The control system elements of the new generation optical switching cell

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Abstract. The new generation switching self-adjusting cell for optical communication systems has been proposed by authors early. Now we present the control system of such a cell. The controlled system includes Bragg filter, frequency detector, optical isolator, and former of a control signal. Here we describe the elements of the scheme: optical isolator, frequency detector, controlled Bragg filter for third transparent window (1550nm). The reflection and transmission coefficients are obtained, the passbands of the Bragg filter are presented, and amplitude characteristic of frequency detector is calculated. To calculate we use accurate analytical methods.

1. Introduction

Today, due to the increasing requirements for the throughput of telecommunications networks, the optical switch design issues become important [1]. There are different architectures of space optical switches which have been discussed in [2-5]. Most of them consist of 2x2 switching cells. We are developing space switches on base of 4x4 and 8x8 elements [6,7]. The feature of our switches is the control method. In general, when a new call arrives at the switch, a connecting path has to be established between one of its inputs and one of its outputs by the external control unit or to be determined by the control switching elements inside the system. Existing external control devices are electronic and limit the speed of optical switching. We proposed the new generation optical switches based on the control elements inside the system. [6,7] The controlled system includes Bragg filter, frequency detector, optical isolator, and former of a control signal.

2. The optical switching cell structure

The next-generation optical switching cell 4x4 developed by us consists of the buffer device and the switching unit (figure 1) [6].

The functional principle of the cell is based on frequency separation of control and information signals. Here an input optical signal consists of a control signal with the wavelength λ_c and an information signal with the wavelength λ_i. These signals are separated in the Bragg filter (BF) of the switching unit. This Bragg filter is actually an isotropic stratified periodic structure. Thus, a control signal with λ_c is reflected from the surface of the Bragg filter and transmitted to the optical isolator (OI) and an information signal transmits through the structure and transmits to the detection system (DS). Then a control signal transmits to the frequency detector (FD) from the optical isolator. The detection system is a controlled photonic crystal. Actually it is multilayered structure including ferromagnetic, optoelectric, thermoelectric or ferroelectric films. The properties of this film can be charged by an external control signal (voltage, current, thermal or optical radiation) and therefore a transmitted angle can be controlled by an external signal. We choose the material controlled by an external magnetic field in our system: ferrite-garnet. It is important that it is the only existing magnetic controlled material in the optical domain. The frequency detector converts the frequency deviation of the control signal into its amplitude deviation. It also is inhomogeneous isotropic structure with linear dependence of the reflection coefficient on a frequency in the operating domain [8,9]. The amplitude-modulated optical signal from the frequency detector is transmitted to the optical signal former (OSF) that includes a controlled light emission diode and low frequency scheme of solenoid control. The operating principle of the deflecting system (DS) is described in [10]. This system has one input and four outputs. For effective control of cell functioning, it is necessary to use two signals with different values. The combination of these two control signals determinates the necessary output.

It is obvious that the buffer-multiplexing device must be used in this scheme as the deflecting system has four outputs and only one input (figure 1). The buffer device includes the optical integrated device (OIU) and the four controlled delay lines (DL). The optical integrated device contains the optical multiplexer and the intermittent device. Let us consider the functional principle of the buffer device. It is assumed that an input signal is arrived at one of the delay lines (DL1, DL2, DL3, DL4). This signal transmits to the integrated optical device of the buffer if no signals are present at other inputs at this time. The intermittent device generates a prohibition signal for the other inputs. Note additionally that the optical integrated device performs spatial multiplexing of signals from four inputs.

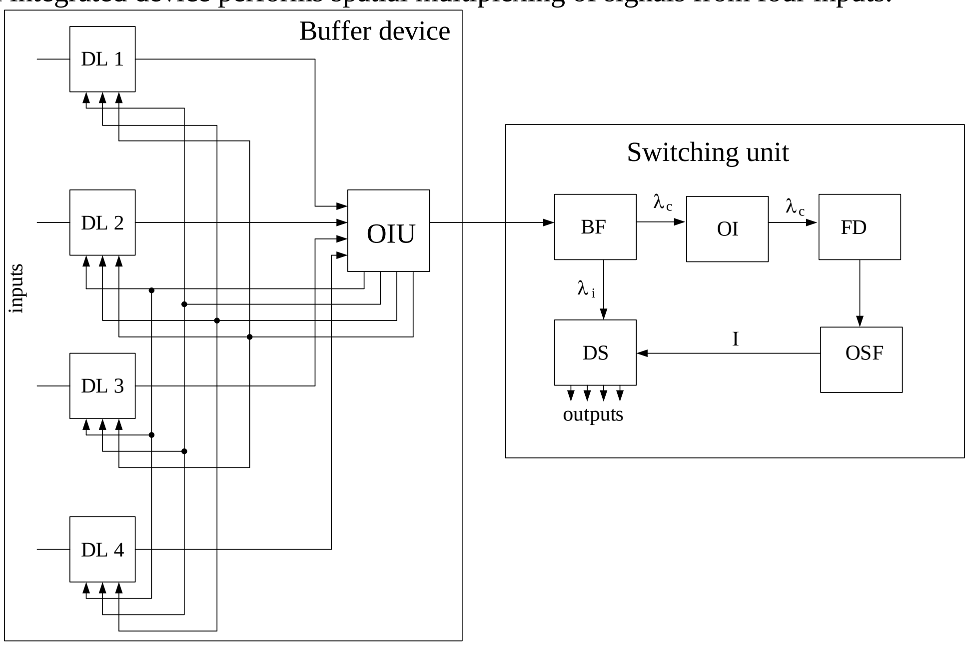


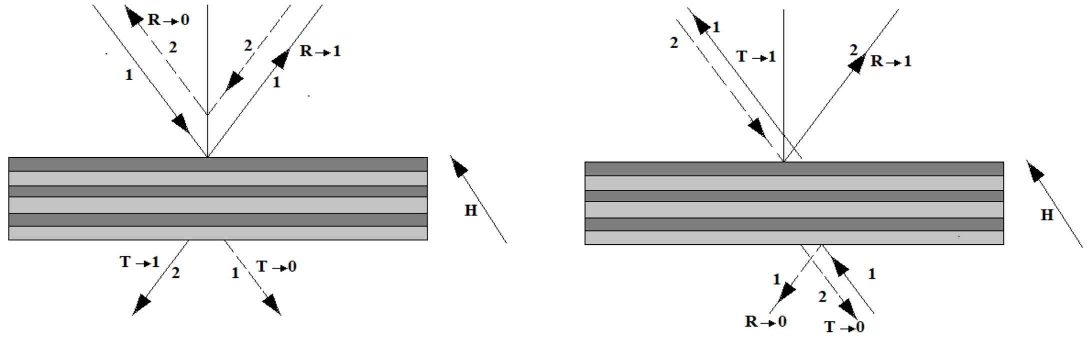
Figure 1. The 4x4 switching element.

3. The optical isolator

The optical isolator is designed to transmit a control signal in one direction only. The operation principle of the optical isolator is shown in figure 2. The isolator contains a radar, a receiver, and a stratified slab. The main element of this isolator is a stratified anisotropic slab possessing nonreciprocal properties. Non-linear properties of the presented isolator is based on a dependence of the medium properties, in particular reflection and transmission coefficients, on an incident angle and an orientation of an external magnetic field. It is important that such properties don't appear in the cases of a normal and tangential orientations of a magnetic field.

For today, we can propose the two types of the isolators. The optical isolator shown in figer 2a is functioning as reflected structure and the one functioning based on transmission principle (figure 2b).

Let us consider the first principal (figure 2a). If an incident control signal passes in the direction 1 than the reflection coefficient is about unit and a maximum power propagates to the receiver (the direction 1). The transmission coefficient is about zero in this case. If an incident control signal passes in the direction 2 than the reflection coefficient is equal to zero and a signal propagates through the slab but not propagates to the radar.



a) b)

Figure 2. The optical isolator a) reflection principle b) transmission principle.

Now let us consider the second structure principal (figure 2b). If an incident control signal transmit along the direction 1 than the transmission coefficient is approximately unit and a signal transmits through the slab to the receiver. In the case of incidence from the receiver (direction 2) a signal is totally reflected and it does not transmit to radar.

A very important characteristic of an isolator is it's amplitude response. During the researches it has been carried out numerous calculations and it has been chosen the optimal structure. [11] This structure includes the 12 double-layered periods. The first layer is FeF_2 and the second one is MnO. Here it is taken $f = 1.93 \cdot 10^{14}$ Hz, $\beta = 30^o$, $\psi = 50^o$. The dependences of the reflection coefficient on an incidence angle for this structure (the amplitude characteristic) are presented in figure 3. It is seen that the reflection coefficient is minimal (R=0.05) at $\alpha = 76.4^o$ and the one is unit at $\alpha = -76.4^o$ for $\beta = 30^o$ (the solid line).

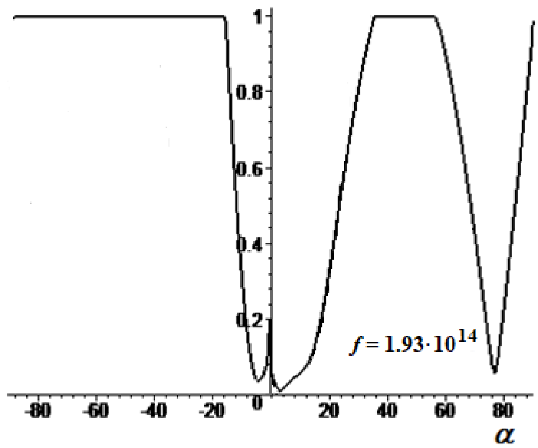


Figure 3. The dependence of the reflection coefficient on the incidence angle for $f = 1.93 \cdot 10^{14}$, $\beta = 30^o$, $\psi = 50^o$.

Thus this structure has the isolator properties and it passes a signal only in a forward direction and doesn't pass a signal in an opposite direction.

Figure 4 shows the results demonstrating the possibility of mechanical tuning of the isolator by changing the angle of the anisotropy axis inclination. The minimum shifts from $\alpha = 72^o$ to $\alpha = 82^o$ if inclination angle changes from $\beta = 25^o$ to $\beta = 40^o$. Simultaneously, the angle bandwidth is narrowed and it is equal to 28º, 10º, and 6º correspondingly. Decreasing the inclination angle less than $\beta = 25^o$ and increasing it more than $\beta = 50^o$ leads to disappearance of the angle selective properties of the structure.

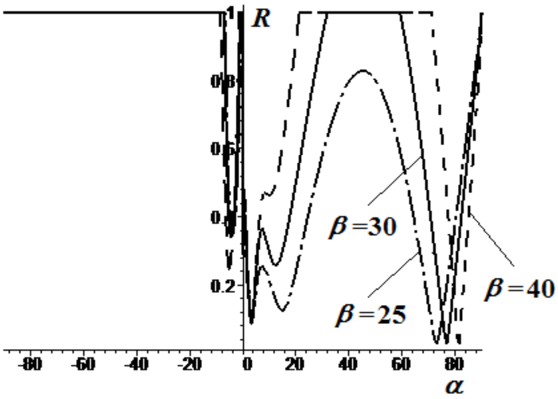


Figure 4. Dependence of the reflection coefficient on an incidence angle for difference inclination angles β at the frequency $1.93 \cdot 10^{14}$.

4. Optical Frequency Detector

Here we also offer frequency detector based on a 1D anisotropic photonic crystal (stratified anisotropic structure). This demodulator transforms a frequency modulated signal to an amplitude modulated signal. Note that the analogous method has been used in the radio frequency domain [8]. For the demodulation it has been used an ordinary electrical oscillating circuit. The central frequency of a signal, in this case, must correspond to a linear interval of the resonance characteristic (figure 5).

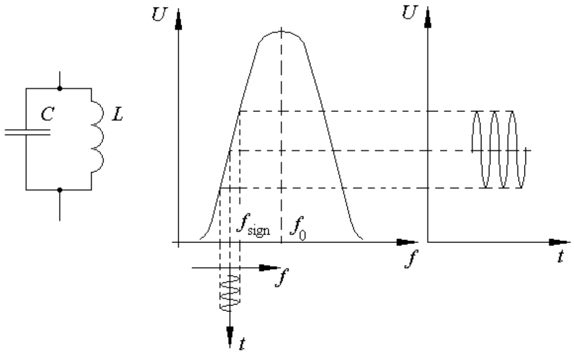


Figure 5. Principle of transformation of a frequency modulated signal to an amplitude modulated.

To realize the described method we used an anisotropic stratified structure with an arbitrary orientation of the anisotropy axis. The important is the fact that a wave is propagating along a slab ($\alpha_{\text{inc}} = 90°$). The functioning principle of the one is based on the so-called "penetration" effect and a dependence of the reflection coefficient on an anisotropy axis orientation.

For this in this work a dependence of the reflection coefficient on an anisotropy axis orientation are studied for the case of tangential propagation of an incident wave (along the y-axis (figure 6 a).

Our main aim is studying a dependence of reflection coefficient on an orientation of the anisotropy axis for the case of a tangential wave propagation and investigating practical applications of the obtained results for a tangential wave propagation under a structure ($\alpha_{\text{inc}} = \pm 90°$) for the arbitrary angles θ, φ (figure 6b), and finding the practical applications of these properties.

Let us consider a dependence of a reflection coefficient on a frequency for $\alpha_{\text{inc}} = 90°$ presented in figure 7. It is seen that this characteristic is resonant and additionally the one is approximately linear in the resonance domain ($f_0 \pm \Delta f \approx 1.93 \cdot 10^{14} \pm 0.03 \cdot 10^{14}\ Hz$). If $f_0 = 1.93 \cdot 10^{14} Hz$ is a center frequency, then for a frequency deviation $2\Delta f = 0.06 \cdot 10^{14} Hz$ the reflection coefficient varies in accordance to the law of an input signal in the scope of $R_0 \pm \Delta R \approx 0.6 \pm 0.3$. Therefore the amplitude of reflected signal varies in accordance to the same law. Thus this structure transforms a frequency modulated signal to an amplitude modulated one. Then an amplitude modulated oscillation can be detected by the well-known approaches.

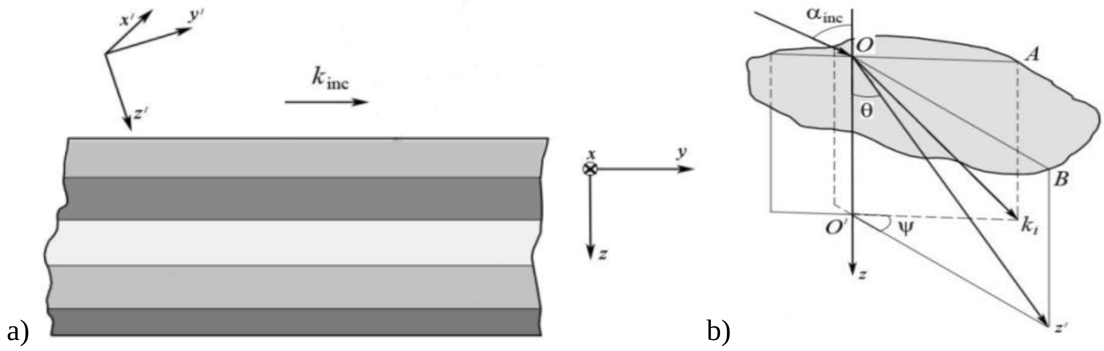


Figure 6. Geometry of the problem: a) a cross-section of a one-dimensional crystal; b) an orientation of the axes within a single layer ($\boldsymbol{k}_i$ is a wavevector of i-th eigenwave within a single layer, $\alpha_{\text{inc}}$is an incidence angle , θ is an inclination angle, φ is an angle between an incidence plane and a plane including an anisotropy axis).

The considered principle can be used in any frequency domain as choosing parameters of a structure it is possible to obtain an analogous resonance characteristic in any frequency domain.
It is obvious that an analogous device can be created for the case of a normal incident wave and the case of an oblique incidence. In our view dimensions of a device must be smaller in the case of tangential wave propagation.

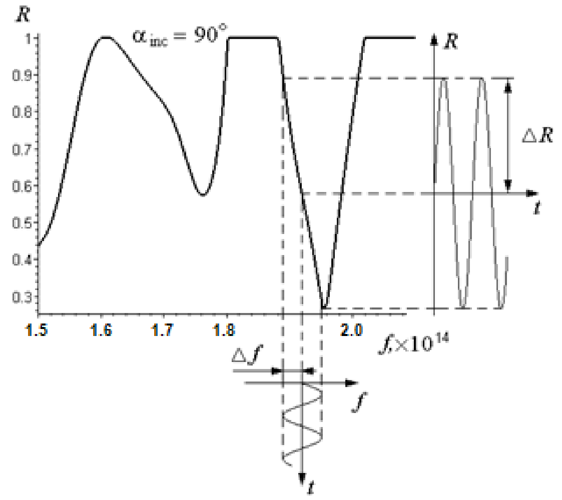


Figure 7. The illustration of principle of frequency detector; it is studied a slab containing 12 double layered periods for $\theta = 5°$; $\varphi = 87°$.

5. Bragg filters

The Bragg filter is used for separating a control signal and an information signal. The pass interference filters under a normal incident of an electromagnetic wave is studied. The filter is based on a plane-parallel isotropic stratified structure.
The calculation of the main optical parameters for the three structures of multi-layered interference filters is carried out in [12]. The layer thickness is multiple of quarter of the wavelength.
The initial data for the calculation are taken in accordance with [12]: the central wavelength of a filter is from 780nm to 1600nm, type of a filter by spectral characteristic is narrow band pass, bandwidth at the level of 3dB is less than 100nm, level of the assured decay is more than 40dB, a total thickness of a multilayered structure is 0.2–1.5mm. A medium is isotropic, lossless, without frequency dispersion. The geometry of the problem is shown on figure 8.
The results of the interference multilayered filters calculation are discussed in this section of the paper. For the calculation the characteristic matrix method [13] and the method of the needle variation of the

refractive index of the layer's material of coating [14] are used for obtaining the best kind of an amplitude-frequency characteristic in the passband.

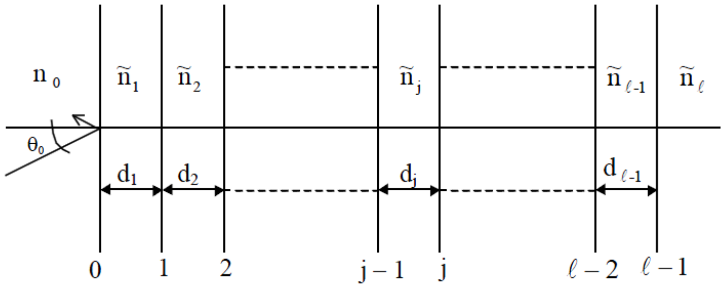


Figure 8. The multilayered optical structure of the filter [9]: $n-$ index of refraction, $d-$ layer thickness, θ – angle of wave's incidence.

During a research with the use of [13] and [14] the three structures of filters are got with the different number of layers and sequence of materials with the different indexes of refraction. So, a filter with a structure 1 ($H34L2(HL)H46L2(HL)H44L2(HL)H34LHG$) contains of 21 layers, where H – a material with the index of refraction $n = 2.3$ and the thickness is quarter of wave-length, L is a material with the index of refraction $n = 1.38$, G is a base sheet of glass with the index of refraction n=1,52. The filter structure 2 (1,35M1,07L0,7M1,27H2(LH)L4H7(LH)L2H8(LH)L4H8(LH) L2H8(HL)4H3(LH)LG) is obtained by using the method [8]. Here M is a material with the refraction index 1.32, H is a material with the greater index of refraction 2.16, the refraction index of L is 1.46, and G is a glass substrate with the refraction index 1.52.
Applying the method [13] to the described in that work structure we obtain the resulting filter with the structure 3 containing 82 layers that can be described as: $1{,}35L\ 1{,}3H\ 2(LH)L4H\ 7(LH)L2H\ 8(LH)L4H\ 8(LH)L2H\ 7(LH)L4H3(LH)G$ (structure 3), where H is a material with the refraction index of n=2,16, L is a material with the refraction index n=1,46, G is the glass substrate with n=1,52.
In figure 9 it is shown an amplitude-frequency characteristic of the filter based on the structure (3). This filter (3) is characterized by the followings parameters: half-width is $\delta\lambda_{0.5} = 16{,}1$nm, decimal width is $\delta\lambda_{0.1} = 21{,}8$nm, slope of characteristic is $\eta = \delta\lambda_{0.1}/\delta\lambda_{0.5} = 1{,}35$, bandwidth at the level of 1dB is $\Delta\lambda_{1\mathrm{dB}} = 13{,}3$nm, bandwidth at the level of 3dB is $\Delta\lambda_{3\mathrm{dB}} = 14{,}7$nm, minimum insertion loss is 0,102dB, maximum insertion loss is 0,245dB, ripple of amplitude-frequency characteristic is 0,143dB, level of the assured fading is 103,54dB, adjacent channel isolation is 24,7dB, non-adjacent channel isolation is 65,7dB, thickness of the stratified slab is 0,206mm, transmittance in a maximum is $T_{max} = 97^0$. The filter with a structure (3) has the best characteristics of the calculated ones. It has more even amplitude-frequency characteristic in the pass band, see figure10. In figure 10 the bandwidths of the obtained filters (1-3) are presented also.

6. Conclusion

In this work the control system of the 4x4 next generation switching cells is presented for the first time. These new cells are all-optical and self-tuning and these cells can be functioning without an external control system. The development of all optical switching elements is an important stage of all optical communication networks transition. The inside controlled system of the cell includes Bragg filter, frequency detector, optical isolator, and former of a control signal. These devices are described in our paper and the calculations of the it's parameters are presented. First, the function principles of these devices are considered and also we obtained the amplitude characteristics of the offered structures in the third transparent window. The optimal structure parameters and reflection and transmission coefficients of the optical isolator are obtained. The reflection coefficient is 0.05 at the incident angle is 76.4º and the one is unit at the incident angle is -76.4º. The optimal parameters and amplitude frequency dependence of the frequency detector are calculated too. We obtained that in the considered case a slab must contain 12 double-layered periods, and it is seen that amplitude frequency dependence is approximately linear in the resonance domain $1.93 \cdot 10^{14} \pm 0.03 \cdot 10^{14}\ Hz$. The passband of the Bragg filter is presented, and amplitude characteristic of frequency detector is calculated. We obtained that the bandwidth of the Bragg filter structure at the level of 1dB is $\Delta\lambda_{1\text{dB}} = 13{,}3$nm, bandwidth at the level of 3dB is $\Delta\lambda_{3\text{dB}} = 14{,}7$nm.

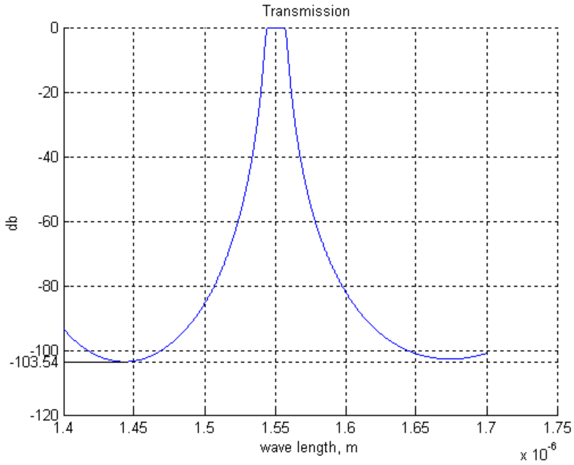


Figure 9. The amplitude-frequency characteristic of the filter (3).

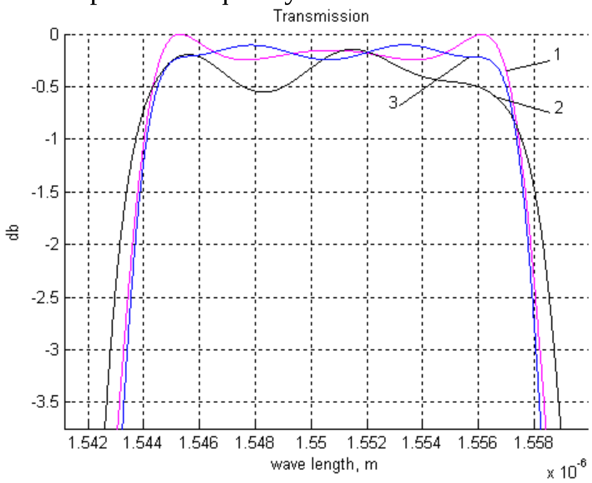


Figure 10. Bandwidths of the got filters: 1) the filter with the structure (1); 2) the filter with the structure (2); 3) the filter with the structure (3).

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