Digital Radio Techniques for Energy Efficient OFDM Basestations

by Steve Cooper, CTO, Axis Network Technology

Axis Network Technology Limited
9/10 Midshires Business Park
Smeaton Close
Aylesbury
HP19 8HL
United Kingdom

Tel: +44 (0)1296 433087
www.axisnt.com

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Traditional basestation (BTS) architectures, where the radio, power amplifier and other electronics are located in a cabinet at the base of the mast have several drawbacks for the network operator. Typically only 2% of the total DC power consumed is actually transmitted as useful RF power. Due to inefficiencies in the power amplifier most of the consumed power is dissipated as heat. This heat requires the use of large heatsinks and cabinets, air conditioning (further increasing energy consumption) and noise pollution. In addition, the feeder cable linking the ground-mounted cabinet is lengthy and attenuates the RF signal. In fact, 50% of the RF power supplied at the base of the tower is lost in feeder cables. RF cables of the nature used in basestation deployments are also expensive to manufacture and transport due to their weight, and difficult to deploy.

The installation of a cabinet basestation is also complex. It typically requires a concrete base, shelter and a crane to install the basestation. This can take many days and considerably limits leasing site options available to a network operator. Real estate works also slows down network rollouts.

It has, therefore, long been a goal for mobile wireless infrastructure suppliers to improve levels of efficiency and integration in order to make infrastructure systems light enough to be deployed next to an antenna. Naturally it is critical that these systems are reliable enough not to require tower climbs for servicing. Products such as Remote Radio Heads (RRHs) and picocells result in significantly lower costs for the operator - both in upfront deployment costs and ongoing leasing and energy costs.

Newer telecommunications standards such as HSDPA, HSUPA, WiMAX, DVB-T and LTE maximize spectral efficiency by using complex modulation schemes that have a high peak-to-average power ratio (also known as PAPR, or “crest factor”). Signals with high crest factors require a large range of dynamic linearity from the amplifier. This means that the power amplifier has to be set to operate well away (backed off) from its most efficient point. Therefore, although spectrally efficient, these newer standards are less energy efficient than their predecessors (such as GSM).

Efficiency

Hardware and site preparation are major contributors to CAPEX costs, while major OPEX costs are site leasing, backhaul, and energy, all of which can be improved by the use of RRHs. Reducing power consumption is key to making RRHs successful in terms of size and reliability. This article describes how Axis Network Technology has used DSP techniques to develop and supply smart, power-efficient RRHs serving both the WiMAX and LTE markets.

A basestation with the enhancements outlined in this article can benefit from a ten-fold increase in conversion efficiency. This significantly reduces heat dissipation in the system, allowing convection-cooled products to be deployed and enabling a dramatic size reduction. Axis Network Technology has developed a 2-channel WiMAX RRH weighing only 12kg. This small convection-cooled product is light enough to be mounted at the antenna, saving the cost of the feeder cable.

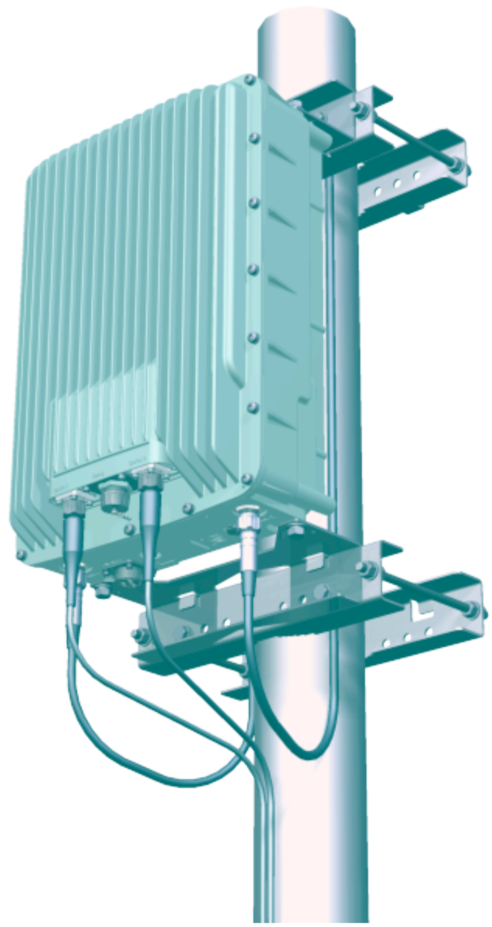


Figure 1: Axis Remote Radio Head – 2 paths of 14 watts (QPSK) RF power in 12kg box

Leasing and installation costs are directly linked to the size, weight, and complexity of a basestation. Small, convection-cooled RRHs provide many more deployment options – and hence a reduction in leasing costs. Naturally, the ten-fold increase in conversion efficiency causes a similarly significant reduction in electricity costs.

Crest factor reduction

As a first step, Axis Network Technology has used Digital Signal Processing to reduce the peaks of the OFDMA signal. Reducing the crest factor makes it possible to obtain significantly more RF power from the same power transistor, or alternatively smaller (and lower cost) transistors can be used and still achieve the same output requirements.

Axis Network Technology has evaluated a number of peak-limiting algorithms. Certain techniques require intervention in the baseband processing layer (before the individual codes or tones are combined into a composite stream) to reduce the incidence of the peaks. For example, code selection and tone reservation are two approaches proposed for WCDMA and OFDMA, respectively. These approaches require close working with baseband partners, but typically have excellent performance.

Axis Network Technology has initially focused on algorithms that are implemented on the composite I and Q signal. In one approach called peak windowing, the signal is attenuated in the region of each peak. An alternative method is to clip the signal using polar or Cartesian clipping. With Cartesian clipping, the in-phase and quadrature components are clipped independently. With polar clipping, the magnitude of the signal is clipped while preserving the phase. Although either method can be used to limit the crest factor of the signal, polar clipping provides better results in terms of overall signal distortion (lower error vector magnitude [EVM]).

An unclipped LTE waveform typically has a 10dB peak-to-average ratio. Thus, a 20W LTE basestation without a crest factor reduction (CFR) algorithm requires 200W of peak power handling. Using one of the crest factor algorithms discussed earlier can reduce the peak requirement by half, saving significant cost and power per transmit path.

CFR significantly improves the power efficiency of the basestation, because not only is the price of the power transistor proportional to its peak power, so is its power consumption. In today's UMTS basestations, the power transistor is biased to handle its peak power. Therefore the peak power determines both the efficiency of the power transistor and the overall system power consumption. For these reasons, CFR algorithms are becoming commonplace in wireless infrastructure systems. Axis Network Technology obtains significant clipping reduction by using CFR algorithms implemented with FPGAs.

An unclipped LTE signal has a cumulative distribution function as shown in Figure 1. If clipping is turned on, the peak power requirement (crest) can be clipped by 2dB to 7.5dB. It is possible to achieve 70% more average power from the same power transistor if clipping is used. However, because the increase in power consumption is only marginal, this leads to significantly enhanced efficiency numbers.

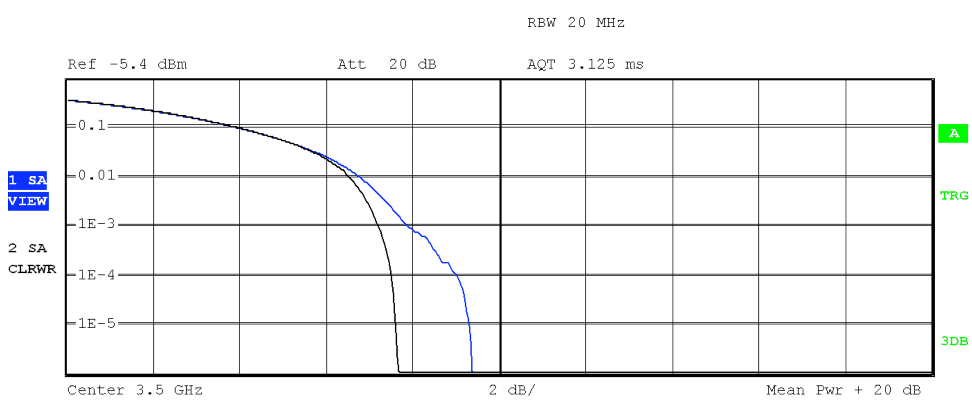


Figure 2: Unclipped and clipped OFDM waveform

Achieving the same performance in adjacent channel and spectral emissions – but driving the amplifier harder – also has a significant impact on amplifier efficiency. An amplifier operates in its most efficient region when it is most compressed. Results on Axis Network Technology LTE amplifiers show that driving the amplifier 2dB higher results in a power consumption increase of only 25%.

Limitations of CFR

There is however a cost for this improved efficiency – clipping the peaks of a signal degrades its purity and increases the occurrence of bit errors, especially in areas of weak reception. UMTS Release 99 uses the QPSK modulation scheme, which is relatively tolerant of signal impurities: the 3GPP standard for UMTS allows as much as 17.5% EVM degradation. As UMTS networks are typically interference limited, the impact of the increased EVM is of limited importance, as other factors dominate the system bit error rate. Axis Network Technology UMTS CFR algorithms demonstrate clipping to a 6dB peak-to-average ratio while meeting 3GPP Release 99 EVM requirements.

As modulation schemes change from QPSK (UMTS Release 99) to higher-level schemes such as 16QAM and 64QAM (used by LTE and WiMAX), the tolerance of the system to any impurity is diminished. This is because the relative distance between each point on the constellation diagram is reduced. Impurities in the signal will cause the detection points to merge together, creating bit errors. Currently algorithms are only providing 8dB of peak-to-average ratio levels while meeting the tight EVM requirements for 64QAM signals.

Clearly, clipping is of value in those systems that can tolerate higher levels of EVM degradation. But to improve the efficiency of systems using higher-level modulation schemes, additional techniques are required.

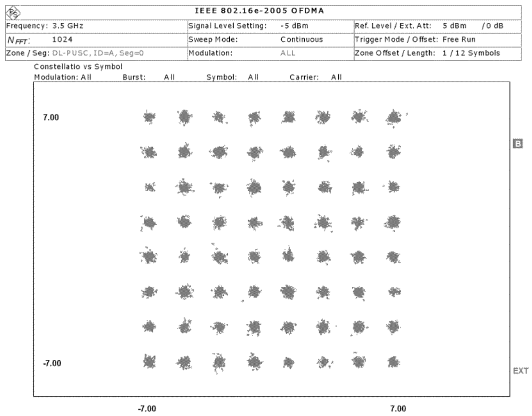
Digital pre-distortion

Another important parameter affecting the power transistor choice is the adjacent channel power ratio (ACPR). Linearization allows the operation of the amplifier even further into its highest efficiency area. A number of available techniques will have this effect. These techniques originated in the analog domain with feed-forward and cross-cancellation and have now moved into digital pre-distortion (DPD) carried out in the I and Q domain.

Pre-distorters have been demonstrated that have almost perfect performance – removing all non-linearities and minimizing the adjacent channel power down to the noise floor of the system. Using the latest DSP techniques to implement pre-distortion allows the power amplifier designer to implement a custom algorithm tailored to the specific amplifier being pre-distorted. This is ideal for compact integrated products, as the transceiver, algorithm, and amplifier are permanently integrated together in one field-upgradeable unit.

By optimizing the design of the power amplifier and focusing the pre-distortion algorithm around the specific parameters of the amplifier, Axis Network Technology has developed very code-efficient, custom DPD algorithms. In addition pre-distortion not only improves the spectral emissions of the amplifier but also has a significantly positive effect on the signal EVM. Axis Network Technology tests show the DPD can provide a typical improvement from a poor -24dBc to a spec compliant -32dBc.

Combined together, DPD and CFR make a significant contribution towards improving the efficiency of Axis Network Technology RRHs.



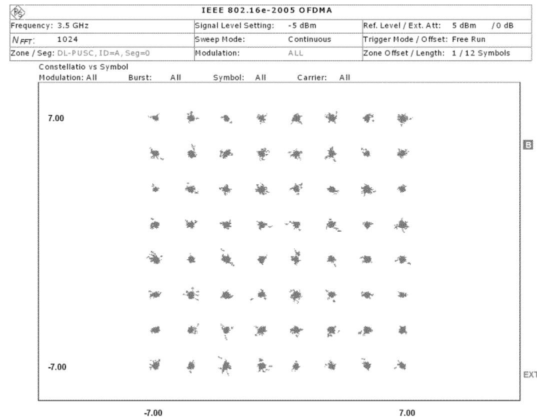


Figure 3 (left) and 4 (right): 64QAM constellation (without and with DPD)

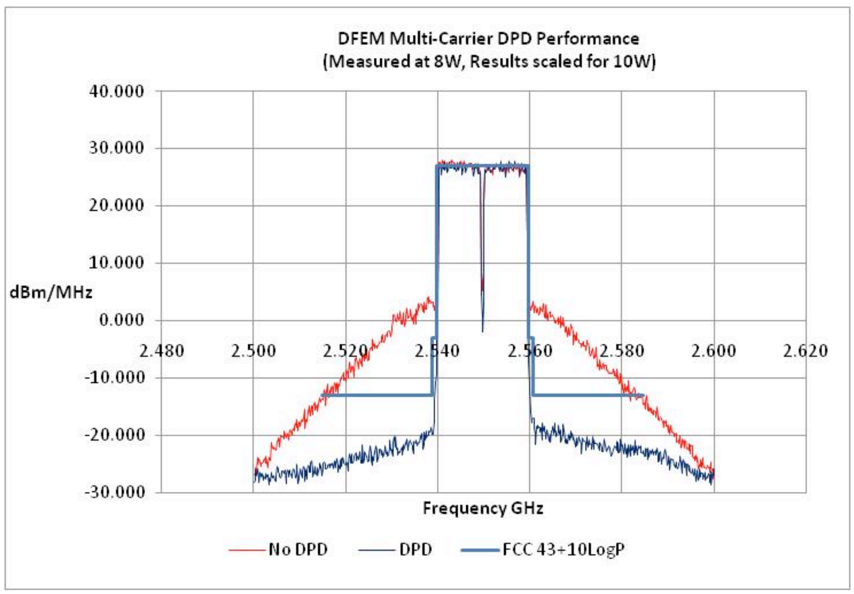


Figure 5: DPD improvement for Axis multi-carrier Doherty Amplifier

Doherty efficiency improvement

Axis Network Technology has implemented additional techniques for improving efficiency in the analogue/RF domain. Specifically the Doherty technique uses two output stage transistors biased at different points: one of the transistors is on all the time; the second only turns on as the signal approaches its peak. This reduces current consumption as the transistors are not constantly turned on, and when they are on they are operating in their more efficient regions. It is important to note that Doherty works at its best for signals with 6dB of peak-to-average. Axis Network Technology has demonstrated efficiencies of 40% for signals with a 6dB peak-to-average ratio.

For signals with more than 6dB peak-to-average, the two transistors are not able to operate completely within their most efficient regions. Therefore for signals such as

64QAM (currently with 8dB PAPR), the improvements obtained with Doherty are not as significant.

Software definition and reconfigurability

In addition to reducing CAPEX and OPEX today, Axis Network Technology RRHs are software defined – meaning that products manufactured to a single build standard can be defined by their software to work to a specific standard, frequency etc. and customised to the requirements of a particular OEM – and reconfigurable. This means that their operation mode can be re-defined or upgraded in the field. As well as introducing economies of scale, this approach means that dynamic configuration of the link can be performed post-deployment to optimise its role in the network and introduce new functionality over the air. It offers flexibility to the operator in terms of migrating to future standards and optimising coverage within buildings as well as outdoors.

Conclusion

Axis Network Technology Remote Radio Heads are now in volume production for WiMAX infrastructure. These advanced digital radio products combine proprietary CFR and DPD with highly efficient Doherty RF power amplifiers. The cumulative affect of these techniques, and the reduction of cable losses by locating the radio adjacent to the antenna, allows operators to see a 60% reduction in their energy bills for running basestations.

These same techniques are equally applicable to all higher order modulation schemes, including LTE. Axis Network Technology RRHs are future proof for use in LTE networks.

Axis Network Technology WiMAX RRHs provide flexible multi-gigabit BTS connections, communicating via OBSAI, CPRI or custom OEM fibre interfaces. Axis Network Technology has RRH models available for use in the 2.3 – 2.7GHz and 3.3 – 3.8GHz spectrum bands, each offering dual channel operation for MIMO, to comply with WiMAX and IEEE 802.16 d/e standards, and capable of 4-channel MIMO operation using 2 x 2-channel units. Support for Adaptive Antenna Systems (AAS) and AISG v2.0 antenna control is also provided.

Superior receiver performance of better than -98dBm can be achieved with single channel operation, and better than -100dBm using MIMO. A distributed BTS using 2-channel RRH with 10W 64QAM output power per channel is the equivalent of transmitting 40W from a traditional BTS, which again contributes to reducing power consumption.

About the author

Steve Cooper is Co-Founder and Chief Technology Officer of Axis Network Technology. Steve worked in GSM BTS Development at Motorola from 1993-1996, then in 1996-97 he was involved in deploying the US CDMA Network for Sprint PCS in Southern California. He then managed Lucent's Digital Radio Team for GSM, CDMA and UMTS BTS during 1997-2003. In 2003 he joined REMEC as VP Engineering to lead the development of a remote radio head opportunity, before co-founding Axis Network Technology in 2005.

steve.cooper@axisnt.com

About Axis Network Technology

Axis Network Technology (AxisNT) was founded in the UK by a team of highly experienced telecommunication executives, with the aim of developing and marketing the next generation of re-configurable digital radio platforms. One of the Company's main strengths is that it combines expertise in RF technology with digital and baseband design experience, and this allows it to deliver fully operational end-to-end systems direct to the OEM.

Axis' goal is to be the number one provider of compact digital radio platform technology and Radio Remote Heads for current and emerging wireless standards, delivering flexible, energy-efficient converged basestation systems for use with global broadband wireless standards – TD-SCDMA, UMTS, WiMAX, LTE and DVB – including triple-play and quad-play voice, video and data services.

The Company's in-house design expertise in digital radios is combined with an established logistics chain that includes circuit manufacture via global EMS and strategic device technology partnerships. For more information see www.axisnt.com.