OPTICAL PACKET PROCESSING BY USING ACOUSTO-OPTIC SWITCHING IN TELECOMMUNICATION NETWORKS

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Abstract

We present experimental characterisations of a 2×2 acousto-optic switch. The switch, developed for telecommunication networks, is based on phased array transducers. The choice of a compact structure implies the superimposition of two diffraction gratings, each one being associated with one optical beam input. In what follows, we present the switch architecture and some experimental characterisations.

Introduction

All optical switch networks play an important role in high bandwidth applications such as telecommunications, notably to avoid the electrical bottleneck. Optical packet switching seems to be a good way to carry information flows through telecommunication networks. The concept of optical packet switching allows the transparency to data payload bit rate and permits to overcome the limitation imposed by the electronic bandwidth. Systems using optical packet switching exploit the best of both electronics and optics. Many researches have been performed on the application of photonic technologies to routing and switching systems to enhance node throughput [1,2].

Among several proposed technologies for optical packet processing, the acousto-optic technology is attractive because it presents some interesting characteristics such as low losses, a short configuration time, and no moving parts [3]. By using the acousto-optic interaction, we take an interest in a 2×2 switching function for telecommunication applications at 1.55 µm wavelength. In order to develop a compact component, we create simultaneously two Bragg gratings in the same TeO_2 crystal using phased array transducers. Each diffraction grating is associated with only one of the two inputs. An optical beam coming from one of the inputs must interact with only the corresponding phase grating in order to assume the correct operation of the switch. One of the diffraction gratings has to be tilted with respect to the other one in order to match perfectly the output beam directions. Each grating is built up by the association of acoustic wave fronts generated by the multi-element transducer array. The transducer elements are driven separately by RF signals. The acoustic beam steering angle is controlled by the phase shift imposed between the RF signals applied on each elementary transducer.

In this paper, we first give the principle of optical packet switching. Then, we present the 2×2 switch architecture based on phased array transducers. In the second part, we present some experimental characterisations of the acousto-optic cell. The static performances of the developed system in terms of diffraction efficiency and optical losses are evaluated. We present the measurements concerning the diffraction efficiency when only one phase grating is generated in the crystal, and then when the two phase gratings are generated simultaneously. We also discuss the generation of some physical phenomena in the Bragg cell and their influence on the switch working.

Principle of the acousto-optic switch

Main objective

The devised system may switch optical packets coming from optical inputs towards optical outputs. The optical packet contains a header with a fixed bit rate and information data bits. An important characteristic is the guard time between two successive packets. The minimum admissible in our configuration is fixed to 300 ns. This format is a simplified shape of the one used in the KEOPS project [2]. We have developed a 2×2 switch, presented in Figure 1, in order to prove the feasibility of such a switch device. Its action consists in sending the optical packets from the input 2 towards the output A (respectively B) and simultaneously the optical packets from the input 1 towards the output B (respectively A). It is constituted by an optical part which allows switching optical packets to the right direction and an electrical part which detects the presence of packets, processes and drives the acousto-optic deflector. Optical packets, at the entrance of the switch, are synchronized with respect to a reference clock, in order to obtain a correct working.

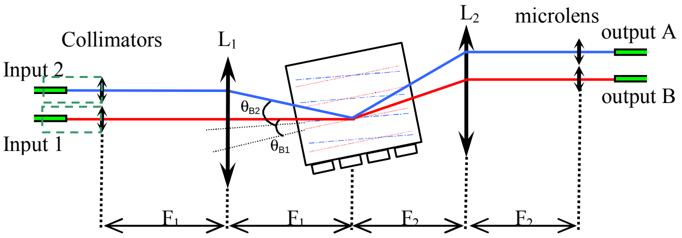


Figure 1: Optical packet switch (only the optical part is shown)

The optical part is made by associating free-space acousto-optic deflectors to optical fibre system. The incident light beams are controlled by two acousto-optic deflectors. Two Bragg gratings are created simultaneously in the same crystal. Each diffraction grating is associated with only one of the two inputs. An optical system made with 2 microlenses (collimators) associated with the lens L_1 are used to adjust precisely the incident optical beam angles on the acousto-optic cell in order to satisfy Bragg conditions. Then, after passing through the acousto-optic cell, a similar optical system is used for optical beam coupling into single mode optical fibres (the Fourier lens L_2 and 2 refractive microlenses).

We will now get interested in the acousto-optic cell architecture.

Acousto-optic cell architecture

In order to develop a 2×2 switch, we superimpose in one crystal two phase gratings with different directions. Those phase gratings are generated by two RF signals with frequency f_1 (grating 1) and f_2 (grating 2), applied simultaneously to the piezoelectric transducers. Each grating acts as a deflector for one of the optical inputs, and should have a weak influence on the other input. To superimpose two phase gratings with different propagation directions of acoustic waves, we use a cell with planar phased array piezoelectric transducers. This technique, well known to increase the acoustic frequency bandwidth of deflectors, is now used to build two separated acoustic wave-fronts.

Figure 2 presents the architecture of such a component. Each grating is built up by the association of acoustic wave-fronts generated by the multi-element transducer array. The transducer elements are equally spaced and are driven separately by RF signals of equal amplitude.

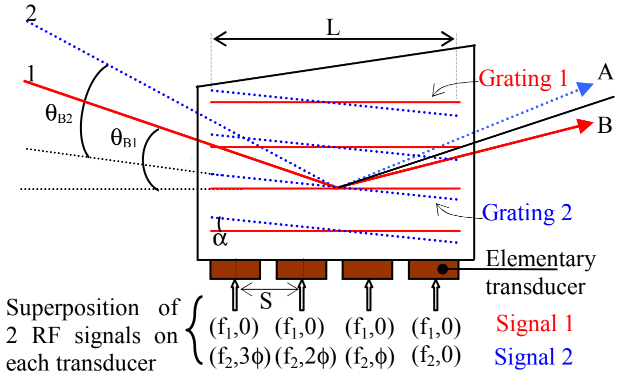


Figure 2: Architecture of the 2 × 2 switch.

Each deflector, associated to one input optical beam (1 or 2), acts respectively around a given Bragg frequency f_{B1} or f_{B2} (grating 1 or grating 2); then the corresponding Bragg angles are different [4]. As a consequence, the tilt, α, of the diffraction grating 2 is necessary to ensure same output directions for both input optical beams. This tilt, $\alpha = \theta_{B2} - \theta_{B1}$, is achieved by the application of an electric phase shift ϕ between neighbour transducers for the signal at frequency f_2.

Figure 3 shows the two required diffraction efficiency curves. The diffraction efficiency corresponding to each grating has to be separated from the other in order to avoid optical losses. The central frequency for each diffraction grating (f_{B1}, f_{B2}) must be then chosen distant enough. The optical beam from input 1 goes through its diffraction grating under Bragg incidence θ_{B1} (defined for f_{B1}). The frequency f_1 can be equal to $f_{1A} = f_{B1} + \Delta f/2$ to connect input 1 to output A, or $f_{1B} = f_{B1} - \Delta f/2$ to connect input 1 to output B. In the same way, the optical beam from input 2 goes through its diffraction grating under Bragg incidence θ_{B2} (defined for f_{B2}), and the RF frequency f_2 can be equal to $f_{2A} = f_{B2} + \Delta f/2$ or $f_{2B} = f_{B2} - \Delta f/2$.

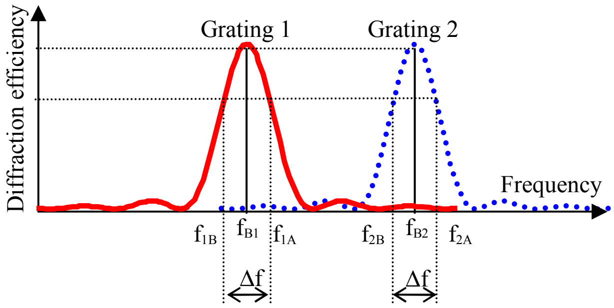


Figure 3: Diffraction efficiency as a function of RF frequency for two gratings superimposed in the same crystal, as shown in figure 3.

An acousto-optic cell, with TeO_2 crystal used in progressive and longitudinal mode along [001] has been made. The cell is equipped with four piezoelectric transducers. The center frequency for respectively the grating 1 and 2 is *75 MHz* and *110 MHz*. The frequency bandwidth for both gratings is $\Delta f = 20$ *MHz* ($f_{1B} = 65$ *MHz*, $f_{1A} = 85$ *MHz*, $f_{2B} = 100$ *MHz* and $f_{2A} = 120$ *MHz*). The required electric phase shift ϕ for the signal at frequency f_2 is equal to *97 degree*.

Experimental characterisations

In order to assess the static performances of the 2×2 switch, acousto-optic cell characterisations are presented, in terms of optical diffraction efficiency for different configurations of electric driving. The following results about diffraction efficiency are obtained for the optical polarisation providing the best result. The incident laser beams with a diameter of 470 µm give a configuration time about 110 ns. All measurements are made at 1.55µm wavelength.

Diffraction efficiency with one supplied RF signal

In this part, we are interested in the measurement of the diffraction efficiency when only one RF signal is applied to each piezoelectric transducer. This measurement of the diffraction efficiency is carried out for a large frequency bandwidth, from 60 MHz to 125 MHz. The optical beam incidence direction under the phase grating is fixed. The results give us information about the switch operation, giving the influence of a rebuilt diffraction grating on the optical beam.

Two series of measurements are presented in Figure 4 for a RF power applied to each elementary transducer equal to *200 mW*. First, the incidence angle is fixed to the Bragg condition for $f_{B1} = 75\ MHz$. In that configuration, the maximum diffraction efficiency is about *58%*. Secondly, the incidence angle is fixed to Bragg condition for $f_{B2} = 110\ MHz$. In that case, an electric phase shift $\phi = 97$ *degree* is applied between neighbour transducers in order to tilt the phase grating with the correct positioning. The maximum diffraction efficiency is then of about *36%*.

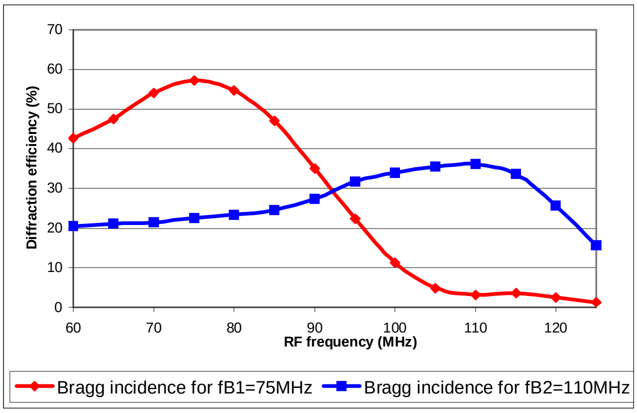
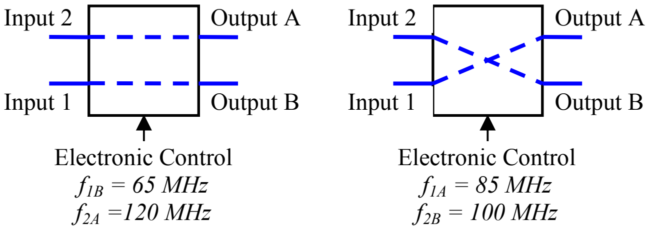


Figure 4: Diffraction efficiency for the two gratings. The optical beam matches the Bragg criterion for $f_{B1} = 75\ MHz$ and then for $f_{B2} = 110\ MHz$.

We can notice that the grating 1 ($f_{B1} = 75\ MHz$), for which there is no phase shift applied between neighbour transducers, allows large diffraction efficiency at Bragg incidence and a significant decrease all around. The grating 2 ($f_{B2} = 110\ MHz$), for which the phase shift is applied, enable a lower maximum diffraction efficiency and a slower decrease around the Bragg angle. If we define a RF frequency bandwidth at $-1.5\ dB$, this bandwidth is equal to *27.5 MHz* for the grating 1 while it is equal to *33.6 MHz* for the grating 2. As a consequence, in the switch operation, the grating 2 may act on the optical beam associated to the grating 1. In fact, the tilt of the phase grating 2 with respect to the phase grating 1 increases the angular separation between the diffraction efficiency curves in space. So, it reduces the unwanted effects of one grating over the unassociated optical beam.

Diffraction efficiency with two supplied RF signals

In this part, we study the static performances of the switch in terms of diffraction efficiency. We only considered the two configurations used in the switch working, i.e. bar configuration $f_{1B} = 65\ MHz$ and $f_{2A} = 120\ MHz$ (Figure 5-a), then cross configuration $f_{1A} = 85\ MHz$ and $f_{2B} = 100\ MHz$ (Figure 5-b). The optical beam incidence matches Bragg incidence for $f_{B1} = 75\ MHz$, then $f_{B2} = 110\ MHz$. A phase shift $\phi = 97$ *degree* is applied between neighbour transducers for the RF frequency f_2. The power for each RF signal applied to each elementary transducer is fixed to *200 mW*.



(a) bar configuration, *(b) cross configuration*

Figure 5: 2×2 crossbar switches connect.

We first estimate the interaction between the two diffraction gratings, and its influence on the switch operation, we measure the diffraction efficiency values for both configurations; first when only one grating is generated and then when both phase gratings are created.

RF Frequency Output	$f_{1B} = 65\ MHz$	$f_{2A} = 120\ MHz$	f_{1B} and f_{2A} simultaneously
A		26 %	24 %
B	47 %		36 %

Table 1:Diffraction efficiency for RF frequencies f_{1B} and f_{2A} applied to the transducers.

RF Frequency Output	$f_{1A} = 85\ MHz$	$f_{2B} = 100\ MHz$	f_{1A} and f_{2B} simultaneously
A	48 %		41 %
B		34 %	30 %

Table 2: Diffraction efficiency for RF frequencies f_{1A} and f_{2B} applied to the transducers.

The tables 1 and 2 show the decrease of the diffraction efficiency between the cases where one single RF signal then two RF signals are applied on each transducer. As a consequence, one grating possibly acts on the optical beam which is not associated, creating optical losses. In reality when two sinusoidal RF signals at different frequencies are applied on a crystal, some spurious optical diffracted beams may appear. The presence of spurious diffraction modes is the result of two different phenomena [4, 5, 6]. First, the *dynamic intermodulation products*. The beam diffracted from the phase grating formed by one of the RF signal, can be rediffracted again by the phase grating formed by the second RF signal. This produces cross modulation and generates intermodulation beams corresponding to sum and difference frequencies. In turn, additional intermodulation beams may be generated. Secondly, the *elastic intermodulation products*. An acoustic wave becomes distorted as it propagates, due to acoustic nonlinearities, and this distortion is the source of harmonic generation. However, when two sinusoidal RF signals are propagating in a crystal, not only the harmonics of each, but also the sums and the differences of these harmonics will be generated [7].

We have recorded the beam profiles for each switch configuration (cross and bar) in order to estimate losses generated by these effects. Figure 6 shows the beam distributions measured in the Fourier plane of the lens L_2 (Figure 1) for both configurations. The RF power is fixed at $200\,mW$ and each profile is normalized by the incident optical beam energies. Precise details about frequencies, output and order for all important beams are noted in Figure 6.

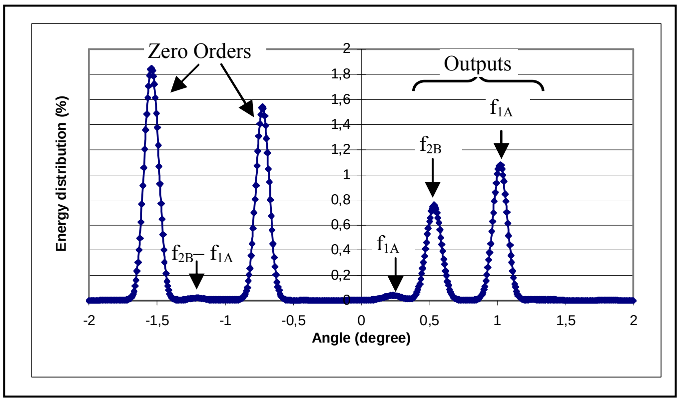


Figure 6-a: Beam profiles in cross configuration

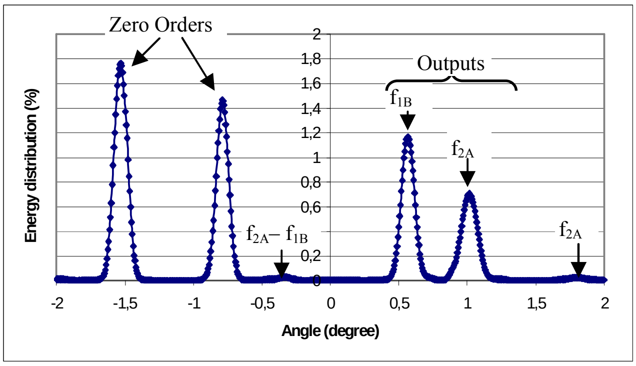


Figure 6-b: Beam profiles in bar configuration

First, we can remark that spurious effects are not significant. In the cross configuration, the most significant are, for input one, the diffracted beam generated by the intermodulation products at the frequencies $f_{2B}-f_{1A}$ and, for the input two, the one generated by the grating 1 with a frequency f_{1A}. Moreover, the diffraction angles of these unwanted beams are sufficiently different from the diffracted angle of the useful signals in order to avoid overlapping. However, some noise can be added on useful signals, through beams diffracted from the grating generated at $2f_{1A}$-f_{2B} and $2f_{2B}$-f_{1A} [7]. The measurement shows that those two unwanted beams have negligible diffraction efficiencies.

In the same manner, the Figure 6-b shows two unwanted diffracted beams generated respectively by the grating 2 on the first input at the frequency f_{2A} and by the intermodulation products at the frequencies $f_{2A}-f_{1B}$ on the second input.

The useful beams are inclined by 1° and 0.58° with respect to the transducer plane for both configurations. They are well separated that avoid overlapping between outputs and allows negligible optical crosstalk. In most cases the diffraction angles of unwanted beams are sufficiently different from 1° and 0.58° in order to avoid spatially interference with the useful signals.

Conclusion

In this paper, an optical packets switch based on an acousto-optic cell has been presented. We have described a schematic principle for the switch setup. Then, a characterisation of the acousto-optic deflector has been carried out showing the suitability of this component for optical packet switching. Afterwards, we have shown the performances of the device by the diffraction efficiency measurements on the acousto-optic cell when both phase gratings are generated in the crystal. In our experimental conditions, we have shown that a TeO_2 crystal allows us to obtain better than -6dB diffraction efficiency with a low cross-talk (<35 dB) and with low non-linear and intermodulation effects.

The next works will investigate the dynamic performances of the switch..

References

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