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Optimum Coherent and Incoherent Demodulators of BPSK and DBPSK Radio Signals with Manchester Encoding

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Algorithms and schemes of optimal coherent and incoherent demodulators of binary radio signals with phase and differential phase shift-keying (DPSK) with Manchester encoding of the modulating signal are proposed. The use of DPSK makes it possible to effectively deal with the phase ambiguity of the reference oscillation generator of the correlation receiver. This solution allows you to overcome the so-called «reverse work» effect in the demodulator of signal with phase-shift keying. Differential and Manchester encoding finds it's application in various areas of use of digital systems for information transmission (DSIT): from local and personal area networks, to space optical communication systems. There are many types of DSIT: radio communication systems (in the Bluetooth standards, in NFC technology, as well as in high-resolution space remote sensing (SRS)), wired data transmission systems (in the local area networks of the Ethernet family), so are optical communication systems (FSO, ISOWC and SpaceWire). It's shown that the joint use of DPSK and Manchester encoding provides higher noise immunity when used in DSIT and retain the advantages of Manchester encoding with respect to symbolic synchronization of the demodulator. The given algorithms and schemes are based on the use of reception in general and the features of Manchester encoding, which allows using the full energy of the information bit for demodulation. To assess the potential noise immunity of the proposed demodulator schemes, it's assumed that the modulated signals are orthogonal in the amplified sense. The conducted mathematical modeling of the proposed technical solutions confirmed their operability and higher noise immunity compared to the symbol-by-symbol reception. It's proposed to use the developed algorithms and schemes of demodulators in the receivers of the SRS with high resolution, in the receivers of optical communication systems and in the receiving part of the equipment of local networks of the Ethernet family.

Keywords: Manchester encoding; BPSK; DBPSK; Ethernet; reception in general; symbol-by-symbol reception; soft decision making; orthogonal in the amplified sense signal

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Introduction

In the development of digital systems for information transmission (DSIT), the main issues to be solved are the choice of signals that provide maximum noise immunity and a specified information rate for a given channel [1]. As it is commonly known, the maximum noise immunity is provided by opposite signals, for which the cross-correlation coefficient is equal to -1. Such signals can be generated by using phase-shift keying with a phase difference 180°.

However, in spite of the high noise immunity of binary phase-shift keying (BPSK), its direct application in DSIT is associated with significant difficulties. They are caused by the need to generate a coherent reference oscillation for the demodulator of the correlation receiver. It is also known that all possible schemes used for the generation such an oscillation are characterized by the phase ambiguity of the output signal which causes the so-called «reverse work» effect. Therefore, in practice, differential phase shift-keying (DPSK) is often used instead of phase-shift keying.

Due to its qualities, differential encoding of the modulation signal most often finds its application in local and personal area networks, satellite radio relay and other DSIT. In general, differential encoding can be used for different types of phase shift-keying. For example, it is known that the popular Bluetooth standard implements such types of phase shift-keying as $\pi/4$-DQPSK ($\pi/4$-shifted Differential Quadrature Phase-Shift Keying) and 8-DPSK [2, 3]. Another example describes that DPSK is used in a space-borne sensor called the Advanced very-High-Resolution Radiometer (AVHRR), as well as a simpler version the sensor with High-Resolution Picture Transmission (HRPT) [4]. In the original sources of the AVHRR

HRPT, this type of modulation is called Digital Split Phase Modulation.

It is known that a special case of BPSK is Manchester encoding [5]. In this case, the information symbols controls the phase of a square wave carrier whose frequency is the data rate. At the same time, information symbols are encoded with a pair of Manchester symbols. In this regard, the idea of differential encoding, phase shift-keying and Manchester encoding should be considered in tandem to combine their qualities when used in DSIT.

However, an analysis of recent publications on the described topic indicates an increase in trends in research and development of free space optics (FSO) technology [6–8]. One of the most important applications of FSO technology is the possibility of its use in satellite applications. Among such systems, the inter-satellite optical wireless communication (IsOWC) system is known [7, 8]. The use of DPSK with Manchester encoding in IsOWC makes it possible to improve the quality performance of the system, in particular, to provide low power, compact size etc [7]. Differential Manchester encoding finds its application as an optional coding scheme for the SpaceWire telecommunications network for spacecraft [9].

In addition to the above areas of application, differential Manchester encoding is proposed to be used in semi-coherent and incoherent detectors of the communication system with backscattering of the environment. It is known that ambient backscatter communication is a newly emerged paradigm, which regarded as a promising solution for enabling large-scale deployment of future Internet of Things networks [10]. Besides that, in the article [11] proposes a novel method of Manchester encoding using the adiabatic technique logic in NFC (Near Field Communication) passive tags for energy consumption minimization. The proposed method can bring large interrogation range, increase security and maximizes the reader's battery life.

Thus, the topic of this article remains relevant in the development of systems for information transmission in various areas of application. let us move on to the statement of the research problem.

1 Statement of the problem

The theory of optimum coherent and incoherent reception of BPSK and binary DPSK (DBPSK) signals is described in sufficient detail in [1, 12, 13]. In known studies, optimum reception algorithms are considered for bipolar representation of the modulating binary non-return-to-zero signal (NRZ encoding) [5]. One of the disadvantages of NRZ encoding is the lack of self-synchronization properties: for long sequences of same symbols (logical ones or zeros) NRZ signal does not change. It's also known that the use of Manchester encoding for the envelope of BPSK or DBPSK radio signals in DSIT provides significant advantages for generating symbolic synchronization signals for the demodulator, since the spectrum of the modulating signal in this case contains a harmonic component that coincides in frequency with the bit rate and has good self-synchronization properties [8].

In turn, the use of Manchester encoding for each information bits assumes the formation of two symbols of half the duration, which causes the expansion of the signal spectrum and requires the bandwidth double increasing of the channel. It should be also noted that in the case of optimum symbol-by-symbol reception of such a signal, the signal-to-noise ratio (SNR) will be twice lower and will reduce immunity. It follows from the above that there is a task of developing such coherent and incoherent algorithms for optimum demodulation of radio signals with Manchester encoding, which are received using the full energy of the information bit, but it remains possible to realize their advantages regarding the formation of symbol synchronization signals.

2 Analysis of recent research and publications

The algorithms of optimum reception using all energy of an information bit with Manchester encoding of an envelope can be created, using not symbol-by-symbol reception, but the reception of the information bit as a whole including two symbol.

In addition, Manchester encoding can be considered as the use of error-correcting code with duplicated number of elements (correlation code). However, such a block code only makes it possible the detection of errors under symbol-by-symbol reception. In this case, the losses of energy of the information's bit can be reduced by implementing decoding in a broad sense with soft decision-making, combining demodulation and decoding operations [14]. A variant of such a solution of the problem using Manchester encoding is proposed in [15].

3 Purpose and objectives of research

The research task is to develop coherent and incoherent algorithms for optimum demodulation of BPSK and DBPSK radio signals in order to increase the immunity of DSIT and maintain the advantages of Manchester encoding. It is also necessary to assess the potential noise immunity of the developed demodulation algorithms using known approaches on this issue.

4 Results

Consider the problem of distinguishing two (binary) deterministic signals. Assume that the signal $s_1(t)$

represents the binary symbol «1», and the signal $s_0(t)$ represents the symbol «0».

According to the accepted assumptions the mathematical model of the signal at the receiver input

$$y(t) = A\, s_1(t) + (1-A)\, s_0(t) + n\,(t)\,,\ 0 \leqslant t \leqslant T, \quad (1)$$

where A is an unknown parameter that can take one of two values: $A=1$ (transmitted signal $s_1(t)$) and $A=0$ (transmitted signal $s_0(t)$); $n(t)$ is an interference in the form of additive white Gaussian noise; T is the duration of information's bit.

The model of the received signal (1) suggest that at the input of the receiver there is one of two possible signals of the same duration and energy it is not known which ($s_1(t)$ or $s_0(t)$). To simplify the problem, it is assumed that the a priori probabilities of the presence of each of them are assumed to be known.

The received realization $y(t)$ shall be used for finding the value of the parameter A^*, i.e. for finding out which of the signals — $s_1(t)$ or $s_0(t)$ — is present in the realization (1). In other words, the task is testing two hypotheses: hypothesis H_0 — the realization $y(t)$ contains $s_1(t)$, i.e. $A^*=1$; hypothesis H_1 — the realization contains the signal $s_0(t)$, i.e. $A^*=0$.

In this case, the algorithm for optimum coherent reception of signals by the criterion of an ideal observer [12, 13] for the decision on the transmitted signal $s_1(t)$ can be represented as follows:

$$\int_0^T y(t)\, s_1(t)\ dt\ \geqslant \int_0^T y(t)\, s_0(t)\ dt, \quad (2\,\mathrm{a})$$

and for the decision on the transmitted signal $s_0(t)$

$$\int_0^T y(t)\, s_1(t)\ dt\ < \int_0^T y(t)\, s_0(t)\ dt, \quad (2\,\mathrm{b})$$

where $\int_0^T y(t)\, s_i(t)\ dt$ are the correlation integrals, the ratio of which evaluates the parameter A, $i = 0,\, 1$.

Assume that the data are transmitted using BPSK with a phase difference 180°. According to the rule of bitstream encoding by the Manchester code (as per IEEE 802.3 standard [16]), the information symbol «1» (Fig. 1a) is encoded by a sequence of two symbols «0 1» of the Manchester code, and the information symbol «0» is encoded by the sequence of symbols «1 0» (Fig. 1b).

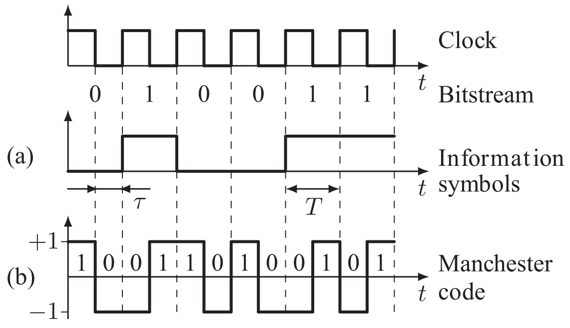

Fig. 1. Bitstream encoding by the Manchester code

Let symbol «0» of the Manchester code corresponds to the elementary signal $-S_0 \cos\omega_0 t$, and the symbol «1» corresponds to $S_0 \cos\omega_0 t$. Then the information symbols «1» and «0» will correspond to the signals $s_1(t)$ and $s_0(t)$ which are sequences of two elementary signals in the interval $[0,\, T]$ which can be represented as follows:

$$s_1(t) = \begin{cases} -S_0 \cos\omega_0 t, & 0 < t < T/2; \\ \ \ S_0 \cos\omega_0 t, & T/2 < t < T, \end{cases}$$
$$s_0(t) = \begin{cases} \ \ S_0 \cos\omega_0 t, & 0 < t < T/2; \\ -S_0 \cos\omega_0 t, & T/2 < t < T, \end{cases} \quad (3)$$

where S_0 is the signal amplitude.

Taking into account (3), the algorithm of optimum coherent reception (2) can be represented as follows:

$$\begin{array}{ll} X - Y\ \geqslant\ 0, & \textit{transmitted signal}\ s_1(t)\,; \\ X - Y\ <\ 0, & \textit{transmitted signal}\ s_0(t)\,, \end{array} \quad (4)$$

where to reduce the formula X and Y are denoted as

$$X = \int_{T/2}^{T} y(t)\cos\omega_0 t\, dt; \quad Y = \int_0^{T/2} y(t)\cos\omega_0 t\, dt. \quad (5)$$

X, Y are the correlation integrals which are determined on intervals $[T/2,\, T]$ and $[0,\, T/2]$ with a duration of $\tau = T/2$, respectively (Fig. 1).

The block diagram of the coherent demodulator which implements the algorithm (4) is shown in Fig. 2. In addition to the multiplier and integrator which calculate the value of the correlation integral on the duration of the Manchester code symbol $\tau = T/2$, the scheme contains a carrier regenerator (CR), a symbol synchronization device (SSD), a delay line on $T/2$, subtractor and a decision-making device (DMD) for the transmitted data symbol. DMD makes a decision in accordance with the signal sign at the output of the subtractor at the end of the moment T of the signal. The positive sign corresponds to the transmitted signal $s_1(t)$, and the negative corresponds to $s_0(t)$.

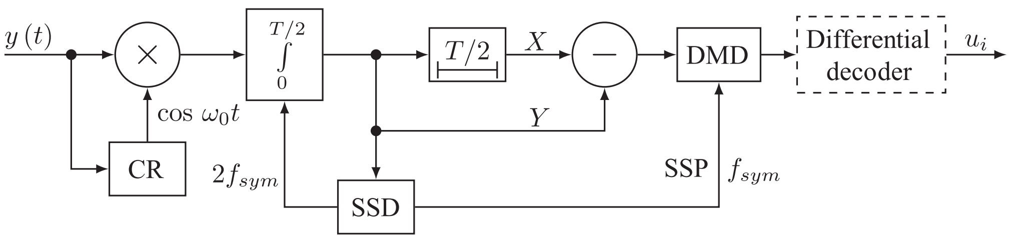

Fig. 2. Block diagram of the optimum coherent demodulator of BPSK (DBPSK) signals with Manchester encoding (differential Manchester encoding)

CR shown in Fig. 2 restores the continuous carrier and can be built according to the known schemes of phase synchronization devices based on Pistolkors, Siforov, Costas [1,5,17]. The integrator performs current integration within $0 \ldots T/2$. The SSD generates symbol sync pulses (SSP) with a frequency $f_{sym} = 1/T$ which determine the time moments of DMD operation. They are also used to reset the integrator (after doubling the f_{sym}). A demodulated sequence of symbols u_i is formed at the DMD output.

To assess the potential noise immunity of a coherent demodulator, we can use the general formula for optimum reception of BPSK signals [5, 13], in which the signals (3) are orthogonal in the amplified sense.

It is worth noting that the orthogonality condition in an amplified sense can be represented in a general form [13, 18] using analytical signals

$$\int_0^T \boldsymbol{S_l}(t)\, \boldsymbol{S_k^*}(t)\; dt = 0, \qquad (6)$$

where $\boldsymbol{S_l}(t) = s_l(t) + j\tilde{s}_l(t)$, $\boldsymbol{S_k}(t) = s_k(t) + j\tilde{s}_k(t)$ are analytical signals; $\boldsymbol{S_k^*}(t) = s_k(t) - j\tilde{s}_k(t)$ is a function complex conjugate with $\boldsymbol{S_k}(t)$; $\tilde{s}_l(t)$, $\tilde{s}_k(t)$ are the Hilbert-transformed signals $s_l(t)$, $s_k(t)$, respectively; T is the duration of signals $\boldsymbol{S_l}(t)$ and $\boldsymbol{S_k}(t)$.

Then, according to (2) and taking into account the SNR q^2, the ratio of the signal energy in the interval of the information's bit T to the noise spectral density N_0, the potential noise immunity of the coherent demodulator of BPSK signals can be represented as

$$P_{err} = \frac{1}{2}\mathrm{erfc}\left(\sqrt{q^2}\right) = \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right), \qquad (7\,\mathrm{a})$$

where $\mathrm{erfc}\,(x) = \frac{2}{\sqrt{\pi}} \int\limits_x^\infty e^{-t^2}\, dt$ is the complementary error function; $q^2 = E_b/N_0$, $E_b = 2E_s = P_s T$ is signal energy per information's bit; E_s is the energy of the Manchester code symbol; $P_s = 0{,}5\, S_0^2$ is the signal power.

It should be noted that various variations of interconnected formulas for calculating the probability of error based on the Gaussian probability distribution are known [1]. However, it is more convenient to use the formula $\mathrm{erfc}\,(x)$ due to its presence in known software packages for mathematical calculations. Therefore, this article will use just such a variant of the error function.

The scheme shown in Fig. 2 can also be used for coherent demodulation of DBPSK signals if a differential decoder is added to its output, as shown by dashed line in Fig. 2. In this case the probability of error caused by the presence of a decoder at the demodulator output will increase approximately twice [5, 13] and can be calculated by the formula

$$P_{err} = \mathrm{erfc}\left(\sqrt{q^2}\right). \qquad (7\,\mathrm{b})$$

The signals encoded by the Manchester code can also be received as a whole in channels with slow fluctuations of an initial phase of signals when the DBPSK is used. As result, we obtain the scheme of the optimum incoherent demodulator using the approach proposed in [13].

DBPSK assumes the bitstream encoding by differential Manchester code. This method is used by IEEE 802.5 specification for Token Ring LAN [2].

The rules for encoding with the Manchester code are presented in Fig. 3. The information symbol «1» of the bitstream (Fig. 3a) is encoded by a sequence of two Manchester code symbols that are inverted relative to the previous two symbols, and the information symbol «0» is encoded by a sequence of two Manchester code symbols that coincide with the previous two symbols (Fig. 3b).

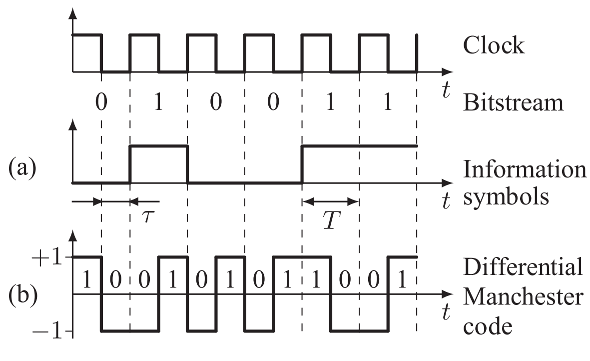

Fig. 3. Differential encoding of the bitstream by the Manchester code

So, in case of DBPSK, the values of the transmitted information symbol are determined not by the two symbols of the Manchester code themselves in the time interval $[0,\, T]$, but by a sequence of four symbols of the Manchester code in the interval $[0,\, 2T]$.

Let symbol «0» of the Manchester code correspond to the elementary signal $-S_0 \cos \omega_0 t$, and the symbol «1» to $S_0 \cos \omega_0 t$. Then the information symbols «1» and «0» correspond to the signals $s_1(t)$ and $s_0(t)$ which are sequences of four elementary signals in the interval $[0,\, 2T]$. The information symbols «1» and «0» correspond to the signals transmission

$$s_1(t) = \begin{cases} S_0 \cos(\omega_0 t + \varphi), & 0 < t < T/2; \\ -S_0 \cos(\omega_0 t + \varphi), & T/2 < t < 3T/2; \\ S_0 \cos(\omega_0 t + \varphi), & 3T/2 < t < 2T, \end{cases}$$
$$s_0(t) = \begin{cases} -S_0 \cos(\omega_0 t + \varphi), & 0 < t < T/2; \\ S_0 \cos(\omega_0 t + \varphi), & T/2 < t < T; \\ -S_0 \cos(\omega_0 t + \varphi), & T < t < 3T/2; \\ S_0 \cos(\omega_0 t + \varphi), & 3T/2 < t < 2T, \end{cases} \qquad (8)$$

where φ is a random initial phase with a uniform distribution.

The algorithm of optimum incoherent reception for two signals of equal duration and equal energy with random initial phases against the background of white Gaussian noise with constant spectral density assumes calculating the square of the modulus of the correlation integral for each signal [13] and comparing their values:

$$\begin{aligned} Z_1^2 &\geqslant Z_0^2, \quad \textit{transmitted signal } s_1(t)\,; \\ Z_1^2 &< Z_0^2, \quad \textit{transmitted signal } s_0(t)\,, \end{aligned} \qquad (9)$$

where

$$Z_1^2 = \left[\int_0^{T_s} y(t)\, s_1(t)\; dt\right]^2 + \left[\int_0^{T_s} y(t)\, s_1^*(t)\; dt\right]^2, \qquad (10\,\text{a})$$

$$Z_0^2 = \left[\int_0^{T_s} y(t)\, s_0(t)\; dt\right]^2 + \left[\int_0^{T_s} y(t)\, s_0^*(t)\; dt\right]^2, \qquad (10\,\text{b})$$

$s_i^*(t)$ is the Hilbert-transformed signal $s_i(t)$, $i = 0,\, 1$; $T_s = 2T = 4\tau$ is the signal duration.

Taking into account (8) and (10), the algorithm for optimum incoherent reception (9) of DBPSK signals with differential Manchester encoding for the decision on the transmitted signal $s_1(t)$ will be presented in formula

$$\begin{aligned} Z_1^2 = &\left[\int_0^{T/2} y(t)\cos\omega_0 t\, dt - \int_{T/2}^{T} y(t)\cos\omega_0 t\, dt - \int_{T}^{3T/2} y(t)\cos\omega_0 t\, dt + \int_{3T/2}^{2T} y(t)\cos\omega_0 t\, dt\right]^2 + \\ + &\left[\int_0^{T/2} y(t)\sin\omega_0 t\, dt - \int_{T/2}^{T} y(t)\sin\omega_0 t\, dt - \int_{T}^{3T/2} y(t)\sin\omega_0 t\, dt + \int_{3T/2}^{2T} y(t)\sin\omega_0 t\, dt\right]^2 \geqslant Z_0^2 = \\ = &\left[-\int_0^{T/2} y(t)\cos\omega_0 t\, dt + \int_{T/2}^{T} y(t)\cos\omega_0 t\, dt - \int_{T}^{3T/2} y(t)\cos\omega_0 t\, dt + \int_{3T/2}^{2T} y(t)\cos\omega_0 t\, dt\right]^2 + \\ + &\left[-\int_0^{T/2} y(t)\sin\omega_0 t\, dt + \int_{T/2}^{T} y(t)\sin\omega_0 t\, dt - \int_{T}^{3T/2} y(t)\sin\omega_0 t\, dt + \int_{3T/2}^{2T} y(t)\sin\omega_0 t\, dt\right]^2 . \end{aligned} \qquad (11)$$

By performing simple transformations and reductions in (11) and using the following notation:

$$\begin{aligned} X_n &= \int_{(n-1)\,T/2}^{n\,T/2} y(t)\cos\omega_0 t\, dt; \\ Y_n &= \int_{(n-1)\,T/2}^{n\,T/2} y(t)\sin\omega_0 t\, dt, \end{aligned} \qquad (12)$$

where $n = 1,\, 2,\, 3,\, 4$ is the symbol number of the Manchester code in the interval $[0,\, 2T]$, we get the algorithm for optimum incoherent reception of DBPSK signals with differential Manchester encoding in a simplified form. For the decision on the transmitted signal $s_1(t)$ algorithm can be represented as follows:

$$Z_1^2 - Z_0^2 = V_a - V_b \;\geqslant\; 0, \qquad (13\,\text{a})$$

and for the decision on the transmitted signal $s_0\,(t)$

$$Z_1^2 - Z_0^2 = V_a - V_b \;<\; 0, \qquad (13\,\text{b})$$

where to reduce the formula V_a and V_b are denoted as

$$\begin{aligned} V_a &= (X_1 X_4 + X_2 X_3) - (X_1 X_3 + X_2 X_4)\,; \\ V_b &= (Y_1 Y_3 + Y_2 Y_4) - (Y_1 Y_4 + Y_2 Y_3)\,. \end{aligned} \qquad (14)$$

It should be noted that the sequence of symbols of the differential Manchester code can be the inverse of the encoding example, which in Fig. 3b. Inversion of symbols can occur when an even number of symbols «1» is presented in the bitstream. It can be assumed that such a situation should affect the results obtained when constructing the algorithm described above. However, as calculations show, formulas (13)-(14) will not change from the inversion of signals (8). This indicates the invariance of the developed algorithm from the inversion of the sequence of Manchester code symbols.

So, on the basis of the proposed algorithm (13), it is possible to construct a block diagram of an incoherent demodulator of DBPSK signals with differential Manchester encoding (Fig. 4).

The scheme (Fig. 4) includes an in-phase channel that calculates the value of V_a and a quadrature channel that calculates the value of V_b in accordance with (14) on an interval of four elementary symbols of the Manchester code $[0, 2T]$. Channel integrators calculate the values of correlation integrals (12) periodically on the interval of the duration of the Manchester code symbol $\tau = T/2$. Components X_1 and Y_1 are formed immediately from the output of the integrators, and components X_2; Y_2, X_3; Y_3 and X_4; Y_4 are obtained from the outputs of three series-connected delay line on $T/2$. In addition, for direct calculate the values of V_a and V_b multipliers, adders and subtractors are used in the scheme. From the output of the last subtractor voltage is formed, which is proportional to the difference $V_a - V_b$. DMD functions in the same way as in the scheme of the coherent demodulator (Fig. 2) make a decision according to the signal sign at the output of the subtractor. The positive sign corresponds to the transmitted signal $s_1(t)$, but the negative to $s_0(t)$. The SSD (does not shown in Fig. 4) generates SSP with a frequency $f_{sym} = 1/T$ which determines the time moments of DMD decision-making to reset the integrators (after doubling the f_{sym}).

From analysis (8) and (11) it follows that the decision on the transmitted signal will not be affected by the random initial phase. Therefore, in the scheme of an incoherent demodulator, the oscillation generator with the carrier frequency ω_0 must be independent.

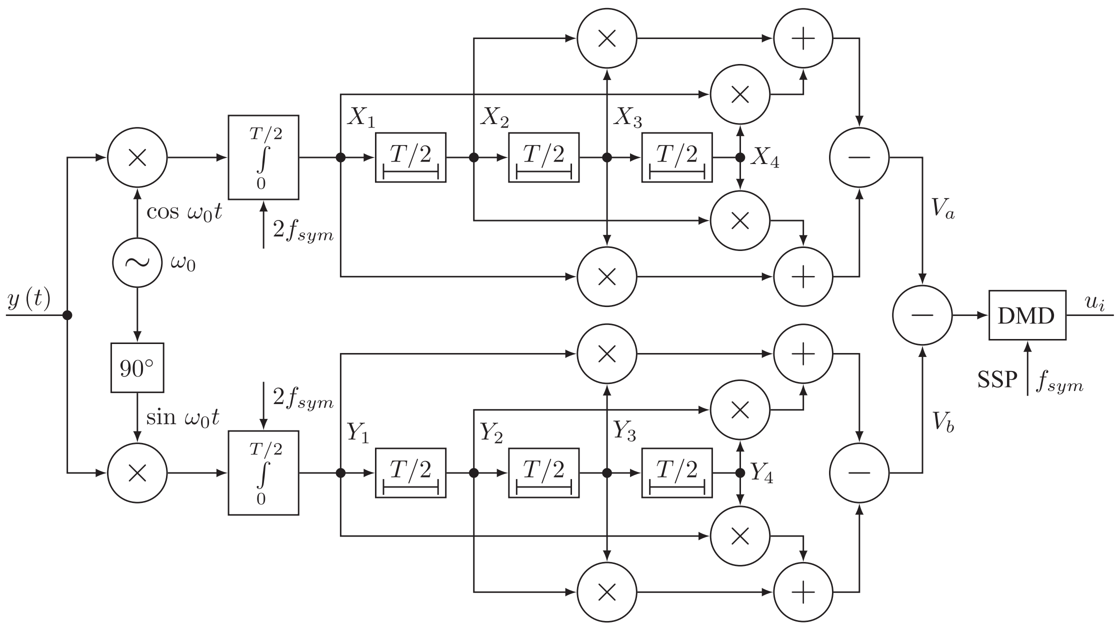

Fig. 4. Block diagram of the optimum incoherent demodulator of DBPSK signals with differential Manchester encoding

To assess the potential noise immunity of an incoherent demodulator of DBPSK signals, the general formula for their optimum reception can be used, given that the signals (8) are also orthogonal in the amplified sense according to (6). Then, according to (10), taking into account the SNR q^2, the ratio of the signal energy in the interval of the information bit T to the noise spectral density N_0, the potential noise immunity of the incoherent demodulator of DBPSK signals with differential Manchester encoding can be determined as

$$P_{err} = \frac{1}{2}\, e^{-q^2}. \tag{15}$$

To verify the operability of the developed demodulator schemes and evaluate their potential noise immunity, mathematical modeling was performed using virtual demodulators developed on a PC in the LabVIEW 2020 development environment for a visual programming. Modeling confirmed the operability of the proposed schemes of the demodulators of signals with Manchester encoding and the possibility of using formulas (7) and (15) to assess their potential noise immunity.

The calculation of results and modeling data are shown in Fig. 5a for the coherent demodulator and in Fig. 5b for the incoherent demodulator of DBPSK signals with differential Manchester encoding.

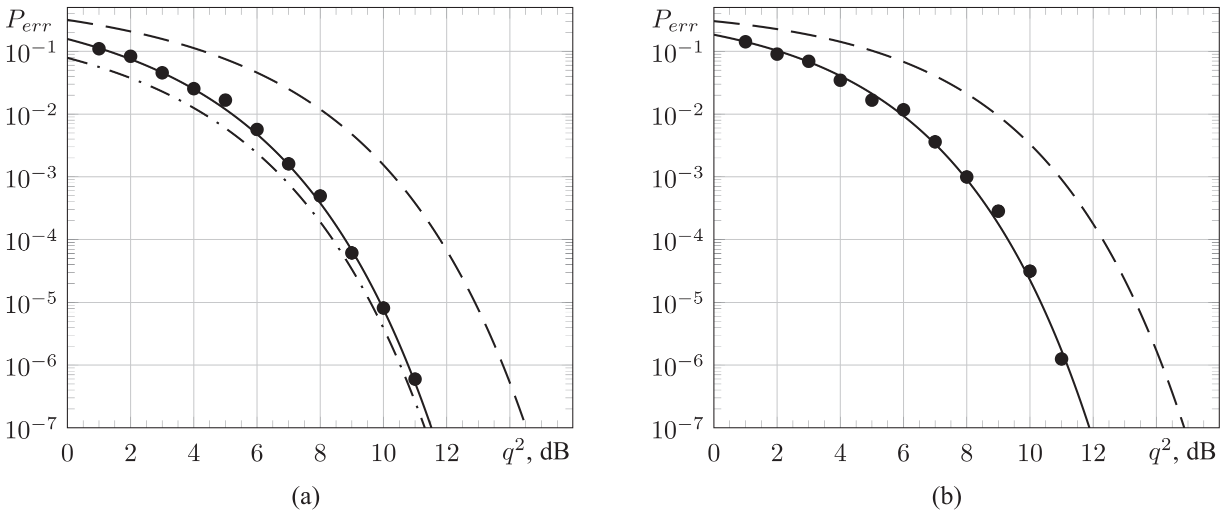

Fig. 5. Curves of potential noise immunity of coherent (a) and incoherent (b) reception of BPSK signals with Manchester encoding and DBPSK signals with differential Manchester encoding

Fig. 5a additionally shows calculations for the coherent reception of BPSK signals with Manchester encoding (dash-dotted line). The dashed lines correspond to the symbol-by-symbol reception of information bits of the Manchester code, the dash-dotted line correspond to calculation by the formula (7 a), the solid lines correspond to calculations by the formulas (7 b) and (15), respectively, and markers correspond to modeling results.

From the analysis of the obtained graphs it follows that the modeling results confirm the expected potential gain of 3 dB of energy for the proposed demodulator schemes compared to symbol-by-symbol reception of information bits of the Manchester code.

Conclusions

The implementation of decoding in a broad sense with soft decision making, in which the operations of demodulation and decoding are combined, makes it possible to reduce the bit losses of energy for the proposed demodulators compared to symbol-by-symbol processing of signals with Manchester encoding.

The obtained results allow us to assert that the proposed schemes of demodulators can be used as part of the receiving devices of DSIT, in particular to increase the noise immunity of the IsOWC and the receiving devices SpaceWire telecommunications networks for spacecraft. Also, the above demodulators schemes can be used in other DSITS that use DBPSK with Manchester encoding.

In addition, taking into account the using of Manchester encoding in a family of wired networking technologies known as Ethernet [2, 16], the proposed algorithms can be modified into low-frequency demodulation algorithms by replacing the elementary radio signals $-S_0 \cos \omega_0 t$ and $S_0 \cos \omega_0 t$ with bipolar signals.

The prospects for further research in this area are associated with the possibility of using other known methods of encoding the modulating signal, in particular, it's worth paying attention to such types of encoding as 3B/4B, 8B/10B and 64B/66B.

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Оптимальні когерентні й некогерентні демодулятори ФМ-2 та ВФМ-2 радіосигналів із манчестерським кодуванням

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Запропоновані алгоритми та схеми оптимальних когерентних і некогерентних демодуляторів бінарних радіосигналів із фазовою і відносною фазовою маніпуляцією (ВФМн) та манчестерським кодуванням модулюючого сигналу. Використання ВФМн дозволяє ефективно боротися із фазовою неоднозначністю генератора опорного коливання кореляційного приймача. Дане рішення дозволяє подолати так званий ефект «зворотної роботи» в демодуляторі фазоманіпульованих сигналів. Відносне і манчестерське кодування знаходить своє застосування в різних областях використання цифрових систем передавання інформації (ЦСПІ): від локальних і персональних обчислювальних мереж до космічних оптичних систем зв'язку. Серед таких ЦСПІ можна виділити як системи радіозв'язку (в стандартах Bluetooth, в технології NFC, а також в космічних системах дистанційного зондування Землі (ДЗЗ) з високою роздільною здатністю), дротові системи передавання даних (в локальних мережах сімейства Ethernet), так і оптичні системи зв'язку (FSO, IsOWC i SpaceWire). Показано, що спільне використання ВФМн і манчестерського кодування забезпечує більш високу завадостійкість при застосуванні в ЦСПІ і зберігає переваги манчестерського кодування стосовно символьної синхронізації демодулятора. Наведені алгоритми і схеми ґрунтуються на використанні прийому в цілому і особливостей манчестерського кодування, що дозволяє застосовувати для демодуляції повну енергію бітової посилки. Для оцінки потенційної завадостійкості запропонованих схем демодуляторів прийнято, що модульовані сигнали є ортогональними в посиленому розумінні. Проведене математичне моделювання запропонованих технічних рішень підтвердило їх працездатність та більш високу завадостійкість порівняно із посимвольним прийманням. Пропонується використовувати розроблені алгоритми і схеми демодуляторів в приймачах систем ДЗЗ високої роздільної здатності, в приймачах оптичних систем зв'язку і в приймальній частині обладнання локальних мереж сімейства Ethernet.

Ключові слова: манчестерське кодування; ФМ-2; ВФМ-2; Ethernet; приймання в цілому; посимвольне приймання; м'яке прийняття рішень; ортогональні сигнали в посиленому розумінні

Оптимальные когерентные и некогерентные демодуляторы ФМ-2 и ОФМ-2 радиосигналов с манчестерским кодированием

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Предложены алгоритмы и схемы оптимальных когерентных и некогерентных демодуляторов бинарных радиосигналов с фазовой и относительной фазовой манипуляцией (ОФМн) и манчестерским кодированием модулирующего сигнала. Использования ОФМн позволяет эффективно бороться с фазовой неоднозначностью генератора опорного колебания корреляционного приёмника. Данное решение позволяет преодолевать так называемый эффект «обратной работы» в демодуляторе фазоманипулированных сигналов. Относительное и манчестерское кодирование находит свое применение в разных областях использования цифровых систем передачи информации (ЦСПИ): от локальных и персональных вычислительных сетей до космических оптических систем связи. Среди таких ЦСПИ можно выделить как системы радиосвязи (в стандартах Bluetooth, в технологии NFC, а также в космических системах дистанционного зондирования Земли (ДЗЗ) с высоким разрешением), проводные системы передачи данных (в локальных сетях семейства Ethernet), так и оптические системы связи (FSO, IsOWC и SpaceWire). Показано, что совместное использование ОФМн и манчестерского кодирования обеспечивает более высокую помехоустойчивость при применении в ЦСПИ и сохраняет преимущества манчестерского кодирования касаемо символьной синхронизации демодулятора. Приведенные алгоритмы и схемы основываются на использовании приёма в целом и особенностей манчестерского кодирования, что позволяет применять для демодуляции полную энергию битовой посылки. Для оценки потенциальной помехоустойчивости предложенных схем демодуляторов принято, что модулированные сигналы являются ортогональными в усиленном смысле. Проведенное математическое моделирование предлагаемых технических решений подтвердило их работоспособность и более высокую помехоустойчивость по сравнению с посимвольным приёмом. Предлагается использовать разработанные алгоритмы и схемы демодуляторов в приёмниках систем ДЗЗ высокого разрешения, в приёмниках оптических систем связи и в приёмной части оборудования локальных сетей семейства Ethernet.

Ключевые слова: манчестерское кодирование; ФМ-2; ОФМ-2; Ethernet; приём в целом; посимвольный приём; мягкое принятие решений; ортогональные сигналы в усиленном смысле