Design and Simulation of 1xN Optical Switch based on LCoS SLM by Using Iterative Fourier Transform Algorithm with the Optimization Method

Zih-Yuan Wong[1], Chien-Tang Wang[2], Wen-Hsu Chen[2], Yuet-Wing Li[2], Kuan-Hsu Fan-Chiang[2], and Hoang-Yan Lin[1]

uan8256@gmail.com

[1] Graduate Institute of Photonics and Optoelectronics, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, Taipei, 10617, Taiwan

[2] Himax Display, Inc. 2F., No.26, Zilian Rd., Xinshi Dist., Tainan City 74148, Taiwan

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ABSTRACT

We design and complete the 1xN optical switch by using the IFTA with a fast optimization step. The nonuniformities of the switches can be reduced to 3.52% and 10.62% by simulation. The insertion loss of the optical switch system is 2.3 to 13.5 dB.

1 Introduction

Fiber optic communication has the advantages of low loss, large transmission bandwidth, resistance to crosstalk, small size, and light weight. Therefore, it has developed rapidly in recent years. At present, wired communication has begun to use fiber optic cables extensively, including in broadcasting, telecommunications, Networking, audio communication, etc.

In addition to a powerful server, fiber optic communication also requires an optical switch mechanism with high bandwidth, high energy efficiency and low latency. Unlike electronic switches, optical switches have smaller heat dissipation issues. Therefore, the cooling cost of the optical switch is low, and it has a strong advantage for long-distance transmission [1]. Today, optical switches can be said to be one of the key components in the field of multiplexing technology. Compared with other types of optical switches, liquid crystal optical switches have no moving parts, so they have high reliability. At present, most liquid crystal optical switches use a liquid crystal on silicon (LCoS) spatial light modulator (SLM) with computer-generated holographic technology (CGH) [2], which has flexible modulation capabilities and can be used to deflect to any direction and position.

The Gerchberg-Saxton algorithm combined with the fractional Fourier transform used with reflective LCoS SLM has been proposed to optimize multicast holograms in switches [3]. But there is still a problem of uniformity when multicasting to different output ports. In this study, we use iterative Fourier transform algorithm with an innovative optimization method to complete the optimization of nonuniformity in a short time. We design 1×6 and 1×12 optical switch, which can deflect the input signal to multiple output fibers to complete multicast. The advantage of this research is that the input signal can be switched to any/multiple output and the output has good uniformity.

2 Design of Optical Switch System

Figure 1 shows the optical switch system in this study. We use a S polarization laser which has the wavelength of 1550 nm as the light source. The input fiber in the system is a single-mode polarization maintaining fiber. After the light is emitted, the light beam is collimated through a collimating lens, and then the light incident on the LCoS SLM (from Himax). Then the light will be focused to the 12 multimode output fiber ribbons by the focusing lens with a focal length of 3 cm. In order to separate the input and output beams, we let the LCoS SLM in the system has an inclination angle of 8 degrees. The LCoS SLM is about 12 cm away from the focusing lens.

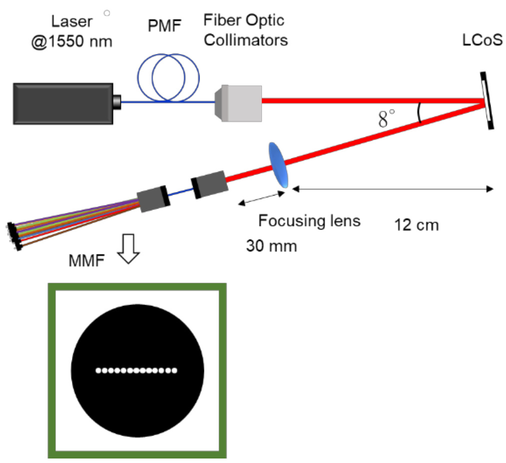


Fig. 1. Optical switch system.

3 Computer-Generated-Holography Used in Optical Switch

3.1 The Optimization Algorithm

For LCoS SLM control, many teams have proposed different algorithm design and optimization methods, such as direct binary search (DBS), iterative Fourier transform algorithm (IFTA), simulated annealing (SA) and genetic algorithm (GA). IFTA is the most commonly used algorithm because it is an algorithm that can quickly reach convergence and reduce errors [4].

Only using the IFTA for multicasting cannot achieve low nonuniformity. We use IFTA with an innovative optimization method to complete the optimization of nonuniformity in a short time. Our goal is to complete a 1x6 and 1x12 optical switch systems.

In our algorithm, we add the step of changing each output target of each fiber in the IFTA to achieve the optimization effect. We compare the converged result with the target. For comparison, each output light is discussed separately and the target of each output for the next iteration is not fixed. The difference between each target for next iteration depends on the result of the previous iteration for each output. Fig. 2 shows our algorithm. The T_0 is original peak amplitude. The purpose of the β value is to enable the algorithm to converge. When the β value is too large, the algorithm cannot converge. When the β value is too small, the amount of modulation in the algorithm decreases.

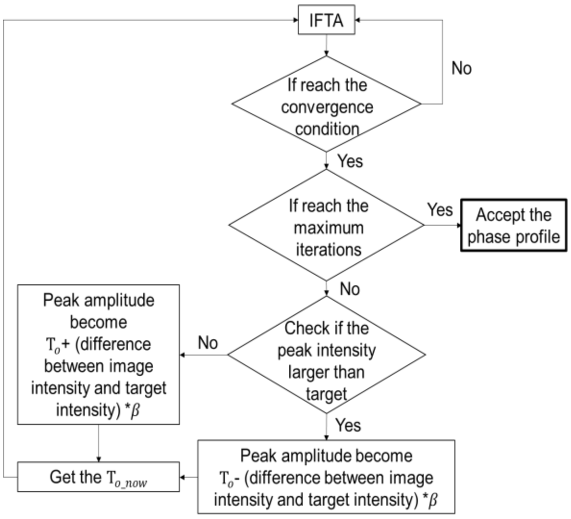


Fig. 2. Flow chart of uniformity optimization algorithm.

3.2 The Evaluation Function for Algorithm

The source of the algorithm is collimated Gaussian light, and the target is Gaussian light suitable for multimode fiber. The Gaussian function form is $e^{\frac{-(x^2+y^2)}{r^2}}$. The r of the target is the half of Mode Field Diameter (MFD) of the fiber, which can be obtained by V number and fiber core radius a [5].

$$\mathrm{r} = \mathrm{a}\frac{V+1}{V}. \tag{1}$$

The parameter that we use to evaluate the convergence of the algorithm is the mean-square error (MSE) value which can be expressed as

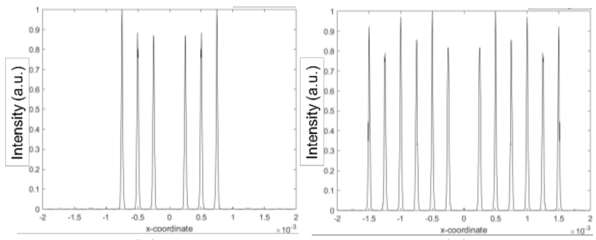
$$\mathrm{MSE} \equiv \frac{\iint_{xy} |\alpha \times \mathrm{I(x,y)} - \mathrm{I_{target}}|^2 \, \mathrm{d}x \, \mathrm{d}y}{\iint_{xy} \mathrm{I_{target}}^2 \, \mathrm{d}x \, \mathrm{d}y}, \tag{2}$$

where I(x, y) is the light intensity on the image surface after the light source is modulated, and I_{target} is our target intensity. The light intensity is the square of absolute value of the field amplitude. The results of MSE of the algorithm are smaller than 2%.

4 SIMULATION

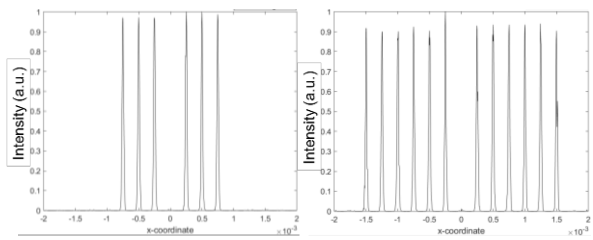
4.1 Simulation Results

We use Matlab, the mathematical simulation software, to do simulation and analysis of this system. And we use the IFTA with a fast optimization step to quickly complete the uniformity optimization of the optical switch. This method not only avoids the possibility of the traditional IFTA from converging to the local optimal value, but also retains the advantage of rapid convergence of the IFTA. Our goal is to reduce the nonuniformity of the system. Nonuniformities is defined as $U=(I_{max}- I_{min})/ I_{max}$,where I_{max} is the maximum spot intensity and I_{min} is the minimum spot intensity. As shown Fig. 3(a) and (b) in the nonuniformities of the 1x6 and 1x12 switches using only the IFTA are 13.02% and 20.79%, respectively. According to the normalized simulation results in Fig. 3(c) and (d), the nonuniformities of the switches by using the optimization method proposed in this study are reduced to 3.52 % and 10.62%, respectively. The coupling efficiency calculated by overlap integrals are all above 93%.



(a) (b)

Fig. 3. The simulation resulted profiles of (a) 1x6 and (b) 1x12 switches only using the IFTA algorithm.



(a) (b)

Fig. 4. The simulation resulted profiles of (a) 1x6 and (b) 1x12 optical switch using the optimization method proposed in this study.

The result of deflecting to any five output is shown in Fig. 5. When the light is deflected to any five fibers, the optimization algorithm proposed in this study can also achieve a good optimization effect. If we only use the IFTA, the nonuniformity is 13.96%. When we use the optimization algorithm proposed in this study, the nonuniformity can be reduced to 2.01%. The crosstalk in other ports are all smaller than −40 dB which is shown in Fig. 5(c). The coupling efficiency calculate by overlap integrals are all above 93%.

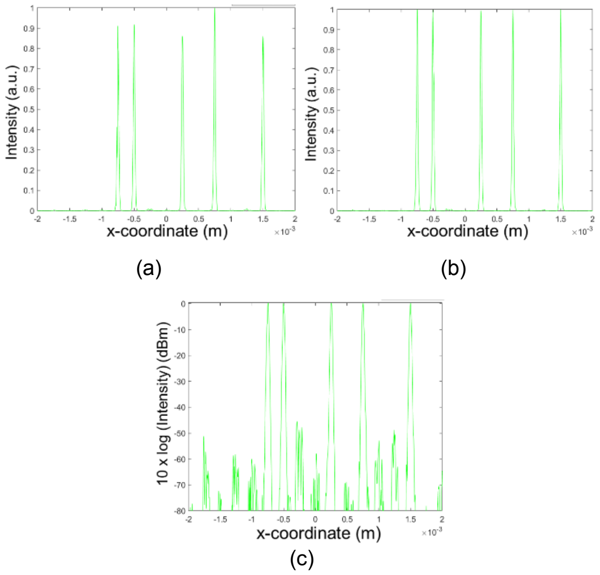


Fig. 5. The simulation resulted profiles of deflecting to any five fibers (a) only using the IFTA algorithm, (b) and (c) using the optimization method proposed in this study.

4.2 Simulation of LCoS Fill Factor and Phase Error

In the experiment, we also need to consider the insertion loss, which may be caused by LCoS modulation error, LCoS fill factor, LCoS fringe field effect, system polarization loss, etc. We try to use simulation to find the cause of the loss. By the LCoS phase modulation measurement, the maximum phase error is 0.2 π without considering the fringe field effect. We add a variable random phase with an error of 0 to 0.2 π and 0 to 0.4 π in the Matlab simulation, the resulting loss is about 0.017 dB and 0.045 dB, respectively.

When the fill factor of LCoS is 75%, the resulting loss of simulation is about 0.83 dB. When the fill factor of LCoS is 93.8%, the resulting loss of simulation is about 0.087dB. The fill factor of the LCoS we use is larger than 90%. Therefore, the fill factor or phase error do not cause much loss. Most of loss in the system maybe cause by fringe field effect and other reasons.

5 EXPERIMENT AND DISCUSSIONS

5.1 Optical Switch of Single-Port Deflection

For analysis, we number the 12 output fibers of the optical switch in Fig. 1. We numbered from 1 to 12 from the inside of the system to the outside of the system.

Insertion loss can be defined as [6,7]

$$\text{Insertion loss} = 10 \times \log_{10} \frac{P_1}{P_2}. \quad (3)$$

And transmission can be defined as [6]

$$\text{Transmission} = 10 \times \log_{10} \frac{P_2}{P_1}, \quad (4)$$

where P_1 is the optical power before entering the system, P_2 is the optical power after passing through the system.

We measure the optical power deflection to a single-port optical switch. The system is set up as shown in Fig. 1. The algorithm of Fig. 2 will be used to design the phase diagrams for optical switch. Then the designed phase information will be uploaded to LCoS SLM. We use a power meter to measure the optical power of 12 output fibers. By calculation, the transmission of each output port is shown in Figure 6.

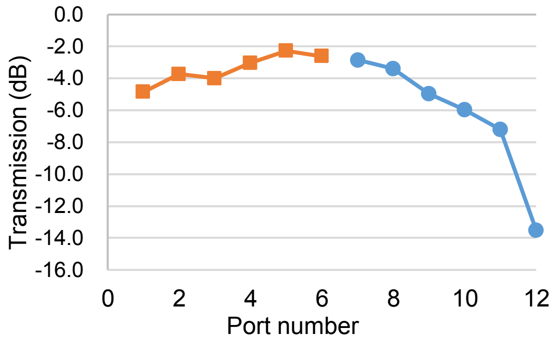


Fig. 6. Transmission of 1 x 12 optical switch deflection to single port in this study.

It can be seen from Fig. 6 that the insertion loss of the optical switch deflected to a single port is 2.3 to 13.5 dB. The insertion loss of the port in the middle of the optical switch is relatively small, and the insertion loss of the ports on both sides is relatively large. This is due to the adjacent pixels in the LC panel, which applying different voltages will affect each other. This phenomenon called fringe field effect [8], which causes phase inaccuracy and a decrease in diffraction efficiency. This effect is most obvious when the phase drops from 2π to 0 in radians. Therefore, when deflecting to a single port, the phase grating required for deflection to the edge of the fiber is denser, and when the periodic grating is denser, the phase decreases from 2π to 0 in radians more times. Therefore, the diffraction efficiency will be relatively reduced [9]. Therefore, both sides in Fig. 6 have larger insertion loss.

In addition, the insertion loss of ports 10, 11, and 12 in Fig. 6 is larger than the insertion loss on the left side. The reason is that the LCoS SLM has an 8-degree inclination angle, which causes distortion in the diffraction imaging of the light after the phase modulation of the LCoS SLM.

5.2 Optical Switch of Multi-Port Deflection

Fig. 7 shows the optical power of multicasting to 12 ports, and the system setup is as shown in Fig. 1. We use the algorithm in Fig. 2 to design the phase information and upload the phase information to the LCoS SLM. The light can be multicast to 12 output ports after LCoS SLM phase modulation. Then we use the optical power meter to measure the optical power of the 12 output fibers. The optical power of laser light source used to the optical switch is 10 dBm. The measured optical power of the output fiber is -3.6 dBm to -22.2 dBm. The power corresponding to each output port is shown in Fig. 7.

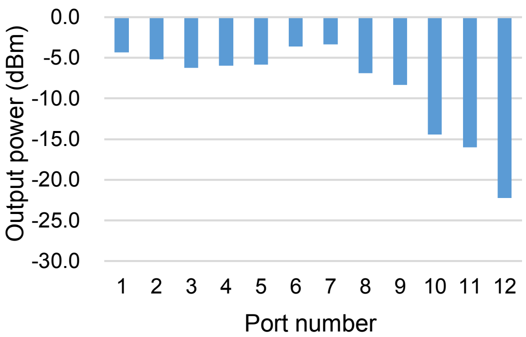


Fig. 7. The energy corresponding to different output ports of the optical switch multicast to 12 ports in this study.

It can be seen in Fig. 7 that the light intensity of ports 10, 11, and 12 has a downward trend. The reason is the same as mentioned in section 5.1. Because the LCoS SLM in the system has an inclination angle of 8 degrees, the diffraction image at the outside of the system has distortion. Thus, the distance between the light points at the outside of the system is slightly elongated. The light cannot be perfectly coupled into the outside ports. The diffraction efficiency decreases. Therefore, the light intensity of ports 10, 11, and 12 outside the system has a downward trend. By calculation, the insertion loss of the switch deflection to 12 ports in this study is 5.4 dB.

6 CONCLUSIONS

This study proposes 1x6 and 1x12 optical switches designed by CGH optimization method. We use the IFTA with a fast optimization step to design and control the CGH phase to achieve the multicast. Our optimization algorithm can achieve low nonuniformity in a short time and can maintain high coupling efficiency of fiber. The crosstalk of the system is smaller than −40 dB. Therefore, the optimization algorithm proposed in this study is competitive. In the future, this design can be actually applied to the LCoS SLM optical switch.

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