

ENERGY EFFICIENCY OF THE TRANSMITTER DVB-T2 SYSTEM

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Abstract

Today, every little bit of energy is very important. Campaigns and appeals have been made to the public, and incentives have been given to save energy. Ministry of Energy Serbia has analyzed ongoing climate change and increasing energy consumption. The request for energy saving from the Ministry of Energy Serbia has reached to the public enterprises PE ETV (Public enterprises Transmitters and Communications) contributed to saving energy consumption by using innovative technologies and equipment. Our goal is to provide a quality TV and radio signal with as little energy consumption as possible. Broadcasters and end users must be satisfied with that level of signal quality. This research paper describes the analysis of the energy efficiency of transmitters. We had to replace the transmitters with more energy-efficient ones in order to meet modern requirements for mode of operation and rational consumption of energy. We broadcast the DVB-T2 signal with transmitters whose amplifiers have been operated in Doherty configuration.

Keywords: Energies consumption, Innovative technologies, DVB-T2, Amplifiers, Doherty configuration

INTRODUCTION

The main idea in the beginning of the paper is to describe an old amplifier system, where the power consumption is not high. These systems have been used for a very long time. Some of them we use currently, and in light of the development of technology and large consumption, this is inadmissible and unacceptable. In the next chapter, we explain our solution for transmitter efficiency. Transmitter efficiency can be improved by various techniques and topologies. The Chireix technique is one of them, based on two outputs being nearly phase-cancelled in order to generate a signal at the low end of the dynamic range in terms of energy efficiency. Various amplifier techniques in class AB have also been developed in order to save energy consumption. We decided on the Doherty amplifier system, which will give us a high-quality signal and preserve the linearity of the signal. We will explain

the criteria and the solution that leads to energy savings. The importance of saving energy, preserving the environment, and maintaining continuity of work in terms of economy. We will propose a technical solution in the paper. We have compared a traditional transmitter system with a new high-efficiency transmitter system. We explain how the amplifiers work now and how we save energy. In the end, we will see the practical results and what we got from them. It is useful for our purposes to see the energy used before and after the establishment of the new system. Our main goal is to reduce energy consumption and CO₂ emissions while preserving the traditional way of broadcasting radio and television programs. We tried to preserve the power of the transmitter and the quality using modern technology in the implementation of the amplifier, which is the biggest consumer of energy in a complex system of transmitters. Also, we

ensure survival on the market in difficult economic times.

EXPOSITION

Operation costs have 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. [1] Also very important for broadcasters and their environmental impact is reduced CO₂ emissions. As a traditional transmitter, we analyze VHF Transmitter Family R&S NM/NW 7000 [2]. This is a liquid-cooled transmitter for analog and digital TV (DVB-T or ATSC). Picture 1 represents a block diagram of a 2.8kW transmitter, NM/NW 7000. This model is useful for our purpose, because it can work in two modes: analog and digital. First, we describe the function and electrical parameters of the RF switch. The RF switch allows you to turn on the backup exciter b when the main exciter breaks down. The Rf switch must be designed to have high isolation (attenuation between the input and output of RF switch). Transmission loss must be as low as possible – that is total power lost through the RF switch (it is working). Switching time (on-off) also must be low, so that the viewers as end users would not notice the program's interruption when changing the switch's state. Knowing the maximum input power of the switch is necessary to operate it properly. RF switch maintains the operating parameters in accordance with the prescribed standards and without degradation of any characteristic. The drive amplifier, VM602 must provide a default level for the next series of amplifiers. This VHF transmitter family, 7000, has 6 drive amplifiers, VM602. In this procedure, we will compare the work, constructive solutions, and efficiency of the current system and the system we describe in this chapter. The harmonic filter suppresses of second and third harmonics of the main DVB-T2 signal. Harmonic was one of the

main factor that degraded signal quality. In order to reduce transient attenuation, the

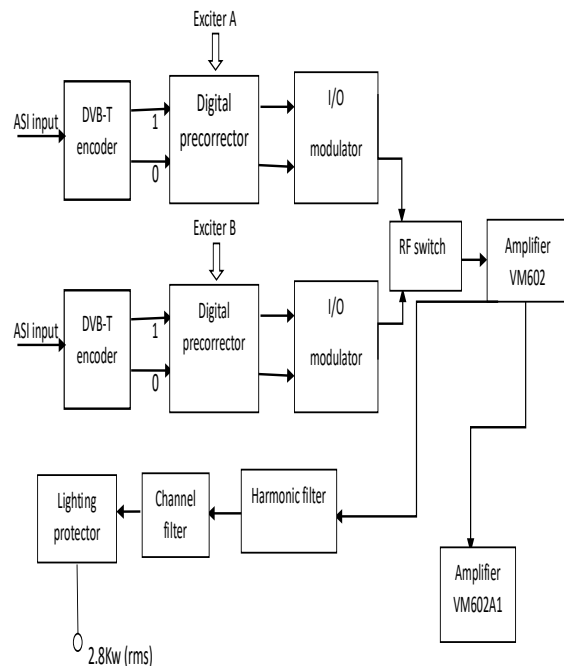


Fig.1. Block diagram of VHF transmitter R&S

the harmonic filter was divided into 4 and 5 bands. The harmonic filter is a Chebyshev filter of 11th order. Chebyshev filters have steep roll-off and low transient attenuation, and they are very suitable for this type of TV signal. Exciter is the most important part of the whole system for several reasons. We are applying one exciter that has the label SC700. Exciter SC700 enables the replacement of your functionality with a digital resume. In exciter, there a large number of complex operations such as encoding, precorrection, and modulations. A channel filter is a bandpass filter that eliminates out-of-band emissions, harmonics, and spurious emissions. The bandpass filter limits the width of the frequency range of the signal entering the system combiner. These filters' insertion loss (transient attention in the bandwidth) is low. The system of amplifier VM602A1 is shown in Figure 2. The preamplifier has only one MOSFET transistor. The main amplifier is a complex system. The main

amplifier is a system of splitters, combiners, and MOSFET transistors. The RF signal is divided into 2 signals from the amplifier, which go to the transistors, and then to the combiner. Again, the amplifier signal goes to the splitters, where it is divided into 8 RF signals, and again into 8

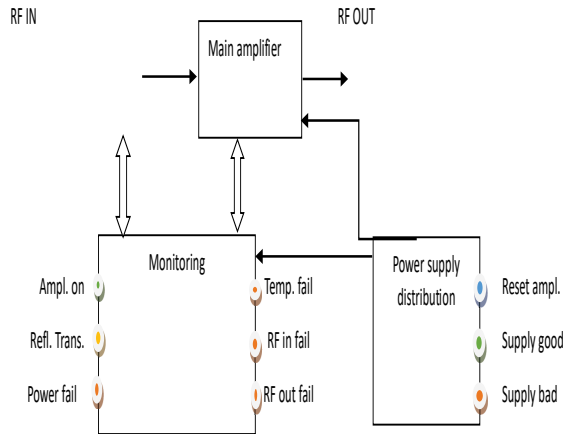


Fig.2. Block diagram of amplifier VM602A1

transistors goes the DVB-T2 signal. Finally, it was combined into a combiner and forwarded to the output of the amplifier. There is a lot of signal processing and then re-adding of the input signal in order to get the desired gain. This approach to realizing the amplifier system is not good in terms of efficiency, and a large part of the energy remains unused. By directly measuring the electricity consumption behind the signal amplification circuit, the efficiency of such a system is only 20%. This is a really big waste of energy. In order to describe the transmitter system more easily and prevent even greater energy losses in the event of a failure of the amplifier system, we will explain the function of the monitoring system at the amplifier stage. Monitoring by the amplifier system gives us a large number of important alarms. In order for the efficiency to be at its highest level, the correctness of each transistor is required. Reflection of the main signal is also very dangerous for the whole system and, of course, the efficiency of such a system. The

amplifier VM602A1 is most important for our purpose in terms of efficiency analysis. MOSFET (the metal-oxide-semiconductor field-effect transistor) is the underlying technology for most discrete transistors, and we use the MOSFET SEMELAB D1029 transistor. This type of transistor has 438W of power dissipation and a maximum operating junction temperature of 200 °C. Degree of utilization, i.e., efficiency of broadcast transmitters, represents a relation between broadcast power and power from electrical distribution networks. In the process of AC/DC conversion, 30-35% of energy is consumed. In the structure of electricity consumption, the power amplifier is the transmitter segment with the highest energy consumption of 55-60%. Following the energy consumption distribution statement above, the efficiency of the power amplifier should be as high as possible in order to reduce energy consumption. The low efficiency of the power amplifier affects the cooling costs and lifetime of the device. With a power amplifier efficiency of 20%, the remaining 80% of the delivered electricity is wasted as heat. The main reason for the low efficiency of MOSFET technology is that it has an integrated multi-component structure. That structure integrated multiple MOSFET semiconductor structures connected in parallel. We have the case in which more MOSFET crystals have connected in parallel, this gives us a smaller on-resistance, but a larger parasitic capacitance. It is a question of the relationship between resistance and capacitance. As little as possible on-resistance brings us reduced conduction losses. However, that gives us another issue, because it increases the parasitic capacitance, which in the end increases switching losses. The losses we can represent above include the difference between the number of high-side MOSFET and low-side MOSFET [3], as shown in Figure 3.

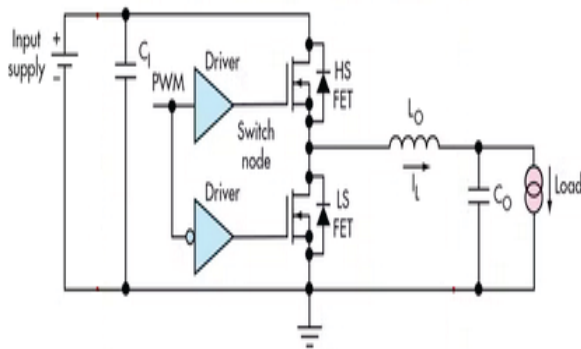


Fig.3. High-side FET and Low-side FET

Conduction losses high-side MOSFET and Low-side MOSFET can be calculated using the following formulas [4],

$$P_H = I_0^2 \times \frac{U_0}{U_{in}} \times R_H [W] \quad \text{for High-side MOSFET} \quad (1)$$

$$P_L = I_0^2 \times \frac{U_0}{U_{in}} \times R_L [W] \quad \text{for Low-side MOSFET} \quad (2)$$

Where are P_H is condition losses High-side MOSFET, P_L is condition losses high-side MMOSFET, I_0 is output current, U_0 is output voltage, U_{in} is input voltage, R_H is high-side MOSFET on-resistance, R_L is low-side MOFET on-resistance. Controlled cooling of the system is required to reduce the temperature of the equipment. The low efficiency of the power amplifier leads to higher costs in the uninterruptible power supply system (UPS and higher power generators), which increases the operating costs of the equipment and location [1]. The waveforms of the current through the transistor collector and the voltage across the collector-emitter (drain-source) overlap significantly, causing a significant fraction of the DC input power to be converted to heat instead of useful transmitter power. This is because the transistor conduction state changes in step with the input waveform without any regard for the voltage or current state of the output circuit [5]. That is why this solution represents an inefficient system. A power amplifier is most efficient at maximum output power near the operating point when it is in

saturation. First, I would explain the characteristics of the input signal and how they affect the efficiency of the amplifier. The digital modulation on which the transmitter's operation is based is represented by COFDM. COFDM signals have been composed of a large number of independently modulated carriers whose power varies in time. A set of modulated mutually orthogonal carriers, each of which have been modulated by a relatively small part of the total information. The content enabled them to achieve high spectral efficiency and, at the same time, high resistance to selective frequency fading. The specific composition of COFDM symbols has been based on the summation of their modulated carriers' frequencies as integer multiples of the frequency step IFFT (inverse fast Fourier transform). The calculation leads to a significant difference between the peak and mean values of the COFDM signal. As a result, we have an amplitude of the composite signal that is not constant over time, and the peak value of the system could be very high compared to the average of the entire system. COFDM signals contain thousands of carriers and signals in the time domain that have higher peaks (signal peaks) than average signal peaks. It is also very important to learn about certain parameters of the transmitter system and their influence on its efficiency, which is the reason for applying the Doherty system. Signal peaks could saturate the amplifier and generate non-linear distortion unless the signal peaks were clipped. Clipping also introduces a degree of distortion, but it can be controlled and set to a certain level. By increasing the transmitter's OBO, the probability of driving the amplifier into the nonlinear region has been reduced, and the slipping level required could also be reduced. OBO represents the ratio of the amplifier's output power produced with an unmodulated carrier at the input to the average power it delivers at the operating point. However, increasing OBO reduces the transmitter's efficiency and results in large transmitters

(footprints) for relatively small power levels. Another important parameter is the ratio of peak to average power, which is called PAPR. A high PAPR level requires the use of amplifier elements with high linearity and poor utilization. So that a high peak-to-average power ratio occurs, an improvement in amplifier efficiency over a dynamic range is required. Various techniques and technologies can improve efficiency. Doherty's power amplifiers are used in the latest generations of transmitters as a solution to improve the efficiency of the transmitter. The power amplifier provided the level necessary at the antenna connection. The amplifier system must be designed to meet the standards that allow the receiver to recognize the transmitted signal and demodulate the required information efficiently. [6] When we talk about high-power transmitter amplifiers for radio and television broadcasting, two important parameters of a power amplifier are linearity and efficiency. Besides, various signal parameters influence the efficiency value of a transmitter. It is very important for the frequency range and power of the transmitter. So power amplifiers (transistors) are more efficient at lower frequencies than higher ones. As the frequency increases, greater losses occur due to the skin effect. Within the frequency band (FM, VHF, UHF) efficiency varies up to several percent. When we reduced the output power of the transmitter, the efficiency decreased. The maximum efficiency of a conventional amplifier has been achieved at the nominal output power for which the power has been declared for the type of equipment. In digital operating modes such as DVB-T2, the envelope of the modulated signal continuously changes. The power amplifier must be able to cover the maximum peaks, and this requires that the power amplifier has operated outside the dynamic range in order not to distort the signal. (Figure 4.)

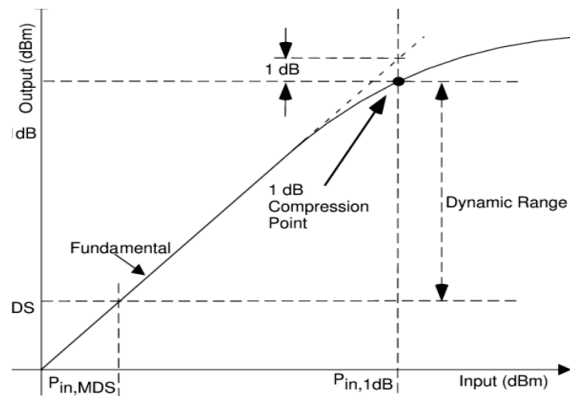


Fig.4. Amplifier's dynamic range

From crossing point DS and point P_{in} to the compression point, this is mainly the linear operating area for the amplifier. In the linear operation of the amplifier (most of the curve, ie., linear part), as the input level increases, so does the output level. Our DVB-T2 signal is the least distorted, and we have high-fidelity signal amplification, unfortunately with very low efficiency. After that, there is a part of the curve of the amplifier's dynamic range where the increase in the input level does not follow an increase in the output level of our useful signal. In this part of the curve, the amplifier's dynamic range started before the compression point and finished in the saturation area. Then we reached maximum efficiency, but we significantly degraded our DVB-T2 signal. Complex modulation formats, such as OFDM transmit information in the phase and amplitude envelopes of the modulated signal. About The efficiency of the amplifiers influences the ratio of peak to average power of a signal (crest factor). For a complex modulation format, it is very important that the amplifier work in a dynamic range, below the saturation point, which means the efficiency will decrease. It shows, how difficult it is to balance the distortion-free operation of complex signals with high efficiency. The signal quality of a digital transmitter has two main parameters: modulation error ratio (MER) and shoulder

distance. These are important parameters that must be within the prescribed limits when we apply another amplifier system in order to have a high-quality transmitted signal. MER represents a measure of all possible interference that might appear in a broadcasting system (TV system, radio system, mobile system, etc...). The positions of the constellation points deviated from the nominal position (decision-making centers of the area) due to interference that may have made amplifiers. In this way, we waste energy unnecessarily, and the transmission system becomes less efficient. If the deviation is too large to cross the boundaries of the decision area, it results in wrong decisions. The wrong decision means the wrong demodulation of complex data symbols, whose demapping will cause incorrect bits to appear in the corresponding bit string. Measurement amplitude deviations of the modulated COFDM carrier from the central zone are a measure of interference. The error vector defines this deviation. In order to cover a larger territory with a quality signal, a large MER is needed. The power amplifier must get a higher amplifier supply voltage, leading to higher energy consumption and lower energy efficiency. This type of modulation can lead to loss of transmitted data caused by the time and temperature nonlinearities of power amplifiers. In the DVB-T2 system, the power amplifier is fed with a complex modulated signal (COFDM), and amplifies this complex signal, but in the process generates unwanted intermodulation products. When the power amplifier operates in the linear region, intermodulation products are generated at different frequencies of multiples of the input signals that do not interfere with the main signal. When the power amplifier approaches the saturation point (enters the non-linear operation region), interference increases and can begin to interfere with main signals, thereby reducing the quality of the output signal [7]. A Doherty amplifier configuration is one solution to achieve a

compromise between distortion-free operation and an efficient amplifier. This technique ensures high efficiency when working with high PAPR signals. With classic amplifiers, the desired gain is achieved by switching the output power of the previous amplifier to the input of the next one. In a Doherty amplifier configuration, maximum efficiency is achieved only at the highest levels of the signal. In the new configuration, a high-efficiency amplifier over a wide range of input levels of the signal consists of parallel amplifiers, each tuned for maximum efficiency in its predetermined input power range. They are connected to the same load and separated from each other by an impedance transformer. That is how we achieved it, and that is exactly what we would like, we tuned each amplifier to the most efficient linearity the power range allowed, and then combined the result. The power amplifiers have a configuration in a parallel branch, and then they are sharing the load. This sharing of the load ensured a constant level of efficiency over a wide power range. We change the actual value of the load by combining the nominal values of the currents from the amplifiers, and modulation of the load is approaching. The name of this approach is known as the load modulation technique. Constant efficiency at different levels of signal on the input creates modulation of the load and parallel branches of the amplifier. In order for the efficiency to be high, it is necessary to increase the load with an increase in power, because two separate signals have been applied to the modulation load, and the value of the modulation load decreased, which means that the efficiency of the generator decreased. The variable value of the modulation load has been realized by means of an impedance inverter (Figure 5.). One of the ways of constructing the impedance inverter is through the use of $\lambda/4$ line [8]. In our conception, the input signal gave us a part of the transmitter called the exciter. Doherty Splitter divided the signal into two lines: the main power amplifier

(for the average signal) and the auxiliary power amplifier (for the peaking signal).

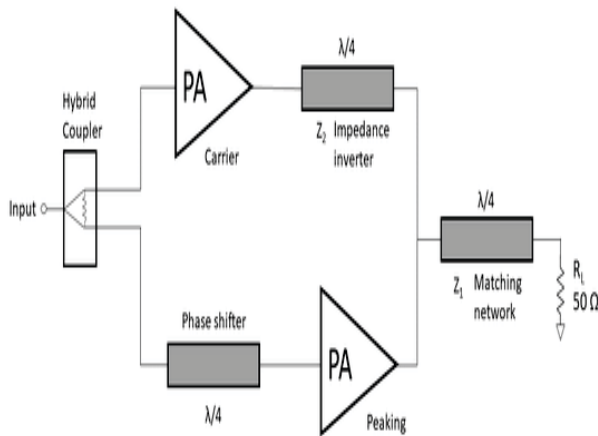


Fig.5. Doherty amplifier configuration with impedance inverter

The main amplifier is a class-AB amplifier, and the amplifier operates when the signal is about your average level. When the signal peaks appear, the class C amplifier starts to operate and upgrades the now compressed class AB stage represented in Figure 6. [9]. The hybrid coupler at the input of the Doherty amplifier generates two outputs that have been phase shifted by 90° . The hybrid coupler performs a 3dB power division, with half the power phase at 0° and the other half power at 90° [10]. Then we did another shifter so that the main and auxiliary amplifiers were in phase. The about amplifier is connected by 50Ω load.

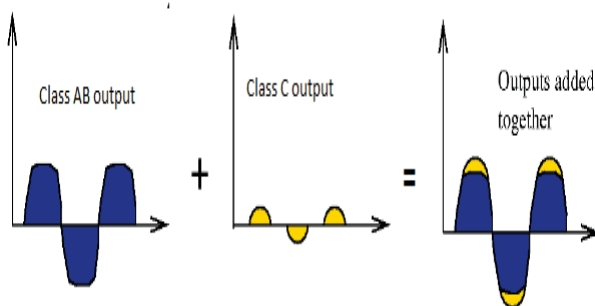


Fig.6. Doherty configuration with main and auxiliary amplifier

The operation of the Doherty amplifier will be able to be divided into three ranges. First range when Doherty amplifier operates with

the lower input signal. The peak amplifier is inactive and behaves as an open circuit. The main amplifier, operates and indicates a large output impedance. That causes saturation of the main amplifiers, and the system operates at maximum efficiency (voltage reached its maximum value). In the second area at a medium level of the input signal, the auxiliary amplifier starts to increase the current value, and the impedance seen by the main amplifier will decrease. As a result, the output voltage of the main amplifier remains approximately constant, and the total current increases, which increases the total output power (high efficiency). Finally, at the high-power level of the level signal, both amplifiers operate at maximum output current, and the system operates at the high power level. This realization of the Doherty system gives us 45% efficiency of the amplifier stage at the output by direct measurement. The amplifier now works in parallel branches, unlike in the solution of the last generation of device. The high-efficiency transmitters THU900evo are operating with subassemblies for voltage regulation. It is a new operating mode for realizing voltage adjustment in relation on the system described previously. The old system gave us, through monitoring, certain data about the amplification level that we had to manually adjust. A sample of the output signal from the directional coupling at the output of the transmitter has returned to the exciter of the transmitter. The voltage supply of the transistor changes dynamically, synchronized with the RF signal passing through the device. Continuous sampling of the output signal enables the system to adjust for changes in amplifier characteristics due to variations in operating temperature and time. This system improves efficiency, especially when the transmitter is operating at reduced output power. Also, the Doherty system, unlike the amplifier system in previously generation, works in sub-band due to greater efficiency. The power amplifiers operate in narrowband Doherty mode in

one of the frequency sub-bands or in a wideband mode in the frequency range from 470MHz to 790MHz. The frequency sub-bands in which the amplifiers operate are D2 Doherty mode from 580 MHz to 651 MHz, D3 from 528 MHz to 580 MHz and 755 MHz to 790 MHz, D4 from 490 MHz to 528 MHz, and from 710 MHz to 755 MHz and finally, D5 is from 470 MHz to 490 MHz and from 651 MHz to 710 MHz. The control unit performed switched of the operating range. We use the BLF888B transistors in the peak amplifier, and they have been optimized to give extremely high power and efficiency in the Doherty system. The BLF888A transistors in the main amplifier have improved robustness that allows them to operate at high mismatch and full power without damage or performance degradation. LDMOS transistors BLF888A and BLF888B reached an efficiency of more than 45%. We did a comparison of the active electricity consumption of two different technology transmitter configurations. Based on the measured consumption diagrams, by replacing the current transmitter configuration with new, more energy-efficient transmitters, the projected average reduction in active electricity consumption is represented in Figure 7.

Consumption of electricity (kW)	Per hour	Per year	Per month Per year
Old system	24	576	17280 207360
New system	12	288	8640 103680

Fig.7. Comparison of old and new systems transmitters

The DVB-T2 transmitter has an output power of 4.5 kW. Because of Doherty technology new system has reduced power consumption by 50% compared to the old system. All public sectors have received recommendations to reduce the

consumption of electrical energy in a letter from the Ministry of Telecommunications Serbia. I would also add efforts to contribute to the reduction of electricity consumption even without replacing the amplifier technology. These are transmitter systems that have not yet been replaced by new ones that work with an amplifier based on the Doherty principle. We had to do something and tried to optimize the system transmitter. Additional savings, apart from the application of new technology, also have been achieved by reducing the power of the transmitter at the time of the last viewing and listening of radio and television programs. In that time period (00:00-06:00), there are the fewest viewers and listeners. It should be noted, however, that one characteristic of the amplifier, above all, has been constantly changing due to such complex interventions on the device, and that the hardware of the entire system suffers. Breakdowns have occurred on transmitter systems due to frequent changes in the parameters, to which the complex control logic is very sensitive. The power change itself causes a change in parameters of linear and non-linear precorrection, calibration of input and output signals, cooling system, and sensor system. The control logic that supports all these systems has not been designed to allow for such frequent changes of parameters. It puts a lot of pressure on the state, and the changes have been confusing, so there have been software errors and even hardware failures. From this short but practical consideration of ways to save energy, the only real solution for telecommunications and broadcast systems is the application of new technology that uses energy as rationally as possible and where losses are minimized. I would also like to mention that the new generation of transmitters has a better cooling and AC/DC conversion system than the old one. I will briefly explain the new solution to the mentioned system that saves even more energy. A complex system is a transmitter system and includes many assemblies and

parts whose energy should be used rationally. It is a very difficult task for both, users and equipment manufacturers. When we have been designing such a transmitter system, the structure is such that the power consumption of the power amplifier is the segment of the transmitter system with the highest power consumption, which accounts for about 60%. The next two subsystems of the transmitter to pay attention to are the cooling system and AC/DC conversion. These parts of the transmitter system consumed about 30% of the energy of the whole system. The power supply has been designed in such a way that it can cope with the maximum demand of the load, and wasted energy will be as low as possible. In other words, the construction of the converter and power supply is such that they are above a certain maximum load for the transmitter system. This solution represents an optimal system with a small part of the energy converted into heat, and is optimized in relation to the old system. The high-efficiency cooling system of the transmitter has been realized with control system cooling. There were some thermal sensors in the transmitter, which allowed us to measure air conditions in real time. In the field of the cooling transmitter on the display, there are notifications about the external temperature and internal temperature, coolant flow, and pump rotation speed. This data goes through a sensor that processes it and optimizes the operation of the cooling system to be highly efficient. The rotation speed of the pumps has adapted to the coolant flow to save energy and extend the life of the transmitter system. This kind of automation of the cooling system did not exist in the old transmitter system and affected the efficiency. The efficiency of the power amplifier should be as high as possible in order to reduce energy consumption. This short analysis has shown exactly the previous claim. The low efficiency of the power amplifier in the transmitter system affects the cooling costs and lifetime of the device. For this reason,

in this paper, we analyzed the part that is the most critical in the system and that wastes the most energy and presented a solution to that problem. The second parameter we will analyze is CO₂ emissions. CO₂ emissions depend on the primary source used to generate electricity and the generation efficiency. CO₂ emission values depend on current commercial technology. For example, hydropower, nuclear, geothermal, wind, solar sources of energy, and related technology have values in the range from 1 g/kWh to 100 g/kWh. Applications of other energy sources and related technologies such as gas, fuel, and coal have been in the range from 500 g/KW to 900 g/kW. Taking into account the Serbian electricity production industry, the technology used, and the primary source, we can say that it has a medium degree of utilization and uses mainly coal and fuel (gas or diesel). In other words, to obtain 1 kWh from coal or fuel, 800 g of CO₂ will be rejected in the atmosphere during the combustion of fossil fuel [11]. Figure 8. shows the reduction of emission CO₂ using a new technology in which the transmitters operate.

Emission of CO ₂ (kg/kW)	Per hour	Per year	Per month Per year
Old system	19.2	460.8	13824 165888
New system	9,6	230.4	6912 82944

Fig.7. *In a comparison of emission CO₂ by an old and new system transmitters*

Table 2. shows that the emission of CO₂ has a very high level of reduction using a new technology amplifier. This analysis refers to one transmitter system. So far, we have done six transmitter systems whose amplifiers work in Doherty mode. There are 11 sites with three transmitter systems each that need to be replaced with a new system whose amplifiers operate in Doherty mode.

That is, we have 33 transmitter systems that we need to replace in total. These transmitters worked with powers ranging from 2 kW to 5 kW. Now we show the calculation when all mentioned transmitter systems are replaced. That means the approximate saving of 90000kg/kWh emission CO₂ should be multiplied by 30. The reduction of CO₂ emissions on the territory of Serbia is 2.7 million kg/kW per year, i.e. when we calculated in kw electrical energy reduction consumption, it was 3 million kW per year. At this moment, has finished 6 new transmitters are on 2 sites. During the 2022 year, we have reduced the emission of CO₂ by approximately 0.5 million kg/kWh, and when we observe the consumption of electrical energy, we have reduced 0.6 million kW.

CONCLUSION

Today, every kilowatt of electricity is worth its weight in gold because energy is not an inexhaustible resource. This is the only way to comply with the requirements that accelerate the already strong desire to increase sustainability in the production process without compromising quality. Six new transmitter systems with energy-saving technology were replaced. Savings were achieved with the new state-of-the-art Doherty system, the economical AC/DC system, and the cooling system of the transmitter system, which uses automatic parameter correction in order to save energy consumption. The second point of analysis that we want to represent is the emission of CO₂, and the size of its reduction. In the following period of time, it will be necessary to replace the remaining 27 transmitter systems that work with technology that does not contribute to saving electricity. We made our contribution in terms of environmental pollution and energy savings, and there are still opportunities for further progress.

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