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Peculiarities of telemetry information transmission using analog fiber-optic communication line over long distances in a complex electromagnetic environment

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Abstract. To implement the environmental monitoring program, it is proposed to use the upper parts of power line towers for the placement of measuring sensors of various kinds. The analysis of possibilities of application of various ways of telemetric information transmission over long distances in the presence of powerful electromagnetic interference is carried out. It was found that the most appropriate in this situation for the transmission of information to use analog fiber-optic communication lines. The use of analog FOCL, which takes into account a number of features we have established the peculiarities of the transmission of analog optical signals, allows you to transmit information at distances greater than 500 km without amplification. According to the results of calculation of the FOCL parameters and experimental studies, the limiting distances for information transmission and the permissible power for the used laser radiation are determined.

Keywords: telemetry information, electromagnetic environment, optical signal, fiber, attenuation, distance, laser radiation power, analog information transmission format, signal-to-noise ratio

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Материалы конференции
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Особенности передачи телеметрической информации с использованием аналоговой волоконно-оптической линии связи на большие расстояния в сложной электромагнитной обстановке

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Аннотация. Для реализации программы экологического мониторинга предлагается использовать верхние части опор линий электропередач для размещения измерительных датчиков различного типа. Проведен анализ возможностей применения различных способов передачи телеметрической информации на большие расстояния при наличии мощных электромагнитных помех. Установлено, что наиболее целесообразно в данной ситуации для передачи информации использовать аналоговые волоконно-оптические линии связи. Использование аналоговой ВОЛС, учитывающей ряд установленных нами особенностей передачи аналоговых оптических сигналов, позволяет передавать информацию на расстояния более 500 км без усиления. По результатам расчета параметров ВОЛС и экспериментальных исследований определены предельные расстояния передачи информации и допустимая мощность используемого лазерного излучения.

Ключевые слова: телеметрическая информация, электромагнитная обстановка, оптический сигнал, волокно, затухание, расстояние, мощность лазерного излучения, аналоговый формат передачи информации, отношение сигнал/шум

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Introduction

The rapid development of mankind has led to a sharp deterioration of the ecological situation on the planet [1–7]. This, in turn, greatly affects the activities of people and the behavior of living organisms [8–10]. In such a situation, environmental monitoring systems that are placed in different parts of the territory become extremely important [11–13]. When placing environmental monitoring complexes in remote from settlements, there are many problems, which are associated with the provision of electric power equipment, its protection from various negative influences and stable transmission of information about the state of the environment in real time over long distances [14–15]. The solution to these problems, in addition to transmitting information, is to place a multifunctional complex for environmental monitoring on top of the power line (transmission line). In this case the information will have to be transmitted in a complex electromagnetic environment. One of the options for solving this problem is the use of fiber optic communication lines (FOCL) [1, 11]. Developed designs of digital fiber-optical communication lines (FOCL) allow information to be transmitted without the use of optical amplifiers for distances up to 500 km. It is proposed to use a 150 mW laser for transmission. If the terrain changes, the distance between the complexes can be reduced. Therefore, it is necessary to search for new solutions for transmitting information from multifunctional complexes of environmental monitoring over long distances. One of the variants of such a solution is presented in the current work.

Construction of analog fiber-optic communication line and its parameters for transmitting telemetric information over long distances

Analog signals with amplitude-pulse modulation are the most appropriate for the transmission of telemetry information. It is proposed that each number (e. g., temperature value) be represented as a sequence of pulses, the amplitude of each of which carries a certain digit. Such sequences are used in radio monitoring and radiolocation systems. Amplitude values in relative units (0.95, 0.955, 0.96, 0.965, ..., 0.995) correspond to digits (0, 1, 2, ..., 9), the comma is transmitted with a relative amplitude of 0.4, and marks the beginning and stopping of transmission - with relative amplitude 1. The duration of the information components of the parcel is 1 ms, the duration of the transmission start and stop marks is 2 ms. The interval between pulses is 2 ms. When using such temporal characteristics of the sequence the overrun of chromatic dispersion at $\lambda = 1550$ nm on the optical fiber length $L = 500$ km is about 2.2 ns. Fig. 1 shows an example signal for transmitting a temperature value $T = 294.5$ K.

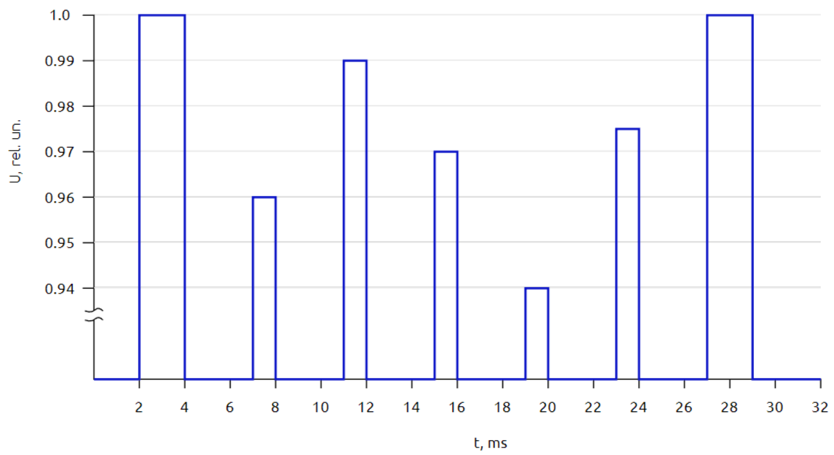

Fig. 1. Sequence of command codes in the form of rectangular pulses to transmit the temperature value $T = 294.3$ K in analog form over the FOCL

The proposed method of information transmission is fundamentally new in the field of telemetry information transmission via fiber-optic transmission system using amplitude-pulse modulation. This method also allows the use of radiation sources with internal modulation by pump current. In this case it is possible to vary the depth of modulation within a large range. In experiments a laser source of radiation with a power of 150 mW is used, the depth of modulation of which varies in the range from 30% to 70%. The level of optical power p_{in} injected into the optical fiber is about 20 dBm. To avoid manifestation of nonlinear effects, further increase in optical power is inexpedient.

Since the telemetry information is transmitted as a sequence of pulses with pulse amplitude modulation, this allows the use of a subcarrier frequency F_s in the range from 100 kHz to 200 MHz. This improves the characteristics of the proposed transmission system, in particular, to provide a large pass-through time of the FOCL when transmitting a signal over long distances, as well as improving the signal-to-noise ratio (SNR), which increases the optical budget of the transmission line. The signal reception bandwidth in this case is from 0.1 to 1 MHz.

Existing digital fiber-optic transmission systems require an *SNR* on the receiving side of at least 20 dB. The proposed system shows that $SNR = 6$ dB is sufficient. In this case the error in determining the amplitude of the pulse is 0.1%, and bit error ratio $BER \approx 10^{-3}$. Modern photodetectors have a sensitivity of up to 90 dB.

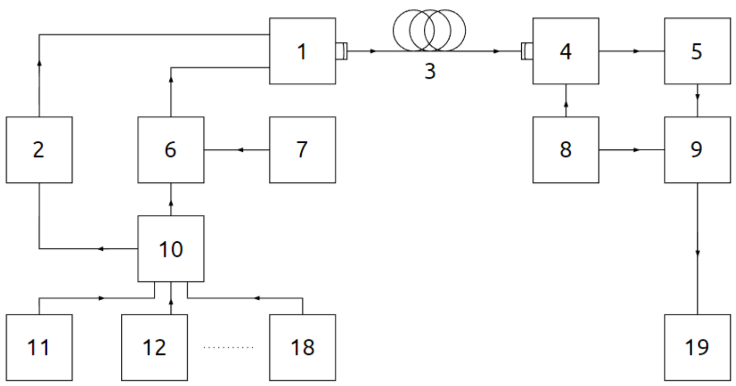

Fig. 2. Structure diagram of the fiber-optic transmission system: semiconductor laser *1* with λ = 1550 nm, direct modulated laser power supply *2*, optical fiber *3*, photodetector *4*, tunable LC-filter *5*, electronic key 6, frequency tunable high-stability quartz generator *7*, multifunction power supply *8*, information processing device *9*, control device *10*, sensors for measuring various physical quantities in the environment *11–16*, personal computer *17*

When transmitting an optical signal over a fiber optic line, the length of which in this case is 500 km, it accumulates noise, which usually does not exceed 8 dB. It is also necessary to take into account the operating margin of 3 dB.

The structural diagram of the proposed fiber-optic transmission system is shown in Fig. 2.

Calculation of fiber-optic communication line

The most important parameters of the designed FOCL are: the rise time τs of the optical system, the time of the signal transmitted through the optical fiber τ_0 and the energy balance a_Σ.

The energy balance a_Σ is the predicted sum of the optical signal losses on all components of the fiber-optic communication line. The energy balance of a fiber-optic communication line is calculated mainly at the stage of line design and selection of channel-forming equipment.

Information is transmitted at a wavelength of λ = 1550 nm. Optical power P_l of the transmitting laser module (Emcore company) is 150 mW (21.8 dBm), modulation depth is 70%, line width $\Delta\lambda$ = 0.112 nm at this P_l, laser bandwidth ΔF_1 = 600 MHz, subcarrier frequency F_s = 100 MHz. G.653 standard single-mode optical fiber with offset zero dispersion (triangular profile) M = 0.3 ps/(nm·km) with attenuation coefficient 0.195 dB/km is used for information transmission. Optical signal reception is carried out by a photodetector module, which has the following characteristics: bandwidth ΔF_2 = 1 GHz, Noice-equivalent power $NEP = 10^{-13}$ W/Hz$^{1/2}$.

$$\tau_0 = B/F_s = 0.35/100\cdot10^6 = 3.50 \text{ ns.} \quad (1)$$

The time τs is calculated as follows: $\tau_1 = B/\Delta F_1$ is the rise time at the transmitter; $\tau_2 = B/\Delta F_2$ is the rise time at the receiver; $\tau_3 = B/\Delta F_3$ is the rise time on optical fiber; B = 0.35 is the coefficient, taking into account the nature of the linear analog signal.

$$\Delta F_3 = 0.35/(M\cdot\Delta\lambda\cdot L\ ) \approx 18.5 \text{ GHz}, \quad (2)$$

$$\tau_1 = 0.35/600\cdot10^6 = 0.58 \text{ ns},$$

$$\tau_2 = 0.35/1\cdot10^9 = 0.35 \text{ ns}, \quad (3)$$

$$\tau_3 = 0.35/22\cdot10^9 = 0.017 \text{ ns}$$

$$\tau_s = \sqrt{(\tau_1^2 + \tau_2^2 + \tau_3^2)} = 0.519 \text{ ns.} \quad (4)$$

The energy balance is calculated as follows:

$$a_\Sigma = a_1 - (a_2 + N\cdot a_3 + a_4 + a_5), \quad (5)$$

where $a_1 = p_{Tx} - p_{Rx}$ = 104.8 dB is the optical loss budget; $p_{Tx} = p_{in} - 2$ dB = 19.8 dBm is the level of power injected into the optical fiber; p_{in} = 21.8 dBm is the transmitted power; $p_{Rx} = -$ 87 dBm is the the sensitivity level of the photodetector. Calculated for SNR (dB) = 10, with a bandwidth of ΔF_t = 1 MHz according to the formula (6):

$$p_{Rx} = 10\cdot\log(NEP/10^{-3}) + 5\cdot\log(\Delta F_t) + 0.5\cdot SNR \text{ (dB)}; \quad (6)$$

a_2 is the FOCL losses; α_{1550} = 0.195 dB/km is the attenuation coefficient at a wavelength of 1550 nm; L = 500 km is the FOCL length;

$$a_2 = 0.195\cdot500 = 107.25 \text{ dB}; \quad (7)$$

a_3 = 0.05 dB is the losses at welded joints; N = 50 is the number of connections; a_4 = 1.5 dB is the losses at the 70% modulation depth of the signal on the transmitting side; a_5 = 3 dB is the operating reserve.

$$a_\Sigma = 106.8 - (97.5 + 50\cdot0.05 + 1.5 + 3) = 2.3 \text{ dB.} \quad (8)$$

The data obtained show that at distances $L = 500$ km the conditions necessary for information transfer are fulfilled: $\tau_0 > \tau_s$ and $a_\Sigma > 0$.

Experimental results and discussion

The main characteristic of FOCL for the transmission of analog signals is the dynamic range.

Fig. 3 shows as an example the results of measuring the output power P_{out} from changes in the laser radiation power P_{in}, which enters the optical fiber for different values of L.

Analysis of the results showed that the dynamic range of our developed FOCL for $L = 100$ km is 85 dB, for $L = 150$ km is 76 dB. The established tendency of changing the value of the dynamic range shows that the developed FOCL allows to provide a stable transmission of information with an increase in L up to 500 km.

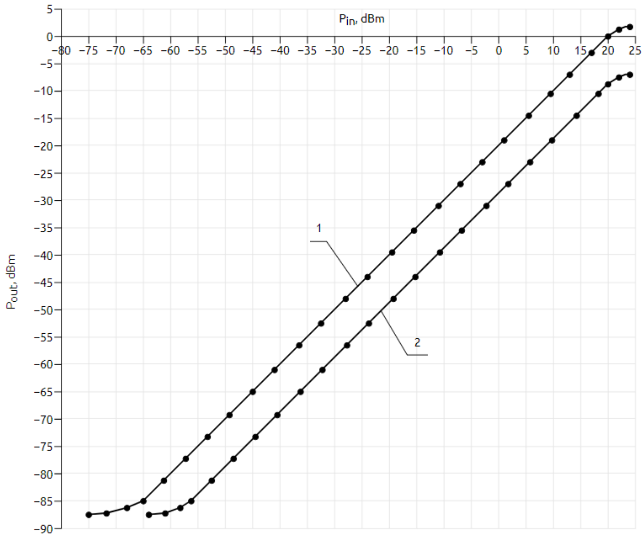

Fig. 3. Amplitude response of the FOCL. Graphs 1 and 2 correspond to the value of L in km: 100 and 150

Fig. 4 shows, as an example, the results of studies of transmission over the developed FOCL of rectangular pulses with durations of 2 ms (start and stop number counting) with an interval between pulses of 2 ms for different values of L.

Analysis of the results shows the stable operation of the FOCL when transmitting information in the form of a sequence of command codes at a power $P_{in} = 100$ mW.

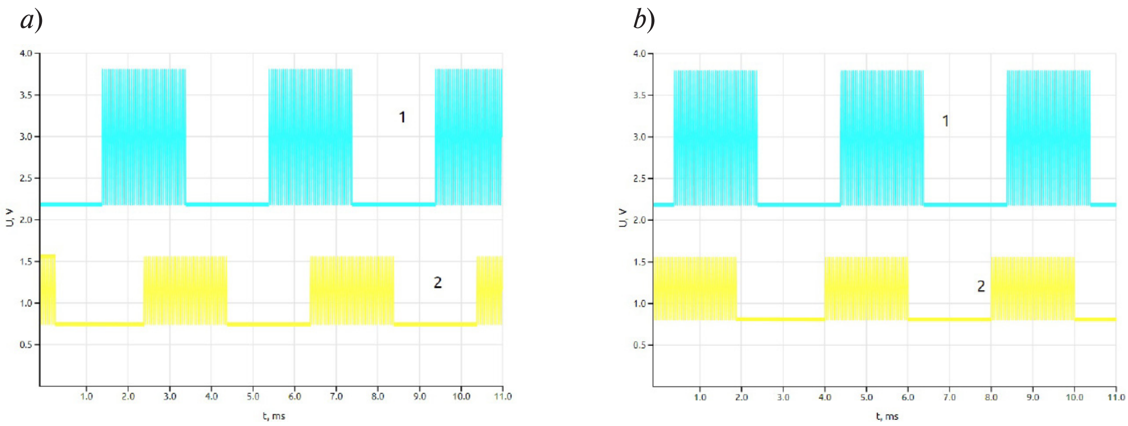

Fig. 4. Pulses for sending start commands and completion of number counting at input 3 and at output 9 for different values of L in km: 100 (*a*); 150 (*b*)

Conclusion

Analysis of the experimental and calculated data confirms the adequacy of the proposed developments to implement the design of the FOCL to transmit information from multifunctional complexes placed on power lines for distances from 4 to 500 km and more (with different configurations). Modernization of multifunctional complexes will affect only the control system.

The most realistic direction is the search for solutions related to increasing the value of L for information transmission using the photodetector module with lower $NEP < 10^{-13}$ W/Hz$^{1/2}$, and the development of inexpensive optical fiber with $\alpha_{1550} < 0.195$ dB/km. At present, it is possible to increase the L to 600 km when using a pure quartz core fiber, if necessary.

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