DTV transmitter power efficiency
— new opportunities for reducing costs and environmental impact

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The worldwide introduction of digital terrestrial TV systems will lead to significant numbers of new transmitters being installed over the next few years. With the recent rise in energy prices, and increasing concerns over the environmental impact, it is important that these new transmitters are as energy-efficient as possible.

This article discusses various issues relating to the power efficiency of digital TV transmitters, and describes how Envelope Tracking technology could make a significant contribution to reducing the operational costs and environmental impact of new digital networks.

The impact of rising energy costs

Operational costs have always been a key issue for broadcasters, and a substantial part of these costs is due to the electricity required to run a transmission network, which can account for over 75% of the total electricity used by a broadcaster. Broadcasters are significant users of energy: for example, a digital TV transmission network for a typical EU country, using today's technology, could use over 12 MW of electricity, and incur an annual cost to the broadcaster of over € 12m a year at today's prices.

Energy costs continue to rise and, in order to manage the financial risk going forward, broadcasters are committing themselves to long-term fixed-price contracts with electricity suppliers. At the same time, attention is now focussed on finding ways of substantially reducing energy usage wherever possible.

Once installed, transmitters typically remain in service for a long time (maybe 10 to 20 years) and hence purchasing decisions being made now will have a significant impact on whole-life costs, which are likely to dwarf the initial purchase price (for instance, a single 8 kW transmitter using today's technology will incur an annual electricity bill of € 42,000 per year, even at current prices). Broadcasters are therefore paying significant attention to the energy consumption of digital TV transmitters.

Environmental impact – a growing concern

Aside from the cost argument for increased transmitter efficiency, there is also a strong desire from broadcasters to improve their environmental or "green" credentials and to be seen to be responsible in their use of energy. For example, to reduce their CO_2 "footprint", many broadcasters are purchasing power from renewable sources of energy – often at higher prices.

Even if they do not take steps to reduce the environmental impact of their activities themselves, government legislation will force them into action. There are already plans in some countries to incentivise industry to reduce CO_2 emissions, and large users of electricity such as the broadcasting industry are an obvious target for these initiatives. For example, the UK Government has proposed a “Carbon Reduction Commitment” scheme to cover large business and public-sector organizations whose annual electricity usage exceeds 6 GWh.

In addressing the issues of energy usage and environmental impact, the broadcasting industry could consider the lead of the cellular industry, where several of the leading operators are making public commitments to reduce the power consumption and environmental impact of their radio networks, and are pushing their suppliers hard for more power-efficient equipment. As a result, base-station vendors have invested heavily in new technologies to reduce power consumption. Although the same has started to occur with digital TV transmitter vendors, the take-up has been slower to date and could be accelerated.

RF Power Amplifier efficiency is the key

Each digital TV transmitter typically uses one exciter or modulator to drive a number of identical RF Power Amplifiers (PAs, often referred to as “Pallets”) – perhaps 20 and 100 for a typical low- to medium-power transmitter, in a “corporate structure” architecture, with the outputs of all the amplifiers combined to produce the total output power.

A breakdown of the energy usage in a typical transmitter shows that a relatively small amount of power is used by the exciter / modulator and interface circuitry. A significant proportion of the overall power (perhaps 55 - 60%) is used by the PAs, and a further 30 - 35% in providing cooling and AC-DC power conversion – where the power used is also largely driven by the power consumed by the PAs (i.e. the greater the power used by the PAs, the greater the cooling power required and the higher the AC-DC conversion losses).

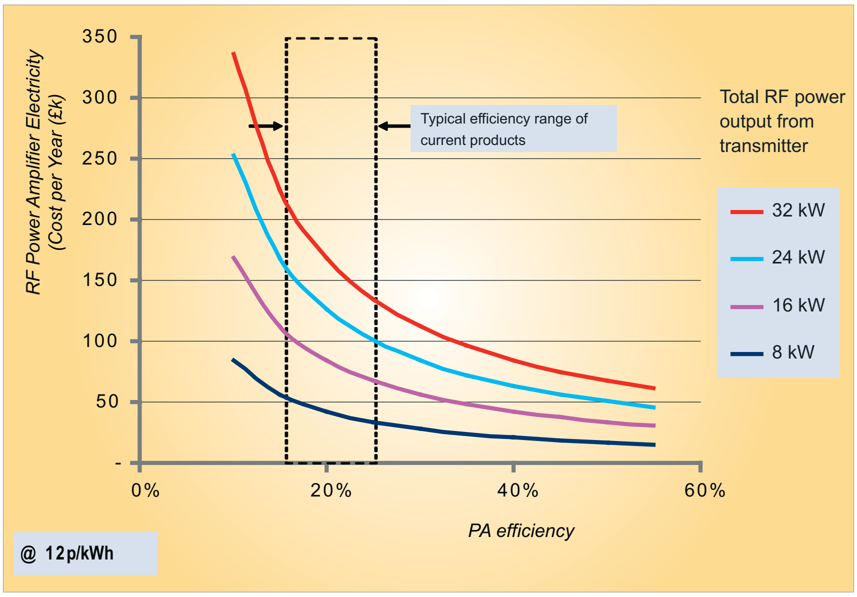

Figure 1
Annual cost of electricity required to power transmitter power amplifier(s), showing variation with PA efficiency

The power required for the PAs is directly related to their efficiency, which is relatively poor in current equipment. *Fig. 1* shows how the annual cost of electricity required to power (just) a transmitter’s PAs varies with the PA efficiency. It can be seen that improving the PA efficiency produces a substantial improvement in running costs.

Secondary effects of poor PA efficiency

Poor PA efficiency has a direct impact on the transmitter’s cooling requirements. With a PA efficiency of 20%, the remaining 80% of the electrical power supplied is wasted as heat, requiring careful cooling design to reduce equipment temperatures and ensure reliability, a significant consideration when broadcasters have a public-service obligation to meet.

Although lower power transmitters can use air cooling (either with or without air conditioning), higher power (or less efficient) transmitters require liquid cooling, incurring further complications. Furthermore, as power density increases, a higher proportion of power is required for cooling.

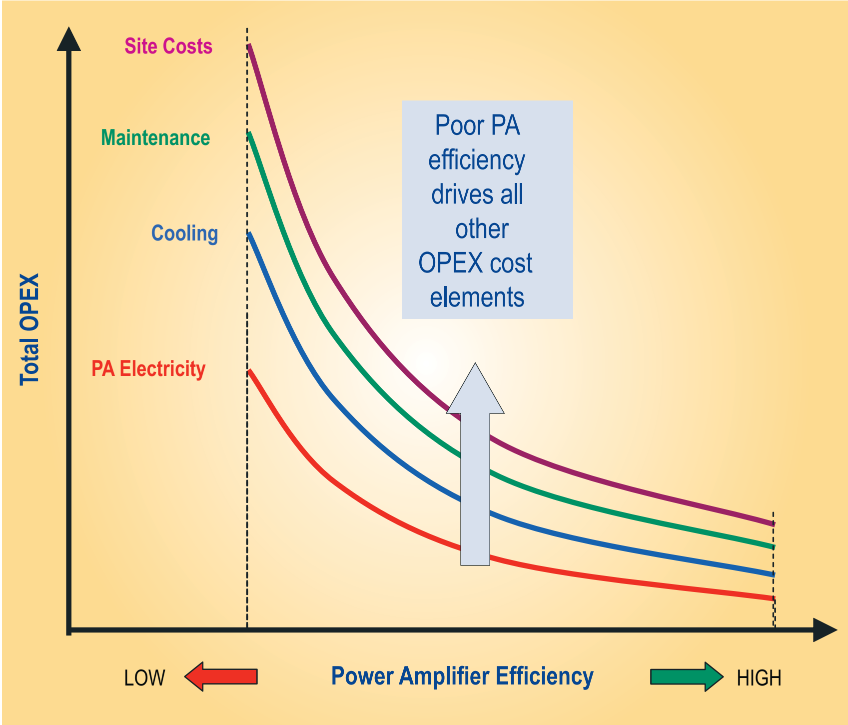

Figure 2
Effect of PA efficiency on overall network OPEX

Cooling is a major concern for broadcasters for a number of reasons. Firstly, all forms of forced cooling involve moving parts in one form or another (fans, pumps, etc.) and other items such as filters that require regular maintenance. Secondly, mechanical noise can be a concern in many urban transmitter locations: some countries are already starting to pass legislation to control noise levels at such sites. Finally, the cooling plant increases the equipment required on-site and hence the site rental costs.

Another impact of poor PA efficiency concerns the on-site backup power supply – higher transmitter power consumption necessitates either larger battery packs or larger diesel backup facilities, both of which again push up equipment and site costs.

It can be seen, therefore, that poor PA efficiency has a significant impact not just on the design of the transmitter itself, but also the cooling and backup facilities required on site, impacting both initial costs (CAPEX) and also long-term operational costs (OPEX). The overall impact on the total OPEX spend of poor PA efficiency is shown in diagrammatic form in *Fig. 2*.

RF Power Amplifier design

All DTV systems use OFDM (Orthogonal Frequency Division Multiplexing), broad channel bandwidths and complex modulation schemes to achieve high spectral efficiency. Unfortunately, the modulation accuracy, noise and spurious requirements effectively mandate the use of linear (Class AB) RF Power Amplifiers in the transmitter.

Fig. 3 shows a conventional Class AB amplifier as used in traditional DTV transmitters.

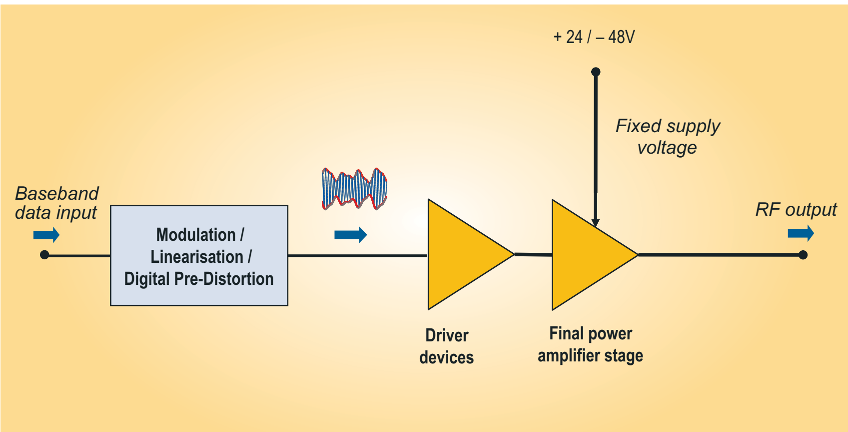

Figure 3
A conventional Class AB power amplifier configuration

Linear PAs can be very efficient when operating close to their peak power and, with careful design, this can be achieved over a relatively broad bandwidth. However, they are unfortunately very inefficient when handling real-world signals with varying amplitude components, such as OFDM signals.

OFDM signals are composed of a large number of individual components, the power of each varying with time. The resultant amplitude of the composite signal over time is therefore not constant but "peaky" in nature, and can be characterised by its "PAPR" (Peak-to-Average Power Ratio) or "Crest Factor". PAPR values for broadcast TV signals can in theory be quite large (> 35 dB) but in practice values of 11 - 12 dB are more commonly observed.

High PAPR signals make the design of PAs difficult for two reasons:

1) The amplifier must be linear over a wide dynamic range to preserve modulation accuracy and spurious performance. It is possible to use a technique called "Crest Factor Reduction" (CFR) to allow the PA to operate closer to peak power for most of the time, by limiting the peaks of the signal using DSP techniques. However this needs to be done with care to minimize distortion and maintain adequate signal EVM (Error Vector Magnitude). Typically, CFR will reduce the PAPR to around 8.0 - 8.5 dB.

2) The variation with time of the PA output power results in a poor overall power efficiency. The reason for this is shown in *Fig. 4*. A Class AB (linear) PA is at it's most efficient at peak power, but the drain (power conversion) efficiency, as shown by the solid line, drops off rapidly as the output power decreases. The probability distribution of instantaneous output power for a typical OFDM signal (dashed curve – not to a specific scale) shows that for much of the time the signal power lies well below the peak power and hence the device is operating at low (average) efficiency. Note that the PAPR value shown in this diagram assumes that CFR has been used to reduce the PAPR of the transmitted signal: without this, overall efficiency would be even lower.

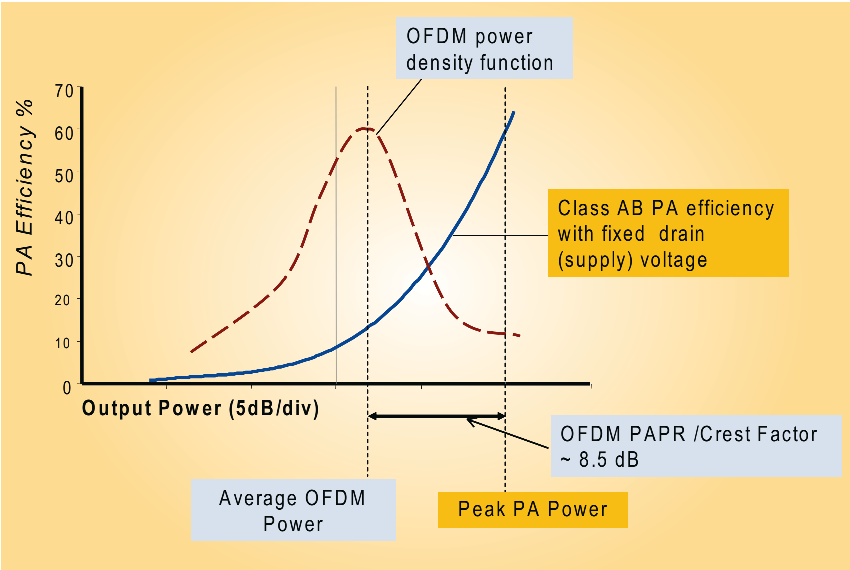

Figure 4
Comparison of drain efficiency vs. power output and probability distribution of the instantaneous output power value

It can be seen, therefore, that designing a linear PA to meet the system performance requirements, and to be power-efficient at the same time, is extremely difficult.

Possible solutions for improving PA efficiency

A number of techniques are now being used to improve PA efficiency. The majority of these have found their first use in the cellular industry, where the problems of high network power consumption and environmental impact have already caused many network operators to force the pace of change and to demand significantly improved equipment efficiency from their suppliers.

The major techniques are:

- Digital Pre-Distortion (DPD) and Linearization
- Envelope Tracking

DPD and Linearization

As already noted, Crest Factor Reduction can make a useful contribution to improving PA efficiency by allowing controlled compression of peak signals, effectively allowing the PA to operate nearer peak power and hence at a higher efficiency.

DPD and Linearization techniques build on this by compensating for non-linearities in the final RF output stage. In the process they also improve adjacent channel and EVM performance and, by allowing some compensation for the distortion caused by non-linearities near compression, the PA can be driven harder, resulting in an improvement in power efficiency.

The best improvements result when DPD and Linearization are used as part of a system architecture incorporating active sampling of the output signal as part of a feedback loop: only then can the system fully compensate for changes in amplifier characteristics with time, temperature and signal characteristics. This "adaptive" pre-distortion is in widespread use in the cellular industry but is more difficult to implement in the "corporate structure" PA architecture used in TV transmitters, and most systems in use today use simpler open-loop (predictive) DPD/linearization.

Envelope Tracking

Envelope Tracking (ET) uses a completely different technique: instead of the final RF-stage power transistor being supplied with a constant voltage, the supply is changed dynamically, in synchronism with the envelope of the modulated RF signal passing through the device. This ensures that the output device remains in its most efficient operating region (i.e. in saturation). The "modulation" of the supply voltage is performed by a Power Modulator device which replaces many of the features of the normal DC-DC converter that provides the supply voltage.

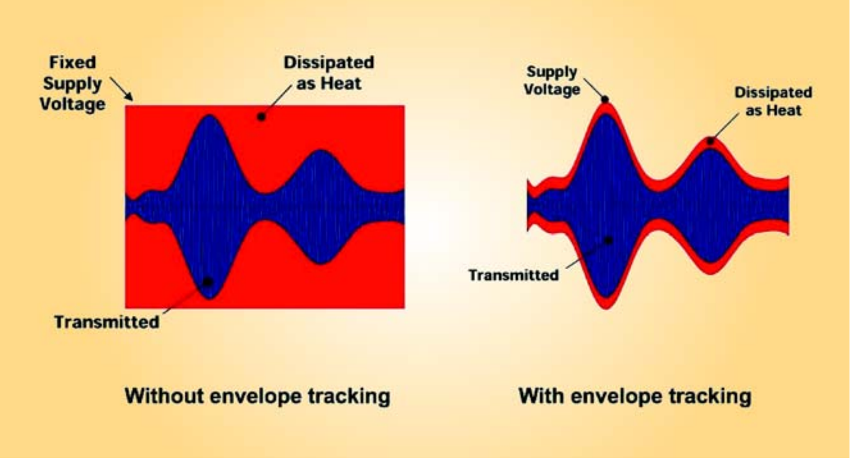

Figure 5
Envelope tracking reduces the voltage difference between the supply voltage and the signal envelope, dramatically reducing the energy dissipated as heat

Fig. 5 shows the Envelope Tracking system in operation: without envelope tracking, the difference between the fixed supply voltage and the required output waveform is dissipated in the RF power transistor as heat. With envelope tracking, the supply voltage tracks the signal envelope, dramatically reducing the energy dissipated.

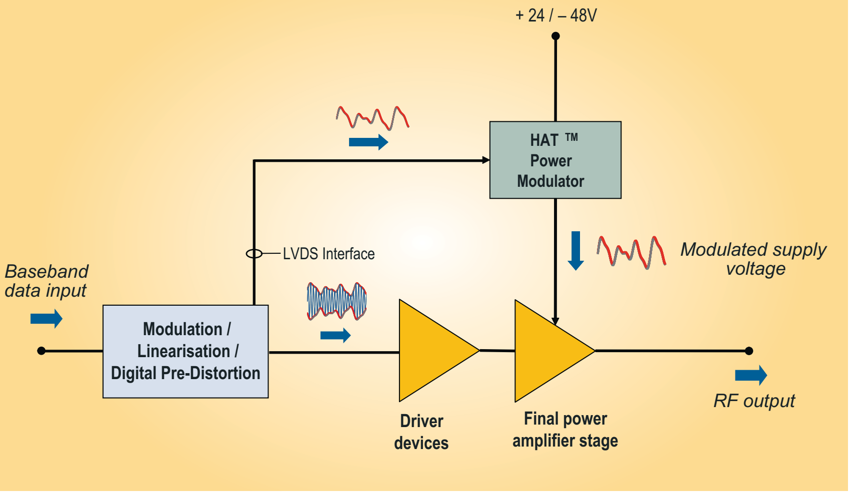

Figure 6
Application of Nujira's High Accuracy Tracking Power Modulator to a standard power amplifier

Although the principles of Envelope Tracking have been known for some time, the practical difficulties of implementing a working system have prevented the concept from being employed until recently. The first practical implementation is Nujira's High Accuracy Tracking (HAT™) technology.

Fig. 6 shows how Nujira's HAT Power Modulator is used in conjunction with a typical (single) PA. The only addition required to the standard PA architecture is an output from the DPD/Linearization function to drive the HAT Power Modulator with a digital representation of the modulation envelope.

Fig. 7 shows the Nujira HAT Power Modulator integrated with a typical PA.

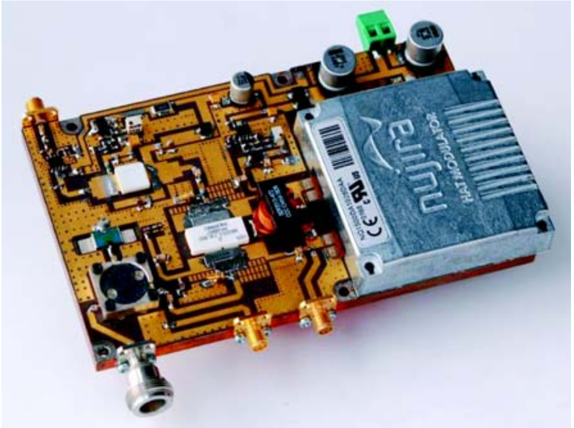

Figure 7
Nujira HAT Power Modulator integrated with PA

The practical implementation of Envelope Tracking is critically dependent on the design of the Power Modulator, which has to track the rapidly-varying envelope of the (wideband) RF signal with very high accuracy, in order to achieve the OFDM specifications. Accurate time synchronization between the signal passing through the device and the modulated drain voltage is also critical. Finally, the Power Modulator itself must be able to supply high peak power levels and at the same time have a very high power-conversion efficiency in order to achieve a high overall system efficiency.

Envelope Tracking can be used with a variety of transistor types – the main one for the broadcast industry being LDMOS.

Benefits of Envelope Tracking

The primary benefit of employing Envelope Tracking is the substantial gain in PA efficiency. Efficiencies of 40 - 45% are already possible with this technology, with higher levels expected in the future when RF devices optimized for ET operation become available (the major change required here is to optimize the RF device efficiency for the target PAPR value instead of peak efficiency at maximum output power).

Even at the conservative figure of 40%, an improvement in efficiency from the current level of 23% results in approximately 50% less heat dissipation in the PA, reducing and simplifying the cooling requirements, and increasing the threshold at which water cooling becomes necessary.

Other benefits include smaller equipment size, reductions in maintenance costs and improved equipment reliability, plus lower site installation and rental costs.

Despite the additional cost of the Power Modulator, the overall impact on transmitter manufacturing cost is expected to be minimal, due to the reduction in heatsinking and other metalwork, and from the overall reduction in size that is possible once power densities are reduced.

Abbreviations

AC	Alternating Current
CAPEX	Capital Expenditure
CFR	Crest Factor Reduction
DC	Direct Current
DPD	Digital Pre-Distortion
DSP	Digital Signal Processor / Processing
DTV	Digital Television
DVB	Digital Video Broadcasting **http://www.dvb.org/**
DVB-T	DVB - Terrestrial
ET	Envelope Tracking
EU	European Union
EVM	Error Vector Magnitude
LDMOS	Laterally-Diffused Metal Oxide Semiconductor
OFDM	Orthogonal Frequency Division Multiplex
OPEX	Operational Expenditure
PA	Power Amplifier
PAPR	Peak-to-Average Power Ratio
RF	Radio-Frequency
UHF	Ultra High Frequency

The other significant advantage of ET is that Envelope Tracking amplifiers are inherently broadband and work with all modulation schemes. One power amplifier design can be used for all UHF frequencies, and future enhancements to DVB-T and other systems can be easily accommodated without further hardware changes.

The financial and environmental benefits arising from the use of this technology are discussed in a later section.

Application of Envelope Tracking to typical UHF transmitter architecture

Fig. 8 shows how envelope tracking is applied to a typical multi-element UHF transmitter using a number of PAs connected in parallel to achieve the required output power. Each PA is equipped with a Nujira HAT™ Power Modulator which dynamically varies the supply voltage in line with the signal envelope, all driven in parallel from the envelope signal generated by the exciter.

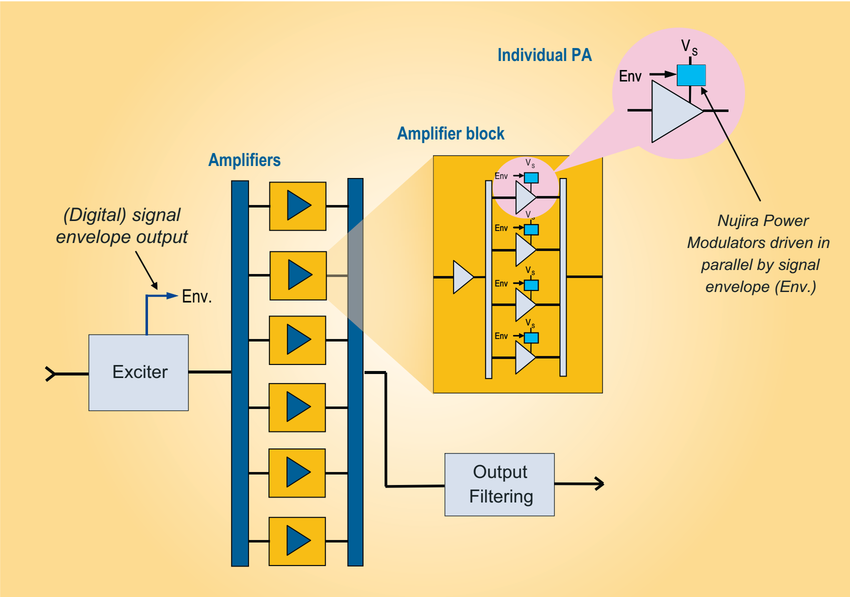

Figure 8
Typical transmitter architecture using Envelope Tracking power amplifiers

Economic and environmental benefits of using Envelope Tracking

Table 1 shows the potential savings in energy costs and environmental impact that are possible using Nujira's HAT technology as applied to a typical digital terrestrial television network. As can be seen, the savings in both energy cost and environmental impact are substantial. Note that these savings are based on a conservative value for the PA efficiency using Envelope Tracking, and electricity costs typical of long-term contracts negotiated before the recent price rises, so actual savings with ET-enabled transmitters are likely to improve on these figures.

Applicability to Mobile TV

Although this article has focussed on digital terrestrial television systems, the same problems (and benefits of adopting Envelope Tracking) apply equally to Mobile TV systems such as DVB-H and MediaFLO.

The key differences between Mobile TV and terrestrial broadcasting systems are mainly concerned with the network topology and transmitter power levels. Since much of the usage is expected to be in-building, it is likely that Mobile TV systems will be more "cellular-like", with a much greater number

		Current Technology	HAT™ Technology	Saving
	PA efficiency:	20%	40%	
Transmitter (32 kW)	Total transmitter power consumption:	239 kW	117 kW	122 kW
	Overall transmitter efficiency:	13.4%	27.3%	
Network (1.6 MW)	Total network power consumption:	12.0 MW	5.9 MW	6.1 MW
	Total yearly consumption:	105 GWh	51 GWh	53 GWh
	Yearly energy cost:	$ 12.6 M	$ 6.2 M	$ 6.4 M
	CO2 emissions (Tonnes per year):	45,040 t	22,040 t	23,000 t
			overall saving:	51.1%

Key Assumptions:
RF power per multiplex: 8.0 kW
Number of multiplexes: 4
Number of transmitter sites: 50
Electricity cost: 12 ¢/kWh

Table 1
Operational savings through the use of Nujira technology

of lower power transmitters. The total aggregate power required is likely to be of the same magnitude as current terrestrial systems (with in-building coverage in major centres of population only), although it could be several times higher if better coverage is required.

The business case for Mobile TV remains a major issue, delaying adoption of the technology: the significant reductions in direct operating costs possible with transmitters equipped with high-efficiency PAs will make a strong contribution to improving this. Envelope Tracking systems are ideally suited to this environment, since they are already being adopted for 3G and WiMAX cellular base stations.

Summary

As digital TV networks (both terrestrial and mobile) grow to support the digital switchover and bring new services to customers worldwide, the energy required to run these networks will substantially increase. The power efficiency of the RF power amplifiers within the transmitters is the critical issue in reducing this energy usage and the associated environmental impact.

Bringing more than 20 years of experience to the Nujira management team, **Keith Pruden** was most recently the Global Vice President of Networking Sales with Agere Systems Inc. and prior to that held sales leadership positions with Agere in both Europe and Asia.

Prior to joining Agere, Mr Pruden ran the Wireless and Multimedia business unit for Cadence Design Systems and this followed on from his role as Northern European Sales leader for VLSI Technology. Prior to moving into sales, he worked as an ASIC and DSP Field Application Engineer and received his engineering training and degree whilst employed by the Royal Air Force in the UK.

There are several techniques that can be used to improve power amplifier efficiency: of these, Envelope Tracking (e.g. Nujira's High Accuracy Tracking technology) provides the best improvement in efficiency, combined with inherently broadband operation, and has the potential to reduce the overall power consumption of a digital TV network by 50%. This technology is expected to play a large part in helping to improve both the economics and the environmental impact of new digital TV networks.