

## *Chapter 4*

# *Coding Development for Automated Waveguide Alignment and Direct UV Writing*

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This chapter discusses the approach taken in obtaining automated waveguide alignment and also in controlling the 3-axis stages for direct UV writing of optical channels. These coding architectures were developed using the LabVIEW software.

### *4.1: Brief Introductory on Laboratory Virtual Instrument Engineering Workbench, LabVIEW*

LabVIEW is an acronym for *Laboratory Virtual Instrument Engineering Workbench* and a graphical programming language from National Instrument Inc. Instead of using texts as commands as in traditional programming languages such as C++ and Java, it uses graphical icons to program. As such, because of this, Labview is referred to as G-language by most users. LabVIEW is a cross Operating System (OS) platform software which allows the program created in Windows based OS to work functionally in UNIX or LINUX environments, and vice versa [1]. This software was developed for the purpose of measurements, data manipulation and analyzing, and result presentation. Due to such functionality and flexibility, it is widely applied by researchers to create their very own virtual instrument for their work [2, 3].

## *4.2: Automated Waveguide Alignment*

### *4.2.1: Simple Vision System for Automated Waveguide Alignment*

A simple vision system composed of Universal Serial Bus (USB) web-cameras and high precision alignment stage (Suruga Seiki E4010A) has been built for the purpose of waveguide alignment. This technique is based on a simple analysis on the fiber and waveguide position via pictures taken by installed web-cams. The analysis procedure is simply by introducing a Cartesian coordinate system on picture based on its resolution with upper left corner of picture as the origin of the coordinate system; hence, a picture with a resolution of 640x480 has 640 units in abscissa and 480 units in ordinate for instance. With this designation, coordinates of fiber is defined and thus the stage where fiber sits can be commanded to move through the commands from computer. Both the web-cams were set perpendicularly to each other to provide top- and side views for the alignment; the set up is shown by the Fig. 4.1 and Fig 4.2 below.

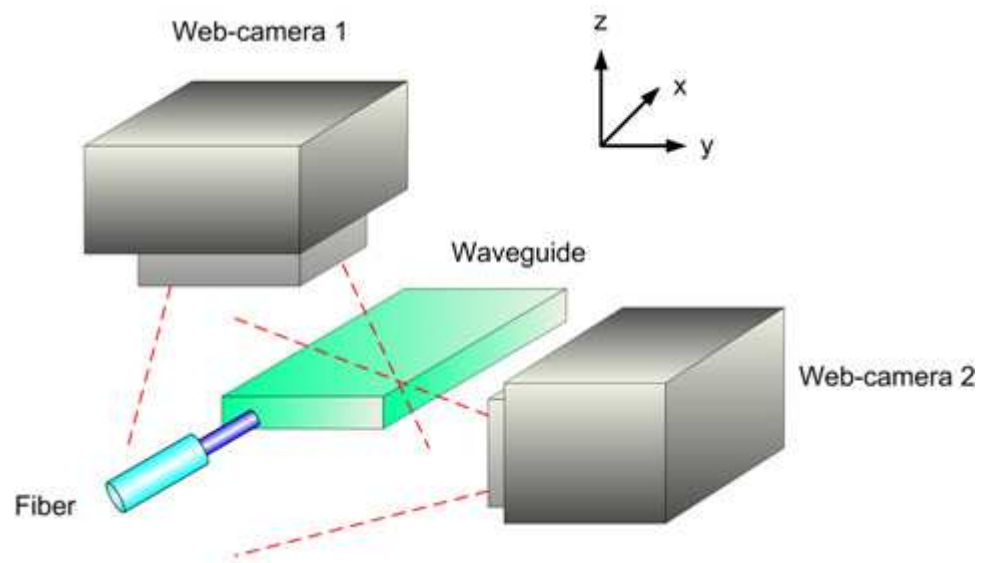


Fig. 4.1: Schematic on simple vision system for waveguide alignment

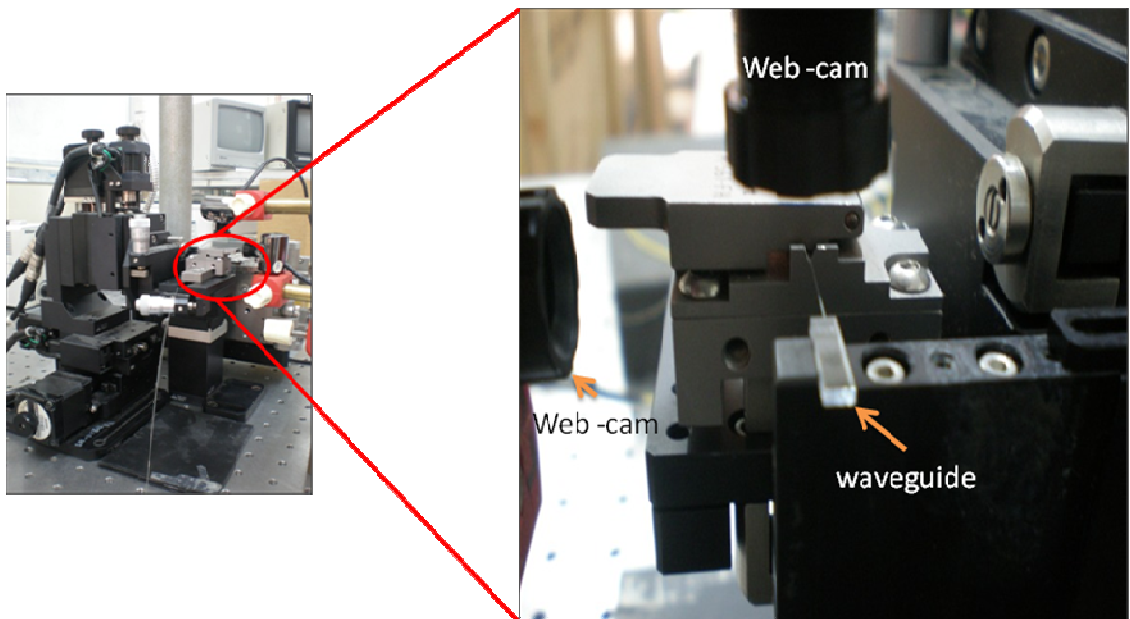


Fig. 4.2: Alignment setup for simple vision system

In this work, picture taken by the top web-cam on closely aligned fiber-waveguide was first to analyze the respective positions according to the definition mentioned. As soon as the position of fiber and waveguide were known, fiber is then moved closer with the waveguide with a fix amount of steps. That was used to determine the change of steps per pixel within the constant steps of movement and the number of pixels separating fiber and waveguide. When the separation value is identified, number of steps needed to move the fiber is therefore determined. Following mathematics demonstrates the situation mentioned:

*Initial position of fiber =  $F_1$ ;*

*Steps of movement =  $h$ ;*

*Second position of fiber after movement =  $F_2$ ;*

*Waveguide position =  $W$ ;*

*Numbers of pixels represent the movement of  $h$  value:*

$$F_2 - F_1 = h$$

*Change of steps per pixel,  $m$ :*

$$m = h / (F_2 - F_1) \quad \text{Eqn. 4.1}$$

*Number of pixels separating fiber;  $k$ ;*

$$k = W - F_2 \quad \text{Eqn. 4.2}$$

*Steps for fiber to touch the input of waveguide;  $n$ :*

$$n = k * m \quad \text{Eqn. 4.3}$$

After the fiber has moved with the steps number as prescribed by Eqn. 4.3, it is directed to move to the vicinity of input channel of the waveguide with the same principle. Location of the input channel is only estimation and with assumption that the input channel was *printed* precisely at the middle of waveguide. Next, web-cam set at the side of the alignment setup will take picture from side to confirm the fiber is in not situated at above nor at bottom of the waveguide. Fig. 4.3 shows the front panel of the simple vision system and the respective coding is shown in Appendix B.

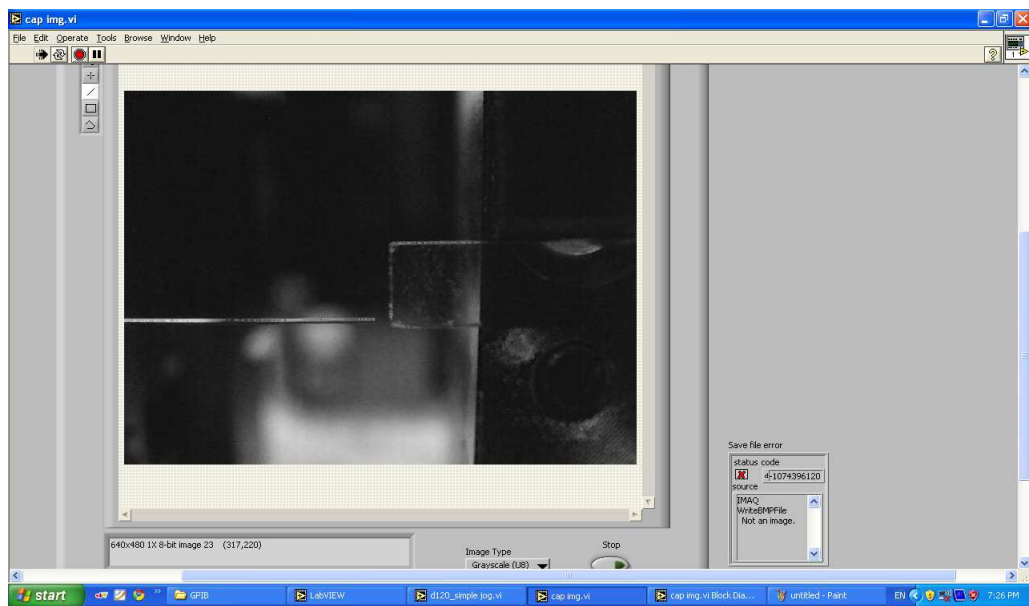


Fig. 4.3: Front panel of developed simple vision system during operation

### 4.2.2: Active Alignment Setup Configuration

Apart from the vision simple vision system which had developed in this work, waveguide alignment has been also carried out through a high resolution stepper motor (Suruga Seiki E4010A) with the control from a computer via General Purpose Interface Bus (GPIB) interface to the stepper motor controller (D120), a manual alignment stage and an optical multimeter. Fig. 4.4 illustrates the experimental setup.

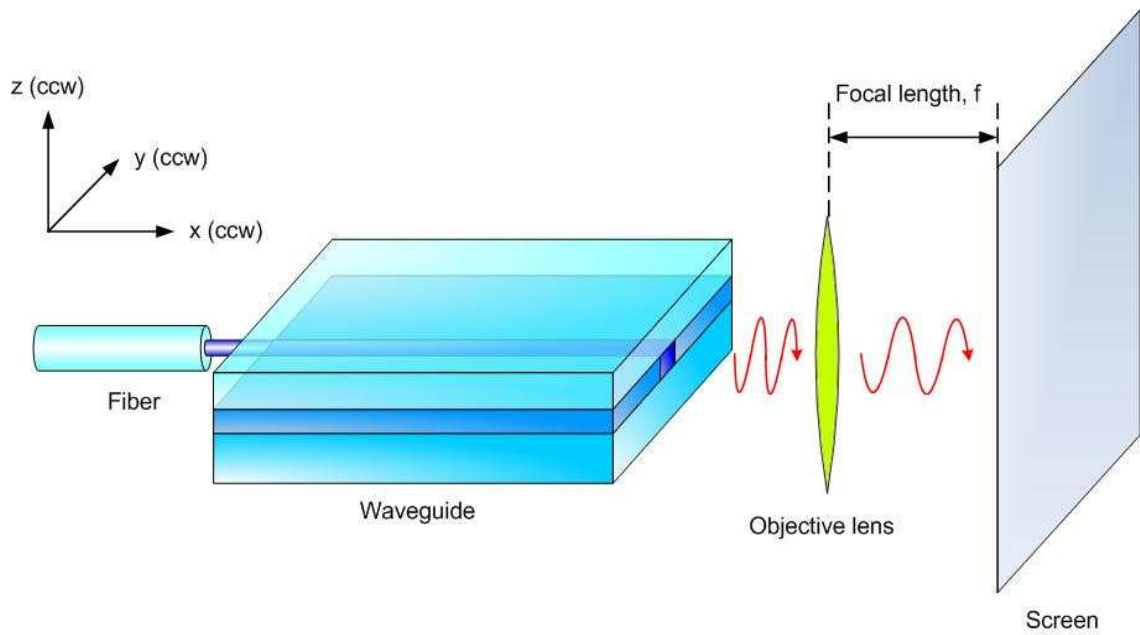


Fig. 4.4: Waveguide alignment setup for channel search

Fiber which is used to deliver optical signal was placed on a high precision stepper motor alignment stage with six degrees of freedom (DOF). In order to locate the input channel before the alignment with light detection method; an interference based method is used to perform the task. A 1-by-4 optical power splitter (silica-on-silica) sitting on waveguide holder was coupled with an optical signal at the wavelength of 650nm and is scanned vertically through the input facet. The scanning was first started at one of the upper corners of the power splitter and making the way down to the bottom of waveguide. During the process, interference fringes were produced from the

waveguide's output and projected to a screen made of graph sheet via a 40X objective lens sitting on a manual alignment stage.

During the vertical scan process, number and size of fringes change with response to different fiber position. At certain when fiber travels from over-clad to under-clad of the waveguide, number of fringes reduces to a minimum and increase after that; at the same time, size of each fringe becomes larger up to a maximum and becomes slimmer slowly. When that turning point of both parameters has reached, light source is scanned through the input facet laterally to look for the embedded physical channel in the waveguide which will be represented by a dot on screen. In general, guiding line represented by a single dot on screen will be the first to meet before the input channel in which will be represented by multiple dots on screen. As soon as the position of the input channel has been recognized, fine tune procedure on the input's channel position is initiated through active alignment algorithm. Formation of interference fringes from waveguide's output may be linked to the structural property of the waveguide.

When light source is coupled into the over-clad of the waveguide, they were guided inside the layer and refracted at the output and interfered with each other when they are leaving from output. Fringes become larger in the aspect of size when the light is move near to core layer. The moment where the optical signal moves into the core region, they are refracted at largest angle. As they move away from the core region and heading towards to under-cladding layer, they refracted at smaller angle similar with what they had face in the over-cladding layer. The underlying physics on these phenomena is just the relationship between the angle of refraction and index of refraction which as described by Snell's Law. Since the index of refraction of over- and under-cladding is lower than the core, light will be refracted at largest when it travels from core to air.

### 4.2.3: Peak Power Detection

A simple peak power scanning algorithm has been developed for the fine tuning procedure to locate the optimum fiber position for maximum output power. This alignment procedure is initiated when the physical property of the waveguide is located which as represented by bright dots on screen. Basically, this is a semi-automated algorithm; hence, it was used with the soft-joystick of the stepper controller to perform the task. Fig. 4.5 shows the front panel of this algorithm during operation and corresponding coding is shown in Appendix B.

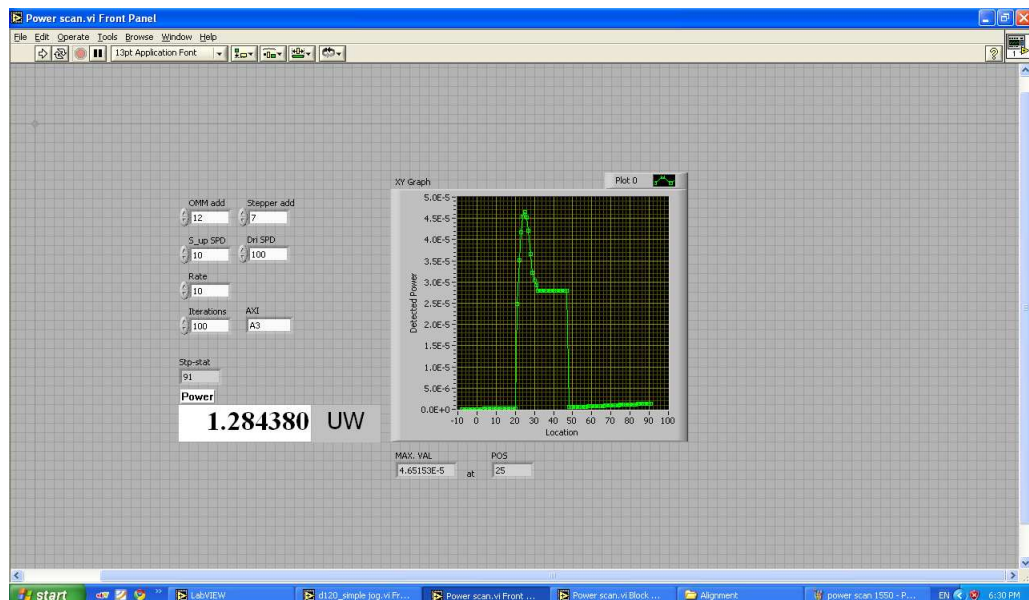


Fig. 4.5: Front panel of peak power detection algorithm

First, this algorithm will perform vertical axis scanning in the waveguide's input face for some distance to ensure the input channel will be covered by the scanning process. Power at any channel is then pick up by the optical power detector which set for free space measurement and transfer to the algorithm for output display and data storage. On the completion of the vertical scan, optimum location corresponds with maximum output power is determined; translational stage is moved to the location using



the soft-joystick then. Immediately after the relocation on z-axis position, this algorithm is started once again where the scanning will be in y-axis direction in order to locate the optimum position of maximum output in y-axis direction. Again, the translational stage will be relocated into the optimum position in y-axis. As soon as the fiber is placed in the optimum positions determined by this algorithm, output power of each channel is measured. These output readings are compared to the results obtained from manual alignment with the soft-joystick.

#### 4.2.4: Manual Alignment on Launch Fiber

A manual alignment technique has also been used to refine the input's location apart from the active alignment. This manually method was done by measuring one of the free space output powers while the translational stage is controlled to move step by step in z-axis via self-developed soft-key pad. On the earth of a local maximum power is recorded for a particular z-position, same procedure is repeated for y-axis to look for the location to which correspond to other local maximum power. The whole process is repeated up to a point where global maximum power is recorded by the optical power detector. Once this had achieved, power from each outputs is recorded for the relevant input wavelengths. The front panel of the developed soft-key pad is showed in Fig. 4.6 and the corresponding coding is shown in Appendix B.

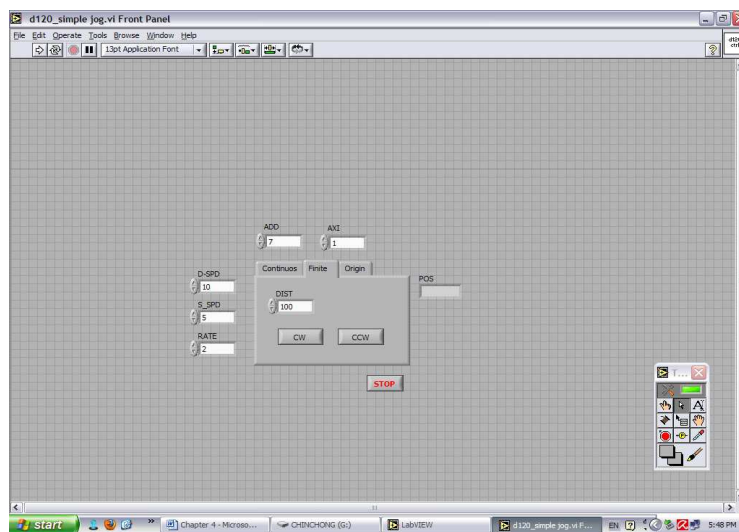


Fig. 4.6 Front panel of soft-key pad of stepper motor controller

### 4.3: Direct UV writing

In our work, a frequency doubled UV laser operating at 244nm has been used to write the desired optical channel design. The movement of the sample exposed to the laser was done via stepper motors and controller from Suruga Seiki. The translational stage is composed of three individual stages. Circuitry designs were first transferred to pieces of name cards which have been cut into dimensions similar to the in-house fabricated samples in order to check that the program functionalities. Fig. 4.7 shows the schematic diagram for the direct UV writing setup used in this work.

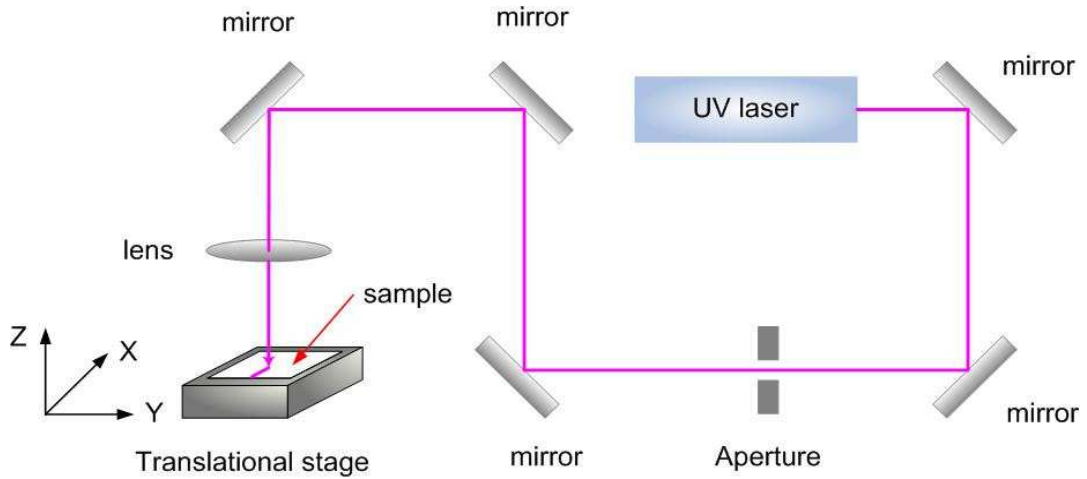


Fig. 4.7: Schematic diagram of direct UV laser writing setup

Alignment of the laser was done step by step by first determined the height of laser beam from optical table level. Secondly, the first reflective mirror is adjusted the position so that the beam will hit on the center of the mirror preferably. As soon as the first mirror is aligned into the position, the same procedure was repeated on the rest of the reflective mirrors in order to direct the beam to the center of focusing lens. Attributable to the non-Gaussian profile exhibited by the UV laser, an aperture is used to trim the beam into a single spot beam by blocking the side modes before the beam is focused on the translational stage. The focus point was determined by adjusting the height of the stage relatively to the focusing lens until the tiniest luminescence spot, the luminescence being due to UV absorption, is observed from the card.

The designed circuitries are 1-by-2 power splitter and Mach Zehnder interferometer, and the underlying structures of these designs are just straight and slanted channels. Therefore, the key-point of waveguide writing program is about the manipulation the two fundamental designs in the Labview algorithm.

The aspects requiring attention in the software development of UV-written waveguides are the translational speed of stages as this the only parameter having direct influence on the writing *fluence* in this case. In order to have a uniform refractive index change throughout the whole optical circuitry, the corresponding UV writing coding architecture is preferably designed in such a way where any part of the circuitry design will not be written twice. In case that cannot be avoided in some particular designs such as intersection of two channels or either arm of power splitter has to be written twice, the speed of UV writing has to be increased for the first and subsequent writing respectively.

Besides from the driving speed denoted by DRV\_SPEED (in the unit of pulse per second, pps) as the main speed controller of the stepper motor, there are another two parameters were used for the same purpose: start up speed which denoted by S\_up SPEED (in the unit of pulse per second, pps) and rate of acceleration and deceleration (in ms) denoted by RATE. The pulse in the unit of these parameters represents the distance unit used in stepper motors which will be  $\mu\text{m}$  throughout this work. Since the stepper motors comprise off electric motors, it is therefore important for the motors to operate at a relative low speed before they reach the driving speed in the rate of time specified. That is nothing special but just to prevent accelerated aging of the instrument. The relationship between these three parameter can be represented by a graph which shown by Fig. 4.8

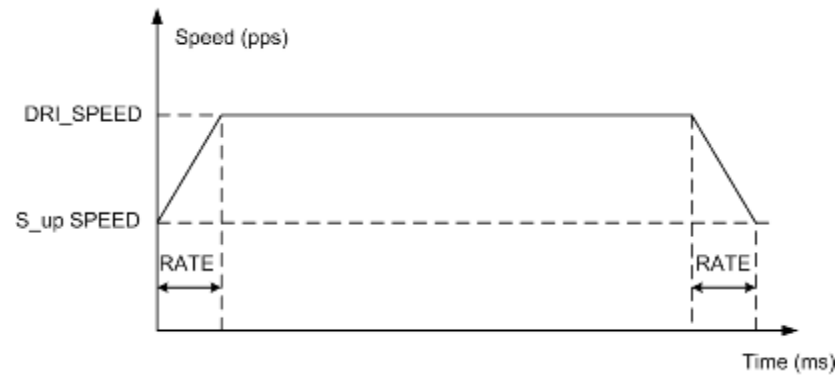


Fig: 4.8: Relationship between driving speed (DRI\_SPEED), start up speed (S<sub>up</sub> SPEED) and rate of acceleration and deceleration (RATE) [4]

### 4.3.1: 1-by-2 Optical Splitter

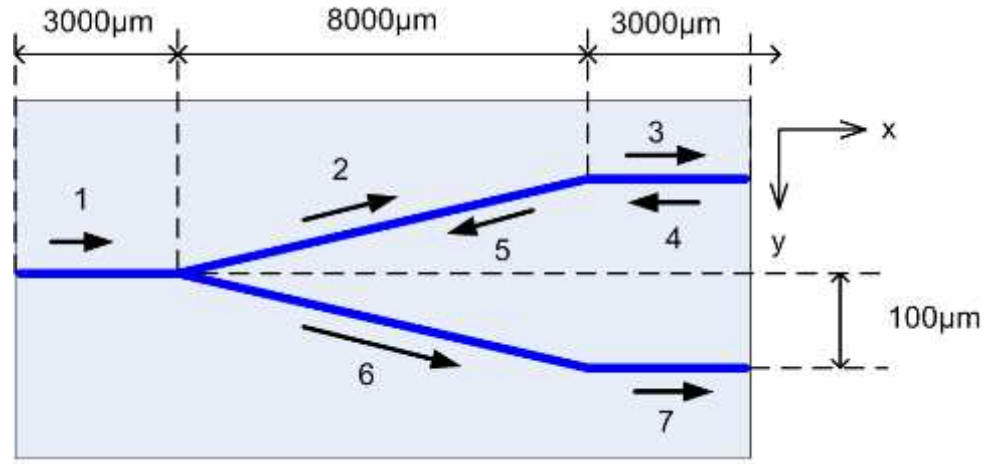


Fig. 4.9: Circuit layout of 1-by-2 optical power splitter

Fig. 4.9 shows the circuitry design of 1-by-2 optical power splitter designed in this work where the arrows indicate flow of the UV writing process. As shown by the arrows, the UV writing process was started by performing straight channel writing by process 1 and this channel design is repeated by process 3, 4, and 7 accordingly. Slanted channel design writing is continued as soon as process 1 completed, and it is repeated by process 5, and 6. Since there was no electronic controlled shutter being used during UV writing process, upper arm of circuit is written twice at two-times the speed after process 1 and this setting continued until process 5. The reason to doubled up the writing speed of upper arm is to standardized the total dosage of UV receive by the sample.

Particulars on the channel length as well as the value of  $\Delta x$  and  $\Delta y$  which yield the slanted design can be changed within the coding and with correspondence modification on the stepper motor controller's resolution. In order for hassle less operating commands environment, this coding architecture has been designed to accept the commands of controller's GPIB address, driving speed, start up speed and rate only; whereby the direction of where the stage should moved has been

pre-fixed within the coding. Fig. 4.10 shows the interface or the front panel of this coding architecture.

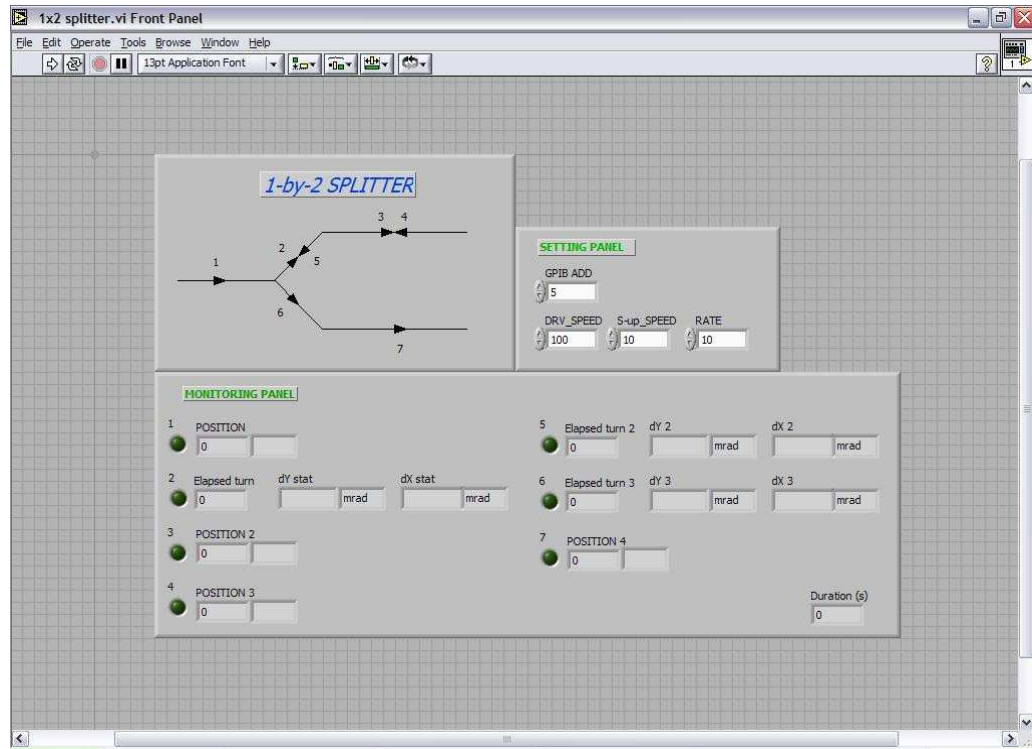


Fig. 4.10: Front panel of 1-by-2 optical power splitter coding architecture

Basically, this coding architecture is started by moving the translational stage further away (clockwise direction, CW) from motor which controls the stage movement in x-direction. As the straight pattern command has been fulfilled, the stage will be moved in  $1\mu\text{m}$  in CCW of y-direction and  $8\mu\text{m}$  in CW of x-direction; and this synchronous movement is repeated for 100times in order to produce the slanted pattern. Next, the stage is moved in CW in x-direction only to complete the intention to create upper of splitter. Once the arm is created, stage is moved along the same path which creates the upper arm in counter direction; and is followed by movement of  $8\mu\text{m}$  in CW of x-direction and  $1\mu\text{m}$  in CW of y-direction concurrently for 100times of iterations. Again, the stage is moved in CW in x-direction to complete the circuit of 1-by-2 optical power splitter. The complete coding of this coding architecture is shown in Appendix C.

### 4.3.2: Mach Zehnder Interferometer

Apart from designing a circuitry for optical power splitting, a circuitry for optical signal phase modulation is designed as well and is shown by Fig. 4.11.

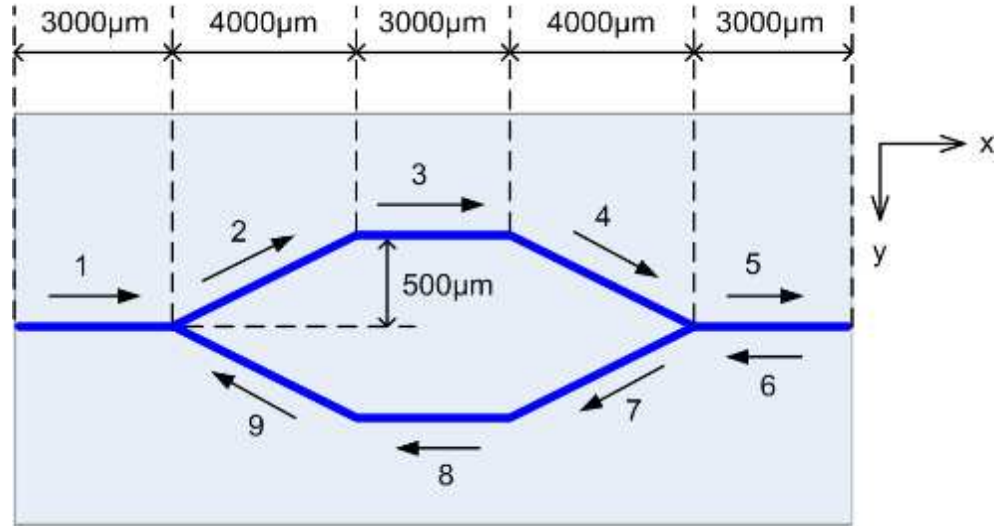


Fig. 4.11: Mach Zehnder Interferometer layout

First channel of Mach Zehnder interferometer design is started by writing a straight channel design in the CW direction of x-axis, and is continued by continuous 500times parallel process in x-and y-axis:  $8\mu\text{m}$  in CW direction of x-axis and  $1\mu\text{m}$  in CCW direction of y-axis; where both of these processes are represented by arrow 1 and 2 respectively. Next, the same instruction of straight pattern of process indicated by arrow 1 is repeated in process 3. As soon as the process 3 ended, stage will be moved in  $8\mu\text{m}$  in CW direction of x-axis and  $1\mu\text{m}$  in CW direction of y-axis at the same time with 500 of iterations. Starting from this moment, the driving speed of the stage is doubled up from previous in order for process 5 and 6 to produce a straight design with similar UV exposed dosage with previous. Soon after that, process 7 in which correspond to the concurrent movement of stage with  $1\mu\text{m}$  in CW direction of y-axis and  $8\mu\text{m}$  in CCW direction of x-axis is taken up with the original driving speed. For completion of circuit



design, stage is moved in the CCW direction of x-axis and continued by the slanted channel design by the 500 instructions of  $8\mu\text{m}$  movement in CCW direction of x-axis and  $1\mu\text{m}$  movement in CCW direction of y-axis. Again, the steps for the stage to move can be changed with correspondent change with stepper motor controller's resolution. Fig. 4.12 shows the front panel of this circuit design, and the complete coding of circuitry design is shown in Appendix C.

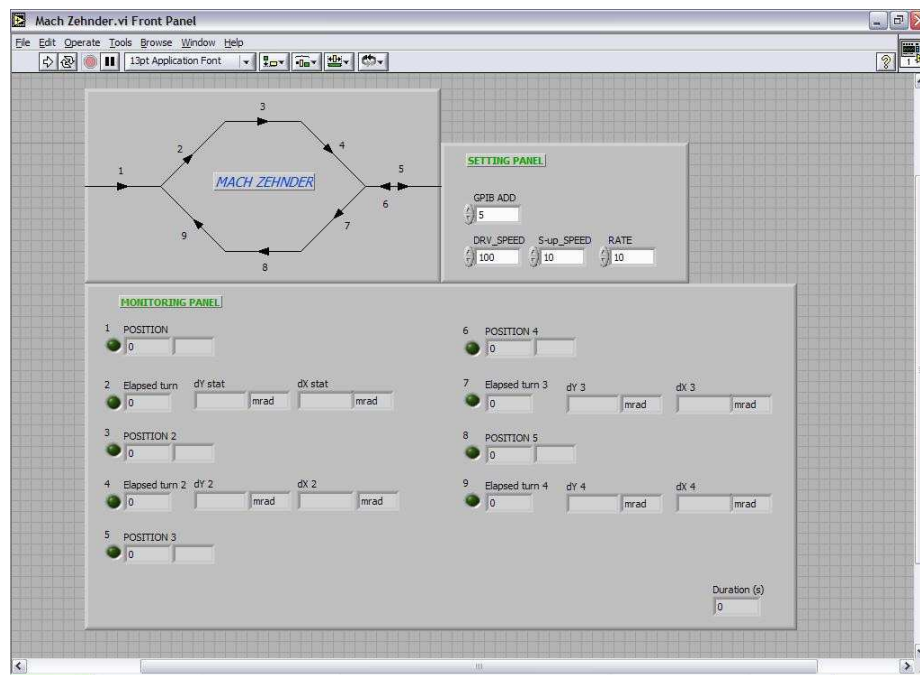


Fig. 4.12: Front panel design of Mach Zehnder Interferometer coding architecture

## 4.4: *Summary*

Throughout this chapter, ideas on the coding architectures of direct UV writing and waveguide alignment methods have been presented. 1-by-2 optical power splitter and Mach Zehnder Interferometer are the optical circuitries which have been developed in this work by transferring the designs into pieces of cards in the size of real waveguides, and they are composed by series combinations of simple straight channel and slanted channel designs. The concern on designing the circuitries is to ensure the designs are able to deliver even UV irradiation to the sample during the writing process, and a compensation step on the driving speed of translational stage may be useful to unify the UV irradiation if any part of the circuits needed to be written twice by UV laser. As for the purpose of pigtailling the 1-by-4 splitter optical power splitter, simple vision system, interference fringes based alignment, peak power detection algorithm and manual alignment have been used. The major focus on device alignment was optimizing the input location of the input channel by detecting the free space output power from output channels.

## *References*

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4. D220 stepping motor controller operation manual (Suruga Seiki, 2009).