IEEE SENSORS JOURNAL, VOL. 3, NO. 4, AUGUST 2003

Optical Router for Optical Fiber Sensor Networks Based on a Liquid Crystal Cell

Carmen Vázquez, *Member, IEEE*, José Manuel Sánchez Pena, *Member, IEEE*, Salvador Elías Vargas, Angel Luis Aranda, and Isabel Pérez

***Abstract*—Optical fiber sensor networks are evolving rapidly. They are used because of the inert nature of optical fibers allowing no electromagnetic interference and safe applications in inflammable atmospheres; other relevant characteristics are their low weights and wide bandwidths as a transmission medium. In any case, it is very interesting to have specific components such as optical routers for selecting a certain path in a network with no optical to electrical and electrical to optical conversions. In this paper, we propose an all-optical router based on liquid crystals, polarizers, and a spatial split polarization beam splitter. The implemented device is designed to operate with visible light and it has been tested with plastic optical fibers. It has a crosstalk of 14 dB between selected ON channels and nonoperative OFF channels and 11-dB insertion losses. An average switch time of 100 ms is measured. The device checks the optical power level in each channel and, in case of failure, automatically switches to an operative channel while an alarm is activated.**

***Index Terms*—Liquid crystal cell, optical router, sensor network.**

I. INTRODUCTION

OPTICAL FIBER network technologies are evolving rapidly, driven mainly by demands for enormous bandwidths on the data networks. This situation has made possible a significant progress of capacity in optical fiber systems. Wavelength division multiplexing (WDM) is currently one of the preferred technologies for building these optical networks. This technique is also used for sensor multiplexing [1], [2]. Optical networks require a variety of active and passive devices to accomplish connectivity such as switching and routing elements [3], [4]. These switching and routing elements use technologies that go from mechanical movement [5], passing through biconical wavelength division multiplexers [4], Faraday rotators and quarter wave plate components, MEMs [6], spatial filtering and acoustooptic tunable filters [7], to liquid crystal based routers [3], [8]. Plastic optical fibers (POFs) are increasing their use in fiber optic sensors and as transmission media in LAN and automotive networks [9], [10].

In this paper, we propose an all-optical router for use in optical sensor networks, but working at visible region wavelengths. This device is made of nematic liquid crystals (LCs) and other optical components having the capability to operate on light depending on its state of polarization. The implemented device has been tested with plastic optical fibers as the transmission medium. POFs are used because of their low transmission loss, their commercial availability at low cost, and their high flexibility and ease of use. Our router has a rejection ratio of 14 dB between selected ON channel and nonoperative OFF channel and 11-dB insertion losses. An average switch time of 100 ms is measured. The device checks the optical power level in each channel and in case of failure, automatically switches to an operative channel while an alarm is activated. So, it will be very useful in LANs using POFs, for example, to connect a main network (ring or bus) with a secondary network for security purposes. Another application is time multiplexing two optical sensor networks, increasing the capability of the final network. On the other hand, an implementation to 1550-nm range is straightforward using the version of the same components that work in that telecommunication window. In that case, the device can also be used for time multiplexing of individual wavelengths of the WDM spectrum, multiplying the capacity of sensor networks. Section II describes the different elements the device is made of. Section III gives the functionality analysis of the router. Section IV gives the experimental data; there are general measurements to show the feasibility of the device and specific parameters such as the insertion losses, the crosstalk, and the response time. Section V briefly shows the use of the router in conventional fiber sensor arrays and Section VI concludes the paper.

II. DEVICE ARCHITECTURE

The device has an optical part and an electronic part. In Fig. 1, a schematic of the optical part of the proposed device is shown. It is made of two sets of lenses, the first one to collimate the input light and the second one to focus on the optical power in any of the output fibers. There is a polarizer and a low cost nematic liquid crystal, with a low power consumption, to force a certain state of polarization in the incident beam depending on the electrical signal that excites the liquid crystal. A 90° spatial split polarization beam splitter (PBS) separates the incident optical beam into two orthogonal polarized beams with a 90° spatial deviation. Output lenses are used to focus PBS output light in the input arms of a 90/10 POF splitter; the 10% output port is used for monitoring the output power and the 90% output port is used for connecting the switch to the fiber link.

A. Liquid Crystals

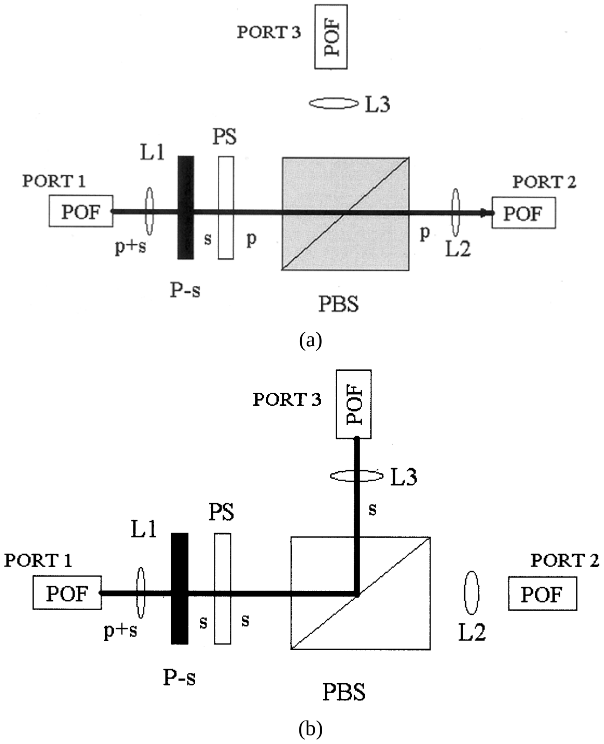
Liquid crystals are fluids which have orientational order because the long axes of the molecules lie roughly parallel to each

---

Manuscript received February 21, 2002; revised February 18, 2003. This work was supported in part by CAM under 07T/0011/2001 and in part by the Spanish CICYT under TIC2000-1594-C02-02. The associate editor coordinating the review of this paper and approving it for publication was Dr. Richard O. Claus.

The authors are with the Departamento Tecnología Electrónica, Universidad Carlos III, Madrid, Spain. (e-mail: cvazquez@ing.uc3m.es; jmpena@ing.uc3m.es; sevargas@ing.uc3m.es; aranda@ing.uc3m.es; isaper@ing.uc3m.es).

Digital Object Identifier 10.1109/JSEN.2003.815770



(a)

(b)

Fig. 1. Schematic of the optical part of the router in its two working states. POFs; PS: NLC polarization switch; PBS; P-s: s-polarizer; L1: input focusing lens; L2 and L3 output collimating lenses. (a) CH1 ON, the LC is not excited; (b) CH2 ON, the LC is excited.

other. The local average orientation of the long axis is represented by a unit vector called director [11]. A direct consequence of this ordering is the anisotropy of mechanical, electric, magnetic, and optical properties [12].

In order to build practical devices, liquid crystals are sandwiched between two transparent electrodes. The space between the electrodes is filled with liquid crystal. The thickness of the LC layer is kept uniform using spacers.

Liquid crystals are very sensitive to an electric field [11], and it is precisely this property which allows their application to optical device technology. There are several LC configurations that can be employed for optical applications. The geometry that occurs when the directors at both surfaces of the electrodes are perpendicular to eachother is called twist structure. In this geometry, the LC behaves as a uniaxial material, whose refractive index can be changed by using a small electric field applied in the perpendicular direction of the plane of the LC director. Typically, two polarizers are placed on both electrodes with their transmission axes parallel to the LC director.

The operation of a twisted nematic device is based on the waveguiding property. In the absence of an applied electric field, the light polarization vector follows the director and, consequently, the structure rotates such vector an angle of 90°. This specific waveguide regime (Mauguin's regime) takes place when the phase delay satisfies the following condition [11]:

$$\frac{\Delta n d}{\lambda} \gg 1$$

where Δn is the optical birefringence of the LC material, d is the thickness of the LC layer, and λ is the wavelength of the light.

On the other hand, when the applied voltage exceeds a certain threshold value, the director deviates from the initial orientation and shows a tendency to orient perpendicular to the electrodes (if $\Delta n > 0$, as it is usually). In this case, the average value of Δn decreases and at a certain voltage (optical threshold of the twist effect), the waveguide regime vanishes. When this condition occurs, the LC behaves as an isotropic medium.

B. LC and PBS as Parts of the Router

In general, the switching function requires a path selection mechanism that can be used in conjunction with a PBS to choose the direction of the output path of the light. In the PBS, if incident light is horizontally polarized, the ray path is not modified coming out of the PBS in the same direction [see Fig. 1(a)]. If input light is vertically polarized, the ray is diverted ±90°, depending on the cube face under used [see Fig. 1(b)]. In our device, if we control the polarization state of the input light falling on the PBS; we can, thus, control the path chosen by the output light beam.

As previously mentioned, a twisted nematic LC cell with a single polarizer in the front of the LC cell (to ensure a beam of linearly polarized light) can meet such condition. In the absence of an applied voltage, such a device would rotate the input polarization by approximately 90° [situation shown in Fig. 1(a)]. If, however, a sufficient voltage is applied to the LC cell, the twist of the LC director is eliminated and the light is transmitted with no change of its polarization state [see Fig. 1(b)].

In order to eliminate elliptical polarization states of the transmitted light, the LC cell should operate at Mauguin's regime. Since we have used a commercial LC mixture (E7, BDH) with a birefringence of $\Delta n = 0, 23$ at $\lambda = 500$ nm, and a thickness $d = 20$ μm, we can reasonably assume that such condition is satisfied.

The PBS is a cube beamsplitter 03PBB003 from Melles Griot operating from 450 up to 680 nm with a p-polarized light transmittance and s-polarized light reflectance >95%.

C. Optical Fiber Splitter and Lenses

Lenses are used to collimate input light and to focus output light. The following lenses are mounted.

Input: $\phi = 25, 5$ mm $f = 25$ mm, biconvex lens.

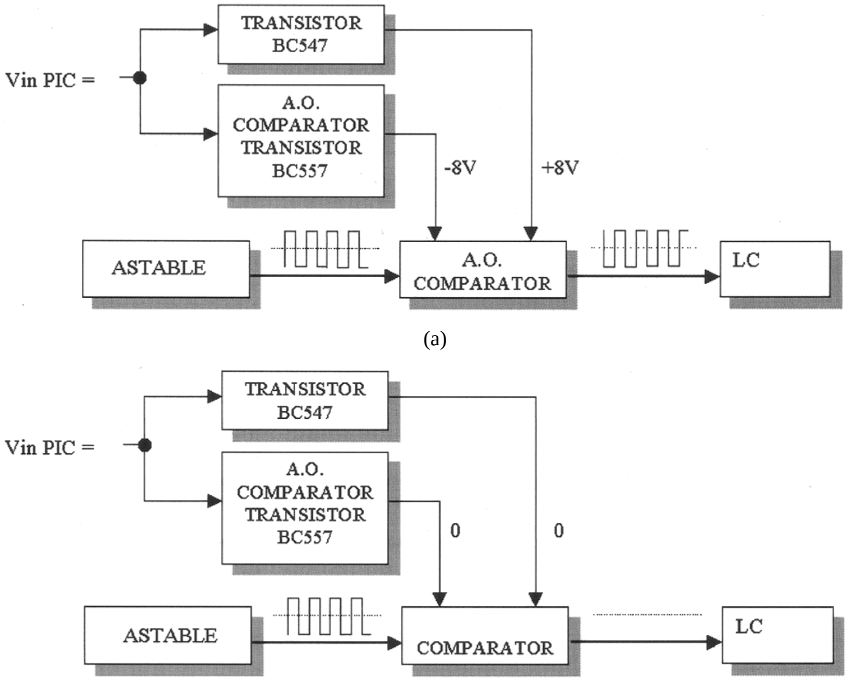
Output: $\phi = 5$ mm $f = 5, 5$ mm, plano-convex lenses.

At the output ports, two POF splitters are used for monitoring the output powers of both channels. They are 90/10 POF splitters 91 102TK0PP901 from Ratioplast.

D. Electronic Part

The electronic part has an analog and a digital block. The analog block has the optical to electrical (OE) conversion and the oscillator to excite the liquid crystal. A transimpedance amplifier with LM124 operational amplifier (O.A) and a SFH350 phototransistor are utilized in the OE conversion. The SFH350 is sensitive in the visible and the near IR range with a good linearity and it has a 2.2-mm aperture, which holds standard 1000-μ plastic fiber.

A square-wave generator (astable multivibrator) with a 7,2-kHz oscillating frequency and 15-Vpp amplitude is implemented using a TL081 OA and 3, 3-nF capacitors. There is also



(a)

(b)

Fig. 2. Square-wave generator system diagram. (a) Driving the LC. (b) The LC is not excited.

a switch to excite or not to excite the liquid crystal with the oscillator. This is made with a TL081 in an inverse comparator configuration with a ±8 Vsupplied voltage and using NPN and PNP bipolar transistors as switches of the positive and the negative supplied voltage, respectively. The control signal comes from the digital block. It is one of the output pins of the microcontroller PIC16F877 of microchip. A schematic of the different elements of the square-wave oscillator, depending on whether the LC is driven or not, is shown in Fig. 2. There are also three sets of two LEDs to indicate the state of the different channels (CH1 and CH2) and the state of the input and a ±8 V power supply.

On the other hand, the digital block includes the microcontroller PIC16F877; which has an internal 10-bit AD converter with eight input channels. It can operate up to 20 MHz and in the sleep mode. It is the control unit of the system, converting the data from the transimpedance amplifier and taking the required actions depending on the measured values. It also controls the block of LEDs, the oscillator that excites the liquid crystal and the LCD that shows the optical power in each channel. There is also a configuration and network revision menu in the LCD.

III. SYSTEM OPERATION

System operation is based on the capability of routing an optical signal depending on its state of polarization. Optical input light, coming from an optical fiber, is constantly changing its state of polarization so that a polarizer is used to force a certain state of polarization [in our design, a vertical polarization (see Fig. 1)]. The LC cell will or will not cause a change of polarization, depending on the electrical signal that excites the liquid crystal (see below). In this way, we will have two states of polarization electrically controlled. Finally, the device must divert the light to one of the outputs; to do so, a PBS is used. If the LC cell is not excited, the ray path is not modified coming out of the PBS in the same direction [see Fig. 1(a)]. If the LC cell is electronically excited, the ray is diverted 90° [see Fig. 1(b)]. Two photographs of the implemented device are shown in Fig. 3; a top view and a lateral view show part of the electronics and the POF splitter.

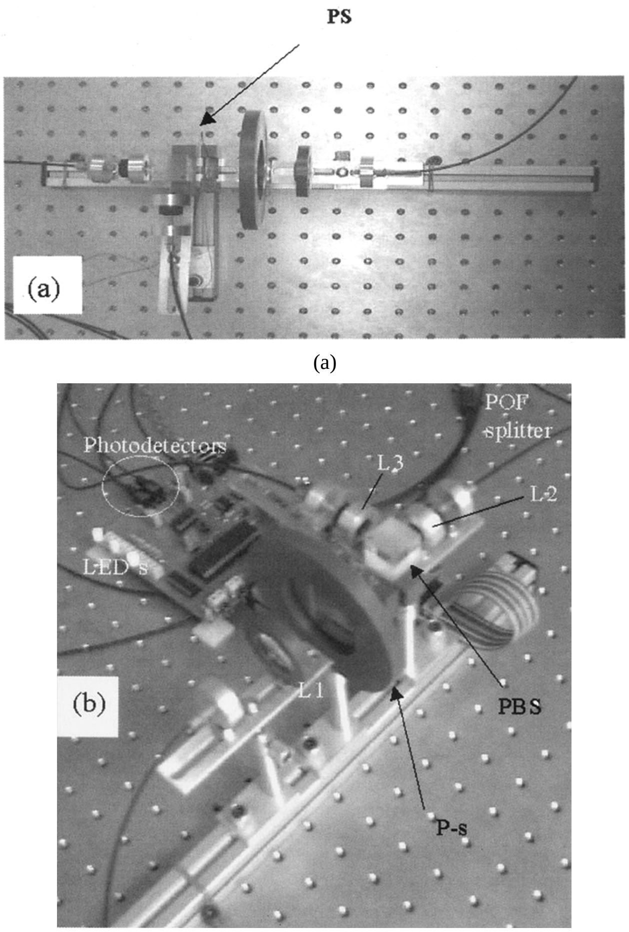
On the other hand, the main function of the electronic part is generating and controlling the electrical signal that excites the liquid crystal. Other functions of the electronics are measuring the output optical power of each channel, showing different information on the LCD, the alarms activation, and automatically checking and the selection of the working channel.

A fraction of the output power of each channel, from a passive POF splitter, is measured and stored in the PIC. Only a channel is measured at each time. This information is shown on the LCD along with the state of the different channels, that is, which channel is working. There is also the possibility to access at a LCD internal menu with the following options.

1) Potencia CANAL1: shows optical power in the CHANNEL1 (CH1).
2) Potencia CANAL2: shows optical power in the CHANNEL 2 (CH2).
3) Cambiar CANAL: to force a change in the output channel
4) Conmutar CANALES: auto-testing mode, a constant change in the output channel is developed, showing the output power in every position to verify that the device and the network are working.
5) EXIT: exiting the menu.

A block of three LEDs is controlled through the PIC, with the following coded message.

- Input LED green: one of the output channels is working O.K.



(a)

(b)

Fig. 3. Photographs of the implemented device. (a) Top view. (b) Lateral view including part of the electronics and the POF splitter.

- Input LED red (flickering and the other two LEDs red): none of the two channels is working.
- CH1 LED is green: that channel is O.K (main ring).
- CH1 LED is red (flickering): that channel is not working properly.
- CH2 LED is green: that channel is O.K (secondary ring).
- CH2 LED is red (flickering): that channel is not working properly.

The square-wave generator excites the liquid crystal to select the working output channel. The PIC16F877 is the responsible for controlling that signal, securing that there is always a working communication channel. If the PIC detects an optical power level below a certain predetermined value (in the present development it is fixed to -12 dBm), it will send an order to activate the liquid crystal and force a channel change.

IV. MEASUREMENTS AND DISCUSSION

In Section V, we are going to describe the different measurements we have taken to show the operability of the system from a preliminary test to a final characterization.

Input light comes from a semiconductor laser, as in the case of any optical network, to address multiple sensors. It is a ROITHNER 660/3LJ laser with a central wavelength of 660 nm and a maximum output power of 2,7 mW with a 3VDC polarization.

It is very important to know the plane of polarization of input light in order to use as much optical power as possible. The ideal situation would have the predominant axe of polarization aligned with the polarizer axe. The state of polarization of the laser output is being measured using two polarizers and an optical power meter RIFOCS 557B. Measurements are taken for different orientations of the two polarizers as reported in Table I. A maximum output power is obtained for a 145° orientation (see column 5). From columns 1 and 5, and from 1 and 9, it can be calculated that each polarizer has 3-dB insertion losses.

Optical fiber in the input and output ports is the POF HFBR-E889 328-C, with a 1-mm core, a numerical aperture of 0.447, and 0.25-dB/m losses.

After being propagated through the POF, light has an arbitrary state of polarization, although laser output is linearly polarized. To verify that fact, the following measurements are carried out. Laser output is launched at one end of the POF and a polarizer and a photodetector is placed at the other POF end. In these conditions, the same optical power at any polarizer position has been measured.

The 90° polarization spatial split polarization beam splitter (PBS) has been characterized. Output powers at both faces of the device have been measured at the same input conditions, using orthogonal positions of the polarizers. The device is symmetric showing the same output power levels.

A. System Parameters

A balance power at the device allows determining its *insertion losses*

$$\text{Optical Loss} = L_{\text{pol}} + L_{\text{cou}} + L_{\text{PBS}} + L_{\text{LC}} + L_{\text{OS}}$$

where L_{pol}, L_{cou}, L_{PBS}, L_{LC}, and L_{OS} are the optical losses in decibels from the polarizer, free-space fiber-to-fiber coupling with the two lenses, the PBS, the LC device, and the passive POF splitter, respectively. An optical loss of 11 dB has been measured with the following distribution: $L_{\text{pol}} = 3$ dB; $L_{\text{cou}} = 6$ dB; $L_{\text{OS}} = 2$ dB, $L_{\text{PBS}} + L_{\text{LC}} \ll L_{\text{pol}} + L_{\text{cou}} + L_{\text{OS}}$.

This optical loss value can be reduced improving optical coupling, using antireflections coatings at the operation wavelength of the polarizers and the NLC cells and implementing a symmetric configuration to the one reported in this paper for using all input power.

Polarization extinction ratios (PERs) of the PBS and the LC device are crucial to determine the *crosstalk* performance of the device. Theoretically, the PBS has a PER of 95:1 while the PER of the LC cell depends on its thickness.

The device crosstalk is defined as

$$\text{Crosstalk} = 10 \log\left(\frac{P_{1\text{ON}}}{P_{2\text{OFF}}}\right) \text{ or } 10\ \log\left(\frac{P_{2\text{ON}}}{P_{1\text{OFF}}}\right).$$

Measurements report a value around 14 dB in any case. This value can be improved fabricating thicker LC cells, but at the expense of increasing the time response, or using other LC mixture.

The device needs a certain *time to switch* from ON to OFF states. The relaxation of LC is slower than the reverse process

TABLE I

MEASUREMENTS TO DETERMINE THE STATE OF POLARIZATION OF THE SEMICONDUCTOR LASER LIGHT AND THE POLARIZER LOSS. THE LASER OUTPUT POWER WITHOUT POLARIZERS (COLUMN 1), USING ONE POLARIZER WITH DIFFERENT ORIENTATIONS (COLUMNS 2–5) AND USING TWO POLARIZERS WITH DIFFERENT ORIENTATIONS (COLUMNS 6–9)

	1 P(mW)	2 P(mW)	3 P(mW)	4 P(mW)	5 P(mW)	6 P(mW)	7 P(mW)	8 P(mW)	9 P(mW)
OUTPUT POWER	2.850	0.750	0.125	0.279	1.050	0.310	0.000	0.086	0.380
FIRST POLARIZER ORIENTATION	-	↕	⤢	↔	⤡	⤡	⤡	⤡	⤡
SECOND POLARIZER ORIENTATION	-	-	-	-	-	↕	⤢	↔	⤡

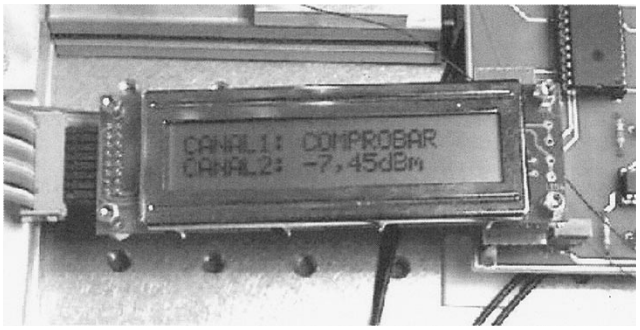

CANAL1: COMPROBAR
CANAL2: -7,45dBm

Fig. 4. LCD message showing output power at working channel (CH2) while CH1 must be revised (COMPROBAR).

so the times are not symmetrical. The worst measured switch times are as follows.

Switch from CH1 to CH2 = 100 ms.

Switch from CH2 to CH1 = 140 ms.

Those times are in accordance with the response times of typical nematic LC cells and allow transmitting high-speed digital signals with no interference.

B. Tests

Different tests have been implemented to verify the correct operation of the device. The most relevant ones are included in the following list.

- It has been forced to change the working channel through the LCD menu.
- A deliberated failure of the main channel (CH1) has been brought about so the device has automatically changed the working channel to CH2, showing a failure message in the LCD (see Fig. 4).
- Output power at each channel has been measured for different working channel conditions.
- LEDs light code has been verified.

V. ROUTER APPLICATION IN DIFFERENT FIBER SENSOR ARRAY TOPOLOGIES

In the following, we are going to briefly discuss the possibility of using the router in simple sensor networks. A range of basic topologies or network architectures for implementing multiplexed or fiber sensor arrays has been developed [13]. Fig. 5 shows serial and ladder topologies where the implemented router is included for redundancy purposes. In the serial topology, there are two measuring lines (or serial arrays of sensors) and the 1 × 2 switch selects from which array the measurements are going to be taken. The main objective will be to improve the security of the measurement system without duplicating the source and detector elements and circuits, but at the expense of increasing the overall losses of the system.

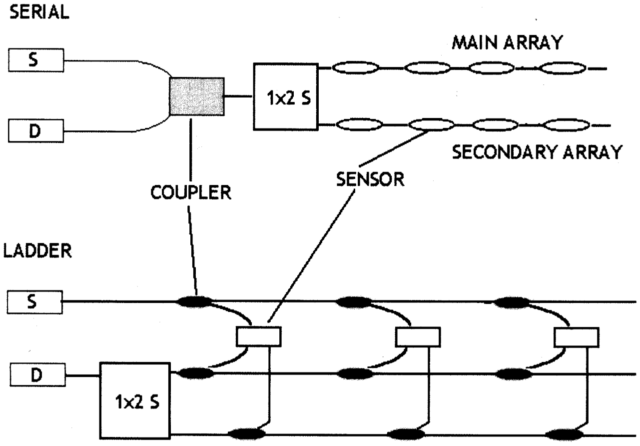


Fig. 5. Application of the switch (1 × 2 S) in two basic fiber sensor array topologies.

In the ladder topology, the 1 × 2 switch is used to improve security in the output fibers coming from the array of sensors and another 1 × 2 switch can also be used in the source line.

VI. CONCLUSION

We have presented a novel optical router architecture using nematic liquid crystals. It is a compact, simple structure designed to operate with visible light and plastic optical fibers. Experimental results on the implemented prototype show an optical loss of 11 dB, a crosstalk of 14 dB, and 100-ms switching time with low power consumption. There is a trade between crosstalk and switching time, which can be solved using other LC mixtures. The same architecture can be duplicated, in its optical part, for using all input power reducing optical losses. The current prototype is designed for using the router in a ring network for improving reliability. So, the system automatically switches from the main to the auxiliary channel in case of any failure.

ACKNOWLEDGMENT

The authors would like to thank J. M. Otón, X. Quintana, and J. L. Gayo for building the practical LC cell from the commercial LC mixture.

REFERENCES

[1] E. Achaerandio, S. Jarabo, S. Abad, and M. López-Amo, "New WDM amplified network for optical sensor multiplexing," *Photon. Technol. Lett.*, vol. 11, no. 12, pp. 1644–1646, Dec. 1999.

[2] A. D. Kersey, "Multiplexing techniques for fiber-optic sensors," in *Optical Fiber Sensors: Vol. IV: Applications, Analysis and Future Trends*, J. Daking and B. Culshaw, Eds. Boston, MA: Artech House, 1997, ch. 15.

[3] S. Sumriddetchkajorn, N. Riza, and D. Sengupta, "Liquid crystal-based self-aligning 2×2 wavelength routing module," *Opt. Eng.*, vol. 40, no. 8, pp. 1521–1528, Aug. 2001.

[4] S. Abad, F. M. Araújo, L. A. Ferreira, J. L. Santos, and M. López-Amo, "Multiplexing of fiber intensity sensors using fused biconical wavelength selective couplers," *Electron. Lett.*, vol. 37, no. 8, pp. 490–491, Apr. 2001.

[5] M. S. Borella, J. P. Jue, B. Ramamurthy, and B. Mukherjee, "Optical components for WDM lightwave networks," *Proc. IEEE*, vol. 85, pp. 1274–1307, Aug. 1997.

[6] N. A. Niza and J. Chen, "Ultra-high -47 dB optical drop rejection multi-wavelength add-dropp filter using spatial filtering and dual bulk acousto-optic tunable filters," *Opt. Lett.*, vol. 23, no. 2, pp. 945–947, June 1998.

[7] R. A. Jensen, "Comparing of optical switching technologies for intelligent optical networks," in *Proc. LEOS*, vol. I, Nov. 2002, pp. 230–231.

[8] N. A. Riza, "High-optical isolation low-loss moderate-switching-speed nematic liquid-crystal optical switch," *Opt. Lett.*, vol. 19, pp. 1780–1782, 1994.

[9] V. A. Svirid, V. León, and S. N. Khotiaintsev, "A prototype fiber-optic discrete level-sensor for liquid propane-butane," *IEICE Trans. Electron.*, vol. E83-C, pp. 303–308, 2000.

[10] C. Vázquez, J. Garcinuño, J. M. S. Pena, and A. B. Gonzalo, "Multisensor system for level measurements with optical fibers," in *Proc. 28th Annu. Conf. IEEE Industrial Electronics Society*, 2002, pp. 2657–2662.

[11] P. G. de Gennes and J. Prost, *The Physics of Liquid Crystals*, 2d ed. Oxford, U.K.: Oxford Univ. Press, 1993.

[12] P. Yeh and C. Gu, *Optics of Liquid Crystal Displays*. New York: Wiley, 1999.

[13] A. D. Kersey, *Fiber Optic Smart Structures*, E. Udd, Ed. New York: Wiley, 1995, ch. 15.

Carmen Vázquez (M'00) was born in Madrid, Spain, in May 1968. She received the M.S. degree in physics (electronics) from Complutense University of Madrid in 1991 and the Ph.D. degree from the Telecommunications Engineering School, Polytechnic University of Madrid (UPM), in 1995.

In 1991 she was a Fellow at TELECOM, Denmark, working on erbium-doped fiber amplifiers. From 1992 to October 1995, she worked at the Optoelectronics Division of Telefónica Investigación y Desarrollo, Madrid. She was involved in III/V integrated optics devices characterization, design, and fabrication. In October 1995, she joined Carlos III University, Madrid, where she is currently an Associate Professor in the Electronics Technology Department. Her current work includes the design of fiber optics, LC and integrated optic devices and their application to optical communications, instrumentation, and sensor networks.

Dr. Vázquez is a member of the Society of Photo-Optical Instrumentation Engineers (SPIE), the Optical Society of America (OSA), and the Sociedad Española de Óptica (SEDO).

José Manuel Sánchez Pena (M'95) was born in Lugo, Spain, in 1962. He received the M.S. and Ph.D. degrees in telecommunication engineering from the Polytechnic University of Madrid, Madrid, Spain, in 1988 and 1993, respectively.

From February to September 1993, he was a Visiting Researcher at Exeter University, U.K., engaged in the modeling of the electrooptical properties of liquid crystal displays (LCDs). In March 1995, he joined Carlos III University, Madrid, where he is currently an Associate Professor and Head of the Displays and Photonic Applications Group in the Electronics Technology Department. His main research interests include electrooptical characterization of liquid crystal displays, design of optical sensors, and optoelectronic instrumentation for rehabilitation technology applications and optical communications.

Dr. Pena is a member of the Society of Photo-Optical Instrumentation Engineers (SPIE), the International Liquid Crystal Society (ILCS), and the International Society for Augmentative and Alternative Communication (ISAAC).

Salvador Elías Vargas was born in Panamá in 1973. He received the M.S. degree in electrical and electronic engineering in 1996 from the Technological University of Panamá. He is currently pursuing the Ph.D. degree in the design of fiber optics and LC devices for their application to optical communications, mainly to WDM filters.

He is an Assistant Professor with the Electronics Technology Department, Carlos III University, Madrid, Spain.

Angel Luis Aranda was born in Madrid, Spain, in 1978. He received the B.S. degree in industrial electronic engineering in 2001 from Carlos III University, Madrid.

He is with the Electronics Technology Department, Carlos III University, Madrid, working in researching and developing drivers for industrial applications based on LC technologies.

Isabel Pérez was born in Albacete, Spain, in 1969. She received the M.S. degree in telecommunication engineering in 1995 from the Polytechnic University of Madrid, Madrid, Spain. She is currently pursuing the Ph.D. degree in electrooptical optimization of LCDs.

She is an Assistant Professor with the Electronics Technology Department, Carlos III University, Madrid, Spain.