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Method of parallel switching of optical channels

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Abstract. **The possibility of creating parallel-type switches for $N \times N$ optical waveguide channel communication is studied. A method based on bit-by-bit channel addressing is proposed and one of its possible implementations using the photorefractive effect in the waveguide material is considered. The method is modelled by the example of switching of 8×8 channels, controlled by reconfigurable matrix of light signals.**

Keywords: *switching optical signals, photorefractive waveguide, assembly – channel compaction.*

1. Introduction

Today it is impossible to imagine modern high-performance computing, communication systems, signal processing, and control systems without the use of optical technologies. On the one hand, this is a consequence of fast development of waveguide and integrated optical devices, and on the other hand, this is dictated by the requirements to increase information capacity of channels and speed of message processing as well as to improve reliability of communication systems.

Development of all-optical communication networks [1], providing due to optical technologies and components, maximal parallelism and reliability in the implementation of multiplexing, regrouping and other functions required for switching, is in progress.

The goal of this work was to create a simple and efficient all-optical method for switching $N \times N$ optical channels, based on bit-by-bit channel addressing and providing the desired commutation simultaneously for all channels, without interruption or crossing of optical paths, and with minimised latent time of channel-to-channel connection.

In the paper we describe the method itself and one of the ways of its possible implementation.

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2. Method of parallel switching of $N \times N$ waveguide optical channels

The proposed method of bit-by-bit parallel (non-crossing) switching of $N \times N$ optical channels is schematically illustrated in Fig. 1 by the example of an eight-channel (three-bit) device.

At the first stage two operations are fulfilled: the operation of channel doubling ($1'$) with separation on 0 and 1 in the highest digit of addresses and the operation of double reduction of the number of channels (channel compaction) ($2'$) in both arms by means of the assembly of opened (signal) channels and removing closed (without a signal) channels. As a result, in both arms four signal channels remain. At the next stages the same operations are performed for the next digits of addresses. This leads to the fact that at the second stage ($1''$, $2''$) four arms with two signal cannels are formed, and at the third stage ($1'''$, $2'''$) eight arms with one signal channel are formed. Each of them brings a light signal to the selected address.

It is clear that for the number of channels $N = 2^n$ one needs n stages to connect each of N channels with one of N given addresses. For 16-, 32, 64, and 128-bit switches the number of stages equals to 4, 5, 6, and 7, respectively. From Fig. 1 it is also seen that in the proposed method all channel connections are executed parallel within each bit of address.

Simultaneous doubling of all channels may be easily implemented using an optical splitter, and the 0-1 sorting by means of an array of light modulators. As splitter one can use an optical cube (Fig. 2) composed of two prisms *1′*. Here the pair of arrays *2′*, one of which is always an inverter, i.e., specifies not unit address bits, but zero ones, can be implemented on the basis of electro-optical crystals, e.g., lithium niobate. By switching on the appropriate modulators, one can selectively transmit light, thus providing the signal addressing.

3. Modelling of the switching process by means of photorefractive waveguides

The main problem in the implementation of a parallel switch using the proposed method is the operation of parallel assembly, i.e., simultaneous compression of channels in all arms by removing the gaps, i.e., the channels free of informative signal. The choice of the waveguide medium, maximally suitable for implementing the assembly function, is one of the main problems in designing switches of the described type. Below we present the result of modelling an 8×8 switch in photorefractive waveguides, considered as one of such media.

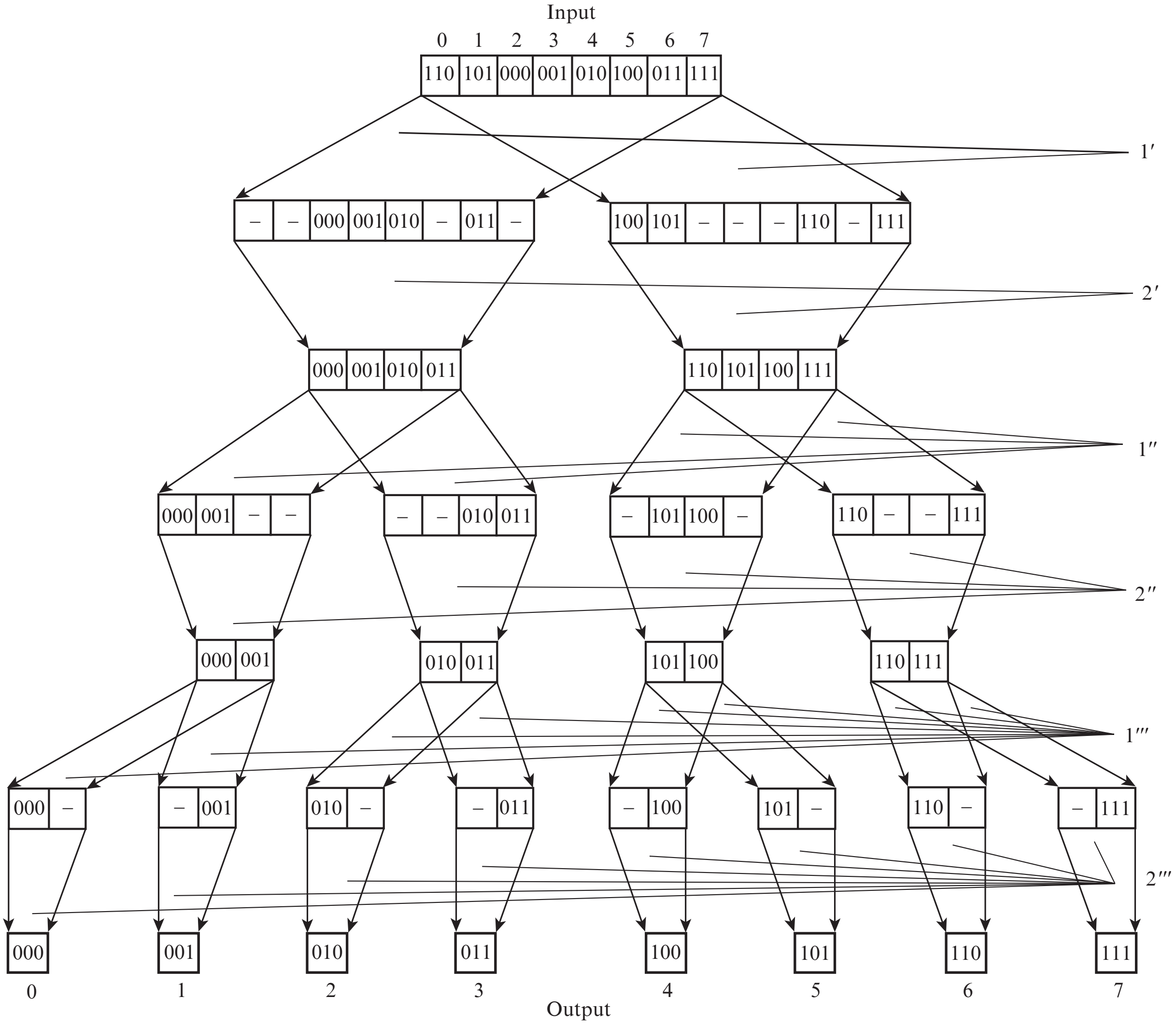

Figure 1. Schematic diagram of a $N \times N$ switch of parallel type with eight channels.

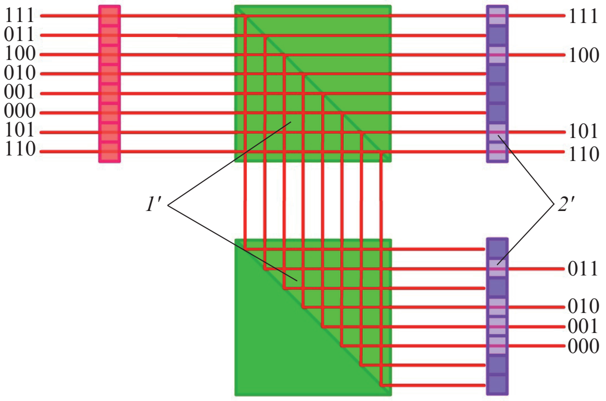

Figure 2. Example of implementation of doubling operation in eight information channels by means of optical cubes *1′* and addressing of channels at the first stage (by the high-order bit) using light modulators *2′*.

To control the transmission of signals from one waveguide to another in the process of channel assembly (multiplexing), a reconfigurable matrix of light signals is used, having the radiation wavelength, to which the switched connections of waveguide channels are sensitive. The connections are determined by the input and specified addresses using a computer, and according to the results of calculation the light beams are produced, spatially matched with the location of switchable connections of waveguide channels. Due to the photorefractive effect, under the action of the light beams, coming from the matrix of light emitters (MLE) or from the spatial light modulator (SLM), the refractive index of the material of waveguide connections is changed, which provides the transmission of information into the appropriate waveguide.

Figure 3 presents the schematic diagram used in the model and illustrating the principle of all-optical control of switching of the adjacent channels, made of photorefractive material, in order to transfer optical power from one channel into another. As an example, four channels are shown with two data flows being input. In the MLE (*1*) the appropriate cells are addressed, and the optical signals from them pass through the optical mask and/or the holographic optical element (HOE, necessary when the laser radiation is used) (*2*), where they acquire the needed configuration and then arrive at those locations (connections) of the photorefractive waveguides (*3*), which redirect the optical data flow in the prescribed direction.

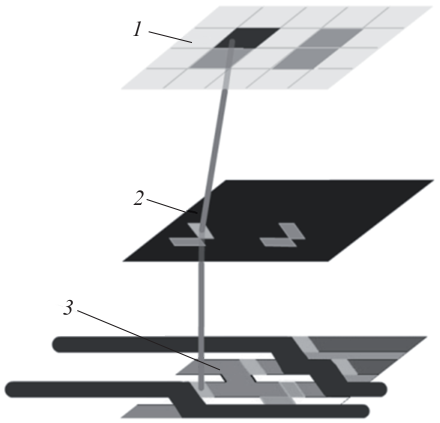

Figure 3. Schematic diagram of implementation of the channel assembling operation using photorefractive waveguides:
(*1*) MLE (or SLM); (*2*) optical mask (or HOE); (*3*) photorefractive waveguides.

It is important that the implementation of optical control does not require feedback elements, in contrast to Ref. [2], and is executed for all bits simultaneously, due to which the control of channel switching is essentially simplified, and the process becomes faster.

The general scheme of operation of the eight-channel switch, modelled for the case when the channel commutation is finished and the data flow propagates through them, is presented in Fig. 4. The switch comprises optical gates *1*, implemented on the basis of light modulators and playing the role of input ports of the switch; semitransparent cubes *2′*, *2″*, and *2‴*, each composed of two prisms; arrays of modulators *3′*, *3″*, and *3‴*, used for signal addressing; and photorefractive waveguides *4′*, *4″*. Figure 4 also shows the connections of photorefractive waveguides *5′* and *5″*, in which under the action of optical signals *8′*, *8″* from the MLE (or SLM) *6′*, *6″* the refractive index of material is changed. As a result, the optical data flow passes into the adjacent open waveguide and propagates through it. For each combination of light beams a special previously programmed combination of control signals is supplied into the MLE (or SLM). The optical masks (or HOEs) *7′*, *7″* are necessary here for specifying the desired configuration of optical signals at the photo-excited segment of the waveguide. Input and output switched flows are denoted by figures *9′* and *9″*.

The calculations show that for 8-, 16-, 32-, 64-, and 128-bit switches 64, 352, 1664, 7296, and 30720 controlling light beams are required, respectively, which is rather simple to implement practically using the available MLEs or SLMs.

In the considered switch one can use different optical elements without changing its architecture. For example, the role of optical splitters may be played not only by double-prism optical cubes, but also by semitransparent mirrors, HOEs, or other elements, designed for the same purpose. In the compact and rapid-action optical modulator arrays one can use not only the lithium niobate modulators, but also the ones, made of other electro-optical materials, including integral optical, micro-mirror, and semiconductor (e.g., on the base of Franz–Keldysh effect) modulators.

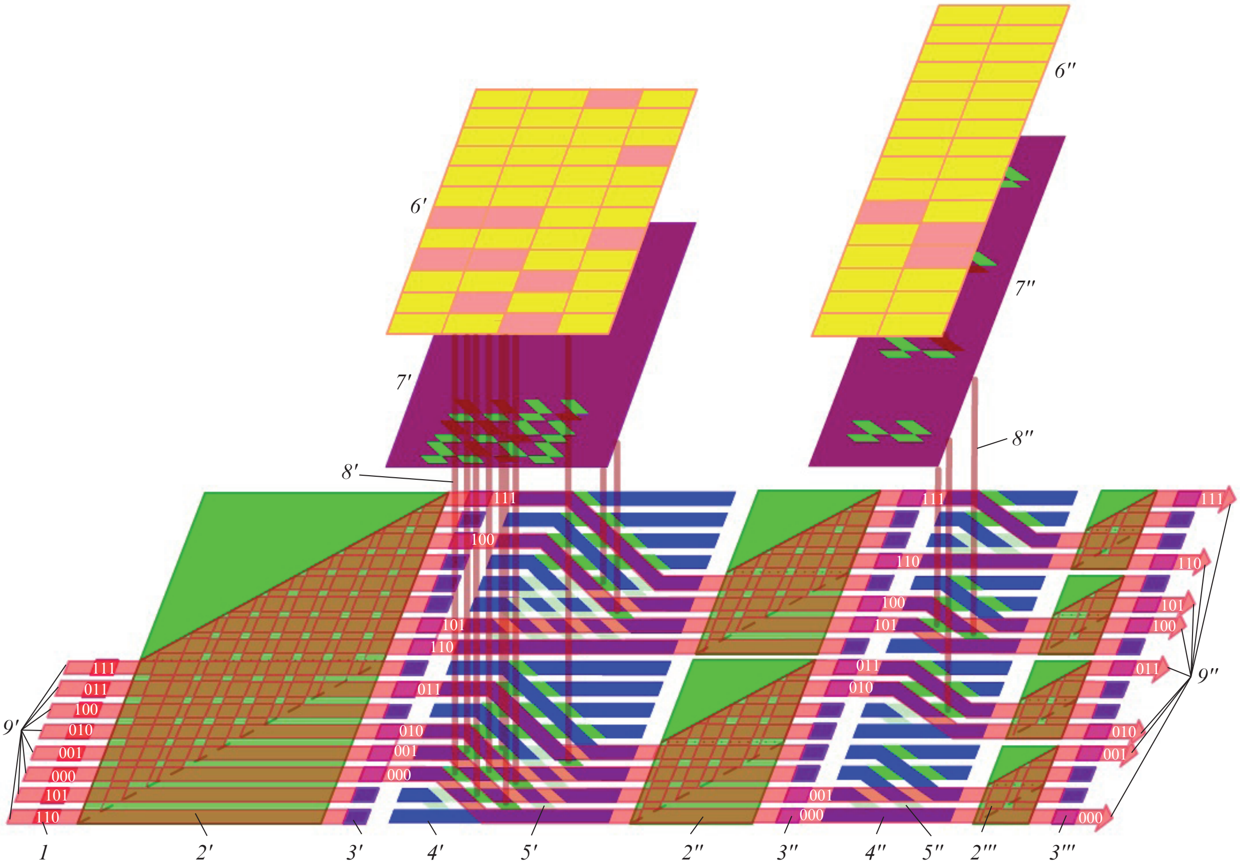

Figure 4. Modelled scheme of multichannel switch operation using the photorefractive effect (by the example of an eight-channel device).

For spatiotemporal modulation of the controlling optical radiation, to which the photorefractive material is sensitive, it is preferable to use the most rapid micro-mirror modulators or liquid-crystal modulators on the base of ferroelectric smectics. The holographic optical element may be fabricated using photorefractive crystals, chalcogenide glass, silver-halogen and other materials, possessing high diffraction efficiency, and insensitive to this radiation. Moreover, the HOE may be replaced with a spatial mask, if the used radiation is emitted by non-laser sources, e.g., photodiodes.

In multibit switches one will have to provide amplification of optical flows (with conservation of their information characteristics) by means of compact semiconductor or fibre lasers and matching elements.

The authors of the present paper still have to make the choice of particular elements for implementing the switch design, which will also allow estimation of its mass, overall dimensions and energy characteristics.

4. Conclusions

A method of bit-by-bit (starting from the high-order address bit) parallel switching of $N \times N$ optical channels is proposed, that differs from the known switching methods [3–5] in simplicity and reliability due to the absence of channel crossing. For the number of channels $N = 2^n$ all N channels can be connected with given N addresses via n stages. At each stage the operation of doubling of the channel number (with sorting the addresses with respect to 0 and 1 in the current bit) is performed followed by compression, in which the channels, free of informative signal, are eliminated.

The operation of parallel assembling – compaction of channels – is the most difficult one. Here it is implemented by using photorefractive waveguides and parallel optical control of connections, the location of which is determined by means of a computer using the input and the specified addresses.

The operation of a switch with photorefractive waveguides is modelled by the example of 8 × 8 channels with simultaneous irradiation of all switched connections by the light beams that modify the refractive index of the material of the waveguide connections and thus provide the transmission of information signals into appropriate waveguides.

Note, that the proposed parallel architecture of a multichannel switch, as well as the method of optical control of channel switching, is applicable also to various switches of electric signals.

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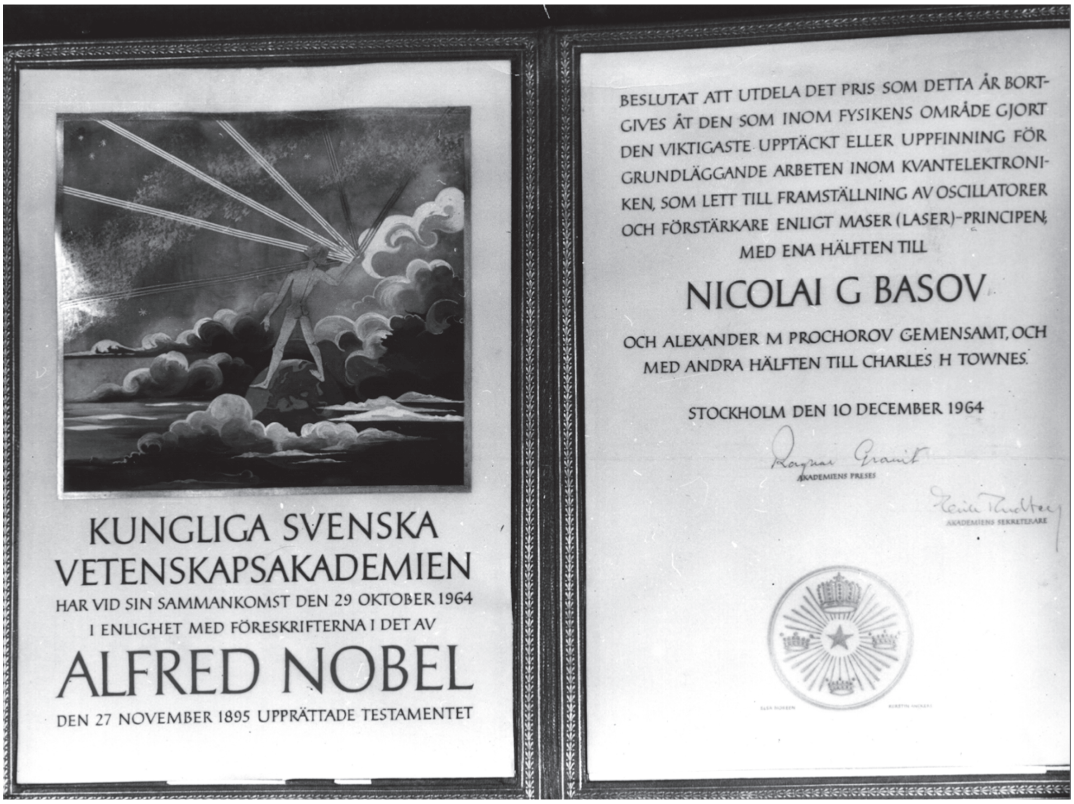

KUNGLIGA SVENSKA
VETENSKAPSAKADEMIEN
HAR VID SIN SAMMANKOMST DEN 29 OKTOBER 1964
I ENLIGHET MED FÖRESKRIFTERNA I DET AV
ALFRED NOBEL
DEN 27 NOVEMBER 1895 UPPRÄTTADE TESTAMENTET

BESLUTAT ATT UTDELA DET PRIS SOM DETTA ÅR BORTGIVES ÅT DEN SOM INOM FYSIKENS OMRÅDE GJORT DEN VIKTIGASTE UPPTÄCKT ELLER UPPFINNING FÖR GRUNDLÄGGANDE ARBETEN INOM KVANTELEKTRONIKEN, SOM LETT TILL FRAMSTÄLLNING AV OSCILLATORER OCH FÖRSTÄRKARE ENLIGT MASER (LASER)-PRINCIPEN;
MED ENA HÄLFTEN TILL

NICOLAI G BASOV

OCH ALEXANDER M PROCHOROV GEMENSAMT, OCH
MED ANDRA HÄLFTEN TILL CHARLES H TOWNES.

STOCKHOLM DEN 10 DECEMBER 1964

Ragnar Granit
AKADEMIENS PRESES

AKADEMIENS SEKRETERARE

Nobel Prize Laureate diploma in Physics (1964).