R&S®THU9

Efficiency is the key factor when choosing a high-power broadcast transmitter

Broadcasting

Brochure | 01.00

ROHDE&SCHWARZ

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Introduction

Energy consumption accounts for more than half of all the costs associated with the operation of high-power broadcast transmitters, which is why network operators are always looking for the highest possible efficiency in the transmitters they deploy in their networks.

There is plenty of room for improving efficiency. Today's high-power broadcast transmitters typically consume four to five times more energy than they actually transmit on air. Improving transmitter efficiency has a greater financial impact than simply lower energy bills. Cost-of-ownership can be reduced, for example. And since efficient transmitters dissipate significantly less energy more of them can be accommodated in a single rack, which reduces the cooling burden and saves valuable space. In an era of increased environmental awareness, reducing energy bills also has the positive societal effect of reducing carbon emissions.

Several approaches have been proposed to improve transmitter energy efficiency. This document explores some of the technology options and gives appropriate guidance for selecting the best high-power transmitter from the new generation coming on the market.

The specific characteristics of COFDM and 8VSB broadcasting signals account for much of the difference between the energy required by the transmitter and the energy that is actually transmitted on air. Both COFDM and 8VSB signals have a high average power level as well as signal peaks that must be amplified.

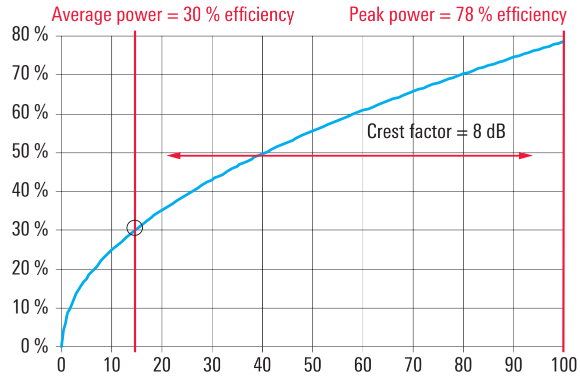
An amplifier working at its saturation point delivers its highest energy efficiency. But the characteristics of high-power broadcast signals mean that the amplifier cannot work at its saturation point because it reaches saturation only when the amplifier is operating at peak power. It hardly needs to be said that an amplifier is less efficient when it operates at a lower power level.

This relationship between average and peak power is represented by a ratio called the "crest factor" or peak-to-average power ratio (PAPR).By defining the relationship between average and peakpower, this ratio becomes useful for analyzing efficiency. Lowering crest factor values is a direct path to greater potential efficiency.

Crest factor

When operating a broadcast amplifier in normal class A/B mode, the amplifier's theoretical power efficiency is 78%. But this theoretical figure is significantly affected by the crest factor. It is widely accepted that 8 dB is an excellent crest factor value for broadcast amplifiers.

Theoretical efficiency of an amplifier in class A/B mode with CF = 8 dB



Converting 8 dB to its linear value of 6 dB and using the formula below makes it clear that the highest possible average power that can be amplified with a broadcasting amplifier in class A/B mode is just 1/6 of the peakpower (that is, about 15% of peak power):

Crest factor (CF) = peak power / average power

The figure on the left illustrates how the CF affects amplifier efficiency. The point at which the vertical line (CF = 8 dB) intersects the transistor's characteristic efficiency curve determines the amplifier's efficiency. Therefore, taking all losses (such as those caused by combining components) into account, an excellent average value for amplifier efficiency is 30%.

As mentioned. an average amplifier efficiency of 30% leaves a good deal of room for improvement. To date, design engineers have come up with several approaches for optimizing energy efficiency.

They include:

- Crest factor reduction, which has at least three approaches
  - Tone reservation
  - Active constellation extension (ACE)
  - Rohde & Schwarz crest factor reduction method
- Switched mode power amplification (SMPA)
- Drain voltage regulation / envelope tracking
- Doherty amplification technology

Crest factor reduction

Although reducing the CF is the most straightforward approach, it has the complications of possibly affecting signal quality and not being applicable to ATSC signaling. Just clipping the peaks by reducing the transistor's voltage supply, for example, would also eliminate the transmission of some signal peaks and cause a modulation error ratio (MER) increase.

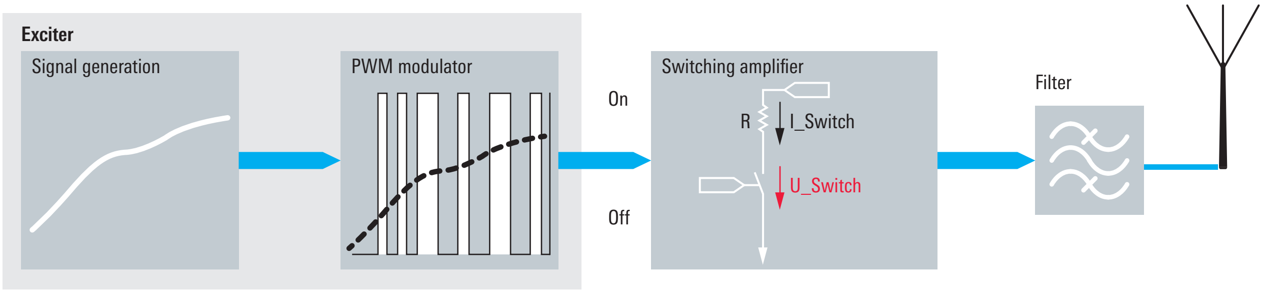
There are currently three solutions for reducing the CF without negatively impacting signal quality:

- Tone reservation improves the CF by targeting subcarriers without signal information – these are reserved for being switched on and off or modified. This results in a slight increase in bandwidth and improves efficiency by approximately one percentage point.
- Active constellation extension involves adjusting the constellation diagram and taking advantage of the fact that the outer constellation points can be moved further outward. The CF is reduced by adding all the carriers and changing their amplitude. This approach does not work for rotated constellation diagrams as specified in DVB-T2.
- Algorithmic signal analysis has the potential of reducing the CF by about 2%. An algorithm created by Rohde & Schwarz analyzes the signal and reduces the peak values without affecting signal quality.

Three additional approaches

Switched mode power amplification (SMPA) is a promising but unproven technology in which the transistor is operated with a pulse code. In other words, the amplifier is constantly being switched on and off. In the "off" mode, zero power is required. In the "on" mode, the amplifier works with full saturation and maximum efficiency is achieved. This can lead to high efficiencies but the challenge to successful implementation of SMPA is that the normal amplitude modulated signal must be converted into a pulse width modulated (PWM) signal. This calls for very high switching frequencies that have the unwanted effect of generating spurious signals in the spectrum. These signals must be filtered out in the RF spectrum. This transforms the system into a narrowband solution, which reduces power efficiency. The figure below illustrates the concept used in SMPA.

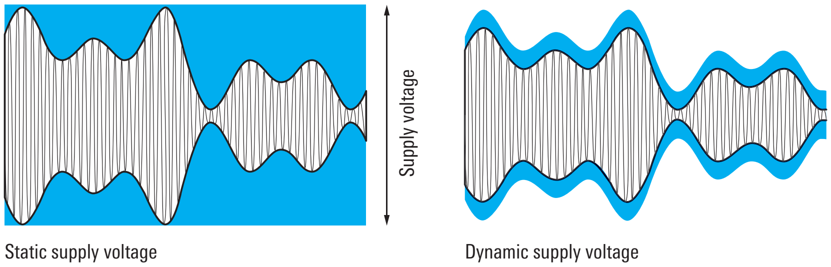
Theoretical block diagram of an SMPA system



Because both the modulators and the amplifiers must be developed for SMPA, it is the most complicated of all technologies discussed in this document. New transistors are also required and these have not been field-tested for broadcasting applications. It will probably be a few more years before SMPA has much appeal for the broadcasting market. The expected increase in power efficiency is > 20 %.

Drain voltage modulation (also known as envelope tracking) adjusts the transistor's supply voltage to match the respective signal. A large amount of additional hardware and software components are needed to analyze the signal, modulate the drain voltage and adjust the characteristics of the transistors. These modifications increase hardware costs and reduce the power density of the amplifier. The number components needed reduces the availability of these systems. The expected increase in power efficiency is about 10 % to 15 %. The figure below illustrates the envelope tracking concept.

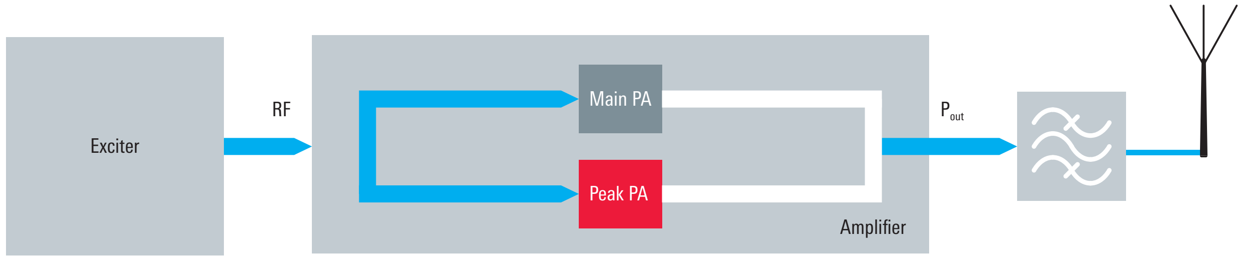
Envelope tracking



Doherty amplification is the most effective approach to date because it has been field-tested, is available today and achieves superior efficiency performance. Developed by William H. Doherty in the 1930s, the technology has not been adapted for high-power broadcast transmitters until recently.

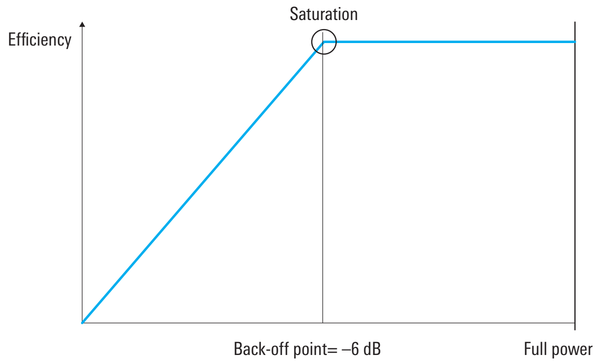
The basic idea, as shown in the figure below, is to separate the amplification of peak and average power by using a main and peak amplifier and operating them separately, which results in a 10% to 15% improvement in amplifier efficiency.

Block diagram of a transmitter system with Doherty amplifier

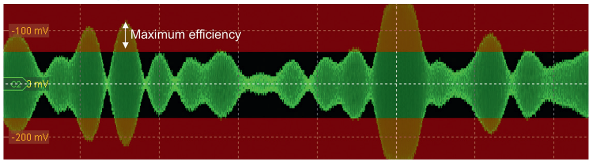


The fundamental principles are illustrated graphically in two diagrams below. The main amplifier constantly works in saturation after reaching the back-off point. This is achieved with load modulation. In the illustration, the back-off point is –6 dB. In our example, a load resistor with double the load is used. Meanwhile, the peak amplifier does not operate (i.e. work in Class C mode) until the back-off point is reached, meaning that no energy is required by the peak amplifier before reaching this point. At the back-off point, the peak amplifier starts reducing the load resistance of the main amplifier, which now provides more power but is still working in saturation.

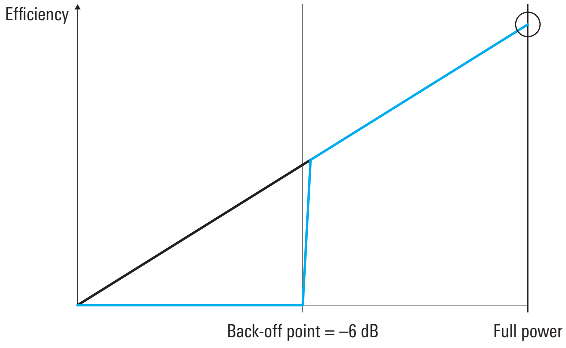
Main amplifier – with double load resistor in saturation



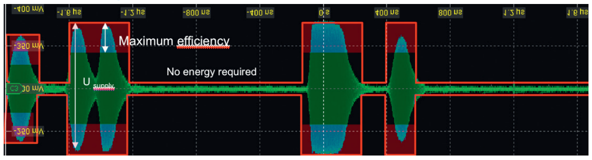
DVB-T2 signal – main amplifier



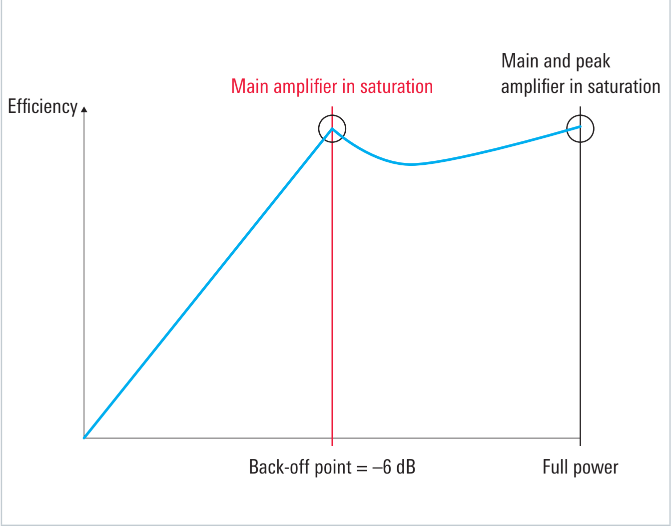
Peak amplifier – not operating until back-off point



DVB-T2 signal – peak amplifier



Theoretical Doherty efficiency



The peak amplifier further reduces the load resistance until the normal value is reached. Now half of the nominal output power is supplied by the peak amplifier and the other half by the main amplifier. Because the peak amplifier does not consume energy before the main amplifier approaches its saturation point, and because the headroom required for the main amplifier is very low, the level of efficiency that can be reached with a Doherty amplifier is 10 % to 15 % greater than that of a Class A/B amplifier. The diagram on the left illustrates how Doherty amplification attains its high operating efficiency.

Doherty technology was created as a narrowband solution with a possible relative bandwidth of about 10 %. This is because a λ/4 matching line is required to handle load modulation. This operational drawback can be avoided with intelligent amplifier design. Doherty technology is now used extensively in mobile base stations where it has proven to be robust and reliable. After examining each of these possible solutions for improving the power efficiency of a broadcast transmitter, Doherty technology is widely considered to be the best approach.

Doherty technology makes it possible to improve the efficiency of a broadcast amplifier with COFDM modulation from an average of 20 % in the past to 39 %, thereby offering energy savings of almost 50 %. As such, it is the most promising of the technologies reviewed in this document.

Beyond amplifier design

While amplifier design has the greatest impact on energy efficiency, network operators must also consider the performance of the entire transmitter system when evaluating a high-power broadcast transmitter for purchase. Intelligent system design can deliver significant benefits such as lower cost of ownership, reduced service costs and reduced maintenance costs. In addition to energy efficiency, network operators need to consider:

- Space efficiency
- Time efficiency in terms of operation
- Service efficiency
- Investment efficiency

Every aspect of system and semiconductor technology has advanced since the previous generation of high-power broadcast transmitters. Network operators can take advantage of the full range of these innovations by seeking out products that are the result of extensive hardware and software optimization.

Two examples are the utilization of state-of-the-art LDMOS power transistors with 50 V supply voltage and new signal processing and system control concepts.

Integrating 50 V LDMOS power transistors is not a trivial task. The system manufacturer must work closely with its semiconductor supplier to ensure that the right features are included. A matching circuit must be intelligently designed to guarantee long-term stability of the amplifier board. The RF coupling network after the transistors in the signal path should cause only minimal attenuation; and new power combiners and harmonics filters must be developed with the focus on reducing attenuation.

Signal processing deserves just as much design focus as the transistor circuit itself. Power supplies should be designed with redundancy to allow the transmitter control unit to adapt dynamically to the transistor supply voltage. This capability and an automatic, adaptive pre-correction capability will boost transmitter efficiency, which is particularly important at low output power. Because of the sophistication of the operating concepts, the amplifier's aluminum heat sink must be designed to ensure that all transistors operate at the same temperature.

The transmitter's voltage regulation circuit also offers system design teams opportunities to increase efficiency. In particular, intelligent design can allow transmitter efficiency to be optimized for all digital TV standards. To manage this, the signal can be decoupled by the directional coupler at the transmitter output and routed back to the exciter where it is analyzed. The exciter itself can be redesigned to deliver lower crest factors for all COFDM standards.

When viewed from a cost-of-ownership perspective, space efficiency ranks second in importance to energy efficiency. The ability to pack more transmitters into fewer racks because of lower power density is just the beginning.

External liquid cooling systems by their very nature require less space than air cooled systems but intelligent design can maximize the inherent advantages. The pump unit should fit into a minimum amount of space and smart frame design can ensure installation flexibility. The pump should be designed so that two pumps can be stacked on one another. Intelligent design also allows the pump unit to be installed on the floor or on the wall. Heat exchangers should be designed so they can be installed horizontally or vertically.

Conclusion

Keeping in step with rapidly developing component technologies presents a major challenge for high-power broadcast transmitter design teams. Every new component requires a design change, of course, but it also impacts the design of other components. In addition to integrating advances in semiconductor and mechanical innovations, the design team also has to accommodate the requirements of evolving broadcast standards.

This document has outlined some recent technology advances, particularly in the area of amplifier design and energy efficiency. The R&S®THU9 liquid-cooled high-power transmitter is an excellent example of establishing new performance benchmarks by combining the best component technologies with intelligent design. The R&S®THU9 integrates Doherty technology and all of the other design concepts mentioned in this document.

The results of this well-considered integration are summarized below:

- In normal operation, the R&S®THU9 attains efficiency values of up to 28 % for COFDM standards and up to 30 % for ATSC, including the cooling system.
- In Doherty operation, users can save up to 50 % of energy costs compared with conventional transmitters. Intelligent system design gives the R&S®THU9 unparalleled flexibility and scalabilty in an extremely compact design.
- The R&S®THU9 transmitter family's portfolio ranges from single transmitters with built-in pump unit and bandpass filter to multitransmitter systems and even N+1 configurations in a single rack.

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PD 3606.8520.62 | Version 01.00 | May 2013 |
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