The Development of Automatic Light Tracing Alignment Technique for a 1×2 Mechanical Optical Switch

Kuang-Chao Fan, Wu-Lang Lin, Hung-Yu Wang
Department of Mechanical Engineering
National Taiwan University
10627 Taipei
Taiwan, R.O.C.
fan@ntu.edu.tw

Abstract

This paper presents the Automatic Light Tracing Alignment (ALTA) system and its application to a 1×2 mechanical optical switch, which has been developed by the authors. The input fiber is firstly manually adjusted through a 6-axis micro stage to the vicinity of the two output fibers. Then, based on the two output light intensities a 3-axis PZT stage is commanded to fine tune the input fiber for light tracing. The search direction and step of motion is calculated by the optimization technique using quadratic estimation algorithm in association with the hill-climbing algorithm. Integrating the developed optimization software with image processing technique, PZT motion control module, and the light detection module, the ALTA system has been developed in the LABVIEW environment. Experiments demonstrate that for the investigated 1x2 mechanical optical switch carrying multimode fibers the optimum insertion loss of ch1 can be controlled to 0.47dB and ch2 to 0.51dB within 383 seconds. Comparing with the normal tedious manual alignment process, this ALTA technique can save tremendous time in mass production.

1. Introduction

The popularization of Internet network causes double growth at the speed of every nine months in average. The technology of DWDM (Dense Wave Length Division Multiplexing) enables coupling and transmitting signals of different light wavelengths in one single fiber. In case the distribution between the data flow and bandwidth is poor, it will cause the bottleneck for communication. Therefore, it needs the component of optical switch to make the best use of DWDM as the moderate distribution of data flow [1]. Optical switches play an important role in fiber-optic communication for mapping wavelength from input ports to appropriate output ports based on their destination. Hence, the popularization of optical switch is one of the keys to the future DWDM network development.

The mechanical type optical switch will play an important role for the business market of DWDM network. It does not require the transformation of the optical signal between O/E/O as with the conventional method. Thus, it has the advantages of low insertion loss and low cross-talk, but its disadvantages are large size and high costs [2]. Fan et al. [3] had successfully fabricated a novel 1×2 mechanical optical switch that is small in size (20×16×7.5mm^3), low cost (US$10) and highly reliable compared with other mechanical types of optical switches, such as the DICON 1×2 optical switch (67×23×16 mm^3), JDSU 1×2 optical switch (48.36×18.14×8.86 mm^3). Moreover, due to the omission of expensive collimators and prisms, our switch costs only 1/5~1/10 of the others. When comparing to MEMS type optical switch our switch is similar in size to the DICON 1×2 (20.83×12.7×7.21 mm^3) but vastly reduces the complexity. In terms of the cost, it is only about 1/10~1/20 of the MEMS process. As with the moving fiber type, for example the Hitachi (28×15.6×8.3 mm^3), our switch is only about 2/3 of the size due to omission of extra-precision components and only 1/5~1/10 in cost. Thus, our switch is the smallest and cheapest among all existing mechanical optical switches.

The automatic alignment technique between the channels is the key to the mass production of low cost mechanical optical switches [4]. So far, the majority of the optical switch alignment is implemented by manpower, which results in very low yield rate and high cost, yielding to the stoning block in the development of fiber-optic industry. This research has successfully developed an Automatic Light Tracing Alignment (ALTA) system with the core technology of optimization technique. This system consists of the developed optimization software, image processing technique, PZT motion control module, and the light detection module. The operating software is developed by LABVIEW tool. It can quickly find out the best insertion losses for both ch1 and ch2 within a short automatic alignment time (383 seconds). Experimental tests have shown the applicability in multimode fibers of 1x2 fiber-to-fiber mechanical type optical switch. It can be a useful component in the development of "last mile" fiber-optic communication.

2. Configuration of the 1x2 mechanical optical switch

The developed miniature 1×2 mechanical optical switch is based on the principle of fiber-to-fiber configuration in the design aspect [5]. The special characteristic is to directly switch the input fiber, rather than via any mirrors, precisely to the positions of two output fibers through a switching mechanism, as schematically shown in figure 1. We use an industrial miniature relay (14×9×5mm^3), made by OMROM Co., as an actuator for switching the input fiber, and use a "Ferrule" as a holder to achieve the switch displacement of the input fiber to 125μm, as shown in figure 2. This switch needs only the near-field co-axial alignment, which promises less optical loss than other light bending configurations. The photo of figure 3 clearly reveals its small scale of 20×16×7.5mm^3 in size. It has special features of low cost (US$10) and high reliability compared with other mechanical types of optical switches [3]. Moreover, simpler configuration yields to easier assembly process to high precision. Using the ALTA program to drive PZT, the input fiber will be initially position to the output fibers. With the quadratic estimation algorithm and the hill-climbing algorithm the input fiber is quickly aligned to the two output fibers.

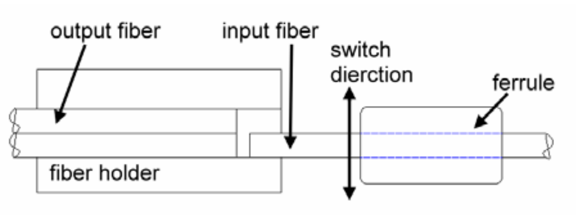

Fig.1: Schematic of Fiber-to-fiber optical switch

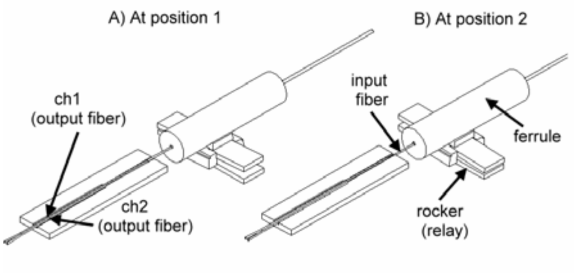

Fig. 2: Configuration of the switching mechanism

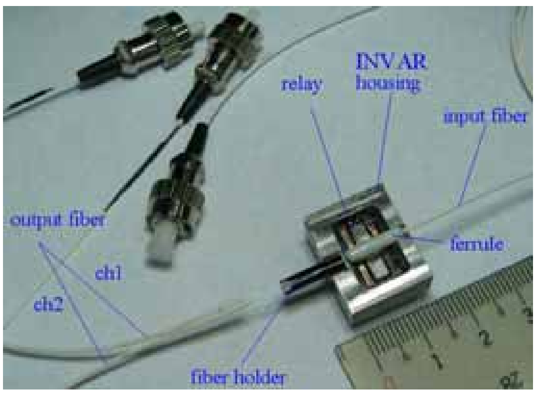

Fig. 3: Photo of the 1×2 mechanical optical switch

3. Automatic alignment system

The alignment technique of optical switch is more complicated than the fiber fusion splicing or the pigtailed laser diode (LD) alignment [7] for those require only 1x1 fiber alignment technique. The 1x2 fiber-to-fiber optical switch requires dynamic and simultaneous alignment between one input and two output fibers. The insertion loss is the key factor of the alignment process that requires as low as possible. According to the criterion specified in the Bellcore specifications [8], the required insertion loss for both two output signals should be less than 1dB. To achieve this goal, we propose the two-stage alignment technique, namely the rough alignment procedure assisted by a manual type 6-axis micro stage and the CCD image processing, and the fine alignment assisted by the 3-axis PZT stage, the CCD image processing and the power meter, as shown in figure 5. The first stage moves the input fiber to the vicinity of the front line of two output fibers until and output signals are detectable by the power meter. The orientation alignments in three axes are presumed completed at the end of this stage, since the core of the multimode fiber has large diameter of 65μm. The second phase will be computer-controlled by the PZT stage in three linear directions with the light intensity as feedback signal and the search command derived by the alignment algorithms.

3.1 Alignment algorithms There are many alignment algorithms that have been developed to find out the minimum value of fiber insertion loss, for example: Quadratic estimation, Hill-climbing, MSM algorithms etc. [9-13]. Any method requires the proper starting point followed by numerous iterations until the system finally converges.

In this paper, we have adopted the quadratic estimation algorithm and hill-climbing algorithm for our switch alignment. Details are explained in the following.

a. Quadratic estimation algorithm Reklaitis [9] had developed the Quadratic Estimation algorithm for searching the optimal value of a given function. In the fiber alignment procedure the objective function is the detected light intensity of the output fibers, and the design variables are the three linear displacements of the input fiber in X, Y, Z directions respectively. Although this is a multivariable optimization process, however, during each directional search only the step size α is the required variable. Suppose that the PZT stage moves in three consecutive steps to positions of α_1, α_2 and α_3, the corresponding output fiber signals are f_1, f_2 and f_3 respectively. If f_1, f_2 and f_3 are continuously increasing then moves to the next step to replace the first point (α_1, f_1) and renumbers the order. Continuous iteration of this process we can reach to the state of $f_1<f_2$ and $f_2>f_3$. Within the zone of α_1-α_2-α_3 the maximum $f(\alpha^*)$ should be located. In order to find the maximum f, we can then fit a second order polynomial function passing through these three points, namely $f(\alpha) = a + b\alpha + c\alpha^2$, where a, b, c are coefficients to be found as shown in figure 4. The optimal value of $f(\alpha^*)$ can be obtained by differentiation and interpolation of the $f(\alpha)$ curve.

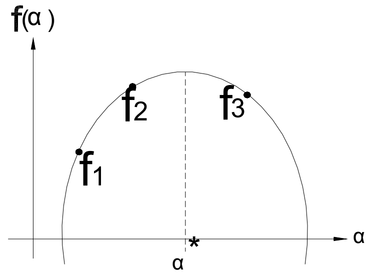

Fig. 4: The quadratic estimation curve

b. Hill-climbing algorithm During the quadratic estimation process the step size is comparably large in order to reach to the optimum zone quickly. The optimum point is only approximate to the real point. Therefore, a second smaller step process for fine tuning the PZT motion is necessary. The ALTA program will move the PZT stage to one side of the optimum point with very close distance, say 2μm, and start to move with very fine steps, say one tenth of the quadratic estimation step. During each step we can see the incremental increase of the output fiber's light intensity. The program iterates until the maximum intensity is found. Any further motion away from the maximum point will result in the decade of the function. This is called the Hill-climbing algorithm [10]. This algorithm is easy to implement and ensures convergence for the alignment system.

Fig. 5: Experimental setup of the ALTA system

3.2 Alignment procedure The construction of ALTA alignment system is shown in figure 5. In order to meet the BELLCORE standards requirement for the 1×2 optical switch, the insertion loss for both ch1 and ch2 must be below 1dB. Moreover, the difference of the insertion loss between ch1 and ch2 must be below 0.1dB.The ALTA procedure is as follows:

1. With the aid of the CCD module the ALTA program calculates the initial position of the input fiber, which is then moved by the PZT module close to the ch1 output fiber.

2. The ALTA program will carry out the quadratic estimation algorithm and then the hill-climbing algorithm to bring the insertion loss of ch1 below 1dB.

3. When the insertion loss for ch1 is under controlled, the input fiber will be switched to ch2. Due to the ch1 loss already being below 1dB, the ch2 insertion loss might be over the criteria. The ALTA program will only carry out hill-climbing algorithm (fine alignment) for ch2 and terminate when the insertion loss is below 1dB. Once this is completed, the system then switch to ch1 and the dynamic switch alignment process is executed. The system will then decide its next step based on one of the following conditions:

   a. Ch1 loss still falls below 1dB. The probability of this occurrence is only about 10% in our experiment. In this case, the dynamic switch alignment is skipped and two-channel automatic light tracing balance alignment (ALTBA) is carried out.

   b. Ch1 loss rises above 1dB. This occurs as a result of the influence from machining precision, surface roughness of the fiber holder, and fiber bending resulting from fiber switching. If this occurs, the ALTA program is executed.

4. Within the ALTA stage, two directions for ch1 are first chosen and the system attempt to find the lowest loss values in the positive and the negative direction of the two coordinates axes The end result is a vector cycle from +Y to -Z (**+Y→-Y→+Z→-Z**, X axis is fixed), as shown in figure 6. The loss values for four directions are first recorded. The best searching direction is then determined from the four-recorded directions; the search continues in the best direction until the optimal loss is below 1dB.

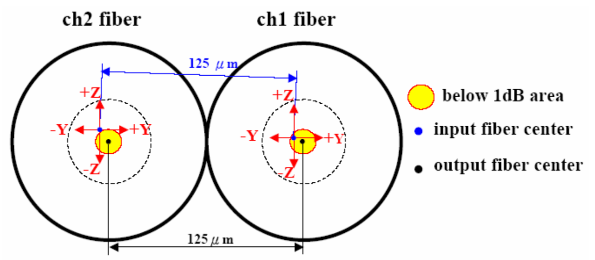

Fig. 6: The search of motion direction

5. After completion, the system switches to ch2 and the same steps are repeated.
6. The ALTA program will reiterate the process: Ch1→Ch2→Ch1→Ch2 until the ch1 and ch2 insertion losses are all below 1dB.
7. When both of the insertion losses of ch1 and ch2 are below 1dB, the ALTBA program will carry out automated switch balance alignment. The method is to raise the loss value of the lower loss channel and lower the loss value of the higher loss channel so that the difference between ch1 and ch2's insertion loss is below 0.1dB. The ALTBA rule is similar to ALTA, both search the best direction from the positive and negative directions of the chosen coordinate axes (**+Y→-Y→+Z→-Z**, X axis is fixed), but in this case the four directions are seen as a vector cycle and after each vector movement, the system will switch

to the other channel until the optimal balance loss value of the two channels are found, (namely loss value <0.1dB). The flowchart of ALTBA is as shown in figure 7.

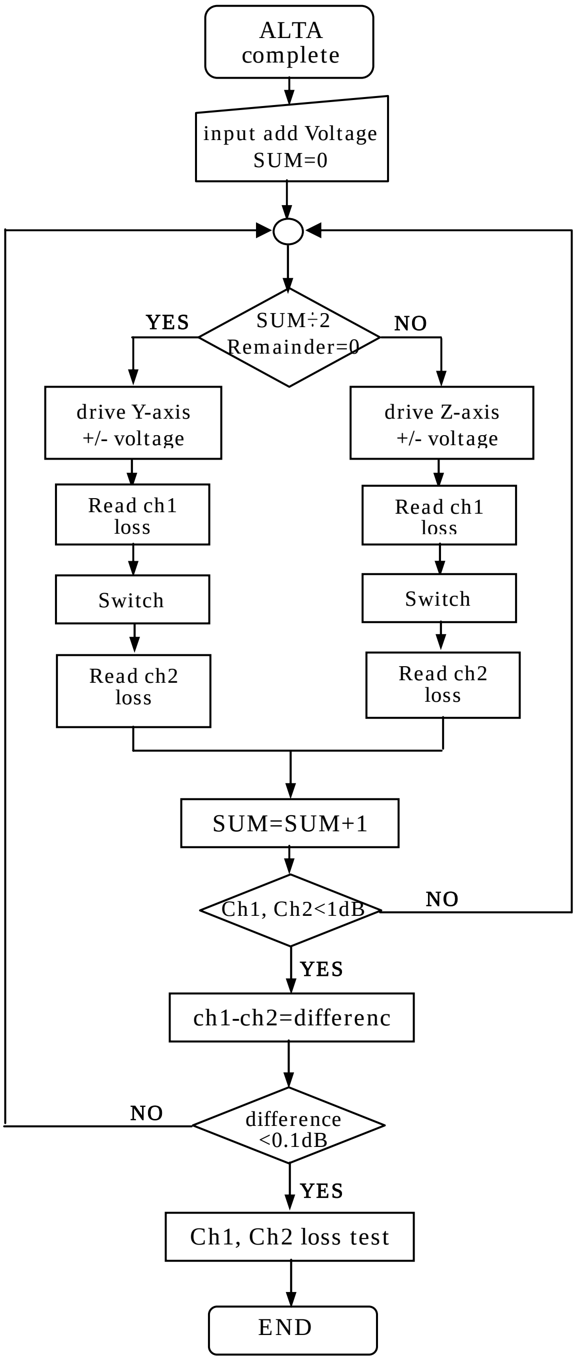

Fig. 7: Flow chart of ALTBA process

4. Test results

The fibers used in this experiment have the following specifications: multi-mode fiber: outer diameter 125μm, core 62.5μm, zero degree of the fiber tip angle and non anti-reflection coating. The resolution in all axes of PZT is 10nm. By using the ALTA and ALTBA techniques for the quick alignment of 1×2 mechanical optical switch, we have acquired the optimal insertion loss and balance the two channels' difference.

The initial rough positioning of the input fiber to the vicinity of the ch1 output fiber was achieved to about 2dB.

(1) Switching to the fine motion controlled by the PZT stage and using the ALTA program, ch1 could be aligned to 0.69dB, as shown in figure 8(a). It took about 290 seconds.

(2) The input fiber is then switched to ch2. Carrying out the ALTA program the final insertion loss could be gained to 0.93dB, as shown in figure 8(b). It took about 20 seconds.

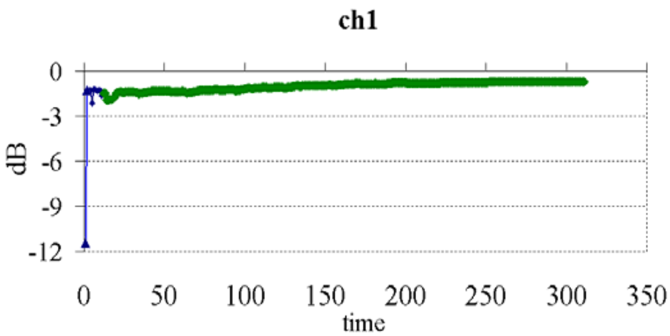

Fig. 8(a): Initial alignment of Ch1

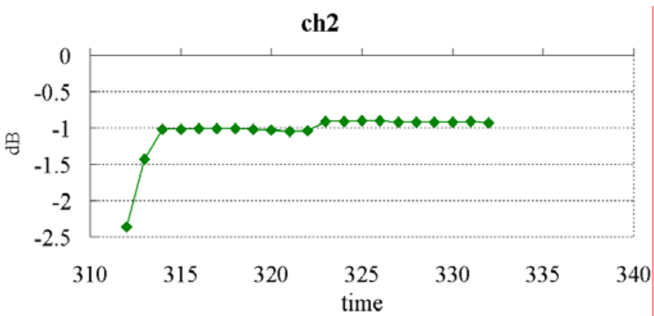

Fig. 8(b): Initial alignment of Ch2

(3) Implementing the balance alignment using the ALTBA program to negotiate the insertion losses between ch1 and ch2, the final alignment results are presented in figures 8(c) and 8(d). The insertion loss of ch1 was controlled to 0.47 dB and ch2 was within 0.51 dB. The difference was under 0.1 dB. This status has met the Bellcore requirement. The total time is 383 seconds.

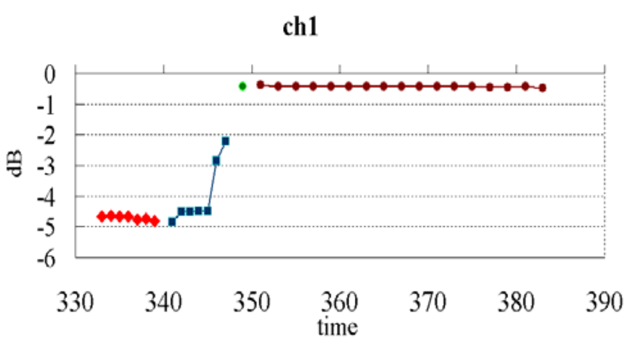

Fig. 8(c): Final alignment of Ch1

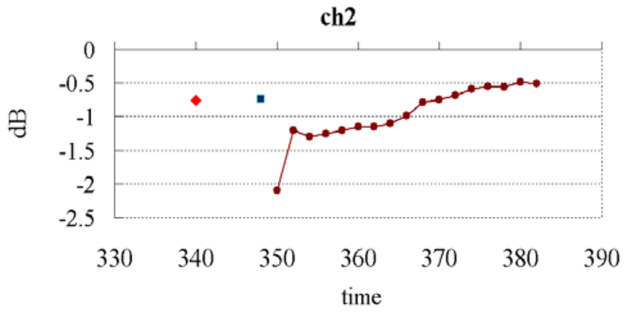

Fig. 8(d): final alignment of Ch2

(4) Figures 8(e) and 8(f) present the reliability tests. For continuous 100 times switch motion, both channel remained in satisfied insertion losses. The entire automatic light tracing alignment process is completed.

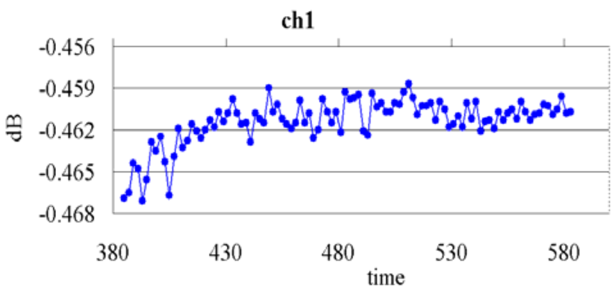

Fig. 8(e): Reliability test of ch1

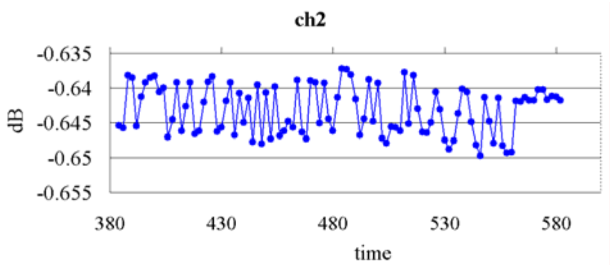

Fig. 8(f): Reliability test of ch2

5. Conclusions

Using the automatic light tracing alignment (ALTA) technique we have successfully demonstrated the alignment of 1×2 mechanical optical switch. For two-channel output the light intensities should negotiate to each other. This is the essence of the developed ALTBA program. The results show the best insertion loss of ch1, ch2 are 0.47dB, 0.51dB, respectively and the total alignment took only 383 seconds. The difference between the ch1 and ch2's insertion loss is 0.04dB (below 0.1dB). In order to test for the switch reliability we continue to switch for 100 times after the automated alignment. The end results are ch1 0.48dB and ch2 0.63dB in average, respectively. Comparing with the normal tedious manual alignment process, this ALTA technique can save tremendous time in mass production.

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