

# Improvement of information reliability of digital systems with QAM/COFDM modulation

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**Abstract - Ensuring a high level of information reliability is one of the most important tasks of the synthesis of digital transmitting systems for various applications. In this paper it is suggested to use the code tag-based encoders and decoders (codecs) with distributors on multidrop delay lines (MDL) for improving the reliability of the information digital transmitting systems with QAM/COFDM-modulated signal; the benefits of the principle of self-synchronization while substantially reducing the guard interval in the structure of the transmitted signals are described; a possibility of excluding the analog signals in the channel is shown.**

## I. INTRODUCTION

In modern responsible digital systems characterized by high values of information capacity and speed of information transmission, for ensuring high levels of information reliability signals with QAM/COFDM modulation are widely used. Mathematical model of this type of modulation is given in [1, 2]. Modulated parameter of carrier signal takes a number of discrete values which transmission is implemented in analog format. In this case in channels with interference of high intensity when  $i_{c.n.} = f_{c.n.} / f_{p.k.} \gg 1$  ( $i_{c.n.}, f_{c.n.}$  - the average intensity and frequency of random impulse noise, respectively;  $f_{p.k.}$  - average frequency of the formation of the working code words in the channel), it is not always possible ensure the necessary requirements for noise immunity [3]. Analysis of models of such systems allows to be identify two basic problems. Solving of these problems allows significantly improving of their quality.

One of them is related to the fact that a serial synchronous interface of the systems requires a reliable synchronizing of all transceiver tract, especially codecs. Traditionally the different variants of the principle of cyclic (start-stop) synchronization with the formation of special clock signals are used. This case requires constant monitoring and correction of synchronization disturbances (crash). Studies show that errors caused by a failure of synchronization, exactly reduce parameters of reliability of the transmitting information even using powerful error-correcting codes [4, 5].

Another problem - the existence of guard intervals in the structure of the transmitting signal which are introduced to reduce the influence of interference errors caused by multipath reflections of signals in the channels, but reduce the speed data transmitting and, therefore, channel capacity [6].

## II. MAIN PROBLEMS IN QAM/COFDM MODULATION

Classical variant of geometric interpretation of COFDM-signal - modulation constellation (constellation diagram). Each operating point (OFDM-symbol) of this diagram is corresponding to the coordinates of  $\mu_1$  and  $\mu_2$  (for the real and imaginary axes, respectively) transmitted by QAM-signals.

One of the known ways for improving noise immunity of researching QAM/COFDM systems is the use of conversion which is achieved by turning the operating points of the modulation constellation in the complex plane at a certain angle (Fig. 2), which depends on the modulation mode ( $29^\circ$  for QPSK;  $16.8^\circ$  for 16-QAM;  $8.6^\circ$  for 64-QAM;  $\arctg(1/16)$  for 256-QAM). By rotation of the constellation on the exact angle each selected operating point of the constellation gets unique coordinates ( $\mu'_1$  and  $\mu'_2$ ) that do not coincide with the coordinates of the other points. Each coordinate of point is processed in the modulator and transmitted separately one from another. Coordinates  $\mu'_1$  and  $\mu'_2$  are combined in the receiver. Thereby the original constellation restores. When the information about one coordinate in the channel is lost due to the presence of the interference and noise, the information about another coordinate is stored. This allows the receiving side to restore OFDM-symbol completely, although with a lower level of signal/noise (C/N).

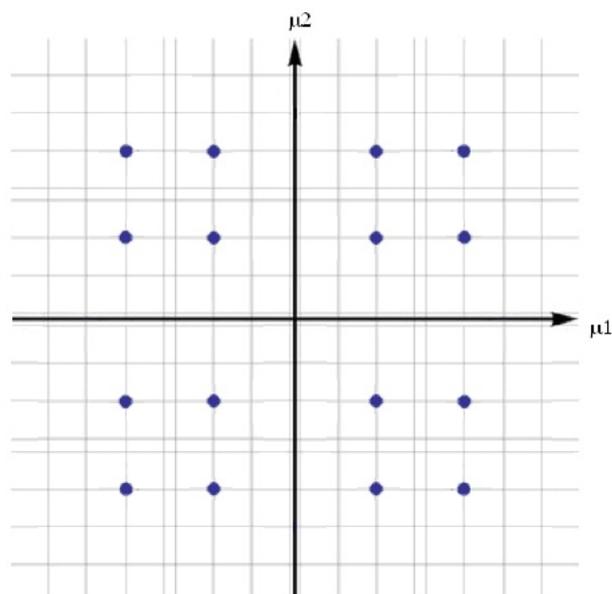


Fig. 1. Modulation constellation of 16-QAM

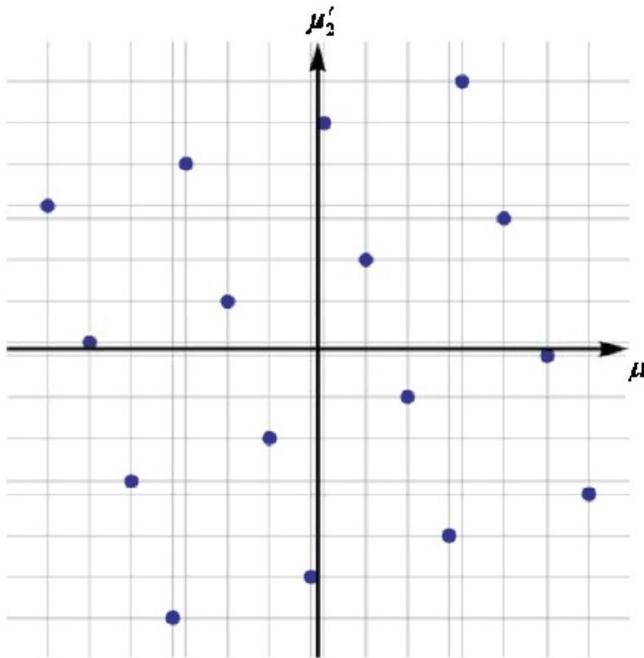


Fig. 2. Modulation constellation of 16-QAM after rotation

Furthermore, the possibility of transferring coordinates of only one operating point appears. If the transmission of two coordinates carried out by two orthogonal analog signals, then for transferring one coordinate only one of them is sufficient.

In most modern digital systems in the transmitted data stream for transmitting ancillary (service) correction information are used pilots, which formed as a result of subcarrier modulation by pseudo-random sequence. Continuous and distributed pilot signals are transmitted on the same frequency subcarriers in each OFDM-symbol, their amplitude and phase of the received signal are known. Therefore they can be used for the synchronization, getting information about the characteristics of the channel evaluation, particularly its phase noises [7].

In OFDM-modulation points of constellation diagram corresponding to the pilot signals have only one meaningful coordinate and belong to the real axis. But there may be variants, in which the abscissa of one or several operating points coincides with abscissa of pilot signal. For avoidance of incorrect identification of operating points of the transmitted signal in such situations it is proposed to transmit the ordinates of operating points of the rotated constellation.

Application of the rotated constellation can also increase the data capacity of the system due to the simultaneous using of several options of constellations at different angles of rotation. Thus, 16-QAM modulation let us get 32, 64, 128 ... operating points (respectively at 2, 4, 8, ... different values of the angles of rotation of the constellation). Nevertheless, data

transfer is still carried out by an analog signal, and it is also necessary to have a guard interval between symbols transmitted transport stream.

### III. USING OF CODECS WITH CODED SIGNAL SIGN FOR TRANSMISSION OF COFDM-SIGNALS

A special feature of the code signal sign on basis of codecs distributors on MDL (in previous authors' papers - with distributors on DMD - dynamic memory devices), is a representation of each transmitted bit of data stream by pulse sequences - code series of pulses of short duration rigidly interconnected by fixed time intervals, which are multiple to a certain time delay  $\Delta t$  of elements of MDL.

Block diagram of the coder with a code signal sign in  $(n+1)$ -bit distributor is shown in Fig. 3. The control unit is the scheme executes the following main functions:

- definition of the time of submission of code symbols to the input of the distributor;
- setting the switching law of outputs of the distributor;
- Implementation of the switching of elements  $\&_1$  and  $\&_0$  by signals  $1_{\cdot 1}$  or  $1_{\cdot 0}$  depending on the current input binary symbol.

The signal at the first output of the distributor is formed with a delay  $\Delta t_0$  respect to the input signal (for coder - on the zero output). On all other outputs of the distributor signals appear sequentially and alternately in time with delays  $\Delta t$ . Researches have shown that to ensure correct work of codecs durations of delays  $\Delta t_0$  and  $\Delta t$  must be strictly constant, the same for the coder and decoder, and thus must be satisfied the condition  $\Delta t_0 \neq k\Delta t$  ( $k$  - integer coefficient). Furthermore, the code pulse sequences generated by coder should not be cyclic shifts of each other. The signals from outputs of the distributor, passing through the switch block according to the law given by the control unit, control the operation of the schemes  $\&_1$  and  $\&_0$ , which form code series for "1" and "0" at the outputs of the coder.

A polynomial of the output signal of the coder relatively the dummy variable  $x$  can be represented as:

$$y(x) = \sum_{i=1}^n a_{n-i} x^{n-i} = a_{n-1} x^{n-1} + a_{n-2} x^{n-2} + \dots + a_0. \quad (1)$$

Coefficients of the polynomial (1) can be represented as delay functions of the distributor:

$$a_i = f(\Delta t_0 + (n-i)\Delta t), \quad i = \overline{1, n}. \quad (2)$$

Thus, a polynomial which describes code series coming to the channel from the output of the coder and corresponding to one bit of the input signal takes the form:

$$y(x, t) = f(\Delta t_0) x^{n-1} + f(\Delta t_0 + \Delta t) x^{n-2} + \dots + \dots + f(\Delta t_0 + (n-2)\Delta t) x + f(\Delta t_0 + (n-1)\Delta t). \quad (3)$$

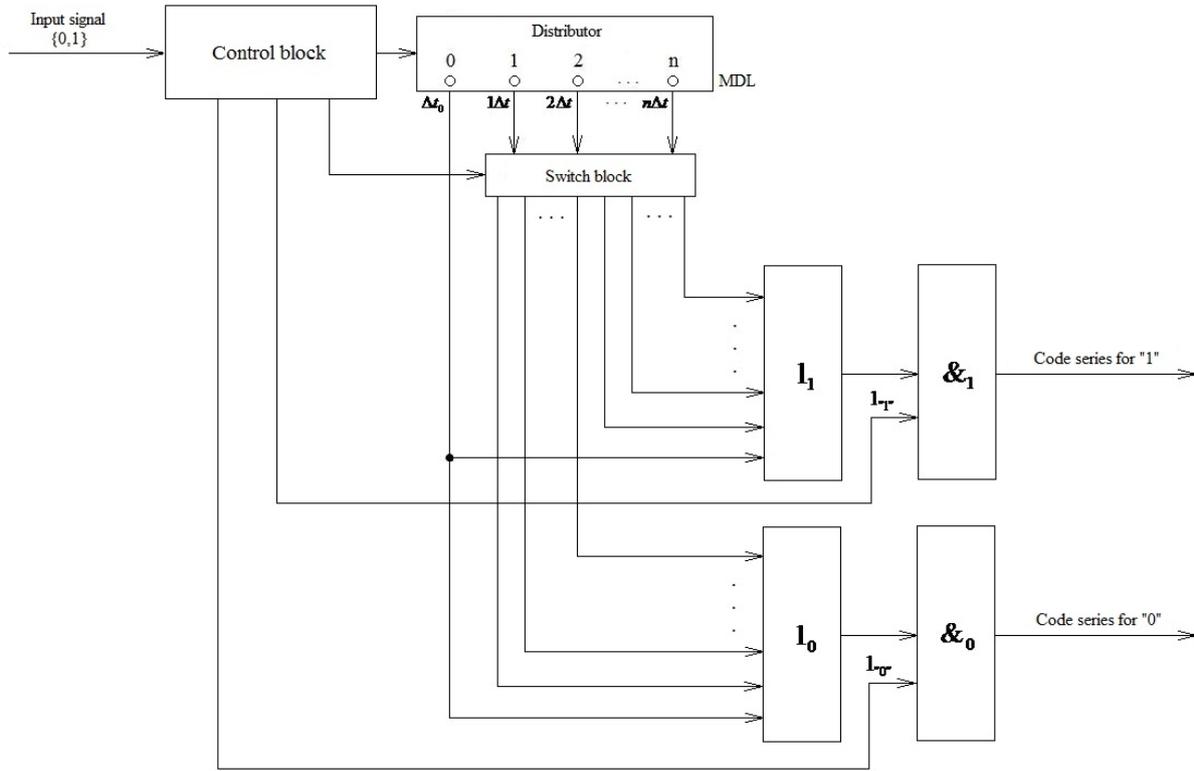


Fig. 3. Block diagram of coder with code signal sign with (n+1)-bit distributor on MDL

Block diagram of the decoder is shown on Fig. 4. The control signal which is part of the received signal is applied to control unit. Control unit provides switching law similar to law that is implemented in the coder scheme.

Actuation of logic element "AND" (&1 or &0) at the output of decoder occurs at the moments of coincidence of pulses from outputs of the distributor, the numbers of which coincide with the numbers of pulses in the decoding pulse sequence, appearing on the corresponding numbers on the outputs of the distributor.

As research shows, codes with code signal sign with distributors on MDL allow to implement the principle of self-synchronization and transmit information without using special clock signals. This fact significantly increases the information reliability of digital systems.

Polynomial of output signal of decoder:

$$y'(x) = \sum_{i=1}^n b_{n-i} x^{n-i} = b_{n-1} x^{n-1} + b_{n-2} x^{n-2} + \dots + b_0. \quad (4)$$

Coefficients of polynomial (4) may be represented as delay functions of distributor:

$$b_i = f'(\Delta t_0 + (n-i)\Delta t), \quad i = \overline{1, n}. \quad (5)$$

Thus polynomial (4) can be represented as:

$$y'(x, t) = f'(\Delta t_0) x^{n-1} + f'(\Delta t_0 + \Delta t) x^{n-2} + \dots + \dots + f(\Delta t_0 + (n-2)\Delta t) x + f(\Delta t_0 + (n-1)\Delta t). \quad (6)$$

As the outputs of the distributor of the decoder are numbered in reverse order according to the order of output numbers of distributor of the coder, the following relations hold:

$$a_{n-k} = \overline{b_k}, \quad k = \overline{0, n-1}. \quad (7)$$

At the COFDM-modulation information is transmitted symbol by symbol. The number of bits included in one OFDM-symbol is determined by the modulation mode. At QPSK it is 2 bits, at 16-QAM - 4 bits, at 64-QAM - 6 bits, at 256-QAM - 8 bits. Therefore, in the description of the code series for OFDM-symbol the degree of the polynomial depends on the applied modulation mode:

$$y(x, t) = f(\Delta t_0) x^{k(n-1)} + f(\Delta t_0 + \Delta t) x^{k(n-2)} + \dots + \dots + f(\Delta t_0 + k(n-2)\Delta t) x + f(\Delta t_0 + k(n-1)\Delta t), \quad (8)$$

where  $k$  is the number of bits constituting OFDM-symbol.

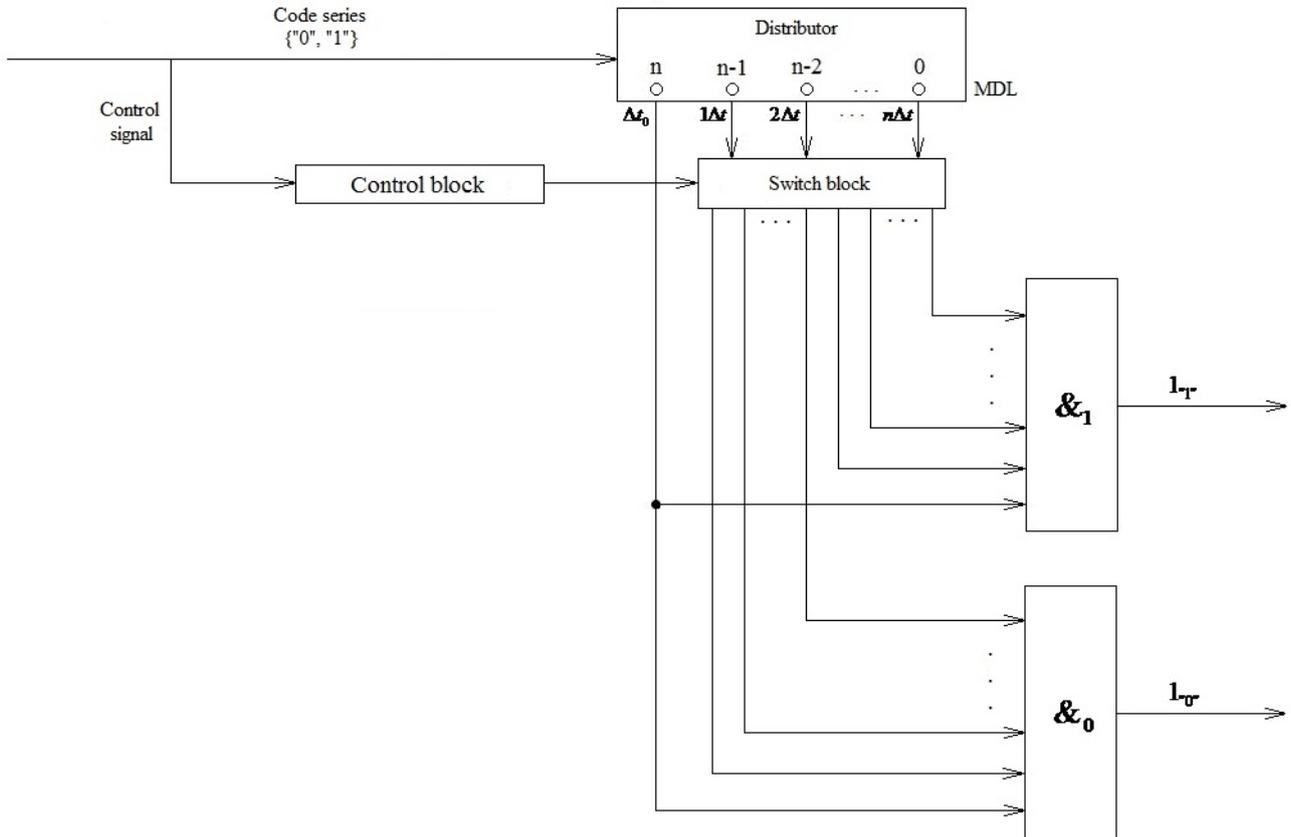


Fig. 4. Block diagram of decoder with code signal sign with (n+1)-bit distributor on MDL

Mathematical description (8) is universal for any mode of COFDM-modulation.

Research [8, 9] has shown that the use of codecs with code signal sign can significantly reduce inter-symbol guard intervals, and in some cases completely eliminate them completely from the transport stream. Besides, the proposed variant of the principle of self-synchronization has advantages in comparison with other known methods of its implementation.

Codecs with code signal sign can also be used to transmit information about the operating points (symbols) of the modulation constellation. In this case, each operating point is assigned to a certain number - the number of point (for example, for QPSK - from 1 to 4, for 16-QAM - from 1 to 16, for 256-QAM - from 1 to 256). Coder generates code series corresponding to the numbers of transmitted symbols. On the receiving side numbers of transmitted symbols are reduced by code series and coordinates of adopted operating points are calculated. Thus, there is no need to transfer information by analog signals.

Implementation of codecs with code signal sign and distributors on MDL is possible in the case of using of non-binary (in general –  $K$ -ary) channel alphabet. In this case, coder generates  $K$  code series (each series from a corresponding output chain “OR” – “AND”); control unit generates  $K$  control actions. According to this fact the schemes of codecs are converted.

## RESULTS

The main results of work are:

- new possibilities and advantages of using rotated modulation constellation;
- implementation of the principle of self-synchronization on base of codecs with code signal sign for using binary and non-binary codes;
- significant reduction of inter-symbol guard interval using codecs with code-signal sign;
- possibility of transmitting and decoding of information about the operating points of the modulation constellation which are presented by code series of signal with code signal sign without using the analog signals.

According to the results of modeling, the probability of false receiving in systems with codecs with code signal sign is reduced by one to two orders in comparison to traditional options of QAM/COFDM codecs in conditions of action high-intensity noise.

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