ENERGY EFFICIENCY OF THE POWER AMPLIFIER ACCORDING TO W. DOHERTY'S SCHEME WITH AUTOMATIC POWER ADJUSTMENT

Roman Yu. Ivanyushkin [1], **Kirill O. Razin** [1],

[1] Institute of Radio and Information Systems (IRIS), Vienna, Austria; rivanyushkin@gmail.com

ABSTRACT

At present, in relation to the power amplifiers of digital television broadcast transmitters, the scheme proposed by engineer William Doherty for the construction of broadcast transmitters with amplitude modulation is widely used. W. Doherty's method, today is practically the only solution for improving the energy efficiency of OFDM signal power amplifiers, as applied to terrestrial digital television transmitters, when the wide band of the envelope of such a signal does not allow the construction of a transmitter based on a polar architecture. Transmitters for digital terrestrial television broadcasting using linear power amplifiers built on the basis of the W. Doherty method are developed and produced. When building transmitters for terrestrial digital television broadcasting, the problem of ensuring an acceptable efficiency of a linear power amplifier is very acute. The main reason for the low efficiency of such amplifiers is the high OFDM crest factor of the digital television radio signal. The problem of increasing the linear power amplifiers average efficiency of digital broadcasting transmitters is considered. The joint application of two methods for constructing high-efficiency linear power amplifiers is discussed: the method of William Doherty and method of automatic power mode control. Preliminary assessment results of the energy gain from the combined use of these two methods, obtained by computer circuit simulation, are presented.

KEYWORDS: *Linear power amplifier, Doherty circuit, automatic mode control, Energy efficiency, Efficiency, Digital television.*

DOI: 10.36724/2664-066X-2023-9-1-25-29

Received: 05 May 2022
Accepted: 20 June 2022

Citation: Roman Yu. Ivanyushkin, Kirill O. Razin, "Energy efficiency of the power amplifier according to W. Doherty's scheme with automatic power adjustment," *Synchroinfo Journal* **2023**, vol. 9, no. 1, pp. 25-29.

1. Introduction

When building transmitters for terrestrial digital television broadcasting, the problem of ensuring an acceptable efficiency of a linear power amplifier is very acute. The main reason for the low efficiency of such amplifiers is the high OFDM peak factor of the digital television radio signal, the value of which for the DVB-T2 standard can reach 13 dB. At the same time, even the transition from the amplifier operating mode in class A to the class AB mode (with the corresponding linearization of the amplifier by adaptive pre-correction methods) does not allow obtaining a significant energy gain.

At the same time, due to the wide bandwidth of the transmitted OFDM signal, it is not possible to use highly efficient nonlinear methods of linear power amplification, including synthetic polar, or envelope elimination and restoration (EER) [1,2], or a combination of various methods [3,4]. The use of automatic mode control (envelope tracking) in this case also has significant limitations [5]. At present, one of the most appropriate methods for constructing such linear power amplifiers is the use of the W. Doherty scheme [6].

Despite the fact that this circuit provides a significantly higher efficiency compared to a conventional linear power amplifier operating in class AB mode (and, moreover, in class A mode), with average values of the envelope of the amplified radio signal, this gain is not very big. The use of envelope tracking in W. Doherty's scheme [7], taking into account its limitations when amplifying radio signals with a broadband envelope, makes it possible to provide an additional energy gain.

2. Methods and Solutions

With regard to the power amplifiers of digital television broadcast transmitters, the scheme proposed in relation to the construction of broadcast transmitters with amplitude modulation as early as 1936 by engineer William Doherty is widely used [6]. W. Doherty method, today is practically the only solution for improving the energy efficiency of OFDM signal power amplifiers, as applied to terrestrial digital television transmitters, when the wide band of the envelope of such a signal does not allow the construction of a transmitter based on a polar or EER architecture. Transmitters for digital terrestrial television broadcasting are being developed and produced using linear power amplifiers built on the basis of the W. Doherty method [6].

Figure 1 shows a graph of the dependence of the efficiency on the amplitude of the input signal for a linear power amplifier based on the W. Doherty scheme. This dependence was obtained by computer circuit modulation methods, in relation to the amplifier circuit discussed below. This dependence somewhat differs from the idealized theoretical one [8, 9] and corresponds to the real scheme.

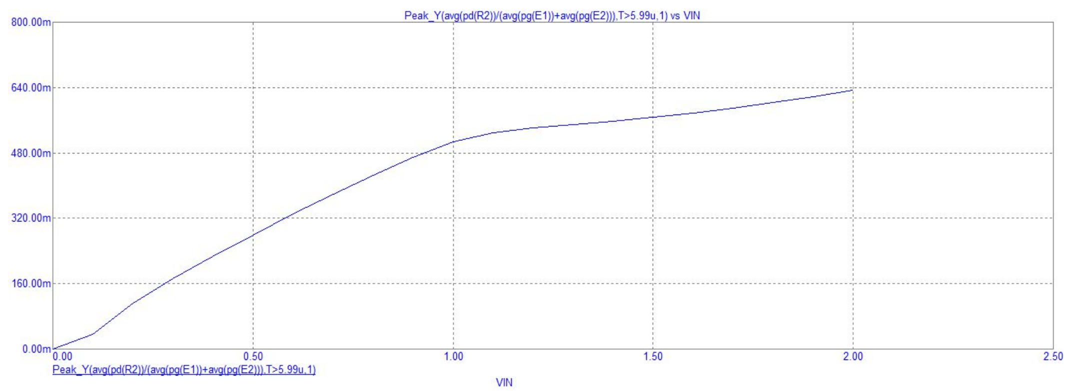

Fig. 1: The dependence of the efficiency on the signal amplitude in the amplifier W. Doherty

Another possible solution is the use of automatic adjustment of the power regime (called Envelope Tracking) [7]. When adjusting the supply voltage of a class AB linear power amplifier in proportion to changes in the amplitude of the amplified signal, a significant efficiency gain is provided in the region of its small and medium amplitudes, and, consequently, the average efficiency of such an amplifier also increases significantly.

The increase in efficiency is ensured by maintaining the intensity of the amplifier operation mode close to the boundary mode with any changes in the amplitude of the amplified signal. To achieve this adjustment, an envelope of the amplified radio signal is introduced into the controlled power supply (containing a highly efficient [5] or switching voltage control circuit).

As studies of this method have shown in relation to the construction of digital broadcasting transmitters in the VHF range [8-13], the greatest energy gain is ensured by the use of a nonlinear (quadratic) law of supply voltage regulation, which takes into account the nonlinearity of the static characteristics of modern field-effect transistors in the region of the current decay line (then is fully open).

However, since the resulting efficiency of such an amplifier is determined by the product of the efficiency of the directly controlled linear power amplification stage and the efficiency of the key supply voltage regulator, the overall energy gain can be significantly reduced if the efficiency of the latter is low. As shown in the same studies [8-13], already in relation to digital broadcasting transmitters in the VHF range, where the channel bandwidth does not exceed hundreds of kHz, the task of constructing a highly efficient switching supply voltage regulator is quite difficult [14, 15].

This is due to the fact that the bandwidth of the envelope channel (to which the switching supply voltage regulator also applies) during automatic adjustment of the power supply mode should not be narrower than the bandwidth of the transmitted radio channel. With a decrease in the bandwidth of this control channel, in order to avoid the occurrence of irreparable nonlinear distortions of the amplified signal, it is necessary to reduce the depth of supply voltage adjustment, which inevitably reduces the energy gain from such adjustment.

Considering that the speed of modern high-power switching transistors is still significantly limited, this problem does not allow for full-fledged automatic control of the power supply mode in relation to linear power amplifiers of digital television transmitters, where it is required to provide the envelope control channel bandwidth much wider compared to similar power amplifiers digital broadcast transmitters.

However, automatic power mode adjustment can be applied to the main and “peak” arms of a linear power amplifier built according to W. Doherty's scheme. Even under the condition that the depth of adjustment will be significantly reduced (due to the need to significantly limit the bandwidth of the control channel of the envelope), such adjustment will provide an additional gain in efficiency in the W. Doherty amplifier in the region of average statistical values of the amplitudes of the amplified OFDM signal.

At the same time, the resulting average efficiency is expected to be higher, both in comparison with the efficiency of the amplifier according to the W. Doherty scheme without such adjustment, and in comparison amplifier efficiency with only automatic power supply mode control, taking into account the necessary restrictions on the regulation depth. It is advisable to introduce supply voltage regulation into the main arm of the W. Doherty amplifier, which will ensure an increase in its efficiency in the region of average statistical amplitudes in amplified radio signal. The introduction of a similar adjustment also in the "peak" arm of the W. Doherty circuit allows you to further increase the efficiency in the region of large amplitudes. When determining the control law for the supply voltages of the main and "peak" arms, it must be taken into account that the adjustment in the main arm must be carried out only from zero to the middle of amplitude characteristic, and adjustment in the "peak" arm must be carried out from its middle to the maximum point.

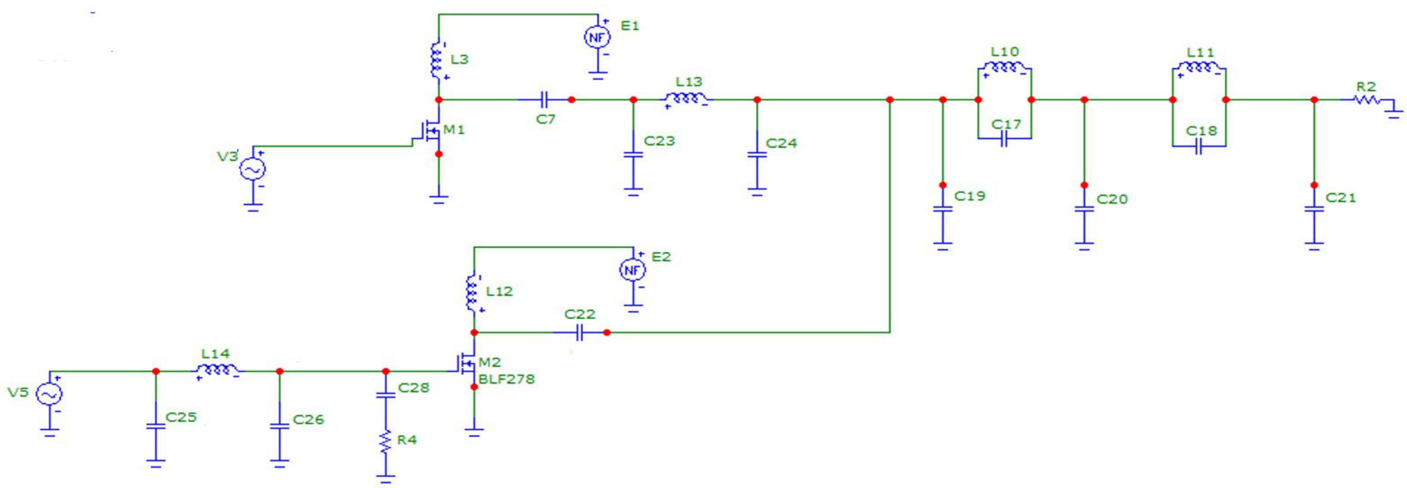

Fig. 2: Computer model scheme of an amplifier by W. Doherty with power supply mode automatic control

For a preliminary assessment of the energy gain from the automatic power mode control introduction in an amplifier built according to the W. Doherty scheme, a computer model was created in Micro-Cap 12 (circuit modeling package). The model diagram is shown in Figure 2. Here are the sources of input signals for the main (upper) and "peak" (lower) arms of amplifier provide the supply of harmonic oscillations with variable amplitude values and with the ratio between them required for the amplifier according to the W. Doherty scheme. The necessary laws for regulating the supply voltages (depending on the amplitudes of the input voltages) of the main and "peak" arms of the circuit are set in functional voltage sources included in the drain circuits of transistors as power sources. In the output circuit of the amplifier, in addition to the inverting U-shaped four-port, a harmonic filter with the Zolotarev-Kauer characteristic is also included. The operating modes of the transistors are selected to meet the requirements of W. Doherty's circuit: main-arm transistor operates in class AB mode, and peak-arm transistor operates in class C mode.

Figure 3 shows a graph of the dependence of the efficiency on the amplitude of the input signal for the case of introducing automatic control of the power mode only in the main arm of the amplifier by W. Doherty, and Figure 4 shows a similar graph for the case of introducing adjustment in both arms of the circuit. The above graphs show a significant increase in the efficiency of the amplifier in the lower part of the amplitude characteristic, compared with the efficiency of the W. Doherty amplifier without automatic control of the power supply mode (see Fig. 1).

Fig. 3: The efficiency dependence on the signal amplitude in the W. Doherty amplifier with power supply mode automatic control in the main arm of circuit

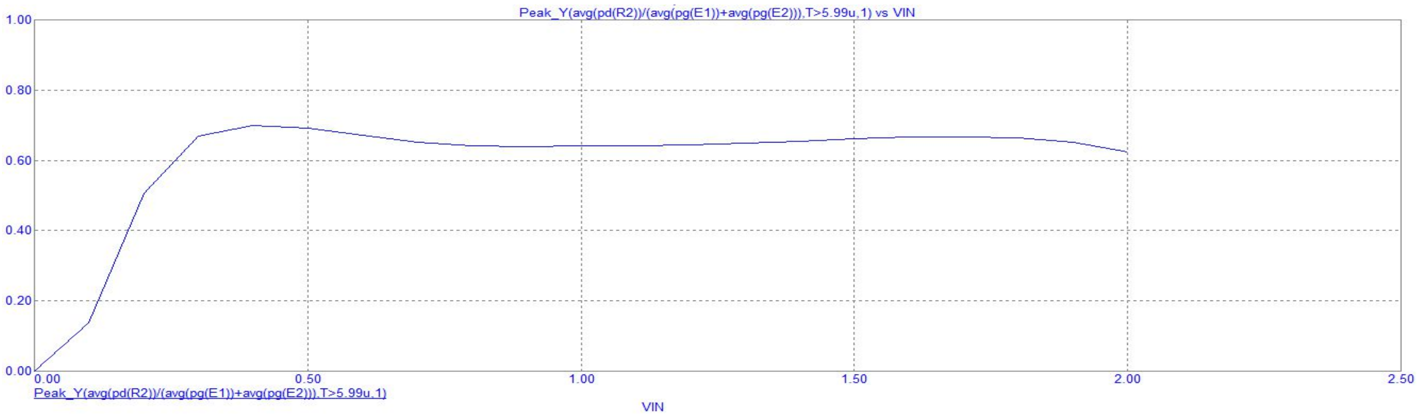

Fig. 4: The efficiency dependence on signal amplitude in the W. Doherty amplifier with automatic power supply mode control in the two arms of circuit

3. Conclusion

The conducted study shows that the automatic control introduction of power supply mode leads to an increase in the efficiency of a linear power amplifier built according to the W. Doherty method in the region of average statistical amplified OFDM signal amplitudes. However, the obtained results require further clarification, taking into account the actual bandwidth of the envelope channel, determined by possible speed of switching supply voltage regulators, limited by modern switching transistors parameters. It should also be noted that the combined use of W. Doherty's methods and automatic adjustment of power supply mode will inevitably lead to the complication of linearization methods used in power amplifiers of digital television transmitters. This requires additional research, and is directly related to the specific non-linear distortions inherent in both the W. Doherty method and the method of automatic power mode adjustment.

REFERENCES

[1] V. N. Gromorushkin and O. V. Varlamov, "Experimental Studies of the Envelope Elimination and Restoration HF Power Amplifier Characteristics with Broadband Unmatched Load," *2021 Systems of Signal Synchronization, Generating and Processing in Telecommunications (SYNCHROINFO*, 2021, pp. 1-4, doi: 10.1109/SYNCHROINFO51390.2021.9488387.

[2] O. V. Varlamov and A. Grebennikov, "Experimental Studies of Envelope Elimination and Restoration HF Power Amplifier Characteristics with Narrow-band Matched Load," *2022 Systems of Signal Synchronization, Generating and Processing in Telecommunications (SYNCHROINFO)*, 2022, pp. 1-4, doi: 10.1109/SYNCHROINFO55067.2022.9840873.

[3] O. V. Varlamov, D. C. Nguyen and S. E. Grychkin, "Simultaneous Application of Several Synthetic Methods for High Efficiency Radiofrequency Amplification," *2021 Systems of Signals Generating and Processing in the Field of on Board Communications*, 2021, pp. 1-5, doi: 10.1109/IEEECONF51389.2021.9416126.

[4] O.V. Varlamov, D.C. Nguyen, S.E. Grychkin, "Combination of synthetic high-performance RF amplification techniques," T-Comm, 2021, vol. 15, no.9, pp. 11-16. DOI: 10.36724/2072-8735-2021-15-9-11-16

[5] O. Varlamov, D. C. Nguyen, and A. Grebennikov, "Broadband and Efficient Envelope Amplifier for Envelope Elimination and Restoration/Envelope Tracking Higher-Efficiency Power Amplifiers," *Sensors*, vol. 22, no. 23, p. 9173, Nov. 2022, doi: 10.3390/s22239173.

[6] W.N. Doherty, "A New High Efficiency Power Amplifier for Modulated Waves," *IRE Proc*., vol. September 24, 1936, pp. 1163-1182.

[7] Y. Cho, K Moon, J. Kim, B. Park and B. Kim, "Linear Doherty power amplifier with adaptive bias circuits for average power tracking", *Microwave Symposium (IMS) 2016 IEEE MTT-S International*.

[8] R. Y. Ivanyushkin, K. O. Razin and N. D. Shmakov, "Perspective ways of construction of the tract of amplification of transmitters for digital television broadcasting," *2018 Systems of Signal Synchronization, Generating and Processing in Telecommunications (SYNCHROINFO)*, Minsk, Belarus, 2018, pp. 1-5, doi: 10.1109/SYNCHROINFO.2018.8456978.

[9] R. Beltran and F. H. Raab, "VHF Doherty amplifier with GaN FETs and independent drive-signal control," *2011 IEEE MTT-S International Microwave Symposium*, Baltimore, MD, USA, 2011, pp. 1-4, doi: 10.1109/MWSYM.2011.5972732.

[10] A. Grebennikov and S. Bulja, "High-Efficiency Doherty Power Amplifiers: Historical Aspect and Modern Trends," *Proceedings of the IEEE*, vol. 100, no. 12, pp. 3190-3219, Dec. 2012, doi: 10.1109/JPROC.2012.2211091.

[11] N. Giovannelli et al., "A 250W LDMOS Doherty PA with 31% of fractional bandwidth for DVB-T applications," *2014 IEEE MTT-S International Microwave Symposium (IMS2014)*, Tampa, FL, USA, 2014, pp. 1-4, doi: 10.1109/MWSYM.2014.6848331.

[12] J. He, J. H. Qureshi, W. Sneijers, D. A. Calvillo-Cortes and L. C. N. deVreede, "A wideband 700W push-pull Doherty amplifier," *2015 IEEE MTT-S International Microwave Symposium*, Phoenix, AZ, USA, 2015, pp. 1-4, doi: 10.1109/MWSYM.2015.7166772.

[13] X. A. Nghiem and R. Negra, "A 100 W GaN HEMT SPA-D with 57% fractional bandwidth for DVB-T applications," *2016 IEEE MTT-S International Microwave Symposium (IMS)*, San Francisco, CA, USA, 2016, pp. 1-4, doi: 10.1109/MWSYM.2016.7540202.

[14] J. Cai and G. Bu, "Design of a switch-controlled multi-mode Doherty power amplifier," *2022 International Applied Computational Electromagnetics Society Symposium (ACES-China)*, Xuzhou, China, 2022, pp. 1-3, doi: 10.1109/ACES-China56081.2022.10065204.

[15] P. Chen, X. Yi, H. Yin, X. -W. Zhu and C. Yu, "A Cascaded Envelope Tracking-Doherty Approach for Gain and Efficiency Enhancement of GaAs Power Amplifiers," *2021 IEEE International Workshop on Electromagnetics: Applications and Student Innovation Competition (iWEM)*, Guangzhou, China, 2021, pp. 1-3, doi: 10.1109/iWEM53379.2021.9790368.