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ABOUT A SWITCHING PRINCIPLE OF INFORMATION FLOWS

The principle of constructing a multichannel and multifunctional optical switch is considered. It is shown that the proposed principle of an optical switch extends the functionality of an optical network.

Keywords: *multichannel and multifunctional optical switches, information flows and fiber-optic networks.*

Introduction

Evidently, the main advantage of fiber-optic networks is their unlimited bandwidth. The practical significance of this property lies in the possibility of a multiple increase in the speed of global scale data transmission via fiber optic communication channels. Therefore, the studies in the field of optical networks are very relevant.

Today, the area of telecommunications and data transmission is mainly characterized by an increase in the number of Internet users, including the growing interaction of international operators and the increase in the volume of information transmitted. In addition to the important task of improving the parameters and designs of fiber-optic cables, the issue of developing reliable switches for optical signals is equally critical [1, 2], without which multifunctional and branched optical networks are impossible to be built.

The proposed study considers one of the possible principles of creating multichannel and multifunctional optical switches (or cross-switches) of information flows. Since the trajectory of the beam propagation in optical devices is of a reciprocal nature, when describing the principle of functioning of the proposed optical switch in one operating mode, we will recognize that the reverse operation of this optical switch is easily accomplished by reversing all flows in the opposite direction. In other words, the optical systems are reversible, and it is sufficient to describe the beam path in one direction. Therefore, in the switches considered below, all signal transmission lines can be bidirectional, and the signals in both directions are transmitted by light streams with different wavelengths.

All-Optical Network is one of the promising technological fields of the recent times, in which all the transformation operations and formation of user information are performed without transforming the optical signal into electrical signal and vice versa [3]. Eliminating the transformation of the information flow into an electrical form significantly reduces the cost of the network. Nevertheless, the potentials of the optical technologies are still insufficient to create absolute optical networks of the required scale. Therefore, the practical application of such networks is limited to network fragments, within which only the electrical regeneration of the signal is performed. However, studies in this field is being intensively conducted. Currently, a number of active and passive quantum and optical elements and devices with highly stable parameters are being developed. The most "responsible" passive elements are the optical switches.

Switch based on semi-transparent mirrors

It should be noted that the switch is one of the most important nodes of information transmission systems, built on the basis of the hierarchical structures. It is almost impossible to automatically control the movement of the optical data flows and monitor the branched network without them.

The switches are generally the devices enabling the instantaneous transmission of the original signal with minimal distortion, which is received by one of several inputs and outputs in accordance with the specified switching algorithm. Accordingly, the optical switches are commuting the signals represented in the form of optical radiation.

The static switches are of great interest among the vast variety of devices used in technology that perform the function of switching optical signals [4, 5]. These switches have a low rate of establishing a signal transmission path. Subsequently, in each case of such change, the position of one or several mirrors in the path of luminous flux propagation is required to be manually changed. However, in the absence of path changes, such switches have the maximum data transmission rate (the signal is transmitted at the speed of light), regardless of the data format and the wavelength of the luminous flux. On the other hand, the switches based on moving mirrors have a low cost.

Apparently [4], the general structural diagram of the static switch, shown in Figure 1, consists of "own switch" SW and the associated control unit. The optical signals entered to the inputs $Input1 \div InputM$ through independent channels M are transmitted to the optical outputs $Output1 \div OutputM$ in accordance with the links, the structures of which are specified by the control unit. In the case, shown in Figure 1, the number of inputs M coincides with the number of outputs.

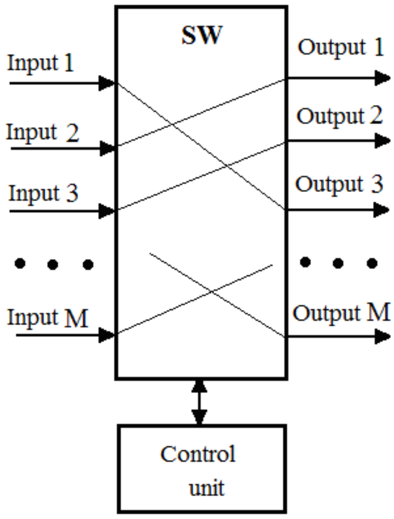

Fig. 1. General structural diagram of a static switch

As provided in [4], the distinguished feature of static switches is that the connections are set by the control unit for a relatively long period of time and can change. This can be due to the connection to the system of previously uninvolved devices, traffic redistribution depending on the time of day, failure of an external fiber-optic communication line, and when switching to a backup line within a switching time of no more than 50 ms.

For example, the principle of construction and operation of a switch consisting of three inputs and three outputs, shown in Figure 2. We note that, based on the principle of construction and operation discussed below, it is possible to build a switch consisting of inputs M and outputs M . At the same time, the combinations $(M^2-1)\cdot M$ (24 combinations can be built at the output when $M=3$) of the input streams can be created at the output of the switch. Moreover, the passage of the optical flows in the opposite direction is also changed, as was noted above.

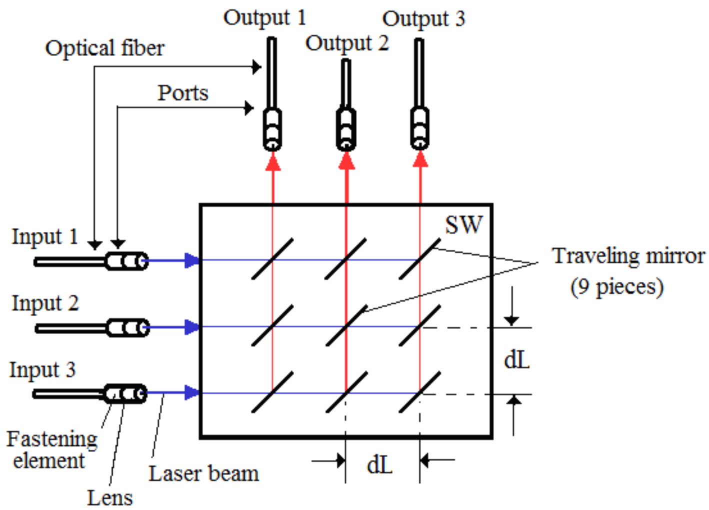

Fig. 2. Diagram of an optical switch SW based on movable mirrors

As provided in Figure 2, the switch transmits optical signals from three input ports Inp 1 - Inp 3 to three output ports Outp 1 - Outp 3. In this simplified example, the switch contains a matrix of 9 moving semitransparent mirrors located at the intersections of three rows and three columns. The step of placing the semitransparent mirrors in the matrix is denoted as dL, which depends on the overall dimensions of the actuators of the mirrors (linear reciprocating motion). Each semitransparent mirror can be in two stable states. One of the states of semitransparent mirrors is initial or passive, in which the semitransparent mirror does not intersect the path of the optical flow and is indicated by the dotted lines in the switch circuit. The second state of semitransparent mirrors is elevated position state or active (vertical), in which the semitransparent mirror crosses the path of the optical flow and divides it into two mutually perpendicular flows with the same power (intensity). The active state of semitransparent mirrors is shifted through the linear displacement actuator. The switch circuit indicates the active position as solid lines.

Obviously, the transition speed of the semitransparent mirror from one state to another determines the speed of the optical switch. As can be seen from Fig. 2 (where the state of all semitransparent mirrors is shown as active), each port can additionally contain the elements for fixing the optical fiber to the switch basis and lens, which adjusts the spatial divergence of the laser beam as it propagates.

Implementation Options

It should be noted that the sections of the optical switch, shown in Figure 2, have the same form in a row or column. Therefore, one of the possible options for the appearance of an optical switch is shown in Figure 3.

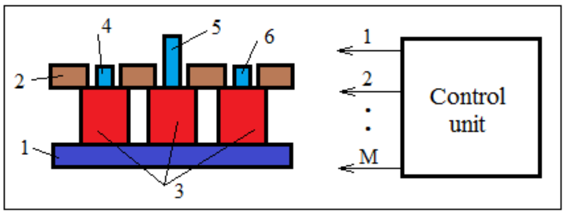

Fig. 3. Sections of the switch

1 - basis, 2 - top cover, 3 - linear actuators, 4 - first,
5 - second, 6 - third semitransparent mirrors

In Figure 3, the switch consists of a control unit, a basis - 1, a top cover - 2, linear actuator of the reciprocating motion - 3, semitransparent mirrors - 4, 5, 6. All semitransparent mirrors are firmly fixed to the moving part of the actuator.

The operating surface of all semitransparent mirrors 4, 5 and 6 is covered with a layer with the required coefficient of reflectance and transmission of the optical flux. In Figure 3, the semitransparent mirrors 4 and 6 are in the passive state, whereas the semitransparent mirror 5 is in the active (vertical) state.

The operating position of the mirrors is set by the control voltage of the control unit, which is determined by the state of the network.

Figure 3 provides that the optical switch has a rather simple design and its dimensions are determined by the size of the linear displacement actuator.

When the switch is implemented as an actuator, the electromagnetic (Figure 4), the systems with flat spring-loaded plates (Figure 5) [6], packet and differential [7] piezo-motors (Figure 6), piezo-electric deflectors, reversing actuators [8-10] and other micro electromechanical and piezo-ceramic actuators [11, 12].

The minimum dimensions of miniature linear piezo-electric actuators [13] are 1.55x1.55x6 mm, an operating stroke of 3.3 mm with a resolution of 50 nm and motion speed of up to 80 mm/s. The characteristics of the current linear displacement engines reach micron and submicron accuracy [14]. By using these linear actuators, miniature and fully optical switches of high accuracy and high-speed data streams switching can be built.

Each linear-input motion actuator affected by the signals received from the control unit (shown as a square in figure 3) can be in a passive (flush) or active (vertical) position.

As indicated in Figure 4 and Figure 5, the semi-transparent mirror can transmit an optical ray (Fig. 4a and Fig. 5a) in a passive position, or divert it at an angle of 90°, dividing it into two equal streams (Fig. 4b and Fig. 5b).

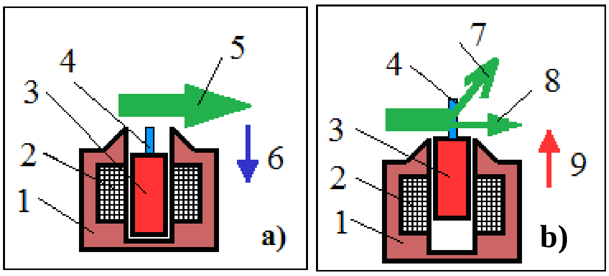

Fig. 4. Electromagnetic actuator of reciprocal motion

Here, 1 is an actuator base, 2 - solenoid, 3 - anchor, 4 – semi-transparent mirror, 5 - optical ray of a direct passage, 6 - direction of the anchor's movement (drowning of the semi-transparent mirror) down, 7 - deflected ray, 8 - ray transmitted through the semi-transparent mirror, 9 - direction of the anchor's movement (raising the semitransparent mirror) upwards.

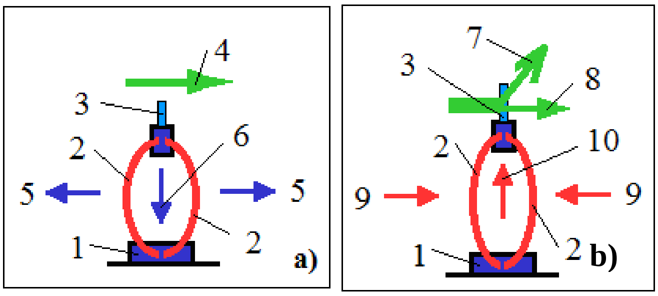

Fig. 5. Kinematics of a system with flat spring-loaded plates

Here, 1 is the base, 2 -spring-loaded plate, 3 - semi-transparent mirror, 4 - optical ray of the straight passage, 5 - plate drawing force, 6 - direction of the reduction in the system height (drowning of the semitransparent mirror) down, 7 - deflected beam passed through a semitransparent mirror, 9 - plate compression force, 10 - direction of increasing the system height (lifting the semitransparent mirror) up.

A distinctive feature of the system with flat spring-loaded plates (Figure 5) is that due to the spring-loaded drive [15], the system returns to its primary (initial) position, when the operating voltage is removed. The system uses both an electromagnetic and a piezoelectric actuator of translational motion as an actuator.

Piezo motors of linear displacements operate respectively in sub-micrometer and micrometer, second and minute ranges. Their frequency range is limited to the area up to the first electromechanical resonance.

Packet construction [7] is built based on packet type actuators. They can consist of disks, rings, cylinders, etc. Figure 6a presents the simplest design version of such engine. The piezo package 2 consists of piezodiscs and power transmission pads installed in the body 1. The mechanical contact of the rod 3 and the body 1 is implemented through the steel centering balls 5. The plate spring 4 serves to provide a preliminary compression of the package. Semitransparent mirror 6 is rigidly fixed on the operating element 3. Such an engine serves for linear micro-displacements.

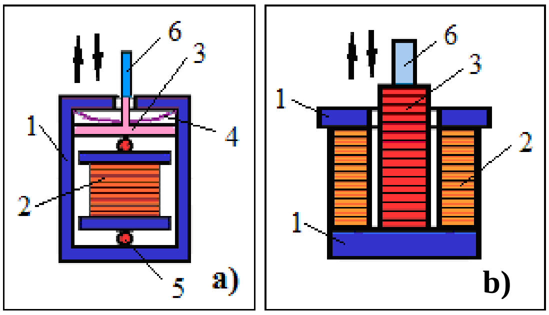

Fig. 6. Packet and differential piezo-motors of translational motion

Here 1 is the basis, 2 - piezo package, 3 - operating element (rod), 4 - spring, 5 - steel ball, 6 - semitransparent mirror.

The frequency range of the packet piezoelectric motor is limited by its own electromechanical resonance, the scope of which depends on the magnitude of the object to be moved, and the range of movement from 2 to 50 mkm depends on the number of elements and the control voltage. Figure 6b shows the differential construction on the package type elements, which is used when it is necessary to compensate for the temperature error (thermal expansion of the operating element) and to increase the range of movements without significant change in the magnitude of the actuator voltage and dimensions.

Such construction can be built both on the packet type elements and on bimorph elements [7]. Operating element 3 consists of piezoelectric elements made in the form of washers (disks), while the element 2 consists of rings. Both elements are attached to the movable base 1. The free end of element 3 performs operating displacements with a semitransparent mirror 6 rigidly fixed on it. The control voltage is applied simultaneously to both elements, subsequently the element 2 expands and the element 3 contracts.

The operating principle of the switch

In this section, some examples of the principle of the operation of optical switches are provided. Each mirror can be in a passive (flush) and (or) active (vertical) position. Later on, the active mirrors are described in the form of thick solid lines, whereas the passive mirrors are shown in the form of thin lines. As mentioned above, the operating surface of all semitransparent mirrors is covered with a layer of 50% reflection coefficient and 50% transmission of the optical flux. Figure 7a illustrates that all the light beams are divided into streams with the required power. The light beam λ_1 from the port Imp 1 is reflected from the semitransparent mirror and enters the port

Outp 2. The light beam λ_2 from the port Imp 2 is transferred to the port Outp 3. Finally, the light beam λ_3 from the port Imp 3 is sent to the port Outp1.

In the example illustrated in Fig. 7b, all the light beams are similarly divided into streams with the required power. The streams λ_1, λ_2 and λ_3 from Imp 1, Imp 2 and Imp 3 also pass a similar path according to Figure 7a. Moreover, in contrast to Figure 7a, all the streams λ_1, λ_2 and λ_3 are simultaneously transmitted to Outp 4, Outp 5 and Outp 6 in the form λ_1, λ_2 and λ_3 accordingly.

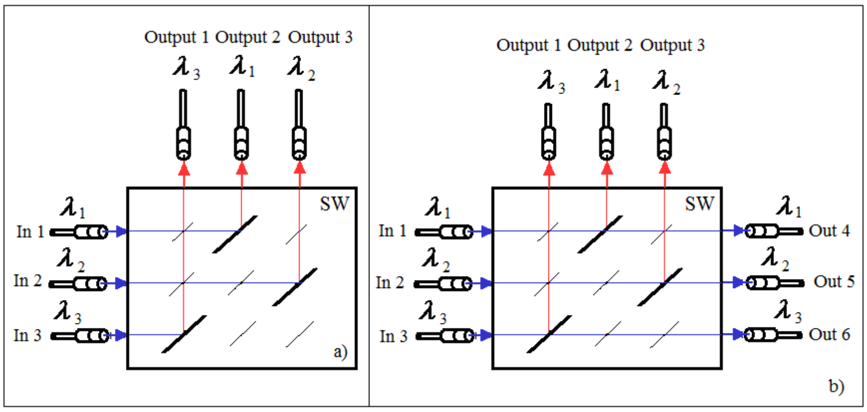

Fig. 7. Operation Principle of the optical switch-repeater

In the example in Figure 8a, all the light beams are divided into streams with the required powers.

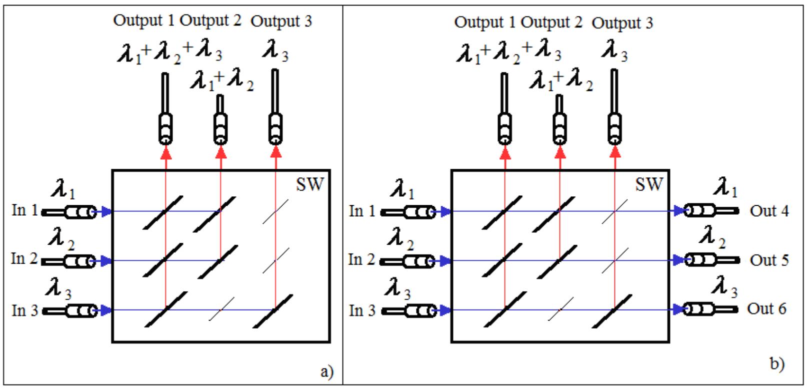

Fig. 8. Switching of input optical signals

The first part of the streams λ_1, λ_2 and λ_3 from Imp 1, Imp 2 and Imp 3, respectively, are reflected from own semi-transparent mirrors and is summed in port Outp 1 as $\lambda_1 + \lambda_2 + \lambda_3$. The second part of the stream λ_1 and λ_2 from Imp 1 and Imp 2, passing through the first semitransparent mirror and being reflected from the second semitransparent mirror, is respectively summed in Outp2 as $\lambda_1 + \lambda_2$. The stream λ_3 from Imp 3, passing through the first semitransparent mirror and reflected from the third one, is transmitted to Outp3 as λ_3. In the example in Figure 8b, all the light beams are similarly divided into streams with the required powers. Furthermore, the streams λ_1, λ_2 and λ_3 from Imp 1, Imp 2 and Imp 3 pass a similar path according to Figure 8a, and in addition, in contrast to Figure 8a, all streams λ_1, λ_2 and λ_3 are simultaneously transmitted to Outp 4, Outp 5 and Outp 6 as λ_1, λ_2 and λ_3 respectively. The example in Figure 9 illustrates an optical switch, where all light beams can simultaneously pass in a reciprocal way with different wavelengths and combinations, and they are previously divided into streams with the required powers.

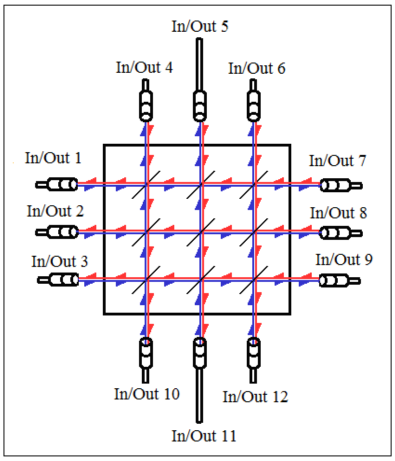

Fig. 9. Multifunction Switch

According to Figure 9, all ports are both input and output ports.

Conclusion

Given the principle of the operation of the optical switches described in Figure 7 and Figure 8, we can conclude that, based on the proposed scheme, it is possible to develop a multifunctional fully optical switch (Fig. 9). Thus, a unique principle of constructing a multichannel and multifunctional optical switches was proposed. It was shown that the proposed principle expands the functionality of an optical network.

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