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DEVELOPMENT OF METHOD FOR INCREASING SENSITIVITY IN WIRELESS OPTICAL DATA TRANSMISSION CHANNELS IN VISIBLE WAVELENGTH RANGE

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The original method for encoding binary data streams based on QPSK quadrature phase shift keying in a wireless optical communication channel in the visible range is suggested. The algorithm for analyzing signals in the receiving tract is presented. It allows to analyze the presence of two or three pulses of different colors at the input, which will signal the presence of interference or the occurrence of "illumination". In addition, the algorithm provides a possibility of dynamic compensation of external "illumination" by changing the gain of the photodetectors and adjusting the brightness of emitting LEDs. The functional scheme of the device for realization of the offered coding method in the wireless channel on the basis of optical radiation has been developed. Given that most photodiodes are sufficiently wide-band in the visible range of light waves, to increase sensitivity of each color channel and selectivity of the receiving tract it is necessary to apply optical filters for each color channel. The most effective are interference filters made of optically transparent materials with different physical characteristics. The approach for calculating optical filters has been presented.

Keywords: wireless data transmission, optical data transmission channel in the visible wavelength range, encoding based on quadrature phase shift keying, color channel, Li-Fi.

РАЗРАБОТКА СПОСОБА ПОВЫШЕНИЯ ЧУВСТВИТЕЛЬНОСТИ В БЕСПРОВОДНЫХ ОПТИЧЕСКИХ КАНАЛАХ ПЕРЕДАЧИ ДАННЫХ В ВИДИМОМ ДИАПАЗОНЕ СВЕТОВЫХ ВОЛН

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Предложен способ кодирования двоичного потока данных на основе квадратурной фазовой манипуляции QPSK, обладающий высокой скоростью и контролем наличия ошибок в канале передачи данных. Представлен алгоритм анализа сигналов в приемном тракте, позволяющий анализировать присутствие двух или трех импульсов разных цветов на входе, что сигнализирует о наличии помехи или возникновении «засветки». Кроме того, алгоритм обеспечивает возможность динамической компенсации внешней «засветки» путем изменения коэффициента усиления фотоприемников и регулировки яркости излучающих светодиодов. Разработана функциональная схема устройства для реализации предлагаемого способа кодирования в беспроводном канале на основе оптического излучения. Учитывая, что большинство фотодиодов являются достаточно широкополосными в видимом диапазоне световых волн, для повышения чувствительности каждого цветового канала и селективности приемного тракта, предложено использовать оптические фильтры для каждого цветового канала. Наиболее эффективными являются интерференционные фильтры из оптически прозрачных материалов с различными физическими характеристиками. Представлен подход для расчета оптических фильтров.

Ключевые слова: беспроводная передача данных, оптический канал передачи данных в видимом диапазоне длин волн, кодирование на основе квадратурных фазовых манипуляций, цветовой канал, Li-Fi.

Introduction. In order to organize safe data transmission, it is proposed to build a wireless optical channel based on three-component (RGB) LEDs for room lighting and information transmission.

It is known [1] that the human eye is unable to detect pulsations of light flux at a frequency above 100 Hz. Thus, the use of pulse modulation at frequencies from 100 kHz to 10 MHz will allow data transmission and room lighting without harm to health. Additionally, transmission of information over the wireless optical channel allows to precisely determine the perimeter of the protected area to ensure confidentiality of data transmitted [2].

A phase keying-based encoding method. In order to perform secure data transmission over a wireless optical communication channel, a method of encoding information based on quadrature phase keying has been developed. The encoding process is shown in fig. 1. A serial stream of input data bits $I(t)$ is converted into a series of N bit blocks $b_N, b_{N-1}, \ldots, b_1, b_0$, each encoded by an RGB pulse burst. The pulse burst is represented as a set of pulses on each of the color channels during the reference signal period. Coding occurs on the basis of quadrature phase manipulations to four possible conditions of a phase in reference to basic signal (45°, 135°, 225°, 315°) [3]. Thus, the number of color channels $CC = 3$, the number of possible phase states $FC = 4$, the total number of unique combinations according to the rules of combinatorics [4] $M = CC^{FC} = 3^4 = 81$ state.

As a further limitation, it is determined that in one period of reference signal each color channel generates not more than one pulse, and also that in single period there cannot be two or more pulses with the same phase. Thus, the number of unique phase states is defined as

$$M = \prod_{j=0}^{CC-1} (FC - j) = 4 \cdot 3 \cdot 2 = 24. \qquad (1)$$

When encoding binary signals, the number of bits transmitted over the reference signal period is given by

$$M_2 = div\left[\log_2 \prod_{j=0}^{CC-1} (FC - j)\right] = 4. \qquad (2)$$

According to (2), in the case of a binary input data flow $I(t)$, the number of bits in each transmission unit is 4.

The remaining 8 states can be used to transmit overhead messages such as start and end of transmission, error, and data flow control.

Fig. 2 shows the coding diagram of one of the possible states for each of the channels. The dashed line diagram shows the possibility of pulse width modulation (PWM) of luminous flux intensity, which allows to adjust luminance of lighting devices to create comfortable operating conditions or to make adaptive adjustment of luminous flux level from the light source taking into account the change of illumination in the room. Similar technology is offered in [5].

Radiation power control when using LED lighting sources as transmitters has its limitations related to creation of required illumination or compensation of external illumination [6; 7]. Automatic adjustment of the photodetectors sensitivity takes precedence over the power of light sources adjustment, as it allows to adjust it independently to the value of total illumination, and compensate for the constant component from additional light sources.

<table>
<tr><td rowspan="4">$b_3b_2 = "00"$
$\varphi_R = 45°$</td><td rowspan="2">for $b_1 = "0"$
$f_1 = \varphi_G(\varphi_R) = 90 - \varphi_R$</td><td>for $b_0 = "0"$
$f_3 = f_1 - 90$</td><td rowspan="4">F_1</td></tr>
<tr><td>for $b_0 = "1"$
$f_3 = f_1 + 90$</td></tr>
<tr><td rowspan="2">for $b_1 = "1"$
$f_2 = \varphi_G(\varphi_R) = 180 - \varphi_R$</td><td>for $b_0 = "0"$
$f_3 = f_2 - 180$</td></tr>
<tr><td>for $b_0 = "1"$
$f_3 = f_2 - 90$</td></tr>
<tr><td rowspan="4">$b_3b_2 = "01"$
$\varphi_R = 135°$</td><td rowspan="2">f_1</td><td>for $b_0 = "0"$
$f_3 = f_1 + 90$</td><td rowspan="4">F_2</td></tr>
<tr><td>for $b_0 = "1"$
$f_3 = f_1 - 90$</td></tr>
<tr><td rowspan="2">f_2</td><td>for $b_0 = "0"$
$f_3 = f_2 + 180$</td></tr>
<tr><td>for $b_0 = "1"$
$f_3 = f_2 - 90$</td></tr>
<tr><td rowspan="2">$b_3b_2 = "10"$
$\varphi_R = 225°$</td><td>f_1</td><td rowspan="2">F_1</td><td rowspan="2"></td></tr>
<tr><td>f_2</td></tr>
<tr><td rowspan="2">$b_3b_2 = "11"$
$\varphi_R = 315°$</td><td>f_1</td><td rowspan="2">F_2</td><td rowspan="2"></td></tr>
<tr><td>f_2</td></tr>
</table>

Fig. 1. The table of phase states of information encoding based on phase manipulations in a channel with spectral division

Рис. 1. Таблица фазовых состояний кодирования информации на основе фазовых манипуляций в канале со спектральным разделением

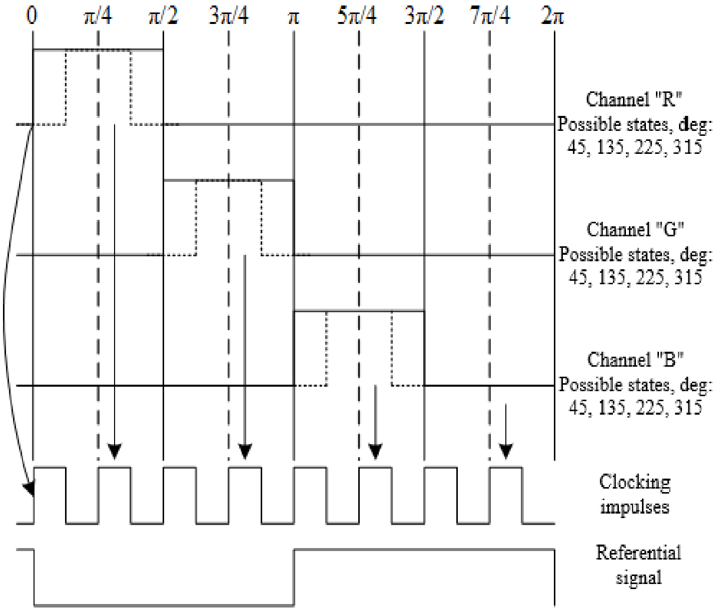

Fig. 2. The diagram of information encoding based on phase manipulations in a channel with spectral division

Рис. 2. Диаграмма кодирования информации на основе фазовых манипуляций в канале со спектральным разделением

Monitoring data link errors. The encoding method assumes that in one reference signal period, each color channel will generate one pulse of equal duration and all three color components will have different phases. Simultaneous presence of two or three pulses of different colors at the input will signal the presence of interference or occurrence of "illumination" – change of intensity of additional natural or artificial lighting [8]. Here, it is necessary to distinguish short-term pulses $\tau \sim 10^{-8} \div 10^{-6}$ c ($\tau \sim 10^{-8} \div 10^{-6}$ c) in three color channels, which are recognized as an error in the active phase of data transmission, or are used for synchronization of receiver and transmitter between data packages, and slowly variable signal ($\tau \sim 10^{-3} \div 10^{1}$ c) at the receiver input, which is a characteristic of illumination with natural or artificial light [9; 10]. When generating sync pulses, simultaneous pulses are proposed on all color channels for phase state $\varphi = 45°$. Fig. 3 shows the flow chart of signal analysis in the receiving tract.

Such method ensures control and possibility of dynamic compensation of external "illumination" by changing the gain of photo-detectors and adjusting the brightness of emitting LEDs.

Functional diagram of fixed and mobile transceiver device. Fig. 4 is a functional diagram of an apparatus for implementing a wireless channel coding method according to the invention based on optical radiation. Input data stream of binary sequence $I(t)$ is supplied to input of digital data processing unit (DDP) [11]. The functions of the DDP unit are to generate a sequence of rectangular pulses for synchronization with the data source, to buffer the input data and control the flow, as well as to convert the sequence of bits into a sequence of four-bit units. The synchronization signal is input to the clock to provide phase locked loop (PLL) [12; 13], and the output data stream enters the input of the serial encoding device (SED). SED operation algorithm implements the table of phase states shown in fig. 1.

Output signals from SED are transmitted to light intensity control units based on PWM, then to current keys of LED control. Receiving side consists of photodetectors (photodiodes) with corresponding optical color filters, signal from which is supplied to input of operational amplifiers (OA) with adjustable gain factor, followed by a signal transmitted to the input of data processing device. The main functions of the DP unit are to generate a rectangular sequence of pulses for synchronizing the receiver and transmitter, as well as to analyze the state of signals of each of the color components (determine an error or "illumination"). Simultaneously, signals from outputs of OA of each color channel are supplied to the input of serial decoding device (SDD) which implements algorithm, reverse to initial one. Output stream of binary sequence data is generated at output of SDD.

Calculation of optical transmission filters. Given that most photodiodes are sufficiently wideband in the visible range of light waves, optical filters for each color channel need to be used to increase sensitivity of each color channel and selectivity of the receiving tract. Interference filters of optically transparent materials with different physical characteristics are considered to be the most effective [14].

Sufficient transmission functions can be obtained using just two different dielectric materials, with refractive indices n_L and n_H. Supposing you want to create a filter that passes the center wavelength λ_0, a general scheme for constructing such filters is to use alternating layers of high and low refractive index dielectric having a thickness of 1/4 or 1/2 wavelength λ_0. The quarter-wave dielectric plate with refractive index n_L should have thickness of $\lambda_0/4n_L$. Since these thicknesses are very small at optical wavelengths, 'thin film' is more commonly used term instead of the term 'plate'. Dielectric thin films half wavelength thick λ_0 are called filter bands. The thin film filter structure used consists of several bands separated by several quarter-wave films. If *H* and *L* denote quarter-wave films (for wavelength λ_0) of high and low refractive index dielectrics, respectively, then we can imagine a design of any filter using an *HL* sequence. Two characters *H* or *L* in a row denote a half-wave film. For example, if the slightly hatched dielectric has a low refractive index and the highly hatched dielectric has a high refractive index, the filter consisting of a number of dielectric films may be represented by the sequence *HLHLLHLH*. If the surrounding dielectrics are indicated by a symbol *G* (glass), the complete structure can be represented by the sequence *GHLHLLHLHG*.

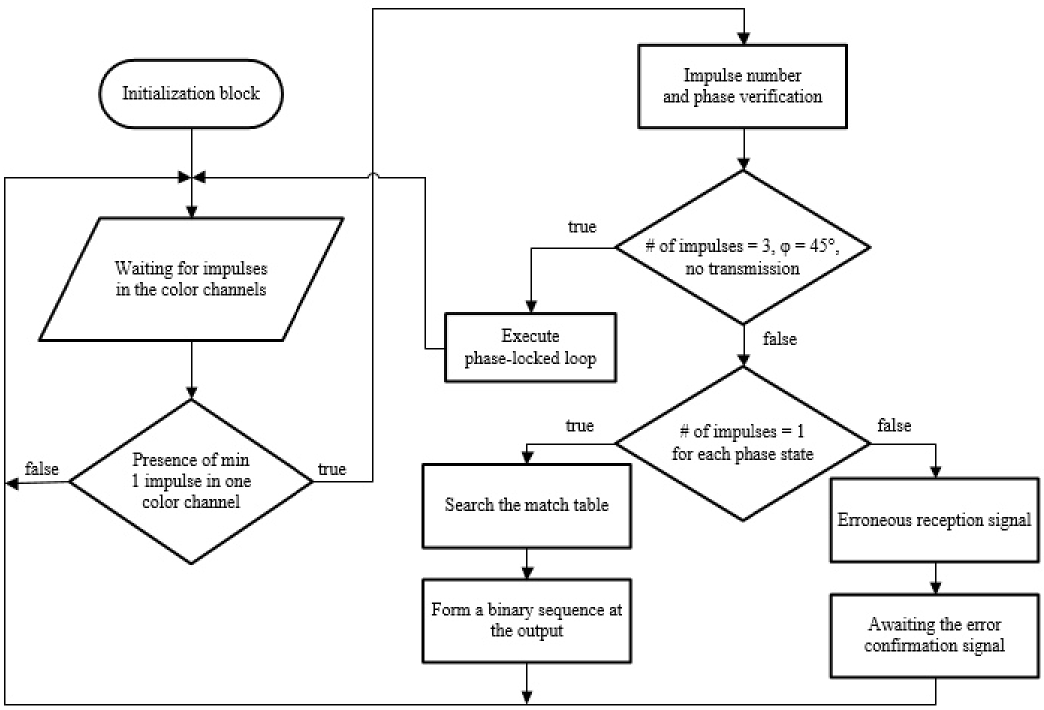

Fig. 3. The algorithm of signal analysis in the receiving tract

Рис. 3. Алгоритм анализа сигналов в приемном тракте

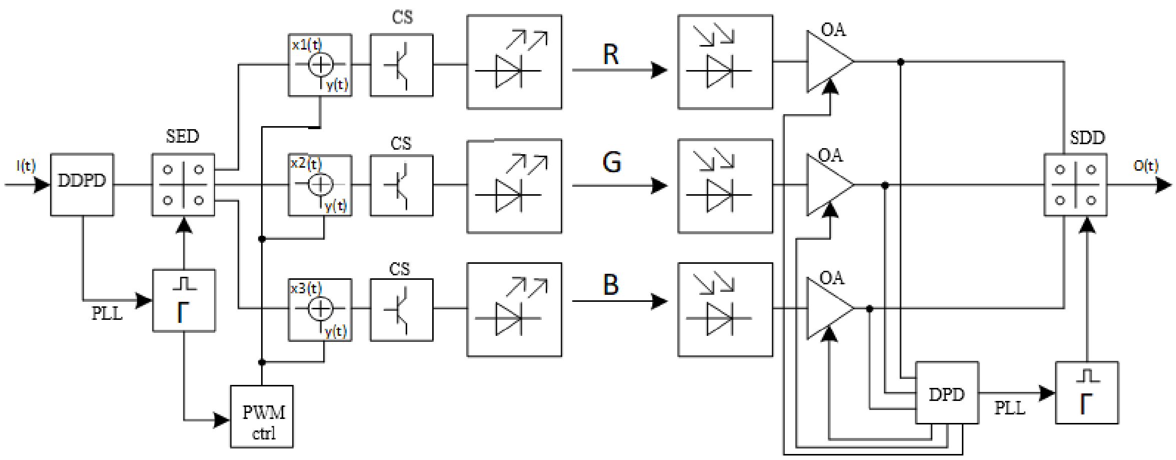

Fig. 4. The functional scheme of the device required to implement the suggested encoding method

Рис. 4. Функциональная схема устройства для реализации предлагаемого способа кодирования

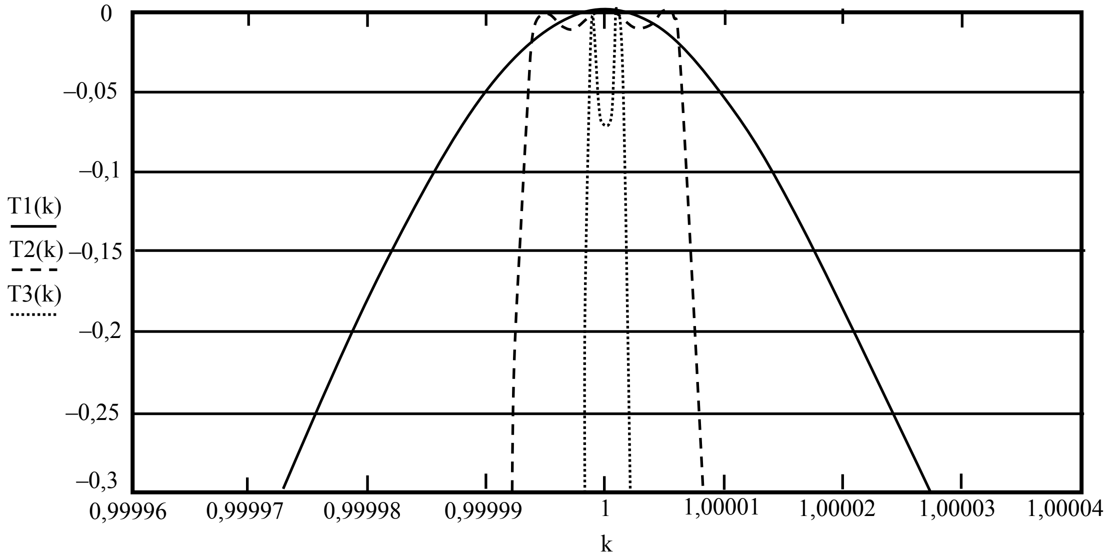

Fig. 5. Comparison of one-, two- and threeband filters

Рис. 5. Сравнение одно-, двух- и трехполостного фильтров

A narrower region of transmission and a stronger suppression of lateral wavelengths can be achieved by using more than three quarter-wave films [15]. As an example, the filter described by a sequence $G(HL)^9 HLL(HL)^9 HG$ is suggested. Marking $(HL)^k$ corresponds to a sequence *HLHL…HL(k* times).

The use of multiple bands results in a flatter bandwidth and a sharp drop at the edges. Both effects are shown in fig. 5, in which the transmission function close to the center wavelength λ_0 is depicted for a one-, two-, and three-band dielectric thin film filter.

One-band filter is similar to the one described above. Two-band filter is described as a sequence

$$G(HL)^{12} HLL(HL)^{24} HLL(HL)^{12} HG .$$

Three-band filter is described as a sequence

$$G(HL)^{10} HLL(HL)^{21} HLL(HL)^{21} HLL(HL)^{10} HG .$$

Conclusion. Among the advantages of the proposed approach are: increase of information transfer speed in wireless channels based on VLC technology; improvement of noise immunity due to the applied coding technology and compensation algorithm of external light source luminance flux change (“illumination”); high channel security against unauthorized access to information implemented by means of distributed spectral coding; and possibility of more efficient filtering of light flux from VLC transmitter in red and blue color bands.

Thus, a method of encoding data in wireless optical communication channels having high noise immunity has been developed.

In order to increase sensitivity of each color channel and selectivity of the receiving tract, it is proposed to use optical filters for each color channel. Interference filters of optically transparent materials with different physical characteristics are the most effective.

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