

Optimizing efficiency of high-power TV transmitters

Various methods are available to optimize the efficiency of transmitters. This article examines why Rohde & Schwarz has adopted the Doherty concept and why this choice helped to make the company's transmitters such a big success around the globe.

Optimizing efficiency – but how?

Today's advanced high-power transmitters are almost exclusively equipped with solid-state amplifiers. Although recent years have brought major advances in the efficiency of these broadband amplifiers, which normally operate in class AB mode, the results achieved for OFDM signals are still only in the rather moderate range of 25 % to 28 %. Efficiency is defined as the ratio of the average emitted RF power to the power consumed from the power grid. In order to reduce transmitter system energy costs and CO₂ emissions, manufacturers are working to significantly increase the efficiency of solid-state amplifiers. Suitable architectures have already existed for many years, but their application was simply not feasible in the past due to the large RF bandwidths (e.g. band IV/V from 470 MHz to 862 MHz) and signal bandwidths between 6 MHz and > 20 MHz.

Recent advances in solid-state and circuit technology as well as in digital signal processing are now making it possible to exploit these architectures for use in amplifying digital broadcast signals. Besides the increase in efficiency, however, there are certain disadvantages that must be taken into account during transmitter development. It is important to look beyond the reduction in energy costs and keep in mind the total costs during the entire lifetime of the transmitter. These costs consist of the capital expenditure (CAPEX) and most importantly, the operating expenses (OPEX) including energy, maintenance, repair and logistics costs.

Switched-mode power amplifiers (SMPA)

The SMPA architecture achieves the highest efficiency among all of the solutions presented here. However, it also has the largest impact on the transmitter system, because it affects almost all of the transmitter components including modulators, excitors, amplifiers and filters. Amplifiers based on this concept use high switching frequencies in the transistor output stage, making it necessary to use GaN semiconductors. This technology has not yet attained the level of maturity required for use in commercial high-power transmitters. Suitable power semiconductors are not yet available and expected to cost significantly more than conventional LDMOS transistors. Accordingly, switched-mode power amplifiers currently cannot compete in the price-sensitive broadcast market and will require more years of development before they become relevant. The capital expenditure will be significantly higher than for conventional transmitters.



Fig. 1: R&S™TMU9 transmitter system, configured for three transmitters with six R&S™PMU901 amplifiers based on Doherty technology. Each transmitter delivers 1.14 kW.

Envelope modulation

With this method, the supply voltage of the RF power transistors is modulated with the envelope of the RF signal (Fig. 2). In order to ensure the high quality of an OFDM-modulated signal, e.g. in terms of the modulation error ratio (MER), the supply voltage must track the envelope with adequate speed and the envelope must remain in sync with the modulated RF drive of the transistor. In case of a mismatch, the MER needs to be corrected using adaptive precorrection. This involves complex control circuitry when multiple transistors are connected in parallel in an amplifier. The use of complex envelope modulators requires a significantly larger number of (power) components (resulting in lower MTBF) and results in significantly higher production costs compared to class AB amplifiers. The efficiency of the output stage is highly dependent on the efficiency of the envelope modulator.

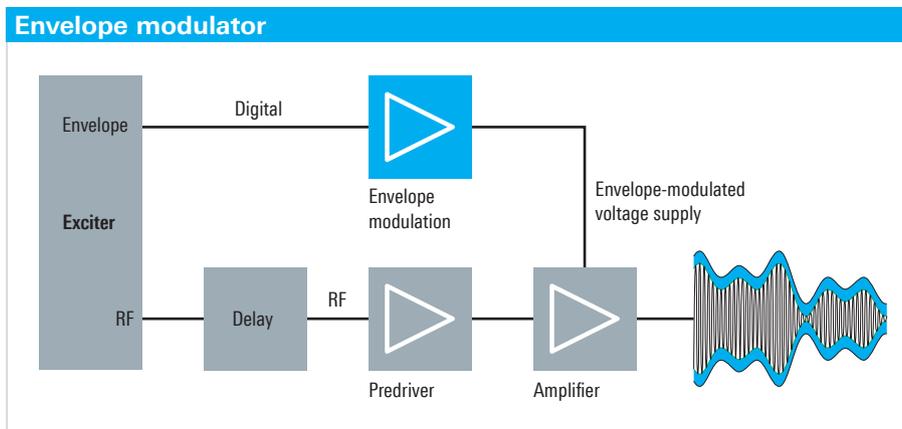


Fig. 2: Envelope modulation: The supply voltage to the RF power transistors is modulated with the envelope of the RF signal.

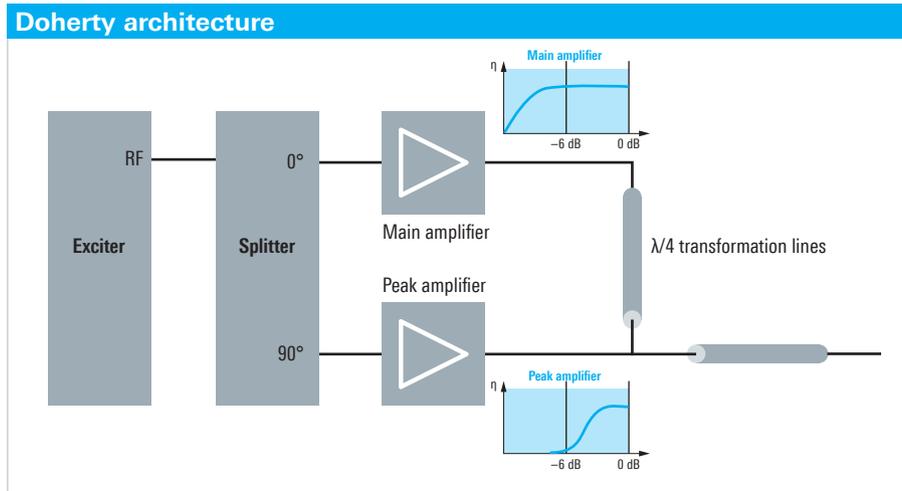


Fig. 3: The Doherty architecture splits the input signal into two paths.

The bias behavior of the transistors is another disadvantage. Since the supply voltage is not constant, the biasing will fluctuate, especially at low supply voltages (variation in gain factor and linearity properties). The benefit of envelope modulation is related to the broadband nature of RF amplifiers.

Due to lower MTBF as well as long-term stability problems and high production costs, envelope modulation is not the preferred solution for Rohde&Schwarz high-power transmitters when using amplifiers with multiple output stage transistors connected in parallel. In addition to increased capital expenditure, the operating expenses are also higher due to the necessary maintenance and repair.

Doherty amplifiers

The Doherty architecture was already patented in 1936. The method involves splitting the input signal into two paths: the main amplifier and the amplifier for peak signals (Fig. 3).

An amplifier achieves optimum efficiency when it is operated in compression. Since the load impedance is constant in class AB amplifiers, this occurs only in the (rare) case of peak modulation. The Doherty method uses load modulation. In case of a symmetrical Doherty amplifier (identical main and peak path), only the main amplifier operates when the modulation is low. The load impedance is chosen so that the main amplifier operates with high efficiency at low modulation and goes into compression already at a quarter of the output power, attaining maximum efficiency. If the input signal level increases further, the peak amplifier will also amplify the input signal and the load impedance of the main amplifier is dynamically reduced. Starting at this time (back-off point), the main amplifier always operates at maximum efficiency and can also output more power (up to the peak modulation as in class AB operation) due to the reduced load

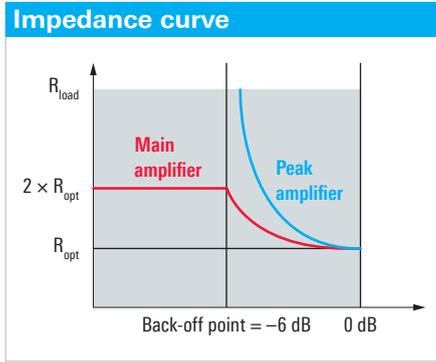


Fig. 4: Impedance curves of the main and peak amplifiers.

impedance. Fig. 4 shows the load impedance curves for the main and peak amplifiers, while Fig. 5 illustrates the efficiency curve. Although the transistor in the main amplifier delivers significantly higher AVG power than in the class AB amplifier, the junction temperature is much lower due to the good efficiency, resulting in higher MTBF. The disadvantage of the classic Doherty architecture is the very narrowband combiner based on $\lambda/4$ line transformation for load modulation. The result are increased logistics costs due to the need for multiple narrowband amplifiers.

Compared to classic transmitter systems, the advantage of Doherty technology is that no changes are required in the architecture of the transmitter system. The only difference arises in the structure of the amplifier. Among all currently discussed solutions for improving the efficiency of power amplifiers for broadcast applications, the Doherty design represents the optimum solution for reconciling CAPEX versus OPEX:

- ▮ No increase in required components, meaning no reduction in MTBF
- ▮ Significantly higher efficiency
- ▮ Lower junction temperature for transistors, leading to higher MTBF
- ▮ Long-term stability

Fig. 5: Efficiency curve of a Doherty amplifier.

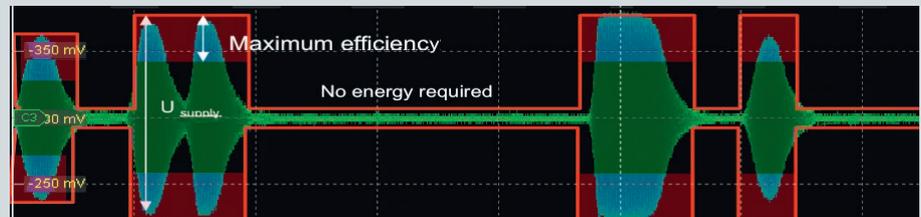
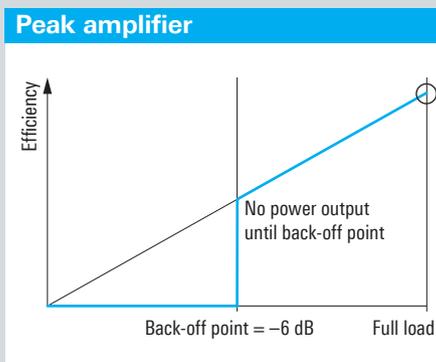
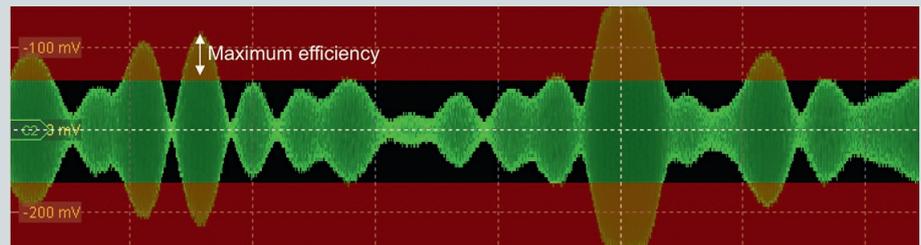
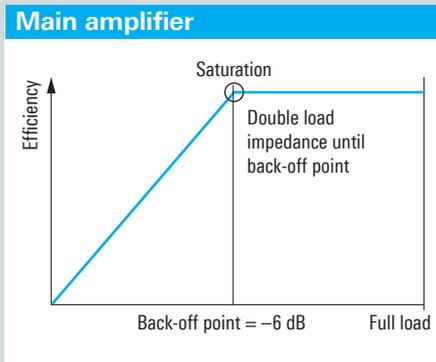




Fig. 6: R&S®PMU901 600 W amplifier.

Multiband Doherty amplifiers from Rohde & Schwarz

High-power transmitters from Rohde & Schwarz are based on the Doherty concept while avoiding the disadvantages associated with narrowband combiners. Two transmitter systems of the first Doherty generation are currently in series production:

- R&S®TMU9 transmitter family (600 W to 3 kW AVG in one rack, Fig. 1), air-cooled with R&S®PMU901 600 W amplifiers (Fig. 6)
- R&S®THU9 transmitter family (1.2 kW to 14 kW AVG in one rack), liquid-cooled with R&S®PHU902 1200 W amplifiers

All amplifiers have a broadband design (470 MHz to 862 MHz) and a patented combiner with feedback function. The Doherty architecture is narrowband by nature. The patented Doherty Tunit frequency option in the R&S®PMU901 air-cooled 600 W amplifier along with the built-in combiner with feedback function turns a broadband class AB amplifier into a band-limited Doherty amplifier. The available Doherty range is replicated using the combiner with feedback function. As a result, only a few different Tunit variants are required to cover the entire band IV/V. The Tunit can be exchanged or replaced without any alignment and without opening the amplifier at the transmitter site. In an (n+1) transmitter configuration, it can be necessary to operate the standby transmitter in broadband mode. In this case, the amplifier can be switched from band-limited Doherty mode to broadband class AB mode.

The R&S®PHU902 liquid-cooled high-power amplifier can also be operated in two different modes: in band-limited, efficiency-optimized Doherty mode or in broadband mode. Band IV/V is divided into four Doherty ranges to optimize efficiency. Four suitable Doherty options come preinstalled in the amplifier and can be activated depending on the required operating frequency. If the operating frequency is outside the amplifier's selected Doherty range, the amplifier automatically switches to broadband mode. This allows unlimited usage, even in the standby transmitter in (n+1) systems.

The Doherty ranges are carefully coordinated to maintain efficiency as constant as possible across band IV/V. The efficiency of the R&S®PHU902 amplifier (referred to the input power from the grid) is 39 % to 40 % (typ.) for OFDM signals and 42 % to 43 % (typ.) for ATSC signals.

Thanks to Doherty technology, transmitter efficiency is typically increased by $\geq 10\%$ compared to conventional class AB amplifier architecture, corresponding to energy savings of 40 %. The higher efficiency allows operators to save even more by redimensioning the cooling system.

Due to their advanced technology, it should come as no surprise that Rohde & Schwarz transmitters based on Doherty technology were deployed in TV projects around the globe shortly after their market launch.

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