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Design How-To

Improving multi-carrier PA efficiency using envelope tracking

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Modern complex modulation schemes have the disadvantage of requiring linear power amplification, which compromises overall system efficiency because RF power amplifiers (PAs) are much less efficient when backed off from maximum power. The power amplifier and its associated components consume up to 50% of the overall power in a cellular basestation and account for a similar proportion of operating costs. Conventional techniques for improving PA efficiency are inherently narrowband, and are unable to span more than a single band. This article describes a technique based on envelope tracking that has been proven to offer a dramatic improvement in efficiency, from typically low 20% for a class AB amplifier to mid 40%, while offering multiband performance.

Manufacturers of cellular basestations are under considerable pressure on numerous fronts and need to innovate to survive. In particular, the demands on RF PA designers continue to increase. These demands arise from the following factors.

Firstly, the continued evolution of the UMTS and WiMAX standards, and further evolved standards such as Long Term Evolution (LTE), are generating challenging technical requirements, including the need to support a variety of different channel coding and modulation techniques (CDMA, OFDM, etc.), broader channel bandwidths, and high peak-to-average power (PAPR) modulation schemes.

Secondly, factors such as deregulation and the growth of new networks, particularly in parts of the world not yet well equipped with cellular networks, have created a requirement for basestations to support a wider range of frequency bands as new spectrum is released to meet urgent capacity demands.

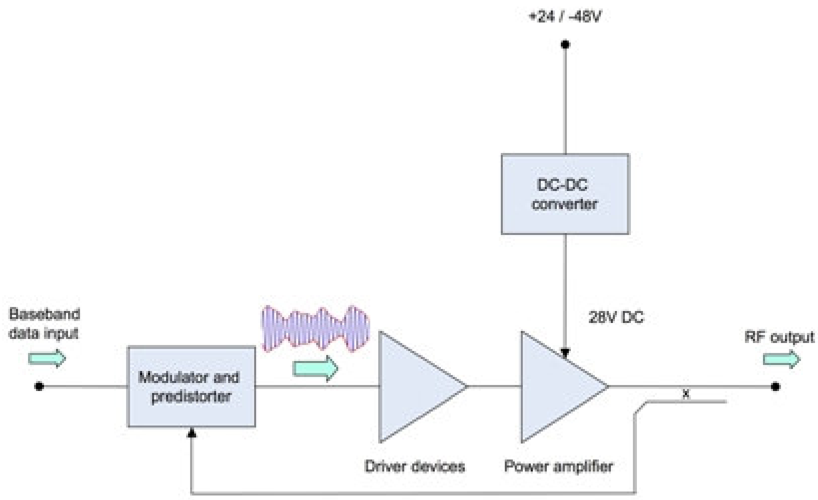
Thirdly, environmental or 'green' issues, such as the desire to reduce both direct and indirect CO_2 emissions, and equipment size, are also moving up the agenda. Several operators have pledged to work with suppliers to increase the energy efficiency of their networks. For example, Vodafone aims to improve the average energy efficiency of new network equipment by 33% by March 2008 compared with its 2006 figures. The savings, in both cost and carbon emissions, which could be made by realizing these improvements are huge. Vodafone has stated its intention to remove air conditioning units from sites where possible, which alone account for about 25% of network energy usage, and use remote radio heads where possible. But the removal of air conditioning units and the deployment of remote radio heads are only feasible if PA efficiency is greatly improved. Improving PA efficiency with high peak-to-average power (PAPR) systems is particularly challenging due to the need to use linear PAs to meet the critical RF performance criteria.

Finally, the increased level of competition on a global scale puts increasing pressure on design teams to use the latest and greatest technology in order to stay competitive, in turn leading to the need for faster design cycles. This, coupled with an equally strong need to contain development costs (again for competitive reasons) has meant that PA design teams need to focus on generic platforms which can be deployed into a number of different products with minimal or no change. A reduction in the number of design variants also allows improved inventory management.

In summary, the technical design challenges are increasing, and infrastructure vendors are under pressure to produce complex product families supporting different frequencies, power levels and standards, at lower prices, with shorter product development times, while at the same time achieving significant reductions in power consumption. The requirements of lower power consumption and streamlined inventory management are both critical factors driving the development of very high efficiency, RF frequency agnostic and modulation agnostic broadband PAs for wireless infrastructure.

The industry has devoted years of R&D effort to developing software defined radios (SDRs) to address these goals, but the engineers have been frustrated in their attempts to build equipment fulfilling all of the requirements because of the need to incorporate narrow band high power PAs and band specific front-end filters. Only recently have advances in PA technology made it possible to overcome one of these 'final barriers'.

Flexible BTS architecture
Figure 1 shows a traditional basestation PA configuration. Flexible, wideband basestation architectures are already possible for the lower power RF circuitry, but are more difficult for the PA final stage. A short term solution is to make 'band selectable' PA modules but in the longer term multi-band PAs will be the preferred solution.



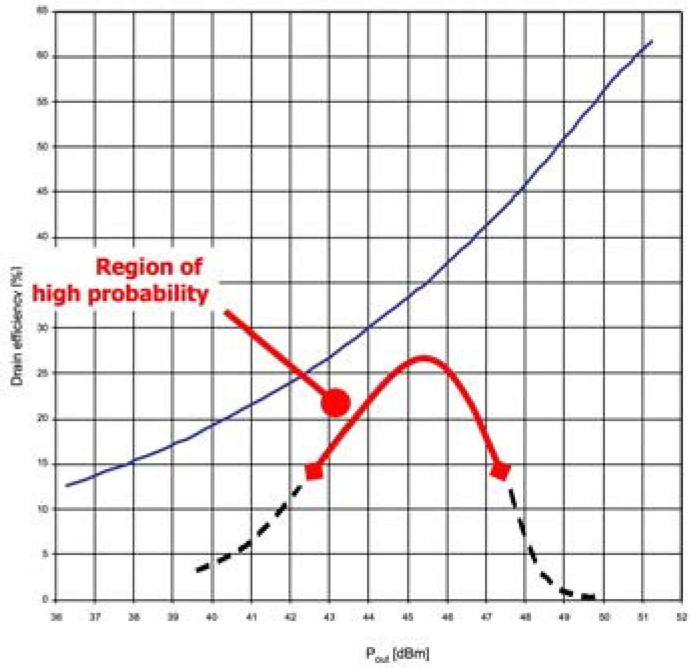
1. A conventional basestation PA configuration without envelope tracking

The efficiency of the PA is dependant on the 'crest factor', or peak/average power ratio (PAPR) of the signal being amplified. In a W-CDMA system, the PA is usually operating far below peak power, as the signal crest factor is typically 6.5 - 7.0dB. OFDM systems such as 3GPP LTE and WiMAX use even higher crest factors (typically 8.5 - 9.5dB) for improved spectral efficiency but this results in traditional PA designs having even lower efficiency.

It is difficult to achieve flexible, high efficiency, broadband PA designs by means of 'RF only' efficiency enhancement techniques, such as Doherty. A large number of variants are required to cover all the different frequencies, powers and PAPR values, as these designs have inherently narrow bandwidth. It also takes considerable development time to achieve high production yields, and it is difficult to maintain the efficiency as systems evolve to higher PAPR values.

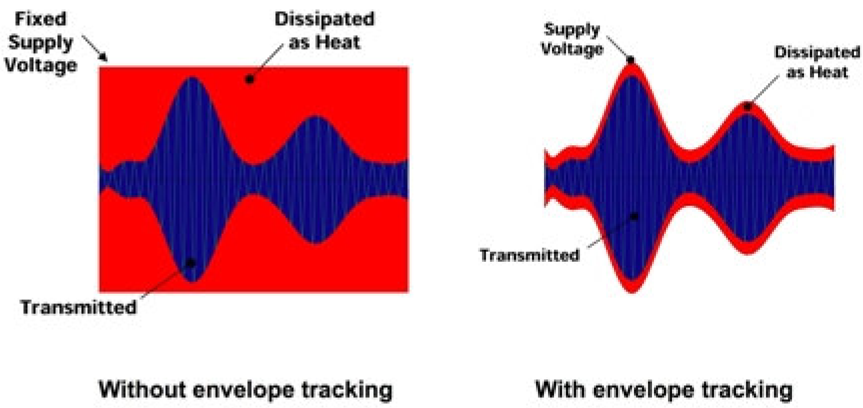
Envelope tracking
The classic Class AB amplifier technology offers efficient operation when the RF envelope waveform is close to peak power, and with careful design this can be achieved over a relatively broad bandwidth. When amplifying high crest factor RF signals though, it is less

efficient, typically in the range 15-25% for W-CDMA and WiMax. The reason for this is shown in Figure 2, where the solid blue curve represents drain efficiency vs. power output and the dashed curve is the probability distribution of instantaneous output power value. As can be seen, for much of the time the signal power lies well below the peak power and hence the device is operating at low efficiency.

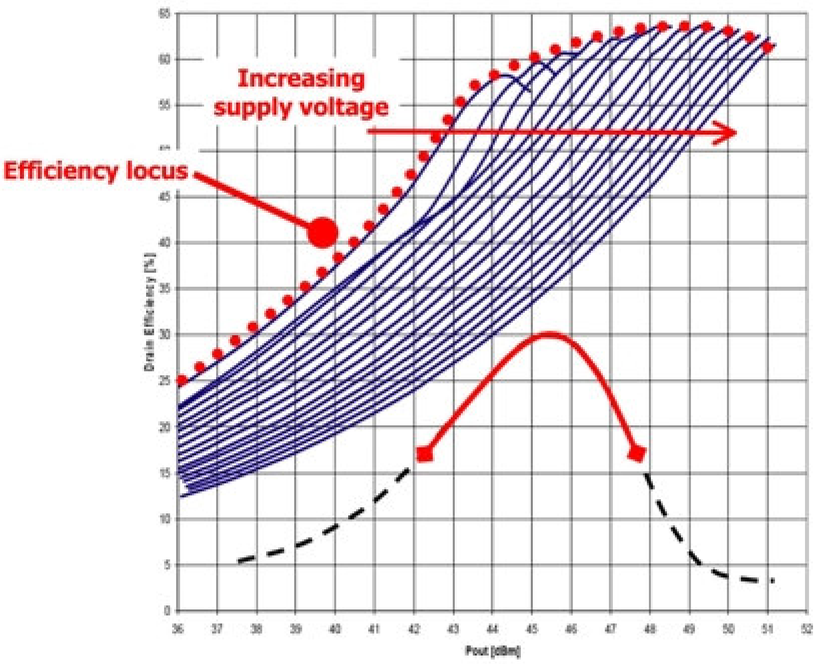


2.Main curve shows drain efficiency vs. power output, and dashed curve shows the probability distribution of the instantaneous output power value

It is possible, however, to achieve a significant improvement in PA efficiency (and hence the efficiency of the entire network) without compromising bandwidth using envelope tracking (ET). Here the voltage supplied to the final RF stage power transistor is changed dynamically, synchronized with the RF signal passing through the device, to ensure that the output device remains in its most efficient operating region (in saturation). This technique can significantly increase the energy efficiency of 3G, WiMAX and DVB transmitters. With envelope tracking, the supply voltage is reduced from its maximum value so that it 'tracks' the signal envelope, and this reduces the energy dissipated as heat as shown in Figure 3. An ET amplifier operates at its optimum efficiency at all envelope levels, and hence offers greatly improved efficiency when operating with envelope varying signals, as shown in Figure 4.



3. Envelope tracking reduces the voltage difference between the supply voltage and the signal envelope, which determines the amount of energy dissipated as heat.

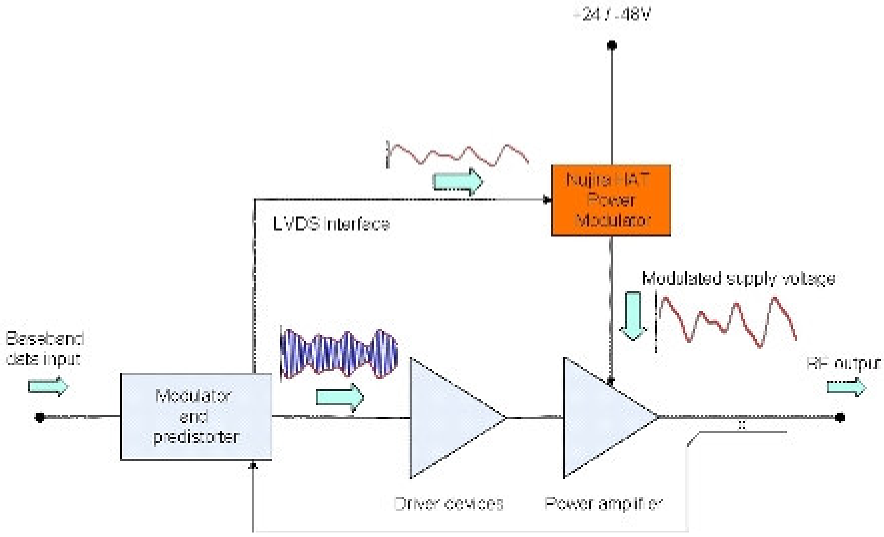


4. Efficiency locus when envelope tracking is applied

As well as reducing power consumption, the reduced heat-sinking requirements allow PAs to be smaller and more reliable. Lower base station power consumption also has beneficial effects further down the chain, allowing reductions in battery back-up requirements, for instance. ET is fully compatible with contemporary digital pre-distortion techniques, and does not significantly degrade system linearity.

While the principle of ET has been known for many years [1], it has not been commercialized until now because of the difficulty of implementing a power supply modulator capable of achieving the accuracy, bandwidth and noise specifications necessary for wideband signals such as multi carrier WCDMA, WiMAX or DVB operation. These parameters all relate directly to the detailed design of the power modulator, which has to track the rapidly varying envelope of the RF signal with very high accuracy, but also has to achieve high power conversion efficiency for the benefits of ET to be fully realized.

Figure 5 shows how Nujira's High Accuracy Tracking (HAT) power modulator is used in conjunction with a PA. The only addition required to the standard basestation architecture described in Figure 1 is an envelope tracking interface to drive the HAT power modulator. The result is an efficient, flexible basestation architecture which preserves the standard PA footprint, signal interfaces and power supplies within a modular PA design, and moves one step closer to a 'plug & play' basestation.



5. Application of High Accuracy Tracking power modulator to the standard power amplifier architecture

The same ET approach is equally applicable for 2500MHz WiMAX, 850MHz CDMA2000, and 2100MHz or 900MHz W-CDMA, and can be used with LDMOS, GaAs FET, GaAs HBT or GaN based PAs. The emerging GaN technology offers not only high efficiency but also the possibility of implementing broadband designs; hence it is an excellent partner for envelope tracking.

Summary

The use of envelope tracking technology enables the efficiency of high crest factor RF PAs to be significantly increased, regardless of device technology, while preserving the benefits of high spectral efficiency possible with modern wireless communication standards such as WCDMA, WiMAX, LTE and DVB. Envelope tracking is also inherently RF frequency agnostic and opens up the possibility of future broadband 'multi-band' PAs.

Operators are now demanding radio equipment that offers high flexibility, small size and above all, high energy efficiency. The availability of broadband PAs with efficiencies approaching 50% is critical to meeting these needs, and envelope tracking is a key enabling technology. An essential element of any envelope tracking solution is the power supply modulator, and Nujira's HAT technology is rapidly becoming established as the industry benchmark for high efficiency power amplifier performance.

References

1. Khan, L.R., "Single Sideband Transmission by Envelope Elimination and Restoration", Proc. IRE, Vol.40, July 1952, pp803-806.

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