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# Broadband fiber-optic 1x2 switch using an electrically controlled liquid lens

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## ABSTRACT

To the best of our knowledge, proposed is the first liquid lens technology-based 1x2 fiber optic switch using a single Electronically Controlled Variable Focus Lens (ECVFL). By controlling the focal length of the liquid ECVFL, the input optical beam is spatially adjusted to couple into the respective output fiber port. The switch demonstrates a 3-dB bandwidth of 175.67 nm, with a center frequency of 1550 nm, and features low power consumption suitable for mobile applications. The proposed switch can be useful in communication and control systems, in roadway sensor systems, vehicle detection systems, and monitoring systems.

**Keywords:** fiber optic switch, liquid lens

## 1. INTRODUCTION

Fiber optic switches are used in optical communications systems and control systems, in roadway sensor systems, vehicle detection systems, and monitoring systems. The design of fiber optic switches has employed many different technologies such as liquid crystals [1-2], acousto-optics [3], and MEMS [4]. In some applications broadband design is desirable and MEMS technology has been useful in such designs. The liquid lens is another commercially successful micro-device that has broadband characteristics [5]. Recently, liquid lens-based ECVFLs have been demonstrated in various fiber optic attenuator designs [6-7]. In this paper, an electro-wetting liquid lens is used to design a 1x2 switch that is inherently wideband and also has low power consumption [8].

## 2. PROPOSED ECVFL-BASED FIBER-OPTIC SWITCH DESIGNS

The top view of the proposed 1 x 2 fiber optical switch design using an ECVFL is shown in Fig. 1. The input fiber port IN1 laser beam from the fiber lens FL1 is aligned so that the free-space beam hits between the center of the ECVFL and its edge so that when the voltage  $V$  to the ECVFL is adjusted, there is no focusing. In this digital state of the switch shown in Fig.1(a), the beam goes into the fiber lens FL2 and the first output port labeled OUT1. As shown in Fig 1(b), the state the focal length of the ECVFL is adjusted and the beam deflects to the fiber lens FL3 and into the Single Mode Fiber (SMF) port OUT2.

Fig. 2 shows a novel ECVFL-based 2 x 2 free-space switch that can also function as a 2x2 Fiber-Optic Switch. The two ECVFLs are separated by a distance  $D$  and the beams entering and exiting the switch are parallel to one another. The beam pair is positioned so that they are equidistant from the central axis of the switch. As shown in Fig. 2(a), control of the ECVFL drive voltage can set the two beams to pass straight through the switch structure to give the straight state of the switch. On the other hand as shown in Fig.2(b), changing the ECVFL pair voltages  $V_1$  and  $V_2$  can cause the beams to be deflected to give the crossed state of the switch. Note that for the switching operations,  $F_1$  should be equal to  $F_2$  so that no magnification occurs while beams pass through the structure. Also note that the ECVFL1 focal length  $F_1$  and ECVFL2 focal lengths  $F_2$  can be used to magnify or de-magnify the output beams.

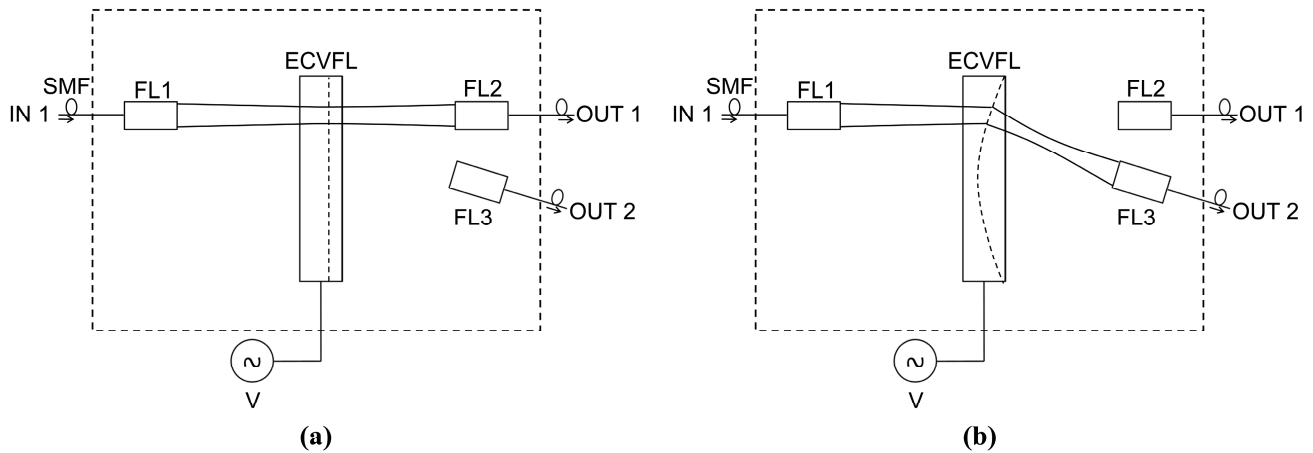


Figure 1. The top view of the proposed liquid lens-based 1x2 fiber-optic switch design. (a) The straight state and (b) crossed state of the switch.

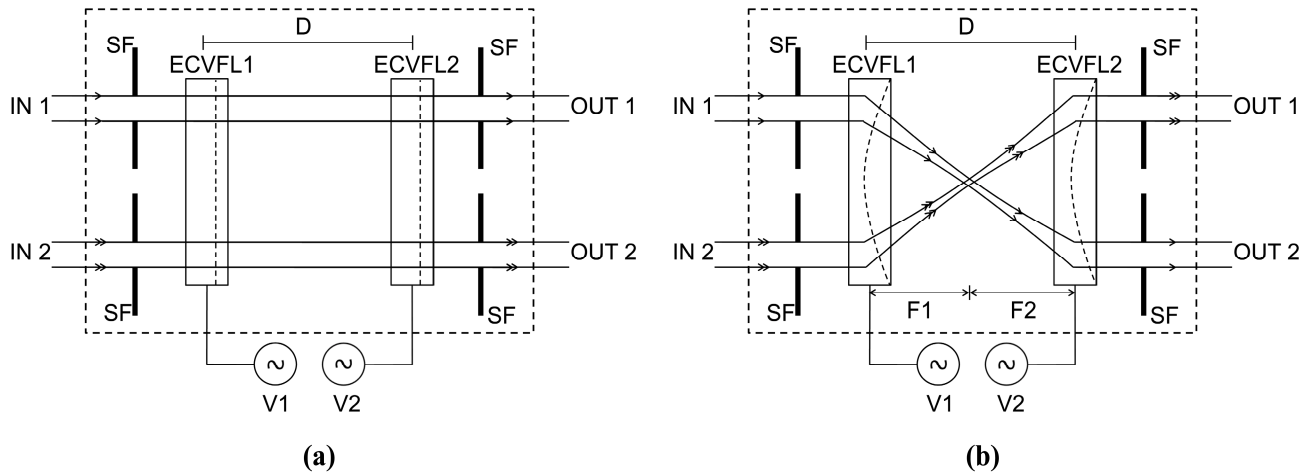


Figure 2. The top views of the proposed liquid lens-based 2x2 free-space optical switch design. (a) The straight state and (b) crossed state of the switch. The design can also be applied to fiber switching using fiber lenses and SMFs.

### 3. EXPERIMENTAL RESULTS

For demonstration purposes, the Fig.1 1x2 fiber-optic switch in the 1500-1600 nm band was constructed using SMFs coupled to Graded Index (GRIN) fiber lenses. The GRIN lenses used in the experiment were designed for 1550 nm operation and have a null-to-null beam diameter of 1.38 mm. The source for the experiment is a tunable laser set to 1550 nm. Arctic Model 320 liquid lenses by Varioptic are used for the experiment. To measure the switch bandwidth, an Optical Spectrum Analyzer (OSA) with a built-in infrared source is used. This source was connected to the switch input and the OSA is used to measure at the switch output. This OSA spectrum measurement is subtracted from the direct OSA spectrum measurement for the internal optical source. The 3-dB bandwidth of the switch is measured to be from 1469.13 nm to 1644.8 nm. The 1x2 fiber-optic switch gives a measured within-channel optical Signal-to-Noise Ratio (SNR) of 32.87 dB. The switch insertion loss is 8 dB and is presently high because the Varioptic lenses are designed for visible light and not Infrared (IR) band light. Specifically, without IR antireflection coatings on the Varioptic lenses, a large 6.5 dB optical loss is caused by the two lenses. In addition, some light is lost for operating near the edge of the

ECFVL with a limited aperture for the given IR beam size. It is expected that with IR beam optimized ECVFLs, the switch loss will be around 1.5 dB or less that is appropriate for practical deployment. Fig.3 shows the switching operation of the beams between the two output ports that are recorded by an IR camera. One can clearly see the switched beam positions.

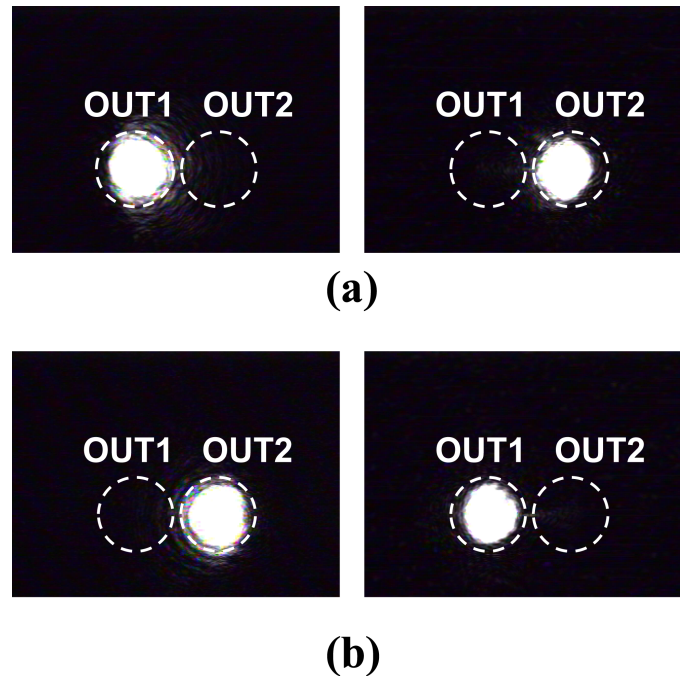


Fig.3 Shown is the switching operation of the 1x2 Fig.1 switch. One can see the switched beams between the two output ports that are recorded by an IR camera.

#### 4. CONCLUSION

An ECVFL-based broadband 1x2 fiber-optic switch design along with its experimental results is presented. The IR band demonstrated 1x2 switch is based on electro-wetting liquid lens technology and shows a within-channel SNR of 32.87 dB and a 3 dB optical bandwidth of 175.67 nm. Two ECVFLs can be used to make a 2x2 switch. These switches can find uses in communication and control systems, roadway sensor systems, vehicle detection systems, and monitoring systems.

#### 5. ACKNOWLEDGEMENTS

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