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Variable Fiber-Optic Attenuator using Optofluidics

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Abstract

Proposed is a Variable Fiber Optical Attenuator (VFOA) using an electronically controlled, variable focus liquid lens. The demonstrated experiment for the VFOA is shown for operation over the communication C-Band (1530nm-1560nm).

1. Introduction

Narrowband VFOA implementations have used liquid crystals [1-4], acousto-optics [5], analog [6-7], digital [8] and hybrid [9] optical Micro-Electro-Mechanical Systems (MEMS) technologies. VFOAs have also been designed for a broad band of optical wavelengths and include implementations using motion control [10-12] and movable mirrors [13-14] as well as, more recently, digital MEMS. Furthermore VFOA designs based on beam spoiling using motion control of mirrors have also been proposed [15-17]. The purpose of this paper is to show a VFOA implementation using the electronically controlled optical wedge. In the recent past, small tunable focus liquid lenses [18-19] have found commercial success in multi-focus cameras for cell phones. The proposed VFOA design employs this existing technology and explores its use for potential application in test and measurement systems.

2. Proposed VFOA Design

Fig.1 shows the design of the proposed VFOA. The electronically controlled variable focus lens (ECVFL) in the VFOA design is not used as a classical multi-focus device but rather as an electronically controlled optical wedge which is used to deflect the incoming optical beam depending on the applied voltage V to the ECVFL. Fiber coupled light enters the VFOA through the Single Mode Fiber (SMF) connected to the fiber lens FL1 and leaves the system through fiber lens FL2. FL1 and FL2 are identical with a self-imaging distance 2d. The ECVFL is placed next to FL1 such that the optical beam passes through its edge hence exploiting the region where there is a maximum change in the radius of curvature of the ECVFL. This electronically controlled wedge having a wedge angle α steers the beam and this beam motion results in an angular tilt misalignment [20] and hence decoupling at FL2 resulting in optical attenuation and VFOA design. Note that the zero attenuation setting for the VFOA is one where there is

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maximum coupling between FL1 and FL2. The system has been aligned such that this zero loss state occurs when the ECVFL is in its flat state (i.e. V=38V).

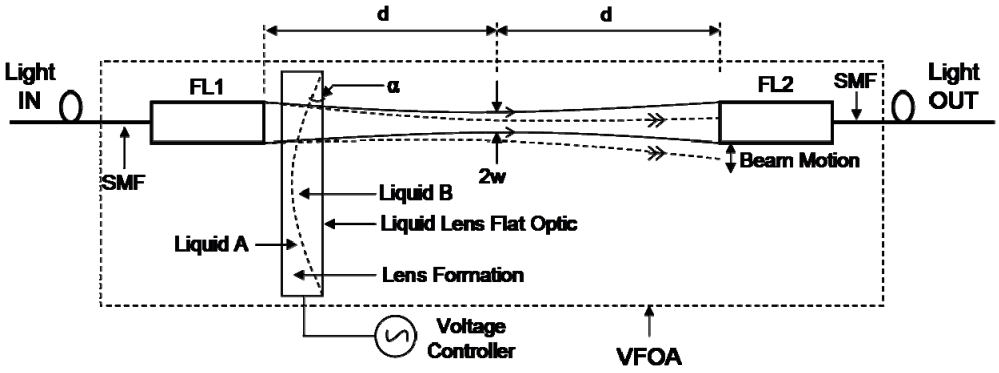


Fig.1 The proposed broadband VFOA design using a voltage controlled liquid lens and two Single Mode Fiber (SMF) coupled fiber lenses FL1 and FL2. Solid line: Zero attenuation setting; Dashed line: Voltage controlled attenuation setting; α: Wedge angle.

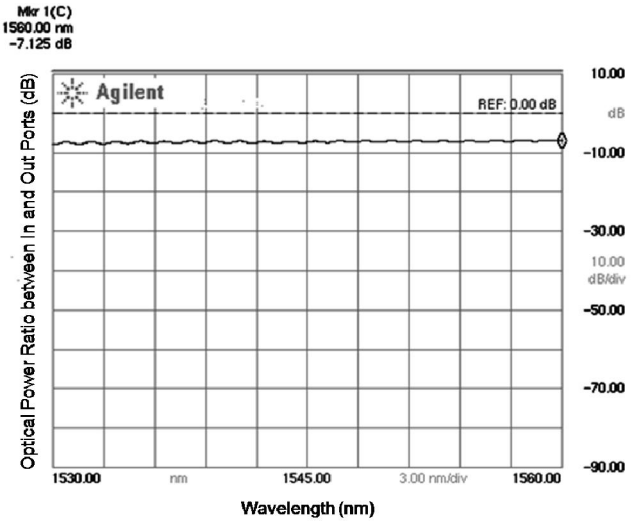
The ECVFL operates as an optical flat as well as in convex and concave configurations. The wedge angle α determines the magnitude of optical attenuation.

3. Experimental Demonstration

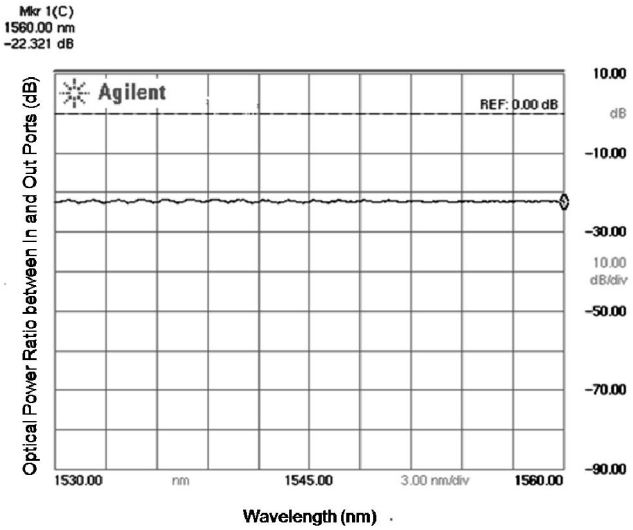
The proposed VFOA design shown in Fig.1 is implemented using two self-imaging fiber lenses with d = 6.25 cm and w = 0.5 mm for the C-Band infrared design λ=1530-1560nm. A Varioptic France Model Arctic 320 liquid lens is used for the liquid lens [21]. The ECVFL focus changes based on the principle of electrowetting [22] which is the change in the wettability of a liquid when it comes in contact with a conducting surface. The attenuation range of the proposed VFOA is demonstrated to be 40 dB. Fig.2 shows the measured attenuation values of 0 dB, 15 dB and 30 dB for the C-Band of operation.

The measured 3 dB bandwidth of the VFOA is 190 nm between 1510 nm and 1700 nm wavelength range as shown in Fig.3. As the ECVFL is designed for the visible band of operation (430 nm to 700 nm), the C-Band light experiences a 3.9 dB loss. The free space fiber-to-fiber coupling loss is measured to be 0.4 dB. Hence the total fiber in to fiber out loss comes out to be 4.3 dB. If the ECVFL is designed for the C-Band, most of the transmission loss through the ECVFL can be eliminated. The VFOA Polarization Dependent Loss (PDL) is measured to be 0.3 dB for the C-Band. The power consumption of the ECVFL is 12mW and its reset time is 100msec. Therefore the VFOA response time is 100msec which makes the proposed VFOA design ideal for test and measurement applications. For further details on the working of the proposed opto-fluidic-based VFOA, see [23-24].

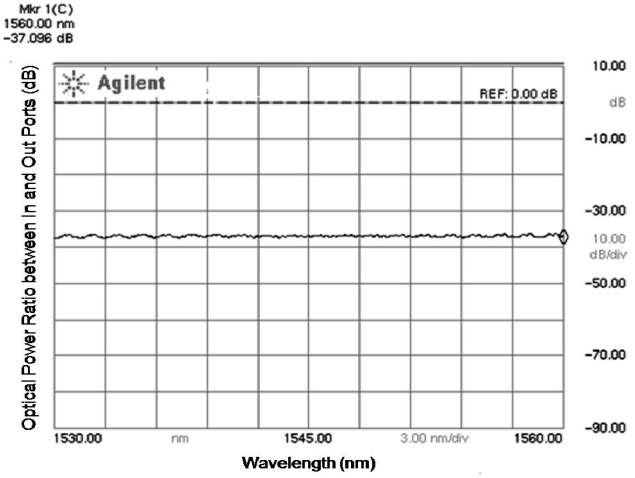
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(a)



(b)



(c)

Fig.2 Measured VFOA broadband operation at (a) 0 dB, (b) 15 dB and (c) 30 dB attenuation levels for C-Band operations with OSA resolution of 10 dB/div.

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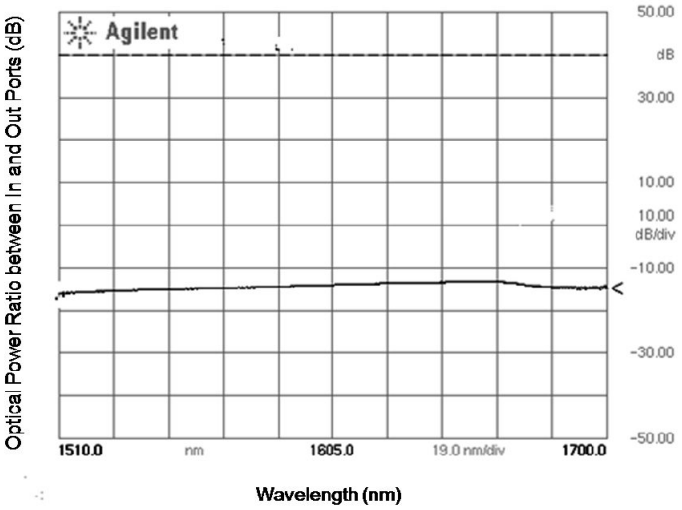


Fig.3 The measured 3-dB bandwidth of the VFOA showing a 1510 nm to 1700 nm response.

4. Conclusion

In conclusion, an ECVFL-based VFOA is demonstrated in this paper. The proposed VFOA is a broadband design intended for operation in the communication C-Band. The simple design and electronic controls make the proposed VFOA repeatable, reliable and accurate.

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