TRENDS IN ACHIEVING LINEARITY WHILE INCREASING EFFICIENCY AND LOWERING COSTS IN HIGH POWER RF AMPLIFICATION

One of the missions of Triad RF Systems is to push the boundaries of linearizing RF Solid State Power Amplifiers (SSPAs) while maintaining a price structure that allows our products to meet the customer's cost targets. We have structured the company in such a way to achieve this goal. Our founders have over 20 years of experience developing linearization techniques to improve the distortion products of SSPAs in RF radios. They developed an entire company around an open-loop predistortion method which was eventually sold for said technology.

The key engineers moved on, started Triad RF, and have developed enhanced technologies to further push linearization techniques beyond the original open loop model. This was done due to the problem that open loop linearizers require a predictable P_{IN} vs. P_{OUT} curve of the RF amplifier. Since Class A devices compress with a predictable curve, they work best with an open loop linearizer. See Figure 1.

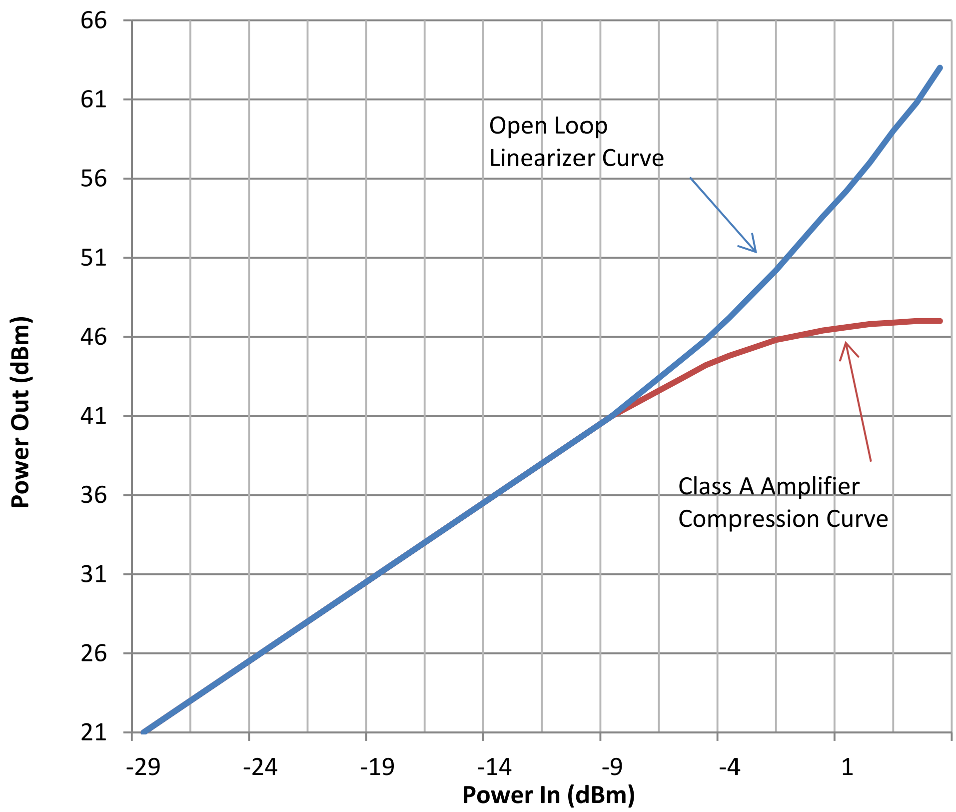

Figure 1. Typical P_{IN} vs. P_{OUT} Curve of a Class A SSPA and Open Loop Linearizer

Class A amplifiers can be simply characterized as constant DC current draw, regardless of RF output power, which means no matter what RF power the amplifier produces, the DC current draw will change very little. Gallium Arsenide (GaAs) is a typical Class A device technology that has been around since the 70's and 80's. SSPA's that use GaAs typically are linear as far as intermod distortion products (IMD) are concerned, however, when operating at their peak linear region, their efficiency can be typically 10% or less. In other words, only 10% of the DC power put into the amplifier comes out as RF power. For example, if a unit requires 100W of DC power, 10W goes to RF power and 90W is dissipated as heat. This type of technology was acceptable when ample air conditioned rooms were available to keep the amplifiers operating at reasonable temperatures. This is why there are fairly large buildings below most radio towers. This type of infrastructure and cooling is very costly for the wireless providers which prompted them to find other more efficient solutions.

The other problem with this type of solution is that over the years, thanks to the lack of knowledge of the general population in regards to the dangers of radiation emitted from RF transmitters, it has become increasing difficult to build more infrastructure in populated areas to meet the ever increasing demand for wireless data.

One of the solutions to overcome these problems is to build smaller base stations that produce less RF power, and cover less square miles. This allows more bandwidth per user to be available since less people occupy the cell at any given time. One of many obstacles to this solution is the inability to cool the transmitters, as they would sit out in the elements and can only rely on convection cooling. This requires the transmitter to be very efficient since this type of cooling can only remove a limited quantity of heat. Since the SSPA typically generates the most heat in an RF radio, it requires the most improvement in technology. One of the improvements is to utilize Class AB or B circuits in order to make higher efficient SSPAs. These types of amplifiers draw less DC current when they operate backed off from compression, and then draw more current as they are pushed to compression. A Class AB SSPA operating at compression or saturation, typically have efficiencies near 30 to 50%. Due to the inherent structures of these types of amplifiers, the IMD products are unacceptable to transmit high bandwidth signals that require high linearity in order for the receiver to correctly receive the data. Another issue with Class AB and B circuits is they do not compress in a very predictable manner compared to Class A designs. As an AB amplifier is pushed to its peak power capability, there typically is some expansion, then some compression, and finally full compression. See Figure 2.

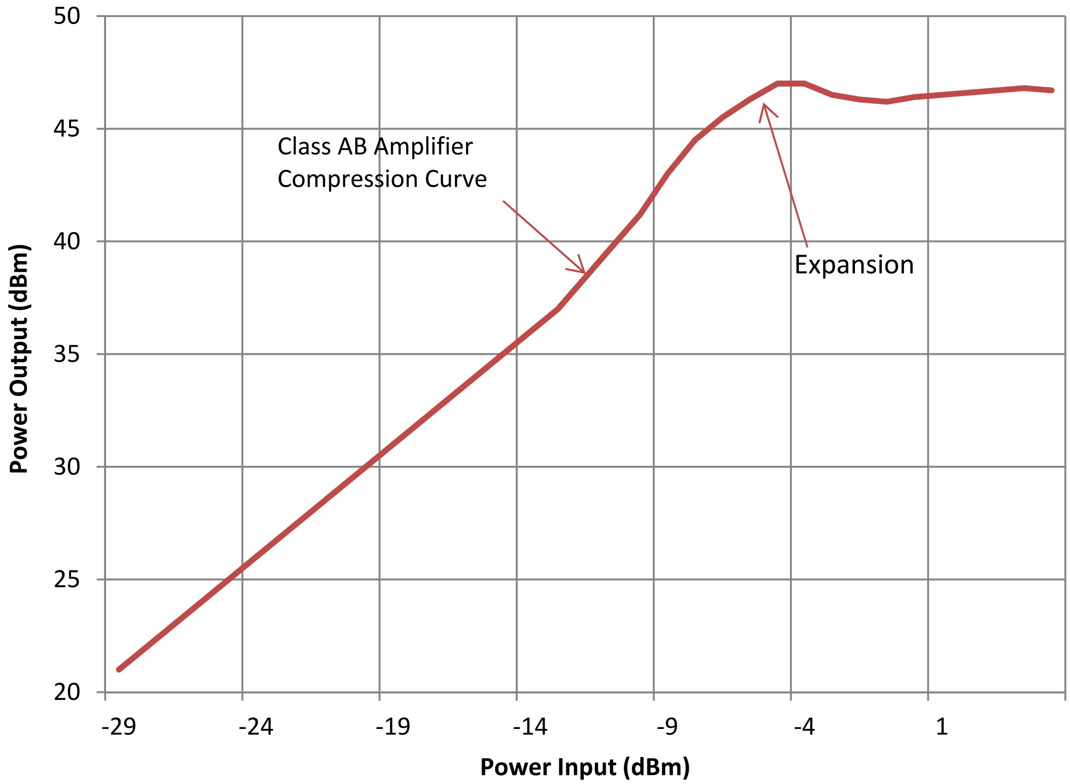

Figure 2. An example of a P_{IN} vs. P_{OUT} curve of a Class AB SSPA

As Figure 2 shows, to model this type of curve with an open loop linearization is quite difficult. In order to properly linearize this type of curve, a closed loop method that incorporates feedback is required.

SSPAs that use linearized Class AB circuits have been development over the last two decades to meet these technical challenges. Most if not all of the 3G and 4G base stations being deployed around the world today utilize some sort of linearization to Class AB amplifiers. Most are very complex and require significant circuitry to meet all of the linear specifications. These amplifiers are also built over seas in order to keep the costs down. Many of these types of amplifiers operate in a narrow frequency band which allows the complex linearization methods to work quite effectively.

Triad RF has taken the position to develop linearization methods that significantly improve the IMD products of Class AB and B SSPAs using less complexity in order to save cost. We also plan on developing circuits which allow us to linearize higher frequency bands that are often ignored since the quantity of units required are low for many of the larger players to pay attention too.

Triad RF recently linearized an amplifier incorporating laterally diffused metal oxide semiconductors (LDMOS) using a closed loop linearization system. The unit was run only a few dB backed off from compression. See Figures 3 and 4 for the before and after linearization plots using a standard CW 2-Tone test.

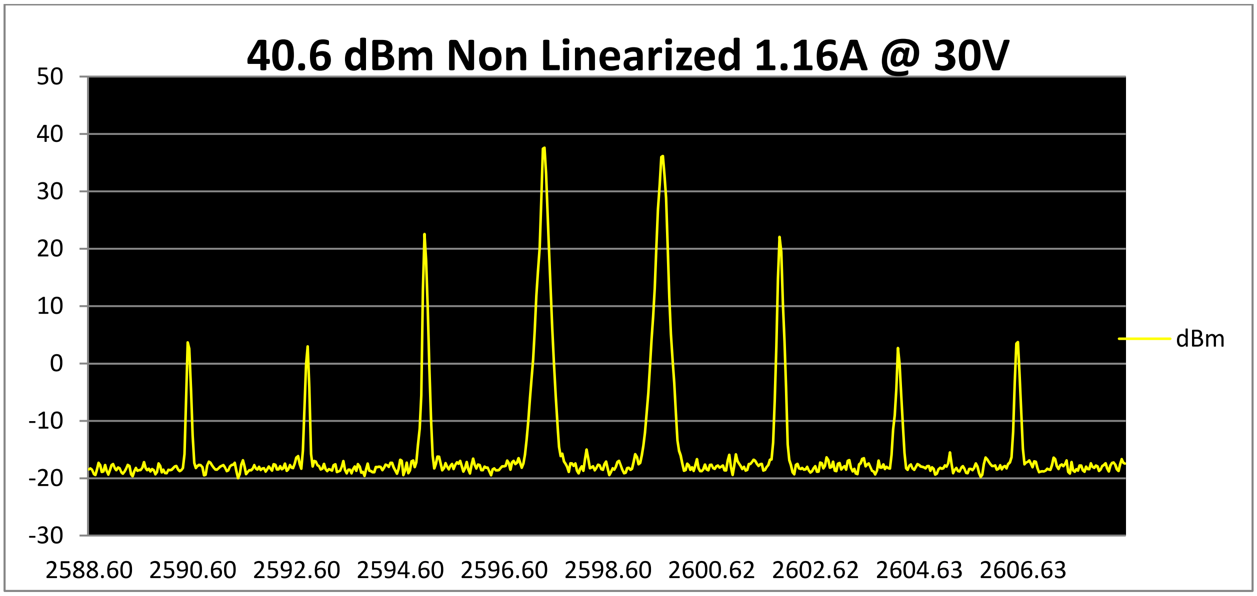

Figure 3. Class AB SSPA **Before** Linearization

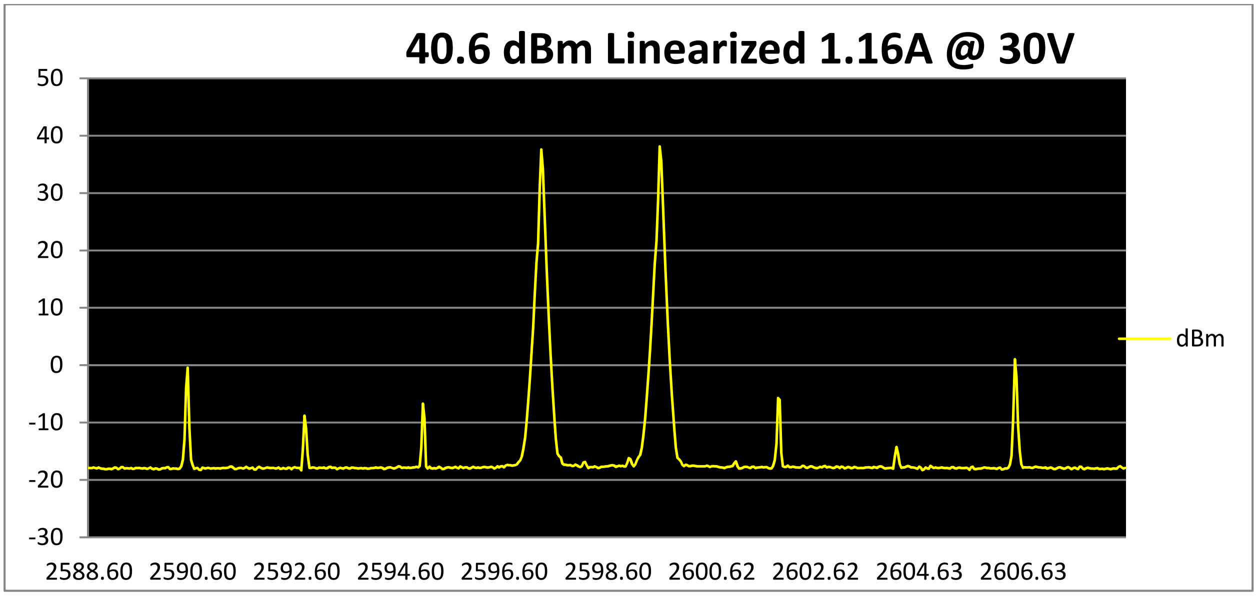

Figure 4. Class AB SSPA **After** Linearization

As can be seen, the improvement is significant. What is equally important is that even with the improved IMD performance, the amplifier is operating at 33% efficiency. Our goal is to have similar results near 50% which will result in a much cooler running SSPA, allowing the provider to transmit more carriers in a given small cell, satisfying the growing demand of users. In order to meet the 50% goal, other amplification technologies will be utilized such as gallium nitride, GaN. This technology has shown great promise in creating amplifiers that operate with efficiencies of 50/60%, while allowing predistortion techniques to improve the IMDs generated to an acceptable level. Many larger companies have already implemented and shipped linearized GaN amplifiers in telecom base stations, however, at this time, the frequency bands are quite narrow.

This type of linearization also improves signals with complex modulations that have high peak to average ratios. To avoid clipping of the output device, a FET that has high peak power capabilities is required. For example, if the peaks are typically 7 to 10 dB higher than the average power, the device must have the power capabilities to handle the peak power, but can be biased at a point needed to operate at the average output power. This maximizes efficiency since the peaks occur only a fraction of the operating time, and linearity is still reasonable for linearization. Efficiency is also maximized since the device is biased for the lower level a majority of the time. As mentioned earlier, linearization of a Class AB device is more difficult due to the expansion characteristics of the power curve. With our closed loop linearizer, we were able to achieve up to 17 dB of improve as shown in Figures 5 and 6 provided below in Adjacent Channel Power (ACP) with a class AB GaN device and operating at 5W average power.

Figure 5. 5W Doherty Amplifier ACP Measurement - Pre-distortion **Off**
(~- 37.5 dBc ACP)

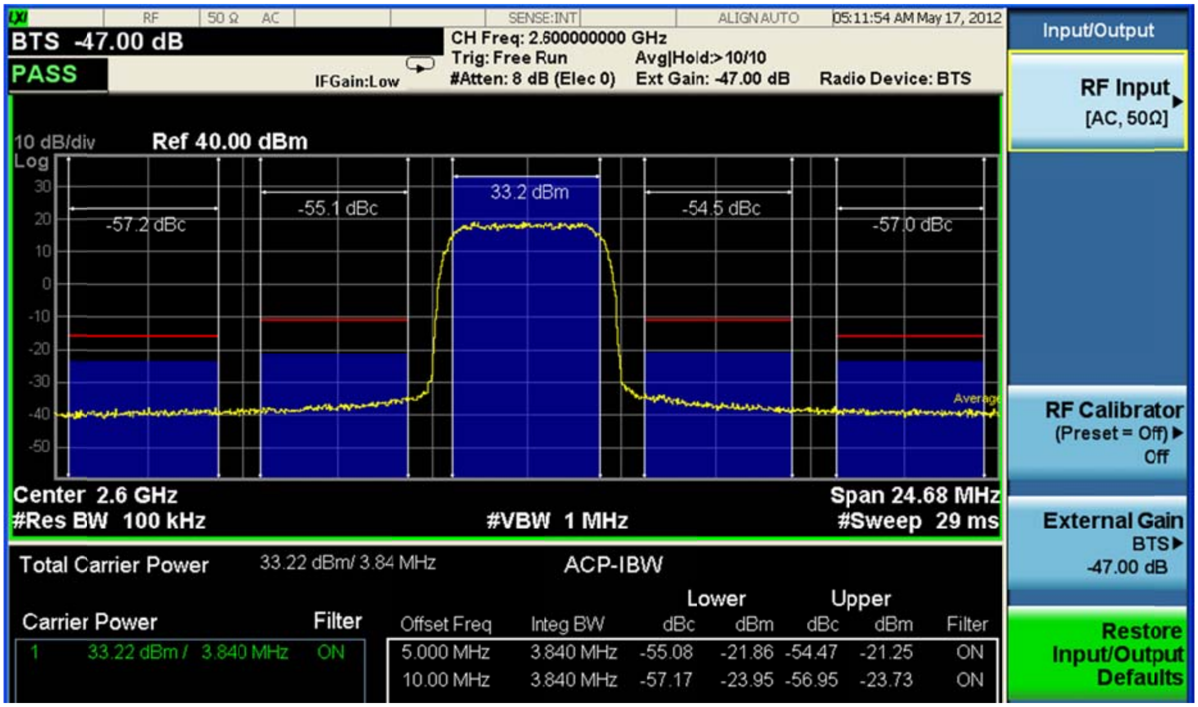

Figure 6. 5W Doherty Amplifier ACP Measurement - Pre-distortion **On**
(~16 dBc ACP Improvement)

Although this type of linearization is more expensive and complex than our open loop design, we believe it can be done cost effectively with some of the new technologies that are coming to market such as chip sets from companies like Linear Technologies. These new circuits will also be compatible with high peak to average signals and modulation bandwidths greater than 40 MHz. This will also allow users in the non-common bands the same benefits that users in the cell phone bands currently enjoy.

In summary, Triad RF has shown capabilities in linearizing Class A and Class AB circuits. We have expertise and the understanding of the complexities and bandwidth limitations of each type of linearizer, open loop and closed loop. We also have expertise in understanding the pros and cons of each FET technology. i.e. GaN, LDMOS and GaAs. Depending on customer needs, we can make an amplifier using the best FET/linearization technology in order to maximize the linearity and efficiency parameters while at the same time, minimize the associated costs.

Please visit our website www.triadrf.com or call us at (855) 558-1001 for more details.