Features of modulation of high-power laser radiation for optical space control systems

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Abstract. In this work we justify the necessity of using shutter-type modulators to create laser radiation with the required parameters in fiber-optic systems. This is necessary to detect the fact of making changes in the optical system (unauthorized connection with the restoration of the function of communication channels). We have developed a shutter-type optical radiation modulator design. This modulator design has no fundamental limitations on the power of laser radiation, which is used to solve various problems. The investigation results of different work regime to the modulator are presented.

1. Introduction
The development of scientific and technological progress has affected various areas of information transmission and control systems for the parameters of various signals [1-12]. A special place among communication systems is occupied by fiber-optic communication lines and various sensors and systems for converting and monitoring the parameters of optical radiation [12-19]. The main advantage of using optical systems is passivity to electromagnetic radiation, which is growing every year [15-17, 20-26]. In addition, the power of electromagnetic interference increases, which leads to malfunctions in different systems. One of the problems that arise during the maintenance of fiber-optic communication lines is unauthorized access to the system [27-29]. Such connections are used to solve various tasks. They must be installed promptly. Various methods and techniques have been developed to detect such intrusions into the optical system. One of them is associated with the modulation of laser radiation at different frequencies.

In communication systems, electro-optical modulators (EOM) are used to modulate laser radiation. This is an expensive technology. And its use for the previously described tasks is irrational, because the cost of the system with, for example, 20 channels will increase very significantly. In addition, in some cases, for space control systems, it is necessary to use high-power laser radiation, which is not always combined with the basic design of the EOM, which is being developed for fiber-optic communication lines, in which the laser radiation power is quite limited. It is also not always advisable to use a laser transmitting module with internal modulation, since the basic designs of these devices...
have power limitations and their service life during long-term operation is much less than that of standard laser systems. Therefore, the development of simple and reliable designs of optical radiation modulators, which do not have fundamental limitations when operating in terms of laser radiation power and can operate in a wide frequency range, is an urgent task.

2. Shutter-type modulator design and experimental setup

In this work we propose a shutter-type modulator design. This construction is a universal for realization of the modulator, since it does not require any unique or special components, and it is also compatible with most of the standard optical components used. Figure 1 shows one of the versions for its design.

![Figure 1](image1.png)

**Figure 1.** Design of a shutter-type optical radiation modulator: 1 – laser radiation; 2, 3 – optical fibers; 4 – movable shutter; 5 – a gap between optical fibers.

We have constructed an experimental setup for the research of a shutter-type modulator. The block diagram is shown in figure 2.

![Figure 2](image2.png)

**Figure 2.** The block diagram of the experimental setup: 1 – LED; 2, 11 – power supply; 3 – multimode optical fibers; 4, 5, 6 – optical translator system; 7 – shutter; 8 – microscope; 9 – piezoceramic; 10 – photodiode; 12 – signal source; 13 – oscilloscope; 14 – a gap between optical fibers.

There is a gap between a pair of optical fibers – “input” and "output" – (3). With the use of an oscillating shutter, placed in this gap, modulation of the laser radiation from the input fiber to the output is performed. The shutter is made of steel and has a size of 37 mm in length and 70 µm in
diameter. It is fixed on a piezoceramic plate (9) connected to a signal generator, the frequency of which can change up to tens of MHz. The fibers and plate are placed in optical translator system, which consists of several independent mechanisms (4-6). They are all placed on one base (small optical plate). This system provides accurate positioning along three axes. The distance between the fibers and the position of the shutter is determined by a specially applied scale using a microscope (8). The modulation process was monitored using an oscilloscope, the input of which was supplied with voltage from the photodetector module. For a more complete representation of the operation of the modulator, standard laser radiation with wavelength of 650 nm (power of laser radiation was changed from 0.2 to 20 mW) was supplied to the input fiber. We have performed a series of experiments to detect the optimal mode of the modulator.

3. Experiment results and discussion

An important characteristic in the operation of the modulator is the dependence of the change in the amplitude of the modulated laser radiation on the amplitude of the voltage of the oscillations applied to the piezoceramic plate. In figure 3, as an example, several such dependences are presented for a frequency F=1742 Hz with a change in the distance between optical fibers from 125 µm to 375 µm.

**Figure 3.** Dependence of the voltage on the photodetector on the shutter oscillation voltage for different distances between the ends of the fibers: 1 – 125 µm; 2 – 187.5 µm; 3 – 250 µm; 4 – 312.5 µm; 5 – 375 µm.

The results show that as the distance between fibers decreases, the efficiency of the modulation process increases. This is due to an increase in the amount of light entering the output fiber, since the light spot has a cone shape, and the ratio of the cone cross-sectional areas in the plane of the end of the output fiber and the core of the output fiber increases.

Another important characteristic of the operation of the modulator is the dependence of the change in the amplitude of the modulated laser radiation on the change in the value of the frequency of oscillations entering the piezoceramic plate. In figure 4, as an example, several such dependences are presented for the value of the oscillation amplitude U=6 V for cases of different distances between the fibers (125 µm-375 µm).
Figure 4. Dependence of the voltage on the photodetector on the oscillation frequency of the shutter for different distances between the ends of the fibers: 1 – 125 µm; 2 – 187.5 µm; 3 – 250 µm; 4 – 312.5 µm; 5 – 375 µm.

The obtained results show that the optimal shutter oscillation frequency is in the range from 1200 to 1230 Hz. This is due to the most linear expansion of the piezoceramic element, on which the shutter is fixed, in the range of specified frequencies.

The last characteristic of the modulator operation is the dependence of the change in the amplitude of the modulated radiation on the position of the shutter between the fibers. Figure 5 shows a few of such characteristics for different values of the depth of introduction of the shutter (from partial to full coverage of fiber cores).

Figure 5. Dependence of the voltage on the photodetector on the shutter oscillation voltage for different values of the depth of introduction of the shutter: 1 – the shutter is in the middle between fibers; 2-5 – shift in steps of 10 µm.
As a result, the most optimal mode of the modulator is the mode when shutter is located exactly in the middle between the optical fibers.

Also as a result of the experiment, it was found that the shutter-type modulator does not distort the signal. It is shown in figure 6. This allows to detect the changes in phase shift in case of unauthorized connection to the system.

**Figure 6.** Oscillograms of voltages: (a) – signal from the generator arriving at the piezoceramic plate, (b) – signal from the photodetector.

Additional experiments have shown that up to 500 mW of laser radiation power in a continuous mode, the modulation mode in the developed design remains almost unchanged (the shutter heats up slowly). Disruption of the modulation process (this is shown in figure 7) in our design with an increase in the power of laser radiation will most likely be associated with heating of the shutter surface (thermal expansion). This fact requires additional research with more heat-resistance materials, which will be the result of our further work.

**Figure 7.** Oscillograms of voltages: (a) – signal from the generator arriving at the piezoceramic plate, (b) – signal from the photodetector.

4. Conclusions
The obtained experimental results showed the presence of modulation in the laser radiation detected by the photodetector. It was found that the optical radiation is modulated with a frequency F. The piezoceramic plate oscillates at this frequency. The optimal range of the laser radiation power is established at which the modulation process is not disturbed.

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