products at their Richardson RFPD storefront.