

IMPROVING THE ENERGY EFFICIENCY OF THE DVB-T2 MODULATOR BASED ON APPARATED OPTIMIZATION METHODS

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Digital television has become an integral part of modern information infrastructure, providing mass access to diverse multimedia services. One of the key standards of terrestrial digital television is DVB-T2, which represents the second generation of terrestrial digital broadcasting and significantly improves transmission characteristics compared to the first generation of DVB-T. DVB-T2 provides higher spectral efficiency, resistance to interference and noise, support for a wide range of modulations, and the ability to transmit high-definition (HD) and ultra-high-definition (4K UHD) video content.

In recent years, there has been a rapid increase in the number of transmitting stations and the growth in the volume of transmitted information. At the same time, the energy consumption of equipment, including DVB-T2 modulators, becomes a significant part of broadcasting companies' expenses. Modulator energy consumption is directly related to operating costs and affects the environmental impact of telecommunications infrastructure. Considering global trends in reducing carbon dioxide emissions and increasing the energy efficiency of industrial and communication systems, optimizing the energy consumption of DVB-T2 modulators is becoming particularly relevant.

The DVB-T2 modulator performs several key functions: encoding the initial digital flow using FEC (Forward Error Correction) methods, signal modulation using QPSK, 16QAM, 64QAM, or 256QAM circuits, forming an OFDM signal with a large number of subcarriers, and processing signals considering synchronization and filtering. Each of these stages requires significant computational and energy resources. Modern research shows that up to 40-50% of the total energy consumed by the transmitting station is spent specifically on the modulator's operation.

There are various approaches to reducing the energy consumption of modulators, which can be divided into hardware and software. Hardware methods include the use of energy-efficient processors and FPGA, power amplifiers optimization (for example, the use of GaN-based amplifiers), and modular transmitter design with the ability to disconnect unused blocks. Software methods involve the dynamic adaptation of modulation and coding parameters depending on the channel conditions, optimization of signal processing algorithms, and transmission time management [1-5].

The relevance of the research is determined by the combination of several factors. Firstly, the growth of digital broadcasting volumes and the expansion of DVB-T2 networks require an increase in the number of transmitting stations, which leads to an increase in electricity consumption. Secondly, the economic efficiency of broadcasting companies directly depends on the costs of electricity. Thirdly, the introduction of energy-saving technologies corresponds to the global tasks of sustainable development and reduction of carbon emissions.

The purpose of this study is to analyze existing energy-saving methods for DVB-T2 modulators and develop recommendations for reducing their energy consumption without compromising signal quality.

The prerequisites and trends for the development of digital television broadcasting formulated in the introduction emphasize the need to increase the energy efficiency of transmission lines. In this regard, approaches aimed at reducing the energy consumption of DVB-T2 standard modulators deserve special attention. Further, key energy-saving methods used in modern DVB-T2 systems will be discussed.

For further research, it is necessary to consider in detail the hardware methods that ensure reduced energy consumption and optimization of modulator operation.

High-efficiency power amplifiers (PAs):

- **classic Doherty** amplifiers are one of the most common ways to improve performance in TV transmitters. The Doherty amplifier consists of two amplifiers - one "main" (carrier) operating in AB class mode and one "peaking" (peaking) operating in C class. At peak loads, both amplify the signal. The DVB-T2 documentation indicates that classical Doherty amplifiers provide ~36-39% efficiency for OFDM television signals [6].

- **broadband Doherty (broadband Doherty)** - modern developments (for example, based on LDMOS or GaN transistors) make Doherty amplifiers wider-band, which is especially important for different broadcast frequencies [6].

- **envelope tracking** - a method in which the power supply of the amplifier cascades changes synchronously with the instantaneous signal envelope. This allows the amplifier to operate at a higher efficiency, especially when the signal amplitude changes significantly. GatesAir's presentation indicates that this approach can increase efficiency to ~37-38% for the OFDM signal [6].

- **automatic power supply voltage regulation (AVS, Dynamic V bias)** - adjusting the amplifier power supply voltage based on the instantaneous signal power helps reduce losses, especially in intermediate modes.

Modern semiconductor technologies:

- **GaN transistors** - the use of gallium nitride (GaN) in power amplifiers significantly increases efficiency compared to LDMOS, especially at high frequencies and high power. GaN allows for reduced losses, increased linearity, and improved thermal characteristics.

- **FPGA and energy-efficient DSP** modulators are often implemented on FPGA or DSP. The use of modern FPGAs with Dynamic Voltage and Frequency

Scaling (DVFS) technology allows for reduced energy consumption, especially during periods when processing load is not maximal.

- **Transmitter modular architecture** - Transmitters can be built in such a way that modules (power amplifiers, modulators, auxiliary units) can be switched off or transitioned to “sleep” mode when they are not used or the load is low.

Reduce peripheral losses:

- **optimization of filtration and alignment circuits** - losses in filters and alignment circuits (for example, alignment transformers) can be significant. High-quality components, low-loss materials (e.g., ferrites or superconducting elements, if applicable), help reduce energy loss.

- **efficient cooling / thermoregulation** - reducing heat loss through improved cooling (liquid, more efficient radiators) allows for a reduction in energy costs associated with the cooling system.

One of the most significant areas of energy saving in DVB-T2 modulators is the optimization of power amplification circuits. This approach allows for a significant reduction in the energy consumption of transmission lines while maintaining signal quality, which will be discussed further.

Value of power amplifiers (PM) in DVB-T2 power consumption.

In DVB-T2 transmission systems, the highest energy consumption is associated with the operation of power amplifiers [6-10].

According to industry studies, up to 70% of the DVB-T2 transmitter's energy is consumed specifically in the power amplifier, while the remaining units (modulator, synchronization, filters, DSP/FPGA) account for less than 30%.

Reasons for high power consumption:

- broadband OFDM signal with high PAPR;
- the need to work with a large power reserve (back-off) for linearity;
- high requirements for spectrum mask and MER;
- heat losses and non-ideality of circuit elements.

Therefore, optimizing power amplification circuits is the largest energy-saving area in DVB-T2.

DVB-T2 OFDM Features Affecting PA Power Consumption. DVB-T2 uses OFDM with up to 32,000 subcarriers, which leads to:

- a high PAPR (10-12 dB);
- the PA is forced to operate in a deep back-off mode (a 6-12 dB reduction in output power) to avoid: intermodulation distortion, spectrum mask violations, and deterioration of BER and MER.

Increased linearity requirements. Due to modulation schemes up to 256-QAM, the amplifier must transmit large constellations without distortion.

Complexity of thermal management. A powerful OFDM signal generates significant heat, which reduces efficiency. It follows that the power amplifier must be specifically optimized for the high-peak OFDM signals of DVB-T2.

Key methods for optimizing power amplification circuits in DVB-T2. The most effective methods for energy saving through PA optimization are listed below:

Doherty-type power amplifiers. The Doherty amplifier is a key technology for DVB-T2. The amplifier consists of two paths: the main (carrier) path, which operates at normal power levels, and the peaking path, which is activated only during OFDM signal peaks. This approach is an ideal match for the characteristics of OFDM, as these peaks occur infrequently.

Advantages:

- High efficiency in the 6-8 dB back-off range;
- Ability to operate at low power without a significant drop in efficiency;
- Energy savings of up to 30-40% compared to Class AB;
- Reduced heat dissipation.

Practical efficiency: 35-45% for DVB-T2.

Using GaN (Gallium Nitride) transistors. GaN transistors are the current standard for DVB-T2 transmitters.

Why GaN increases energy efficiency:

- high input power;
- high operating frequency;
- increased linearity;
- less heat loss;
- greater efficiency at high voltages.

Results:

- 10-15% increase in efficiency compared to LDMOS;
- 20-25 °C reduction in PA temperature;
- enhanced durability.

Digital Pre-Distortion (DPD) of the signal. DPD is one of the key methods for improving PA efficiency. The power amplifier has a non-linear characteristic, which distorts the signal. DPD creates "inverse" non-linearities $F(x)$ such that: $PA(F(x)) \approx \text{ideal signal}$.

Advantages:

- reduces the required back-off by 2-4 dB;
- increases PA efficiency by up to +10-20%;
- improves MER and ACPR metrics;
- prevents the signal from exceeding the spectral mask.

DPD is implemented in the FPGA of the DVB-T2 modulator.

The table below shows the practical effect of PA optimization in DVB-T2.

Practical effect of PA optimization in DVB-T2

Table

Method	Energy Conservation	Increasing the efficiency
Doherty	25–40%	up to 45%
GaN-transistors	10–15%	+8–12%
DPD	10–20%	+5–10%
PAPR decrease	10–15%	darajasiga qarab

Envelope Tracking	10–20%	+8–15%
Smart cooling	10–15%	-

The analysis shows that combined methods provide up to 45-60% total energy savings for the DVB-T2 modulator/transmitter.

Conclusion. Optimizing power amplification schemes is one of the most significant and effective approaches to improving the energy efficiency of modulators and transmission systems for the DVB-T2 standard. The analysis has shown that the power amplifier is the primary determinant of a digital transmitter's total power consumption, and its efficiency directly impacts the operating costs of television and radio broadcasting facilities. The characteristics of the DVB-T2 OFDM signal, such as a high peak-to-average power ratio (PAPR), wide bandwidth, and the need for strict adherence to the spectral mask, present additional technological challenges that necessitate the use of specialized, high-efficiency amplification schemes.

The hardware-based energy-saving methods investigated have identified key technical solutions that provide a substantial increase in energy efficiency. The greatest effect is demonstrated by modern Doherty amplifier architectures, which, by separating amplification into main and peak paths, deliver high efficiency under the significant back-off conditions typical of OFDM modulation. The use of gallium nitride (GaN) transistors also significantly improves the power amplifier's characteristics due to high linearity, increased thermal resistance, and efficient high-power operation.

In parallel, digital predistortion (DPD) methods play an important role by compensating for power amplifier nonlinearities and ensuring compliance with spectral mask requirements without increasing the power margin. DPD reduces the need for a deep back-off, which directly increases power amplifier efficiency and lowers energy consumption. A further contribution to energy saving comes from PAPR reduction through hardware-supported signal shaping methods, which lessens the load on the amplification stages and increases modulator efficiency when transmitting a multicomponent OFDM signal.

The integrated application of these methods allows for a significant reduction in energy costs. For instance, modern solutions that combine GaN technology, digital predistortion, and wideband Doherty amplifier circuits increase transmitter efficiency to 45-50%, which is equivalent to a 30-60% reduction in energy consumption compared to traditional amplification schemes. This result confirms the high practical significance of hardware optimization methods and their ability to substantially improve the efficiency of the broadcast infrastructure.

Thus, optimizing power amplification schemes is a key area for energy conservation in DVB-T2 modulators. Hardware solutions based on modern semiconductor technologies, digital correction, and structural adaptation of amplification paths enable a significant reduction in power consumption without degrading signal quality parameters. Amid the expansion of digital television networks and growing demands for broadcast stability, these methods hold significant scientific, technical,

and economic importance. Their implementation contributes to the creation of more energy-efficient, environmentally friendly, and durable digital television broadcasting systems.

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