ANALYSIS OF METHODS TO IMPROVE ENERGY EFFICIENCY OF DIGITAL BROADCASTING

Kadirova Laylo Imomaliyevna

TUIT Department of Telecommunication Engineering

The main characteristics of the signals of digital broadcasting standards are considered. It is shown that for amplification of digital signals it is necessary to use high-linear amplifiers, which have a significant drawback - low efficiency in the mode of average power. Based on the analysis of the properties of methods for improving the energy efficiency of linear power amplifiers, recommendations have been formulated for using them for signals of various broadcasting standards.

KEY WORDS: energy efficiency, Daugherty, broadcasting, transmitter

1. INTRODUCTION

In recent years, many developed countries of the world have been actively introducing digital broadcasting systems to replace analog broadcasting. In the middle (MF) range, high (HF) frequencies have traditionally been used amplitude modulation, which, combined with a small (no more than 9-10 kHz) band, allocated to each radio channel, provided a fairly mediocre quality of reception, especially in the conditions of multibeam distribution in the range of the test. All these factors prevented high-quality radio broadcasting in these frequency ranges. Transferring broadcasting in low (LF), MF and HF ranges to digital activities will significantly improve the quality of broadcast speech programs without the need to increase the band.

The VHF band today provides high-quality analogue stereo broadcasting, the quality of which most radio listeners are comfortable with. But in the designated VHF sites in large cities, there is a significant shortage of frequency resources through the widespread development of commercial broadcasting. Switching to digital broadcasting will allow several programs, at least of the same quality, to be broadcast in the same frequency band assigned to one analogue broadcast channel.

There is an opportunity to provide the user with additional multimedia services - information about the condition of roads, weather forecasts, timetables, etc.

To date, three standards of digital broadcasting are in force or being implemented in Europe, the main parameters of which are listed in Table 1 [1].

TABLE 1: Key characteristics of digital standards

The name of the standard	**DAB**	**DRM**	**DRM**
Frequency range, MHz	174-240 1452-1492	0.525to1,605 3.2to26.1	47-107
Bandwidth, kHz	1536	4, 5, 9, 10, 18, 20	96
Digital flow speed, kbt/s	< 256	4-20	4-186
The type of carrier modulation	QPSK	4-QAM, 16-QAM, 64-QAM	QPSK, 64-QAM
Number of carriers	192, 384, 768, 1536	88, 90, 102, 104, 114, 138, 178, 182, 204, 206, 228, 280, 366, 410, 412	213
Peak-factor, dB	12	10	8

From the Table 1, it is clear that the DRM standard is designed to replace AM standards in the ranges of LF, MF, and HF standards, and DAB standards, DRM+ to replace the broadcasting world systems in the ranges of UHF, SHF. The DAB system, implemented in some Western European countries, is not compatible with the range World Cup frequency plan adopted in a number of other countries, so this standard is unlikely to be adopted. It is advisable to implement DRM and DRM standards based on the frequency range.

2. GOAL AND OBJECTIVES

The aim of the work is to develop a circuit design solution for constructing output stages of DAB standard broadcast transmitters with the fulfillment of the energy efficiency condition.

Tasks to be solved, achieving the goal:

- Conduct an analysis of existing developments.
- Determine the features of the output stages when using the broadcast standard.
- Determine the circuitry solution and give the basic formulas for the procalculation of the cascade parameters.

3. ANALYSIS OF METHODS FOR IMPLEMENTING THE OUTPUT STAGES OF DIGITAL BROADCASTING TRANSMITTERS

When generating digital broadcasting signals, frequency multiplexing (COFDM) is used. The main advantage of such signals is their weak tendency to fade when received in urban areas, due to the multi-learning propagation of radio waves. A radio signal generated by the COFDM principle is a combination of a large number of subcarrier oscillations, each of which is modulated by a low-speed sub-stream obtained by multiplexing a high-speed transport stream. The number of COFDM signal subcarriers in digital broadcasting can reach several hundred, and in digital television, several tens of thousands. Thus, the COFDM signal is a complex multi-frequency oscillation, has all the problems of group signals with frequency division [2, 3].

One of the main problems of COFDM signals is their significant peak factor, which results in increased linearity requirements in the amplifying tracts of transmitters designed to pass such signals. As you know, the construction of such transmitters requires the use of linear power amplifiers (LPA), which have traditionally low average efficiency, due to significant restrictions on the mode of operation of the amplification cascades, as around the corner cutoff angle and in the mode voltage. Even a very minor nonlinearity of the amp performance of the power amplifier will result in a combination product, with the structure of the COFDM signal very critical. In addition to the combination product falling outside the channel spectral mask, it is equally dangerous that the combination components enter the signal itself at the COFDM subcarrier frequencies, which will lead to problems when decoding the signal at the receiving side. In addition to the high requirements for the linearity of the amplitude characteristics of the power amplifier, the amplification of COFDM signals is equally important and the uniformity of the phase-amplitude characteristic (PhAmp), since the signal is amplitude-phase modulated, for which both amplitude and phaseamplitude distortions are important. The non-uniformity of the PhAmp in power amplifiers is usually caused by a phenomenon called amplitude-phase conversion (AmPh), which occurs mainly due to various parametric capacitances of amplifying devices [4]. When amplifying signals with a variable envelope, the AmPh problem always arises, since the voltages in the input and output circuits of amplifying stages are also oscillations with a variable envelope, which directly affect the electrodes of amplifying devices.

To linearize the phase response of the power amplification path, as well as to compensate for some distortions in the amplitude characteristics of the amplifier (of course, if these distortions are not associated with loss of information due to hard cutoff, or limitation), various linearization methods are widely used in modern radio transmitters. With regard to the construction of digital broadcasting transmitters, the most frequently used today is linearization by the method of over-correction (overdistortion), which is most often adaptive, that is, it is carried out by a control signal that is removed from the output of the transmitter. In almost all modern broadcast transmitters, such correction is carried out programmatically at the stage of generating the COFDM signal and its components.

When developing new radio transmitters intended for digital broadcasting, it is advisable to use methods for increasing the LPA efficiency, which will solve the problem of a low transmitter efficiency as a whole. Among all the existing methods for increasing the LPA efficiency, when constructing transmitters for digital broadcasting, it is most advisable to consider the method of automatic mode regulation (AMR), the L. Kahn method with separate amplification of the envelope and phase-modulated filling of the amplified signal, the Doherty scheme and the dephasing method .

The named methods can be conditionally divided into two groups - methods without non-linear transformations of the amplifier signal and methods with non-linear transformations of the amplifier signal [4].

The Doherty method, first proposed in 1936 for use in high-power transmitters, is the easiest way to increase efficiency. The Dougherty configuration uses an active load conversion technique.

In Fig. 1 (a) shows a diagram of the active conversion of the load resistance. According to circuit theory, G1 sees the load resistance R_L if no current is supplied from G2. When a current begins to flow from G2 in proportion to I_1, the resistance with which G1 is loaded will correspond to the expression (1)

$$R_1 = R_L(1 + I_2 / I_1). \qquad (1)$$

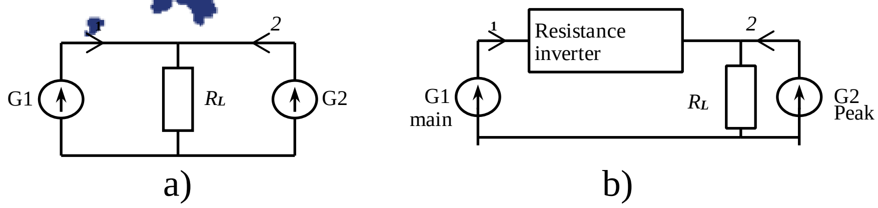

FIG. 1: Scheme of active load conversion techniques (a) with a resistance inverter illustrates the configuration of the Dougherty amplifiers (b) [7]

When I_2 increases, the resistance of R_1, which is loaded with G1, also increases. In addition, the G2 is loaded with resistance (2)

$$R_2 = R_L(1 + I_1 / I_2). \qquad (2)$$

Also in Fig. 1 (b), the resistance inverter is added so that the resistance to which the G1 is loaded decreases, and the current fed on G2 increases.

On the scheme PD - power divider; In CC, Out CC – input and output conciliation chains; CA - carrier amplifier; PAmp - peak amplifier; z_0 - every wave line.

The most configuration of the Dougherty (two-channel) circuit consists of two amplifiers: the “main” or “carrier oscillation” ($Amp_{carrier}$), and the “assistant” or “peak” (Amp_{peak}). Heart wave transmission line (resistance inverter), as shown in Fig. 2, so that the diagram corresponds to Fig. 1(b) with G1 as the main, and G2 as an additional amplifier.

The main concept of the Dougherty amplifier is that the main amplifier operates at maximum efficiency (maximum power), while the auxiliary amplifier is designed to provide modulation peaks. When the input signal is low, the auxiliary amplifier is locked, and the main amplifier operates in linear mode, as shown in Fig. 2. If a Class B power amplifier is used as the main amplifier, and a Class C amplifier as an auxiliary amplifier, the class amplifier is turned off because the signal is too small. If the excitation signal increases, the main amplifier begins to saturate, and the auxiliary amplifier begins to give off current. This opening point of the auxiliary amplifier is called the transition point. At the transition point, the efficiency of the entire system becomes high.

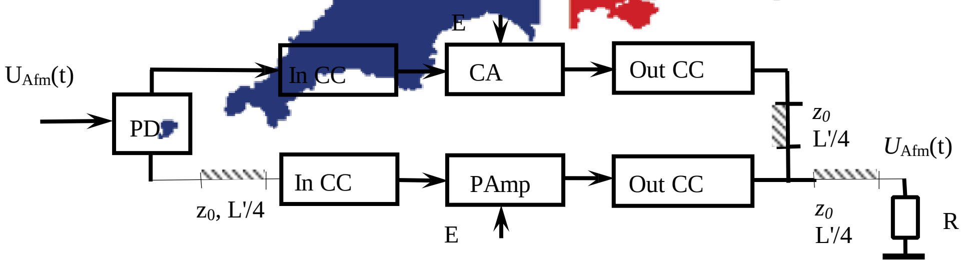

FIG. 2: Daugherty amplifier structure

Above the transition point, the impedance of the main amplifier decreases through the current supplied from the auxiliary amplifier. Due to the "load conversion" effect, the main amplifier provides a larger load current and acts as a controlled voltage source while it is saturated. On the other hand, the auxiliary amplifier takes over the job as a linear amplifier. In this area, both devices form the output power. At peak envelope power, the auxiliary amplifier is also saturated and the efficiency of the system as a whole becomes high. Thus, the two amplifiers give a component of the linear power characteristic, maintaining efficiency close to the maximum, for a typical point a power reduction of 6 dB. (As a rule, for a two-channel Doherty amplifier, the transition point is selected 6 dB below the maximum total power point). Fig. 3 shows the characteristic currents and voltages for the main and auxiliary amplifiers in the entire range of input voltages.

The overall performance of Dougherty amplifiers depending on the power reduction shown on the Fig. 4.

If a Class B amplifier is used as the primary and, Class C as an auxiliary amplifier, the theoretical maximum efficiency is 78.8%. Efficiency is close to maximum at levels above 6 dB. A small efficiency gap between the transition point and the full power (i.e., 6 dB below the maximum) is due to a decrease in the efficiency of the auxiliary amplifier, which operates in the power reduction mode

Recent studies have shown ways to further increase energy efficiency and linearity. In [7], envelope tracking is used to change the supply voltage of the main amplifier along the envelope of the input signal, and reduces power consumption at low levels of the input signal. To increase the efficiency of the transmitter, an Nchannel amplifier can be used. In a Doherty amplifier of N channels, one carrier amplifier and N-1 auxiliary amplifiers are usually connected in parallel.

The first group of methods for increasing efficiency also includes the automatic mode control (APP) method shown to the Fig. 5, which in foreign terminology is referred to as "Envelope Tracking" (ET) - envelope tracking.

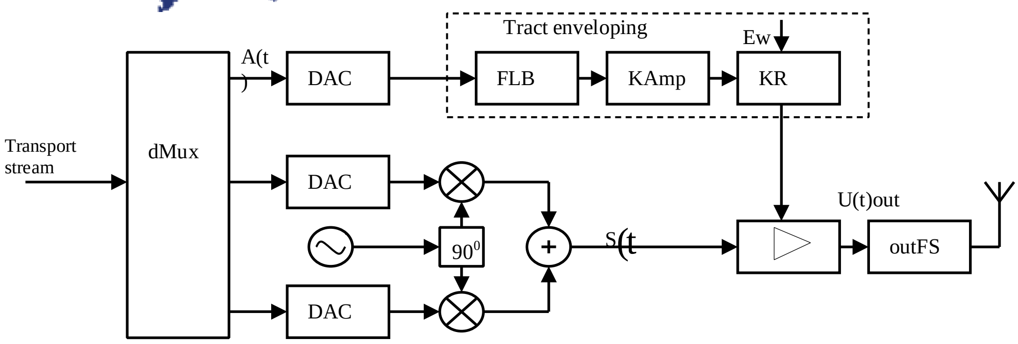

FIG. 5: Power amplifier with AMR, built with a digital grating selection

ET was first described by Bell Laboratories in 1937 as a way to improve the efficiency of the power amplifier. For a conventional power amplifier, a constant high voltage is fed to a high-frequency powerful transistor to prevent the distortion of the output signal, even if its amplitude is maximum. Digital broadcasting, modulated signal amplitude fluctuates a significant degree over time.

According to ET, the voltage of the power on the transistor is adjusted according to the input amp to save electricity, will be wasted in conventional power amplifiers. Until recently, it was difficult to develop a power system [5] (ET of the power supply) that could accurately track the vibrations of the input amplitude. However, the combination of recently improved fast-acting semiconductors and advanced digital signal processing technologies, which has allowed us to put in practical use ET.

To track the level of the deflection, it is digitally formed in the transmitter's processor node, where the counting of the modulated signal itself is formed. Enhanced by a key amplifier (KAmp) and supplied to a key regulator (KR) of the feeding voltage, which regulates by law the enveloping voltage of one or two of the transmitter's most powerful cascades.

As you can see from the Fig. 6, when the amplitude of the amplified signal is reduced, the tension of the cascade regime decreases (transition from the point I to point II).In doing so, it is important that such regulation does not lag in relation to the change in the envelope signal requiring a delay in the amplification signal relative to it. mushrooming to compensate for the inertia of the FLB in the regulatory tract.

Advantages of AMR in drain/collector voltage [6]: The main advantage of APP in drain/collector voltage compared to the Doherty circuit is that this method is not an RF whose bandwidth is limited. This makes it possible to build a broadband RF line amplifiers with high efficiency. AMR can also be several percents more efficient than a dual-channel Doherty amplifier with a PAR above 7.5 dB.

AMR's downsides compared to Dougherty:

- The complexity of additional equipment and pre-correction.
- Reducing reliability by increasing the number of items.
- Increasing the cost of additional equipment.

- Increase development time for the market.

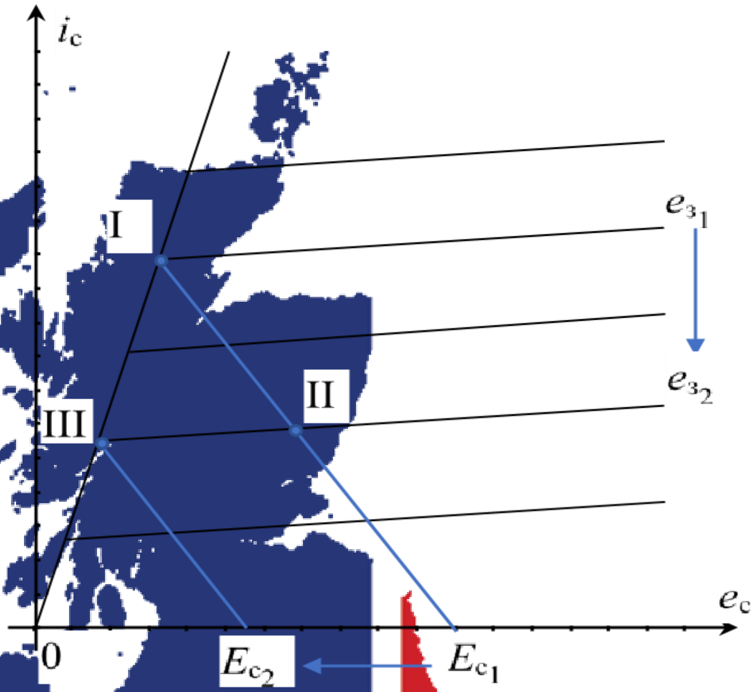

FIG. 6: Power voltage regulation

AMR for runoff/collector voltage bringing significant efficiency benefits at PAR more than 6 dB, and increases as PAR increases signals with high PAR.

The second group of methods - with non-linear transformations of the amplified signal can be attributed to the Kahn method and the method of degassing - the Shirex method.

The L. Kahn method provides separate amplification of the envelope and phasemodulated RF filling (ORFF) of an amplifier signal with a variable envelope, followed by highly effective amplitude (HEA) modulation (by controlling the supply voltage) in the output stage of the transmitter, where the amplifier signal is restored. The method was developed by American engineer Leonardo Kahn in 1952. He called it "Envelope Elimination and Restoration" - "eliminating and restoring the envelope." Later, M.V. Verzunov, who made a significant contribution to the development of the practical implementation of this method, called it synthetic. Due to the fact that only phasemodulated filling (having a constant bypass) is amplified in the transmitter power amplification path, and highly efficient amplitude modulation is performed in the output stage, high efficiency is provided. The use of key voltage regulators also contributes to this. Separation of the amplification signal into bypass and phasemodulated filling is currently carried out digitally. When a modulated signal is generated in the processor, the signals of the envelope A (t) and phase φ (t) of the amplified signal are formed at the outputs of the digital-to-analog converters (Fig. 1). Signal φ (t) carries out phase modulation of the carrier oscillation at the operating frequency of the transmitter Fp, and signal A (t) is converted into a KAmp sequence, fed to high-power envelope amplifiers (PSA) for amplitude modulation (after filtering the clock frequency fT in the low-pass filter) in the initial and output stages of the transmitter, similarly to how this is done in broadcasting AM transmitters with anode or collector modulation.

Today, the method of L. Kahn is widely used. Similar developments exist in many leading companies specializing in both broadcasting equipment and mobile communications. Modern implementations of the L. Kahn method are almost always close in the structural diagram shown in Fig. 7. In modern foreign literature, such architectures are called the "Polar Modulator" at the construction of the radio transmission tract. Output of the transmitter is formed as a result of phase and amplitude modulation of the oscillating signals of the social A(t) and phases of q(t), which are, in essence, the polar coordinates of the signal vector that, today, most often appears to be its Cartesian coordinates I and Q, called square-urn components [5].

It is impossible not to note the inherent shortcomings of the L. Kahn method. The main one is related to the non-synchronicity of the transmitter's exit cascade (where the sourcing variable is restored) of the envelope and phase of the intake and filling, due before the more inertia of the COFDM in the envelope tract maximum allowable delay. The second flaw is related to the amplitude-phase conversion in the powerful cascades of the transmitter, in which amplitude modulation is carried out. Both of these problems lead to specific non-linear distortions of the amplifier signal requiring the application of special measures to linearize the transmitter. Finally, the third drawback is the need to pass the entire band enveloped through a highly efficient power control channel of those power-enhancing cascades in which amplitude is carried out. The more the clock of the pulsed power voltage control device is needed, which inevitably leads to a decrease in the resulting efficiency of the transmitter. However, at the current stage of technology development, these problems are increasingly becoming solvable. This indirectly confirms the fact that the L. Kahn method is now quite successfully used in transmitters of digital broadcasting of the DRM standard bands LF, MF and HF, both in foreign and domestic developments. Due to the fact that the channel bandwidth is low in these frequency ranges (usually not wider than 10 kHz), the task of temporarily synchronizing the envelope channels and the phase-modulated filling becomes quite feasible. The required bandwidth of the envelope channel does not exceed 40 kHz, which allows you to build key switching voltage regulators with high energy performance (since this requires a KAmp clock frequency of only 280 kHz), which makes this method quite effective.

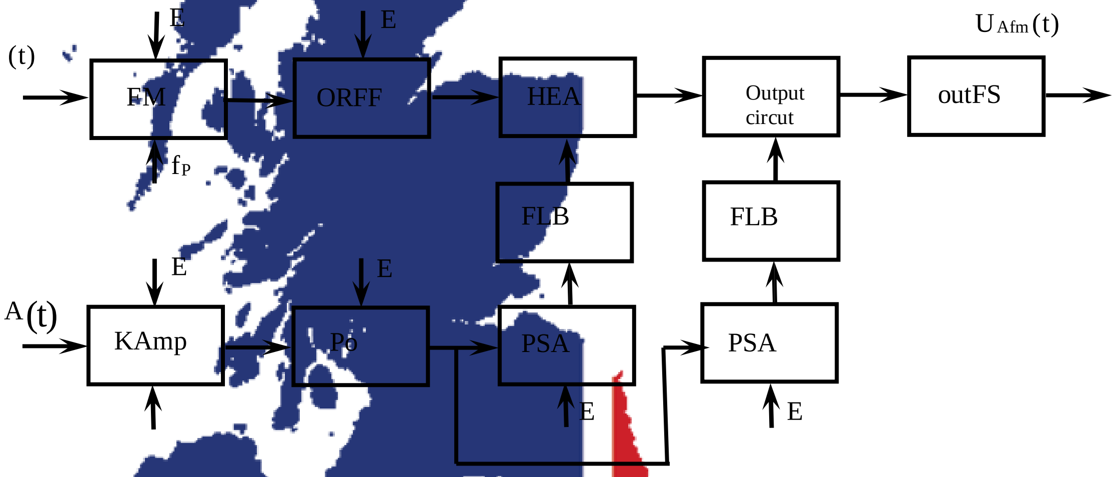

FIG. 7: Structure of the transmitter radio mission, built on the method of L. Kahn

When building digital broadcast transmitters in the UHF range, where the channel band is 100 kHz for the DRM standard, the possibility of using the L. Kahn method requires additional research.

The method of data skive, proposed by M. Shirex in 1931, as a way of obtaining amplitude modulation with high efficiency, and later common by D. Cox for the case of any AFM signals, provides for strengthening in powerful cascades of transmitter signals with constant the bypass that provides them with high efficiency. This method is also called LANC (linear amplification with non-linear components) when it came into use on microwaves in the 1970s. The sum of two signals $S_1(t)$ and $S_2(t)$ with constant amplitude and variable phase, changes with the opposite sign, according to the vector chart in the Fig. 8. With elementary trigonometry, it is obvious that the phase corner modules defined by modulation of signals $S_1(t)$ and $S_2(t)$ associated with the amplitude of the enhanced signal S(t) through the function of the arccosine. It is difficult to have a different approach to receiving these signals today.

When digitally forming signals $S_1(t)$ and $S_2(t)$, they are formed to the vector in a way (which is very characteristic building modern digital signal transmitters) using two square modulators (Fig. 9) directly on the working frequency of the f. As you can see from

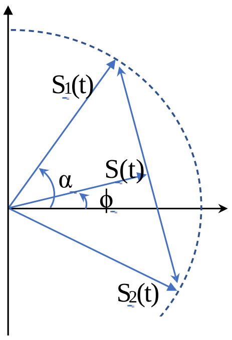

FIG. 8: Vector chart

Figure 9, the in-phase component of (t) for S_1(t) and S_2(t) signals is the same, and the square S(t) is marked, requiring the introduction of a phase-inverter. Is carried out in summer, which is quite a challenge to build, as the phase shift between the S_1(t) and S_2(t) signals during the roundabout change period varies from zero to 180 degrees of a moustache. Just as important is the specific non-linear distortions that occur afterward, not the identity of the two amplifying tracts, both in the gain factor and in the phase, which requires the use of complex methods of auto compensation and linearization.

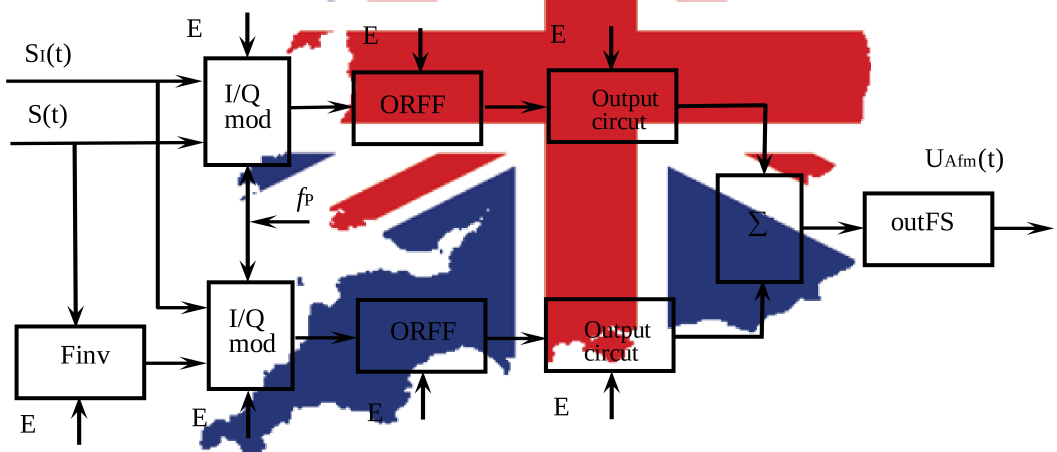

FIG. 9: Dephasevaning method

Disadvantages of the method:

– Pulse amplifiers such as Class-E are desirable for potentially high efficiency. Unfortunately, Class E PPs are not well suited to the phase-deflection system due to changes in load resistance while reducing capacity;

– Output power is extremely sensitive to the phase of the phase, especially for small output amplitudes and, therefore, a phase misalignment between the two channels (in some cases, 1 ° phase of phase can lead to - 40 dB change in the output power). Therefore, this method is best suited for a modulation scheme that avoids zero crossings as π / 4-shifted-DQPSK.

It's a good way to get to the imbalance of phases, and it's a method that doesn't go any closer for signals.

In Fig. 10 [7] the results of modern modes of operation in one of the main areas. You can see that the technique is not used in the diagrams of the Khan's diagram of the key mode. But due to the relative low-frequency of key circuits, the Khan method is recommended for use in DRM transmitters. Approximately the same energy values at a level higher than -6 dB provide a Dougherty scheme (Doh) and a scheme Chirax (Chir). The Dougherty scheme is easy to manufacture and operate, with good quality indicators, has found significant use in mobile communications transmitters of 3 and 4 generations. In digital broadcasting systems, the Doherty scheme is still limited in use due to its narrow band. Despite the high energy performance, the scheme of decussation did not find much use in radio transmitters, which is determined by the complexity of its configuration and the instability of the work.

FIG. 10: The splice of the coefficient of performance

The voltage-coupled circuit (ET), although having energy values is slightly lower than that of other circuits, but the simplicity of its practical implementation, the absence of drawbacks that are typical of the Cana and Shirex schemes, suggests that this scheme is one of the most promising in terms of building a non- editors of digital broadcasting in the range of the UHF.

For comparison, in Fig. 10 also shows the dependencies of the efficiency of the relative output power for amplifiers operating in modes A and B.

4. A POSSIBLE VARIANT OF THE CIRCUITRY FOR THE OUTPUT STAGE OF THE DIGITAL BROADCASTING STANDARD

Having analyzed all the disadvantages and advantages of the circuitry implementations of the output amplifier stages, we can see that a Doherty scheme can be used to implement digital broadcasting in the above range. The scheme that implements the considered method is presented in Fig. 11.

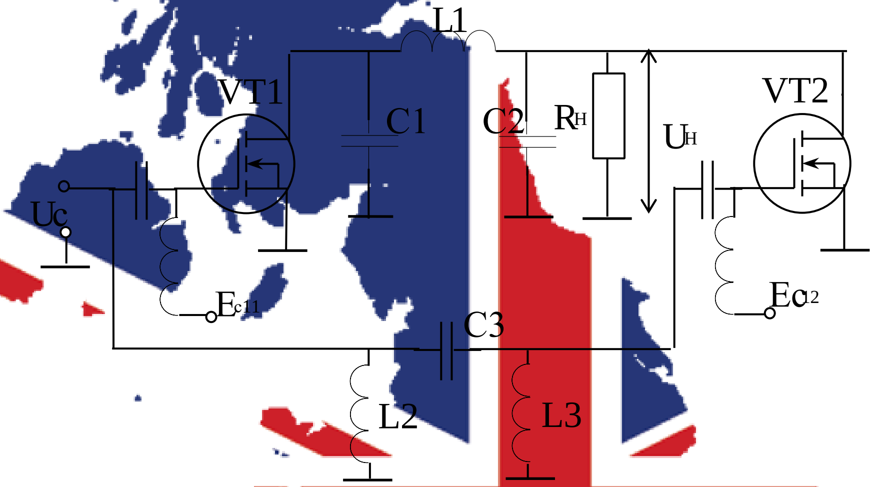

FIG. 11: A variant of the Doherty scheme

Here VT1 is the active element for amplifying the “carrier”, VT2 is the active element for amplifying the “peak” signal values; C1, C2, L1 - four-terminal; L_2, L_3, C_3 - phase shifter, which compensates for the shift due to the matching quadrupole; E_{11}, E_{12} - bias voltage at the gates, which provide an output mode of operation. The operation of the circuit Fig. 11 can be explained in this way. In standby mode, the transistor VT1 operates in the boundary mode for the load R_{ecv} VT1 = x^2 / Z_n. Values are calculated by setting the following parameters $Z_n = R_n$ and $x = 2R_n$; therefore, the expression above is validly written in the form R_{ecv} VT1 = $4R_n$. The transistor VT2 is in the closed state, which is provided by the bias voltage Ec_{12} at the gate, and the current $IC_{12} = 0$. A transistor working to amplify the carrier oscillation gives off power (3), which is the fourth part of the power that is allocated to the load in the maximum permissible operating mode scheme.

$$P_{1T} = \frac{1}{2}\frac{U_{C1T}^2}{R_{RkvV1}} = \frac{1}{2}\frac{U_{C1T}^2}{2(4R_n)} = \frac{1}{2}\frac{U_n^2}{R_n} \qquad (3)$$

When “down” modulation (when changing the amplitude of the input RF signal from 0 to the value of $U_{C1} = C_{CT1}$, which corresponds to the average signal level mode), a linear (at θ = 90°) change of the amplitude of the first harmonic of the drain current I_{C1} and the amplitude of the RF voltage at the drain U_{C1}. Transistor VT2 is closed, current I_{C12} =0.

Taking into account the properties of a four-terminal device, it is possible to determine the current and voltage at the output of the transistor precisely at the load. The value of the first harmonic of the current is $I_{C11} = U_{input}/x = U_{C1}/2R_n$, and the voltage amplitude is $U_n = I_{C1} \times x = I_{C1} \times 2R_n$. Based on the fact that the voltage and current at the input of the matching four-terminal network are respectively equal to $U_{C1} = I_{C1} \times 4R_n$ and $I_{C1} = U_{C1}/4R_n$, we obtain $I_{C1} = 2 \times I_{C11}$, $U_n = U_{C12}$.

5. CONCLUSIONS

The research results presented in the article make it possible to evaluate existing methods for constructing output stages of connected and broadcasting radio transmitters. The goal of providing amplification of output oscillations for the digital broadcasting standard was accomplished by applying the Doherty scheme. The selected scheme has good quality indicators, it is easy to build and operate. The paper presents a diagram of Fig. 11 and the main analytical expressions for calculating the values of voltages and currents in the output load. The features of the cascade operation are considered, it is shown that in the operating mode on the “carrier” the second transistor is closed and the consumption from the power source tends to zero. The latter feature ensures the fulfillment of energy efficiency conditions.

REFERENCES

1.Varlamova L. et al. Fuzzy logic traffic management model //InterConf. – 2020.

2.Muazzam A. Image constrict by the wavelet shrink //International Journal of Recent Technology and Engineering. – 2019. – Т. 8. – №. 1 S4. – С. 862-864.

3.Артиков Т. У., Ибрагимов Р. С., Артиков М. Т. Развитие сейсмического процесса в очаговых зонах сильных землетрясений Узбекистана и долгосрочный прогноз сейсмической активизации //Геология
и минеральные ресурсы (Ташкент). – 2009. – №. 1. – С. 23.