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# DESIGNING THE PRINCIPAL TRANSMISSION SCHEME FIBER OPTIC DEVICE FIBER OPTICAL GYROSCOPE

**Abstract. The subject of the article** is the fiber-optic fiber-optic gyro system used in inertial navigation, control and stabilization systems. **The purpose of the article** is to study the design of the schematic diagram of the transmitting device of the optical fiber system and to make the necessary calculations for the transmitting device of the optical fiber system. **Problem to be solved** is the justification of technical solutions, the implementation of which in the practice of measurement will allow to substantiate the process of designing the schematic diagram of the transmission device of the fiber-optic system of the fiber-optic gyroscope used in inertial navigation, control and stabilization systems. **The article deals with:** stages of designing the schematic diagram of the transmitting device of the fiber optical system; certain calculations have been made regarding the damping of the site in relation to the designed single-fiber communication system; diagram of the optical transmission device under development. Conclusions: It is advisable to use the proposed technical solutions both in the modernization of existing fiber-optic gyroscopes and in the creation of perspective samples intended for use in inertial navigation, control and stabilization systems.

**Keywords**: optical transmitter, inertial navigation, control and stabilization systems.

## Introduction

**Formulation of the problem.** Potential opportunities for the use of fiber optic gyro(FOG) are based on its potential applications as a sensitive element of rotation in inertial navigation, control and stabilization systems. Industrial development of single-mode low-attenuation dielectric fiber has allowed to create highly sensitive(FOG) used as a rigidly fixed on the body of the carrier of the sensitive element (sensor) rotation in inertial control and stabilization systems. But, when designing FOG, there is a number of problems, namely, the technology of producing elements FOG; extreme sensitivity to very small external and internal disturbances and instability. The solution to these problems is by improving the technology of element production in (FOG), one of which is the development of a transmission device for a fiber optic system, which is not possible without the designing of its schematic diagram, which confirms the relevance of the proposed article.

**Literature analysis.** The principles and organizational foundations of metrological support, as well as the role and place of metrological support in Ukraine, are set out in the Law of Ukraine “On metrology and metrological activity” [1], State standard of Ukraine 2681-94. Metrology: terms and definitions [2], in ISO [3, 4], in articles [5-8], in literature [9 - 14]. Mathematical models for determining the number of orders for guaranteed metrological servicing of weapons and military equipment samples, taking into account their importance, are set out in [5]. The technique of forecasting the capabilities of metro-technical units for the repair of damaged military measuring equipment is described in the article [6]. Theoretical models of heavy objects are described in [7].

The issues of compensation for excess noise in a fiber-optic gyroscope are thoroughly discussed in [8]. General theoretical information about fiber-optic gyroscope has been thoroughly considered in the literature [9]. At the same time, issues related to dynamic pressure measurement remain open.

**The purpose of the article** is to study the design scheme of the transmitting device of the optical fiber system and to make the necessary calculations for the transmitting device of the optical fiber system.

## Basic material

The first step in the design of the principle scheme of the transmitting device of the fiber optic system is to select the type and brand of optical emitter based on the requirements to its technical characteristics, namely: radiation power; wavelength of radiation; the width of the radiation spectrum; modulation frequency; pumping current; threshold current. For the correct selection of the optical emitter in the first stage, you must specify the determination of the radiation power. To do this, determine the required optical power at the output of the optical transmitter. The final decision on the choice of a brand of emitter is made on the basis of compliance with the technical characteristics of the device, the required radiation wavelength, the width of the radiation spectrum and the time of increase of the optical signal power.

In the second step, the transistor V2 is selected in the direct modulator circuit (DMC) and the modulator is calculated. The transistor is selected based on the characteristics of the previously determined optical emitter, namely the pumping current and the threshold current. It is necessary to take into account the maximum allowable power of the transistor and its limiting frequency. Next, the operating point is specified and the elements of the modulator circuit are calculated. In the third stage, the power amplifier should be calculated (ПП) through the use of a high-speed operational amplifier, which is included in the circuit voltage-to-current converter. It is necessary to correctly select the type of operational amplifier according to the required upper frequency and power, which is the scattering, and and-each to calculate the elements of the circuit voltage - current converter.

In the fourth stage, the device of automatic control of the optical signal level at the output of the transmitting device is organized (АРП). his will use a VD3 photodiode connected to one of the poles of the directed optical coupler(OC) and detector АРП, made on the integrated circuit К175ДА1 (Fig. 1). Let's consider the more carefully proposed steps. When calculating the transmitter power output and selecting the type of radiation emitter, it should be taken into account that the value of the power difference at the output of the optical emitter and at the input of the optical receiver should exceed maximum attenuation made by station and line structures on the transmitter-receiver section. Currently available optical modules provide a sufficiently low level of reception. Reception devices of some systems provide a level of reception of 0.01 mkV (-50 dB), which when performing the calculations, we will assume the default.

We propose the damping of the plot on the designed single-fiber communication system:

$$\alpha = I\left(\alpha_{OB} + \frac{\alpha_{H3}}{I_\sigma}\right) + 2\alpha_3 + 2\alpha_{PZCLK} + 2\alpha_1, \quad (1)$$

where is $I = 8\,km$ - length of the plot; $\alpha_{OB} = 2DB$ - attenuation of one kilometer of optical fiber; $\alpha_1 = 2DB$ - attenuation of the signal in the device combining and branching signals; $\alpha_{PZCLK} = 1DB$ - attenuation of the signal in the device PZCLK; $\alpha_3 = 1{,}4DB$ - attenuation of the signal in the plug connectors (the norm $\alpha_{P3} = 1{,}5DB$); $\alpha_{H3} = 0{,}2DB$ - signal attenuation in non-detachable connectors (by norms, $\alpha_{H3} = 0{,}2DB$); $I_\sigma = 2км$ - the optical fiber cable length.

Let's make some calculations.

We calculate the damping of the plot for the designed single-fiber communication system:

$$\alpha = 8\left(2 + \frac{0{,}2}{2}\right) + 2\cdot 1{,}4 + 2\cdot 1 + 2\cdot 2 = 25{,}6\ dB.$$

Calculate the minimum power level:

$$P_1 = P_{PR} + \alpha = -50 + 25{,}6 = -24{,}4\ dB., \text{ or}$$

$$P_2 = 10^{0{,}1(-24{,}4)} \cdot 1mW = 1{,}585\ mW.$$

where is $P_{PR}$=-50 *dB* - optical signal level at reception.

Thus, the output power of the transmitter module must be at least 1.5 *MW*.

In addition, the radiation source must operate at a wavelength of 1550 *µm* and provide a modulation frequency of at least 8.5 *MHz*. The ILPN-1500 semiconductor laser best meets the following requirements and has the following characteristics:

1) radiation power: *Pz* = 5 *MW*;
2) radiation wavelength: λ =1 310 *µm*;
3) the width of the radiation spectrum: Δ=3 *nm*;
4) modulation frequency: $F_m$ = 250 *MHz*;
5) pumping current: $I_n$=50 *mA*;
6) threshold current: Iпор=30 *mA*;
7) operating voltage: 1,5 *V*;
8) operating temperature range: $-40° \pm 60°$.

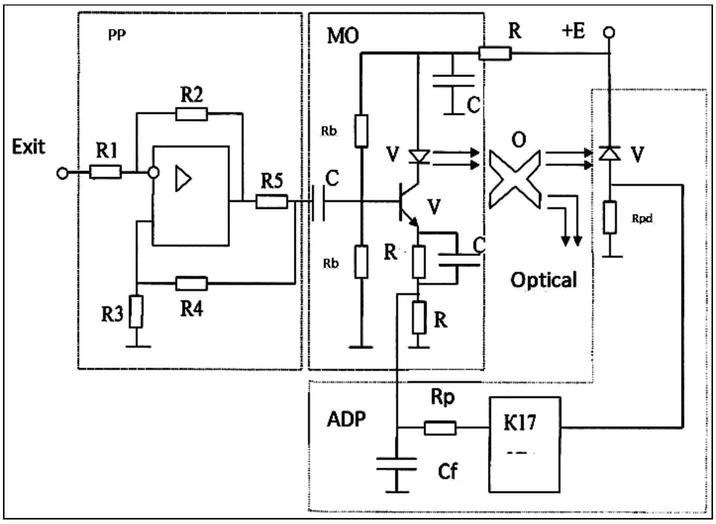


**Fig. 1**. Schematic of the optical transmission device

The next step is to calculate the output stage. First of all, let's choose a transistor, where we will be guided by the following requirements to its technical characteristics, namely: DC collector current of at least 120 *mA*; Frequency gain greater than 8.5 *MHz*. The following requirements are satisfied by the silicon n-p-n transistor КТ660В. Which is intended for use in switching and switching devices, in circuits of computers, in generators of electrical oscillations, and having the following electrical parameters:

- static coefficient h21e current in scheme 3E at $U_k$= 10 in $I_e$= 2 mA: $h_{21}$ = 450;
- saturation voltage of the collector - emitter $U_k$ при $I_к$=500 mA $I_б$=50 mA, not more than 0.5 *V*;
- saturation voltage base - emitter $U_b$ at $I_к$=500 *mA*, not more than 1.2 *V*;
- the capacity of the collector junction $C_k$ at $U_k$= 10 *V*, not more than 10 *pF*;
- the reverse current of the collector $U_k$ at $U_k$ = 10 *V*, not more than 1 *µA*;
- the reverse current of the emitter $U_e$ at $U_{be}$= 4 *V*, not more than 0,5 *µA*;

Limiting operational data:

- constant voltage collector - base Uкбmax 30 *V*;
- constant voltage collector - emitter Uкэmax при $R_{be}$ < 1 *kΩ* 30 *V*;
- constant voltage collector - emitter Uкэmax при $I_e \leq 10$ *mA* 25 *V*,
- constant voltage base - emitter Uбэmax 5 *V*;
- constant power collector Iкmax 800 *mA*;
- constant power dissipation of the Pmax 0.5 **W**.

Next, determine the mode of operation of the transistor (operating point). To select the mode, we use the family of the output characteristics of the transistor for the scheme with a common emitter whick parameter is the base current (Fig. 2).

It is necessary to fulfill the condition regarding the collector rest voltage: $U_k \leq 0.45E_{k\max}$ (taking into account the given condition) $U_k = 6V$. Considering that a threshold current of 40 мА, is required to modulate a semiconductor laser, then $I_{ко} = 40\ mA$. In this case, the rest current of the base

$I_b = 0.135E\ mA$. . Since the maximum pumping current of the laser is 120 $mA$, the maximum collector current will be, $I_{k\max} = 120\ mA$, in this case $U_{ke\max} = 1.7\ V$ and $I_{\sigma\max} = 0.47\ mA$. According to the input characteristics of the transistor (Fig. 3) we determine the voltage of the rest base and the amplitude value $U_{\sigma 0} = 0.71\ V$ and she amplitude characteristics $U_{\sigma\max} = 0.74\ V$.

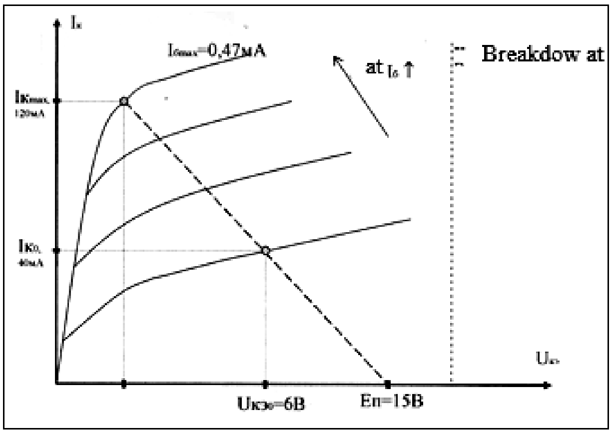


**Fig. 2.** Family of the output characteristics of the transistor for the circuit with the common emitter

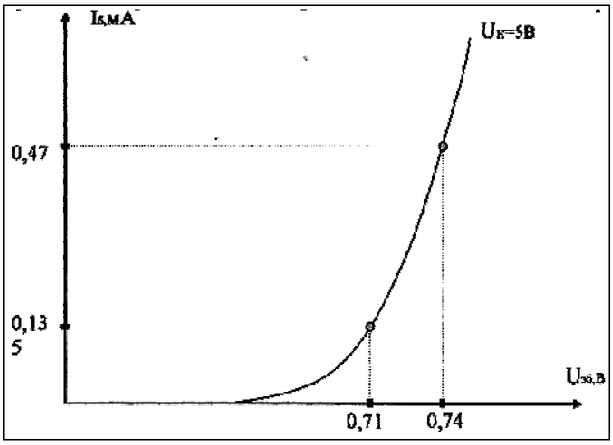


**Fig. 3.** Family of input characteristics of a transistor for a circuit with a common emitter

Thus, the mode of operation of the transistor is determined by the following parameters:

- collector rest voltage: $U_{ko} = 6\ V$;
- collector rest current: $I_{ko} = 40\ mA$;
- base rest current: $I_{bo} = 0.135\ mA$;
- base rest voltage: $U_{бo} = 0.71\ V$;
- base current amplitude: $I_{бмax} = 0.47\ mA$;
- collector voltage amplitude: $U_{\kappa\max} = 1.7\ V$;
- collector current amplitude: $I_{\kappa\max} = 120\ mA$;
- voltage amplitude at the base: $U_{бмax} = 0.74\ V$.

The transistor is included in the scheme with a common emitter, and the semiconductor laser is in the collector circuit. In this case, the voltage drop in the emitter circuit must satisfy the following condition:

$$U_E^R = 0.15\ E_n, \qquad (2)$$

where is $E_n$ - where is the supply voltage of the modulator.

Define the supply voltage $E_n = 15\ V$, in this case: $U_{R_E} = 0.15\,15 = 1.8\ V$, where the resistance $R_E$ will be calculated by the formula:

$$R_E = \frac{U_{R_E}}{I_{KO} + I_{BO}} = \frac{1.8}{(40 + 0.135) \cdot 10^{-3}} = 44.85\ \Omega.$$

The current $I_D$ of the divider should be at least 5 - 10 times lower than the rest current of the base $I_{VO}$:

$$I_D = 10 \cdot I_{VO} = 10 \cdot 0.135 = 1.35\ mA.$$

In order to stabilize the mode of operation of the circuit between the voltage at the emitter resistance and the filter resistance, we define that the filter resistance voltage is equal $U_{Rf} = 1\ B$. In this case, the filter resistance is determined as follows:

$$R_f = \frac{U_{R_f}}{I_{KO} + I_{BO} + I_D} =$$

$$\frac{1}{(40 + 0.135 + 1.35) \cdot 10^{-3}} = 24.11\ \Omega.$$

The voltage drop at the divider support is $R_b$ equal to the sum of the voltage drop at the support in the emitter circuit and the shear voltage at the base of the transistor at the emitter resistance and the filter resistance, we define that the filter resistance voltage is equal. In this case, the filter resistance is determined as follows:

$$U_{R_b} = U_{R_E} + U_{bo} = 1.8 + 0.71 = 2.51\ V.$$

In this case, the resistance of the divider is $R_b$:

$$R_b = \frac{U_{R_b}}{I_D} = \frac{2.51}{1.35 \cdot 10^{-3}} = 1.86\ кОм.$$

Find the resistance in the emitter circuit $R_e$:

$$R_E = \frac{E_n - U_{R_b} - U_{R_f}}{I_D + I_{BO}} =$$

$$= \frac{12 - 2.51 - 1}{(1.35 + 0.135) \cdot 10^{-3}} = 5.72\ k\Omega.$$

For a circuit with emitter stabilization, the supply voltage is distributed between the three resistors of the output circuit $(R_E, R_K, R_F)$, by a laser emitter and a transistor:

$$E_P = U_{KEO} + U_{R_E} + U_{R_K} + U_{RF} + U_D. \qquad (3)$$

where is $U_D = 2\ V$ - voltage drop on a semiconductor laser; $U_{RF}$ - voltage drop at the support in the collector circuit.

From here:

$$U_{R_K} = E_n - U_{K_{EO}} - U_{R_E} - U_{R_f} - U_D = 1.2\ B$$

In this case the resistance in the collector circuit is:

$$R_K = \frac{U_{R_K}}{I_{KO}} = \frac{1.2}{40 \cdot 10^{-3}} = 30\ \Omega.$$

The next step is to calculate the matching amplifier. For what, as a reinforcing element, it is intended to use a high-speed operational amplifier included in the scheme of the Converter voltage - current (also known as an amplifier with complex steepness). The scheme of the matching amplifier is presented in Fig. 1 (functional group PP). A resistor that selects a current that is designed to provide feedback to a positive input clamp. The resistance value $R_5$, is determined based on the following condition:

$$R_5 = \frac{R_H}{10}, \tag{4}$$

where is $R_H$ – the load resistance of the amplifier, which is the input resistance of the direct modulator and exactly parallel connection of the resistor divider $R_D$ (of two in parallel connected resistors in the base circuit $R_B$) and the input resistance of the transistor $R_{0_E}$, equal to:

$$R_H = \frac{R_{0_E} \cdot R_D}{R_{0_E} + R_D}. \tag{5}$$

The input resistance of the transistor is calculated according to the following relation:

$$R_{0_E} = \frac{U_{VM} - U_{VO}}{I_{VM} - I_{VO}} = \frac{0.74 - 0.71}{(0.47 - 0.135) \cdot 10^{-3}} = 90\ \Omega.$$

The resistance of the divider is calculated according to the following relation:

$$R_D = \frac{R_V^{/} \cdot R_V^{//}}{R_V^{/} + R_V^{//}} = \frac{5.72 \cdot 10^3 \cdot 1.86 \cdot 10^3}{(5.72 + 1.86) \cdot 10^3} = 1.40\ k\Omega.$$

In this case, the load resistance of the amplifier is equal to:

$$R_H = \frac{R_{0_E} \cdot R_D}{R_{0_E} + R_D} = \frac{90 \cdot 1.4 \cdot 10^3}{90 + 1.4 \cdot 10^3} = 84\ \Omega,$$

and the resistance $R_5$ is equal to:

$$R_5 = \frac{R_H}{10} = \frac{84.18}{10} = 8.5\ \Omega.$$

The amplitude value of the voltage drop at the resistance $R_5$ is equal to:

$$\Delta_{U_{R5}} = I_V \cdot R_5 = (0.47 - 0.135) \cdot 10^{-3} \cdot 8.42 = 0.003\ V$$

Required from the scheme, the gain is equal to the ratio of the amplitude of the output voltage to the amplitude of the input voltage. Since the input of the coordinating amplifier is signal from the code converter, the amplitude of the input signal is

$$\Delta_{U_0} = 5 - 0.7 = 4.3\ V.$$

In this case, the gain of the scheme is:

$$K = \frac{\Delta_{U_{R5}}}{\Delta_{U_0}} = \frac{0.003}{4.3} = 0.000653.$$

Let's resistors denominations $R_1$, $R_2$, $R_3$ and $R_4$ are chosen to be the same, each of which must exceed the resistance $R_5$ at least 20 times. Consider the following resistance values under this condition:

$$R_1 = R_3 = R_4 = 2000 \cdot R_H = 2000 \cdot 84.18 = 168\ k\Omega.$$

The resistance $R_2$ sets the gain of the circuit and is defined as follows:

$$R_2 = R_1 \cdot K = 168.36 \cdot 10^{-3} \cdot 6.56 \cdot 10^{-4} = 110\ \Omega.$$

Next, we calculate the device automatically adjusts the level of the optical signal at the output of the transmitting device, which provides stabilization of the average power of the laser radiation.

The device ARP includes the following basic elements (functional group ARP in Fig. 1): a photodiode for converting the optical radiation emitted from the output of the laser into an electric current; an automatic level control detector and a DC amplifier made on an integrated circuit.

It should be noted that the sensitivity of the photodiode does not play a role in this case, therefore, when choosing the type of photodiode, we will be guided by such parameters as reliability and low cost. In our case, when using a semiconductor laser ILPN-1550, the manufacturer of this laser predicted that when using semiconductor lasers in different devices, the developers would use a radiation-based stabilization method based on feedback.

And according to this, the design of a semiconductor laser ILPN-1550 already contains a photo sensor with an optical splitter.

## Conclusions

1. The article proposes a schematic diagram of the transmission device of a fiber-optic system of a fiber-optic gyroscop.

2. The proposed scheme (Fig. 1) used a laser emitter ILPN-1550 operating at a wavelength of 1550 nm and 5 mW, which has an output optical power of radiation. In the scheme of the direct modulator used silicon n-p-n transistor KT660B which is intended for use in switching and pulse devices. To match the output of the code converter and the input of the modulator, a matching amplifier is introduced on a high-speed operational amplifier KP140YD11. To stabilize the average laser power, a device for automatic control of the optical signal level, including the integrated circuit K175DA1 used as an ADC detector and DC amplifier.

3. The proposed transmission device is designed to work in the composition of digital optical gyroscopes operating at a speed 8 Mbits/s.

4. It is advisable to use the proposed technical solutions both in the modernization of existing fiber-optic gyroscopes and in the creation of perspective samples intended for use in inertial navigation, control and stabilization systems.

References


1. Кононов В.Б., Бурцева В.В. Математичні моделі визначення кількості замовлень на гарантоване метрологічне обслуговування зразків озброєння та військової техніки з урахуванням їх важливості Системи обробки інформації: зб. наук. пр. ХНУПС. – Вип.1 (147). – Харків, 2017. – С. 88 –92.
2. Кононов В.Б. Методика прогнозування можливостей метрологічних підрозділів з відновлення пошкоджених засобів вимірювальної техніки військового призначення //Авиационно-космическая техника и технология. – Харків: НАУ ХАИ—2011.-№ 8 (85) -С.231 – 234.
3. Кононов В.Б., Науменко А.М., Водолажко О.В., Коваль О.В., Кондрашова І.І. Основи експлуатації засобів вимірювальної техніки військового призначення в умовах проведення АТО. - Харків: ХНУПС, 2017. – С. 288.
4. Коваленко А. А., Кучук Г. А. Методи синтезу інформаційної та технічної структур системи управління об'єктом критичного застосування. *Сучасні інформаційні системи*. 2018. Т. 2, № 1. С. 22–27. DOI: https://doi.org/10.20998/2522-9052.2018.1.04
5. Свиридов А. С., Коваленко А. А., Кучук Г. А. Метод перерозподілу пропускної здатності критичної ділянки мережі на основі удосконалення ON/OFF-моделі трафіку. *Сучасні інформаційні системи*. 2018. Т. 2, № 2. С. 139–144. DOI: https://doi.org/10.20998/2522-9052.2018.2.24
6. Кучук Г.А. Управління трафіком мультисервісної розподіленої телекомунікаційної мережі / Г.А. Кучук // Системи управління, навігації та зв'язку. – К.: ЦНДІ НіУ, 2007. – Вип. 2. – С. 18-27.
7. Кучук, Г.А. Концептуальний підхід до синтезу структури інформаційно-телекомунікаційної мережі / Г.А. Кучук, І.В. Рубан, О.П. Давікоза // Системи обробки інформації. – Х.: ХУ ПС, 2013. – Вип. 7 (114). – С. 106-112.
8. Коваленко А. А., Кучук Г. А. Методи синтезу інформаційної та технічної структур системи управління об'єктом критичного застосування. Сучасні інформаційні системи. 2018. Т. 2, № 1. С. 22–27. DOI: https://doi.org/10.20998/2522-9052.2018.1.04
9. Кучук Г. А., Можаев А. А. Прогнозирование трафика для управления перегрузками интегрированной телекоммуникационной сети // Радиоэлектронные и компьютерные системы. 2007. № 8 (27). С. 261-271.
10. Кононов В.Б. Застосування електричних вимірювань засобами вимірювальної техніки в умовах проведення АТО: навч. посіб./ В.Б. Кононов, А.М. Науменко, О.В. Коваль та ін.. – Х.:ХНУПС, 2018. – 392 с.
11. Instrumentation and general principles of sensors. Part 1 / В.Б. Кононов, А.М. Науменко та ін. – Х.:ХНУПС, 2018. – 64 с.
12. Організація метрологічного забезпечення військ (сил). Ч. 1 : навч. посіб. / І. Б. Кузнецов, П. М. Яблонський. – К. : НУОУ, 2009. – 356 с.
13. Організація застосування пересувних засобів метрологічного обслуговування: навч. посіб. / І. Б. Кузнецов, О. В. Ярошенко. – К.: НУОУ, 2009. – 356 с.
14. Кузнецов І. Б., Марценківський В. Т., Ярошенко О. В., Буяло О. В., Проценко В. О. Удосконалення парку пересувних лабораторій вимірювальної техніки як фактор підвищення оперативності та ефективності метрологічного обслуговування складних систем // Збірник наукових праць КНУ. Вип. 32. – К. : ВІКНУ, 2011. – С. 33–46.


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**Проектування принципової схеми передавального пристрою волоконно-оптичної системи волоконно-оптичного гіроскопу**

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**Анотація.** У статті запропоновано принципову схему пристрою передачі волоконно-оптичної системи волоконно-оптичного гіроскопа .**Предметом** вивчення в статті є волоконно-оптична система волоконно-оптичного гіроскопу, що використовуються в інерціальних системах навігації, керування й стабілізації. **Метою статті** є дослідження щодо проектування принципової схеми передавального пристрою волоконної оптичної системи та проведення необхідних розрахунків щодо передавального пристрою волоконної оптичної системи. **Задача, що вирішується, –** обгрунтування технічних рішень, впровадження яких в практику вимірювання дозволять обгрунтувати процес проектування принципової схеми передавального пристрою волоконно-оптичної системи волоконно-оптичного гіроскопа, що використовуються в інерціальних системах навігації, керування й стабілізації. **В статті розглядається**: етапи проектуванні принципової схеми передавального пристрою волоконної оптичної системи; проведені певні розрахунки,щодо загасання ділянки щодо проектованої одноволоконної системи зв'язку; схема оптичного передавального пристрою, що розробляється. Запропонована схема використовувала лазерний випромінювач ILPN-1550, що працює на довжині хвилі 1550 нм і 5 мВт, що має вихідну оптичну потужність випромінювання. У схемі прямого модулятора використовується кремнієвий n-p-n транзистор КТ660В, який призначений для використання в комутаційних та імпульсних пристроях. Для відповідності виходу перетворювача коду та входу модулятора на швидкісний операційний підсилювач КР140YD11 вводиться відповідний підсилювач. Для стабілізації середньої потужності лазера встановлено пристрій для автоматичного управління оптичним сигнальним рівнем, включаючи інтегральну схему К175DA1, що використовується як детектор АЦП та підсилювач постійного струму. **Висновки.** Пропонований пристрій передачі призначений для роботи у складі цифрових оптичних гіроскопів, що працюють зі швидкістю 8 Мбіт / с. Запропоновані технічні рішення доцільно використовувати як при модернізації існуючих волоконно-оптичних гіроскопів, так і при створенні перспективних зразків, що призначені для роботи в інерціальних системах навігації, керування й стабілізації.

**Ключові слова:** оптичний передавальний пристрій, інерціальні системи навігації, керування й стабілізації.