# Development and construction
# of an automatic calibration unit for a
# differential absorption LIDAR system.

Diploma Paper
by
Fabian Mellegård

# Abstract

This diploma work is part of a larger project in the development of the LIDAR-system at the Department of Physics at Lund Institute of Technology. The LIDAR-equipment, which is used for environmental measurements, operates like an optical radar. Pulsed laser light is sent through the atmosphere and back-scattered light carries information about the elements in the air. The purpose of this part of the project is to automatize and improve the wavelength calibration for the laser. This will lead to more accurate results in LIDAR measurements.

Today the calibration system has been constructed and the program and unit have been integrated to the main LIDAR-system. The system is fully implemented.

# Table of contents

Department of Atomic Physics, Lund Institute of Technology

# 1. Introduction

## 1.1 Purpose

The purpose of this diploma work is to replace and improve the calibration unit for the laser in a LIDAR-system. This work is a part of a larger work to improve and automate the LIDAR system at the Department of Atomic Physics at Lund Institute of Technology

Previously the laser was calibrated by hand, after which measurements were performed. During the measurements the laser can drift, for instance due to temperature changes. There where no way to know whether the laser drifted during the measurements or not. The new calibration system will make it possible to check the calibration whenever desired.

The department has also replaced the old laser system with a new OPO-system. This new system sets new requirements on the calibration system. The unit must perform in a wider wavelength span. For this reason automatic change between optical components in the unit is necessary. Another improvement is the possibility to place up to seven cells in the unit. This will make it possible to measure on more than one substance during a LIDAR-experiment.

The work will result in:
- Improved and automatic wavelength calibration of the laser.
- Improved calibration unit to contain seven cells.
- Improved calibration unit to function from 250 to 3500 nm.
- Improved uncertainty calibration in the measurement.
- Improved detector system for more reliable calibration evaluations.
- Improved user interface.

To achieve this it is needed to:
- Design a new calibration unit.
- Design the electronics for the detectors.
- Design the electronics for the stepper motors.
- Chose components allowing the unit to work in the desired wavelength span.
- Purchase the components for the calibration unit.
- Program the automatic calibration of the laser.
- Program the uncertainty calculations in measurements.
- Program the user interface.
- Integrate the system in the total LIDAR-system

In summary, design, construct, and implement the new calibration unit.

## 1.2 Limitations

Some time into the project it became clear that it would take too long time to make the system work in the whole wavelength span. For this reason the unit is only equipped to make measurements up to 1100nm. In other words only one detector and beam splitter is installed. Additional beam splitters and detectors have to be mounted to make the unit to work up to 4800nm.

Furthermore no experiments have been done to calculate the errors in the measurements. This has been left out for future development.

## 1.3 Results

The calibration system has been constructed and the program and unit have been integrated to the main LIDAR-system. The system is fully implemented.

The task that was not completed in this project was a fully implemented and tested calibration method. However experiments have been performed that clearly indicates that the unit can perform a calibration, see section 7 Evaluation. But more study and development are needed to achieve a fully automatic calibration mechanism.

Further developments on the calibration system have started to improve its performance. These will make the unit work in the infrared region.

## 1.4 The progress of the project:

This project has been ongoing since September 1995. During the period up till now many things have happened that have changed the direction of the project.

When the project started in 1995 the purpose was to develop a calibration unit as well as a program for the existing system that operated with a Nd:YAG-pumped dye laser. The laser was controlled by an external PC, which was steered from the calibration system through a serial port. The intention of the LIDAR-group was to change this laser system to a new OPO-system (Optical Parametric Oscillator). The unit should be prepared for this. The unit was constructed as well as the electronics and program.

In 1998 the OPO-lasers were ready to be installed. For this project a decision had to be taken. Should it be completed using the old system or be adjusted for the new. The decision was to use the new system. This had vital impact on the project. The whole program had to be rewritten. The detector electronics had to be redesigned.

## 1.5 History and background

LIDAR- (*Light Detection And Ranging*) measurements have been performed since the 1930's. In those early days searching light was used for measurements on aerosols in the stratosphere.

When lasers where developed, they were found to be a superior light source. In 1963 the ruby laser came into use for LIDAR measurements, and in 1966 it was possible to measure gas concentrations with differential absorption LIDAR (DIAL).

Improvement of the LIDAR technique has continued during the last 30 years along with development of electronics, lasers and computers. In the end LIDAR technique has become fast and cost-efficient.

The need for efficient monitoring of the atmosphere has dramatically increased since it has become clear that man has a profound impact on the global environment. The LIDAR technique has became a very useful tool for performing these environmental measurements.

## 1.5.2 The LIDAR group

The Department of Physics has had a LIDAR-group for 15 years. During this period of time the group has developed the technical know-how and the existing system. It has also generated a spin-off company in this field.

The previous system was a Nd:YAG-pumped dye laser which covers the wavelength region from the ultra violet to the infra red. With this system it is possible to measure substances like $SO_2$, $O_3$, NO, $NO_2$, $Cl_2$ and Hg. It is not possible to measure volatile hydrocarbons (VOC). The need to measure VOC is great in petrochemical and chemical industry. In those industries there can be diffuse discharge of VOC and normally only rough estimations of these can be made. That is why the use of remote analysing technique is very interesting in these areas.

The new laser system that has been installed contains one OPO and two YAG-lasers. With these lasers a larger wavelength interval can be covered. This will make measurements on VOC possible. To make reliable measurements it is necessary to calibrate the laser precisely and to know the errors.

Another improvement done by the LIDAR-group is the development of a user friendly and automatic system using LabVIEW [1]

# 2. Theory

## 2.1 The LIDAR technique

LIDAR, which is an acronym for Light Detection And Ranging, is a measurement technique working a lot like a common radar. The main difference is that a LIDAR system uses light pulses instead of microwave pulses. Pulsed laser radiation is transmitted into the atmosphere and a photo multiplier tube (PMT) detects back-scattered light. The distance to the molecules is determined by measuring the time it takes for the light to travel from the laser and back to the detector. The principle of LIDAR is illustrated in Figure 1.
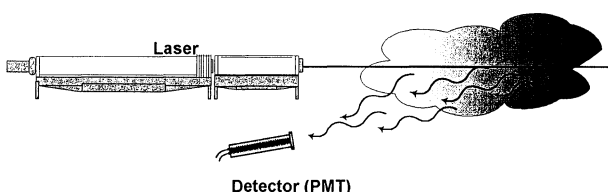
**Figure 1** *The principle of lidar*

Different processes cause the back scattering. The main ones are Rayleigh, Raman process and Mie scattering [2]. One example of LIDAR measurement is shown in figure 2.

## 2.1.1 DIAL, a LIDAR technique

LIDAR is a common name for measuring methods where light is transmitted and the back-scattered light is detected. The technique used at the LIDAR-group is called DIAL (DIfferential Absorption LIDAR)
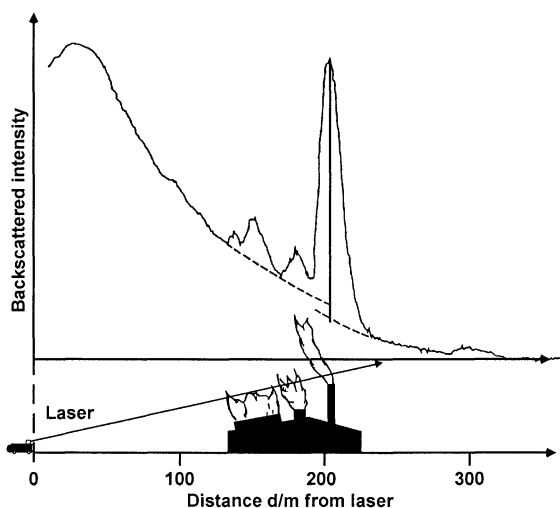
**Figure 2** *Particle monitoring with LIDAR technique. The Mie scattering process is used to resolve the particle concentration. [3]*

In DIAL, the differential absorption at close lying wavelengths of molecules is used. In practice this means that two laser beams are sent into the atmosphere. One with the wavelength of a absorption peak ($\lambda_{on}$), and the other of a close lying minima ($\lambda_{off}$). See figure 3.

This method is useful for qualitative as well as for quantitative range resolved measurements of molecules in the air.

**The principles of a DIAL measurement**

A laser shoots alternately on a known absorption wavelength $\lambda_{on}$ and on a nearby reference frequency $\lambda_{off}$, for the molecule measured (see figure 3 and figure 4).
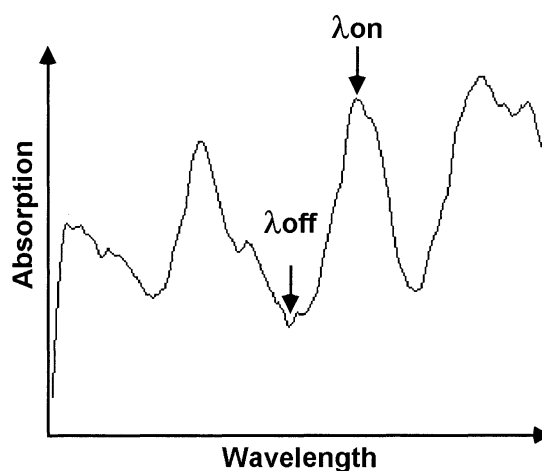
**Figure 3** *a small segment of an absorption spectrum of a molecule. The wavelengths ON and OFF the peaks are displayed.*
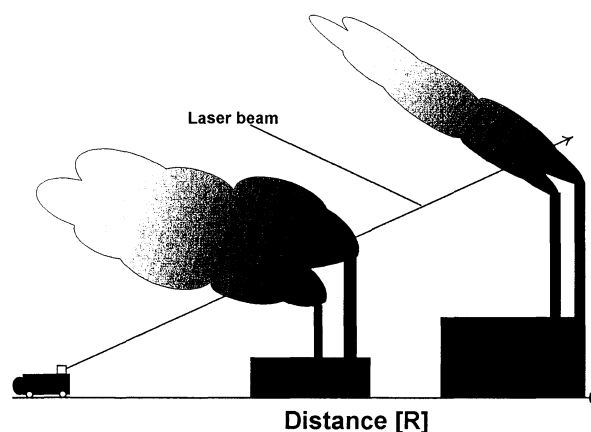
**Figure 4** *The mobile LIDAR-system measuring the outlet from two factories.*

The back-scattered light from both laser beams is recorded over time. This time resolution will give the distance in the measurement. See figure 5.

For the laser light that is not absorbed ($\lambda_{off}$) on its way through the air the back scattered intensity will show a simple $1/R^2$ dependence (R is the distance).

The light that is absorbed will have the same $1/R^2$-dependency, where the molecule is not present. In the plume (where the molecule is present) the light will be absorbed and the back-scattered intensity will decrease.

The presence of an absorbing gas is best illustrated if the two curves are divided by each other, as illustrated in the figure 6. If this curve is differentiated the distance and concentration of the gas is found, see figure 7. Mathematically the ratio is found from the DIAL equation [5]:

$$P_{\lambda on}(R,\Delta R) / P_{\lambda off}(R,\Delta R)=\exp(-2[\sigma(\lambda_{on}) - \sigma(\lambda_{off})] \int N(r)dr$$

Where N(r) is the concentration, $\sigma(\lambda_{on})$ is the absorption cross section at $\lambda_{on}$.

If the measurement is carried out in several directions in a plane and the wind velocity is determined the total outlet from the factories can be calculated.

## 2.2 The principle of calibration

The principle of calibration is simple. A cell is filled with a gas with a known absorption spectrum. From this vapour you take up an absorption spectrum. The measured spectrum is compared to the known spectrum for the gas. By comparing the two it is easy to determine the wavelength inaccuracy of the laser. The normal case is to try to find one absorption maximum for the gas. An example would be to scan over the peak at $\lambda_{on}$, in figure 3. When the max value is found, the wavelength displayed by the laser is compared to the known table value.

Even if the principle is simple it is hard to accomplish. There are lots of obstacles to overcome. The laser energy is fluctuating, the detector characteristics are not linear, and so on. The biggest problem is that it has to be done automatically by a program, and not by a person. A person knows what is needed to find in the spectra to be able to calibrate; he knows when to ignore values that are out of bound and so on. The program has to be made robust so it always is able to calibrate. Since every absorption spectra is unique a variety of calibration algorithms are possible. The one developed in this project is described in the programming documentation.

### The principle of the calibration unit

The principle of the unit is shown in figure 21. A laser beam is directed into the unit. The beam is split into two. One of the beams passes through the known gas (cell

beam) and the other is directed straight to a detector (reference beam). The measured energy of the pulses is corrected for the detector characteristics. Then the measured energy of the cell-beam is divided by the energy of the reference beam. This gives a value proportional to the absorption of the gas
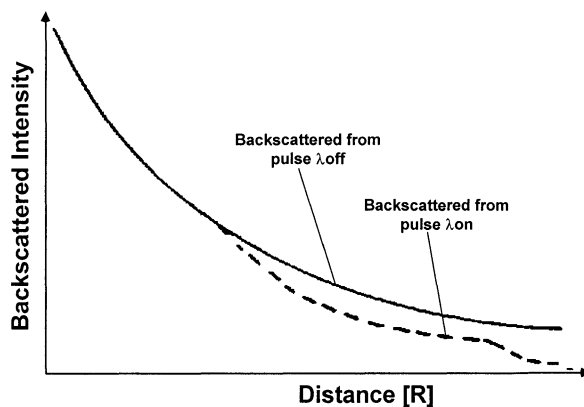


**Figure 5** *The measured back scattered intensity. [4]*
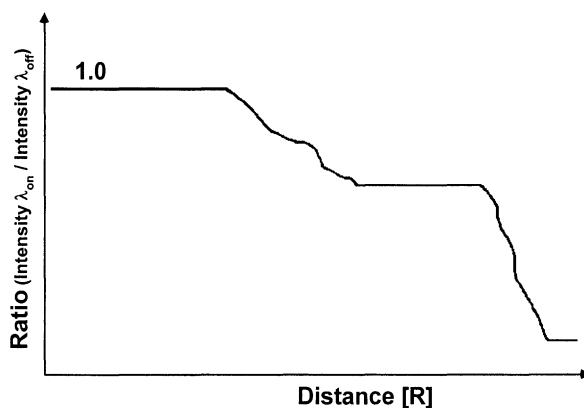


**Figure 6** *The quotient between $\lambda_{on}$ and $\lambda_{off}$ [4]*
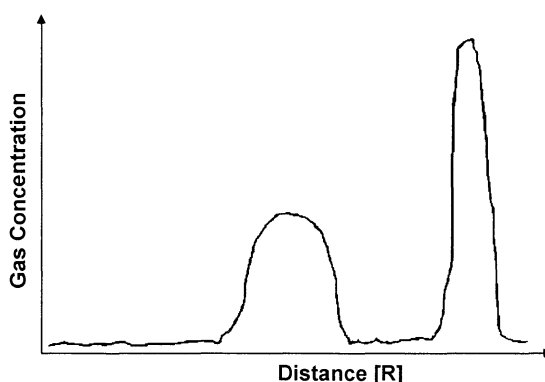


**Figure 7** *The differentiated ratio from the curve in figure 6. From this curve you can read out the distance and the concentration of the gas that was measured. [4]*

## 2.3 LabVIEW software

LabVIEW is a modern graphical programming system for data acquisition and control, data analysis, and presentation.

The idea of such a programming tool came up when Jeff Kodosky began to think of a new way of programming. He focused on what the program user wanted to see on the screen. The idea was that the screen should look like an actual instrument. When he started to work for National Instruments (USA) the idea was put to practice. In April 1983 LabVIEW was born.

In the beginning there were considerable problems with the performance of the program, this due to the graphic technology of the language. The computers of that time did not have enough process power or memory to handle graphics. The Macintosh computer platform was the only one where LabVIEW could perform properly. During the 1990's the PC-computers began to be powerful enough and when Microsoft launched Windows 3.1 it was possible to run LabVIEW on a PC (The development of LabVIEW is seen in figure 8).

Another big problem was the speed of the program. In 1986 when a new version of LabVIEW 1 was launched the speed of the program was equivalent to BASIC. But some applications could be up to 20 times slower. Today these problems are overcome. The execution speed of the program is determined by the C-compiler alone.
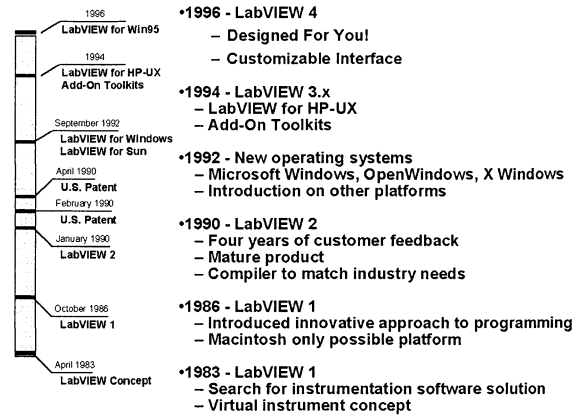


**Figure 8** *The LabVIEW development milestones [6]*
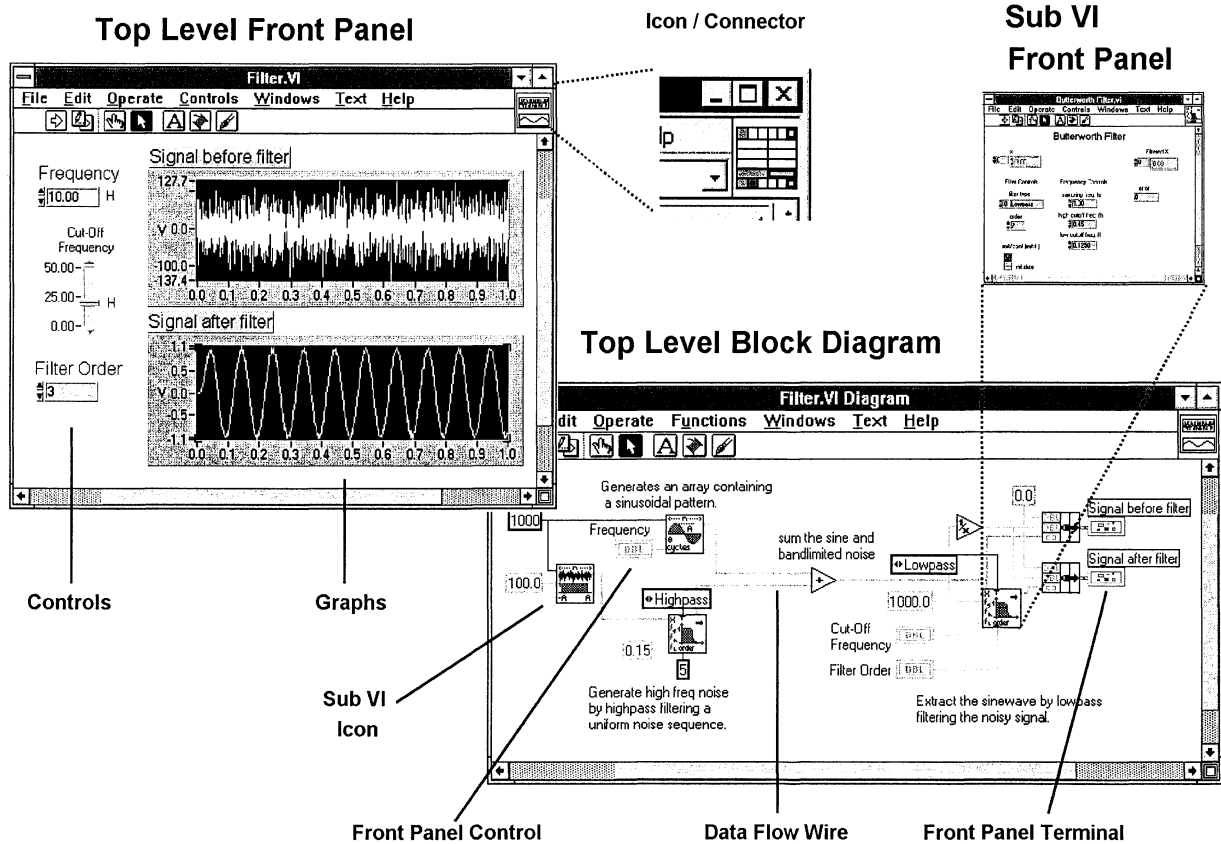


**Figure 9** *The different components in a LabVIEW program*

## 2.3.2 General description

LabVIEW is a graphical programming system for data acquisition and control, data analysis, and presentation. The whole idea of the language is to generate programs that look and perform like all other instruments that are found in a lab.

LabVIEW is designed for instrumentation and is equipped with the tools needed for test and measurement applications. In LabVIEW, you build programs called virtual instruments (VIs) instead of text-based programs. From the VIs it is possible to control plug-in-boards and external equipment via serial communication, VXI/VME or GPIB. Through these interfaces the program can control all the instruments in a lab. It is easy to change the set-up and the presentation of an experiment, see figure 10.
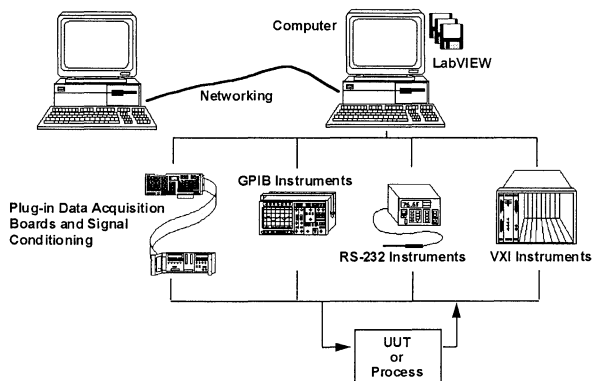


**Figure 10** *The different ways LabVIEW controls surrounding equipment [6]*

## 2.3.3 The structure of a LabVIEW program

The components of a LabVIEW program are the VIs. Each VI consists of two different windows a *front panel* and a *block diagram*. These windows also have an *icon/connector*. See figure 9.

**The front panel**

The front panel is the user interface in a LabVIEW program. This is the "virtual instrument" that the users will se while executing the program. On this panel all the control components for user input are found (knobs, buttons, switches...) Here are also the graphs and indicators used for data presentation found.

The idea is to construct a program that looks like a real instrument. For example, if a radio was to be constructed the knob to change frequency can be put on the panel. When the knob is turned a linear display can show the current frequency. Just like an old radio receiver.

All the controls and indicators on the front panel are found in the block diagram as controls and terminals see figure 9.

**The block diagram**

The block diagram is the VI's source code. In this window the actual programming is done.

In the block diagram all the components from the front panel are found (controls and indicators.) Here you will also find Sub VIs. The programming is done by binding these components together by Data Flow Wires.

This creation of data flow between the objects is called data flow programming. Se section 2.3.3.

Every object in the block diagram is the graphical representation of the object's code. The actual code for each object is written in C. This makes the performance of the program fast and efficient.

**The icon/connector**

The icon/connector is the calling interface for a VI. The icon is displayed in the block diagram of a calling VI. The connector shows what input/output the VI has. See figure 11.



**Figure 11** *A VI and its icon and the data flow wires that is attached to the VI*

**Sub virtual instrument**

When making a program you have to divide the code into smaller parts. This is done to get a better overview of the program. It is also done to recycle code that has once been written or to use code that someone else has written (in order not to invent the wheel again). In LabVIEW this is achieved by using Sub VIs.

A Sub VI is actually a VI but it is called from another VI, i.e. the caller VI has the Sub VI in its block diagram. All I/O communication to external instruments is done through Sub VIs. In LabVIEW you can find hundreds of VIs for data acquisition, data control and data analyses. For more information about the VIs that can be found in LabVIEW please see the LabVIEW documentation [7].

A powerful feature of the program is that each VI can be run by it self or be called from another VI and be used as a Sub VI. This means that each VI can be changed, tested and debugged by itself before put into a larger program.

### 2.3.3 Data flow programming

In LabVIEW each node (VI or object) starts operating only when data is available at all of its inputs. When the node finishes executing, it produces data for all of its outputs. This data-driven method of execution is called data flow.

Data flow programming releases the developer from the linear architecture of text based languages. The execution order between different objects is determined by the data flow between the objects. This makes it possible to create multiple data paths and simultaneous operation. This is a totally different programming method compared to the sequential structure of a text-based language. This is also a more realistic and logical programming method when creating programs for a lab environment.

Even in a data flow program some tasks have to be executed in a sequential order. This is achieved by having one or several data flows that tie the sequence together see figure 12.
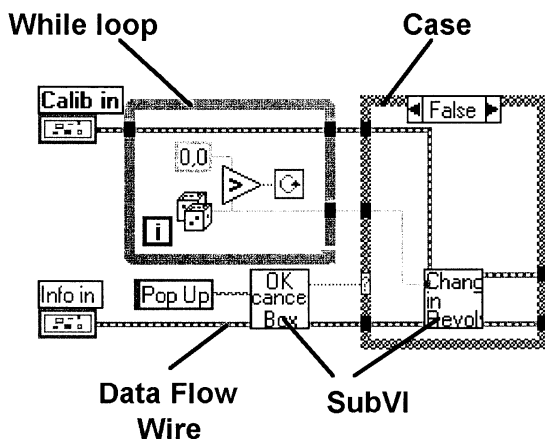


**Figure 12** *An example of data flow programming. The sequence is determined by the two flows starting with "Calib in" and "info in"*

In the example the program starts with two parameters "Calib in" and "Info in". The data flow from these two parameters controls the main sequence. The "while loop" and the VI "OK cancel Box" can execute independently of each other, but the "case" can not start until the while loop as well as the VI have finished their tasks.

### 2.4 Laser theory

In the LIDAR-system a tuneable laser is required to perform the measurements. Historically, pumped dye lasers have been used for the tuning. The problem with them is that many different dyes are required. This since one dye only has a limited tuning range. Another disadvantage is that several dyes are toxic.

In the modern LIDAR-system an OPO-system is used as laser source. The advantage is that it can tune over a large range using doubling and mixing systems. The ranges the system can be used within are specific for each OPO-system. The OPO-system that is used in Lund can be tuned between 220-690nm, 730-1800nm and 2800-4800nm, see figure 13

Operation of the optical parametric oscillator (OPO) is different from the traditional laser-system. Traditional laser systems derive their gain from stimulated emission generated by atomic transitions. The OPO derives its gain from a non-linear frequency conversion process.
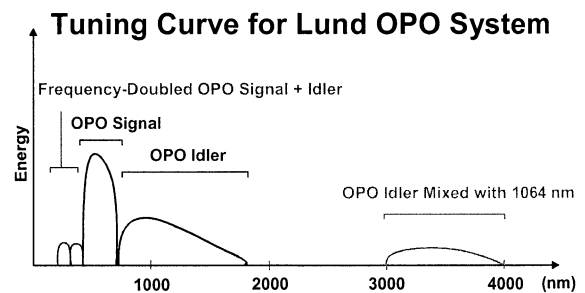


**Figure 13** *Tuning curve for Lund OPO-system [8]*

### 2.4.1 Traditional laser operation

In a traditional laser, gain is derived from energy that is stored in excites of an atomic or molecular transition. The principle is shown in figure 14.
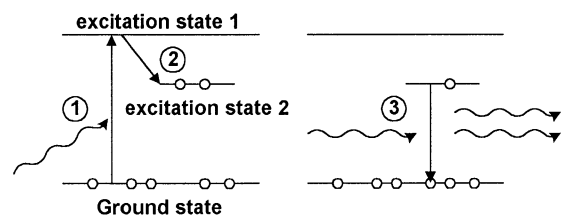


**Figure 14** *The principle of laser.*

Electrons are excited (pumped) from the ground state to an upper state (excitation state 1). This can be achieved with flash bulbs or with electrical discharge (1). From the upper state the electron will recombine to a lower energy level. When doing this, the electron can recombine either to excitation state 2 or to the ground state (2). The

transition between excitation state 2 and the ground state is a so-called forbidden transition. An electron in excitation state 2 will therefore remain in this state.

If a photon passes, with the same energy as between state 2 and the ground state, the photon will make the electron recombine to the ground state (3). This will result in two coherent photons with the same energy (wavelength) i.e. light has been amplified. [9]

A dye has an energy level band structure instead of distinct energy levels, see figure 15. Due to this band structure the laser light is tuneable. Electrons are pumped from the ground state to the upper energy band. From this higher level the electrons can recombine to any level in the lower band. This gives a broad fluorescent signal. By using a wavelength dispersive element the laser light can be to any wavelength within this fluorescent band.

## 2.4.2 The OPO theory

The gain on an OPO system is derived from the non-
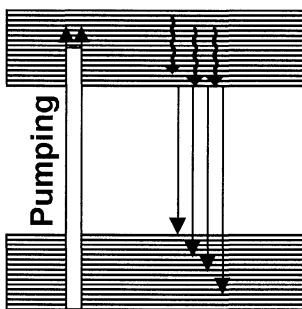
**Figure 15** *Principe of dye laser.*

linear interaction between an intense optical wave and a crystal having a large non-linear polarisation.

In principle this means that an incoming photon, from the pump laser, is transformed into two photons in the crystal, see figure 16.

The difference between this process and the laser process is that it does not require a real atomic or molecular
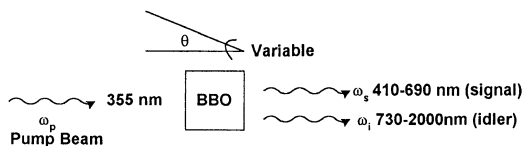
**Figure 16** *Principal operation of the OPO. [10]*

transition. Thus, there is no energy storage capability.
This transition has to follow the energy conversion law: $\omega_p = \omega_s + \omega_i$, where $\omega_p$ is the input frequency, $\omega_s$ is the signal wave and $\omega_i$ is the idler wave. In terms of wavelength the equation is $1/\lambda p = 1/\lambda s + 1/\lambda i$.

In theory an infinite number of signal and idler wavelengths can exist to satisfy the energy conversion law. Fixing the pump wavelength and rotating the crystal derives the tuning of the OPO. The change of the angle will cause the signal and idler output to vary. In figure 17 the tuning region is illustrated.

By placing the crystal in an appropriate resonant cavity,
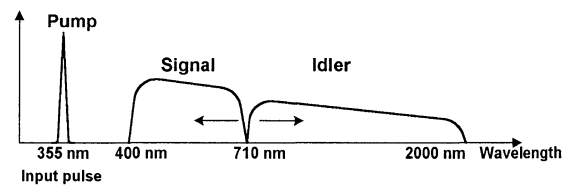
**Figure 17** *Signal out from an OPO-system. [10]*

oscillation at the signal and/or idler wavelength can be obtained.

The output of an OPO is very similar to that of a laser. The signal and the idler beam is have strong coherence, are highly monochromatic, and have spectrum consisting modes. [11]

The theory of OPO has been known for 25 years but commercial systems have not been available until recent years. The problem has been the lack of suitable non-linear materials. The crystals must fulfil the following conditions:

- Phase matching conditions for the pump, idler and signal laser beams over the entire tuning region.
- High damage threshold to sustain the high energy in the pump pulses needed.
- Low absorption over the entire tuning region.
- No significant degradation over time.
- Possible to manufacture in large enough sizes to reasonable cost.

One of the best-suited crystals forfeiting these criteria is the BBO crystal.

13

# 3. General description

## 3.1 The LIDAR system

The LIDAR system is mounted in a Volvo F610, see figure 18 and figure 19. This makes the system easy to place wherever the discharge may be.
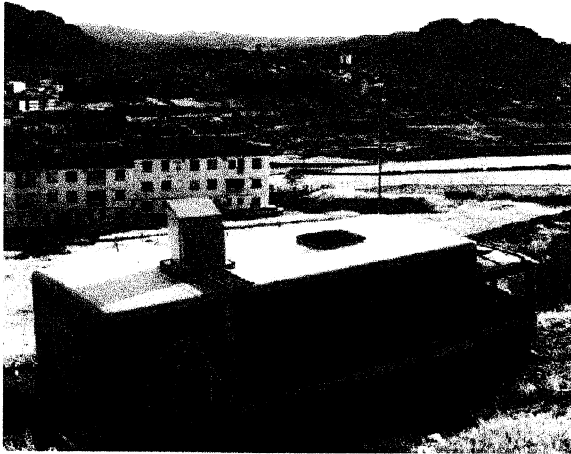


**Figure 18** *The mobile LIDAR system. Mounted in a Volvo F610 [12]*
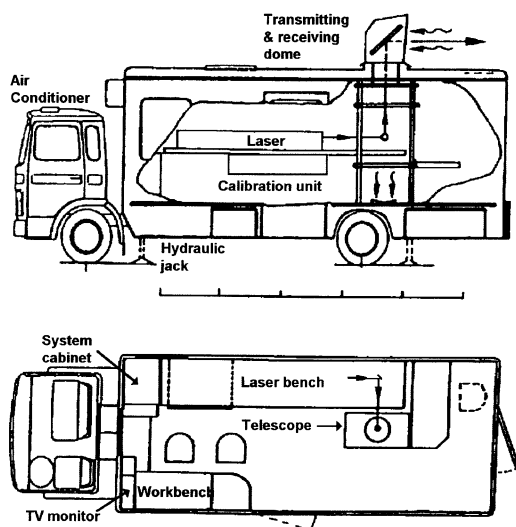


**Figure 19** *Principal drawing on the LIDAR-bus. [13]*

A laser is used to produce pulses that are transmitted into the atmosphere via a planar mirror in the telescope. The same mirror is used for directing back-scattered light down into a fixed telescope. In the focal plane of the telescope there is a polished metal mirror with a small hole, which defines the field-of-view of the telescope. In order to suppress background light it is essential that the telescope only observe regions where laser photons can be back scattered. A photo multiplier tube detects the light passing through the aperture. All the other light is directed into a TV camera that produces a picture of the target area, except for the laser beam region, which is seen as a black spot. The detected LIDAR signal is transferred to a transient digitizer and is read out to a computer system. The computer system is mounted in the system cabinet. One of the computers is used for controlling the planar mirror, the laser wavelength, etc. It also performs signal averaging and necessary processing of the LIDAR signals.

## 3.2 System cabinet

The system cabinet is the heart of the LIDAR-bus. In this rack processing, control and power units are installed, see figure 20. For detailed information se [1].
The Rack contains of:

* Security Unit
  This unit controls the output from the laser. If a security switch is activated then the unit will stop the laser pulses. [1]
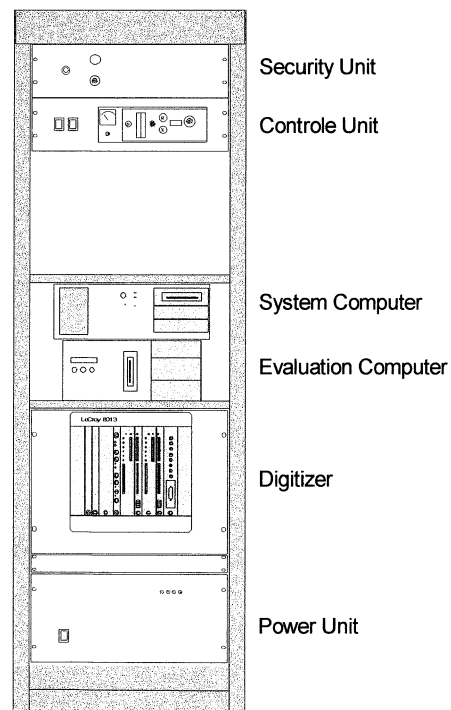


**Figure 20** *The system cabinet.*

- Control Unit
  This unit handles the Input and Output between the system computer and the units in the bus. See section 4.13

- System Computer
  This is the main computer in the system from which the applications are run. This computer has plug-in boards that are the interfaces towards the Control Unit. These boards are AT-MIO-16, PC-TIO-10, GPIB and network board [1]. For detailed information on the interaction with the calibration program see section 4.14.

- Evaluation Computer
  This computer is used for processing and presenting data from a LIDAR-measurement [1].

- Digitiser
  The digitizer is responsible for capturing the signal from the PMT during a LIDAR-measurement. It is controlled through the GPIB-board in the system computer [1].

- Power Unit
  This unit powers and controls stepper motors, choppers and other equipment in the bus [1]. For information on the interaction with the Calibration Unit, see section 4.12.

## 3.2 Calibration unit

The calibration unit illustrated in figure 21 performs the wavelength calibration. A diffuse reflex from the laser is transmitted into the unit where it is divided into two parallel beams. One passes through a reference cell with the gas that is to be measured and then to a detector (cell detector). The other passes directly to a second detector (reference detector). The output signals from the detectors are sent to the system computer via the Control Unit in the system cabinet. Looking at the quotient between the pulses you can determine if the laser has drifted during a measurement and it is possible to calculate the errors in the measurement.

All interactions between the calibration program and the unit are done through the Control Unit. All components in the unit are powered from the Power Unit. For details see appendix 1.

## 3.3 Laser system

When the project started the laser-system used in the LIDAR-system was a tuneable dye laser pumped with a Nd:YAG laser. This system was replaced with an OPO-system, the MOPO-730 from Quanta ray. For details see appendix 13.
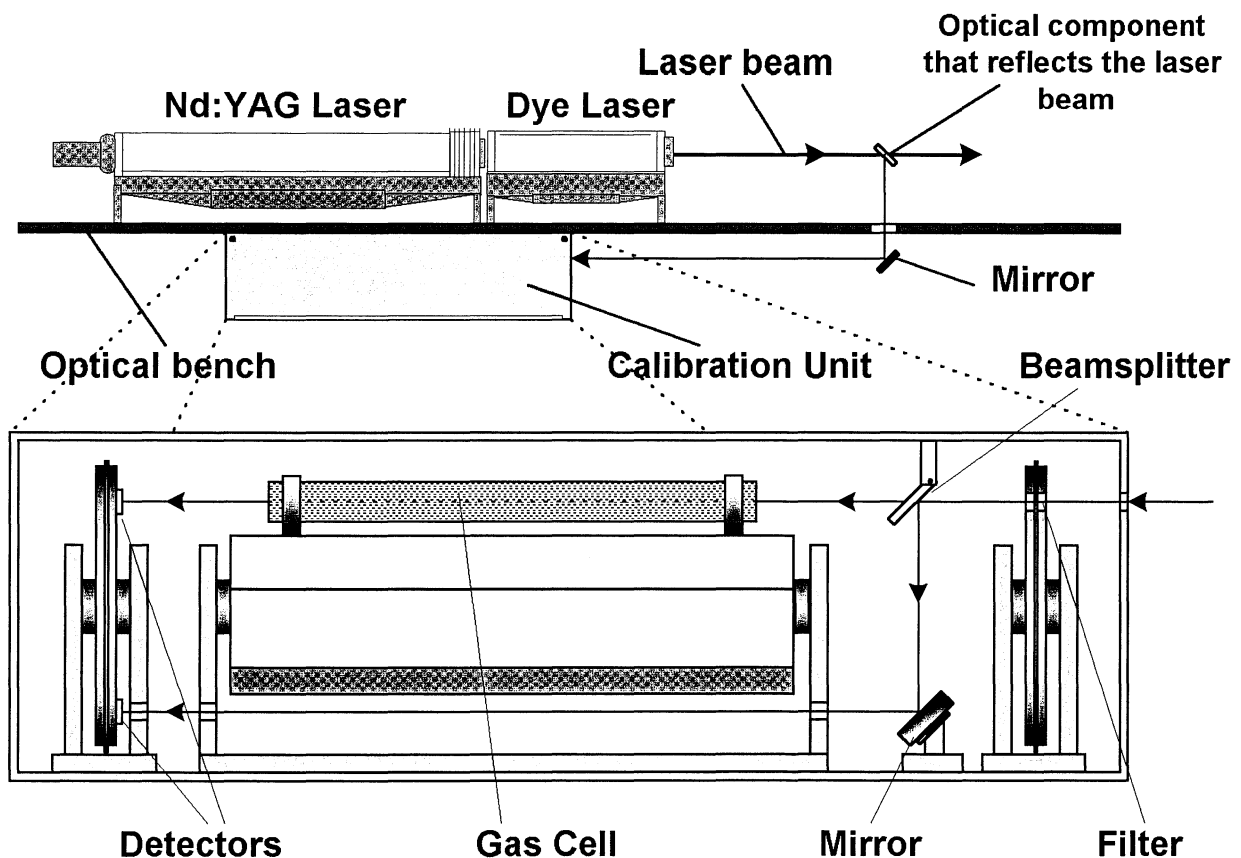


**Figure 21** *Principal sketch on the calibration unit*

# 4. System design

## 4.1 Introduction

This section describes the components, electronics and the communication in the calibration system. It also describes how and why the parts have been designed or selected.

## 4.2 General

To be able to choose components and design the electronics one has to understand the purpose of the measurement, what will be measured and what problems arise when measuring.

### 4.2.1 Purpose

The purpose of the laser calibration system is to find the deviation in frequency (wavelength) between the laser's setting value and its real value.

This is achieved by comparing the spectrum of a known and well-defined vapour in a gas cell with the results from a measurement. I.e. measuring an absorption spectrum in a region where the physical data is known for the vapour.

When designing and selecting components for the calibration system it is important to know what should be achieved. At a first glance it may seem like it is the energy of every pulse that is important to measure. But in this case the absorption is relevant. Knowing the exact energy of every pulse may give more information but it is probably unnecessary to measure. Furthermore, it is not the actual absorption (in exact figures) that is relevant. It is finding the pattern of the absorption for the vapour.

### 4.2.2 Measuring conditions

The laser pulses that are measured contain typically some $10^{-3}$ Joule of energy. The length of the pulse is about 3-4ns and the laser repetition frequency is 20Hz (20 pulses per second.) The wavelength range is between 250nm to 4800nm. The energy of the laser pulses fluctuates with about 10%.

The pulses are transmitted into the calibration unit from a reflection of the DIAL laser beam.

### 4.2.3 Problems

To be able to measure the exact appearance of the pulses a fast detector is needed. To be able to hit the detector when aligning the system, the active area must be at least 50mm$^2$. These conditions contradict each other. The bigger the detector becomes, the slower it gets.

The frequency range of operation is vast. It is a problem to a find detector that is big enough and yet operates fast enough in the whole range.

A fluctuating laser is a problem. If every laser pulse does not have the same energy, it is not possible to know if a change in measured energy is due to the laser or to a change of absorption in the vapour.
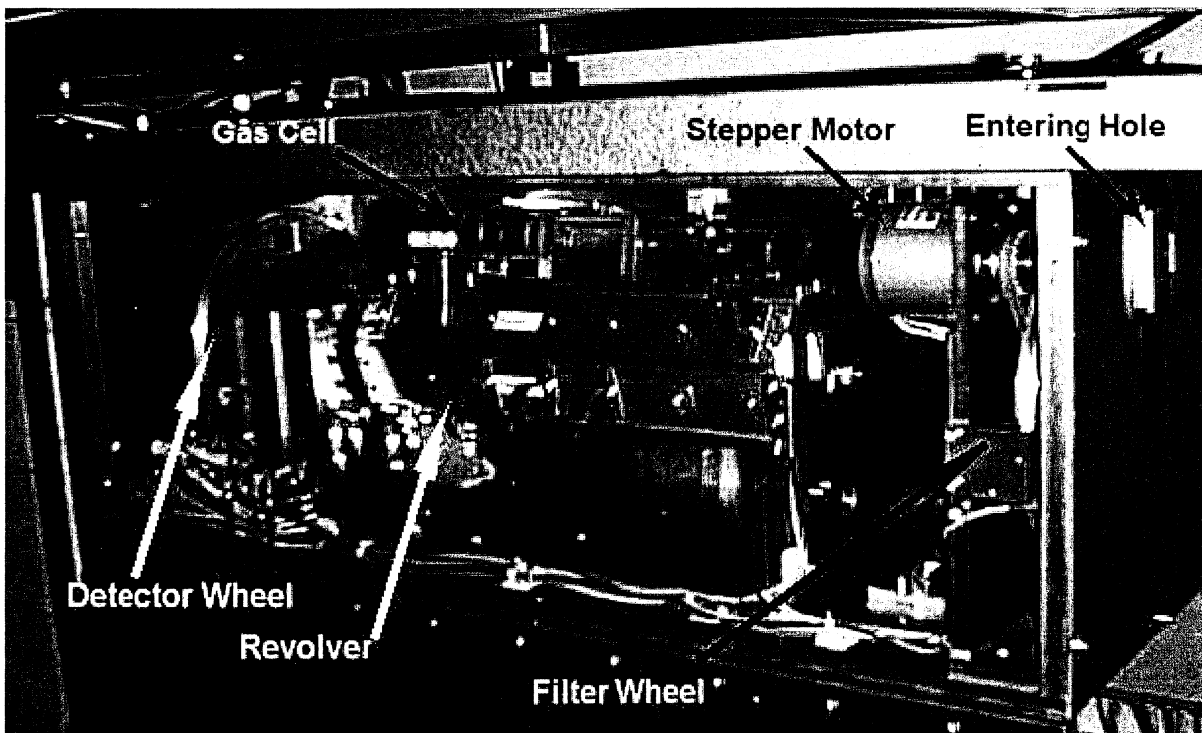


**Figure 22** *Picture of the calibration unit in operation.*

The intensity of the pulse varies between different experiments. The actual energy is dependent on how the pulse was received (which reflection used) and how it is transmitted to the calibration unit. The intensity can vary several powers of ten.

The laser pulse is extremely short. This makes it extremely difficult to read the values directly from the detectors with the computer A/D-electronics.

## 4.3 The calibration unit

All components that are chosen should manage the strain in the lorry. Every thing has to be built robust. This can be seen in figure 21 and figure 22.

In order to get the right amount of energy in the laser pulses is must be possible to reduce the intensity. A wheel with neutral density filters at the entry does this.

Splitting the beam into two beams reduces the problem of a fluctuating laser. One beam is used as a reference. When the energy of the pulses change it will change with the same factor in both beams. By dividing the energy value of the pulse travelling through the vapour by the reference value the fluctuation is annihilated.

To come around the problem with the large frequency interval a detector wheel is constructed. On this several detectors can be installed.

The detector electronics must be constructed to measure the value of the energy and then to hold the signal until the computer program registers it.

Since everything will be controlled from a computer program the unit also has to be completely automatic. For this reason all components that need to be changeable are mounted on wheels or cylinders that are controlled by stepper motors.

To be able to measure on several gases during one measurement a revolver wheel is constructed. In this revolver up to 7 different cells can placed.

The parts in the calibration unit are constructed in blocks. This is done to make it easy to rebuild or change the components. The moving parts are mounted with the stepper motor on a plate. This plate can easily be removed from the unit for modification or replacement. The modular construction also has the advantage that parts not needed for the moment can be developed and manufactured when needed.

Smooth operation of the unit is considered in the design. Changing of the cells must be simple. This is achieved with clips to which cells can be attached. These clips can be mounted with different sizes and at different distances so all kinds of cells can be used.

## 4.4 Detector

The detector and its electronics are the most vital parts for the calibration. These components determine the different parameters needed in the program: maximal intensity, minimum intensity and so on.

Speed, size and operation-region are taken under consideration when selecting detector.

### 4.4.1 Useable detectors

One detector that would serve the purpose is the SD290-11-31-241 from Advanced Photonix Inc [14]. This diode detector can measure between 300nm to 1100nm.

Other alternatives could be the S3590-05 or S3590-06 from Hamamatsu [15]. These detectors are fast and big enough, 9×9mm. If the S3590-06 is chosen it could be used between 190nm to 1100nm. One problem with this detector is that it does not have any protection window. This would make it sensitive to humidity and human touch. To get around this problem a quarts window with good quality could be mounted in front of the detector.

One detector that would work is the 2-Watt Broadband Power/Energy Meter from Melles Griot [16]. This detector can measure from 200nm to 20μm, i.e. more than enough. It works with frequencies up to 60Hz. The problem with this detector is that it can not be connected directly to the computer. It comes with a control unit. Another problem is that it needs rather high pulse energy. High pulse energies can cause stimulated emission in the gas cell that disturbs the measurement.

The detector from the old calibration unit is the S1337-1010BQ from HAMAMATSU, for detailed data see appendix 17. This detector is too slow to measure the actual pulse. When looking at the output from the detector in an oscilloscope it is found that the length of the pulse is some μs but it is know that the laser pulse is some ns long. But since it is the absorption and not the actual energy in the pulses that is of interest, it is possible to use this detector. In an experiment that was performed it was shown that the two detectors are linear towards absorption.

## 4.4.2 The chosen detector

The old detectors were chosen since they fourfold the necessary conditions.

To be able to understand why this slow working detector works one has to understand how a photodiode works.

### Basic photodiode theory

A photodiode is a solid state device that converts light into electric current. It normally consists of doped silicon that forms a so called p-n junction, see figure 23.
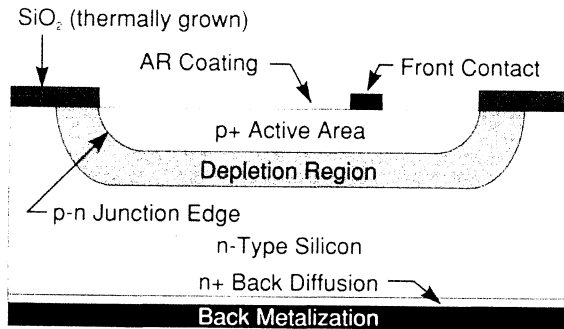
**Figure 23** *Basic configuration of a photodiode [17]*

The n-type region is created when impurities, i.e. other atoms, with extra electrons are defused into the silicon. These atoms are called donors since they "give" away their extra electron. The p-type silicon is created in the same way but the silicon is doped with acceptors, or holes. These atoms accept electrons.

When the two regions are in contact the electrons in the n-doped region and the holes in the p-doped region feel a lower potential on the opposite side of the edge. This potential difference makes the electrons and holes flow across the p-n junction. This charge movement establishes an electric field that works against the movement. After some time equilibrium is established and a depletion region has been created between the two regions.

When photons fall on the device, they are absorbed and electron-hole pairs are created. The electron hole pairs drift apart, and when the minority carriers reach the junction edge, they are swept across by the electric field. If the two sides are electrically connected, an external current flows through the connection. The photodiode behaves as a current source when illuminated.

If the created minority carriers of that region recombine before reaching the junction field, the carriers are lost and no external current flows. An external voltage is applied to the photo diode to increase the sensibility. This will increase the depletion region i.e. make it more likely for

the minority carriers to reach the region before they are recombined.

### How the old detector works

The old detector does not measure the actual laser pulse. The fast pulse injects electrons and holes into the depletion region. These charged carriers drift towards the depletion region. If the carriers reach the region before they recombine the charge can be measured. This process in the detector is much slower than the actual laser pulse but if the number of carriers that is measured is proportional to the energy in the laser pulse, there is no problem using these detectors.

## 4.5 Digitizer trigger delay

The laser triggers the synchronisation of the system. The laser sends out a trigger pulse, see figure 24. This pulse is transmitted to the control unit where a new pulse is generated by the digitizer trigger delay, see appendix 12.

This new trigger pulse is then used to synchronise the electronics.
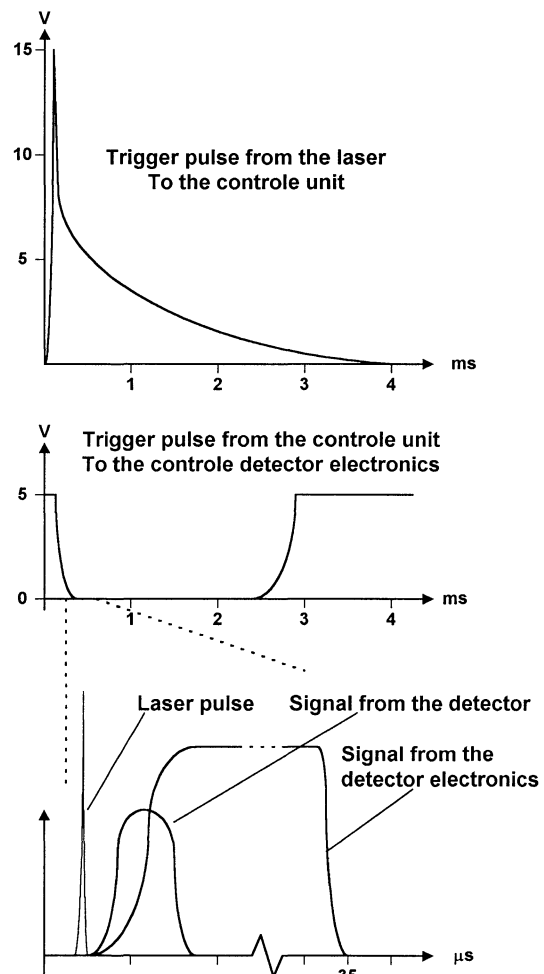
**Figure 24** *The trigger pulses*

## 4.6 Detector electronics

The detector electronics will amplify the signal from the detectors, integrate the signal and hold the value until the computer reads it. All this has to be done in synchronisation with the laser.

Details about the detector electronic are found in appendix 11.

### 4.6.1 Basic design

In the lorry the voltage is 12V. This voltage is transformed on the circuit board to 5V that is used as input by the components, see appendix 11.

The pulse from the detector has to be amplified. A preamplifier does this, see figure 25.

The signal from the preamplifier is then integrated with a standard integrator, see figure 26.

After the integrator the signal is again amplified by a follower, see figure 27.
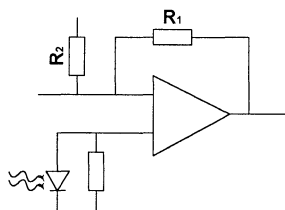


Amplification = (R1+R2)/R2

**Figure 25** *Preamplifier.*
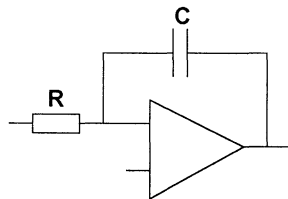


Output = -1/(RC) ∫u dt

**Figure 26** *Integrator.*
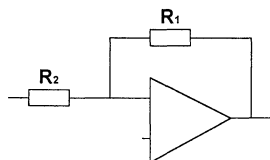


Output = R1/R2

**Figure 27** *Follower.*

The mechanism to hold the signal until the computer can read it is constructed by using the fact that there is a large difference in energy between the laser pulse and the background. The signal from the detector is almost zero when there is no laser intensity.

The integrator will accumulate the signal from the time when the trigger is received until the value can be read by the computer, but since there is no output after the laser pulse the circuit will "hold" the signal even though it is integrated.

To reset the integrator a short circuit is put over the integrating capacitor. This short-circuit is kept until the low flank of the trigger signal is received, see figure 24. The detector pulse is then integrated until the capacitor is short-circuit again, see figure 28.
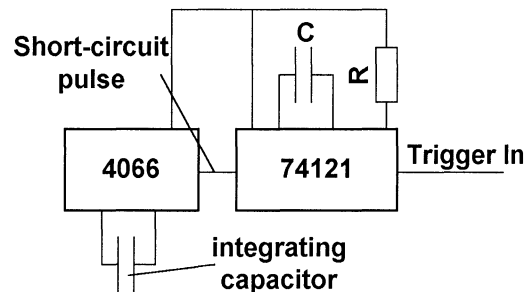


**Figure 28** *Short-circuit part.*

*When the low flank is received in the trigger in, the short-circuit is released and the capacitor can integrate the signal.*
*The integration time = 0,7\*RC*

### 4.6.2 Trimming the parameters

Trimming the circuit parameters is done on the integrator circuit. If one part is badly adjusted other parts can not correct this error.
The dynamics in the system must be as big as possible at the same time as no part should be saturated.

To be able to determine the values of the resistors and capacitors an experiment was conducted on the detectors with electronics, see appendix 18. This experiment showed problems with offset and badly balanced electronics. This is illustrated in figure 29. If the detector electronics are not balanced the output value can increase or decrease over time. It takes some time until the computer reads out the value. During this time the value can change, see figure 29. This will lead to errors in the measurements.
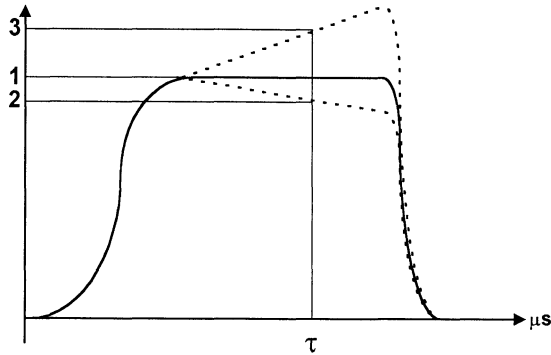
**Figure 29** *Problem with offset.*

## 4.7 Beam splitter

The beam splitter divides the light from the laser to the detectors. This is done in order to use one detector as reference. In this way compensations for the fluctuations in the laser energy can be made.

The demands on the beam splitter are

- A 50/50 distribution, but if slightly more of the intensity travels through the gas cell it would be good since the gas will absorb some light.
- Operate in the entire specified wavelength region with the same splitting ration.

A problem when splitting laser beams is that the laser-light is polarised. Beam splitters often split the light differently in the p- and s-plane. The pulses that will be used are derived from a reflection from some optical component in the beam path of the OPO-system. Which component used depends on the experiment the OPO-system is used for, i.e. the direction of the polarisation will change between experiments. For this reason the beam splitter must have the same division in both directions.

To be able to cover the whole range a number of beam-splitters need to be installed. A normal beam splitter from manufacturers has its operation region within a couple of hundred nanometers. The problem is to get a reasonable number of beam splitters.

The problem can be solved with the pellice beam splitter nr 03 BPL 001 /04 from Melles Griot [16]. This beam splitter has a 40/40 splitting between 400 to 1060nm. Above this region normal quartz can operate, and below the original beam splitter works fine. In other words three beam splitters would cover the whole region.

The problem with this beam splitter is that it is sensitive. It may not be touched and only be cleaned with a gentle

flow of clean air. If this was to be used then it had to be enclosed.

A decision was taken that it would take too long to make a changeable beam splitter device. Therefore only the original beam splitter was installed.

## 4.8 Neutral density filters

The filter wheel is used to adjust the intensity of the laser light. The problem is that the laser produces light that is much to strong for the unit. Even a reflection from the laser beam has to high intensity. The unit must therefore be able to reduce the intensity of the light several powers of ten.

During the experiment described in appendix 18 the optical density of each different filter was found. The filter wheel has 10 positions. This allows a maximum decrease of intensity down to 4% (9 positions are used for filters and one is blocked to protect the unit). The result is shown in Table 1. Due to economical reasons old filters are used. The filter set-up used is described in table 2

| Position | Transmittance [%] | Rounded OD |
|----------|-------------------|------------|
| 0 | 0 | Blocked |
| 1 | 4 | 1,4 |
| 2 | 6 | 1,2 |
| 3 | 8 | 1,1 |
| 4 | 10 | 1,0 |
| 5 | 20 | 0,7 |
| 6 | 40 | 0,4 |
| 7 | 60 | 0,2 |
| 8 | 80 | 0,1 |
| 9 | 100 | 0,0 |

**Table 1** *The best choice of filters according to experiment in appendix 18.*

.

| Position | Optical Density |
|----------|-----------------|
| 0 | Blocked |
| 1 | Blocked |
| 2 | 3,0 |
| 3 | 2,0 |
| 4 | 1,0 |
| 5 | 0,7 |
| 6 | 0,4 |
| 7 | 0,2 |
| 8 | 0,1 |
| 9 | 0,0 |

**Table 2** *The optical density of the filters that are used in the unit.*

## 4.9 Stepper motor

The chosen stepper motor is the two phase **KP56LM2-502** from ELFA [18]. This motor can operate as a unipolar as well as a bipolar motor. The bipolar configuration is chosen, see appendix 14.

## 4.10 Stepper motor electronics

To power and control the operation of the stepper motor the **GS-D200S** driver from ELFA is used [19], see appendix 15. To be able to configure and use the module it is mounted on a circuit card as shown in appendix 7

The configuration is as follows (for pin description see appendix 15)
- Pin 4 (Half/Full) is connected to earth.
  This means that the full step mode is selected. Half step mode makes the drive module step the motor with half steps i.e. the double number of steps is needed for the motor to make one revolution. The stepper motor has 200 steps/revolution. That is enough for the components in the calibration unit.
- Pin 9 ($I_{0SET}$) is connected to Pin1 (GND1) via a $300\Omega$ resistor.
  This is done to lower the current to the stepper motor in order to prevent over heating. The resistance can be calculated from $R=I/(3.03-1.43\times I)k\Omega$ where I is the current. The operation of the motor does not need high hold torque. Because of this the lowest currency (=0.5A) is chosen. This gives a resistance of $0.22k\Omega$. The resistance is set to **R=300$\Omega$** which gives a current **I=0.64A**. This is below the suggested value when driving the motor in bipolar mode. See appendix 14.
- Pin 1, 4, 6, 7, 9, 12, 13, 14, 15, 16, 17 and 18 are connected to cable connectors.
- Pin 2, 3, 5, 8, 10 and 11 are not used.

The four stepper motor-boards are mounted in the power-unit. Here cables are connected from the cable connector on the circuit card to other cable connectors in the unit. See appendix 6. This is done for easier handling.

## 4.11 Position detector electronics

Finding the exact position of the components is extremely important. If the positions are not known, it would not be possible to select detector, gas cell or neutral density filter i.e. it would be impossible to use the unit.
The position detector is used to find the locations of the components. The circuit drawing is found in appendix 10.

The operation is simple. If the light from the diode hits the detector there will be +5V on the OUT and 0V on "inverse OUT". If the detector light is blocked the opposite will occur, 0V on OUT and +5V on "inverse OUT"

The wheels in the unit are added with a peg or a hole that will block or let the light pass when the start position is found.

## 4.12 Power unit

The power unit consists of several components to control and power the different parts of the LIDAR-system see figure 30. It is connected to the control unit as well as to the calibration unit. For additional information about the components in the unit see [1].

For the calibration system the unit has been fitted with:
- Stepper motor board (motor 5 to 8) to steer the motors in the calibration unit.
- Connector to the control unit for cables related to the calibration system.
- Connector to the calibration unit.
- Additional power supply to the stepper motors.

## 4.13 Control unit

From the control unit the different components of the LIDAR-system are controlled. In this unit there are connection boards for wiring to the AT-MIO-16 and the PC-TIO-10 in the system computer. See figure 31. For additional information about the components in the unit see [1].

For the calibration system the unit had to be added with:
- Connector to the power unit for the cables related to the calibration system.
- BNC connectors from the detectors in the calibration unit.

## 4.14 System computer

A PC is used to run the calibration system. This computer is equipped with several PC-cards to be able to send and acquire data form the LIDAR-system. The PC-cards used to communicate with the calibration system are the PC-MIO-16 and the PC-TIO-10 from National Instruments [7].

## 4.14.1 AT-MIO-16I/O PC-Card

The MIO-16I/O PC-card consists of 12-bits ADC with 16 analogue inputs, two 12-bits DAC's with voltage output and eight lines of TTL compatible digital I/O interface. This card is used to acquire the analogue signals from the calibration system i.e. the signal from the detectors.

The PC-card is connected to the control unit with a flat-cable. The cable is connected to a 50-pins connector board. For details of the wiring see appendix 1 The Wiring of the system.

## 4.14.2 PC-TIO-10 PC-Card

The PC-TIO-10 PC-card is a timing and digital I/O interface. It consists of sixteen TTL compatible digital I/O lines, ten counters and has two edge-sensitive interrupt inputs with programmable edge selection. This card is used for the TTL input and out to the calibration system.

The PC-card is connected to a 50-pin connector board in the control unit. For details of the wiring see appendix 1 The Wiring of the system.
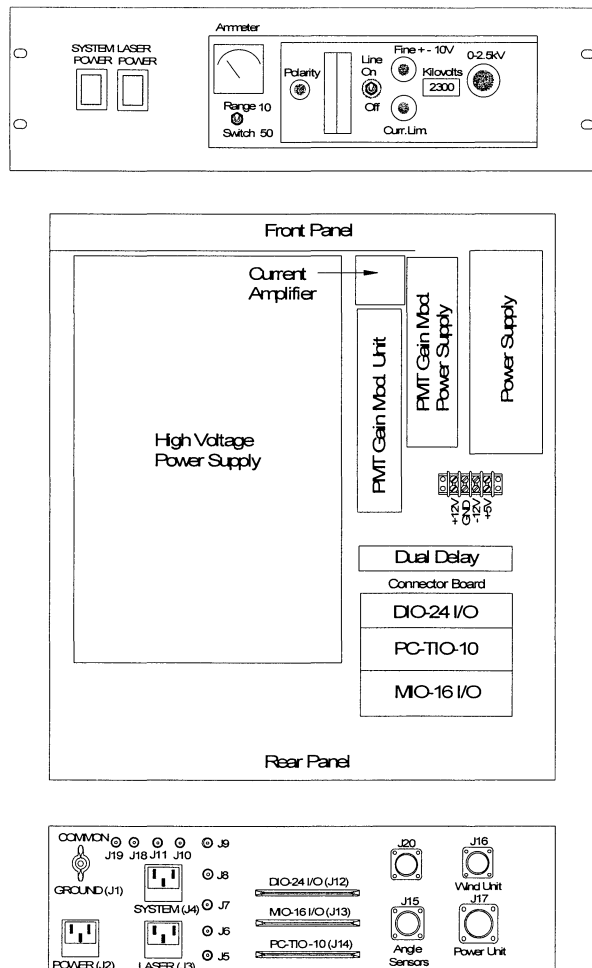


**Figure 30** *Overview of the control nit*
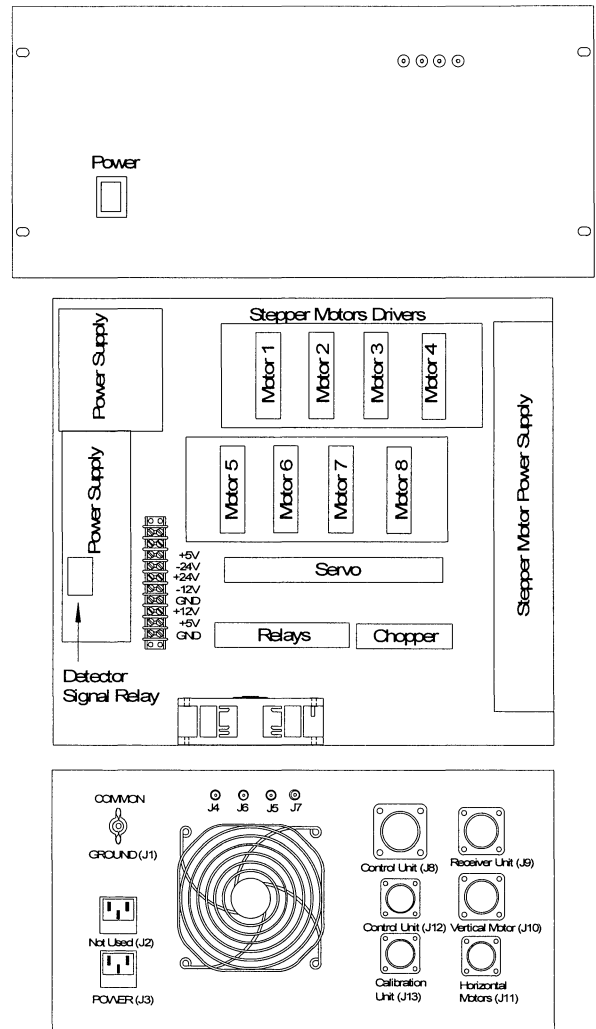


**Figure 31** *Overview of the power unit.*

# 5 User manual

## 5.1 Introduction

This manual describes the calibration program from a user perspective.

The calibration program consists of two parts, configuration and calibration. The calibration part is called from other programs in the LIDAR system. The actual calibration is done automatically even though the calibration properties are retrieved from the configuration part.

The only user interactions in the calibration part are dialogue boxes displayed when errors or problems in the calibration are detected. For this reason only the configuration part is described in this manual.

For a description of the calibration part and for technical details please refer to the *6 Programmer's Guide*.

## 5.2 Configuration part

In the configuration part of the program, the calibration unit is set-up, the cells with vapour are defined and the calibration method is defined. The settings from this part are used when the actual calibration is performed.

The configuration of the unit is done from three main windows:

*   *Current calibration settings.* Used to show the current settings of the calibration unit. From this module the data to the calibration part is passed on. From this panel it is possible to display the "Change in calibration unit" front panel.
*   *Change in calibration unit.* This front panel is used to configure the calibration unit i.e. change the cells in the unit. From this panel it is possible to display the "change calibration data" front panel.
*   *Change calibration data.* This module is used to configure the calibration data for a cell.

In the calibration system many cells can be configured. For each of these cells many calibration regions can be defined i.e. data used when calibrating with that cell. These regions are called Peak or Peak Data. For each cell one peak is defined as the default peak. The data for this default peak are used by the system when calibrating using the cell. This means that if non-default peak (data) shall be used for calibration then this peak has to be changed to the default peak for the cell.

### 5.2.1 Current calibration settings

This module displays the current settings in the calibration unit, see figure 32.

From this screen it is possible to select one cell. When a cell is selected the name of the cell along with the default

peak data for the cell is displayed. The selected cell will be the one used if a calibration is started.

**Current cell selection box**

This box shows the cell that is currently ready for calibration. With this control it is possible to change the cell that the calibration shall be performed for, see figure 33.

If the cell is changed the new cell will be rotated to the calibration position in the unit and the default data for the new cell will be displayed.

**"Change" button**

This button is used when the configuration in the calibration unit is to be changed. When pressed the *Change in calibration unit* front panel will be displayed.
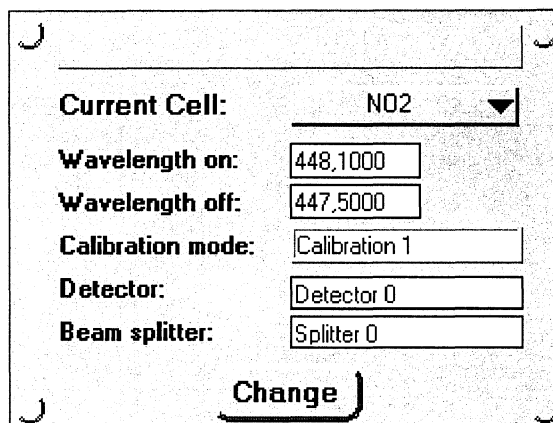


**Figure 32** *Front panel of the Current calibration setting.*
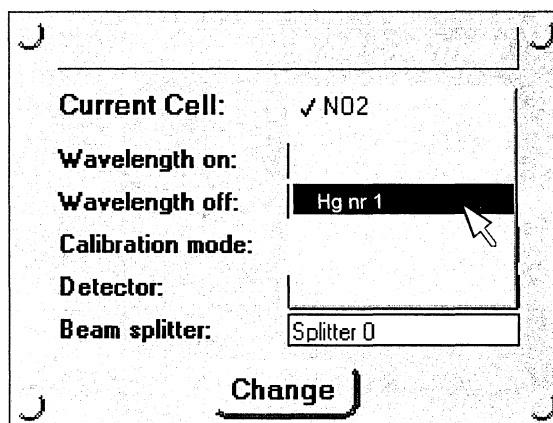


**Figure 33** *Front panel when changing the cell.*

## 5.2.2 Change in calibration unit

This module makes it possible to change the cells in the calibration unit, se figure 34.

**Calibration Cell selection box**

Displays all the calibration cells that are defined in the system.

**Cell in Revolver selection box**

Displays all the cells that are present in the calibration unit.

**Calibration Peak selection box**

Displays all calibration peaks for the cell that is highlighted in the *Cell in Revolver* selection box.

**"Change Data" button**

This button is used if the calibration data for a defined cell is to be changed. To change the data the cell has to be highlighted in the *Calibration Cell* selection box. When the button is pressed the program will open the front panel for the **Change Calibration Data**.

**"New Data" button**

This button is used when a new calibration cell shall be added to the system. When pressed a dialogue box is displayed, in which the new name of the cell shall be typed, see figure 35. After the name is entered the program will open the front panel for the *Change Calibration Data*, see below.

**"Delete" button**

This button is used if a defined cell shall be erased from the system. To delete the cell, highlight it in the *Calibration Cell* selection box and then press the "Delete data" button. A warning message box, in which the action has to be confirmed, is displayed before the cell is removed.
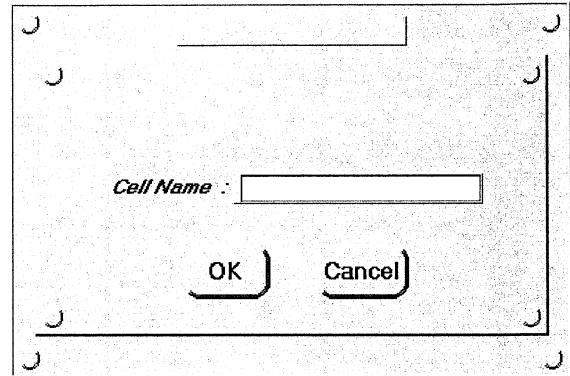


**Figure 35** *Front panel of "New Spiece Name.vi". This VI is used when a new cell shall be added to the system.*
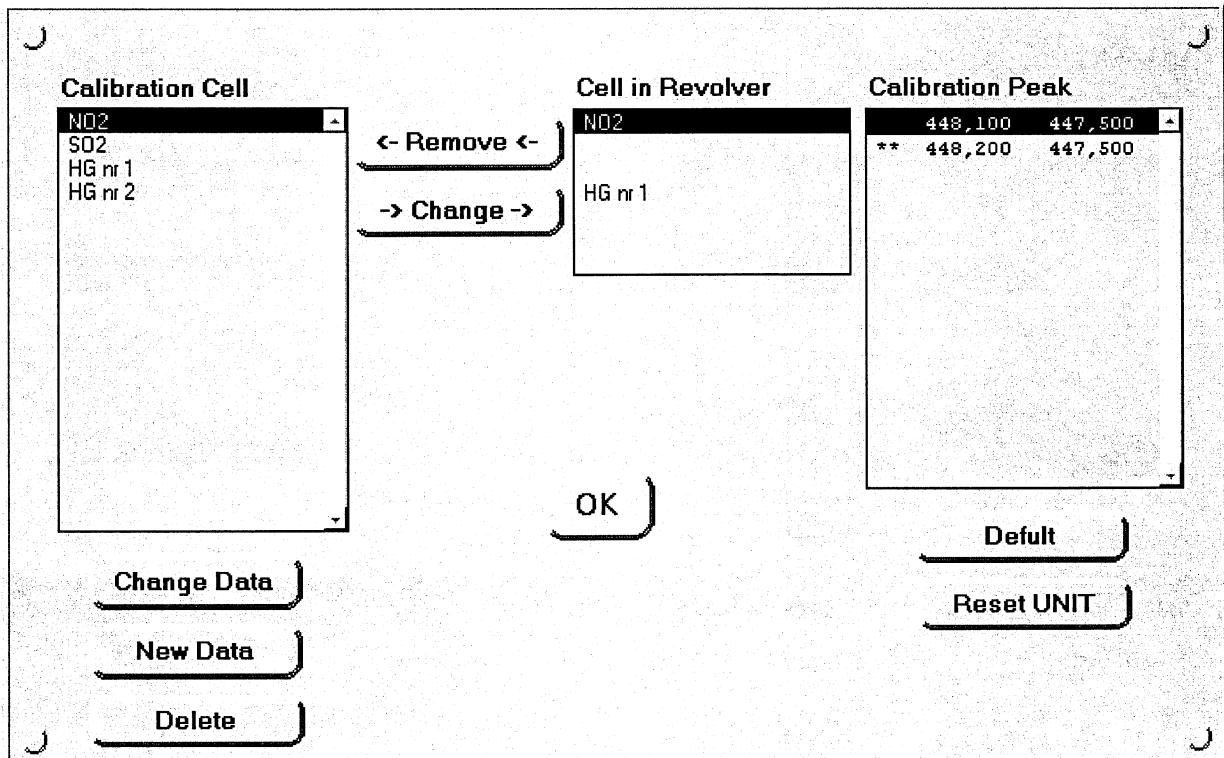


**Figure 34** *The front panel for Change in calibration unit. The configuration of the calibration unit is executed from this VI.*

**"Remove" button**

This button is used when a cell shall be removed from the calibration unit.

The program checks if there is a cell present in the unit. If not, a warning message is displayed.

The revolver will then be moved to make it possible to remove the cell. A dialogue box is displayed, see figure 36, in which the action shall be confirmed.

Confirm when you have
removed the cell
at position: 0

OK        Cancel
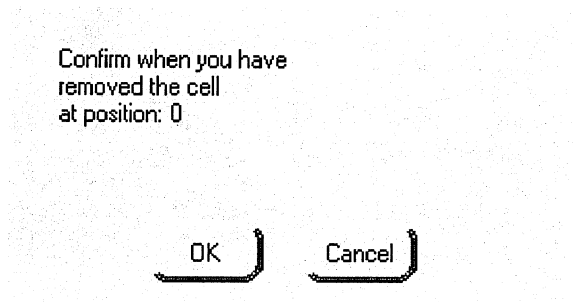
**Figure 36** *Confirmation dialogue box.*

**"Change" button**

This button is used when a cell shall be added to the unit. The cell is highlighted in the *Calibration Cell* selection box. The position where the cell shall be inserted in the unit has to be highlighted in the *Cell in Revolver* selection box.

It is possible to change a cell even if the position is occupied. It is not possible to have the same cell in two positions in the unit at the same time.

When the action is performed the program checks if the cell is present in the unit. A warning message is displayed if the cell has already been added. Then the revolver is positioned so it is possible to add/change the cell. A dialogue box is displayed in which the action shall be confirmed, see figure 36.

**"Default" button**

This button changes the default peak for the cell highlighted in the *Cell in Revolver* selection box. The peak that becomes default is the one that is highlighted in the *Calibration Peak* selection box.

**"Reset UNIT" button**

This button shall be used when the set-up in the program does not correspond to the actual configuration in the unit. This action will **NOT** reset the cells and data defined in the system.

**"OK" button**

Saves all data and exits the panel. The program will returns to the *Current calibration settings* front panel.

## 5.2.3 Change calibration data

This module makes it possible to change the data for a cell, see figure 37. All data needed for the calibration is configured in the display. The data that is used for calibration depends on the calibration mode used. The data for a highlighted calibration peak is displayed in the left field.

**"Calibration Data" box**

In this box the calibration values for a specific region are changed and edited.

**"Calibration Peak" selection box**

Displays all the calibration peaks for the cell.

**"Add Data" button**

When this button is pressed the data that has been entered in the *Calibration Data* box is checked. If the data is correct (within thresholds) it is added to the cell.

**"Change Data" button**

When pressed the data in the edit field is checked. If the data is correct the data for the highlighted peak is changed.

**"Copy" button**

When pressed the data for the highlighted peak is copied to the edit field.

**"Default" button**

Changes the default peak to the highlighted. The default peak is displayed with two stars in front of the data.

**"Delete Data" button**

Deletes the peak that is highlighted in *Calibration Peak selection box*. If the peak is the default one, then default setting will change to the peak that is first in the list.

**"OK" button**

Exits the panel and returns to *Change in calibration unit* front panel.
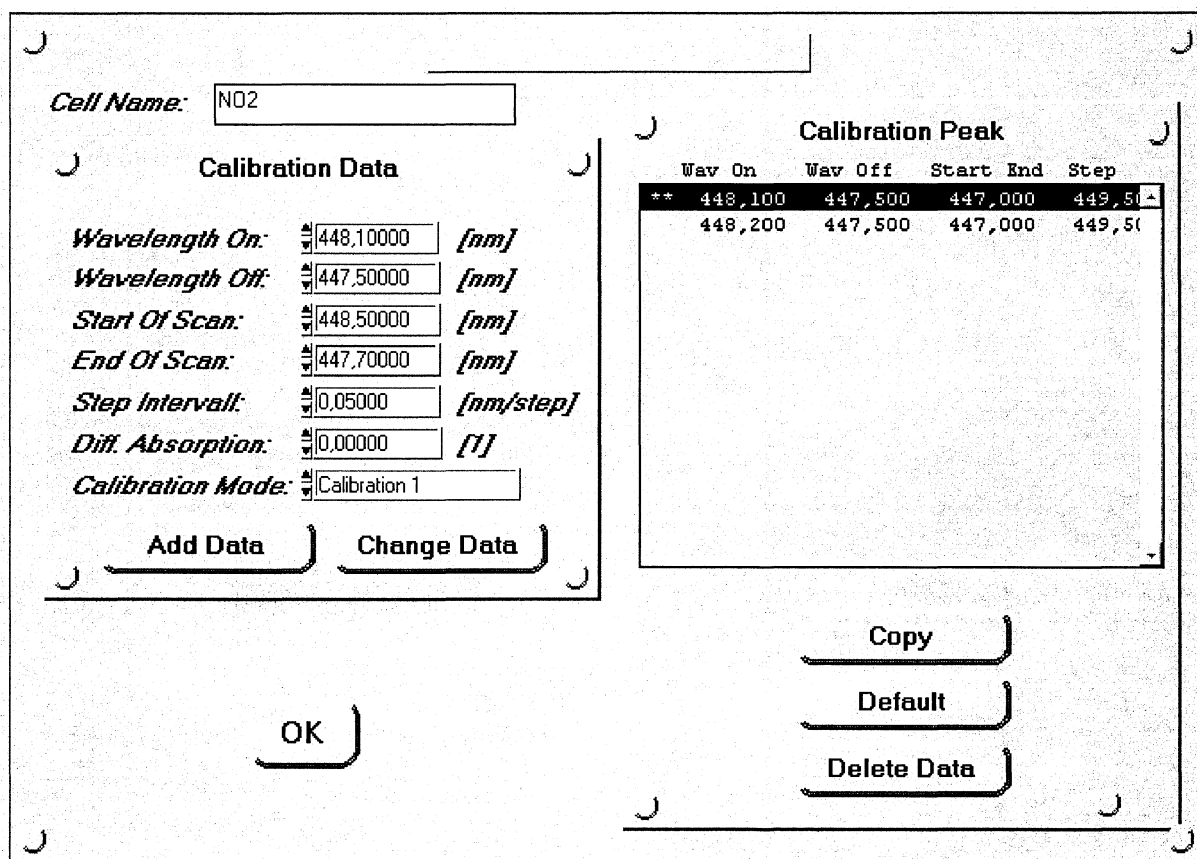


**Figure 37** *Front panel of "New Spiece Data.vi". In this VI the data for a calibrating cell can be changed*

# 6 Programmer's guide

## 6.1 Introduction
This guide describes the concepts of the calibration program. It is intended for programmers and persons who want to change or add functionality to the program.

The guide has three sections. The first section (6.2) describes the basic concepts and the main parts of the program. The second (6.3) describes the program in further detail and how to add functionality. The third section is an overview of the Virtual Instruments (VIs) and the main data clusters in the program. This section is found in appendix 19 VI and Cluster description.

## 6.2 Basic concepts
This section describes the basic design pattern of the program. It also gives an overview of the calibration program.

### 6.2.1 Introduction
The calibration program consists of two parts. One part handles the configuration of the unit and sets the current data that are necessary to calibrate. The second part handles the calibration. These two parts are separated although the calibration part uses the data set by the configuration part.

Since the calibration program is one part of the total LIDAR-system developed by the LIDAR-group, there are some basic rules that must be followed.

### 6.2.2 Basic design
In this section the basics of the program are explained. These things are:
- Stopping of the program. There must be a way to stop the program at any given time.
- Screens for input of data.
- How to control the sequence of execution.
- How data is passed to the different modules.
- The main data clusters in the program.
- Storage of data from the calibration program.
- Parameters in the program.

#### 6.2.2.1 Stopping the program
To be able to stop the program at any time two global Boolean have been implemented. These are "**Change activity**" and "**Run**". If the system has to change activity the "**Change activity**" variable is set to TRUE. All modules in the LIDAR system shall then stop to make the action possible. In the same way the "**Run**" variable is set to FALSE when the system shall be shut down. These two variables are never set in the calibration program, but they are checked to determine if the program shall continue execution or not. Two VIs are implemented to perform the check. These are "*ContinueExecErrorCheck*" and

"*ContinueExecNoErrorCheck*". The difference between these is that the first one also checks if there are any errors in the Info cluster. For further information, see appendix 19. The first thing done when a VI is called is to check if every thing is OK. This is done as in figure 38.

In "For" and "While" loops the *ContinueExecNoError-Check* is used, see figure 39.

#### 6.2.2.2 Input screens
The performance of the input screen is achieved as seen in figure 40.
First the VI checks if it shall execute or not. Then the VI is initialised. After this two loops are started. The lower loop is responsible for collecting the user input, i.e. which buttons are pressed on the front panel. The upper is responsible for performing the tasks related to the button pushed.

An occurrence object achieves the synchronisation of the loops. The upper loop enters the default case where it waits for occurrence from the lower loop. Every 200ms the lower loop checks if any button is pressed. If a button has been pressed the variable *execution frame* is set to the case number that shall be executed by the upper loop, and the occurrence is generated. After this the lower loop waits for the occurrence from the upper loop. The upper loop performs its tasks and when ready it returns to the default case. Here it generates the occurrence, so the
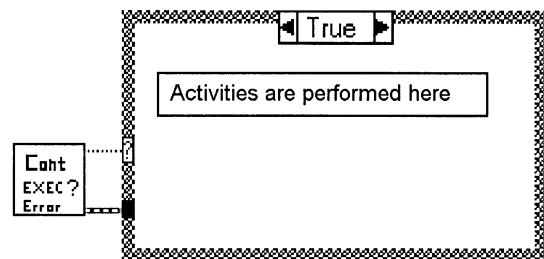


**Figure 38** *Before executing the code the status is with ContinueExecErrorCheck.*
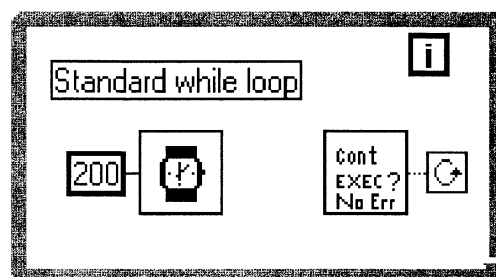


**Figure 39** *for every loop the status is checked with ContinueExecNoErrorCheck.*
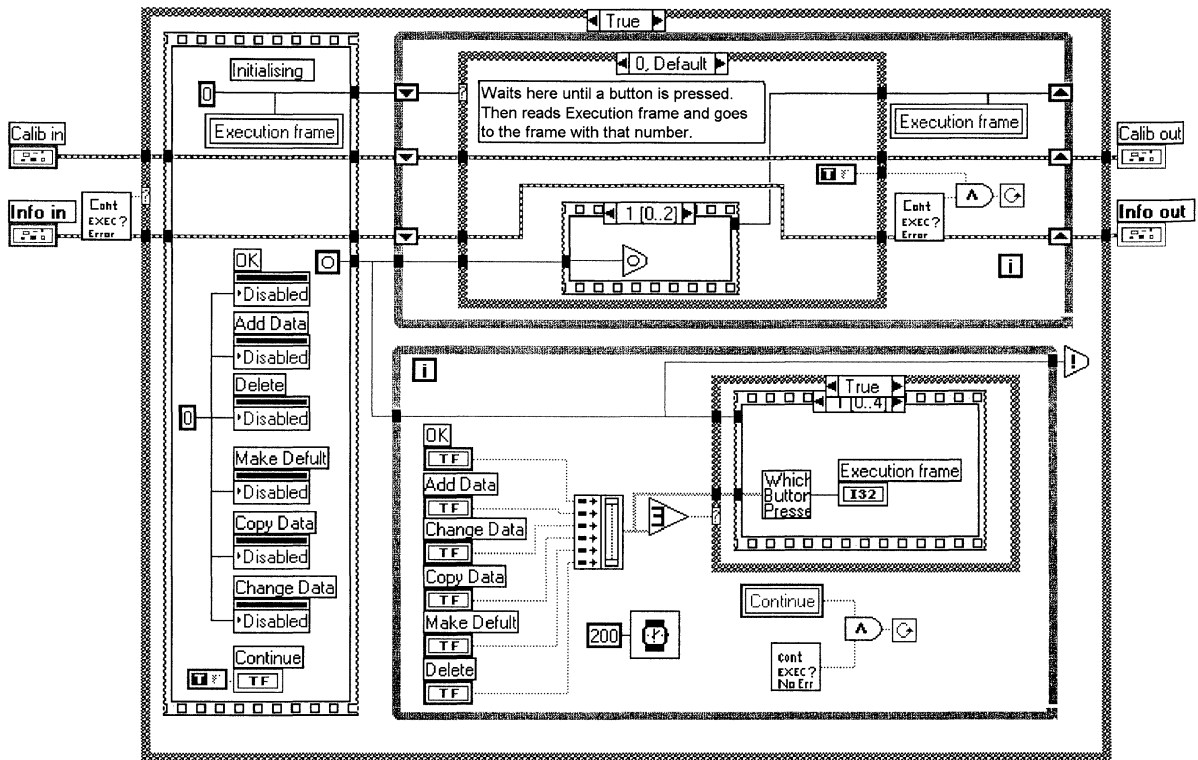
**Figure 40** *Standard code for an input screen.*

lower loop can start again, and then it once more waits for the lower loop.

### 6.2.2.3 Synchronisation in the program.

The execution sequence in the program is achieved by the data flow of three clusters. These are:

- The *"Info"* cluster.
- The *"File Types"* cluster.
- The *"Calib"* cluster.

These clusters carry the data within the system. The *"Info"* and *"File Types"* cluster are general clusters containing data of the total LIDAR-system while the *"Calib"* cluster is used only in the calibration program.

### 6.2.2.4 The "Info" cluster

In the calibration program all the VIs have the *"Info"* cluster as input. This cluster is the main object for the synchronisation. If an error occurs the error number is saved in this object. See figure 41.

This cluster carries all the current settings and data of the calibration program. That is the current position of the revolver, position of the detector etc. It also carries the data used by the calibration part to make the calibration. The different parameters are explained in *6.2.2.7 The data structure.*
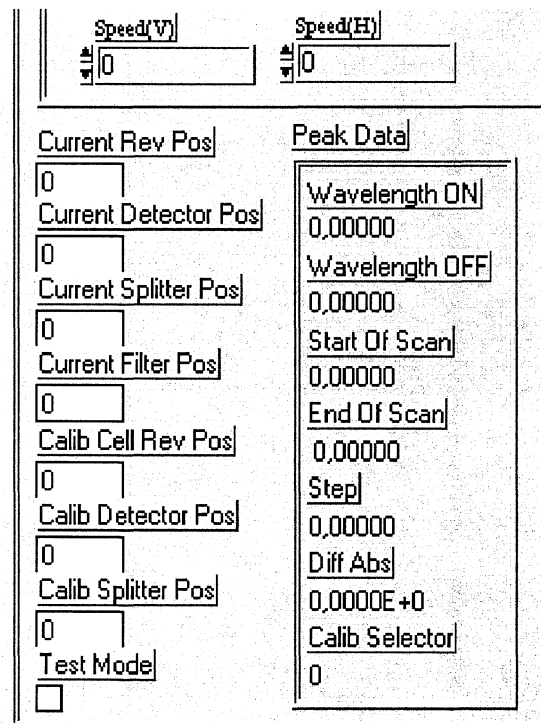


**Figure 41** *The parameters used by the calibration program in the Info cluster.*

### 6.2.2.5 The "File Types" cluster

This cluster contains the data needed when making file transactions. See figure 42. This cluster is only passed on to VIs that need to save or retrieve data from the calibration file. More information about saving the calibration data is found in section *6.2.2.8 Data storage.*

**Parameters used by the calibration program**

*Calib Data File Path*

    The file path to the calibration data file. The path includes the file name.

*Cell*

    The data format that is saved to the file. The information is in the same format as for the Calib cluster, see *6.2.2.7 The data structure.*

*Cell Refnum*

    A position reference used by LabVIEW when reading and writing to the file.

### 6.2.2.6 The "Calib" cluster

It contains all the data that is necessary to configure the calibration unit, i.e. the data for every cell of vapour, the calibration peaks for the cell, the detector and splitter settings. See figure 43.

It is important to see the cells, detectors and beam splitters as physical objects. Each cell that is defined in the system shall have a physical cell. For this cell many different calibration regions (peaks) can be defined.

The different parameters are explained in *6.2.2.7 The data structure.*

### 6.2.2.7 The data structure

The structure of the data in the program is shown in figure 44. In this figure the dependency between the clusters is shown. For detailed information about the different elements in the clusters see appendix 19 VI and Cluster description.

### 6.2.2.8 Data storage

Three things are important when designing data storage:
1. The configuration should not be lost when the program is terminated
2. Dynamic data shall be easy to change.
3. All dynamic data are retrieved at a restart.

When looking at these three criteria it is found that the dynamic data are the cell data with all the peaks (the calibration data) together with which cells are present in the revolver. When restarting the program these data need to be retrieved.

The position of a cell in the revolver is stored in the
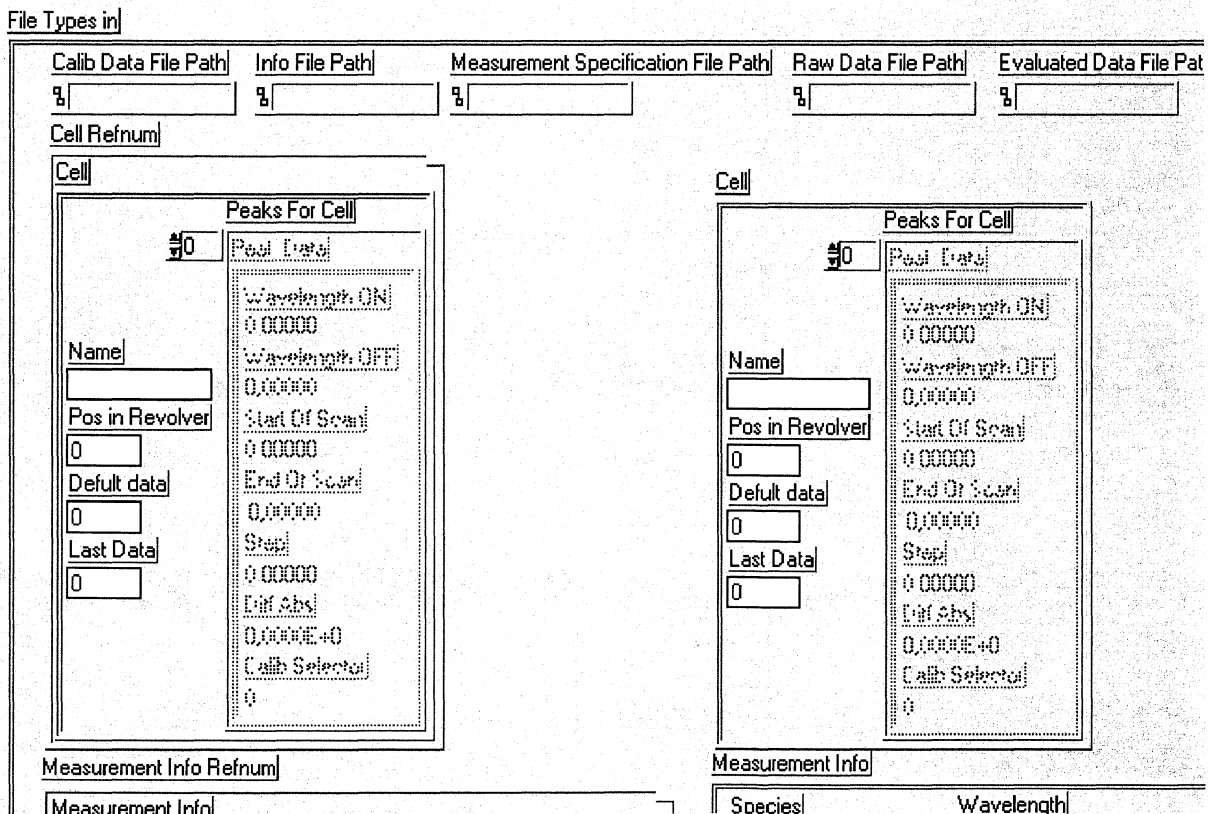


**Figure 42** *The parameters used by the calibration unit in the File Types cluster.*

"Cell" cluster in the array of "Cells" in the "Calib" cluster, see figure 44. This "Cell" cluster is saved to disk.

The data for the detectors and beam splitters are static data i.e. the data does not change often. For this reason the data are not stored on disk, but are instead hard coded in the initialising section of the program.

### 6.2.2.9 Parameters in the program

To be able to run the program some parameters have to be defined. For detailed information on the parameters that can be set see appendix 19 VI and Cluster description.

The configuration of the parameters has to be done for:
- Initialising of the unit.
  Configured in VI: **Init Calibration Unit**
- Checking calibration data.
  Configured in VI: **Check Peak Data**
- Finding motor position 0.
  Configured in VI: **Find Motor Pos 0**
- Moving a motor.
  Configured in VI: **Rotate Selected Motor To**
- Changing cell in the revolver.
  Configuration in VI: **Change In Revolver**
- Finding neutral density filter.
  Configured in VI: **Select Demp Automaticaly 2**
- Calibrating
  Configured in VIs: **Calibration Method 0**
  **Calibration Method 1**
  **Calibration Method 2**
- Indexing of the motors.
  The addressing of motors in the program is done by an index. This index is NOT the same as the motor number in the calibration unit. The difference has evolved since there are more motors in the LIDAR-system. The numbering of the motors in the program is found in table 3 below.

| Index | Motor | Description |
|---|---|---|
| 0 | 5 | The detector motor. |
| 1 | 6 | The revolver motor. |
| 2 | 7 | The filter motor. |
| 3 | 8 | The beam splitter motor. This motor is not implemented in the calibration unit. |

**Table 3** *The numbering of the motors in the program.*
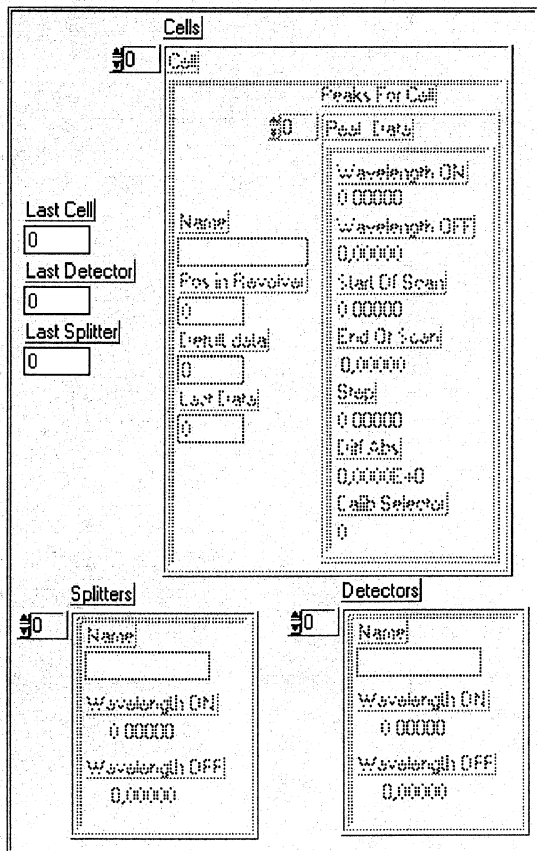


**Figure 43** *The Calib cluster*
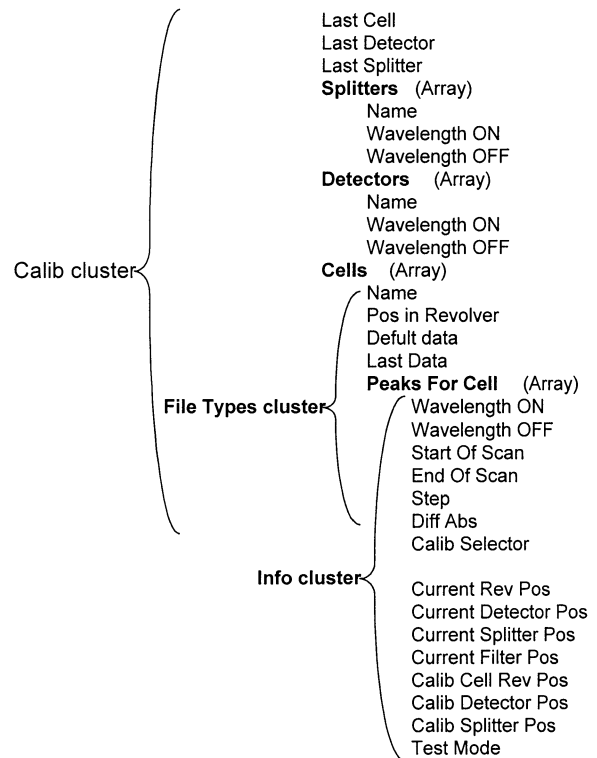


**Figure 44** *The three clusters and the elements that is defined for the calibration program.*

## 6.3 Calibration program

This section describes concepts of the program, i.e. where different data can be found and the logic behind.

The main components of the program are described with a flow chart. For detailed information of the program please see the code.

### 6.3.1 Basic concepts

The basic concepts of the calibration unit and program are as follows:

- Revolver for 7 cells.
- Neutral density filter wheel with 10 positions.
- Detector wheel with 2 positions.
- The unit is prepared for adding a variable beam splitter component. All indexing in the program starts with zero. This means that the first position of the neutral density filters, cell positions, detector

Beginning and end point of the program sequence.

Prosess / Action

A process or action performed by the program.

Manual operation

Manual operation that can be performed by the user. A typical example can be when the user presses a key.

Display

Message or screen that is displayed.

Predefined process

Process containing several actions. An example is another main VI.

Decision

Decision. Typically an if statement.

Case 1

Case 2
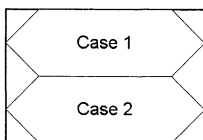
Case sequence.

**Figure 45** *The components used in the flow chart.*

positions, and so on is 0.

- The program can be configured with data for many cells.
- For every cell that is defined there shall exist a real cell.
- For each cell many different calibration wavelengths can be defined.
- For each of the wavelength a specific calibration method can be selected.
- No detector shall be placed at position zero. In other words the first real detector is found at position 1. This is done to protect the detectors. The program will always set the detectors at position 0 (blocked) except when collecting data during a calibration.
- The filter wheel will always move towards a darker filter except when trying to find the optimal filter during calibration. The program starts with the darkest filter.
- Detector 1 is the measuring detector i.e. the detector that collects the signal from the laser beam that passes through the calibration cell.
- Detector 2 is the reference detector.
- The current positions of the detector wheel, the revolver wheel, the filter wheel and the beam splitter are always stored in the **Info** cluster.
- One cell at a time can be selected for calibration. The data needed to calibrate is stored in the **Info** cluster.
- All data configured in the program is stored in a configuration file. This file includes information about which cells that are present in the unit.

**Figure 46** *Main sequence of the calibration program.*

## 6.3.2 Flow charts of main components

This section describes the main program.
The flow chart objects that are used are mainly standard objects. The objects used are displayed in figure 45.

### 6.3.2.1 Main flow chart

The main components of the program are displayed in figure 46. The figure shows the two parts of the calibration program, the configuration part and the calibration part. The main LIDAR program shall, during normal operation, call the configuration part.

The calibration part is also called from the main application. This can be done whenever it is necessary. Since this part is a separate component other interfaces can be constructed to use it.

### 6.3.2.2 Current calibration settings

This VI is the entry point to the configuration section of the calibration program. The VIs front panel is the user interface for selecting which cell shall be used when calibrating the laser. See picture 47.

The name of the VI is: **Cell Selection**.

This VI shall be called with a regular interval from the main program.

The first time the VI is called a parameter shall be set so the program knows it shall initialise the calibration unit. This parameter can be set every time a recalibration is wanted.

When calling the VI the program checks if it shall initialise the unit or not. When initialising the unit the program will set all motors in the unit to their starting positions. Then the saved data is fetched from a configuration file. The front panel screen is updated, and then the VI returns to the main program.

If the VI is called without the initialising parameter set it will check if anything has changed from the "previous visit". The things that can have changed are:

- The change button has been pressed. The VI will then call the VI for configuration of the calibration unit, see section 6.3.2.3.
- A new cell for calibration might have been selected.

In both cases the display will be updated and the configuration data will be stored in the **Info** cluster.

### 6.3.2.3 Configuration of the calibration unit

This is the user interface for configuring the calibration unit. From this screen cells can be added and removed and calibration data can be changed. See picture 48.
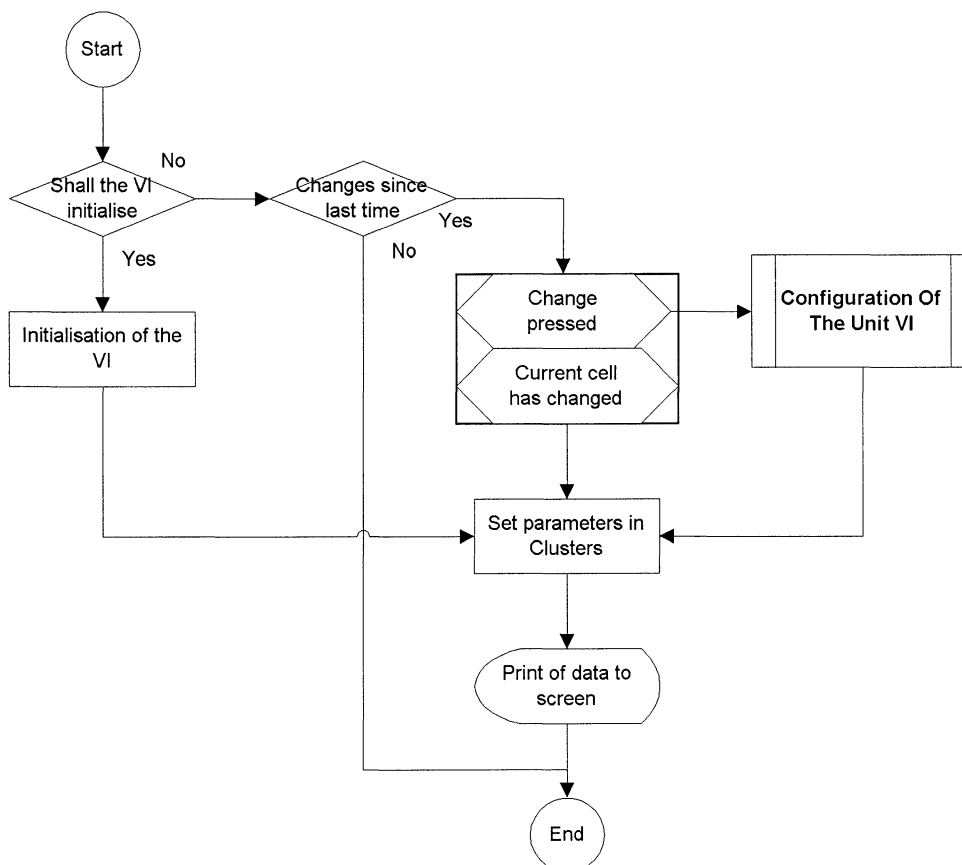


**Figure 47** *Flow chart for Current Calibration Settings*

The name of the VI is: **Configuration Of the Unit**. This VI is called from **Cell Selection**, see section 6.3.2.2.

When called, the front panel of the VI is displayed. This screen will be open until the OK button is pressed or until an error occurs.

When changing in the unit, the current positions of the motors are always stored in the **Info** cluster.

All the cell data that are changed or added is stored in the *Calib* Cluster. This is done instantly when the change is made. The screen is also updated when changes are made. In this way the screen and the *Calib* cluster are always mirrors of each other. Because of this relation, the index of the highlighted field is used directly when operations
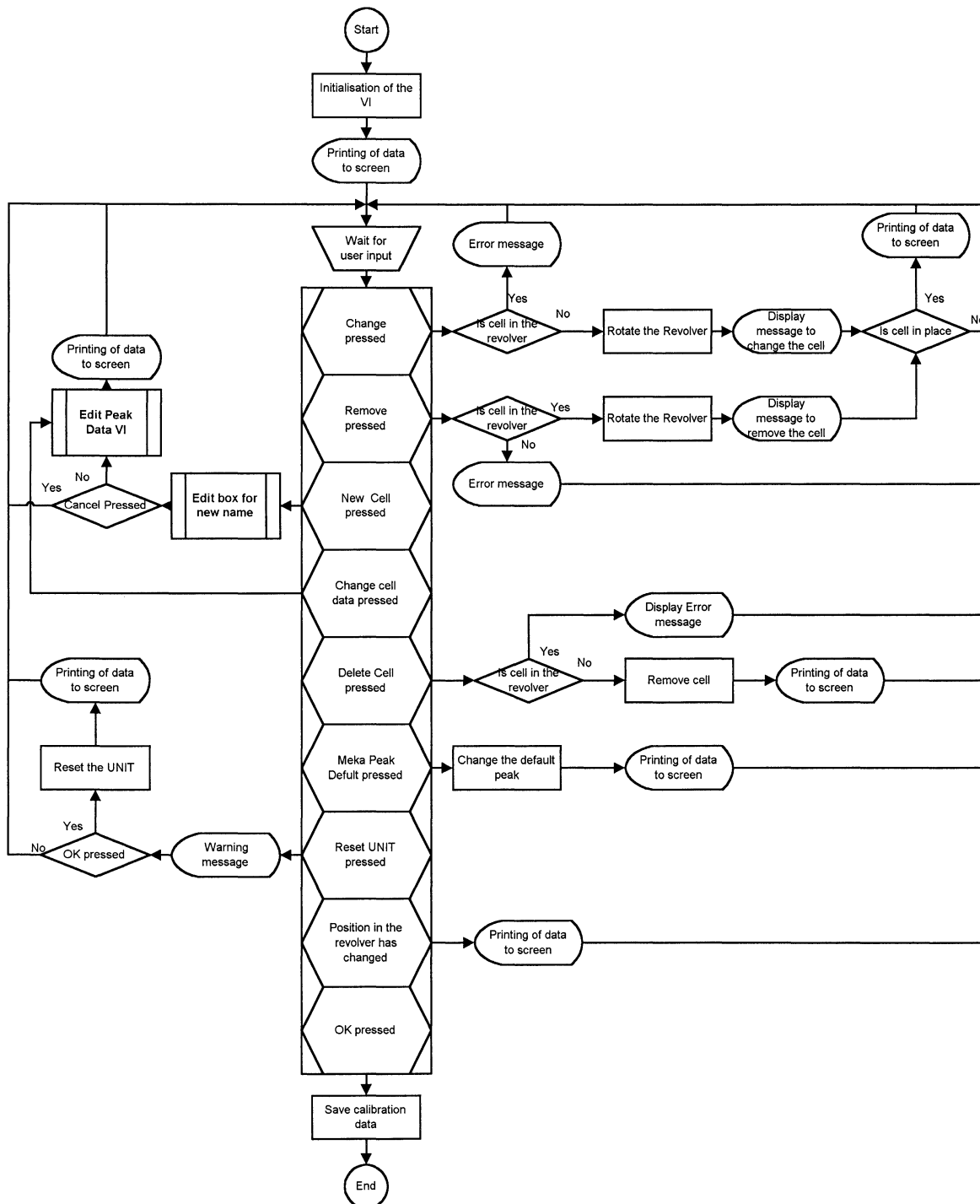


**Figure 48** *Flowchart for the configuration of the unit.*

are carried out on the cluster.

*Example*: If the peak data for an existing cell shall be changed the user will first highlight the cell on the screen and then press the button to change the data. Since the screen and cluster are "reflected images" of each other, the program now know that the index of the highlighted field on the screen is the same as the index for that cell in the array "cells" in the **Calib** cluster. When exiting the **Configuration Of the Unit,** the data of the **Calib** cluster are stored to the calibration file.

### 6.3.2.4 Edit peak data for cell

This is the user interface changing the peak data for one cell, See picture 49.

The name of the VI is: **"Edit Peak Data For Cell".** The VI is called from **"Configuration Of the Unit",** see section 6.3.2.3.

The VI is called with an index parameter. This index is the position of the cell in the array "cells" in the *"Calib"* cluster. All operations will be performed on this cell only.

### 6.3.2.5 Calibrating the laser

This VI is the entry point to the calibration section of the calibration program. The VI is called from the main application and has no direct interaction with the configuration part of the calibration program. But when the VI is called the calibration parameters in the *"Info"* cluster must be set. It is in this VI all the different calibration methods are called, see figure 50.

To move the OPO-laser to a specific wavelength the program uses components developed by Fredrik Nordin [20]. The calibration program calls these VIs with the wavelength the laser shall move to.

The name of the VI is: **Calibrate The Laser.**
**Input parameter:** *"Info"* cluster. The calibration parameters must be set in the cluster, when called.
Output parameters:
1. *"OK out".* Tells if the calibration was successful or not.
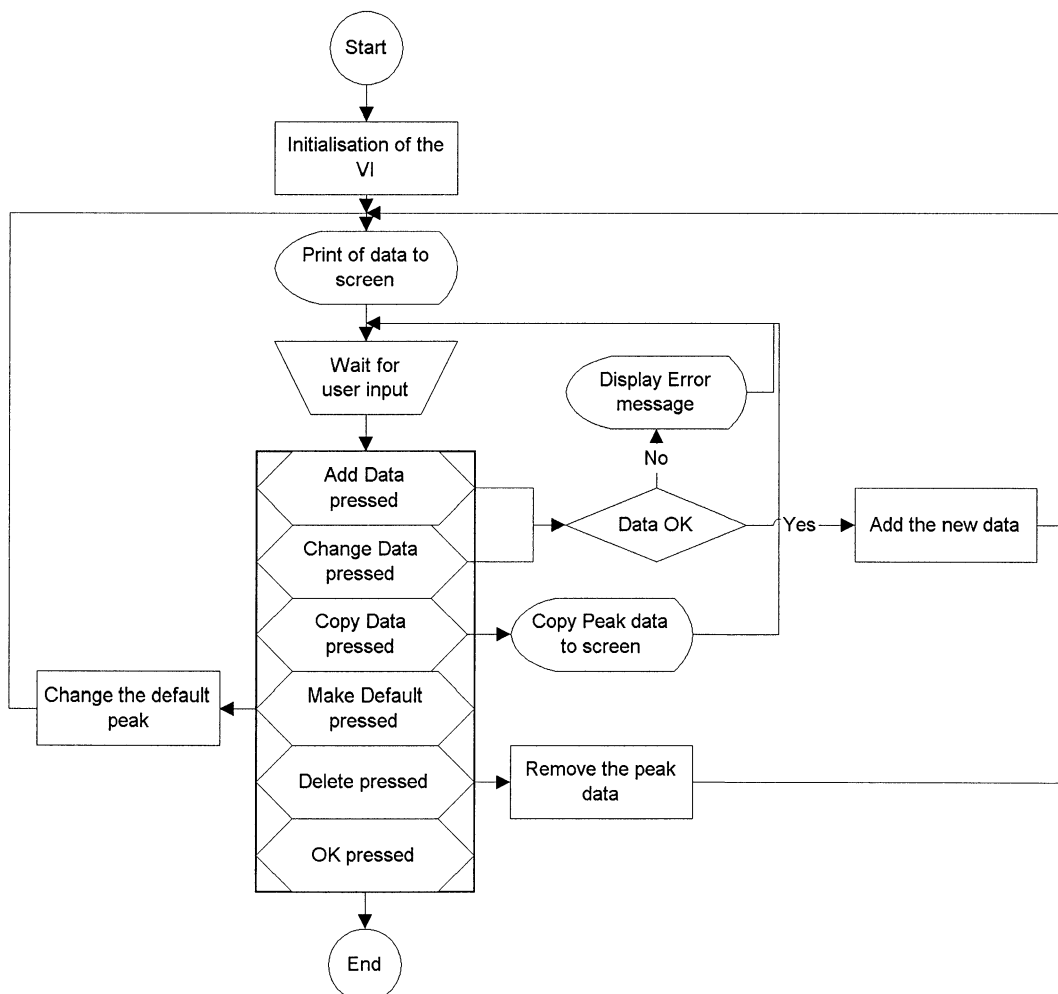


**Figure 49** *Flow chart for the VI Edit Peak Data For Cell.*

2.  *"Offset"* in nm. The offset found on the wavelength scale for the laser.

The VI then performs the steps found in the experiment to determine the performance of the detectors, see Appendix 18.

These steps are:
1.  Let the filter wheel start with as high optical density as possible, i.e. as dark as possible.
2.  Let the laser go to the minimum absorption around the region were the calibration shall be made.
3.  Select lower optical density filters (with the filter wheel) until one of the detectors have an output larger than the minimum output limit from the detectors. Use this detector to find the maximum energy in the pulse.
4.  Select the filter with the lowest optical density but for which the output is below the maximum output from the detector. Now there is as much dynamics as possible in the system.
5.  Check that the second detector is within the operational region (between upper and lower output limit).
6.  Record the offset from the two detectors.
7.  Perform the scan.

Additional steps the procedure performs are:
8.  Check the output from the detectors once more. This is to determine that none of them have passed the output limits.
9.  Move the filter wheel to the OFF position.
10. Move the detector to OFF position.

**Finding neutral density filter**
To find the correct neutral density filter the VI "**Select Demp automatically**" is used.

**The calibration methods**
The recording of offset and the performing of the scan is done by the calibration method used.

Each calibration method can have different ways to find the offset of the laser. They can also include additional user interfaces. For example showing the output from the detectors in a graph and saving recorded data to file. Further additional configuration parameters can be set. For detailed information please see the code.

The outputs from all calibration methods must be:
1.  BOOLEAN, telling if the calibration was successful or not.
2.  The offset in nm.

## 6.3.3 Changing the code
This section describes what steps that has to be taken when changing in the calibration program. Only the most common changes that can be performed are described.

### 6.3.3.2 Adding calibration method
When a new calibration method is to be included the following steps shall be performed:
1.  The name of the calibration method has to be added to the "**Calib Selector**". See appendix 19 for more info.
2.  A new VI for the calibration method has to be created. The VI should preferably be named "Calibration Method X" were X is a number. The VI must have two outputs:
    *   Boolean that indicates if the calibration went OK.
    *   DBL (float) with the offset from the laser.
3.  A new case has to be added in the VI "**Calibrate The Laser**". In this case the new calibration method shall be called.
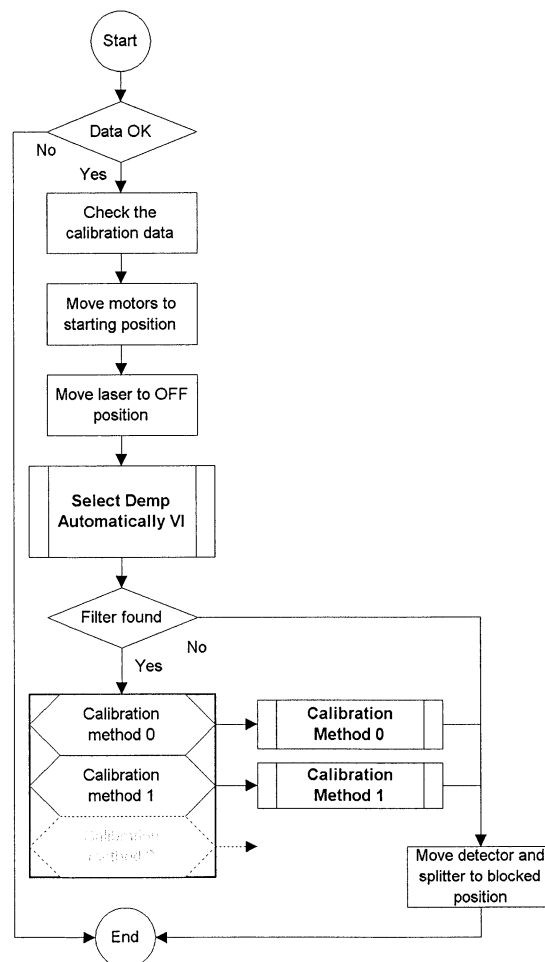


**Figure 50** *The Calibration part*

### 6.3.3.3 Adding/changing calibrating data

If more or different data has to be added to make a calibration the following changes have to be made:

1. The "**Cluster of Peak Data**" has to be updated with the new parameters.
2. The VI "**Edit Peak Data For Cell**" has to be updated to make the user able to change the parameter.
3. The VI "**Check Peak Data**" has to be updated to check the reasonableness of the new parameter.

If the parameter is to be displayed, the following have to be made:

1. The VI "**Get All Peaks From Cell**" have to be changed for the new parameter. The front panels of the VIs "**Configuration Of The Unit**" and "**Edit Peak Data For Cell**" have to be updated with the new parameter.
2. The front panel of the VI "**Cell Selection**" has to be updated.

## 6.3.4 Interacting with the OPO-laser system.

The interaction with the OPO-laser is done through a LabVIEW interface.

All the configuration and interacting needed to control the laser is performed within this interface. This means that the calibration program does not know what laser system it is using [20].

### 6.3.4.3 Changing wavelength on the laser

When the calibration program wants to change the wavelength form the laser it simply sends the value of the new wavelength to the OPO-laser interface. The control of the execution will be returned to the calibration program when the new wavelength is adjusted in the laser.

The only thing that must be taken into consideration when using the OPO-laser interface is that it operates faster when moving the laser towards shorter wavelength. This behaviour appears since the laser can be tuned in two ways. If the wavelength shall be moved a short distance (<1.2nm) a piezo-electrical crystal is used. If the wavelength has to be changed over a larger distance the OPO crystal must be rotated. Rotating the crystal takes considerable longer time to perform, but the piezo-electrical crystal can only change the beam towards lower wavelength.

In other words: the best way of using the OPO-laser interface is by scanning the laser from a higher to lower wavelength.

# 7 Evaluation

## 7.1 Introduction

The performance of the calibration system experiments is performed is studied in two experiments. The purpose of the experiment is to find out if it is possible to use the system for calibration purposes. The experiments are not performed to validate any calibration method. The valuation of the calibration system is performed by hand.

## 7.2 Experiment

The test set-up that is used for the experiments is shown in figure 51.

To validate the system, absorption spectra of $NO_2$ are recorded. These spectra are then compared with table values for $NO_2$, see diagram 1. The vacuum wavelength, in the diagram, has to be adjusted to the air wavelength. This is done according to the following equation:

$\Delta\lambda = (n-1)\lambda_{air}$. By using a wavelength correction curve it was found that the vacuum wavelength has to be adjusted with 0,125nm at 450nm [23].

To be able to know the error in the wavelength scale of the OPO-system and to find out if it is possible for the calibration system to find this error, a wavemeter is used to find the correct wavelength. The wavemeter shows that the wavelength from the OPO-system has an offset of about 0,22nm.

Two experiments are performed. In the first experiment a fast scan is made over the absorption structure. This is done to verify if the system can find the structure when scanning fast. This is necessary when making rough calibration. It is also performed to see if the system can operate with a fluctuating laser power. The second experiment is done to determine if it is possible to find the error in the wavelength scale of the OPO-system.
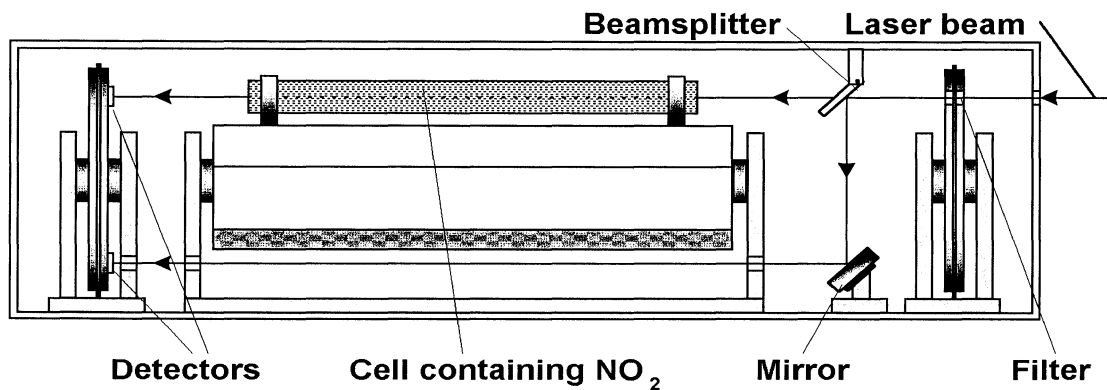


**Figure 51** *Test set-up for the experiments*
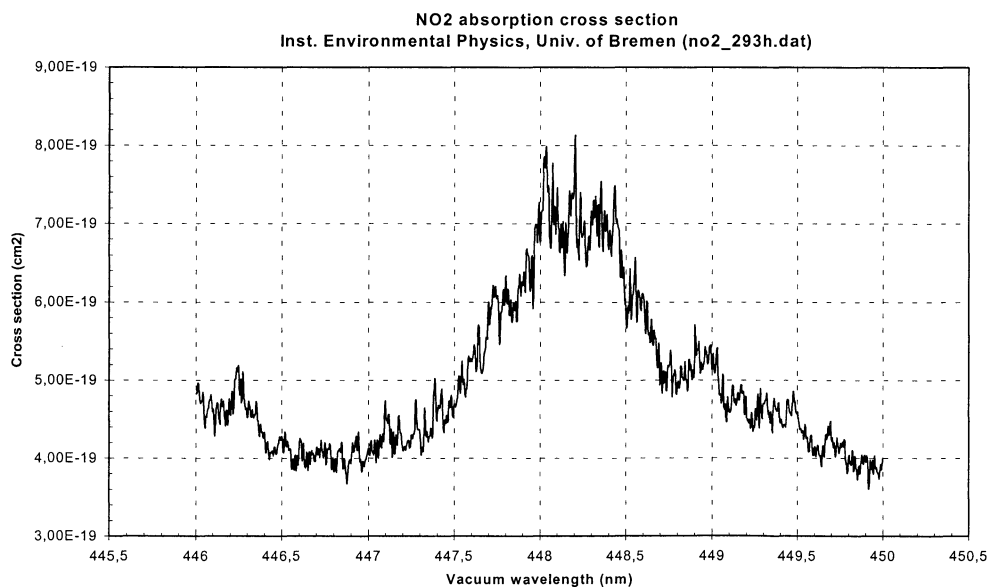


**Diagram 1** *Measured crosssection for NO₂ in vacum [24]*

## 7.3 Result
## 7.3.1 Experiment 1
In this experiment a fast scan is performed over the $NO_2$ structure. This is performed to evaluate if the system can detect the structure even if the laser fluctuates.

For each measuring point the mean value of 5 laser pulses is recorded.
Number of measuring points: 50
Scan region: 447,000 nm to 449,450 nm
The result from the experiment is found in diagram 2 and diagram 3
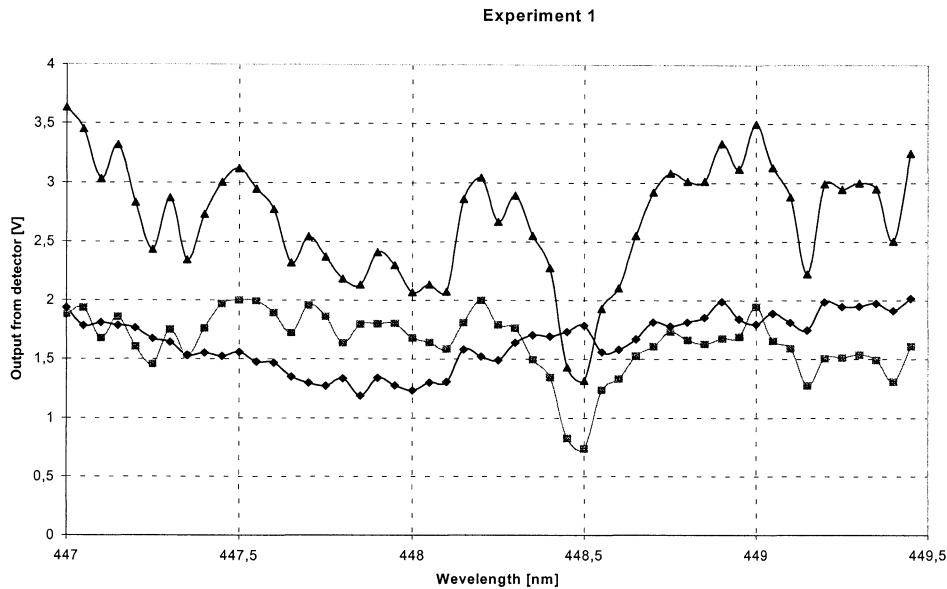


**Diagram 2** *Data from experiment 1*
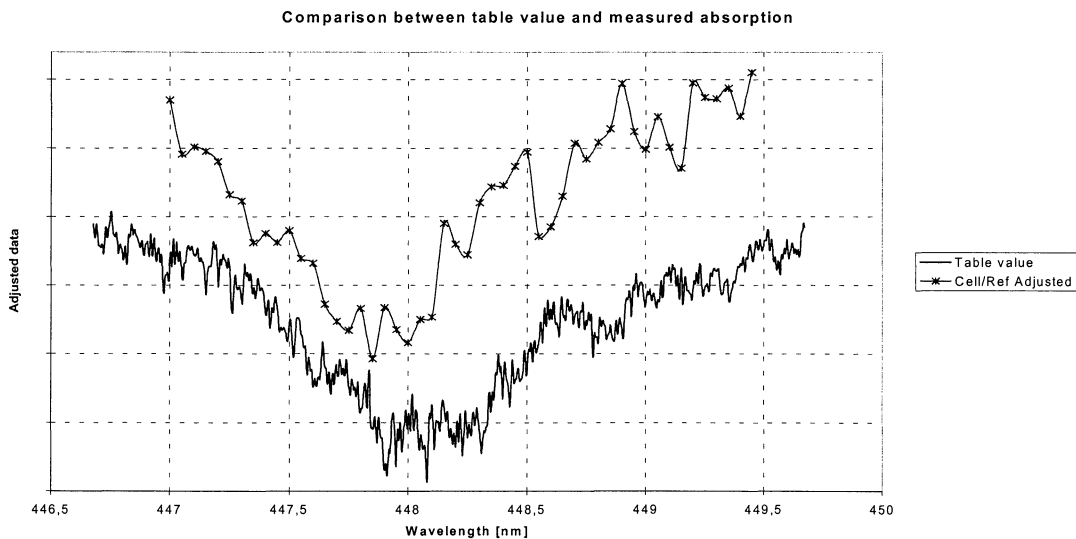


**Diagram 3** *Comparison between the table value and the measured absorption for $NO_2$. The scale for the two has been adjusted to be able to see the structure easier. The table value is adjusted to air wavelength.*

Department of Atomic Physics, Lund Institute of Technology

## 7.3.2 Experiment 2

In this experiment a scan is performed over the $NO_2$ structure. This is done to see if it is possible to use the system to find and (in theory) correct the wavelength scale in the OPO-system. From the first experiment it is found that the laser energy fluctuated with about 90%. In order to get more accurate measurements the reference detector is used as a gate. If the energy in a laser pulse is outside a window of ±25% of a mean value for the reference detector then this value is discarded and a new value is recorded.

For each measuring point the mean value of 5 laser pulses was recorded.
Number of measuring points: 256
Scan region: 447,300 nm to 448,320 nm
The result from the experiment is found in diagram 4 and diagram 5
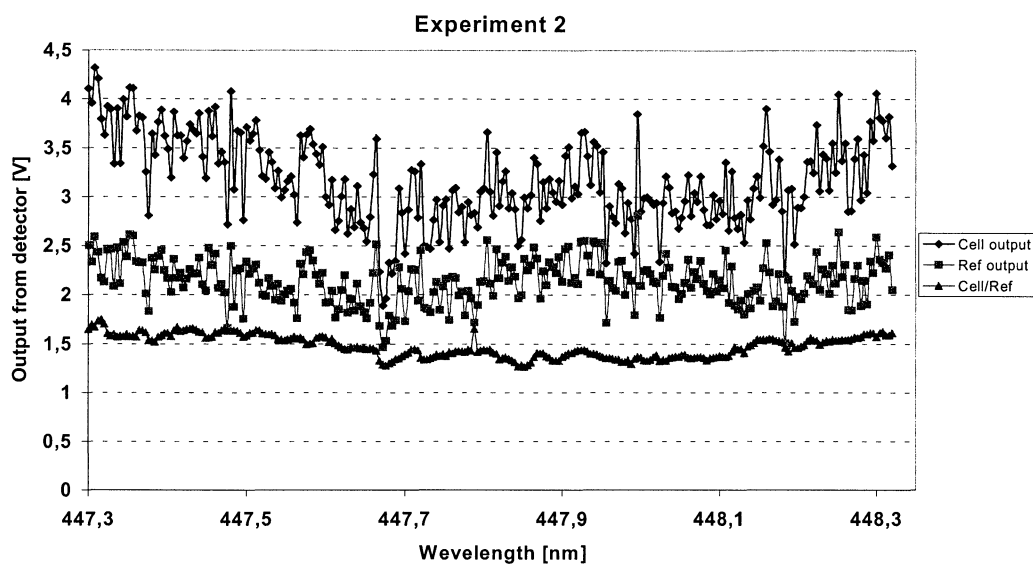


**Diagram 4** *Data from experiment 2*
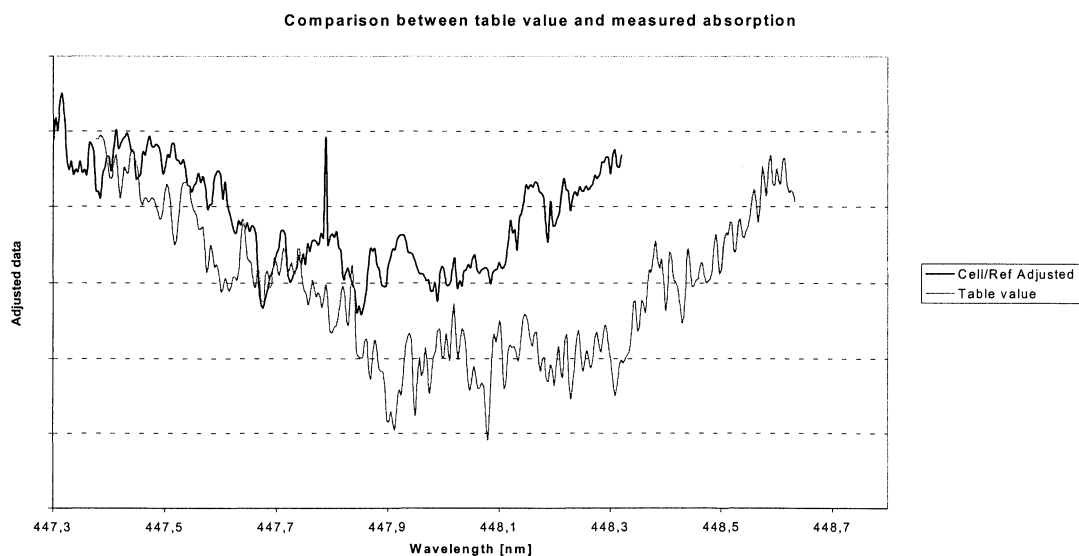


**Diagram 5** *Comparison between the table value and the measured absorption for $NO_2$. The scale for the two has been adjusted to be able to see the structure easier. The table value is adjusted to air wavelength.*

Department of Atomic Physics, Lund Institute of Technology

## 7.4 Discussion

Looking at the result from the first experiment it can be seen that it is possible to se the rough outline of the NO2 structure, see diagram 3. This even though the laser energy is fluctuating with about 90%. It is also possible to see that the wavelength scale of the OPO-system has an error with about 0,2nm.

In the second experiment it is clearly seen that the unit can record the $NO_2$ structure. If the wavelength scale from the experiment is adjusted to fit the table value it is found that the OPO-system has an error of about 0,225nm, see diagram 6. This value is of the same magnitude as the result from the wavemeter. However this does not give the precession of the calibration system. It only displays the fact that the calibration system can be used to find the error.

In the curve from experiment one value seems to be completely wrong (value at ~448,15nm). This indicates that further studies and experiments have to be made on the program.

## 7.5 Summary

From these experiments it has been fond that:

- The calibration system can find the $NO_2$ structure even when the laser fluctuates with about 90%.
- It is possible to find the $NO_2$ structure when making a fast scan. The OPO-system can have a wavelength error with up to 1nm. A fast scan is necessary when making a rough calibration to be able to find out where to start the fine adjustment.
- It is possible to find the error in the wavelength scale of the OPO-system.
- Further studies have to be done how to record the data.
- Further studies have to be performed on calibration methods.
  - One possible calibration method could be to make a fast scan to find a flank of the $NO_2$ structure like in experiment 1. Then to make a more accurate measurement around a defined structure.
  - Another method could be to record the entire structure and then make a convolution with the known table value

**Comparison between table value and measured absorption**
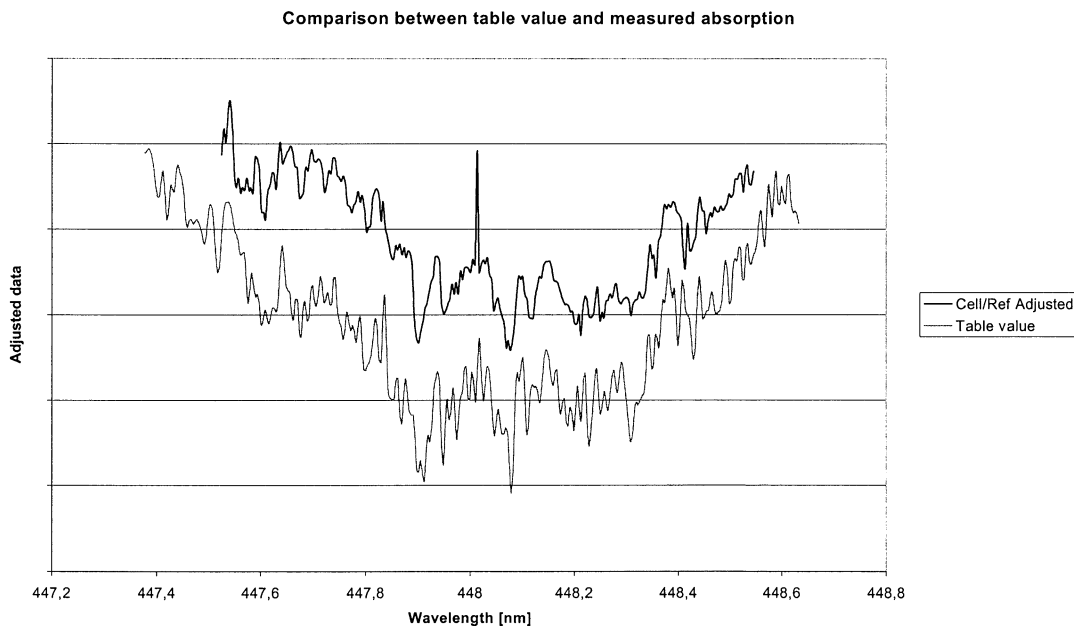


**Diagram 6** *Measured absorption is matched against the table value for NO2. The table value is adjusted to air wavelength.*

# 8 Improvements in the future

## 8.1 Introduction
During development of the calibration system some inconveniences and problems with the unit has been found. Some of these issues have been considered to fall outside the scope of this work. This chapter describes issues that can be improved for the future.

## 8.2 The detectors
The detectors used in the system are to slow to record the actual shape of the laser pulses. In appendix 18 tests are made to find the characteristics of the detectors. The result is that there seems to be a linear response from the detectors. Despite this, it could be a good thing to investigate if other detectors could improve the calibration system.

## 8.3 The beam splitter
The beam splitter used in the system does not operate over the total tuning region of the OPO-system. The calibration unit can be upgraded with a module that can change the beam splitter. The unit and the program are already prepared for this.

## 8.4 The beam aligning of the calibration system
One problem that was found during testing of the unit is that it is rather difficult to align the calibration system. The active area on the two detectors and the holes that the beam travels through are small. This together with the fact that the laser beam is normally received from a reflection from any optical component, which causes the direction and distance to vary sincerely, leads to unnecessary time to align the system.
To improve this the following could be done.
1. Two diode lasers could be mounted on the detector wheel. The beams from these lasers can be used to align the system from the opposite direction. The beams could be used to set up pinholes that would then be used for the aligning.
2. Mount two static pinholes. These pinholes shall be fixed once and for all once the system has been aligned.
3. Widen the hole that is used to pass through the optical table. Widening this hole would make the alignment easier.
4. Use an optical fibre to direct the laser beam into the unit. This would make it extremely easy to get the beam into the unit. A problem would be that different fibres are needed for different wavelength intervals.

## 8.5 The detector electronics
During testing of the calibration unit it has been found that the electronics drift. This causes problem when measuring with the unit. The detector electronics should be changed to include a real sample and hold circuit. The design of today is only an integrator circuit.

It has been found that the detector electronics is badly mounted. It is difficult to adjust and measure on the circuit boards. An easy way to avoid this problem would be to mount the electronics on the inside of the hatch. Placing the electronics there would also make it easy to mount electronics for coming detectors.

## 8.6 The neutral density filter
More filters are needed to adjust the laser input over a wider range. It has been found that 10 filters are not enough.

One other improvement would be the ability to adjust the two laser beams individually. This would make the unit more sensitive

## 8.7 The program
Today configuration components for the unit are spread out over the entire system. It would be better if all the configuration data were fond at one single place. This would help to adjust the calibration program in the future.

It should be possible to change the default wavelength and the calibration method for the wavelength directly from the **Cell Selection VI**. This would make the handling easier when operating the calibration unit. Now the operator has to enter the configuration window to change the default wavelength (the one that will be used for calibration). To change the calibration method, the configuration window for the cell must be entered.

It would be good to develop an interface in which it could be possible to define a calibration program. This would be if the LIDAR system should make measurements involving several substances.

The calibration part of the program can be developed further. Today only a simple calibration is done with the program. Analyses of what outputs the calibration system could produce should be done. From these results further development could be done.

# 9 Acknowledgements

I would like to thank

my supervisor Dr. Hans Edner for all the support and help in this work.

Petter Weibring and Mats Andersson for their extensive help and support throughout many hard and long moments in the LIDAR-bus as well as in the lab.

Professor Sune Svanberg whose enthusiastic lectures caught my interest for this inspiring subject.

Camilla Hilldén and Martin Kurdve for their help and encouragement during the writing of this report.

Bertil Hermansson and Åke Bergqvist for the electronic design and the computer support.

Göran Werner for his work when manufacturing the calibration unit.

Department of Atomic Physics, Lund Institute of Technology

# 10 References

1. Mats Andersson and Petter Weibring, A User Friendly LIDAR System Based on LabVIEW, Lund Reports on Atomic Physics LRAP-201 (Lund Institute of Technology, September 1996)

2. Sune Svanberg, Atomic and Molecular Spectroscopy, page 322-329 (Springer-Verlag 1992) Mie scattering page 60-61, Raman scattering page 58-59, fluorescence page 47

3. Figure modified from Sune Svanberg, Atomic and Molecular Spectroscopy, page 325 (Springer-Verlag 1992)

4. Figure modified from Sune Svanberg, Atomic and Molecular Spectroscopy, page 326 (Springer-Verlag 1992)

5. Sune Svanberg, Atomic and Molecular Spectroscopy, page 326, (Springer-Verlag 1992)

6. Figure from National Instruments. Web address http;//www.national.com or www.natinst.com

7. LabVIEW documentation from National Instruments. Web address http;//www.national.com or www.natinst.com

8. Figure from Petter Weibring at the department of Atomic Physics, Lund institute of Technology

9. Sune Svanberg, Atomic and Molecular Spectroscopy, page 212 (Springer-Verlag 1992)

10. Figure modified from manual for the MOPO-730 system from Quanta ray.

11. Steven E Harris, Tunable Optical Parametric Oscillators, Proceedings of the IEEE, Volume 57, No. 12, December 1969.

12. Picture form LIDAR-measurements in Almadén in Spain

13. Figure modified from Lund Reports on Atomic Physics LRAP-201 Lund, September 1996 [1]

14. Advanced Photonix Inc. Web address: http://www.advancedphotonix.com/

15. Hamamatsu . Web address: http://www.hamamatsu.com/ or http://www.hpk.co.jp/hp2e/main.html

16. Melles Griot. Web address: http://www.mellesgriot.com

17. Figure from Advanced Photonix Inc. Web address: http://www.advancedphotonix.com/

18. ELFA Stepper motor KP56LM2-502. Web address: http://www.elfa.se

19. ELFA Stepper motor module GS-D200S from SGS-THOMSON MICROELECTRONICS. ELFA article number 54-503-33. Web address: http://www.elfa.se

20. Fredrik Nordin, Development of a fast wavelength tuning system for OPO-based lidar measurements, Lund Reports on Atomic Physics LRAP-243 (Lund Institute of Technology, Lund April 1999).

21. Quanta Ray, manual for the MOPO-730 system, page 9.

22. Hamamatsu product cataloug. Web address: http://www.hamamatsu.com/ or http://www.hpk.co.jp/hp2e/main.html

23. Sune Svanberg, Atomic and Molecular Spectroscopy, page 128 (Springer-Verlag 1992)

24. LEROY, P. RIGAUD and E. HICKS, Visible absorption cross-section of NO2 at 298K and 235K by B. Annales Geophysicae, 1997, 5A, (4), 247-250

25. D. J. Brassington, Sulfur dioxide absorption cross-section measurements from 290 nm to 317 nm, Appl. Optics 20, 3744-3779 (1981)

26. N. Takeuchi, H. Shimizu, and M. Okuda, Detectivity estimation of the DAS LIDAR for NO2, Appl. Optics 17, 2734-2738 (1978)

# 11 Glossary and acronyms

| | |
|---|---|
| A/D | Analogue / Digital |
| ADC | A/D converter |
| BBO | Beta Barium Borate |
| DAC | D/A converter |
| DIAL | Differential Absorption LIDAR |
| GPIB | General Purpose Interface Bus |
| I/O | Input / Output |
| IEEE | Institute of Electrical and Electronics Engineers |
| LIDAR | Light Detection And Ranging |
| OD | Optical Density |
| OPO | Optical Parametric Oscillator |
| PC | Personal Computer |
| PMT | Photo Multiplier Tube |
| SubVI | A VI that is found in another VIs block diagram. |
| TTL | Transistor-Transistor Logic |
| VI | Virtual Instruments |
| VME | Versa Module Eurocard or IEEE 1014 |
| VOC | Volatile Hydrocarbons |
| VXI | VME Extension for Instrumentation |

# 12 Appendix

## Appendix 1 The wiring of the system

This section describes all the wiring needed to run the calibration system. First the system overview is described and after that each of the main components. These are the calibration unit, the power unit, the control unit and the system computer. For further description of the LIDAR-system see [1].

## 1 Glossary and acronyms

GRD    Ground
NA    Not Applicable.
PD    Positioning Detector

## 2 System overview

The main components of the LIDAR system are:
- The control unit
- The system computer
- Evaluation computer
- Digitizer
- Power unit
- Laser unit
- Wind unit
- Receiver unit
- Calibration unit

See appendix 2 Cabling between system blocks.

For the calibration system the components needed to be wired are:
- The calibration unit
- The power unit
- The control unit
- The system computer

See appendix 3 communication between blocks in the calibration system.

## 2.1 Connectors

The connector used is of the type MIL-C-26482 from the manufacturer FCI/Souriau, see table 4

| Placed | Product nr | ELFA prod. nr [18] |
|---|---|---|
| Calibration unit | MS3112E-18-32P | 44-540-88 |
| Cable | MS3116F-18-32S | 44-542-11 |
| Cable | MS3116F-18-32P | 44-542-03 |
| Power unit | MS3112E-18-32S | 44-540-96 |
|  |  |  |
| Power unit | MS3112E-16-26P | 44-540-62 |
| Cable | MS3116F-16-26S | 44-541-95 |
| Cabel | MS3116F-16-26P | 44-541-87 |
| Control unit | MS3112E-16-26S | 44-540-70 |

**Table 4** *The connectors used for the calibration system.*

## 3 Calibration unit

The connectors in the calibration unit are shown in figure 52 and are described in table 5.
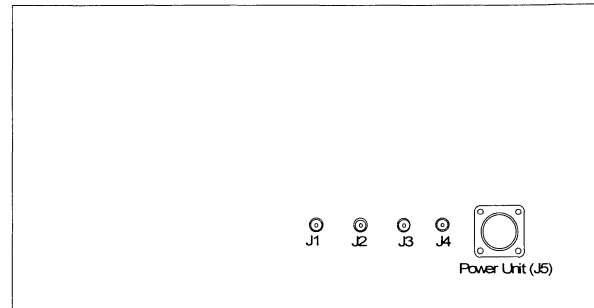


**Figure 52** *The back plane of the calibration unit.*

| Connector | Description | Note |
|---|---|---|
| J1 | Laser trigger plus in |  |
| J2 | Detector 1 signal out |  |
| J3 | Detector 2 signal out |  |
| J4 | To power unit |  |

**Table 5** *Description of the connectors on the calibration unit.*

The cables from the connectors are connected to three connection boards. This is done to make it easy too remove the different components in the unit. For detailed description see table 6 and appendix 4 Calibration unit wiring.

| Connector MS3112E-18-32P | connection board | Description |
|---|---|---|
| K | 1 | Motor 1 A |
| L | 2 | Motor 1 B |
| a | 3 | Motor 1 C |
| b | 4 | Motor 1 D |
| G | 5 | Motor 2 A |
| H | 6 | Motor 2 B |
| J | 7 | Motor 2 C |
| Z | 8 | Motor 2 D |
| f | 9 | Motor 3 A |
| g | 10 | Motor 3 B |
| h | 11 | Motor 3 C |
| j | 12 | Motor 3 D |
| E | 13 | Motor 4 A |
| F | 14 | Motor 4 B |
| X | 15 | Motor 4 C |
| Y | 16 | Motor 4 D |
| M | 17 | PD 1 GRD |
| N | 18 | PD 1 Signal |
| c | 19 | PD 1 +5V |
| NA | 20 |  |

| M | 21 | PD 2 GRD |
|---|---|---|
| P | 22 | PD 2 Signal |
| d | 23 | PD 2 +5V |
| NA | 24 | |
| M | 25 | PD 3 GRD |
| D | 26 | PD 3 Signal |
| W | 27 | PD 3 +5V |
| NA | 28 | |
| M | 29 | PD 4 GRD |
| C | 30 | PD 4 Signal |
| V | 31 | PD 4 +5V |
| NA | 32 | |
| R | 33 | Detector GND |
| U | 34 | Detector -5V |
| e | 35 | Detector +5V |
| A | NA | Shielded GRD |
| B | NA | |
| S | NA | |
| T | NA | |

**Table 6** *The wiring between the connector and the connection boards in the calibration unit.*

## 4 Power unit

The connectors in the power unit are shown in figure 53 and described in table 7The connectors used by the calibration system are J12, used for communication to the control unit, and J13, used to connect to the calibration unit.
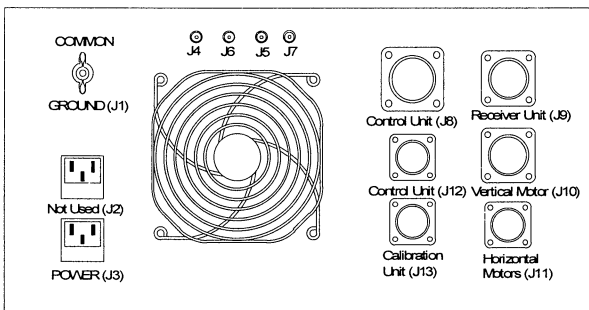


**Figure 53** *The back plane of the power unit. The connectors used by the calibration system are J12 and J13.*

| Connector | Description | Note |
|---|---|---|
| J1 | Ground | |
| J2 | No use | |
| J3 | Power | |
| J4 | Detector signal input | [1] |
| J5 | Detector current | [1] |
| J6 | Detector signal output | [1] |
| J7 | No use | |
| J8 | To control unit | [1] |
| J9 | To receiver unit | [1] |
| J10 | To vertical motor | [1] |

| J11 | To horizontal motor | [1] |
|---|---|---|
| J12 | To control unit, calibration cable | |
| J13 | To calibration unit | |

**Table 7** *Description of the connector on the back plane of the power unit.*

A detailed description of what the pins are connected to on the connectors is shown in table 8 and table 9.

The wiring in the power unit is described in appendix 5 Power unit wiring. The stepper motor driver modules are placed in this unit. The wiring from these modules are shown in appendix 6 and appendix 7.

| Connector MS3112E-16-26P | Description |
|---|---|
| A | Shielded GRD |
| B | |
| C | PD 4 Signal |
| D | PD 3 Signal |
| E | Motor 4 A |
| F | Motor 4 B |
| G | Motor 2 A |
| H | Motor 2 B |
| J | Motor 2 C |
| K | Motor 1 A |
| L | Motor 1 B |
| M | PD GND |
| N | PD 1 Signal |
| P | PD 2 Signal |
| R | Detector GND |
| S | |
| T | |
| U | Detector -5V |
| V | PD 4 +5V |
| W | PD 3 +5V |
| X | Motor 4 C |
| Y | Motor 4 D |
| Z | Motor 2 D |
| a | Motor 1 C |
| b | Motor 1 D |
| c | PD 1 +5V |
| d | PD 2 +5V |
| e | Detector +5V |
| f | Motor 3 A |
| g | Motor 3 B |
| h | Motor 3 C |
| j | Motor 3 D |

**Table 8** *The pin usage of the connector J13 to the calibration unit.*

| Connector MS3112E-18-32S | Description |
|---|---|
| A | Shielded GRD |
| B | |
| C | |
| D | |
| E | PD 4 Signal |
| F | Motor 1 Step |
| G | Motor 1 Dir |
| H | Motor 2 Step |
| J | Motor 2 Dir |
| K | Motor 3 Step |
| L | Motor 3 Dir |
| M | PD 1 Signal |
| N | |
| P | |
| R | |
| S | |
| T | |
| U | |
| V | PD 3 Signal |
| W | Motor GND |
| X | Motor 4 Step |
| Y | Motor 4 Dir |
| Z | PD 2 Signal |
| a | |
| b | |
| c | PD GND |

**Table 9** *The pin usage of the connector J12 to the control unit.*

## 5 Control unit

The control unit communicates with all other components in the calibration system, the power unit, the calibration unit and the system computer.

The back plane with all the connectors is shown in figure 54 and a description is found in table 10.
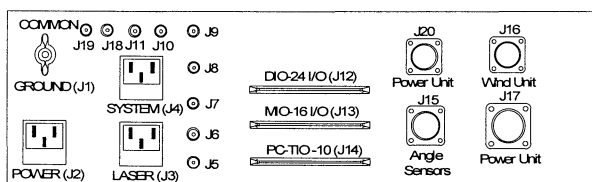


**Figure 54** *The back plane of the control unit.*

| Connector | Description | Note |
|---|---|---|
| J1 | Ground | |
| J2 | Power | |
| J3 | Laser | [1] |
| J4 | System | [1] |
| J5 | PMT –HV | [1] |

| J6 | R2 output | [1] |
|---|---|---|
| J7 | Laser trigger | |
| J8 | Wavelength on/off | |
| J9 | Detector current | [1] |
| J10 | Digitizer trigger | [1] |
| J11 | Calibration trigger | [1] |
| J12 | DIO-24 I/O | |
| J13 | PC TIO-10 | |
| J14 | MIO-16 I/O | |
| J15 | Angle sensor | [1] |
| J16 | To power unit | [1] |
| J17 | To wind unit | [1] |
| J18 | Calibration detector 2 input | |
| J19 | Calibration detector 1 input | |
| J20 | To power unit, calibration cable | |

**Table 10** *Description of the connectors on the back plane of the control unit.*

To the system computer, connection boards are used to connect to flat cables. The pins of the connector on the back plane are connected to the system computer through these connection boards.

Between the control unit and the calibration unit are two BNC cables. These cables are used to receive signals from the detectors. These cables are connected to the MIO-16DL board, see table 13.

A pin description of the cable to the to the power unit is shown in table 11.

A description of the DIO-24 I/O connection board is shown in table 12

The wiring of the control unit is shown in appendix 8 and appendix 9.

| Connector MS3112E-18-32P | connection board | Description |
|---|---|---|
| A | 1 | Shielded GRD |
| B | 2 | |
| C | 3 | |
| D | 4 | |
| E | 5 | PD 4 Signal |
| F | 6 | Motor 1 Step |
| G | 7 | Motor 1 Dir |
| H | 8 | Motor 2 Step |
| J | 9 | Motor 2 Dir |
| K | 10 | Motor 3 Step |
| L | 11 | Motor 3 Dir |
| M | 12 | PD 1 Signal |
| N | 13 | |
| P | 14 | |
| R | 15 | |
| S | 16 | |
| T | 17 | |
| U | 18 | |
| V | 19 | PD 3 Signal |
| W | 20 | Motor GND |
| X | 21 | Motor 4 Step |
| Y | 22 | Motor 4 Dir |
| Z | 23 | PD 2 Signal |
| a | 24 | |
| b | 25 | |
| c | 26 | PD GND |

**Table 11** *The pin usage of the connector J20 to the power unit.*

| DIO-24 (J12) | Nr | To device | Connector |
|---|---|---|---|
| | 1 to 23 | N/A | |
| B3 | 25 | Opto 4 signal | E |
| B2 | 27 | Opto 3 signal | V |
| B1 | 29 | Opto 2 signal | Z |
| B0 | 31 | Opto 1 signal | M |
| A7 | 33 | cw/ccw motor 8 | Y |
| A6 | 35 | Step motor 8 | X |
| A5 | 37 | cw/ccw motor 7 | L |
| A4 | 39 | Step motor 7 | K |
| A3 | 41 | cw/ccw motor 6 | J |
| A2 | 43 | Step motor 6 | H |
| A1 | 45 | cw/ccw motor 5 | G |
| A0 | 47 | Step motor 5 | F |
| +5V | 49 | | |

**Table 12** *Connectors used by the calibration system on the DIO-24 I/O connector board*

| Mio-16DL (J14) | Nr | To device | Connector |
|---|---|---|---|
| ACH4 | 11 | Detector 1 (Cell) | BNC (J19) |
| ACH5 | 13 | Detector 2 (Ref) | BNC (J18) |

**Table 13** *Connector used by the calibration system on the MIO-16DL connector board*

## 6 System computer

The system computer is used to control and acquire data from the calibration system. To perform this the computer is equipped with two PC-cards, the AT-MIO-16 and the PC.TIO-10 from National Instruments [7]. These cards are connected with a flat cable to the control unit. The pin description of these cards are found in table 14 and table 15.

| Signal name | Pin | Pin | Signal name |
|---|---|---|---|
| AIGND | 1 | 2 | AIGND |
| ACH0 | 3 | 4 | ACH8 |
| ACH1 | 5 | 6 | ACH9 |
| ACH2 | 7 | 8 | ACH10 |
| ACH3 | 9 | 10 | ACH11 |
| ACH4 | 11 | 12 | ACH12 |
| ACH5 | 13 | 14 | ACH13 |
| ACH6 | 15 | 16 | ACH14 |
| ACH7 | 17 | 18 | ACH15 |
| AISENSE | 19 | 20 | DAC0OUT |
| DAC1OUT | 21 | 22 | EXTREF |
| AOGND | 23 | 24 | DIGGND |
| ADIO0 | 25 | 26 | BDIO0 |
| ADIO1 | 27 | 28 | BDIO1 |
| ADIO2 | 29 | 30 | BDIO2 |
| ADIO3 | 31 | 32 | BDIO3 |
| DIGGND | 33 | 34 | +5 V |
| +5 V | 35 | 36 | SCANCLK |
| EXTSTROBE* | 37 | 38 | STARTRIG* |
| STOPTRIG | 39 | 40 | EXTCONV* |
| SOURCE1 | 41 | 42 | GATE1 |
| OUT1 | 43 | 44 | SOURCE2 |
| GATE2 | 45 | 46 | OUT2 |
| SOURCE5 | 47 | 48 | GATE5 |
| OUT5 | 49 | 50 | FOUT |

**Table 14** *Pin assignments for the AT-MIO-16 I/O connector [7].*

| Signal name | Pin | Pin | Signal name |
|:---:|:---:|:---:|:---:|
| SOURCE1 | 1 | 2 | GATE1 |
| OUT1 | 3 | 4 | SOURCE2 |
| GATE2 | 5 | 6 | OUT2 |
| SOURCE3 | 7 | 8 | GATE3 |
| OUT3 | 9 | 10 | SOURCE4 |
| GATE4 | 11 | 12 | OUT4 |
| GATE5 | 13 | 14 | OUT5 |
| SOURCE6 | 15 | 16 | GATE6 |
| OUT6 | 17 | 18 | SOURCE7 |
| GATE7 | 19 | 20 | OUT7 |
| SOURCE8 | 21 | 22 | GATE8 |
| OUT8 | 23 | 24 | SOURCE9 |
| GATE9 | 25 | 26 | OUT9 |
| GATE10 | 27 | 28 | OUT10 |
| FOUT1 | 29 | 30 | FOUT2 |
| EXTIRQ1 | 31 | 32 | EXTRIQ2 |
| GND | 33 | 34 | +5 V |
| A0 | 35 | 36 | A1 |
| A2 | 37 | 38 | A3 |
| A4 | 39 | 40 | A5 |
| A6 | 41 | 42 | A7 |
| B0 | 43 | 44 | B1 |
| B2 | 45 | 46 | B3 |
| B4 | 47 | 48 | B5 |
| B6 | 49 | 50 | B7 |

**Table 15** *Pin assignments for the PC-TIO-10 I/O connector [7].*

49

# Appendix 2 Cabling between system blocks

Department of Atomic Physics, Lund Institute of Technology

Department of Atomic Physics, Lund Institute of Technology



POWER UNIT

Shield GND
Opto-Coupler4/signal
Opto-Coupler3/signal
Motor 4/ A
Motor 4/ B
Motor 2/ A
Motor 2/ B
Motor 2/ C
Motor 1/ A
Motor 1/ B
Opto-Coupler GND
Opto-Coupler1/signal
Opto-Coupler2/signal
Detector GND

Detector Supply -5V
Opto-Coupler 4 +5V
Opto-Coupler 3 +5V
Motor 4/ C
Motor 4/ D
Motor 2/ D
Motor 1/ C
Motor 1/ D
Opto-Coupler 1 +5V
Opto-Coupler 2 +5V
Detector Supply +5V
Motor 3/ A
Motor 3/ B
Motor 3/ C
Motor 3/ D

LBLU/BLU
YEL/BLU
WHT/LIC
LIC/BLK
YEL/ROE
GRY/BRN
BRN/BLK
WHT/BLK
GRY/GRN
ORE/GRN
GRN/BLK
WHT/GRN
YEL/GRN

GRN
BLU
BRN
RED/BLK
WHT/RED
YEL/ORE
GRN/BRN
YEL/BRN
RED/BLU
CYN
YEL
WHT
RED
BLK
GRY

CALIBRATION UNIT

CONTROL UNIT

Shield GND

Opto-Coupler4/Signal
Motor 1/Step
Motor 1/Dir
Motor 2/Step
Motor 2/Dir
Motor 3/Step
Motor 3/Dir
Opto-Coupler1/Signal

Opto-Coupler3/Signal
Motor GND
Motor 4/Step
Motor 4/Dir
Opto-Coupler4/Signal

Opto-Coupler GND

GRY
RED/BLU
GRN/BRN
YEL/RED
WHT/RED
RED/BLK
YEL/BLU
ROE

BLK
BRN
LIC
ORE
RED/BRN

BLU

Detector 1/Signal

Detector 2/Signal

Calib. Unit Trigger

| COMUNICATION BETWEEN THE UNITS | LUND INSTITUTE OF TECHNOLOGY DEPT. OF PHYSICS BOX 118 221 00 LUND | | | |
|---|---|---|---|---|
| | Sheet Title: COMMUNICATION BETWEEN SYSTEM BLOCKS | | | |
| Sheet File Name: SCH00.1.sch | Size: A | Document Number: | | Rev.: 1 |
| Sheet Creation date: 04/22/96 | Modification date: 2000-10-12 | | SHEET 1 | OF 1 |

51

THIS PART BELONGS TO THE CALIBRATION UNIT

LUND INSTITUTE OF TECHNOLOGY
DEPT. OF PHYSICS
BOX 118
221 00 LUND

Sheet Title
CALIBRATION UNIT WIRING

Sheet File Name: SCH07.1.sch

SHEET 1 OF 1

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |

**A**

Shield GND — BLK

COMMON GROUND

Opto-Coupler4/signal — ORE
Opto-Coupler3/signal — ORE
Motor 4/ A — BRN
Motor 4/ B — ORE
Motor 2/ A — BRN
Motor 2/ B — ORE
Motor 2/ C — YEL

**B**

Motor 1/ A — BRN
Motor 1/ B — ORE
Opto-Coupler GND — BLK
Opto-Coupler1/signal — ORE
Opto-Coupler2/signal — BLK
Detector GND

YEL 6
GRY 5
RED 4
GRN 3
LBLU 2
BLK 1

(+)24V
(-)24V
+12V
-12V
+5V
GND

**POWER SUPPLY 1**

**C**

Detector Supply -5V — GRN
Opto-Coupler 4 +5V — LBLU
Opto-Coupler 3 +5V — YEL
Motor 4/ C — GRN
Motor 4/ D — GRN
Motor 2/ D — YEL
Motor 1/ C

**D**

Motor 1/ D — GRN
Opto-Coupler 1 +5V — LBLU
Opto-Coupler 2 +5V — LBLU
Detector Supply +5V — BRN
Motor 3/ A — ORE
Motor 3/ B — YEL
Motor 3/ C — GRN
Motor 3/ D

BLK — Common
GRN — -5V
LBLU — +5V
BLK — Common
LBLU — +5V
RED — +18V

**POWER SUPPLY 2**

**E**

R B C D   R B C D   R B C D   R B C D   GND
Motor 1   Motor 2   Motor 3   Motor 4   +5V
+18V

Shield GND — BLK

**STEPPING MOTORS**

9 8 7 6 5 4 3 2 1

**F**

Opto-Coupler4/Signal — ORE
Motor 1/Step — YEL
Motor 1/Dir — ORE
Motor 2/Step — YEL
Motor 2/Dir — ORE
Motor 3/Step — YEL
Motor 3/Dir — ORE
Opto-Coupler1/Signal

**G**

Opto-Coupler3/Signal — ORE
Motor GND — BLK
Motor 4/Step — YEL
Motor 4/Dir — ORE
Opto-Coupler2/Signal — ORE

**H**

Opto-Coupler GND — BLU

| THIS PART BELONGS TO THE POWER UNIT | LUND INSTITUTE OF TECHNOLOGY DEPT. OF PHYSICS BOX 118 221 00 LUND | | |
|---|---|---|---|
| | **Sheet Title:** POWER UNIT WIRING | | |
| **Sheet File Name:** SCH18.1.sch | **Size:** A | **Document Number:** | **Rev.:** 1 |
| **Sheet Creation date:** 04/29/96 | **Modification date:** 2000-10-12 | SHEET 1 | OF 1 |

STEPPING MOTOR
BOARD 1

STEPPING MOTOR
BOARD 2

STEPPING MOTOR
BOARD 3

STEPPING MOTOR
BOARD 4

+10V
GND

STEP1
STEP2
STEP9
STEP4
DIR1
DIR2
DIR3
DIR4
GND

+5V
GND

+10V
GND

THIS PART
BELONGS TO
THE POWER UNIT

LUND INSTITUTE OF TECHNOLOGY
DEPT. OF PHYSICS
BOX 118
221 00 LUND

Sheet Title:
CONNECTION TO STEPPER MOTORS

| Sheet File Name: | Size: | Document Number: | Rev.: |
|---|---|---|---|
| SCH03.1.sch | A | | 1 |
| Sheet Creation date: | Modification date: | | |
| 03/25/96 | 2000-10-12 | SHEET 1 | OF 1 |

# Appendix 7 Stepper motor board

Department of Atomic Physics, Lund Institute of Technology

Department of Atomic Physics, Lund Institute of Technology

MS3112E-16-26S

MIO-16I/O CONNECTOR BOARD

Shield GND — BLK

COMMON GROUND

Opto-Coupler4/Signal — ORE
Motor 1/Step — YEL
Motor 1/Dir — ORE
Motor 2/Step — YEL
Motor 2/Dir — ORE
Motor 3/Step — ORE
Motor 3/Dir — ORE
Opto-Coupler1/Signal

Opto-Coupler3/Signal — ORE
Motor GND — BLK
Motor 4/Step — YEL
Motor 4/Dir — ORE
Opto-Coupler4/Signal — ORE

Opto-Coupler GND — BLK

A B C D E F G H J K L M N P R S T U V W X Y Z a b c

| Pin | Signal |
|---|---|
| 1 | AI GND |
| 2 | AI GND |
| 3 | ACH0 |
| 4 | ACH8 |
| 5 | ACH1 |
| 6 | ACH9 |
| 7 | ACH2 |
| 8 | ACH10 |
| 9 | ACH3 |
| 10 | ACH11 |
| 11 | ACH4 |
| 12 | ACH12 |
| 13 | ACH5 |
| 14 | ACH19 |
| 20 | DAC0 OUT |
| 21 | DAC1 OUT |
| 23 | AO GND |
| 24 | DIG GND |
| 25 | ADIO0 |
| 26 | ADIO0 |
| 27 | ADIO1 |
| 28 | ADIO1 |
| 29 | ADIO2 |
| 31 | ADIO3 |
| 41 | SOURCE 1 |

BLK VHT BLK VHT BLK VHT BLK VHT BLK VHT BLK VHT BLK BLK BLK VHT VHT BLK BLK ORE ORE ORE ORE ORE GRN

FLAT CABLE CONNECTOR (50-POL)
MIO-16I/O
J13

FLAT CABLE
(50-POL.)

BNC
Detector 1/ Signal

BNC
Detector 2/ Signal

BNC

THIS PART BELONGS TO THE CONTROL UNIT

LUND INSTITUTE OF TECHNOLOGY
DEPT. OF PHYSICS
BOX 118
221 00 LUND

Control UnitControl

SCH12.1.sch | A | | 1
04/23/96 | 2000-10-12 | SHEET 1 | OF 1

# Appendix 10 Position detector electronics

Department of Atomic Physics, Lund Institute of Technology

Department of Atomic Physics, Lund Institute of Technology



|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |

THIS PART
BELONGS TO
THE CALIBRATION
UNIT

LUND INSTITUTE OF TECHNOLOGY
DEPT. OF PHYSICS
BOX 118
221 00 LUND

Sheet Title:
Detector Electronics

| Sheet File Name: SCH04.1.sch | Size: A | Document Number: | Rev.: 1 |
| Sheet Creation date: 04/24/96 | Modification date: 2000-10-12 | SHEET 1 | OF 1 |

## Appendix 12 Digitizer trigger delay

This electronics generates trigger pulses to the calibration unit. [1]

DIGITIZER TRIGGER DELAY

CALIBRATION TRIGGER DELAY

DUAL DELAY CONNECTOR

J2

TRIGGER DELAY CAL. UNIT
COMMON GROUND
+12V
COMMON GROUND
TRIGGER INPUT
EXTRA DELAY CONTROL
+5V
COMMON GROUND
TRIGGER DELAY DIGITIZER
COMMON GROUND

1N4007
10k
BC547
33k
100k
BC547
BC547
200  1k
39k
680p
50k
74121
Cext
R/Cext
Rin
A1
A2
B
Q
|Q
GND
43k
330n
C
74121
Cext
R/Cext
Rin
A1
A2
B
Q
|Q
1k
GND
510
2N2219A
BC547
6.8k
10k
10k  150

10u

50k
150n
74121
Cext
R/Cext
Rin
A1
A2
B
Q
|Q
GND
1k  43k
330n
74121
Cext
R/Cext
Rin
A1
A2
B
Q
|Q
GND
+12V
510
2N2219A
BC547
6.8k
10k
10k  150

BC547
200  1k

# DUAL DELAY

[1] 20us EXTRA DELAY

[2] DELAY ADJUST 0 - 25us

[3] DELAY ADJUST 0 - 5ms

THIS PART BELONGS TO THE CONTROL UNIT

LUND INSTITUTE OF TECHNOLOGY
DEPT. OF PHYSICS
BOX 118
221 00 LUND

Sheet Title: DUAL DELAY

| Sheet File Name: SCH06.1.sch | Size: A | Document Number: FIGURE 5.17 | Rev.: 1 |
| Sheet Creation date: 09/11/96 MA | Modification date: 2000-10-12 | SHEET 1 | OF 1 |

## Appendix 13 The MOPO-730 laser system

| Pump beam parameters | |
|---|---|
| Laser type | Nd:YAG |
| Laser wavelength | 355 nm, 3rd harmonic |
| Spatial mode | >70% Gaussian fit |
| Pointing stability | <50 μrads |
| Beam divergence | <0.5 mrads |
| Linewidth | <0.001 cm$^{-1}$ at 355 nm |
| Repetition rate | 20 Hz |
| Pulse width | 5-6 ns |
| **Pump energy by oscillator** | |
| Master Oscillator | n/a |
| Power Oscilator          (min) | 200 mJ |
|                               (max) | 450 mJ |
| **Pump energy in total** | |
| Minimum | 200 mJ |
| Maximum | 450 mJ |
| **Tuning Characteristic** | |
| Signal tuning range (typical) | 440 to 690 nm |
| Idler tuning range (typical) | 730 to 1800 nm |
| Other Output Characteristics | |
| Polarisation | Horizontal > 97% |
| Beam diameter (typical) | 5 mm |
| Beam shape (typical) | Round ± 20% |
| Beam profile | >70% Gaussian fit |
| Beam divergence | <1 mrad |
| Pointing stability | <200 μrad |
| Pulse width (typical) | 2 ns less than pump |
| Resettability | <1 x linewisth/°C/hr |
| Pulse to pulse stability | ±8% |
| Timing jitter | <2 ns |

**Table 16** *MPOP-730 Laser Specification [21]*

# Appendix 14 Stepper motor

Two-phase stepper motor of hybrid type. The motor can be driven in unipolar or bipolar mode [18]. The specified torque is in unipolar mode (50% of the windings are used.) When the motor is configured in bipolar mode the current must be reduced with a factor 0,6 to 0,7, or else the motor will be overheated. The stepper motor uses the Bipolar stepper motor drive module shown in appendix 15.

**Technical data:**

No of phases:          2
No of windings:        4
Torque  :              550 mNm
No of steps/revolution: 200
Stepper angle:         1,8°
Axis diameter:         6,35 mm
Currency/phase:        1.2 A
Resistance/phase:      5Ω
Inductance/phase:      8,5 mH
Temperature range:     -10 to +50 °C
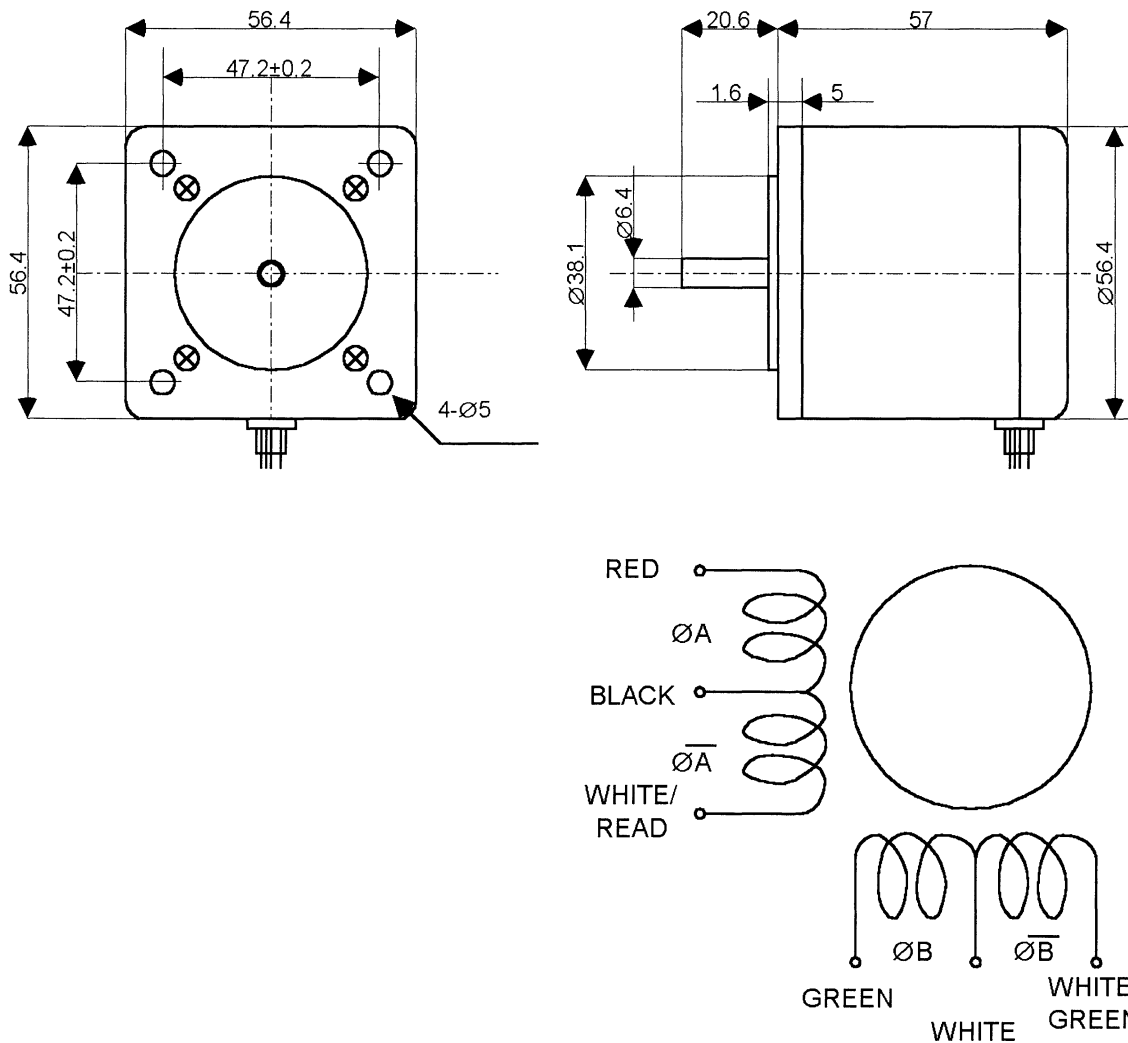


**Figure 55** *Stepper motor KP56LM2-502 from ELFA [18]*

## Appendix 15 Bipolar stepper motor drive module

The GS-D200S driver module can drive a bipolar stepper motor with constant current through a chopper output. The module can drive the motor either with half- or full step. The output current is set in the factory to 2 [A] but this can be modified between 0,5 to 2,5 [A]. The module also has short-circuit protected outputs. For more detailed information see [19]

**Technical data:**

| | |
|---|---|
| Logical voltage: | +5V ($V_{SS}$) |
| Motor voltage: | +12V to +40V ($V_S$) |
| Motor current: | Max 2,5A |
| Logical signals: | TTL/CMOS-compatible |
| Chopper frequency: | 17kHz (can be modified) |
| Dimension: | 85×66×20mm |
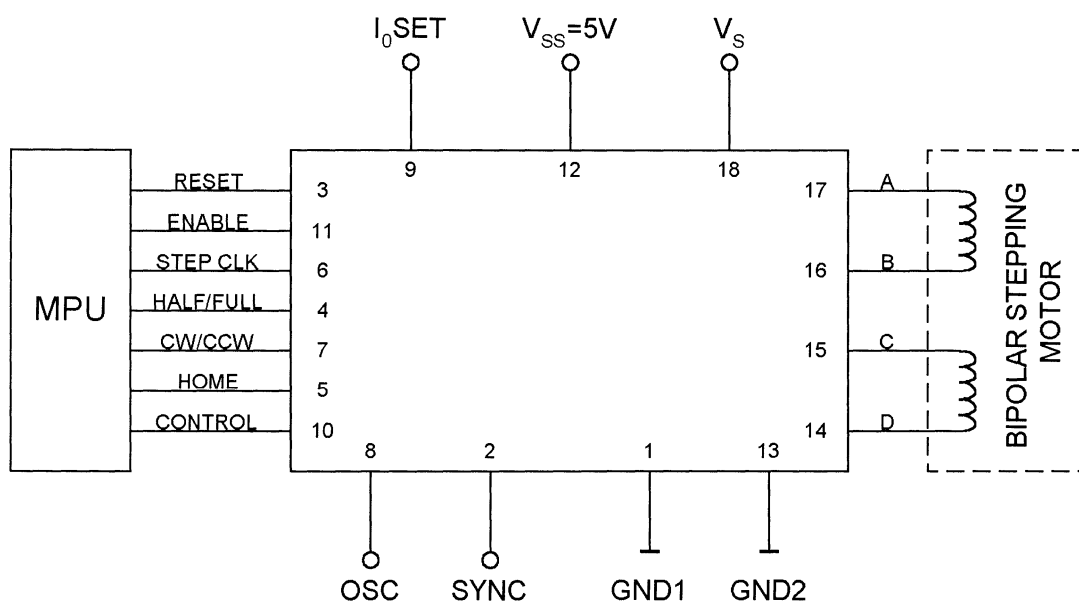


**Figure 56** *GS-D200S Modules typical application [19]*

| Pin | Function | Description |
|-----|----------|-------------|
| 1 | GND1 | Return path for logical signal and 5V supply |
| 2 | Sync | Chopper oscillator output. Several modules can be synchronised by connecting together all Sync pins. This pin can be used as the input for an external clock source. |
| 3 | Reset | Asynchronous reset input. An active low pulse on this input pre-set the internal logic to the initial state (ABCD=0101). |
| 4 | Half/Full | Half/full step selection input. When high or unconnected the half step operation is selected. |
| 5 | Home | When low this output indicates that the internal counter is in its initial state (ABCD=0101). This signal should be ANDed with the output of a mechanical switch to be used as a system Home indicator. |
| 6 | Stepclk | The motor is moved one step on the rising edge of this signal. |
| 7 | CW/CCW | Direction control input. When high or unconnected clockwise rotation is selected. Physical direction of motor rotation depends also on winding connection. |
| 8 | Oscillator | Connecting a resistor between this pin and VSS or a capacitor between this pin and GND1 can modify the chopper oscillator timing, internally fixed at 17kHz. The oscillator input must be grounded when the unit is externally synchronised. |
| 9 | $I_{0SET}$ | Phase current setting input. A resistor connected between this pin and GND1 or $V_{SS}$, allows the factory selected phase current value (2A for GS-D200S) to be changed. |
| 10 | Control | Logical input that allows the phase current decay mode selection. When high or unconnected the slow decay is selected. |
| 11 | Enable | Module enables input. When low this input floats the outputs enabling the manual positioning of the motor. Must be LOW during power-up and down sequence, HIGH during normal operation. |
| 12 | $V_{SS}$ | 5V supply input. Maximum voltage must not exceed 7V. |
| 13 | GND2 | Return path for the power section. |
| 14 | D | D output. |
| 15 | C | C output. |
| 16 | B | B output. |
| 17 | A | A output. |
| 18 | $V_S$ | Module and motor supply voltage. Maximum voltage must not exceed the specified values. |

**Table 17** *Pin description of the GS-D200S [19]*

## Appendix 16 Pictures from the LIDAR-bus and lab
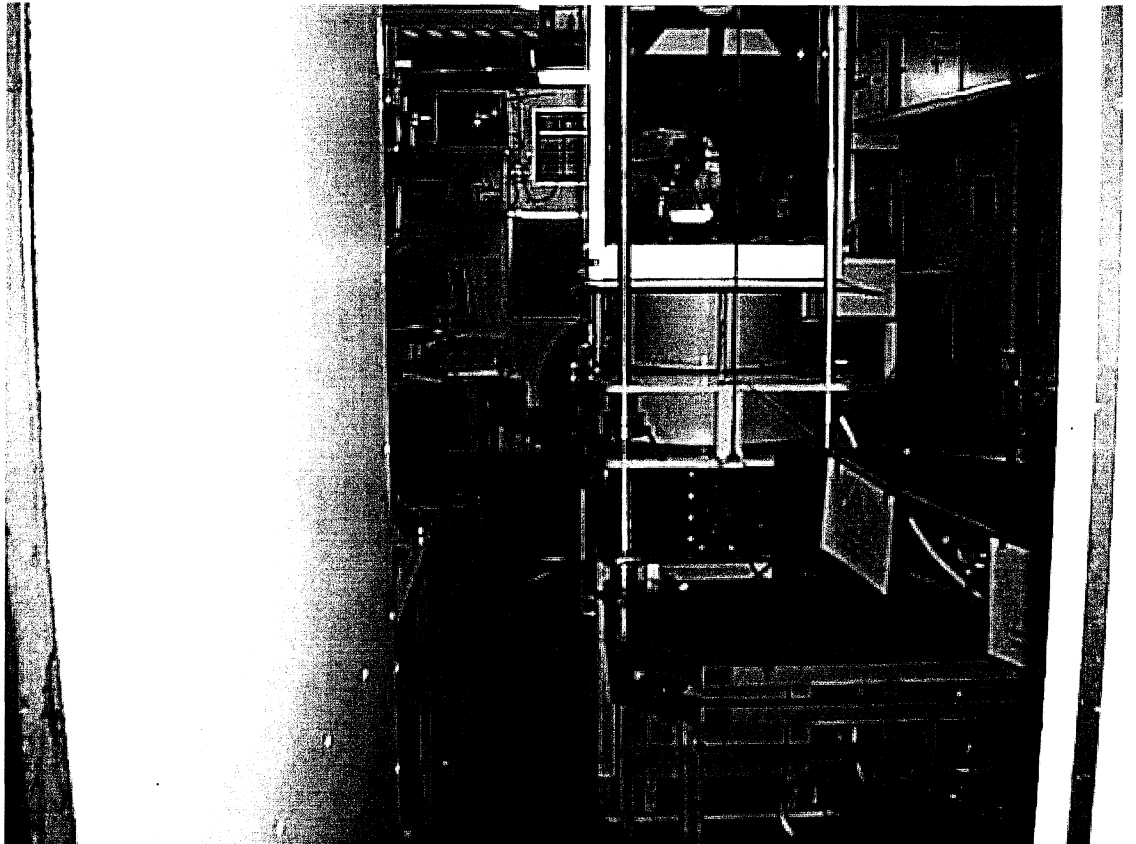


**Figure 57** *Inside the LIDAR-bus*



**Figure 58** *Petter working with the OPO-system*
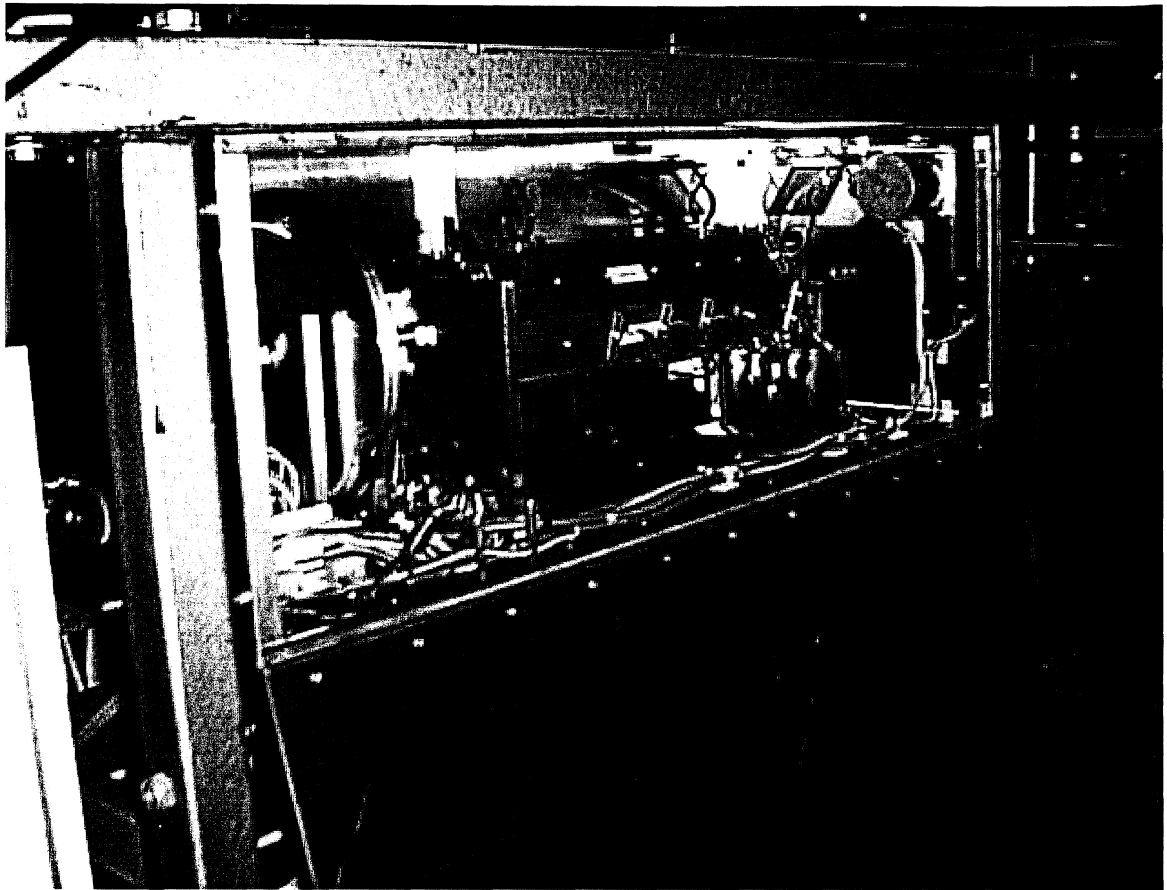
**Figure 59** *The calibration unit*



**Figure 60** Working with the calibration unit

66

## Appendix 17 Detector that is used in the calibration unit

The detector used in the calibration unit is the silicon photocell S1337-1010BQ from Hamamatsu. Below follows the information about the detector [22] [15]

| Photosensitive Surface | | Package (mm) | Characteristics (at 25°) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Size (mm) | Effective Area (mm$^2$) | | Spectral Response | | Typical Radiant Sensitivity (A/W) | | | | NEP* typ. (W/Hz$^{1/2}$) | D** typ. (cm•Hz$^{1/2}$/W) |
| | | | Range (nm) | Peak Wavelength (nm) | Peak Wavelength | Hg-Line (254nm) | He-Ne Laser (633nm) | GaAs LED (930nm) | | |
| 10.1x10.2 | 98 | 15x16.5 | 190-1150 | 950±50 | 0.5 | 0.1 | 0.38 | 0.5 | 2x10$^{-14}$ | 3x10$^{13}$ |

**Table 18** *The characteristics of the detector S1337-1010BQ*

| Characteristics (at 25°C) | | | | | | | | | Absolute Maximum Rating | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Short Circuir Current (I$_{sh}$) 2856K, 100 /x | | Dark Current at V$_R$=10mV | Temperature Dependence of | Shunt Resistance (R$_{SH}$) at V$_R$=10mV*** | | Junction Capacitance (C$_j$) at V$_R$=0V | Rise**** Time (tr) at V$_R$=0V | Reverse Voltage (V$_R$ max) | Temperature Range | | |
| min (μA) | typ. (μA) | | Dark Current | Min (GΩ) | typ. (GΩ) | typ. (pF) | typ. (μs) | (V) | Operating (°C) | Storage (°C) |
| 65 | 80 | 500 | 1.15 | 0.02 | 0.1 | 1100 | 3 | 5 | -10~+60 | -20~+80 |

**Table 19** *The characteristics of the detector S1337-1010BQ*

| * | NEP = Noice Current (A/Hz$^{1/2}$) / Radiant Sensitivity at Peak (A/W) |
|---|---|
| ** | D* = [Effective Sensitiv Area (cm$^2$) /]$^{1/2}$ / NEP |
| *** | R$_{SH}$ = 10 (mV) / Dark Current at V$_R$=10mV (A) |
| **** | t$_r$ is the time required to transition from 10% to 90% of the normal height level output value. |
| | The light source is a GaAsP LED (655nm) and the load resistance is 1kΩ |

## Appendix 18 Experiment to determine the performance of the detectors

### Abstract

The purpose of the experiment is to find out the characteristics of the detector and the detector-circuit.

The aim is to correctly adjust the detector circuit, i.e. to correctly select gains.
This is done to find out the procedure needed at calibration.

### Experiment

The idea of the experiment is to measure the output for different energies at a fixed wavelength. The experimental set-up in figure 61 is used.
To determine if the detectors are wavelength dependent $\lambda$=500nm as well as $\lambda$=448nm are used.
To be able to find the dependency of the gain in the electronics the laser intensity is varied during the experiment.
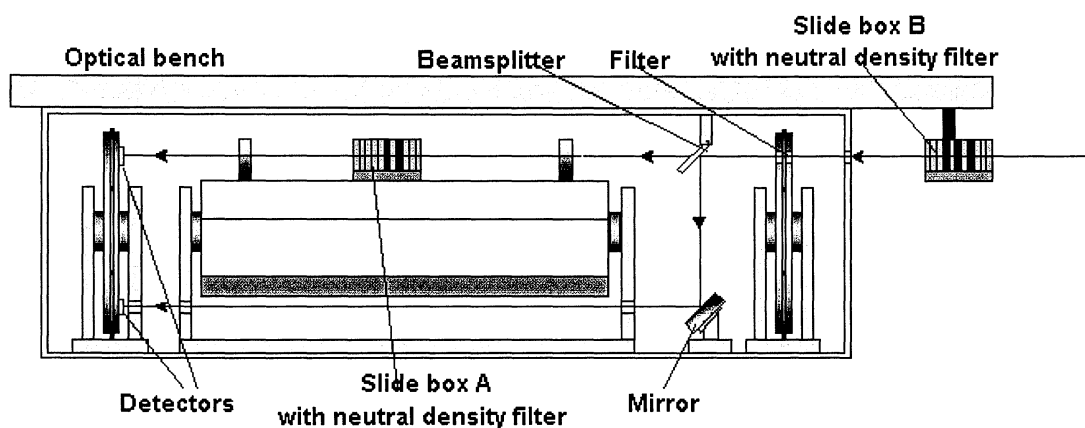


**Figure 61** *Test set-up for the experiment*

Two different set-ups are used. In the first one the energy in the pulses is changed with neutral density filters in slide box B (see figure 61). This is done to determine if the two detectors are linear i.e. to see if the relation between detector 1 and detector 2 is constant. Due to problems with the OPO-system the laser pulses were poor and the intensity fluctuated. This gave poor results.

Using one of the detectors as a reference solves the problem with the laser. When the beam enters the unit it is divided into two beams. One passes a neutral density filter in slide box A before hitting the detector. The other beam is used to find out which pulses have the same energy.

A special LabVIEW program is written for this purpose. The program performs in the following way:
1. The maximum dispersion on the reference value is entered.
2. The average value of the laser beam on the **reference** detector is measured. This value is then used as reference value.
3. When a measure button is pressed an average of 10 laser pulses is measured. Only pulses for which the reference detector is in the range of the reference value ± the dispersion are counted.
4. The result is displayed and a new measurement can be carried out.

It is found that the detector electronics has output offset. To eliminate the effect of offset it is measured and subtracted from the output values.

# Result

## Experiment 1

Description:    In this experiment the energy of the laser pulses are changed by neutral density filters in slide box B, see figure 61. The outputs are measured for different transmittance of the filters.

Wavelength:    500nm

| Optical density | Transmittance | Detector 1 [V] | Detector 2 [V] | Detector 1/Detector 2 |
|---|---|---|---|---|
| 0 | 1,000 | 3,2 | 3,32 | 1,04 |
| 0,03 | 0,933 | 3,2 | 3,2 | 1,04 |
| 0,1 | 0,794 | 3,2 | 3 | 1 |
| 0,13 | 0,741 | 3,2 | 3 | 0,9 |
| 0,3 | 0,501 | 2,7 | 2,2 | 0,82 |
| 0,33 | 0,468 | 2,5 | 2,1 | 0,82 |
| 0,4 | 0,398 | 2,3 | 1,9 | 0,78 |
| 0,43 | 0,372 | 2,1 | 1,65 | 0,79 |
| 0,5 | 0,316 | 1,6 | 1,35 | 0,82 |
| 0,53 | 0,295 | 1,55 | 1,2 | 0,83 |
| 0,6 | 0,251 | 1,4 | 1,15 | 0,83 |
| 0,63 | 0,234 | 1,3 | 1,1 | 0,83 |
| 0,8 | 0,158 | 0,9 | 0,7 | 0,83 |
| 0,83 | 0,148 | 0,75 | 0,61 | 0,8 |
| 0,9 | 0,126 | 0,82 | 0,7 | 0,8 |
| 0,93 | 0,117 | 0,7 | 0,55 | 0,72 |
| 1 | 0,100 | 0,8 | 0,6 | 0,78 |

**Table 20** *Result from experiment 1.*
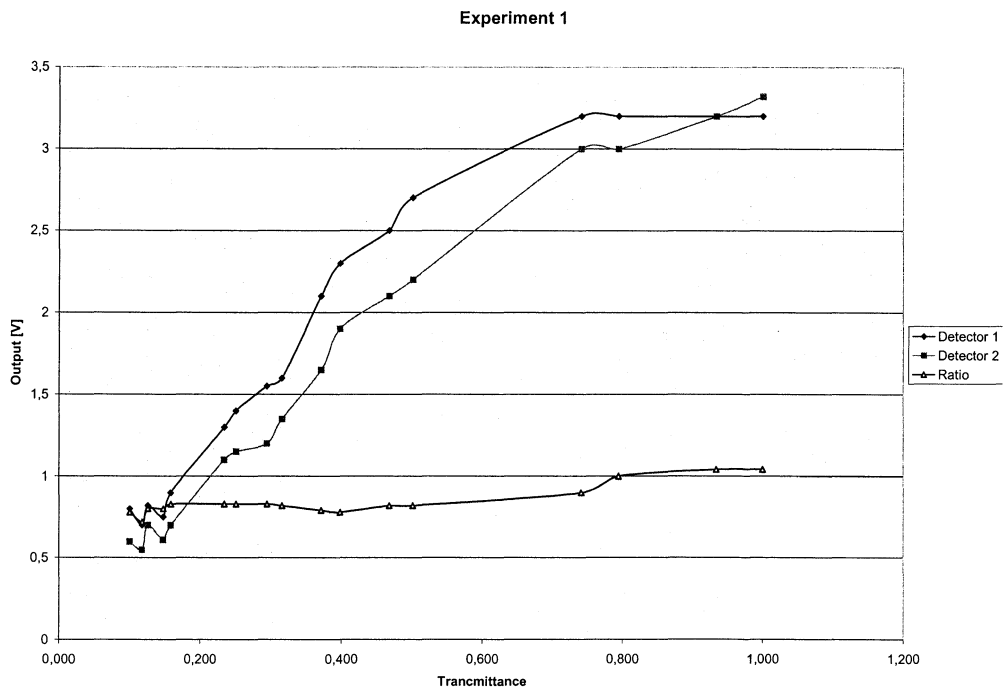


**Diagram 7** *Resutl from experiment 1.*

---

**Experiment 2**

Description:    This experiment is performed in the same way as for experiment 1. The only difference is that the detectors have changed place, see figure 61.

The outputs are measured for different transmittance of the filters in slide box B.

The average of 1200 pulses is used for every transmittance.

Wavelength:    500nm

| Optical density | Transmittance | Detector 1 [V] | Detector 2 [V] | Detector 1/Detector 2 |
|---|---|---|---|---|
| 0 | 1 | 3,2 | 3,32 | 1,04 |
| 0,03 | 0,933 | 3,2 | 3,32 | 1,04 |
| 0,1 | 0,794 | 3,2 | 3 | 1 |
| 0,13 | 0,741 | 3,19 | 2,7 | 0,9 |
| 0,3 | 0,501 | 2,5 | 2,05 | 0,83 |
| 0,33 | 0,468 | 2,4 | 2 | 0,83 |
| 0,4 | 0,398 | 2,3 | 1,8 | 0,78 |
| 0,43 | 0,372 | 2,2 | 1,8 | 0,79 |
| 0,5 | 0,316 | 1,7 | 1,4 | 0,82 |
| 0,53 | 0,295 | 1,65 | 1,38 | 0,82 |
| 0,6 | 0,251 | 1,5 | 1,2 | 0,81 |
| 0,63 | 0,234 | 1,45 | 1,15 | 0,82 |
| 0,8 | 0,158 | 1 | 0,83 | 0,83 |
| 0,83 | 0,148 | 0,9 | 0,78 | 0,83 |
| 0,9 | 0,126 | 0,95 | 0,74 | 0,81 |
| 0,93 | 0,117 | 0,94 | 0,73 | 0,8 |
| 1 | 0,1 | 0,9 | 0,65 | 0,76 |
| 1,03 | 0,093 | 0,84 | 0,61 | 0,74 |
| 1,1 | 0,079 | 0,75 | 0,55 | 0,71 |
| 1,13 | 0,074 | 0,7 | 0,5 | 0,69 |
| 1,3 | 0,050 | 0,46 | 0,25 | 0,61 |
| 1,33 | 0,047 | 0,4 | 0,25 | 0,6 |
| 1,4 | 0,040 | 0,4 | 0,24 | 0,58 |
| 1,43 | 0,037 | 0,26 | 0,15 | 0,58 |

**Table 21** *Result from experiment 2.*



**Diagram 8** *Resutl from experiment 2.*

Department of Atomic Physics, Lund Institute of Technology
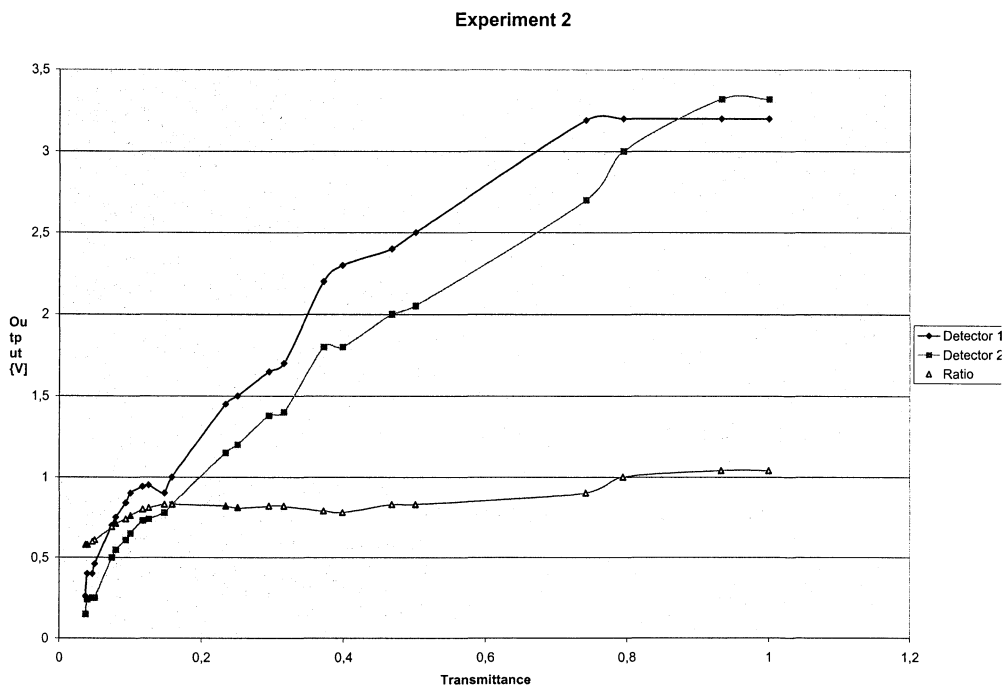
## Experiment 3

Description:  In this experiment the energy of the laser pulses are changed by neutral density filters in slide box A, see figure 61. The Detector 2 is used as a reference detector.

| Recording Optical density | Transmit tance | Nr: 1 $\lambda=500$ R=3,4k Output [V] | Nr: 2 $\lambda=500$, R=5,7k Output [V] | Nr: 3 $\lambda=448$, R=5,7k Output [V] | Nr: 4 $\lambda=448$, R=3,4k Output [V] | Nr: 5 $\lambda=448$, R=3,4k Output [V] | Nr: 6 $\lambda=448$ R=10k Output [V] | Nr: 7 $\lambda=448$ R=10k Output [V] |
|---|---|---|---|---|---|---|---|---|
| 0 | 1,000 | 3,915 | 4,780 | 4,802 | 4,474 | 2,568 | 3,950 | 3,510 |
| 0,1 | 0,794 | 3,075 | 4,783 | 4,808 | 3,599 | 1,980 | 3,217 | 2,892 |
| 0,3 | 0,501 | 2,035 | 4,095 | 3,850 | 2,434 | 1,343 | 2,253 | 2,004 |
| 0,4 | 0,398 | 1,585 | 3,265 | 3,040 | 1,909 | 1,045 | 1,808 | 1,659 |
| 0,5 | 0,316 | 1,161 | 2,270 | 2,135 | 1,374 | 0,771 | 1,367 | 1,274 |
| 0,6 | 0,251 | 0,910 | 1,745 | 1,670 | 1,080 | 0,630 | 1,144 | 1,081 |
| 0,8 | 0,158 | 0,625 | 1,195 | 1,155 | 0,752 | 0,462 | 0,880 | 0,833 |
| 0,9 | 0,126 | 0,525 | 0,965 | 0,925 | 0,620 | 0,385 | 0,815 | 0,705 |
| 1 | 0,100 | 0,425 | 0,820 | 0,798 | 0,501 | 0,343 | 0,653 | 0,603 |
| 1,5 | 0,032 | 0,191 | 0,350 | 0,360 | 0,228 | 0,154 | 0,190 | 0,199 |

**Table 22** *Result from experiment 3.*



**Diagram 9** *Resutl from experiment 3.*

Department of Atomic Physics, Lund Institute of Technology
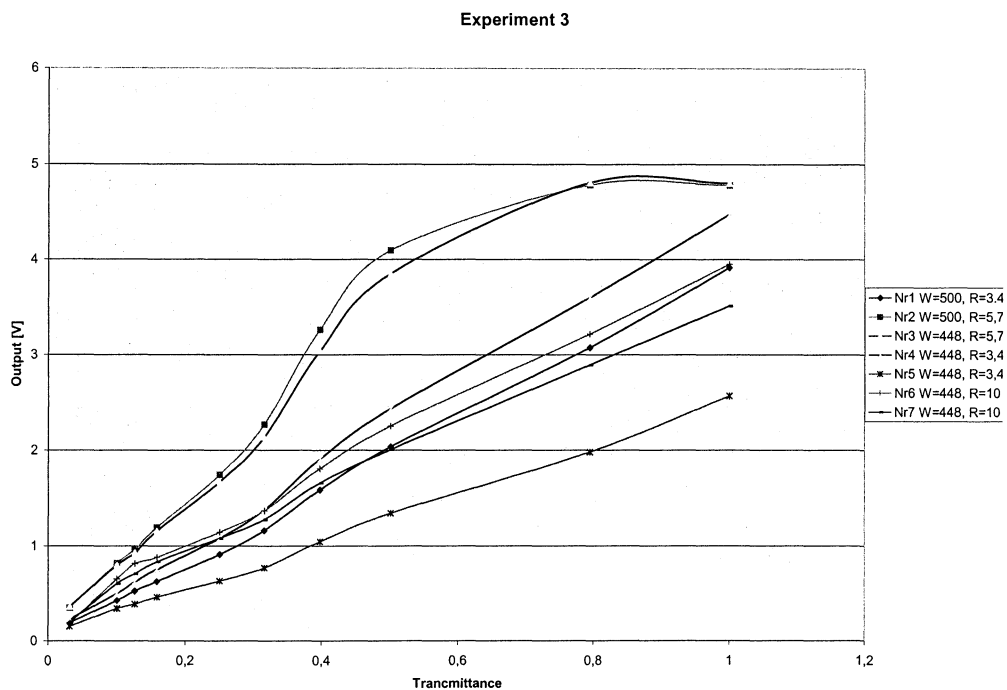
## Detector characteristics of detector 1

Description:     To record the characteristics of detector 1 the energy of the pulses is adjusted until the output reaches a value of ~4,4V. This is done with filters in slide box B, see figure 61. The energy in the laser pulses is changed by neutral density filters in slide box A. Detector 2 is used as reference.

| Recording Optical density | Transmittance | Nr 1 Output [V] | Nr 2 Output [V] | Nr 3 Output [V] |
|---|---|---|---|---|
| 0 | 1,000 | 4,484 | 4,478 | 4,477 |
| 0,03 | 0,933 | 4,396 | | 4,362 |
| 0,1 | 0,794 | 3,826 | 3,945 | 3,888 |
| 0,13 | 0,741 | 3,576 | | 3,598 |
| 0,3 | 0,501 | 2,766 | 2,765 | 2,799 |
| 0,33 | 0,468 | 2,614 | | 2,620 |
| 0,4 | 0,398 | 2,316 | 2,285 | |
| 0,43 | 0,372 | 2,146 | | |
| 0,5 | 0,316 | 1,806 | 1,790 | |
| 0,53 | 0,295 | 1,696 | | |
| 0,6 | 0,251 | 1,506 | 1,505 | |
| 0,63 | 0,234 | 1,426 | | |
| 0,8 | 0,158 | 1,146 | 1,145 | |
| 0,83 | 0,148 | 1,071 | | |
| 0,9 | 0,126 | 0,968 | 0,965 | |
| 0,93 | 0,117 | 0,906 | | |
| 1 | 0,100 | 0,806 | 0,795 | |
| 1,1 | 0,079 | 0,655 | | |
| 1,3 | 0,050 | 0,416 | 0,455 | |
| 1,4 | 0,040 | 0,341 | | |
| 1,5 | 0,032 | 0,251 | 0,235 | |

**Table 23** *Table of the detector characteristics of detector 1.*



characteristics detector 1
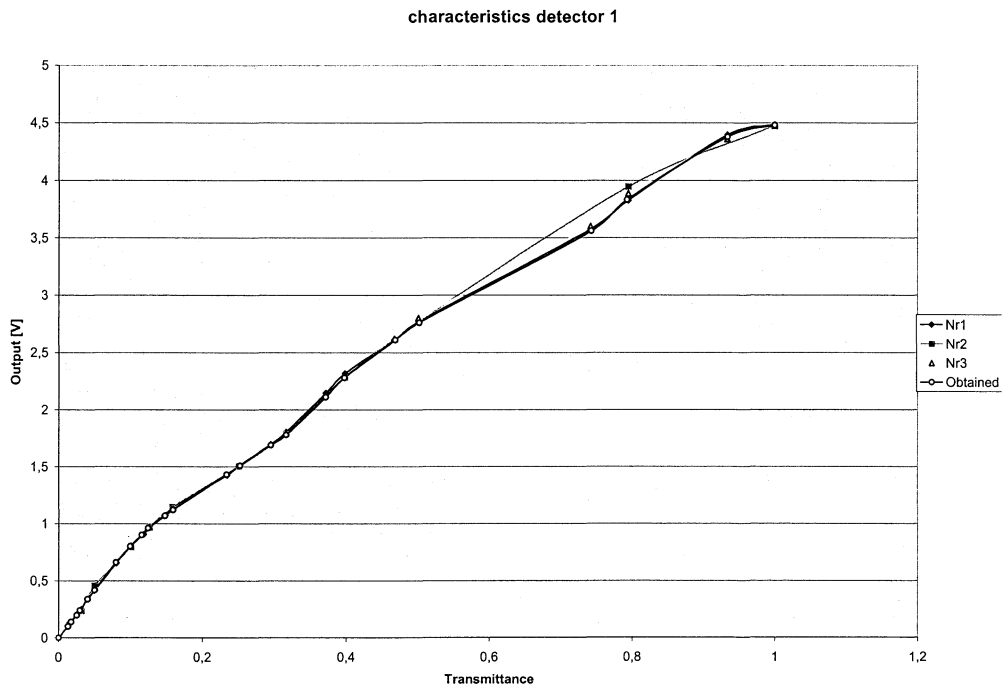
**Diagram 10** *The detector characteristics of detector 1.*

## Detector characteristics detector 2

Description: To record the characteristics of detector 1 the energy in the pulses is adjusted until the output has a value of ~4,2V. This is done with neutral density filters in slide box B, see figure 61. The energy in the laser pulses is changed by neutral density filters in slide box A. Detector 1 is used as reference.

| Recording Optical density | Transmittance | Nr 1 Output [V] | Nr 2 Output [V] | Nr 3 Output [V] | Nr 4 Output [V] |
|---|---|---|---|---|---|
| 0 | 1 | 4,237 | 4,216 | 4,1812 | 4,09 |
| 0,03 | 0,933254 | 4,197 | 4,161 | 4,1112 | 3,97 |
| 0,1 | 0,794328 | 3,947 | 3,67 | 3,7712 | 3,56 |
| 0,13 | 0,74131 | 3,547 | 3,502 | 3,2912 | 3,35 |
| 0,3 | 0,501187 | 3,187 | 2,754 | 2,4812 | 2,54 |
| 0,33 | 0,467735 | 2,747 | 2,484 | 2,3412 | 2,36 |
| 0,4 | 0,398107 | 2,387 | 2,274 | 2,0912 | 2,16 |
| 0,43 | 0,371535 | 2,242 | 2,184 | 1,9712 | 1,97 |
| 0,5 | 0,316228 | 1,742 | 1,82 | 1,6612 | |
| 0,53 | 0,295121 | 1,717 | | 1,5712 | |
| 0,6 | 0,251189 | 1,557 | 1,53 | 1,4412 | |
| 0,63 | 0,234423 | 1,437 | | | |
| 0,8 | 0,158489 | 1,167 | 1,17 | | |
| 0,83 | 0,147911 | 1,137 | | | |
| 0,9 | 0,125893 | 0,992 | 1,032 | | |
| 0,93 | 0,11749 | 0,947 | | | |
| 1 | 0,1 | 0,877 | 0,88 | | 0,79 |
| 1,1 | 0,079433 | 0,717 | | | |
| 1,3 | 0,050119 | 0,487 | 0,54 | | |
| 1,4 | 0,039811 | 0,372 | | | |
| 1,5 | 0,031623 | 0,277 | 0,31 | | 0,267 |
| 1,6 | 0,025119 | 0,207 | | | |
| 1,8 | 0,015849 | 0,132 | 0,24 | | |
| 1,9 | 0,012589 | 0,102 | | | |

**Table 24** *Table of the detector characteristics of detector 2.*



**Characteristics detector 2**
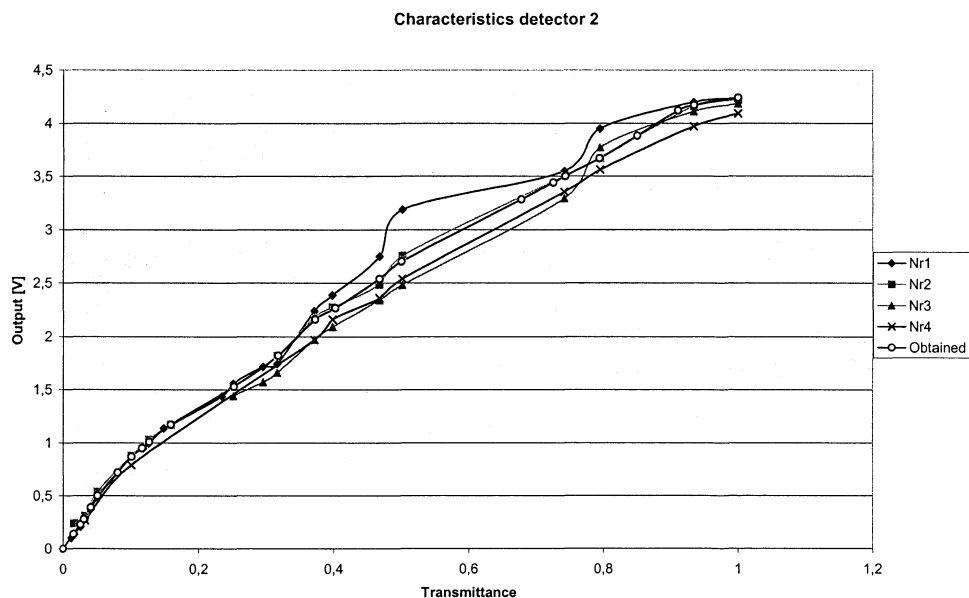
**Diagram 11** *The detector characteristics of detector 2.*

**Obtained detector characteristics**

Description:     The obtained values received from the recording of characteristics for detector 1 and 2
              The Curves for these values are shown in the diagram 10 and diagram 11 above.

|     | Characteristics of detector 1 | | | | Characteristics of detector 2 | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Nr | Output [V] | X-value | Transmittance | Converted | Output [V] | X-value | Transmittance | Converted |
| 1 | 0,00 | 0,00 | 0,000 | 0,000 | 0,00 | 0,00 | 0,000 | 0,000 |
| 2 | 0,10 | 0,53 | 0,013 | 0,053 | 0,14 | 0,62 | 0,016 | 0,062 |
| 3 | 0,14 | 0,70 | 0,018 | 0,070 | 0,23 | 1,00 | 0,025 | 0,100 |
| 4 | 0,20 | 1,00 | 0,025 | 0,100 | 0,28 | 1,20 | 0,030 | 0,120 |
| 5 | 0,24 | 1,18 | 0,030 | 0,118 | 0,39 | 1,60 | 0,040 | 0,160 |
| 6 | 0,34 | 1,60 | 0,040 | 0,160 | 0,50 | 2,00 | 0,050 | 0,200 |
| 7 | 0,42 | 2,00 | 0,050 | 0,200 | 0,72 | 3,20 | 0,080 | 0,320 |
| 8 | 0,66 | 3,17 | 0,079 | 0,317 | 0,87 | 4,00 | 0,100 | 0,400 |
| 9 | 0,80 | 3,95 | 0,099 | 0,395 | 0,95 | 4,65 | 0,116 | 0,465 |
| 10 | 0,90 | 4,60 | 0,115 | 0,460 | 1,01 | 5,05 | 0,126 | 0,505 |
| 11 | 0,96 | 4,95 | 0,124 | 0,495 | 1,17 | 6,35 | 0,159 | 0,635 |
| 12 | 1,07 | 5,90 | 0,148 | 0,590 | 1,53 | 10,10 | 0,253 | 1,010 |
| 13 | 1,12 | 6,35 | 0,159 | 0,635 | 1,82 | 12,70 | 0,318 | 1,270 |
| 14 | 1,43 | 9,35 | 0,234 | 0,935 | 2,16 | 14,90 | 0,373 | 1,490 |
| 15 | 1,51 | 10,10 | 0,253 | 1,010 | 2,27 | 16,10 | 0,403 | 1,610 |
| 16 | 1,69 | 11,80 | 0,295 | 1,180 | 2,54 | 18,70 | 0,468 | 1,870 |
| 17 | 1,78 | 12,65 | 0,316 | 1,265 | 2,70 | 20,00 | 0,500 | 2,000 |
| 18 | 2,11 | 14,85 | 0,371 | 1,485 | 3,28 | 27,10 | 0,678 | 2,710 |
| 19 | 2,28 | 15,90 | 0,398 | 1,590 | 3,44 | 29,00 | 0,725 | 2,900 |
| 20 | 2,61 | 18,75 | 0,469 | 1,875 | 3,50 | 29,70 | 0,743 | 2,970 |
| 21 | 2,76 | 20,10 | 0,503 | 2,010 | 3,67 | 31,75 | 0,794 | 3,175 |
| 22 | 3,56 | 29,70 | 0,743 | 2,970 | 3,88 | 34,00 | 0,850 | 3,400 |
| 23 | 3,83 | 31,70 | 0,793 | 3,170 | 4,12 | 36,40 | 0,910 | 3,640 |
| 24 | 4,38 | 37,35 | 0,934 | 3,735 | 4,17 | 37,35 | 0,934 | 3,735 |
| 25 | 4,48 | 40,00 | 1,000 | 4,000 | 4,24 | 40,00 | 1,000 | 4,000 |

**Table 25** *Table of the derived detector characteristics.*

## Discussion

The first two experiments show that the two detectors seem to be linear between 1 and 3 V. These two experiments also reveal that laser was unstable i.e. had fluctuating energy. Even taking the average of a large number of pulses does not help to get good test results. It is also found that the electronics is saturated at ~3.2V. This is below the expected ~5V (the input voltage (5V) minus the drop in the semiconductors). The problem was found and corrected. After this the output could reach ~4,5V.

To solve the problem with the fluctuating laser energy, the experiment is changed to the second set-up where one of the detectors is used as a reference. From experiment 3 the following is found:

- The detector has two linear regions with a transition area. The characteristics is linear in the region ~4,1V to ~2,0V and from ~1,7V to ~0,7V. Due to this a conversion table is recorded for the two detectors.
- The electronics become saturated above ~4,2V.
- The gain in the electronics has no impact on the characteristics. The important thing is to let the signal start at an as high value as possible without saturating the electronics. When this was found it was decided that the electronics should have high gain. This is also to spare the detector i.e. not illuminate the detector more than necessary. This also implicates that the filter wheel has to be able to suppress the laser beam some magnitudes of ten.
- The detector is not wavelength dependent. At least not in the region 450nm to 500nm.
- The characteristics are not changed over time. The recordings are done during 3 days and the set-up was completely changed one time. This showed that a characteristic that has been recorded can be used again. The active area on the detector is large and it is not important where the beam hits.
- The transmittance of the neutral density filters in the filter wheel was found. The wheel should be able to reduce the intensity over an as large region as possible. At the same time the number of filters can not be too many. The values shown in the summary give a resolution of about 0,8V.
- The electronics have some offset that has to be compensated for. Measuring the offset before a measurement can do this.

The characteristics of the detectors were then recorded. This was done to be able to use the entire span from ~4,1V to ~0,5V. During this recording the laser became worse. This made the recordings on the second detector bad. Even so a conversion table was made for this detector. This table will make the measurements better, but not perfect. It is important to remember that the calibration unit will not measure the exact absorption, it will only find an absorption peak. This implicates that the conversion table will make the measurements better. From these recordings it was also decided that detector 2 would be the reference detector.

When using the results from the experiment the procedure for calibration could be determined, see summary.

## Summary
Detector 2 is to be used as reference detector.

From this experiment the following was determined when making a calibration:
1. Let the filter wheel start with as high optical density as possible, i.e. as dark as possible.
2. Let the laser go to the minimum absorption around the region were the calibration shall be made.
3. Select lower optical density (with the filter wheel) until one of the detectors has an output larger than 1V. Use this detector to find the maximum energy in the pulse.
4. Select the filter with the lowest optical density but for which the output on the detector is below 4,1V. Now there is as much dynamics as possible in the system.
5. Check that the other detector is within the acceptable region 0,5V to 4.1V.
6. Record the offset from the two detectors.
7. When doing the scan, compensate for the offset and then use the conversion tables for the detectors.

The set-up for neutral density filters in the filter wheel (the table show the values for the magnitude of two powers of ten.

| Transmittance [%] | Optical Density | Round Optical Density |
|---|---|---|
| 100 | 0,000 | 0,0 |
| 80 | 0,097 | 0,1 |
| 60 | 0,222 | 0,2 |
| 40 | 0,398 | 0,4 |
| 20 | 0,699 | 0,7 |
| 10 | 1,000 | 1,0 |
| 8 | 1,097 | 1,1 |
| 6 | 1,222 | 1,2 |
| 4 | 1,398 | 1,4 |
| 2 | 1,699 | 1,7 |
| 1 | 2,000 | 2,0 |
| and so on | | |

**Table 26** *The set-up for the neutral density filters.*

## Appendix 19 VI and cluster description

### The VI's

## Calibrate The Laser

**Description:**
This VI is the entry point to the calibration part of the program. When calling the VI the calibration parameters have to be set in the "**Info**" cluster.
The VI:
1. Checks the calibration data.
2. Move the motors to the starting position.
3. Finds appropriate neutral density filter.
4. Selects calibration method.
5. Sets detector and beam splitter to off position.

**Location:** Calibrate.llb

**Input:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Info out | Info Cluster | |
| Offset | DBL | The offset in nm found on the laser. |
| OK Out | Boolean | TRUE if the calibration was successful otherwise FALSE. |

## Calibration Method 0 With GOTO

**Description:**
Calibration method number 0.

In this VI the folowing parameters are set:
1. "*No Samples*" the numbers of samples that shall be recorded for every step in the wavelength scan.
2. "*No Steps*" the number of steps that shall be taken for the scan if the "*Step*" parameter is not set for the "*Peak Data*"
3. "*Threshold %*" the thresholds value. This value defines the maximum region the laser can fluctuate.
4. "*No Threshold samples*" The number of samples that shall be used when finding the average laser intensity.

**Location:** Calibrate.llb
**Input:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Info out | Info Cluster | |
| Offset | DBL | The offset in nm found on the laser. |
| OK Out | Boolean | TRUE if the calibration was successful otherwise FALSE. |

## Calibration Method 1 With GOTO

**Description:**

Calibration method number 1.

In this VI the following parameters are set:
1. "*No Samples*" the numbers of samples that shall be recorded for every step in the wavelength scan.
2. "*No Steps*" the number of steps that shall be taken for the scan if the "*Step*" parameter is not set for the "*Peak Data*"
3. "*Threshold %*" the thresholds value. This value defines the maximum region the laser can fluctuate.
4. "*No Threshold samples*" The number of samples that shall be used when finding the average laser intensity.

**Location:** Calibrate.llb

**Input:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Info out | Info Cluster | |
| Offset | DBL | The offset in nm found on the laser. |
| OK Out | Boolean | TRUE if the calibration was successful otherwise FALSE. |

## Calibration Method 2 With GOTO

**Description:**
Calibration method number 2.

In this VI the following parameters are set:
1. "*No Samples*" the numbers of samples that shall be recorded for every step in the wavelength scan.
2. "*No Steps*" the number of steps that shall be taken for the scan if the "*Step*" parameter is not set for the "*Peak Data*"
3. "*Threshold %*" the thresholds value. This value defines the maximum region the laser can fluctuate.
4. "*No Threshold samples*" The number of samples that shall be used when finding the average laser intensity.

**Location:** Calibrate.llb

**Input:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Info out | Info Cluster | |
| Offset | DBL | The offset in nm found on the laser. |
| OK Out | Boolean | TRUE if the calibration was successful otherwise FALSE. |

## Cell Selection
**Description:**
This VI is the entry point to the configuration section of the program. The VIs front panel is the user interface for selecting which cell that shall be used when calibrating the laser.

**Location:** Program.llb

**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| File Types in | File Types Cluster | |
| Info in | Info Cluster | |
| Initialise | Boolean | Set to TRUE it the program shall be initialised. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| File Types out | File Types Cluster | |
| Info out | Info Cluster | |

## Change In Revolver
**Description:**
This VI is used when the user wants to add/remove or change a cell in the revolver.

When a cell shall be added or removed in the calibration unit the revolver must be moved to make this easy. The configuration of this movement is done in this VI.

**Location:** Revolver.llb

**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Choice | Integer | 0 = Remove cell<br>1 = Add cell<br>2 = Remove and add cell |
| Info in | Info Cluster | |
| New Cell Pos In Array | Integer | The position the new cell has in the array in the ”Calib” cluster. |
| Old Cell Pos In Array | Integer | The position the old cell has in the array in the ”Calib” cluster. |
| Pos In Revolver | Integer | The position in the revolver where the change shall be made. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |
| OK out | Boolean | TRUE if the operation was successful otherwise FALSE. |

## Check If Array Pos Occupied
**Description:**
Checks if an array position is occupied.

**Location:** Spiece.llb

**Input:**

| Parameter | Type | Description |
|---|---|---|
| Array In | Array of strings | Array to be checked. |
| Info in | Info Cluster | |
| Pos In Array | Integer | The position to be checked |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Info out | Info Cluster | |
| Occupied | Boolean | TRUE if the position is occupied otherwise FALSE. |

## Check If Cell Is In Revolver
**Description:**
Checks if a cell exists in the revolver.

**Location:** Revolver.llb

**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Exist In Revolver | Boolean | TRUE if the cell id in the revolver otherwise FALSE. |
| Info out | Info Cluster | |

## Check If Revolver Pos Is Occupied
**Description:**
Checks if a revolver position is occupied.
**Location:** Spiece.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |

3

| Info in | Info Cluster | |
|---|---|---|
| Revolver Pos | Integer | Position to check. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Cell that Occ Pos | Integer | The position in the "calib" cluster of the cell that occupies the position. |
| Info out | Info Cluster | |
| Occupied | Boolean | TRUE if the cell id in the revolver otherwise FALSE. |

## Check Peak Data

**Description:**
Checks if the calibration data has a relevant value.
The data checked is:
- That "*Wavelength ON*" is between 220 and 3600nm.
- That "*Wavelength OFF*" is between 220 and 3600nm.
- That "*Start of Scan*" is between 220 and 4800nm.
- That "*End Of Scan*" is between 200 and 4800nm.
- That "*Step*" in larger then 0nm. If not the value is set to -1.
- That "*Diff Abs*" in larger then 0nm. If not the value is set to -1.

**Location:** Spiece.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Info in | Info Cluster | |
| Peak Data In | Peak Data Cluster | The data to be checked. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Info out | Info Cluster | |
| OK out | Boolean | TRUE if the data is OK otherwise FALSE. |
| Peak Data Out | Peak Data Cluster | |

## CloseFile*

**Description:**
Closes an open file.
**Location:** Lofileop.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| File Type Selector | Integer | The type of file that is to be closed. |
| File Types | File Types Cluster | |
| Ignore Change Activity | Boolean | If TRUE the VI ignores if the change activity is set. |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| File Types | File Types Cluster | |
| Info out | Info Cluster | |

## Configuration Of The Unit

**Description:**
This VI is used to configure the calibration unit. It is also from this VI the calibration data can be set.
**Location:** Program.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| File Types in | File Types Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| File Types out | File Types Cluster | |
| Info out | Info Cluster | |

## ContinueExecErrorCheck*

**Description:**
This VI checks if the program shall continue to execute or not.
**Location:** Execcont.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Ignore Change Activity | Boolean | If TRUE then the VI ignores that change activity is set. |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Execute | Boolean | TRUE if the program can continue otherwise FALSE. |
| Info out | Info Cluster | |

## ContinueExecNoErrorCheck*

**Description:**
This VI checks if the program shall continue to execute or not.
**Location:** Execcont.llb
**Input:**
**Output:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Continue | Boolean | TRUE if the program can continue otherwise FALSE. |

## Convert Detector Data

**Description:**
This VI is used to convert measured detector data towards a look-up table. This is done to minimise the detector characteristics in a measurement.
**Location:** Detektor.llb
**Input:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Detector | Integer | 0 = measuring detector. 1 = Ref detector. |
| In Array | Array of DBL | The measured values. |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Info out | Info Cluster | |
| Out Array | Array of DBL | Converted values. |

## Convert Detector Data2

**Description:**
This VI is used to convert one measured value from the detector towards a look-up table. This is done to minimise effects of the detector characteristics in a measurement.
**Location:** Detektor.llb
**Input:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Detector | Integer | 0 = measuring detector. 1 = Ref detector. |
| Value In | DBL | Measured value. |

**Output:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Value Out | DBL | Converted value. |

## Create Cell Data File

**Description:**
Creates a file for cell data.
**Location:** FileOp.llb
**Input:**

| Parameter | Type | Description |
|-----------|------|-------------|
| File Types in | File Types Cluster | |
| Info in | Info Cluster | |
| Overwrite | Boolean | If true the VI is allowed to overwrite older file. |

**Output:**

| Parameter | Type | Description |
|-----------|------|-------------|
| File Types out | File Types Cluster | |
| Info out | Info Cluster | |

## Delete Cell

**Description:**
Deletes a cell form the array in the "Calib" cluster
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Calib in | Calib Cluster | |
| Cell Pos | Integer | The position of the cell in the "Calib" cluster. |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |

## Delete Peak From Cell

**Description:**
Deletes the data for one peak for a cell.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Calib in | Calib Cluster | |
| Cell Pos | Integer | The position of the cell in the "Calib" cluster. |
| Info in | Info Cluster | |
| Peak Pos | Integer | The position of the peak in the peak array for the cell. |

**Output:**

| Parameter | Type | Description |
|-----------|------|-------------|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |

## Dialogue Box With OK

**Description:**
Displays a message.
**Location:** Popupp.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Info in | Info Cluster | |
| String | String | Message to display. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Info out | Info Cluster | |

## Dialogue Box With OK and Cancel

**Description:**
Displays a message.
**Location:** Popupp.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Info in | Info Cluster | |
| String | String | Message to display. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Info out | Info Cluster | |
| OK out | Boolean | TRUE if the "OK" is pressed otherwise FALSE. |

## Edit Peak Data For Cell

**Description:**
This VI is used to configure the calibration parameters for a cell.
**Location:** Spiece.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Cell Pos In Array | Integer | The position in the "Calib" cluster of the cell for which the peaks shall be configured. |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |

## Find Motor Pos 0

**Description:**
Finds the starting position for a motor.

In this VI the following parameters are set:
1. Maximum numbers of steps per revolution. This is the maximum number of steps the unit will take for finding the position 0.
2. Line for the direction. This is the input line to the AT-MIO-16D card for the direction of the motor.
3. The direction. This is the direction the motor shall have when trying to find the position 0.

4. Line for the motor movement. This is the line to the AT-MIO-16D card for moving the motor.
5. Line for the location detector. This is the line to the AT-MIO-16D card for the position detector.
6. Trigger flank. The appearance of the signal from the position detector when position 0 is found. The signal is either Hi or Low. The trigger flank can also be configured on the position detector circuit.
7. Direction for fine adjusts. The directions the motor shall have to fine adjust the position.
8. Number of steps for fine adjustment.
The parameters are found in table 27.

The device number and the digital channel for AT-MIO-16D card must also be set. The values for these parameters are:
1. Device number for the AT-MIO-16D card: 1
2. Digital channel for motors: 2
3. Digital channel for position detectors: 3

| Parameter | Motor 0 | Motor 1 | Motor 2 | Motor 3 |
|---|---|---|---|---|
| 1 | 55 | 800 | 450 | NA |
| 2 | 1 | 3 | 5 | 7 |
| 3 | F | T | F | NA |
| 4 | 0 | 2 | 4 | 6 |
| 5 | 0 | 1 | 2 | 3 |
| 6 | T | T | T | NA |
| 7 | T | F | F | NA |
| 8 | 0 | 20 | 0 | NA |

Table 27 The configuration parameters needed when finding the motor positions.

**Location:** Revolver.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Choice | Integer | 0 = Detector (motor 5)<br>1 = Revolver (motor 6)<br>2 = Filter (motor 7)<br>3 = Beam splitter (motor 8) |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Info out | Info Cluster | |
| OK out | Boolean | TRUE if the operation was successful otherwise FALSE. |

## Find Offset Method 0

**Description:**
Finds the offset of the laser. Method 0.
**Location:** Calibrate.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| In Array | Array of DBL | Measured values. |
| Info in | Info Cluster | |
| Input Wavelength | Array of DBL | The wavelengths that goes with the measured values. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Info out | Info Cluster | |
| Offset | DBL | Offset in nm. |
| OK out | Boolean | TRUE if the offset was found otherwise FALSE. |

## Get All Cell Names

**Description:**
Returns all the names of the cells.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| All Cell Names | Array of strings | Array with all the cell names. |
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |

## Get All Peaks From Cell

**Description:**
The all the peak names for a cell.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Cell Pos | Integer | The cell position array in the "Calib" cluster. |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| All Peak Names | Array of strings | Array with all the peak names for the cell. |
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |

## Get Cell Data From File

**Description:**
Fetches saved cell data from file. The VI updates the "Calib" cluster with the data.
**Location:** FileOp.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| File Types in | File Types Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| File Types out | File Types Cluster | |
| Info out | Info Cluster | |

## Get Cell Pos From Revolver Pos

**Description:**
This VI is used when a position of a cell is known in the revolver. Returns the position of the cell in the array in the "Calib" cluster.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Info in | Info Cluster | |
| Revolver Pos | Integer | Position of the cell in the revolver |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Cell Found | Boolean | TRUE if the position if found otherwise FALSE. |
| Cell Pos | Integer | The position in the attay in the "Calib" cluster. |
| Info out | Info Cluster | |

## Get Default Peak Data For Cell

**Description:**
Returns the default peak data for a cell.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Cell Pos | Integer | The position of the cell in the "Calib" cluster. |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |
| Peak Data | Peak data cluster | The default peak data for the cell. |

## Get Detector For Peak

**Description:**
Returns the position for a detector that can be used for measuring.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Info in | Info Cluster | |
| Wavelength | DBL | The wavelength for which the detector have to operate for. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Detector Name | String | The name of the detector. |
| Detector Pos | Integer | The position of the detector. |
| Info out | Info Cluster | |

## Get Detector Signal

**Description:**
Returns mean values of the measured signal from the detectors.
**Location:** Detektor.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Info in | Info Cluster | |
| Number Of Points | Integer | The number of values that shall be measured. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Cell | DBL | The mean value from the cell detector. |
| Cell/Ref | DBL | The mean value of the divided signals. |
| Info out | Info Cluster | |
| Ref | DBL | The mean value from the ref detector. |

## Get Detector Signal No Outliers

**Description:**
Returns mean values of the measured signal from the detectors. The VI removes points that differ too much from the mean value.
**Location:** Detektor.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Info in | Info Cluster | |
| Number Of Points | Integer | The number of values that shall be measured. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Cell | DBL | The mean value from the cell detector. |

| Info out | Info Cluster | |
|---|---|---|
| Ref | DBL | The mean value from the ref detector. |

## Get Detector Signal Offset

**Description:**
Returns the offset for the detectors.
**Location:** Detektor.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Info in | Info Cluster | |
| Number Of Points | Integer | The number of values that shall be measured. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Cell Offset | DBL | The offset for the cell detector. |
| Info out | Info Cluster | |
| Ref Offset | DBL | The offset for the ref detector. |

## Get Detector Signal With Threshold

**Description:**
Returns the mean values for the measured signal from the detectors. As input this VI must have a reference value. The VI will only record the signals for which the value from the reference detector is within the threshold.
**Location:** Detektor.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Info in | Info Cluster | |
| Number Of Points | Integer | The number of values that shall be measured. |
| Ref value | DBL | The reference value. |
| Threshold % | DBL | Threshold for which the ref detector have to be within. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Cell | DBL | The mean value from the cell detector. |
| Cell/Ref | DBL | The mean value of the divided signals. |
| Info out | Info Cluster | |
| Ref | DBL | The mean value from the ref detector. |

## Get Detector Signal With Threshold 2

**Description:**
Returns the mean values for the measured signal from the detectors. This VI finds the mean values for the reference detector and uses this value to check that the reference detector is within the threshold. The signals recorded are those within the threshold. The VI also compensates for the offset on the detectors.

**Location:** Detektor.llb

**Input:**

| Parameter | Type | Description |
|---|---|---|
| Cell Offset | DBL | The offset on the cell detector. |
| Info in | Info Cluster | |
| Number Of Points | Integer | The number of values that shall be measured. |
| Ref Offset | DBL | The offset on the ref detector. |
| Threshold % | DBL | Threshold for which the ref detector have to be within. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Cell | DBL | The mean value from the cell detector. |
| Cell/Ref | DBL | The mean value of the divided signals. |
| Info out | Info Cluster | |
| OK out | Integer | TRUE if the collection of data was successful otherwise FALSE. |
| Ref | DBL | The mean value from the ref detector. |

## Get Detector Signal With Threshold and compensated

**Description:**
Returns the mean values for the measured signal from the detectors. As input this VI must have a reference value. The VI will only records the signals for which the value from the reference detector is within the threshold. The VI also compensates for the offset on the detectors and compensates for the detector characteristics.

**Location:** Detektor.llb

**Input:**

| Parameter | Type | Description |
|---|---|---|
| Cell Offset | DBL | The offset on the cell detector. |
| Info in | Info Cluster | |
| Number Of Points | Integer | The number of values that shall be measured. |
| Ref Offset | DBL | The offset on the ref detector. |
| Ref Value | DBL | The reference value. |
| Threshold % | DBL | Threshold for which the ref detector have to be within. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Cell | DBL | The mean value from the cell detector. |
| Cell/Ref | DBL | The mean value of the divided signals. |
| Info out | Info Cluster | |
| Ref | DBL | The mean value from the ref detector. |

## Get Names For Cells In Revolver

**Description:**
Returns the names for the cells that are present in the revolver.

**Location:** Array Functions.llb

**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Cell Names | Array of strings | The names of the cells that are present in the revolver. |
| Info out | Info Cluster | |

## Get Splitter For Peak

**Description:**
Returns the position for a beam splitter that can be used for measuring.

**Location:** Array Functions.llb

**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Info in | Info Cluster | |
| Wavelength | DBL | The wavelength for which the splitter have to operate for. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |
| Splitter Name | String | The name of the Splitter. |
| Splitter Pos | Integer | The position of the Splitter. |

## Goto with comma*
**Description:**
Moves the OPO-laser to a specified wavelength.
**Location:** Sp_mopo.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Goto | DBL | The wavelength that the laser shall be moved to. |
| GPIB Address | String | The GPIB address for the laser. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Wavelength | DBL | The wavelength the laser moved to. |

## Init Calibration Unit
**Description:**
This VI initialises the calibration program. The parameters that are set by the VI are:
1. The file path and name of the configuration file. The path is set to the "Calib Data File Path" in the "File Types" cluster.
2. The parameters of the detector. These parameters are not stored on disk.
3. The parameters of the beam splitter. These parameters are not saved to file.
4. The data for the cells is retrieved from the data file and stored in the "Calib" cluster.
5. All motors are moved to the starting position.

**Location:** Program.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| File Types in | File Types Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| File Types out | File Types Cluster | |
| Info out | Info Cluster | |

## Insert New Cell Into Array
**Description:**
Inserts new cell into the cell array in the "Calib" cluster. The VI sorts the array after the names of the cells.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Info in | Info Cluster | |
| New Name | String | The name of the new cell. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |
| New Cell Pos | Integer | The position the new cell has in the array in the "Calib" cluster. |

## Insert New Cell Into Array No Sorting
**Description:**
Inserts new cell into the cell array in the "Calib" cluster. The VI does not sort the cells. This VI shall only be used when the cell data is retrieved form file.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Cell Data In | Cell cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |

## Insert New Peak Data Into Cell
**Description:**
Inserts a new peak into the peak array for a cell. The VI sorts the peak array after the names of the peaks.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Cell Pos | Integer | The position of the cell in the "Calib" cluster. |
| Info in | Info Cluster | |
| Peak Data In | Peak Data cluster | The peak data that shall be stored. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |

## Insert Peak Data Into Cell
**Description:**
Inserts a peak data into an existing position in the peak array.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Cell Pos | Integer | The position of the cell in the "Calib" cluster. |
| Info in | Info Cluster | |
| Peak Data In | Peak Data cluster | The peak data that shall be stored. |
| Peak Pos | Integer | The position of the peak in |

10

| | | the peak array. |
|---|---|---|

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |

## New Cell Name

**Description:**
This VI is used when the user shall enter a new name of a cell.
**Location:** Spiece.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |
| New Cell Pos | Integer | The position the new cell have in the array in the "Calib" cluster. |
| OK out | Boolean | TRUE if a name has been typed and the OK button is pressed. |

## New Detector Data

**Description:**
Adds a new position to the array of detectors in the "Calib" cluster.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |
| Last Detector Pos | Integer | The position of the last detector in the array. |

## New Splitter Data

**Description:**
Adds a new position to the array of splitters in the "Calib" cluster.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |
| Last Splitter Pos | Integer | The position of the last splitter in the array. |

## OpenFile*

**Description:**
Opens a file for input.
**Location:** Lofileop.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| File Type Selector | Integer | The type of file that is to be open. |
| File Types | File Types Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| File Types | File Types Cluster | |
| Info out | Info Cluster | |

## ReadFile*

**Description:**
Reads from file. The data that is read is stored in the "File Types" cluster
**Location:** Lofileop.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| File Type Selector | Integer | The type of file that is to be read. |
| File Types | File Types Cluster | |
| Ignore Change Activity | Boolean | If TRUE the VI ignores if the change activity is set. |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| End Of File | Boolean | TRUE if end of file is reached. |
| File Types | File Types Cluster | |
| Info out | Info Cluster | |

## Reset UNIT

**Description:**
This VI resets the UNIT, i.e. remove all cells from the revolver. The VI will NOT remove any data that has been entered. It will only remove the references to the positions in the revolver. If someone wants to remove all data, the file with the data has to be removed and the program restarted.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |

## Rotate Selected Motor To
**Description:**
Moves a selected motor to a new position.

The parameters that have to be configured are:
1. Upper position limit. Used to check that the position the motor shall move to. The position the motor shall be moved to shall be below this value.
2. Lower position limit. Used to check the position the motor shall move to. The position the motor shall be moved to shall be equal to or greater than this value.
3. Number of steps between two positions.
4. Number of positions for the motor.
5. Direction of movement.
6. Line for direction. This is the input line to the AT-MIO-16D card for the direction for the motor.
7. Line for movement. This is the line to the AT-MIO-16D card for moving the motor.

The parameters are found in table 28.

| Parameter | Motor 0 | Motor 1 | Motor 2 | Motor 3 |
|---|---|---|---|---|
| 1 | 1 | 7 | 10 | NA |
| 2 | 0 | 0 | 0 | NA |
| 3 | 16 | 100 | 40 | NA |
| 4 | NA | 7 | NA | NA |
| 5 | T | NA | NA | NA |
| 6 | 1 | 3 | 5 | 7 |
| 7 | 0 | 2 | 4 | 6 |

Table 28 The configuration parameters needed when moving a motor.

The device number and the digital channel for the AT-MIO-16D card must also be set. The values for these parameters are:
1. Device number for the AT-MIO-16D card: 1
2. Digital channel for motors: 2

**Location:** Revolver.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Choice | Integer | 0 = Detector (motor 5)<br>1 = Revolver (motor 6)<br>2 = Filter (motor 7)<br>3 = Beam splitter (motor 8) |
| Info in | Info Cluster | |
| New Pos | Integer | The position the motor shall move to. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Info out | Info Cluster | |

## Save All Cell Data
**Description:**
Saves all the data for the cells.
**Location:** FileOp.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| File Types in | File Types Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| File Types out | File Types Cluster | |
| Info out | Info Cluster | |

## Save Detector Data
**Description:**
Saves data from a measurement.
**Location:** Detektor.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Cell Detector | Array of DBL | The data from cell detector. |
| Cell/Ref | Array of DBL | The data from the divided values. |
| Info in | Info Cluster | |
| Input Wavelength | Array of DBL | The wavelengths the data has been recorded for. |
| Path | File path | The path and file name to the file. |
| Ref Detector | Array of DBL | The data from ref detector. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Info out | Info Cluster | |

## Select Demp Automatically 2
**Description:**
This VI selects the neutral density filters automatically.

The following data are set in the VI:
1. *"No points first"* The number of points that shall be used when finding the first output. This shall be low so the beam can be blocked fast if the intensity from the laser beam is to high.
2. *"No points"* The number of points that shall be used to find the average output from the detectors..
3. Maximum output from the detector 1. Is set to **4,0V**
4. Maximum output from detector 2. Is set to **4,0V**
5. Minimum output from detector 1. Is set to **1,0V**
6. Minimum output from detector 2. Is set to **1,0V**

7. The index number of the last neutral density filter. Is set to **9** (this equals 10 filter positions)

**Location:** Dempfilt.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Info out | Info Cluster | |
| OK out | Boolean | TRUE if the VI was able to find a filter. |

## Set Cell Data

**Description:**
The VI sets the parameters for a cell according to the save parameter.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Cell Pos | Integer | The position the cell has in the "Calib" cluster. |
| Default Data | Integer | The position pf the default peak data. |
| Info in | Info Cluster | |
| Last Data | Integer | The position of the last peak data for the cell. |
| Name | String | The name of the cell. |
| Pos In Revolver | Integer | The position the cell has in the revolver. |
| Save | Integer | Determines what dada shall be set:<br>1 = Name<br>2 = Pos in Revolver<br>4 = Default Data<br>8 = Last data<br>If Save = 9 then the Name and Last data is set. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |

## Set Detector Data

**Description:**
The VI sets the parameters for a detector according to the save parameter.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Detector pos | Integer | The position the detector has in the "Calib"cluster. |
| Info in | Info Cluster | |
| Name | String | The name of the detector. |
| Save | Integer | Determines what dada shall be set:<br>1 = Name<br>16 = Wavelength ON<br>32 = Wavelength OFF |
| Wavelength OFF | DBL | The wavelength where the detector stops to operate. |
| Wavelength ON | DBL | The wavelength where the detector starts to operate. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |

## Set Splitter Data

**Description:**
The VI sets the parameters for a beam splitter according to the save parameter.
**Location:** Array Functions.llb
**Input:**

| Parameter | Type | Description |
|---|---|---|
| Calib in | Calib Cluster | |
| Info in | Info Cluster | |
| Name | String | The name of the splitter |
| Save | integer | Determines what dada shall be set:<br>1 = Name<br>16 = Wavelength ON<br>32 = Wavelength OFF |
| Splitter pos | Integer | The position the splitter has in the "Calib"cluster. |
| Wavelength OFF | DBL | The wavelength where the splitter stops to operate. |
| Wavelength ON | DBL | The wavelength where the detector starts to operate. |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Calib out | Calib Cluster | |
| Info out | Info Cluster | |

13

## Test Program

**Description:**

With this VI the calibration program can run by it self with out interacting with the total LIDAR-application. It is possible to enter both the configuration and the calibration part of the program.

From the front panel it is possible to set the Test Mode parameter in the "Info" cluster. If this is done the application can be run as a stand-alone application.

**Location:** Program.llb

**Input:**

| Parameter | Type | Description |
|---|---|---|
| File Types in | File Types Cluster | |
| Info in | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| File Types out | File Types Cluster | |
| Info out | Info Cluster | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| File Types | File Types Cluster | |
| Info out | Info Cluster | |

## Which Button is Pressed

**Description:**

This VI is used to find out which button a user has pressed. The VI checks a string of Boolean and returns the index where a Boolean is true.

**Location:** Array Functions.llb

**Input:**

| Parameter | Type | Description |
|---|---|---|
| Input | Array of Boolean | |

**Output:**

| Parameter | Type | Description |
|---|---|---|
| Output | Integer | |

## WriteFile*

**Description:**

Writes data to file. The data shall be stored in the "File Types" cluster.

**Location:** Lofileop.llb

**Input:**

| Parameter | Type | Description |
|---|---|---|
| File Type Selector | Integer | The type of file that is to be closed. |
| File Types | File Types Cluster | |
| Ignore Change Activity | Boolean | If TRUE the VI ignores if the change activity is set. |
| Info in | Info Cluster | |

# The Clusters

## Calib Selector
**Description:**
This is a calibration selector. The names of the different calibration methods shall be defined in this selector.
**Location:** Controls.llb

| Parameter | Description |
|---|---|
| Calib Selector | Contains all the names of the calibration methods. |

## CalibCluster
**Description:**
The main cluster for the configuration part of the program.
**Location:** Controls.llb
**Parameters:**

| Parameter | Description |
|---|---|
| Cells | Array of all the cells that have been defined in the system. For more info see: **Cluster of Cell Data**. |
| Detectors | Array of all the detectors that have been defined in the system. For more info see: **Cluster of Detector Data.** |
| Last Cell | The index number of the last Cell that has been defined array *"Cells"*. If 5 different cells have been defined this number will be 5-1=4 (since the counting starts on 0). |
| Last Detector | The index number of the last detector defined in the array *"Detectors"*. |
| Last Splitter | The index number of the last beam splitter defined in the array *"Splitters"*. For the time being there is only one which gives *Last Splitter*=0. |
| Splitters | Array of all the beam splitters defined in the system. For more info see: **Cluster of Splitter Data**. |

## Cluster of Cell Data
**Description:**
This cluster contains all the data for one cell.
**Location:** Controls.llb
**Parameters:**

| Parameter | Description |
|---|---|
| Default data | The peak for which the calibration shall be done. The number is the index of the peak in the array *"Peaks For Cell"*. |
| Last Data | The index number of the last peak that has been defined in the array *"Peaks For Cell"*. If 5 peaks have been defined this number will be 5-1=4 (since the counting starts on 0) |
| Name | The name of the cell. |
| Peaks For cell | The array of peaks defined for the cell. This is also the data for which the calibration will be done. For more info |

| | |
|---|---|
| | see: **Cluster of Peak Data**. |
| Pos in Revolver | The position the cell has in the revolver. If the cell is not present in the revolver the value is -1. This value is saved to file through the *"File Types"* cluster. When the system is started this parameter makes it possible to find how the unit was configured when it was last in action. |

## Cluster of Detector Data
**Description:**
This cluster contains the data needed for the detector.
**Location:** Controls.llb
**Parameters:**

| Parameter | Description |
|---|---|
| Name | The name of the detector. |
| Wavelength OFF | This is the wavelength, in nm, for which the detector stops to work. |
| Wavelength ON | This is the wavelength, in nm, for which the detector starts to work. |

## Cluster of File Types
**Description:**
This is the cluster used when saving and retrieving data from file. This cluster contains information for all the elements that are saved fin the LIDAR system. In this description only the parameters used by the calibration program are explained. For additional information see [1]
**Location:** Controls.llb
**Parameters:**

| Parameter | Description |
|---|---|
| Calib Data File Path | The file path to the calibration data file. The path includes the file name. |
| Cell | The format of the data that is saved to the file. The information has the same format as for the Peak Data. For more info see: **Cluster of Peak Data**. |
| Cell Refnum | A position reference used by LabVIEW when reading and writing to the file. |

## Cluster of Peak Data
**Description:**
This cluster contains all the parameters for one peak. This is also the data that is used when calibrating.
**Location:** Controls.llb
**Parameters:**

| Parameter | Description |
|---|---|
| Calib Selector | The type of calibration method that shall be used for the peak. The parameters for the peak can be used differently depending on which calibration method that is used. |
| Diff Abs | The differential absorption cross section for the peak. |
| End Of Scan | This is the wavelength, in nm, where the scan shall stop when calibrating. |

| Start Of Scan | This is the wavelength, in nm, where the scan shall start when calibrating. |
|---|---|
| Step | The step, in nm, that shall be used when calibrating. If the value is not set is should be -1. |
| Wavelength OFF | This is the wavelength, in nm, where the peak has its absorption minimum. |
| Wavelength ON | This is the wavelength, in nm, where the peak has its absorption maximum. |

## Cluster of Splitter Data

**Description:**
This cluster contains the data needed for the beam splitter.
**Location:** Controls.llb
**Parameters:**

| Parameter | Description |
|---|---|
| Name | The name of the beam splitter. |
| Wavelength OFF | This is the wavelength, in nm, for which the beam splitter stops to work. |
| Wavelength ON | This is the wavelength, in nm, for which the beam splitter starts to work. |

## File Type Selector

**Description:**
This selector is used to inform what type of file that shall be used. In the calibration program the type *is "Cell Data"* = 1
**Location:** Controls.llb
**Parameters:**

| Parameter | Description |
|---|---|
| Sorting Selector | Type of file:<br>0 = Info<br>1 = Cell Data<br>2 = Meas Data<br>3 = Raw Data<br>4 = Eval Data<br>5 = Map |

## InfoCluster

**Description:**
This cluster is the main cluster for the LIDAR-system. This cluster contains information for the entire system but only the parameters used by the calibration program is explained. For additional information see [1]
**Location:** Controls.llb
**Parameters:**

| Parameter | Description |
|---|---|
| Calib Cell Rev Pos | The revolver position of the cell for which the calibration shall be done. The calibration data that is to be used for this cell is the default data for the peak. This data is stored in the *"Peak Data"* |
| Calib Detector Pos | The position of the detector that shall be used when calibrating using the cell selected in *"Calib Cell Rev Pos"*. When selecting a cell, the default data for this cell, determines which detector shall be used. |
| Calib Splitter Pos | The position of the beam splitter that shall be used when calibrating using the cell selected in *"Calib Cell Rev Pos"*. When selecting a cell, the default data for this cell, determines which beam splitter shall be used. |
| Current Detector Pos | The position the detector currently has in the calibration unit. |
| Current Filter Pos | The position the neutral density filter wheel currently has in the calibration unit. |
| Current Rev Pos | The position the revolver currently has in the calibration unit. |
| Current Splitter Pos | The position the beam splitter currently has in the calibration unit. |
| Error | This parameter is used to indicate if an error have occurred. |
| Peak Data | This is the data that is used when calibrating. This data is the same as the default data for the cell that is selected in *"Calib Cell Rev Pos"* The data is stored in Peak Data format. For more info see: **Cluster of Peak Data**. |
| Test Mode | This parameter is used to indicate that the program is run in test mode. If it is set then the program can run on a stand-alone PC, i.e. with out being connected to the calibration unit. |