1x2 Polymer optical fíber switches using nematic liquid crystals

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1 Introducción

Perfluorinated (PF) polymer based GI-POF (Graded Index Polymer Optical Fibers) has a low loss wavelength región from 500 to 1300nm [1-2] allowing implementation of coarse WDM in high-speed, reconfigurable POF networks. For doing so, compact, low loss, high isolation, low cost optic switches will be required. On the other hand, POF are becoming an attractive médium in sensor networks, specially in flammable atmospheres because optical fibers are intrinsically safe in nature, with no risk of explosión even under malfunction operation, because they are inert materials [3-4]. The optical technology has other advantages such as no EMI, low weight and as a transmission media: low loss and wide bandwidth. In those networks, being the security a fundamental matter, it is important to have redundant paths and optical elements for switching between them.

Many kind of optical switches have been reported. Nowadays, microelectromechanical systems (MEMS) [5-6] are quiet attractive due to its large scale integration, its fiber-to-fiber coupling, high crosstalk and speed, they use moving parts for switching. Switches based on liquid crystals (LC) cells [7-11] also cover the previous needs with no moving parts, low voltage driving, and low power consumption. However most of them are based on rather complicated structures [7-9] with a great number of elements. A simpler solution is given in [10] but a fibre optic circulator is needed which complícales its integration. An optical switch based on a NLC cell and 2 calcite Thompson-prism polarizing beam splitters is reported in [11]; but working at a single wavelength, not in combination with optical fibers, neither in a multimode configuration for POF networks.

LC switches are based on nematic [7,9,11,13] or ferroelectric liquid crystals (FLC) [8,12] and the last ones exhibit faster switching speeds. Although the novel structures reported in this paper can opérate with both LC cells, the developed prototypes used twisted nematic liquid crystals (NLC) because the devices must opérate at 650nm and 850nm simultaneously. The FLC cells should have different thickness *(d)* for a proper operation at each wavelength *(A);* because the optical birefringence of the FLC material, An, depends on *X* and to have a 90° polarization switch the product *An x d* must be a constant. In NLC cells, only the Mauguin's regíme, *And/A »1,* must be fulfilled at both *X's.*

With these issues in mind, this paper proposes compact, broadband fíber optic 1x2 switches with a reduced number of elements at the expense of a mínimum 3dB insertion losses, and their practical, low cost implementation using NLC cells in combination with plástic optical fibers. These NLC cells require low power levéis for working. Different confígurations are proposed to improve crosstalk figures. Fiber-to-fiber losses are in the order or even better than in other previous designs [12-13] and can be improved using better coupling schemes thanks to the high numerical aperture of the POF. These switches can be used in coarse WDM networks [14], POF LANs and sensor networks for allowing redundant paths and time divisíón multiplexing.

2 Fiber optic switch structures

The simplest structure of the 1x2 fibre optic switch [15], named SI, is shown in Fig.l. Only one polarization is processed for limiting the number of components. In POF multimode fibers, a random polarization will be always present at the input, so the device will opérate properly, but at the expense of a mínimum of 3dB insertion losses. In this 1x2 fibre optic switch, there are two states: straight state (from 1-2) and exchanging state (from 1-3) see Fig. 1. For changing states in the switch, a low cost 90° NLC polarization switch (PS) is used. Three sets of lenses are used, for collimating and focusing the líght. The others elements are a 90° polarizing beam splitter (PBS) and a polarizer, P. In our experiment, an s-polarizer filters the vertical s-polarized líght from the input power, that is 50% of the incident power in a multimode fibre. For the s-polarized beam, when PS is *off* the switch performs the straight state, SS mode. PS rotates the s-polarized beam to a p-polarized beam which pass through the PBS and it is focused to port2. But, when PS is *on* the

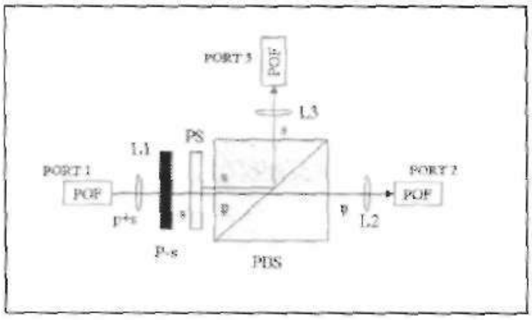

Figura 1: A schematic ofthe switch SI. POF: polymer opticalfibers; PS: NLC polarization switch, PBS: polarizing beam spliíter; P.polarizer; L: focusing/collimating lens

switch performs the exchanging state, ES mode. PS leaves unaltered the s-polarised beam that it is deflected 90° by the PBS towards port3. For monitoring purposes, two 90/10 POF splitters 91102TK0PP901 from Ratioplast, are used at each output. A photograph of the implemented device can be seen in Fig.2. A microcontroller, PIC16F877 of Microchip drives the NLC depending on the desired state of operation.

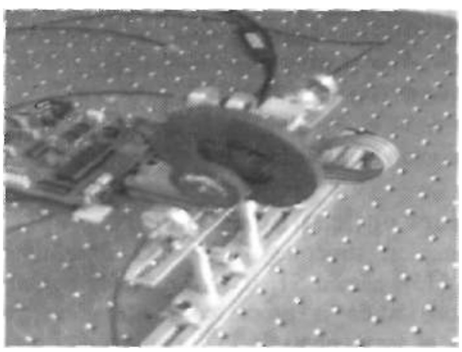

Figura 2: Photograph ofthe 1x2 multimode fiber optic switch implemented.

Other 2 novel structures (see Fig. 3) are proposed to improve the SI switch crosstalk; worsened by the rotations errors in the NLC cell [6]. The S2 switch has 2 new polarisers at each output of the PBS for filtering the undesired polarization component (s at port2 and p at port3). This configuration is used to verify the crosstalk improvement even using the same NLC. But the best results are obtained with the structure shown in Fig. 3, the switch named S3, which has 2 NLC cells and 2 cross-polarisers for each LC cell placed in the outputs.

3 Implemcntation and mcasurements ofthe 1x2 fíber optic switches

The 1x2 fiber optic switches were experimentally demonstrated using lens for collimating and focusing the light. The insertion loss, and the interchannel crosstalk of the switches were measured using 650nm semiconductor láser diodes ROITHNER 660/3LJ working at a central wavelength of 660nm. Switch operation in a lOMBd link was characterized using the transmitter HFBR-1528 (LED) at the input and the receptors HFBR-2528 at both outputs. The POF splitters are 90/10. The input and output fíber ports are made of POF (HFBR-E889328-C) with lmm core, a numérica! aperture of 0.447 and 0.25dB/m losses.

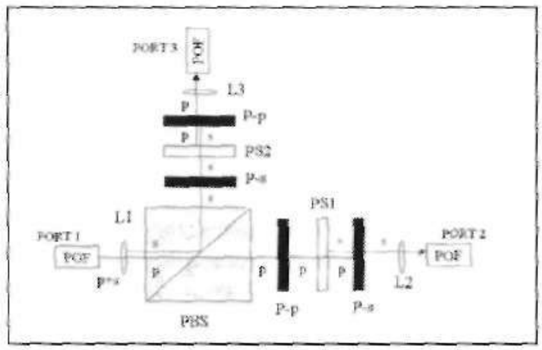

Figure 3. A schematic ofthe switch, S_i, with improved crosstalk.

The interchannel crosstalk is defined as -10 log (P2ON/P_3OFF) and -10 log (P_{3O}N/P2OFF) in the SS stage and ES stage respectively. The PBS has a crosstalk of-18.1dB and the NLC cell of-8.5dB, in both cases the worst valué has been considered. A summary of the measurements of the interchannel crosstalk of the switches in their different confígurations are shown in Table I.

Interchannel crosstalk dB	SI (PS)	S2 (PS)	S3 (PS1/PS2)
SS	-8.4 (OFF)	-16.4 (OFF)[1]	-21.3 (OFF/ON)
ES	-13.3 (ON)	-18.4 (ON)[2]	-26.4 (ON/OFF)

Table I. Worst case experimental measurements of the interchannel crosstalk for the different switching states. SS: Strait State from 1-3, ES: Exchanging State from 1-3, PS= NLC polarization switch (excitation state)
[1] P=P-p, p Polariser, ' P*=P-s, s Polariser.*

An interchannel crosstalk improvement of 13dB from SI to S3 is obtained. It can also be seen that S3 greatly improves the performance of the PBS and the NLC cell, having interchannel crosstalk levéis of -21.3dB and -26.4dB. In [6] it is referred a PBS with -40dB crosstalk, using that device in our switch S3, a crosstalk of -—44dB could be achieved with a simple switch. The improvement in S3 with respect to SI is due to order alteration, using PBS fírst instead of the poor NLC cell in terms of crosstalk.

For the switch SI, in the straight state, the fiber-to-fíber loss is <7.3dB; while in the exchanging state is <7.2dB. In any case, the main contribution is the 3dB intrinsic loss of the polarization sensitive switch and the 2dB POF coupling loss. This last one can be improved with a better coupling scheme. The NLC cell loss is <0.56dB. In S3, losses are higher, fiber-to-fiber losses are <9.6 dB and <9.3 dB in the straight state and the exchanged state respectively. They are comparable to previous reported results for other switches [11-12] and can be reduced using better BPS and NLC cells and reducing air gaps.

Optimum coupling to POF can be reached at a low cost [17]. Measurements are taken using a power meter RIFOCS 557B. The device operates at a low power consumption, requiring a ±8V drive signal for feeding the whole system.

The worst measured switching time is of 140ms, in accordance with the decay times of the nematic LC [7]. This is not a problem in sensor networks where the measurement time is not critical, low cost solutions are required and optical fibers are used because of their non electromagnetic interference and their intrinsic safety. As previously reported, a specific example is the oil tank level measurement using optical fibers in the petrol stations [4]. Anyhow this time response can be reduced (eg. 5ms) at the expense of increasing complexity and cost by using the high-voltage surface-mode or transient nematic effect [16] as previously reported in a NLC switch in [11]. Another feature of the device is that can opérate at 650nm and at 850nm. So we have measured the response of the NLC cell at both wavelengths for different excitation signáis. The NLC cell is placed between two broadband PBS, from Melles Griot 03 PBB 013, acting as two cross-polarizers. Depending on whether the LC cell is excited or not, the minimum or máximum transmission is obtained. The LC cell drive signal is a square wave at different frequencies: 100Hz, 1kHz, 10kHz and 100kHz. The following light sources from Roithner Lasertechnik are used in the characterization: 660/3LJ @ 660nm and LDM808/5LJM @808 nm.

A LC cell, different from the one used in the implemented device reported in Fig. 2, is used. The relative transmission (with respect to the máximum measured transmission value) versus the rms voltage of the driving square signal for different frequencies, can be in seen in Fig. 4 and Fig. 5. From those measurements we see that the NLC cell should be excited with a square signal with an amplitude >5Vrms and a frequency of lOKhz. The NLC cell works properly at both wavelengths reaching the ON/OFF stages at almost the same voltage ranges. So they can be used to implement the broadband switch for

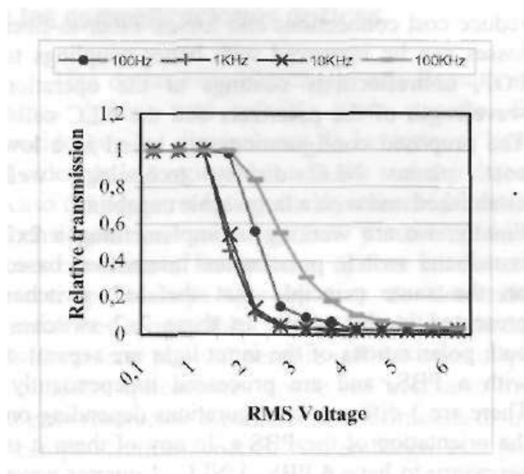

Figure 4. Measurements *ofa LC cell @* 660nm

working at both wavelengths. Other parameters of the LC cell that have also been measured are: insertion losses of 0,7 dB and a crosstalk of 14 dB @606nm and insertion losses of 0,9 dB and a crosstalk of 12 dB @808nm. Relaxation times of 33ms are measured for both wavelengths.

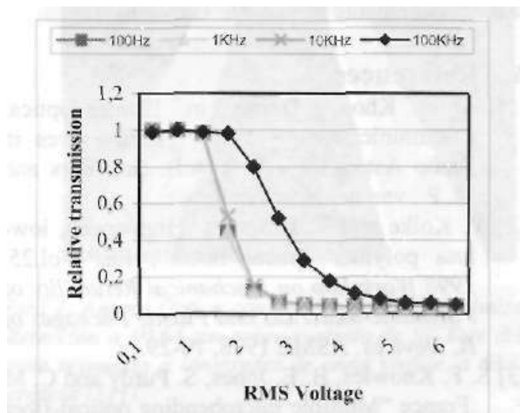

Figure 5. Measurements ofa LC cell @ 808nm.

4 Conclusions

Compact, scalable, broadband, high interchannel crosstalk fiber optic switch configurations are proposed along with their practical, low cost implementation, using NLC cells in combination with plástic optical fibers. These NLC require low power levéis for working. They are very attractive devices to be used in coarse WDM networks using PF GI-POF and in fiber optic sensor networks. Experimental results on implemented prototypes show crosstalk of -22dB with poor NLC cells in terms of polarizatíon crosstalk (-8.5dB). Better available PBS, can improve the crosstalk up to -44dB. Reduction in the number of elements is achieved at the expense of a mínimum 3dB insertion loss. High numerical aperture POF's reduce cost connections and losses. Fiber-to-fiber losses can be improved with better couplings to POF, antireflections coatings at the operation wavelength of the polarizers and the NLC cells. The proposed configurations are based in a low cost, planar NLC display technology well established and with a large-scale capability.

Finally, we are working in implementing a 2x2 broadband switch, polarization insensitive, based on the same principie that the 1x2 switches presented in this paper. In these 2x2 switches, both polarizations of the input light are separated with a PBS, and are processed independently. There are 3 different configurations depending on the orientation of the PBS's. In any of them it is necessary to have 4 PBS, 4 NLC, 4 quarter wave plates and 4 mirrors, and the optics for collimating the input light and focusing the output light.

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