Optical alignment algorithm using Hadamard transformation

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Abstract: In this paper, we propose a new optical alignment system using Hadamard transformation that is designed for aligning multiple channel optical components. A conventional optical alignment system assumes that the whole channels of the components are perfectly aligned with two detectors, which are placed at the end of the outermost channels of the components, indicate the maximum optical power. The proposed system is able to give us the optical power information of each channel with using one detector. The proposed optical alignment system can make up for the drawback of the conventional optical alignment system.

Keywords: optical alignment, Hadamard transform, multiplexing, Hadamard optical mask

Classification: Science and engineering for electronics

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1 Introduction

Packing has played a key role to evaluate the manufacturability and reliability of optical devices. Its significance is due to the stringent alignment tolerances demanded for coupling between the optical devices and optical fibers [1]. It is well known that the alignment of optical fiber to waveguide or fiber array is not the most important but also the most difficult among the packing processes. As optical devices have become more complex, proper alignment becomes more important. The primary goal of optical fiber alignment is to have two fibers perfectly aligned so that transmission of laser light, propagating through the first fiber and the second fiber, is maximized [2, 3]. In other words, the minimum optical loss can be achieved by the finest alignment process.

An automated optical alignment system automatically determines the optimal alignment position between two optical components that have to be aligned when the detector adopted in the alignment system indicates the maximum optical power transmission. When the detector does not indicate the maximum optical power, the alignment system let the fiber array slightly keep moving until the detector indicates the maximum. When the system aligns two optical components having two channels per each, it uses two detectors that are placed at the end of each channel, and it has the components moved to their new positions until the detectors tell the maximum optical power. When the alignment system aligns multiple channel optical components having more than three channels, it determines the optimal alignment position when the two detectors, which are placed at the end of the outermost channels of the components, indicate the maximum optical power [2, 3]. In this case, the alignment system can not guarantee the optimal alignment for the middle channel, the second channel, in this example. This problem can be solved by measuring optical power either one-to-one measurement using the same number of detectors as the same number of channels, or one-by-one measurement with one detector. Both solutions do not seem to be efficient approaches in the respect of cost and time consuming. Also the calibration becomes more difficult as each detector has different efficiency and sensitivity when the alignment system adopts more detectors.

In this paper, we suggest an optical alignment system that is suitable for multiple channel optical components based on Hadamard transformation. It gives us each optical power for each channel of the multiple channel components with one detector avoiding one-by-one measuring no matter how many channels the optical components have. Moreover, the proposed alignment system has excellent signal-to-noise ratio (SNR) advantage as the number of channels increases by using multiplexing technique in the Hadamard transform [4, 5, 6, 7]. We demonstrate the usefulness of the proposed alignment

system for aligning multiple channel optical components through computer simulations.

2 Conventional optical alignment system

A typical automated alignment setup is represented in Fig. 1. It illustrates alignment of an eight-channel optical waveguide to an eight-channel optical fiber array. Once light from light source such as a laser is incited into the fiber, which is coupled into the optical waveguide, two optical detectors monitor laser throughput at the end of the optical fiber array. The automated optical fiber alignment system investigates the optimal alignment position by slightly shifting the fiber array until the detectors have the maximum optical power. In other words, the optical fiber alignment system presumes that all channels are perfectly aligned as long as each of the detectors has the maximum optical power. This method seems quite reasonable. However, there can be misaligned channels even though the two detectors keep indicating the maximum optical power. Figure 1 (b) shows an example of the drawback and limitation of a conventional alignment system. There are a misaligned channel and a blocked channel in Fig. 1 (b). A conventional alignment system tells that the components are perfectly aligned because each of the two detectors indicates the maximum optical power. As mentioned earlier, adding more detectors in this case six more detectors or primitive measuring, one-by-one measuring, with one detector method can be solutions, but they are not enough efficient to overcome this drawback.

Fig. 1. Conventional optical alignment system.

3 Hadamard optical alignment system

The Hadamard transformation is one of well known multiplexing techniques using spatial light modulator called Hadamard encoding mask, which makes the best enhancement of SNR for the reconstructed signals [4]. In the respect of the Hadamard transform applications, Hadamard spectrometry has been studied [5, 6, 7]. The multiplexing advantage offered by Hadamard transform spectrometry can improve the SNR at the output of a spectrometer. The multiplexed signals are produced as the sum of selected original signals according to the transformation matrix of the given multiplexing technique. The original signals can be calculated from the multiplexed signal by taking its inverse transformation used. The number of measurements agrees with the number of the original signals.

The proposed Hadamard alignment system is shown in Fig. 2. The basic Hadamard transform alignment system consists of three components: an encoding mask, an optical lens, and a detector. The encoding mask is made up of two types of elements. A particular location on the mask either transmits or shuts the light. Each element of the beam is either transmitted or blocked, and the detector measures the sum of the transmitted elements. If there are n unknown channel optical powers to be determined, at least n different measurements must be made, each with a different mask position. Each element in the mask transmits the light from the light source or not. The layout of the mask is determined by the transformation matrix of the multiplexing technique.

Fig. 2. Hadamard optical alignment system.

The shutter principle of the mask for the Hadamard transform is shown in Eq. (1), which is called S-matrix. When the elements in the mask transmits the light, it implies 1 in the S-matrix. On the other hand, when the elements in the mask blocks the light, it implies 0 in the S-matrix. We can determine the S-matrix in advance. We can get the measurement one-by-one by shifting the element of mask. Equation (1) is also an example of a cyclic S-matrix. To describe a cyclic matrix, it is sufficient to define its first row. Successive rows are generated by cycling the first row through all its cyclic permutations [4].

$$S = \begin{bmatrix} 1 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 0 & 1 & 0 \end{bmatrix} \quad (1)$$

The measurement can be represented by an $n \times 1$ vector η . Let us define Ψ as a column vector representing each channel optical power. Then the measurement process can be modeled by the Eq. (2)

$$\eta = S\Psi. \quad (2)$$

We can simply get the estimation of each channel optical power using Eq. (3).

$$\Psi = S^{-1}\eta. \quad (3)$$

4 Results and discussion

To evaluate the optical power estimation performance of the proposed method, the computer simulations were carried out. All the results were drawn from 200 independent Monte-Carlo runs. Basically we focused on aligning an seven-channel optical waveguide to a seven-channel optical fiber array. We assumed that a light source with 15 mW and an optical lens with 50% loss were used. We used the Hadamard encoding mask having the same pattern with Eq. (1) and one detector. The simulations were carried out under the four types of experimental scenarios. First, there was no misaligned channel between the two multiple channel optical components. Secondly, there was a channel completely blocked. Thirdly, there were two channels blocked. The one was completely blocked and the other was half misaligned. Finally, two channels were completely blocked. These are the cases of the drawback for a conventional optical alignment system in Fig. 1.

The results for each experiment are shown in Table I. Each channel optical power of the components is almost the same in the column of Scenario

Table I. The estimated optical power for each channel.

channel	scenario 1	scenario 2	scenario 3	scenario 4
1	1.0705 (98.5%)	1.0710 (98.8%)	1.0723 (98.9%)	1.0716 (98.8%)
2	1.0717 (98.6%)	1.0708 (98.8%)	1.0705 (98.7%)	1.0714 (98.7%)
3	1.0718 (98.6%)	1.0709 (98.8%)	1.0714 (98.8%)	1.0719 (98.8%)
4	1.0720 (98.6%)	1.0718 (98.9%)	1.0727 (98.9%)	1.0714 (98.7%)
5	1.0714 (98.6%)	0.0007 (0.1%)	0.0081 (0.7%)	0.0083 (0.8%)
6	1.0716 (98.6%)	1.0720 (98.9%)	0.5364 (49.5%)	0.0080 (0.7%)
7	1.0713 (98.6%)	1.0712 (98.8%)	1.0706 (98.7%)	1.0704 (98.7%)
sum	7.5002	6.4284	5.9020	5.3730

1. It means all channels are almost perfectly aligned. The numerics in the parentheses in Table I imply the ratio of alignment comparing the maximum channel optical power at each measurement. In the column of Scenario 2, we can find the almost zero percent aligned, i.e., almost blocked channel at channel fifth and other channels are well aligned. We can find two misaligned channels in the column of Scenario 3. Note that the alignment ratio of the sixth channel is almost 50% and the fifth channel is almost completely blocked. In the column of Scenario 4, both of the two channels, fifth and sixth channels, are almost completely blocked. The total sum of optical power is decreased as the number of blocked channels is increased.

5 Conclusion

In this paper, we introduced an optical alignment system using Hadamard transform. The proposed alignment system is suitable for aligning multiple channel optical components. It can evaluate each channel optical power information using one detector. From the characteristic of optical components, it is important to know the light transmission for each channel. As the number of channels of an optical component has been increased, a conventional optical alignment system has a limitation to guarantee whether all channels are aligned or not as long as one uses two detectors located at the end of the outermost channels. The proposed optical alignment system can be implemented by minor modification of exiting alignment systems, and it can compensate for drawbacks of a conventional optical alignment system.