Heart- and breathing rate belt – post crash need, cost and demonstrator

Master of Science Thesis

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HEART- AND BREATHING RATE BELT - POST CRASH NEED, COST AND DEMONSTRATOR

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ABSTRACT

Year 2007 nearly 500 persons died in Swedish traffic. In order to lower that number many factors must be changed. After a car collision, it is important to get the injured person to the hospital as fast as possible. This time is crucial for the person's survival and recovery rate and is often referred as the "Golden Hour". An automatic emergency call system integrated with the car that call an emergency operator after an accident has occurred could significantly lower this time. To help the development of these systems, a new standard protocol called eCall has been formed. The eCall protocol will be effective by year 2010. According to the protocol, the emergency systems should at least provide time, location and an identification number for the car at an accident. To additionally improve these systems with information, a prototype with a new technology found by Autoliv has been developed. The prototype uses fiber optics and measures the strain formed in the safety belt with a Fiber Bragg Grating (FBG) that reflects a certain wavelength of the light. These changes of wavelengths are measured by a spectrometer and are used to find the heart- and breathing rate of a person wearing the safety belt. The prototype was built to see if it could find the heart- and breathing rate and not cost more than 40 000 SEK. Before the prototype was built, a thoroughly medical study that aimed to find the interest and need of such an application was conducted. This study was mainly constructed from the interviews of 30 emergency professionals (SOS-operators, Ambulance crews, Fire men, Police men and Hospital personnel) within the pre-hospital chain. The result of the study showed a need for information about how many persons that are involved in the accident and how badly injured they are, parameters that a perfectly working prototype would provide. The different tests with the working prototype aimed to find the heart- and breathing rate during different situations. The results of these tests showed that the heart rate is hard to find because the spectrometer's resolution was to low. They also showed that the breathing rate was fairly easy to detect without any signal processing as long as the person did not move too much. Tests when the test object were wearing different layers of clothes showed that the heart beats could be detected as good when the test object was wear winter clothes as he was bare-chested. During the work have different aspects of consideration been found that would significantly decrease the total cost of the prototype.

Table of Contents

Appendix A

Appendix B

Appendix C

NOTATION

AD	Ambulance Director, **A**mbulans**D**irigerare
CCD	**C**harge **C**oupled **D**evice
dV	**d**elta **V**, the change of speed
ECG	**E**lectro**c**ardio**g**raphy
FBG	**F**iber **B**ragg **G**rating
GNSS	**G**lobal **N**avigation **S**atellite **S**ystem
LC	Fire departments’ command centre, **L**ednings**C**entral
LED	**L**ight **E**mitting **D**iode
MA	Medical commander, **M**edicinsk **A**nsvarig
MOS	**M**etal **O**xide **S**emiconductor
NHTSA	**N**ational **H**ighway **T**raffic **S**afety **A**dministration
RL	Lead commander fire department, **R**äddnings**L**edare
SL	Lead commander ambulance, **S**jukvårds**L**edare
SLD	**S**uperluminescent **L**ight Emitting **D**iode
TIB	**T**jänsteman **I** **B**eredskap
VIN	**V**ehicle **I**dentification **N**umber

1. INTRODUCTION

This master thesis went into the development of a prototype for an application to the automatic emergency call systems built after the standard protocol (eCall). To find the need for this application, a thoroughly medical study was conducted. The study was done by examine literature studies and by constructing a field study by interviewing emergency professionals e.g. SOS operators, ambulance crews, fire men, police men and hospital personnel. Some of the main questions answered in the study were:

- Who is most commonly first on the scene of a car accident?
- What information do the emergency professionals get and what information do they find most important?
- What information would they like to get that are not accessible today?
- Is it desirable for the emergency professionals to get information about the heart- and breathing rate of the car occupants?

The two main goals with the medical study were to find what information the medical professionals want that is not available today and to find if heart- and breathing rate of the car occupants is desirable. The second stage of the thesis, the development of the prototype, was built upon the results from the medical study and aims to get information about heart- and breathing rate via the safety belt. This was done by using fiber optics including a Fiber Bragg Grating (FBG) which was woven into the safety belt. This information could then be sent to the emergency operator which passes the information along to the emergency professionals.

If the outcome of the study showed that the emergency professionals preferred other information than heart- and breathing rate of a car occupant, another useful application using the technology would be identified and investigated.

1.1 BACKGROUND

Around 500 persons lost their lives in Swedish traffic 2007. This was a significant increase from the year before when 440 persons lost their lives. In US and EU were the corresponding numbers 43 500 and 38 500 respectively for 2006 and there were around 5 000 000 motor vehicle in use on the Swedish roads this year [1,2].

In Sweden, all work to improve safety on the roads by the Swedish parliament is based on “Vision Zero”. The vision has a final goal that no one shall be killed or injured for life in Swedish traffic. As a part goal on the way of reaching this goal, no more than 270 persons should die in traffic 2007 (Swedish Road Administration). The vision has an admirable goal, but according to The World Carfree Network statistics, a nine fold increment of cars in the world, from 70 million at the year 1950 to 630 million year 2006, has occurred [3]. With such an increase in cars driven today and a vision of zero deaths, new systems and car safety must be developed to even keep the numbers at a constant level as today. This growth and vision encourages and stimulates companies and organisations to develop these life saving systems.

Autoliv is one of these companies and this thesis describes a part of the work done to develop such a system. The company is one of the world leaders in automotive safety with 42 000 employees in 28 countries worldwide. Products as the safety belt and the airbags are two of the seeds developed by the company. Autoliv was established in Sweden 1956 by Lennart Lindblad and started to produce safety belts. In the late 1960's Autoliv started research in retractor belts and airbags. In 1997, Autoliv merges with Morton ASP to form Autoliv Inc. The American company Morton ASP was pioneers with airbags [28].

The faster an injured person gets to the hospital, the better are its survival and recovery rate. This elapsed time is called the" Golden Hour" and refers to this importance of getting to the hospital within one hour. According to National Highway Traffic Safety Administration (NHTSA), the average time in US is 52 minutes, however that time is assumed to be underestimated [31].

To reduce this critical time and add information about injured persons that can save lives, Autoliv got an idea of measure the heart- and breathing rate of a car occupant when an accident has occurred. The idea was born during a crash test at their own test setup in Vårgårda, Sweden. It could be shown that a force in the safety belt related to the heart- and breathing rate could be measured.

1.2 PURPOSE

The purpose in a first stage was to find out, through some field studies, literature studies and interviews, the way Swedish emergency professionals work and what information that is of importance at the scene of a car accident. The intension in this first stage was also to identify the desired information that are not currently available and presented today. This information exceeds the information sent with the upcoming emergency call system supported by the standardisation protocol eCall, e.g. time of crash, the car's Vehicle Identification Number (VIN), the exact location of the vehicle represented by satellite positioning and which service provider the vehicle is connected to. The main intention of the study was to find out if the emergency professionals need a system that can overview an occupants heart- and breathing rate. It also intended to find other desired applications to the emergency call systems and finding new ideas to Autoliv that could be developed into life saving products.

The second stage of the master thesis was to develop a prototype of the desired application, test and evaluate it.

1.3 DELIMITATION

From the conclusions drawn from the medical study, there are a couple of ideas regarding new products that could help emergency professional in their job to make better diagnoses about sending resources to a car accident. The ideas are obviously mentioned in the thesis, but are not investigated further.

How many lives that can be saved with a system that sends heart- and breathing rate is very hard to find out and require an extended investigation. Those numbers is therefore not considered in this report.

In the second part of the thesis, the work with the development of a prototype is described. The work is limited to just a prototype that measures the heart- and breathing rate of an occupant.
To develop the prototype, 40 000 SEK was disposable. This should include all components bought.

1.4 PROBLEM DEFINITION

- Do the emergency professionals want a system that can present an occupants heart- and breathing rate?
- Is such a system trustworthy concerning the possibility of measuring the heart- and breathing rate or is the technology insufficient?
- Is the developed system cost-effective regarding the automotive industry?

2. THEORY/SCIENTIFIC BACKGROUND

Following chapters describe the theory behind the technology and previous work done within the area.

2.1 PREVIOUS WORK DONE

2.1.1 MEDICAL STUDY

An initial general investigation of advanced eCall protocol has been conducted by Katarina Bohman at Autoliv Research in Vårgårda, Sweden. This investigation was made throughout work shops and interviews with highly experienced persons from hospitals and ambulance services in the region around Gothenburg, Sweden. This investigation showed an indication that an application of getting heart- and breathing rate could be of high interest. A literature study of the concept "Golden Hour" by Katarina Bohman has also been done.

2.1.2 TECHNOLOGY RESEARCH

The Institute of Photonic Technology in Jena (IPHT-Jena) has done initial work on safety belts with FBG sensors. That work aimed to show *the load effect on strain and intensity responses of integrated optical fibers in safety belt*. It also intended to give *an approach to fiber-optic monitoring of mechanical loads* [30]. Their test setup was similar to the test setup in this project except the costs for their components used, which was much higher. The tests was done on FBGs with different reflective wavelengths and intended to investigate properties of the fiber while exposed to strain. The conclusions from the load tests indicated that the fiber could be used for several different applications where measurement of heart- and breathing rate was one of them. According to the tests could these parameters be found when the FBG in the belt was placed over the person's heart.

2.2 ECALL

eCall is a standard protocol for electronic safety system in cars that automatic call emergency service if an accident occurs. The standardisation project is led by the European Commission and their goal is that every new car in year 2010 will have an emergency call system with eCall standard installed [4]. Electronic safety systems have existed for about ten years but have not been standardised and some automotive manufacturer have developed their own systems.

If a car is exposed to a major impact, the system automatically calls the nearest emergency centre. The system could also be triggered manually if needed. What happens next is that the system sends useful information about the crash through a data link and an SOS-operator tries to make contact by voice. If any of the car's occupants is being conscious the operator can be provided with valuable information. The automatic sent information is called "minimum set of data" and contains following details:

- Status: Was the system trigged automatically, manually or is it a test call.
- Vehicle identification: The car’s VIN.
- Time Stamp: Which time the accident occurred.
- Location: Positioning through Global Navigation Satellite System (GNSS). The only full operational GNSS today is GPS but the European Galileo positioning system is scheduled to be operational in 2010. The direction of travel based on the three last positions will also be included.
- Service Provider: The IP address of the service provider used by the system.

In further work, optional data will be included. In the specification of the “minimum set of data” there are 105 of total 140 Bytes that are not yet occupied. This data will be encoded in XML format [4].

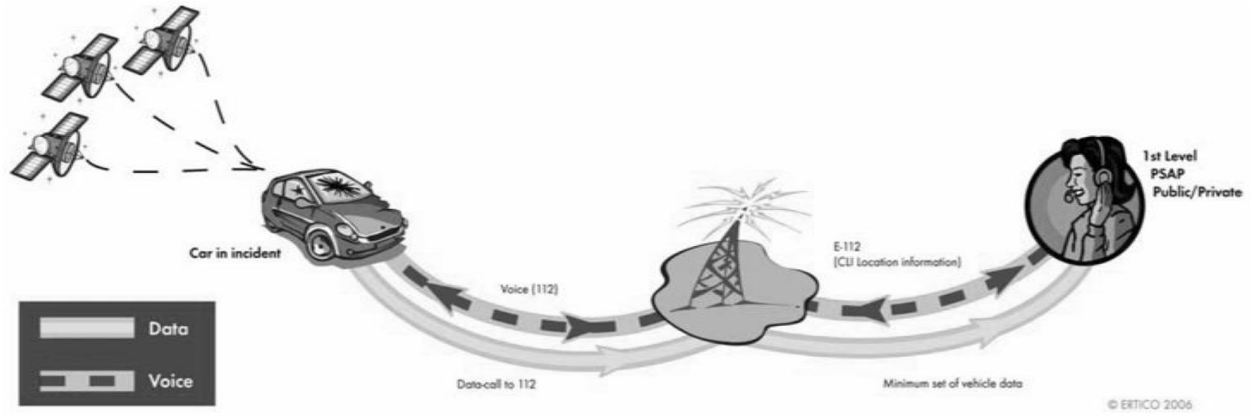


Figure 1. Overview of the eCall system [4].

Information that could be passed within optional data is for example; number of persons in the vehicle, speed and dV of the vehicle at an accident.

A report from the European commission states that over 2500 lives can be saved with an eCall standard system and the severe injuries can be decreased with 15 % in Europe. Due to the known location, the critical insertion time can be decreased with 50 % in rural- and 40 % in urban areas [5]. Faster treatment results in better recovery prospects for accident victims.

2.3 HISTORY OF FIBER OPTICS

Communication through light has been used for thousands of years. One example is the beacons on hilltops that gave an early warning that the enemy was approaching. One big problem the physicists have struggled with throughout the history is to lead light in another way than straight forward. During lectures in science 1841, a Swiss physicist by the name Daniel Colladon showed that light could be led inside a beam of water. He had a tank with two horizontal holes opposite each other, one sealed with a plate of glass which was connected to a light source and the other with a removable plug. He filled the tank with water and pulled the plug, as shown in Figure 2. The water flowed out in a parabolic arc with light trapped inside [6]. D. Colladon had found a way to lead light in another way than straight ahead.

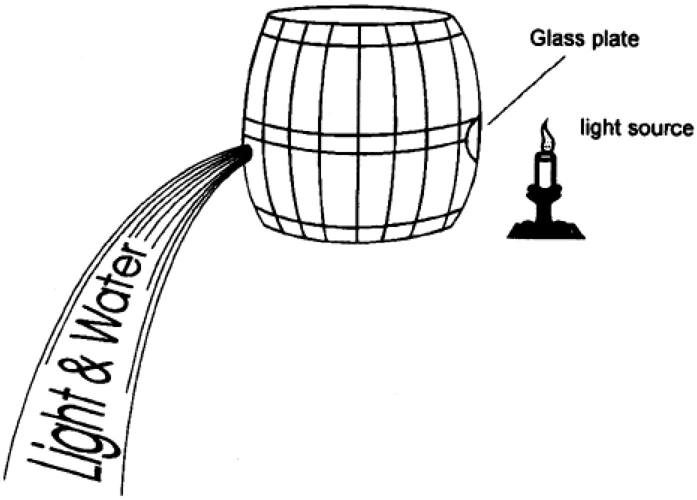


Figure 2. The first experiment of light trapped inside a beam of water [7].

The light was trapped inside the beam of water by a phenomenon called total internal reflection and is described later.

In the early 20th century, the development of glass rods able to lead light started, but it did not have a huge commercial impact on the market. In the late 1920's, an American electrical engineer by the name Clarence W. Hansell found a way to transmit images by thin glass rods tightly packed together. This later led to a patent. When those thin, unprotected fibers were tightly packed togheter, a problem occurred. They were scratched and light slipped out of the fiber. Even small changes such as grease from fingerprints changed the fiber characteristics, see Figure 3. Some sort of protection was needed to preserve the refractive index that made the total internal reflection possible and this will be described later. The Dane, Möller Hansen came up with an idea of coating the fiber with margarine, but this solution became very greasy [6].

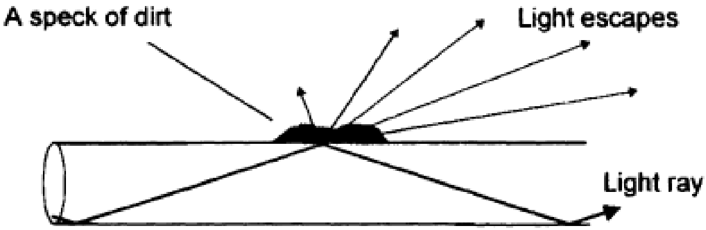


Figure 3. Result of dirt on fiber core [7].

1956, Larry Curtis, an undergraduate student at University of Michigan found a way of melting a tube of glass with a lower index over the pure glass core, see Figure 4. This glass cladding became later a standard procedure [6].

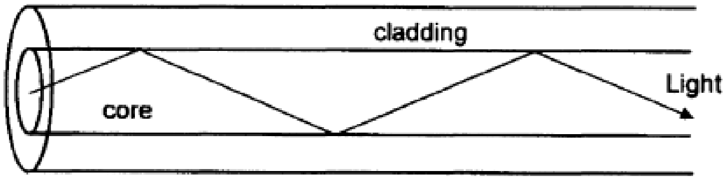


Figure 4. Melted glass cladding over the core [7].

2.4 THEORY OF FIBER OPTICS

The theory behind fiber optics will briefly be described in this section, which mainly is build upon Snell´s law. Snell´s law is in turn build upon the theory that every material has a specific refractive index, n, and is calculated by dividing the speed of light in vacuum with the speed of light in the material, see equation 1.

$$n = \frac{c_{vac}}{c_{mat}} \tag{1}$$

Where:

n= the refractive index in the material.

c_{vac}= speed of light in vacuum.

c_{mat}= speed of light in the material.

This index is always greater than 1 and the speed of light in a material can never be greater than the speed of light in vacuum. A normal index in fibers is 1.5 and for air 1.000293, which is close to 1 and therefore often used as reference [6].

2.5 SNELLS LAW

The Dutch astronomer, Willebrord Snell discovered 1621 that there was a relationship between different materials´ indices and the sine angles between them. This discovery led to equation 2 where n_1 is the refraction index of material 1, n_2 the refraction index of material 2, θ_1 is the angle of refraction by material 1 and θ_2 the angle of refraction by material 2. This is sketched in Figure 5.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \tag{2}$$

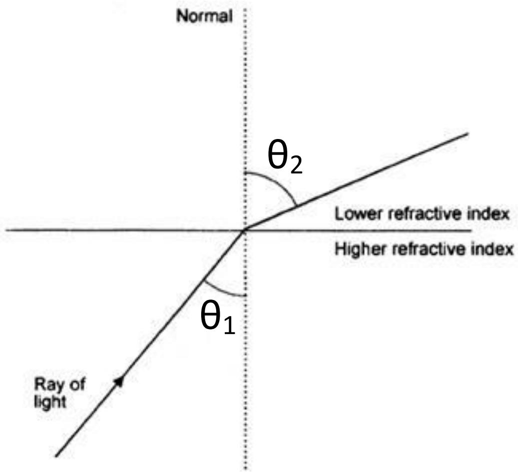


Figure 5. The refraction index and the angles.

By using equation 2 it can be shown that a beam of light goes from one material with a higher refraction index to one with a lower, the angle θ_2 will increase. If angle θ_1 increases until θ_2 will become 90°, Sin(90°)=1, the beam of light will be reflected back into material 1. This angle θ_1 is the *critical angle* and the phenomenon is called *total internal reflection*. Any beam of light with an angle greater than the critical angle will though bounce back into material 1. This is shown in Figure 6.

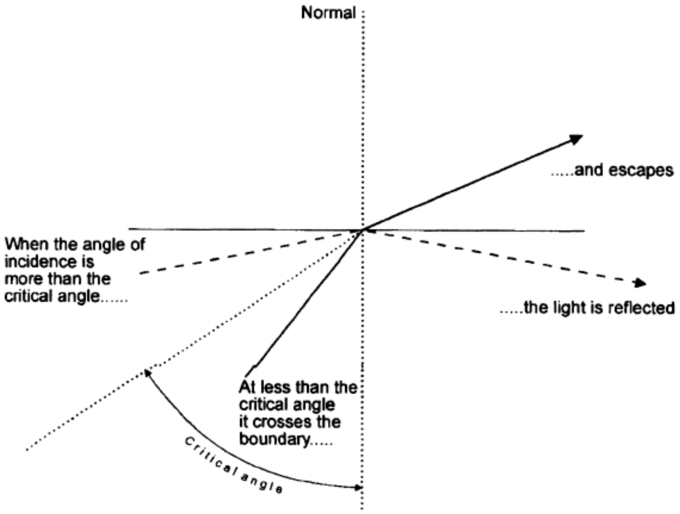


Figure 6. The total internal reflection [7].

2.6 FIBERS

There are mainly two types of optical fibers, single- and multi mode. The meaning of modes in fiber optics is the number of different paths the light propagates through the fiber. As the name says, single mode has only one mode and multi mode several. The numbers of modes (N_m) depends on the fibers´core diameter (D), the numerical aperture (NA), e.g. the angle of acceptance (critical angle described earlier) for the specific fiber. It also depends on the light's wavelength (λ) in the fiber and is calculated by equation 3 [6].

$$N_m = 0.5\left(\frac{\pi * D * NA}{\lambda}\right)^2 \tag{3}$$

The NA is in turn depending of the different refraction indices of core and cladding and calculated by equation 4 [9].

$$NA = \sqrt{n_{core}{}^2 - n_{cladding}{}^2} \tag{4}$$

The NA is very small in single fibers and it can therefore be a small problem to lead light into the fiber. This is not a big problem when using multi mode fiber where the NA is larger. The big advantage with single mode in this application is that only one wavelength is bouncing back from the FBG used and therefore only one wavelength to handle. If multi mode was used, there would be many wavelengths to distinguish between and would be harder to handle. This because of the different modes that light propagates through the core. The differences between single and multi mode fibers regarding how light propagates is shown in Figure 7.

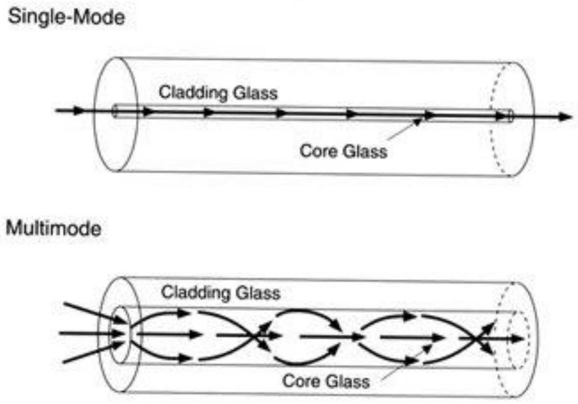


Figure 7. Comparison between light propagating in single and multi mode [8].

2.7 SCHEMATIC PICTURE OF THE WHOLE SYSTEM

The system is consisting of a light source, connectors, a coupler, the safety belt with a Fiber Bragg Grating (FBG) and a spectrometer. A schematic picture of the system is shown in Figure 8. The including components of the system will in turn be more described in the following paragraphs.

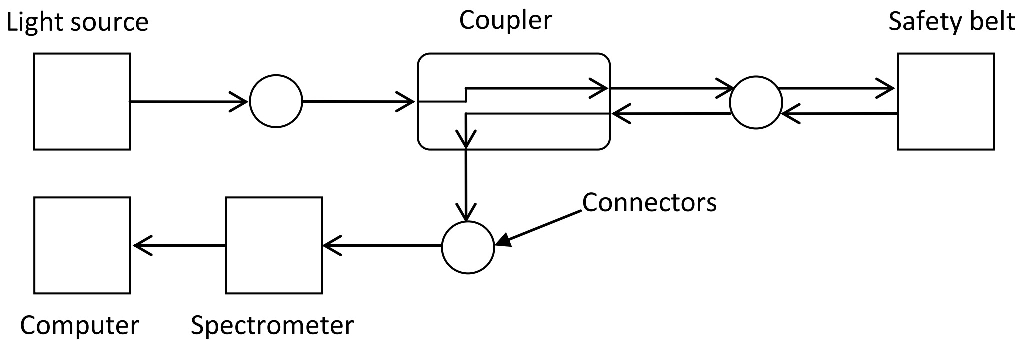


Figure 8. Block diagram of the whole system.

2.8 LIGHT SOURCES

When working with fiber optics, there are basically three different sources available, lasers, Superluminescent light emitting diodes (SLD) and light emitting diodes (LED). The main differences between the three are; lasers have higher output power and narrower bandwidth than LED. SLD is something between lasers and LEDs. Figure 9 shows the comparison with a laser and a LED, regarding output power and bandwidth. A typical laser has a bandwidth of about 2 nm and a LED has 30 nm.

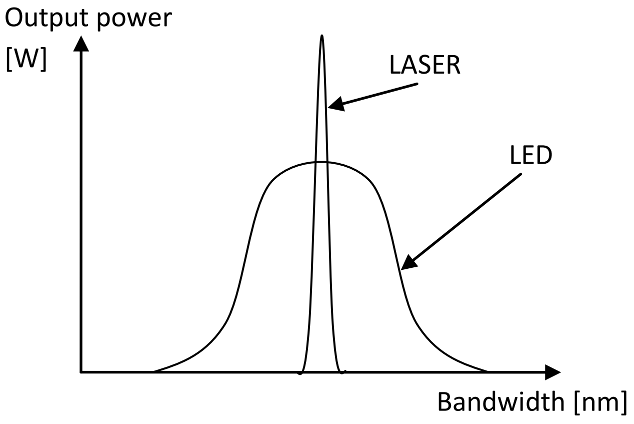


Figure 9, Comparison between LD and LED.

2.8.1 SUPERLUMINESCENT LIGHT EMITTING DIODES - SLD

"SLDs are based on laser diodes (LD). Superluminescence is the same as amplified spontaneous emission: The emission of fluorescence which experiences significant optical gain within the emitting device, and therefore can be relatively intense" [18].

SLD has some of p-n junction based LD's properties. It has the LD's high output power and low beam divergence but with a wider spectrum and low coherence. The big difference is that SLDs do not have optical feedback which suppresses the laser effect. This is done by reducing the reflection at either or both facets of the laser diode structure [19-21].

2.9 COUPLER

The coupler used in this project work has four ports and is a device that split up an incoming signal (Port 1) into two outgoing (Port 2 and Port 3). There is a fourth port as well, Port 4, see Figure 10. The function of the coupler is to transfer light from a light source, through the coupler. Port 2 is connected to the FBG in the safety belt. The reflected light is then transferred back via Port 2 and measured with a spectrometer connected to Port 4. Port 3 is not in use in this application and is therefore terminated, but is during the tests connected to a power meter.

There are mainly two types of couplers; mechanical- and fusion made. In mechanical made couplers, the connected fibers are held together with either glue or clamps. In fusion made couplers the fibers are instead melted together [6].

There are several ratios regarding the amount of light divided between port 2 and port 3, typical rations are 90:10 or 50:50 e.g. 90 % of the light transferred from port 1 to port 2 and 10 % of the light to port 3. 50:50 is the ratio used in this work.

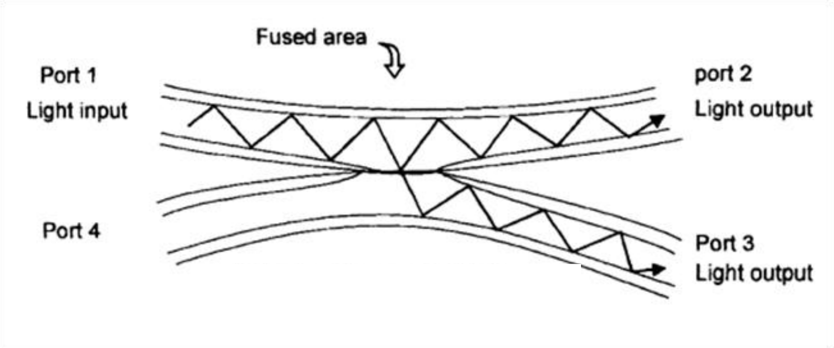


Figure 10, The principle of a coupler.

2.10 FIBER BRAGG GRATING - FBG

FBG sensors are based upon three principals, Fresnel reflection, the theory of Bragg's law and the discovery of fiber photosensitivity.

The French Augustin-Jean Fresnel made a lot of research in optics and was active in the early 19th century. He came to the conclusion that when light travels from a medium to another with a different reflection index, light can be both reflected and/or refracted.

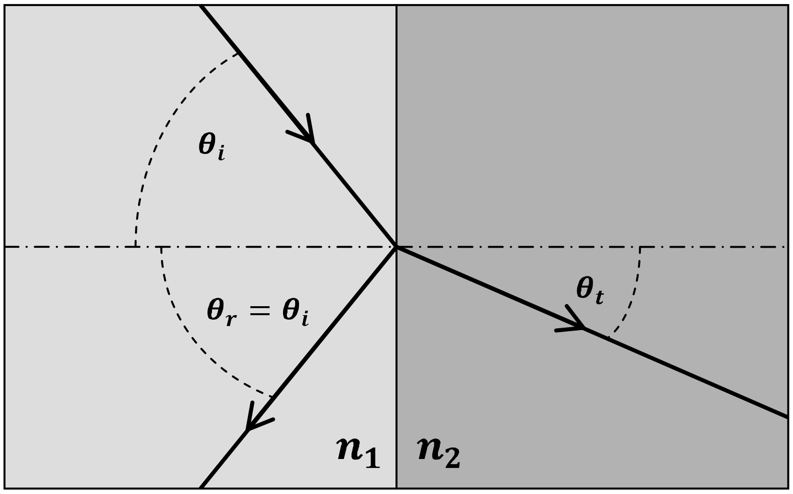


Figure 11. The figure describes a beam's possible direction and scattering when entering a medium with another index of reflection. $\theta_i = \theta_r$. θ_r is the angle of the refracted beam.

In 1915 William Lawrence Bragg and his father William Henry Bragg were awarded the Nobel Prize in Physics. The Bragg's law is the outcome of research showing why x-ray radiation is reflected from NaCl, ZnS and diamond crystals. The law is also applicable with other radiations and materials. If the Bragg's law is fulfilled the phase of the beams will coincide after bouncing against the crystal's atom plane [10].

Bragg's Law is

$$n\lambda = 2d\sin\theta \tag{5}$$

where n is an integer, λ is the wavelength, d is the distance between the layers and θ is the incident angel. For example fulfils the following input the law: $\lambda = 3.0$, $d = 3.0$ and $\theta = 30.0°$ and gives

$$3.0 = 2 * 3.0 * \sin(30.0)$$

which is true. If the distance between the layers is changed the law is no longer fulfilled and the beams will not coincide.

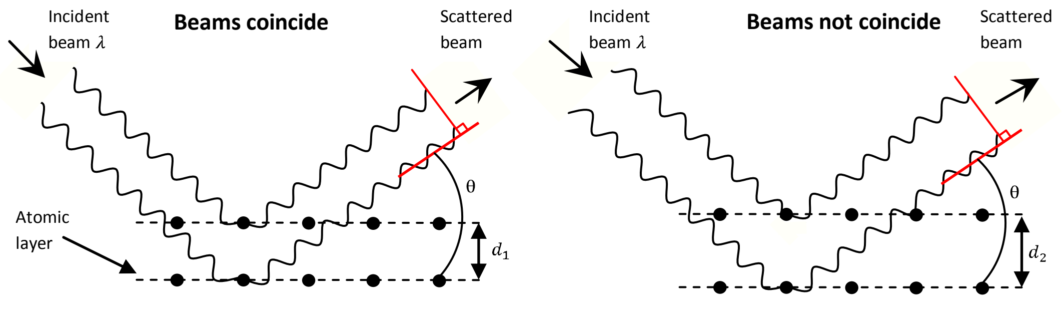


Figure 12. Conditions for when beam's coincide with each other depending on the length (d_1, d_2) of the atomic layer.

In 1978, Ken Hill and his co-workers at the Canadian Communication Research Center made the discovery that a germanium-doped (Ge) fiber was photosensitive. When testing a special designed Ge-doped fiber and its nonlinear effect with a visible argon ion laser (488 nm) as a light source something unpredictable happened. After extended exposure, an increasing attenuation in the fiber was discovered and a closer investigation also showed that the back reflected light increased considerable during exposure. What happened was that due to the chopped open end of the fiber, 4% of the light was reflected back in the fiber. This is a known phenomenon when light from a fiber travel into air and is called *Fresnel reflection*. The reflected beam initially formed a weak standing wave intensity pattern and the high intensity points changed the refraction index in the fiber core permanently. This refractive index grating did now work as a distributed reflector and is explained by Bragg's law. The reflected beams now coincide with each other and the reflection got stronger until the refraction index level was saturated [26]. This new invention was given the name Fiber Bragg Grating.

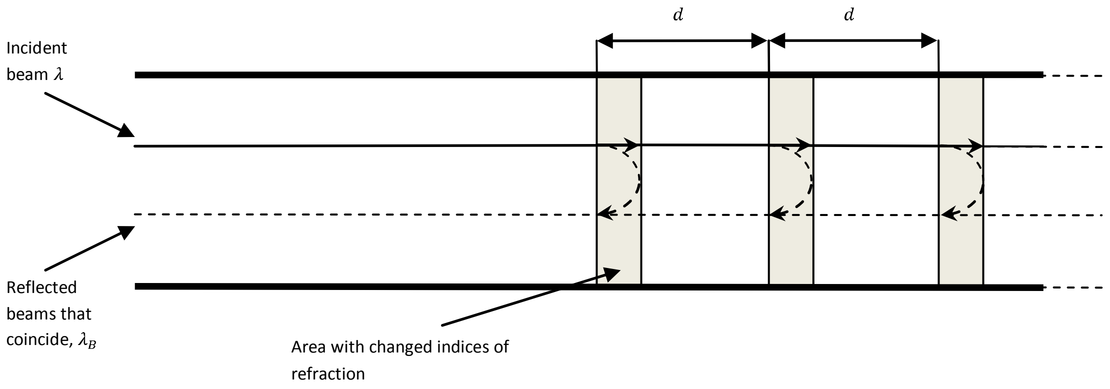


Figure 13. A simplification of how light travel inside a fiber with a fiber Bragg grating. The areas with changed indices of refraction now work as the atomic layers in Figure 11 due to the Fresnel reflection. The more of the areas with different indices, the greater the reflection gets. *d* is the distance between the areas and is often named *Λ*.

In 1989 Meltz et al. showed that a change of the refraction index occurred when a Ge-doped fiber was exposed to single-photon UV light. Later studies have shown that other fibers doped with Europium, Cerium and Erbium also change their indices of reflection but Germanium is more sensitive. The most sensitive are fibers doped with Germanium and Boron and this is the fiber used in this work [27].

Fiber Bragg gratings are today created with UV laser. The UV laser “writes” a desired pattern into the core of the fiber. Different pattern gives special properties that may be desired.

A Fiber Bragg Grating basically reflects a specific wavelength. The wavelength reflected depends on the distance between the gratings. When the fiber is stretched or bended the distance between the areas with different indices of refraction is changed. This is why different wavelength is reflected and it is called *Bragg wavelength*.

The formula that decides which wavelength that is reflected by the grating is

$$\lambda_B = 2\, N_{eff}\, \Lambda \tag{6}$$

and based on Bragg’s law [22]. λ_B is the Bragg wavelength. N_{eff} is the effective reflective index of N_2 and N_3 and Λ is the grating period, see Figure 14.

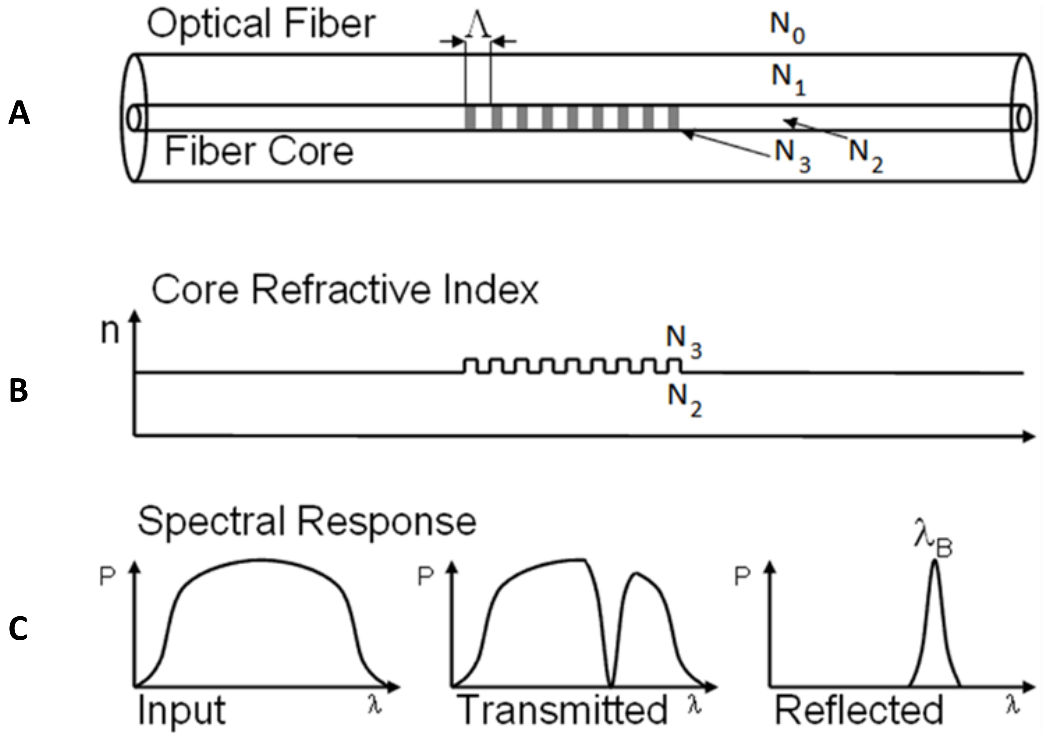


Figure 14. A diagram of a Fiber Bragg Grating (A). How the refractive index is changed along the core is shown in part B. The spectral response when transmitting a broadband source in the fiber is given in part C. The reflected signal is about the Bragg wavelength.

2.11 THE SPECTROMETER

The spectrometer is the measuring device in the system, where the intensity of the wavelengths of the light is measured. The spectrometers today come in a very broad range of sizes and shapes. The performance and prices varies a lot and can to some extension be related to an abundance of applications. Two common applications are to measure the wavelengths and their intensity in a beam of light and to find molecules in different gases, liquids and masses. Many of the spectrometers are built upon some different general principles. The spectrometer used in the prototype is built upon the *Czerny-Turner method* where mirrors, diffraction grating and charge coupled device (CCD) are the main components. This method measures the intensity of the different wavelengths and uses *Fourier Transform* in the data process.

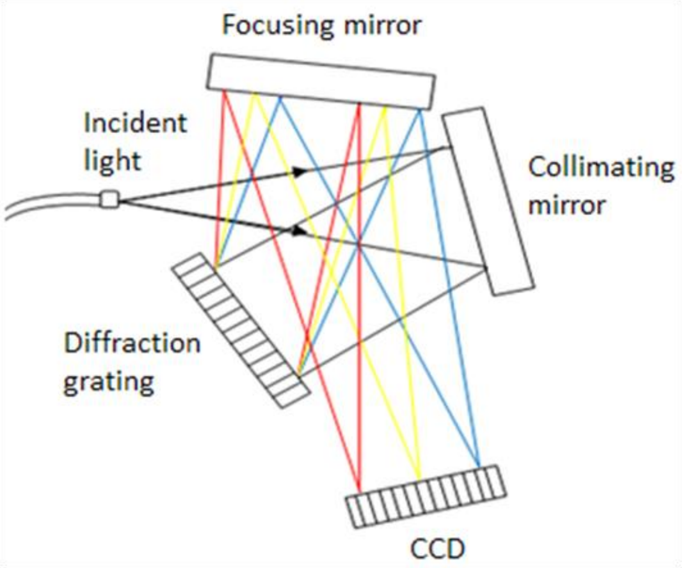


Figure 15. Main components and principle of the spectrometer. The incident light hits a collimating mirror that arranges the light to parallel beams, these beams hits the diffraction grating that disperse the light into a spectrum. The wavelengths in that spectrum is focused to a wavelength corresponding position on the CCD.

The incident light from the fiber propagates into the spectrometer with a certain angle. This angle depends on the dimensions of the fiber and if it is a single or multi mode fiber, the single mode fiber has a narrower angle than the multi mode one. This beam of light hits a collimating mirror which adjusts the beams to parallel beams. These beams of light hit the diffraction grating that disperses the beam to a spectrum of lights with different wavelengths. The spectrum is also reflected at the diffraction grating and the spectrum hits a focusing mirror which focuses the different wavelengths to a certain wavelength related position on a CCD. The CCD transforms the intensity of the wavelength to a voltage which is measured and translated with a data acquisition device [11-13].

2.11.1 THE DIFFRACTION GRATING

The diffraction grating is used for spectral dispersion and consists of parallel slits etched on a holographic or reflective surface. These are very closely placed, usually 1800 – 3600 slits/mm and it is very important that the distances between the slits are equal and that they are of the same size. When the beam of light hits the grating, they are diffracted and create a spectrum of different wavelengths. The slits also make the light disperse and the more slits, the wider dispersion. When the light is diffracted and the spectrum is created, spectrums of higher orders are created. These are displaced in wavelength and are of lower intensity. To avoid these undesirable spectrums an inbuilt filter is used. The diffraction grating used in the spectrometer for the prototype uses equidistant slits placed upon a reflective coating on a plane surface and have 1800 slits/mm [14]. Another method to separate different wavelengths to a spectrum is a prism, but this method is not commonly used in spectrometers today.

2.11.2 MIRRORS

The incident light from the fiber hits first a mirror that collimates the light to parallel beams. The second focusing mirror is used to focus the wavelength to the CCD.

2.11.3 CHARGE COUPLED DEVICE - CCD

The CCD is the part in the spectrometer which transforms the light to an electrical signal. The CCD is a plane plate which consists of many closely parallel spaced series connected semiconducting capacitors which reacts by the intensity of the light [15]. These small semiconducting capacitors are made from silicon (often a metal oxide semiconductor, MOS) which has been doped with other materials to construct positive and negative layers in its structure. Each semiconducting capacitor has a gate at one end of the surface. The intensity of the light that hits the CCD causes movement of the electrons and creates a voltage that is stored in a bulk of the semiconducting capacitor. The higher the intensity, the higher voltage is created inside the capacitors. The capacitors in the CCD are commonly described as pixels and every pixel is placed so they only get the light from a certain known wavelength of the light. The central CCD pixel in the spectrometer used is calibrated to measure the intensity in the wavelength of 837 nm. The voltage created in the different pixels works as charge storage that are transferred to an output from the CCD as in a shift register [16]. This transport of analogue voltage packages is done by sending digital pulses to the gate on the pixels. When a clock pulse is sent to the gate, the voltage package in one capacitor is transferred to the one next to it. By sending adequate pulses, all voltage packages can exit and be transformed and processed. These pulses are frequently sent and the CCD in the prototype has a maximum trigger frequency of 500 kHz. The size of every pixel is 7 × 200 µm.

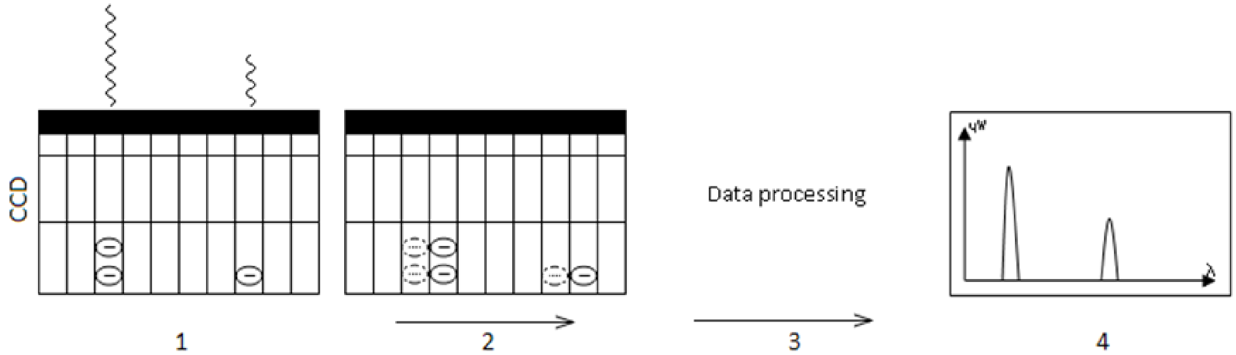


Figure 16. 1) The incident light hits the CCD and some electrons are transferred from one state to another. 2) The created voltage is transferred to the output via added clock pulses to the CCDs gates. 3) The output voltage is processed and transformed. 4) The transformed voltage to wavelength and intensity is visualised.

2.12 THE CONNECTORS

In the system presented, the FC/APC connectors are used at as many places as possible. This is done in order to avoid unnecessary reflections in the connections between the different fibers. This connector has an angle of 8° which deletes the Fresnel effect of 4 % reflection in the junctions that otherwise is created. At the connection between the coupler and the spectrometer, a SMA connector is used which is not angled and increases the rate and possibilities of reflection. This problem can not be avoided when that component only was manufactured with this design.

2.13 THE SAFETY BELT

If a gentle force is applied at one of the in-woven fiber ends the fiber glides inside the belt. This makes the extension of the fiber lesser than if it would be fixed to the belt. The signal from the FBG depends on the extension and would therefore in some way be attached to the belt. Though, some kind of rubber band solution is preferred, the thin glass fiber could otherwise break if a large and sudden force should be applied to the belt, e.g. a crash. Figure 17 shows the bare fiber end out from the safety belt.

Figure 17. The bare fiber end out from the safety belt.

2.14 HEART- AND BREATHING RATE

When diagnosing a patient, the heart- and breathing rate is of great importance for evaluating vital status. At the scene, emergency professionals make a first judgment by looking at the patients consciousness and if it is possible to communicate with the injured.

By investigate the heart rate, a first diagnose can be made. If there is no pulse, the patient is often beyond rescue. This could be due to ventricle fibrillation and is causing the heart to mechanical failure e.g. the heart is not possible to beat depending of too intense electrical signals from the muscle. Another reason could be that the heart muscle is damaged. Measuring fibrillation is only possible with Electrocardiography (ECG) and not with mechanical measurements.

A high heart rate, above 90-100 beats/min depending on age, indicates on stress reaction. The reason for this could be pain or inner bleedings.

An irregular heart rate is telling that something is wrong with the heart. This could be due to a cardiac infarction that made the driver lose control of the car and crash. A low heart rate, 30-40 beats/min, is also an indicator of a cardiac infarction.

A fast breathing rate is another indicator of stress. A very low breathing rate is dangerous because the blood will not get enough oxygenated and this may lead to unconsciousness and brain damages. A to high breathing rate make the oxygenated function of the lungs inefficient and could lead to the same cause, a normal breathing rate is 12 breaths/min.

The most important of heart and breathing rate is the heart rate [23].

By logging these two rates over time you can get a reference to the specific person and this could be of use to determine if any of the rates are rising and falling. This information is of high use to emergency professionals in order to see if the person's vital status gets better or worse.

3. METHOD

3.1 DESIGN OF MEDICAL STUDY

The study will be done by examine literature studies and by constructing a field study with interviews of emergency professionals.

There are different methods to collect information about possible new products. The two main methods are observation– and question based. Observation based is useful when studying a customer's behavior or a competitor's marketing etc. Question based methods are based on different forms of interviews and surveys. In this case, the question based method was chosen because of its ease to use and carry out. There was not an option to go with an ambulance or fire truck and study the crew. In an early product development phase it is also recommended to use a qualitative method instead of a quantitative [24].

Question based methods could have the form of very structured to a non-structured design and include one individual to a group of people. An example of a non-structured design is written surveys and interviews with in advance made questions. A non-structured interview is based on an *interview plan* with different subjects that could be interesting to discuss. In an interview like this the interviewed person has the freedom to discuss and express them self about the subject. The result is a summarized picture [25].

An interview plan is built up with a few common questions in the beginning and later with more specific and deeper going subjects.

Another aspect to consider is how many people that should be interviewed. The more the better is often an aim. According to several studies, it is enough to interview a smaller group of people and still identify the main demands and problems. 10 participants are often an insufficiently amount and 50 is unnecessary [24].

When choosing the participants it is recommended to use representative users of the target group. *In this case the target group is, in a first stage, emergency professionals and the aim is to help them prepare and to get a better picture of the crash scene.* To make a trustworthy result it is also important that expert users are included [24]. This would be doctors and higher ranking officers in this case.

The general disposition of the *interview plan* was to first get a general picture of how the participant works during an assignment. Later the participant was guided to think and explain things that in the future could help them do a better job. The last question was if heart- and breathing information could be of interest. In the second part it is important to avoid leading questions to the participant.

3.2 DEVELOPMENT OF PROTOTYPE

The free fiber end from the safety belt is welded onto a patch cable which is cut off at the welded side, (SM800-5.6-125) this is done by using Ericsson FSU 925 splicer at MC2, the fiber group at Chalmers. It is very important that the dimensions of the two fibers are similar, regarding losses and reflections. For more data of components used, see appendix A.

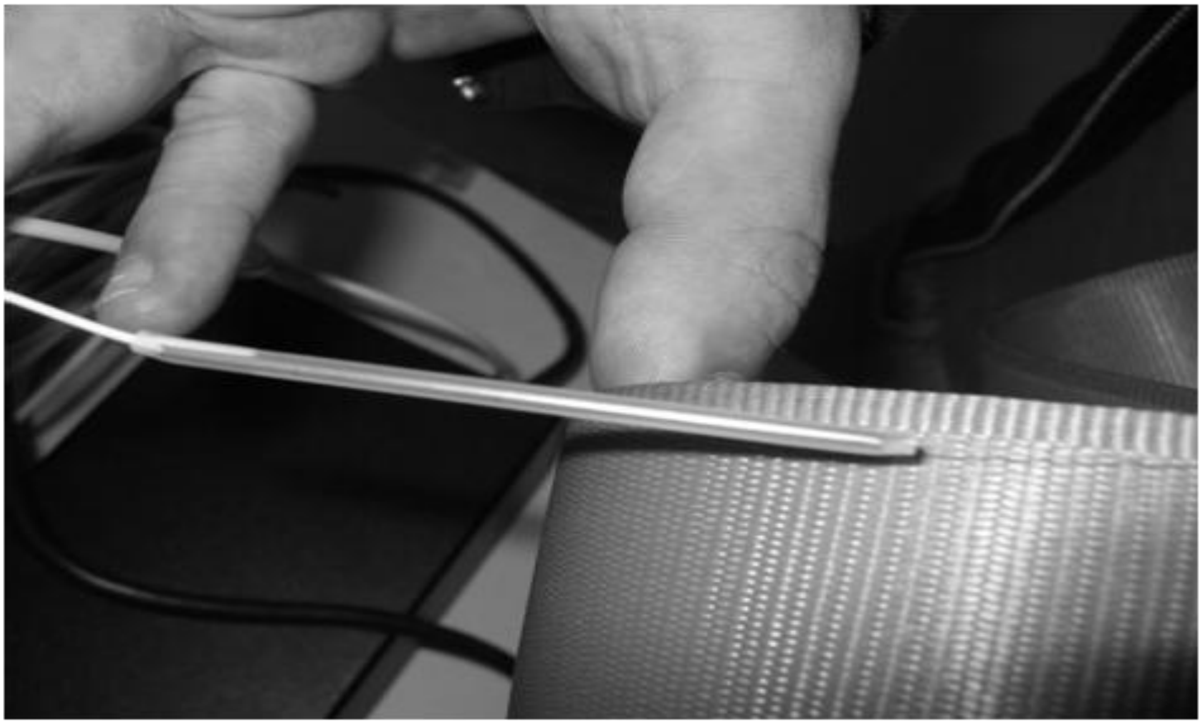


Figure 18. The welded patch cable and free fiber end from the safety belt.

The SLD (SOA-370-TO5.6) used is very sensitive regarding current and voltage peaks and was therefore connected to a laser diode controller, LDC 2000. It is also important to limit the forward current to the SLD which is 90 mA. To be on the safe side, the limitation was set to 80 mA. This was done with a small adjustment screw on the controller unit. To lead light into the fiber core, a frame construction was used, see Figure 19. The frame is equipped with three adjustable micrometer knobs. A schematic sketch of how to tune in the light into the fiber is shown in Figure 20.

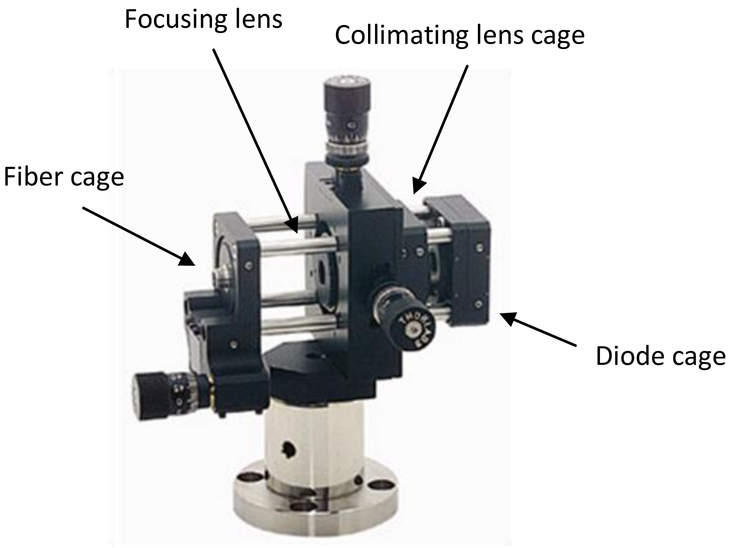


Figure 19. The KT112/M and its different parts.

The light is first cumulated to parallel beams by a collimated lens. When the SLD and the collimated lens are placed inside their cages, they can be moved in z-direction on its sliding rods. The collimating lens cage was locked with its locking screws, the SLD was switched on and its cage was moved back and forth until the spot of light one meter away from the frame was as small and concentrated as possible. To be able to see the IR light, a fluorescence card, VC-VIS/IR, was used which translates the IR light into a wavelength that can be seen by the eye. When the collimated lens was optimized, the size of the spot was not changed over distance, e.g. the size of the spot is the same when moving the card back and forth in space. This step was done in a dark room, the spot could otherwise not be seen.

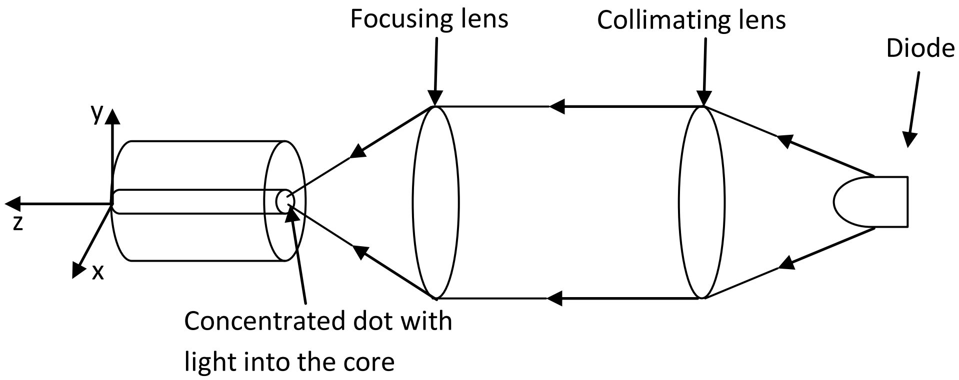


Figure 20. The idea of tuning the light source into the fiber.

Next step was to focus the spot into the fiber. This was done by placing the focus lens and the fiber in their cages. The focus lens can be moved in x- and y-direction by turning the tuning knobs. The fiber can be moved in z-direction by its knob. By connecting a power meter PM20A at the other end of the fiber, the x- and y-direction was tuned until an optimum was reached. Then the z-direction was tuned. Those steps are then done all over again until the maximum was reached. The knobs are locked by locking screws and the light source was tuned.

Next step was to connect all parts in the system, light source, coupler, safety belt including FBG and spectrometer. The test setup for the whole system can be shown in Figure 21.

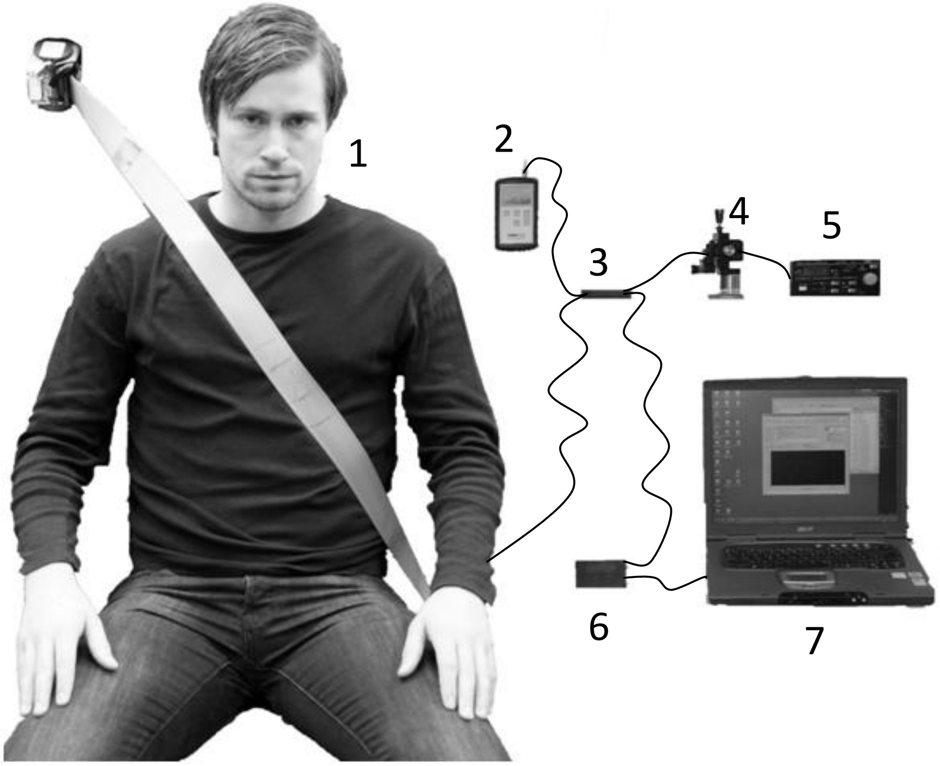


Figure 21. The test setup, 1) Test object, 2) Power meter, 3) Coupler, 4) The frame construction which lead the light into the fiber core, 5) Laser Diode controller, 6) Spectrometer, 7) Computer.

With the test setup above, the tests can be started. To collect data from the spectrometer, a modified version of the program Sample was used. The data is saved in three text files, log_intesity.txt, log_wavelength.txt and log_info.txt. The log_intesity file logged the intensity from the peaks, log_wavelength corresponding wavelength and log_info saved the setting for the spectrometer, e.g. integration time, manufacturer, Serial number etc. To analyze data, a written Matlab program, wave_at_level.m is used, see appendix C. This m-file imported the saved text files; log_intesity and log_wavelength respectively. The saved data is stored as a vector where every row in the vector is one set of data (screen dump) and corresponding columns is the absolute intensity for the log_intesity.txt file. The m-file is then finding the maximum values of the intensity (y-axis) and the positions of those maximum values are saved in another vector. Corresponding wavelengths at those positions are then found, saved and plotted against the elapsed time.

4. MEDICAL STUDY

This medical study of car accidents intend to show the way emergency professionals work after such an accident. It will focus on identifying the information passed along throughout the so called “Golden Hour-chain”, from accident to that the injured person get medical care at the hospital. The information between the different professionals, what information they get and what information they would like to get was also focused. The desired outcome of the study was to find what information, in an early stage that could be passed along in order to improve the emergency professionals rescue work so they at a higher level could save lives. The study was based on information and statistics from people involved in Swedish car accidents, from literature studies done in the area and most important, from interviews and discussions conducted with Swedish emergency professionals.

In total, 30 persons were interviewed and we would like to give a special thank to those persons, for their great interest to participate and to their forthcoming. The time they took to show us around and share their thoughts and experiences were very much welcomed and the medical study could not have been done without them. The following persons were interviewed;

Victoria Ingefors SOS operator (nurse) Gothenburg, Cindy Bergström SOS operator/Ambulance director Stockholm, Pia Johansson Ambulance nurse Sotenäs, Reile Hellqvist Ambulance nurse Borås, Pontus Tännström Ambulance nurse Tyresjö, Anette and Markus Ambulance nurses NÄL, Petter Sparringman and Anders Törmlänk Ambulance nurses Öjersjö, Kathrine Ringvall Director of Ambulance Kiruna, Stefan Good Director of Ambulance Borås, Anders Bodén Chief physician Ambulance Borås, Michael Johansson Special emergency car Huddinge/Södertälje, Lars-Göran Special emergency car NÄL, Annika Hultstrand and Annika Anesthesia nurses in special emergency car NÄL, Christian Karlsson Firefighter Borås, Håkan Karlsson Firefighter Torslanda, Peter Westman, Leif Karlsson and Martin Ekdahl Firefighters Öjersjö, Thomas Hjelm Fire officer Öjersjö, Per-Anders Näsström Fire officer Borås, Björn Elfström Fire department command centre operator Gårda, Ulf Magnusson Fire department command centre chief Gårda, David Westholm triage nurse Skövde, Gunilla Wihlke Chief nurse trauma unit Stockholm, Jonas Bengtsson Emergency doctor (helicopter) Gothenburg, Anders Östlund Anesthesia doctor trauma unit Stockholm, Robert Cleverup Police Borås, Henrik Barkestam Police academy Växjö.

The questions asked to these persons varied from general questions to get a broad view of their work, to very specific questions to identify the access, lack, need and desire of information. Some examples of typical questions were:

- What is the first information you receive?
- What information do you need in an early stage?
- What information is the most important for you?
- What information would you like to get in the future?

4.1 THE "GOLDEN HOUR-CHAIN"

To find and identify the flow of information, it is important to understand and get a big picture of how the pre-hospital care is made out; from the witness calling to that the injured person is on the hospital. The next chapter will briefly describe this care. It can be divided into following main subdirectories:

- Notification phase, often a phone call (112) to an SOS-operator. The phone caller gives information about the accident.
- Emergency operator dispatches ambulance crew and fire department (emergency professionals) to the crash site.
- Emergency professionals transports to the crash site via car, truck or helicopter.
- Emergency professionals arrive at crash site and makes necessary procedures.
- Ambulance crew transports the injured patient to hospital.
- Arrival at hospital and the injured patient is handed over to hospital personnel for further treatment.

4.1.1 SOS-OPERATOR

When a car accident happens, most commonly, a witness calls in the accident to an SOS-operator at the common European emergency phone number 112. At some rare cases, the person involved in the accident is calling, but commonly not at severe single accidents. Depending on time, place and number of witnesses, the operator evaluates the reliability of the call. If there is only one witness calling in rush hour, it can probably be a prank caller. The SOS-operator asks the witness a couple of basic questions stated below [17]:

- What has happened?
- Where has the accident occurred?
- What phone number are you calling from?
- How many are injured and what kind of injuries do the wounded persons have (e.g. head injuries, large bleedings and fractures etc.)?
- Is anyone jammed inside the car?
- What kinds of vehicles are involved in the accident?
- If it is a truck, can you see if there is an orange sign with the text; "hazardous goods"?
- If it is an accident on a motor way, in which direction?

Based on the answers the SOS-operator gets from the witness, the operator connects the call to the fire departments' command centre (LC) and a SOS-operator that only works with dispatching ambulances, the ambulance director (AD). The persons at those positions can now hear the call as well. The LC and AD can state and support the SOS-operator with further questions when the call is ongoing but can not talk to the witness in person. LC is in charge of the fire department and AD to the ambulance personnel respectively.

The AD summarise the information collected from the witness and send it to one or several ambulance crews depending the extent of the accident. The crew gets the information as a selective search to their personal pager via radio and in most regions also as a printed text message via the system Mobitex installed in the ambulance. This information can sometimes be very brief, but more witnesses are calling and updates about the accident are made. The updates are henceforth made by radio.

In similar ways, the LC is summarising the information and passes it to the fire department.

4.1.2 EMERGENCY PROFESSIONALS TRANSPORT TO THE CRASH SITE

AMBULANCE

When the ambulance crew receives the selective search on their radio and the text message via the mobile data communication system Mobitex, they respond to the radio call and confirm that they have received the information on the text message. They also confirm that they are on their way to the location stated on the written text message and calls in to SOS if they are in need of more information. If only one ambulance is sent or if the ambulance crew are the first ambulance on the scene of the accident, it is common that the initial information is the only information the ambulance crew receives before arrival. If some vital additional information is found by the SOS operator, this is also sent.

FIRE DEPARTMENT

The fire department is the only rescue service in Sweden that stands in standby and just waits for an alarm. When an accident occurs they get the alarm about the accident throughout a speaker at the station or through a selective search on their pagers (part time workers). Depending if the station is a full time or a part time working station and what region the department is located the response time varies, but a typically response time is (i.e. the elapsed time from notification by the alarm to when the crew leaves the station) 90 seconds. The call they receive from the speaker at the station is directed from the LC. On the way to the accident, the crew receives more information through a speaker in the fire truck. The commanding fire man is able to exchange information with the LC on the way to the accident.

POLICE

The police get the information about the accident through the police dispatcher. Due to a heavy work load and lack of resources, the police almost never arrive first to the accident.

4.1.3 EMERGENCY PROFESSIONAL ARRIVE AT CRASH SITE

AMBULANCE

When the ambulance crew arrives at the scene of accident, they first send a brief report to the AD, a so called windshield report (vindruterapport). This report usually contains brief information about how many cars or what kind of motor vehicles and an estimation of how many persons that are involved in the accident. After this report they (if they are first on the scene of accident) first place their car in such a way that their working environment is safe to work in and walks around the accident to get an overview to find more details to report back. They walk around and do a brief categorisation of the persons involved and start to take care of the most injured occupant. If there is an accident with several persons involved, which requires more ambulances, the first ambulance crew takes a command position where one of the two in the ambulance crew becomes ambulance lead commander (sjukvårdsledare, SL) and the other becomes the responsible medical commander (medicinsk ansvarig, MA). The SL team up with the lead commander from the fire department (räddningsledare, RL) and they act as a command post at the accident. All information back to SOS goes through these persons and they can request more resources through SOS. The MA and SL keep a close connection at the accident, but the MA has more responsibilities to take care of the persons involved and to inform the arriving ambulance crews where they are most needed and what status the persons have. The SL also finds out to which hospital the injured person shall be taken, this is done via SOS that gets the information from the TIB (Tjänsteman i beredskap) which stands in preparedness for this task.

FIRE DEPARTMENT

The first thing they do at the accident is also to place their fire trucks in such a way that they get a safe environment to work within. Then, every fire man has its special tasks at the scene. Their main tasks are to make the scene safe, both for themselves and for the ambulance crew. They also make the injured persons accessible for the ambulance crew by cutting rooftops, disconnect airbags and release jammed occupants. If the car is on fire or if there is any other danger for the person inside the car, they do an immediate evacuation of the occupant, no matter what the extra damage could be.

POLICE

The police are responsible for shutting down the road to make the working environment for the rescue workers safe. If necessary, they redirect the traffic to other roads or direct the traffic next to the accident. They sometimes also have to search for missing shocked persons that have walked away from the accident. If the police arrive first at the scene, their first task is to give life supporting aid to the persons involved.

4.1.4 TRANSPORTATION TO HOSPITAL

AMBULANCE

When the persons involved in the accident are transported to the hospital, the ambulance driver calls either directly to the hospital via mobile phone or to SOS which calls to the hospital. They verbally send information about vital status of the patient and estimated time of arrival. If there is a major change in the information which is sent, the ambulance calls again and makes necessary updates.

FIRE DEPARTMENT

When all persons have been taken care of and the last person is on the way to the hospital, the fire men are usually still at scene of accident to clear and decontaminate the location. When this is done, the lead commander at the scene decides that the mission is over and they return to the fire station.

POLICE

The police are usually the last service to leave the scene of accident and it is their responsibility to open the road again. They must also decide the course of events that caused the accident, if there are any criminal aspects involved in the accident and write a report about this.

4.1.5 ARRIVAL AT HOSPITAL

When the ambulance crew arrives to the hospital, the injured person is often taken to the emergency room (ER) at the emergency department. In most cases, the first contact is made by a triage nurse. In those cases, the nurse is re-evaluating the status of the patient done earlier by the ambulance crew to figure out if or how soon and what kind of medical treatment the patient need and what can be done at once.

In more severe cases, the ambulance crew or the AD already has been in contact with the emergency department about the status of the patient. The triage nurse has different alarm buttons connected to pagers bound to key positions at the hospital, e.g. surgeon, orthopaedist and anaesthetist depending on how severe the injured patient is. Those persons in question must then leave their post at the hospital and rush to the emergency department. The different alarm categories vary at the Swedish hospitals.

When the ambulance arrives at the hospital, the hospital personnel called to the emergency room are waiting. The ambulance crew verbally reports the status and other important details about the accident without interaction from the hospital personnel. This one way communication is quite short and takes about a minute. When they are finished, the hospital personnel can ask questions to the ambulance personnel and start treating the patient

4.1.6 AMBULANCE HELICOPTER AND SPECIAL EMERGENCY CARS

Most regions in Sweden have an ambulance helicopter to their disposal. The ambulance helicopters covers all area of Sweden and is specially good in the Swedish coastal regions and in the northern parts of Sweden where it could be hard or take long time to reach the accident. The ambulance helicopter is though used as a special resource where a specialist could be needed in an early stage. On the helicopter, there is always an anesthetise nurse on board and in some regions also an anesthetise doctor. Some regions also have a special emergency car with an anesthetise nurse or doctor on board. This resource is used at severe accidents and at larger accidents which demands a longer operation on the scene. The crew in this car takes the commanding position on the accident and acts as SL and MA.

4.2 IDENTIFIED INFORMATION FLOW, NEEDS AND DESIRES

4.2.1 SOS-OPERATOR

The information that the SOS-operator receives from the witness is essentially the most important information in the whole pre-hospital chain. To be able to reduce the lead time to the hospital, right resource to the right place need to be sent as fast as possible. In order to get this important information from most often inexperienced witness, as good questions as possible must be asked. The SOS-operator then bases their decisions on these answers from the witnesses, but also with their own experience. The questions that they state to the witness are predefined after what information that is of most importance, these questions are stated earlier and depending of the answers collected, the resources will be sent. The most important information from the answers were:

- Location of the accident.
- How many persons involved.
- The vital status of the persons involved.
- If any persons are jammed and indication of high velocity impact.

This information is today often hard to get and it is rare that they have all four parameters to make their decisions on and pass along to the dispatched personnel.

The SOS-operator handles the contact with the witness, but is commonly not involved with the contact of the emergency personnel at or on the way to the scene of the accident. That work is done by the AD and LC, which works with a close contact to the SOS-operator. A large part of the SOS-operators work is to find the witness closest to the accident that has best information. This is especially important when there are many persons calling. The SOS-operators work in the chain does commonly end when the first emergency professional has arrived and the witness is not of so high importance anymore.

4.2.2 AMBULANCE PERSONNEL

The information received by the ambulance personnel is as stated earlier often very brief and inconsistent. This causes not only problems for the crew in form of bad preparations, it also results in difficulties to find the best route to the accident. Another problem is that the text message rarely has any good structure which sometimes makes the message unnecessarily confusing. An example of a message could be:

- Location description on the first row.
- Very brief information about what kind of accident on the second row.
- Road directions on the third and last row.

Another example could be:

- Single accident, two persons involved, persons outside the car.

When they respond to the selective search, they confirm that they have received the information. This information is often unclear and they then try to get more and clearer information during the respond call. Unfortunately, it is common that no additional information has been reviled by the witness and can therefore not be sent. At these cases, it is very hard for the ambulance personnel to mentally and practically prepare themselves before they arrive. This information based preparation is together with their personal experience a very essential part in order to do a good job on the scene. When the information is unclear, the time at arrival to get a good overview of the accident get longer. At arrival, they must identify how many persons that are involved and how injured the persons are before they can start take care of them. Even when a lot of information are known, the way they prepare themselves vary a lot, but it is common that many professional prepare for worst case scenario, to be on the edge when there is an indication on severe accidents. These differences in preparations among the professionals can to some extent be related to the region they work in, but mostly to their experience within the area. There are also other factors than the lack of information that causes problems. The time is such a factor and the time to prepare varies a lot between accident to accident and region to region. In high density urban areas, the ambulance can be on location within minutes from the alarm and in low density rural areas as up north of Sweden, it could take as long as one hour. In so short time described, very small preparations are possible and the only communication with the AD is the confirmation of the selective search. During long transportations to the accident, the AD and the ambulance crew can have a longer communication and continued updates from witnesses or emergency professionals on location can be made.

The information that they would like to get from the witnesses to best be prepared, but as they rarely get are:

- The number of persons involved.
- Indication of how severe injured they are/anyone deceased or indication of the velocity/force.
- Exact location of the accident.
- If anyone is jammed in the car.
- Which resources that have been called.

As soon as an emergency professional is located at the accident, the quality of the information gets better, a clearer picture resolves and many of the parameters above becomes obvious. The ambulance crew always collect a general picture of the scene if they are the first emergency professionals at the accident. This general picture is passed along to the AD, which shares the information to the emergency units which also might be on its way to the accident. This first general information often consists of:

- Confirmation of the location.
- An approximate number of persons involved.
- If any person still is in the car.

As fast as they get more information at the scene, this is forwarded to the AD and an ongoing communication starts. Their first main priorities are to get the vital status of the persons involved, do a quick categorisation of these persons and to see what kind of resources that is necessary. The AD is then using this information to send more or the right resources or stop unnecessary resources. The crew in the first arriving ambulance automatically takes the roles as SL and MA and get the very important communication role. All decisions about resources, where the injured should be transported and injured persons in need of care, go through these persons or persons close connected to them. Most often, not more than two ambulances are needed at the accident, but at large severe accidents with many persons involved, those roles gets even more important to sustain a controlled working environment. At these large accidents, it is common that the crew from special emergency cars takes over the role as AD and MA from the first arriving crew. At the scene, the communication between the different ambulance personnel is done verbally or over a special radio channel dedicated appropriated to them. This varies a lot depending on the distances at the accident. The information about vital status of the persons involved is not reported to the hospital until the person is on its way, unless there is a large accident with many persons involved. When the triage nurse receives this information via the AD verbally, the person is already categorised by the ambulance crew.

At the first categorisation of the persons involved, it is not the person that screams most they suspect having most severe injuries, their experience show that it is the persons that are quiet that have the most severe injuries. If a person is out of the car and walking, he or she gets lower prioritised than the person still in the car.

Most commonly, two ambulances are sent to the accident. At more severe accidents, one additional ambulance per injured person is sent. It is also very common that the ambulance crew tend to step a little harder on the gas pedal at these accidents and when the crew know that children are involved.

4.2.3 Fire department

The initial information about a traffic accident either goes via the fire men's personal pagers or through a speaker in the station. In some regions, they have also started to send a pre-alarm as soon as the SOS-operator gets information from the witness calling. In these regions, the information received are keyboarded into the SOS-operators system and sent to the station where the text appears on a screen and throughout the speakers via a digital voice. This is done to prepare the fire men additionally before the selective call. When the selective call arrives, the fire men usually have 90 seconds to get dressed, go to the fire truck and to be on route. The information in these early stages is very brief and it is not until they are in the fire truck and the RL start the communication with the LC more and better information is revealed. The information is still based on the information from the witness and it is common that very little new information can be told until any emergency professional is located at the scene and sends additional information. When the emergency professionals arrive at the accident, their first priority is to create a safe work environment for themselves. This is done by either closing the road or by placing the vehicle in such a way that the traffic has difficulties to pass the accident without heavily reducing their speed. The fire truck provides a very good protection in these cases and it is of high importance that they can arrive early to create this protection. Which emergency professional services that arrive first differ a lot between the regions and where the accidents occur. By only looking at the areas in and around the two biggest cities in Sweden, Gothenburg and Stockholm, it also varies a lot. In Gothenburg it is more common that the fire department arrives first and in Stockholm it is more common that the ambulance crew arrives first. Due to the importance of the fire truck protection, the information of the location is of high importance. The other information of importance is used to mentally prepare in the same way as the ambulance crew, but also to get the right resources to the accident. A full time station is always manned with one fire crew at all times and at an accident, they are using one fire truck and one tanker. If the accident occurs far away from a full time station, fire crews from both a part time station and a full time station usually are sent. At large accidents or at accident where special resources are needed, more than one fire crew could be sent. These special resources are for example used in accidents where chemical decontamination and special cutting tools are needed. In order to the get these vehicles fast to the accident, sufficient information are needed. Such information are:

- If any person is jammed inside the car.
- If the car must be cut or sawn to access the person inside.
- If any vehicle containing hazardous signs involved in the accident.

On location of the accident, all work is initially pre-organised and every fire man has his own special task and the RL creates a command post and get a general view of the scene. The communication at the scene is done via radio and the fire men get a special frequency accessible for themselves. Sometimes, this frequency is shared with the ambulance personnel. The RL has an ongoing communication and close collaboration with the LC and the SL at the accident. The RL and SL works as the command post at the accident and all major decisions and resource requests goes through them. If more resources are needed, the LC is asked to send these. It is the inner commander at LC who decides if the request can be fulfilled or not. He must always have resources left in case of an other accident should occur and must reassemble part time fire men to take the working fire men's' stand by position.

4.2.4 HOSPITAL PERSONNEL

The incoming call to the emergency department from the ambulance crew goes to a special nurse or the triage nurse. The ambulance crew sends the most important information so the nurse can decide which resources he or she must get to the emergency room. The most important information is of course how many persons which are on its way, but on these persons, the following parameters are the most important:

- Heart rates.
- Breathing rate.
- Oxygen saturation.

If these parameters are known, the nurse can get a good indication of the person's vital status. If they also would know how the patient's status has change over time since the accident, they would know in which direction the vital status is going and be able to start giving the right treatment in a much higher rate. Other information that are of interest and that the nurse asks for are:

- Blood pressure.
- Age.
- Oriented about time and place.
- On any medication.
- Bleeding, haemorrhage and fractures.
- Head injury.
- Time of arrival.

The trauma team has other functions around the different departments at the hospital and is called when a trauma has occurred. To get the trauma team consisting of orthopaedist, anaesthetise and surgeon doctors and nurses, the triage nurse has a special system to alert these persons. The system varies on different hospitals, but the personnel in the trauma team always carry a pager or telephone with a connection to the triage nurse. When the alarm is made, the persons in the trauma team initially only get a categorisation of the incoming person. This categorisation is often done by the ambulance crew and these categorisations vary a little between the different regions. An example of a categorisation (in Stockholm) is:

- Priority 1: Severe injury, head.
- Priority 2: Severe injury, no head injury.
- Priority 3: Not severe injury.

In this example, all priority one and two injuries are transported to the same hospital within the area and a special trauma unit, while the priority threes is transported to the closest hospital. This trauma unit, which is located at Karolinska University Hospital, get about 100 patients per month.

4.3 DISCUSSION

The workplace for Swedish emergency professionals are in many senses similar, but can also be very different depending if the workplace is in a rural or urban area, but also between different regions. The northern parts of Sweden have a very low density population and the distances that a rescue service sometimes has to travel to an accident could be longer than 150 kilometres. While in large cities, the rescue service can be on the scene of accident within a couple of minutes. The tasks and priorities are different between the rescue services, but it is quite common that at least one fire man in the fire crew has tasks similar to those of the ambulance crew. The priorities also vary depending when they arrive at the accident. The Swedish ambulance service was recently re-organised and every ambulance crew must today contain at least one educated nurse. Before the re-organisation, many fire men without nurse education worked part time within the ambulance service and many nurses in the ambulances worked at hospital. It is also a requirement at most regions that at least one SOS-operator has a nurse education at every shift. This experience and knowledge from different areas make a bigger understanding for each others work and improves the work at the accident.

Several decisions made in the pre-hospital chain are related to the information the SOS-operator collects from the witness. Even though many professionals involved in the Swedish rescue work have a broad knowledge and a lot of experience, they often find this information insufficient for practically and mentally prepare themselves on the way to the accident. The information could also cause problems at the accident. Several interviewed emergency professional states that the information received in an early stage sometimes contradicts with the situation on the scene of accident. One common example is when the first information show more people involved than it really are. This result in an unnecessary search for persons that never was involved in the accident and takes resources that could have been useful elsewhere. There are frequent examples where the information in an early stage shows one thing, but later on cause that additional resources must be sent, which could have been sent in the first place. The interviews show a large lack of information in many cases and a large desire of receiving more accurate information. The information that almost every emergency professional wants to know and that often is wrong is the number of persons involved. Information about the exact location of the accident and in which direction, velocity, airbags deployed and if any person is jammed in the car are also desirable. Other usual information wanted is if the car has rolled over, belt or no belt, where the car is damaged, frontal or side collision, multiple hits, if the person still is in- or outside the car and if the person is conscious and orientated. The information of interest also varies depending where in the chain the emergency professionals are working and what their tasks are. The fire department is for example very interested of the car model, if any hazardous goods are involved and if they have to decontaminate the location. Information about the person's condition is more important for the ambulance crew which gets more important when he or she gets closer to the hospital. The personnel at the hospital are interested of heart-, breathing rate and oxygen saturation, which indicate a lot about how severe injured the person is. Receiving this information in an early stage and use it as a reference to see how the person's vital status has changed could save crucial time when the patient arrives at hospital and be a matter of life or death. Rapid changes in status could also be identified by the ambulance crew which to a higher rate would be able to priority the person that needs to get to the hospital fastest better. At the cases, when it takes long time for the ambulance crew to get to the accident and receiving the vital status of the person, an application of heart- and breathing rate becomes even more important.

If an application that gives heart- and breathing rate would be implemented to give this important information in an early stage an another factor must be considered. That factor is that the interviews showed that when an accident has occurred, the persons involved often can be found outside the car when emergency professionals arrive. The general picture from the interviewed professionals is that the persons involved gets out of the car as soon as possible after a collision if they are able to do so.

Attempts to estimate the number of how many lives that could be saved if these parameters would be known in an early stage have been unsuccessfully. Some of the reasons for this are that the persons knowing the statistics at SOS are hard to find and the person's interview have difficulties to do a good estimation. One of the reasons that they have difficulties in making good estimations are that the persons interviewed has problems referring to the idea, which some find like science fiction.

4.4 CONCLUSIONS

The need of information is essential in the pre-hospital chain. The important information for the emergency professional varies between the different services and which information they find important also varies from person to person. The difference between a highly experienced emergency professional and one not so experienced is in many cases, the experienced have seen the information so many times and he or she can therefore in a higher grade decide if it is trustworthy or not. The desire to get more information on the way to the accident location is large, especially for professionals not so experienced, but there is also a limit where too much information is hard to handle and can not be taken in.

The decision making to send the right resource to the right location is completely built upon the information found and received by the witness or person on the scene. This information is often wrong and not enough which results in wrong decisions and unnecessary or insufficient use of resources. With a system that directly can give an indication of how many persons that are involved in the accident and their vital status would significantly increase the possibilities to send the right resources to the right location. If they also receive the heart- and breathing rate of the occupants, they can get an indication of the vital status of the patient and additionally increase the possibilities to send right resources such as the ambulance helicopter in an early stage. This information gets even more important up north in Sweden, where the time to accident can be very long. This information would also significant increase the possibility to prepare themselves on the way to the accident, speed up the job at the scene and decrease the time for the person to the hospital. However, the trustworthiness of the information sent is of most importance and the fact that the person is moving or are trying to get out (if the person is not to severe injured or unconscious) of the car after the accident must be considered. At these cases must the application present a good and fast reading before the person takes of the safety belt.

How many lives that can be saved with a system that sends heart- and breathing rate is very hard to find out and require an extended investigation. Those numbers is therefore not considered in this report.

5. PROTOTYPE

5.1 TESTS

The tests done during development of the prototype was divided into following sub directories:

- Tuning the light source.
- Output power.
- Data acquisition.
- Heart- and breathing rate measurements.

5.1.1 TUNING THE LIGHT SOURCE

With the test setup describe in chapter 2, the tuning started. The diode was installed into the small cage provided with the KT112/M. The small collimating lens was then installed in its cage, see Figure 22. The diode was connected to its power source, LDC 2000. The trick was to tune the light into parallel beams. This was done by moving the diode cage back and forth on its sliding rods. By looking at a fluorescence card, the spot the beam made should be as small and concentrated as possible. It was a very sensitive task to do, small changes made a big difference. Locking screws was then tightened and the two cages were locked into place. The whole procedure was made in a dark room, the light could otherwise not be seen.

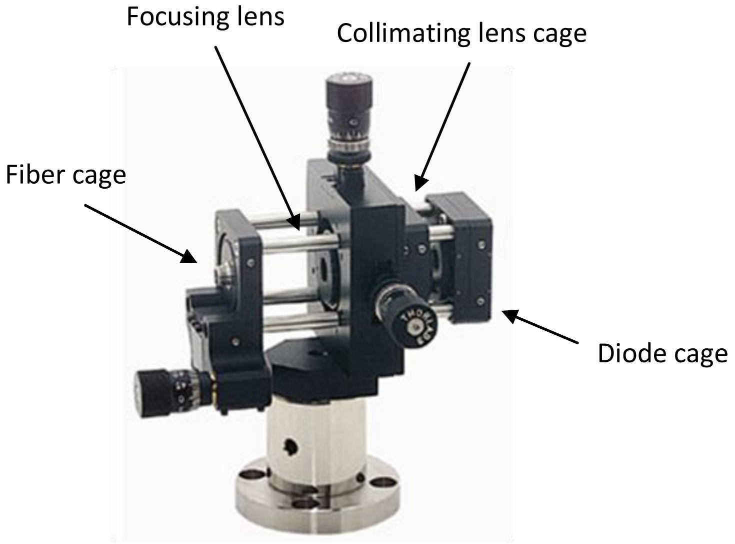


Figure 22. The KT/112M and its different parts.

Next step was to focus the light into a small spot, this was made with the focusing lens installed in the KT112/M. This lens can later be moved in x- and y-direction by the micrometre screws. The fiber (port 1 from the coupler) was put into its cage and could be moved in z-direction. By connecting the power meter, PM20A, to port 3 of the coupler, the tuning started. The whole system was then tested with the attached program Splicco. Port 1 and port 3 was still connected to respective devices. Port 2 was connected to the safety belt and port 4 to the spectrometer and the connections can be seen in Figure 23.

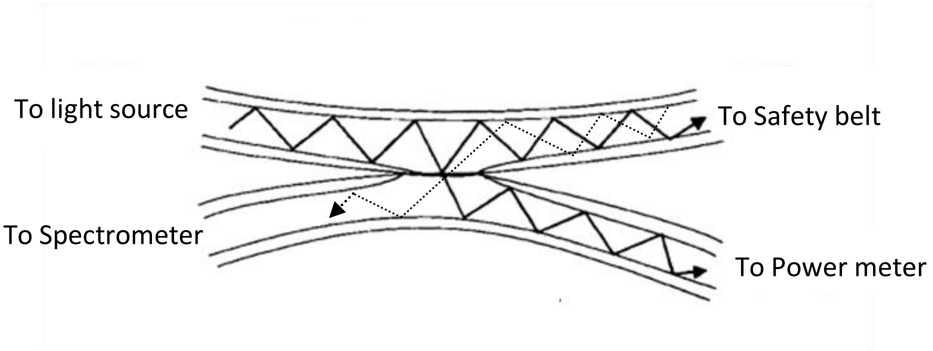


Figure 23. The coupler and respective connections.

5.1.2 OUTPUT POWER

The minimum required power is measured by lowering the current to the SLD, read the power from the power meter and do a test if the heart- and breathing rate can be identified. The integration time is also changed, from the normal 20 to 100 ms. Longer integration time is needed when weaker signals must be separated from the noise.

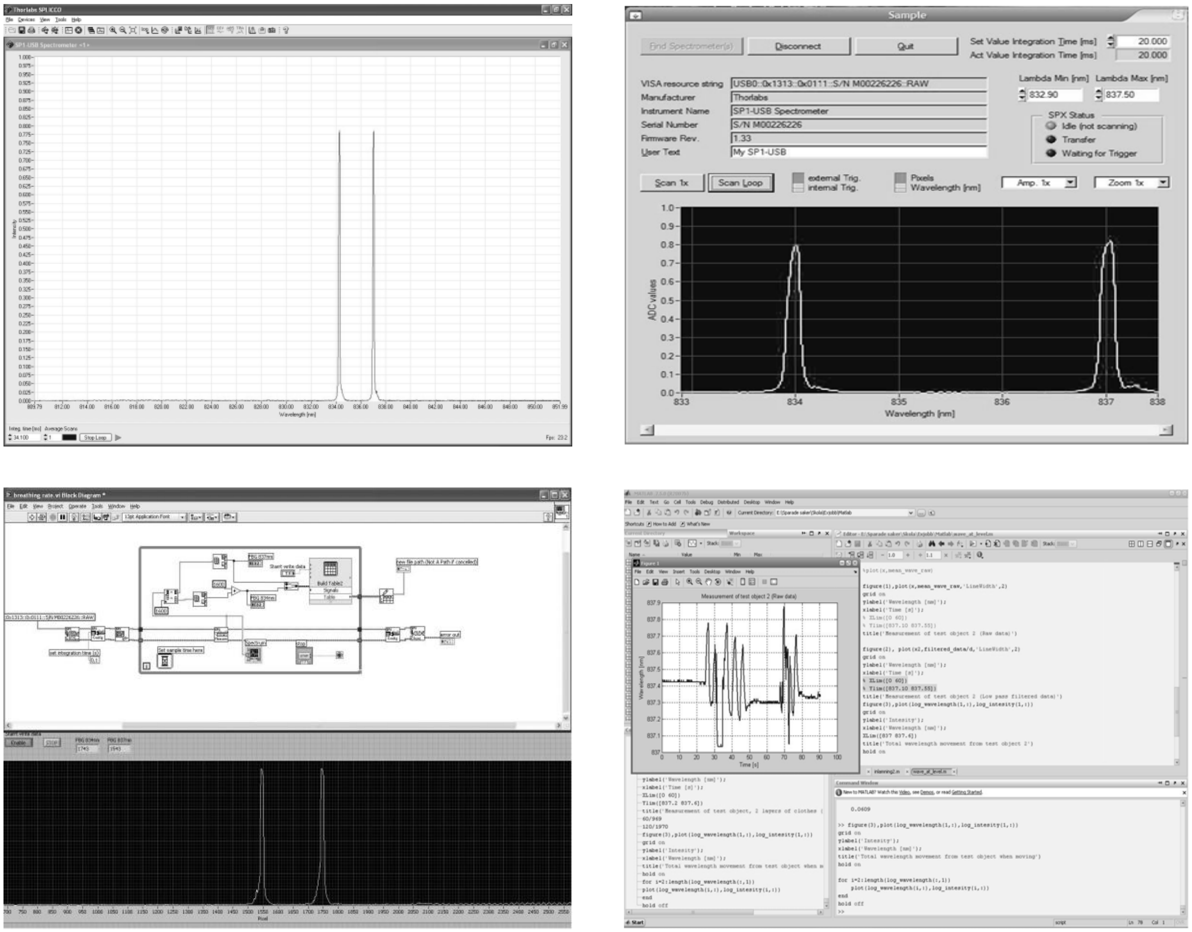
5.1.3 DATA ACQUISITION

Two software programs were included with the spectrometer, Splicco and a sample software with source code. Splicco has a graphical user interface (GUI) in which the user can see the spectrum recorded by the spectrometer. The operator can do some very basic settings and use a few functions to process the data. A snapshot of the data can be saved, but it was not able to log data over time. To log data in order to do signal processing and to further investigate the signal in Matlab other programs had to be used.

To collect, visualise and analyse data directly using the powerful mathematical program Matlab could not either be done as the instruments driver was not compatible with the program. The spectrometer is a VISA device and VISA is a software interface for instruments connected to a computer. The Matlab toolbox Instrument Control supports VISA. However this is only true for devices using VISA::INSTR, a version with standardised communication protocol. The Thorlabs spectrometer uses another version, called VISA::RAW. In this version it is up to the manufacturer to decide how the instrument communicates with the computer. This could be useful if a very fast communication between the instrument and the computer is desired.

The included sample software could also just visualise the data and was not able to log it. The solution was to modify the source code included. This program was written in C with the development tool LabWindow/CVI.

To verify the modified software, LabView was used. Labview is a powerful program where the user easily can make virtual instruments to process data. The program is made by the company National Instruments and is widely used by persons from a lot of different areas. The program's good instrument interface makes most instruments accessible in the program. Licenses to the program can be found at Chalmers, but not at Autoliv. The different programs can be shown in Figure 24.



Set Value Integration Time [ms] 20.000
Act Value Integration Time [ms] 20.000
VISA resource string USB0::0x1313::0x0111::S/N M00226226::RAW
Manufacturer Thorlabs
Instrument Name SP1-USB Spectrometer
Serial Number S/N M00226226
Firmware Rev. 1.33
User Text My SP1-USB
Lambda Min [nm] 832.90
Lambda Max [nm] 837.50

```
%plot(x,mean_wave_raw)

figure(1),plot(x,mean_wave_raw,'LineWidth',2)
grid on
ylabel('Wavelength [nm]');
xlabel('Time [s]');
% XLim([0 60])
% YLim([837.10 837.55])
title('Measurement of test object 2 (Raw data)')

figure(2), plot(x2,filtered_data/d,'LineWidth',2)
grid on
ylabel('Wavelength [nm]');
xlabel('Time [s]');
% XLim([0 60])
% YLim([837.10 837.55])
title('Measurement of test object 2 (Low pass filtered data)')
figure(3),plot(log_wavelength(1,:),log_intesity(1,:))
grid on
ylabel('Intesity');
xlabel('Wavelength [nm]');
XLim([837 837.6])
title('Total wavelength movement from test object 2')
hold on
```

```
    0.0609

>> figure(3),plot(log_wavelength(1,:),log_intesity(1,:))
grid on
ylabel('Intesity');
xlabel('Wavelength [nm]');
title('Total wavelength movement from test object when moving')
hold on

for i=2:length(log_wavelength(:,1))
    plot(log_wavelength(i,:),log_intesity(i,:))
end
hold off
>>
```

Figure 24. Upper left corner) Splicco, Upper right corner) Modified sample software, Lower left corner) Labview and the Lower right corner) Matlab.

To analyse the data, Matlab was used.

5.1.4 HEART- AND BREATHING RATE MEASUREMENTS

The test setup for the whole system can be shown in Figure 25 and has been used during all tests presented. Following heart- and breathing measurements were done:

- Different layers of clothes.
- Test object talking.
- Test object moving.
- Test object holding breath (heart beat measurement).
- Differences between two test objects.
- Breathing slowly, to detect heart beats during breathing.

The software's used during the tests were the modified sample software and Matlab. The modified software was used to collect and Matlab to process and analyse data. The test procedure was done in following way if not stated otherwise.

The duration was one minute, where the test object first held his breath for ten seconds, then took four breaths and after the forth inhalation held his breath once more for ten seconds. After that the object was breathing normally until the minute was past.

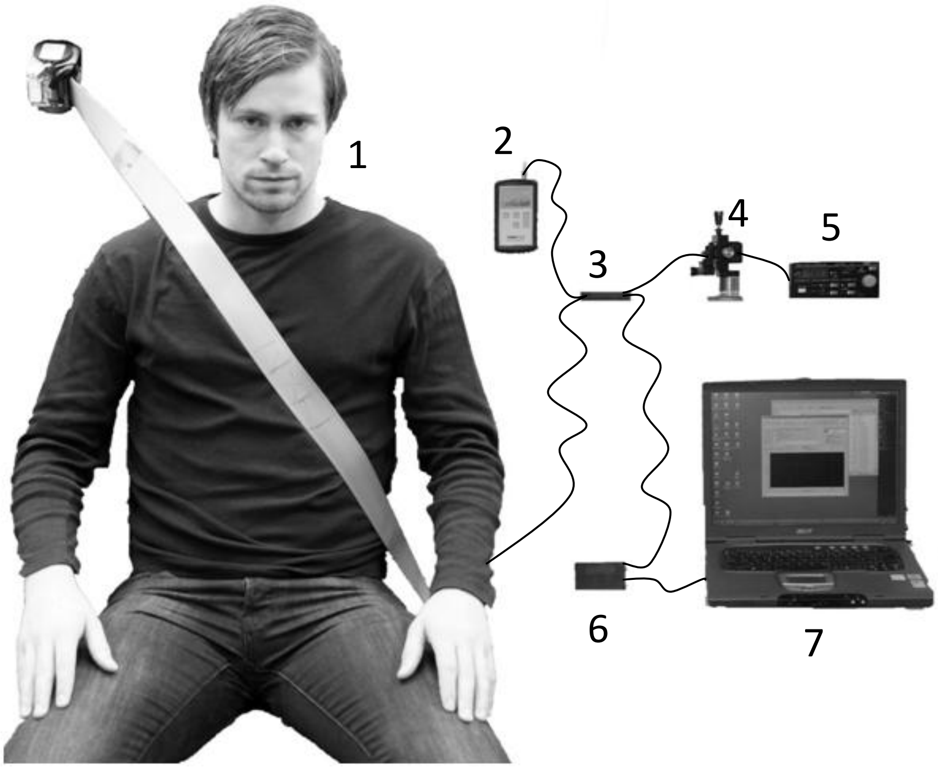


Figure 25. The test setup, 1) Test object, 2) Power meter, 3) Coupler, 4) The frame construction which lead the light into the fiber core, 5) Laser Diode controller, 6) Spectrometer, 7) Computer.

- The first test with different layers of clothes which corresponds to zero, one, two and three layers. The meaning with zero layers of clothes is bare-chested, one layer is a polo shirt, two layers are with a slip-over and three layers are with a winter coat. Figure 26 shows the test object with three layers of clothes.

Figure 26. Test object with three layers of clothes.

- The second test was made to see if it was possible to recognise the heart- and breathing rate when the test object was talking. The duration is one minute.

- The third type of test was when the object moved heavily in the chair. For two minutes, the test object was breathing normally, moving back and forth and turning left and right.

- The fourth one, the test object exhaled all air from his lungs and held his breath for 20 seconds. This to see if it was possible to determine the heart beats.

- The fifth type of test done was to discover if there were any differences with the detection of heart- and breathing rate if there were different test objects involved.

- The sixth and final test was made to see if it was possible to detect the heart rate if the test object was breathing very slowly and gentle.

5.2 RESULTS

5.2.1 TUNING THE LIGHT SOURCE

At first an ordinary LED with an output power of 18mW was tested. This did not work out very well, only 5 nW was transferred into the fiber. This was probably because of the emitting area of the LED and its properties, where not enough light hit the collimating lens. For this reason, a SLD was chosen.

Maximum power reached at port 3 of the coupler was 175 µW, which means that the effective fiber coupled before the coupler was twice as big, e.g. 350 µW at a current of 80 mA. Data from the manufacturer of the SLD, see appendix A, stated that the power the diode can deliver is 2.2 mW at 65 mA, which means that approximately 1/6 of the power was coupled into the fiber.

A plot from the program Splicco can be shown in Figure 27. It can be seen that it is two main peaks, one at 834 and one at 837 nm. This is the two FBGs woven into the safety belt.

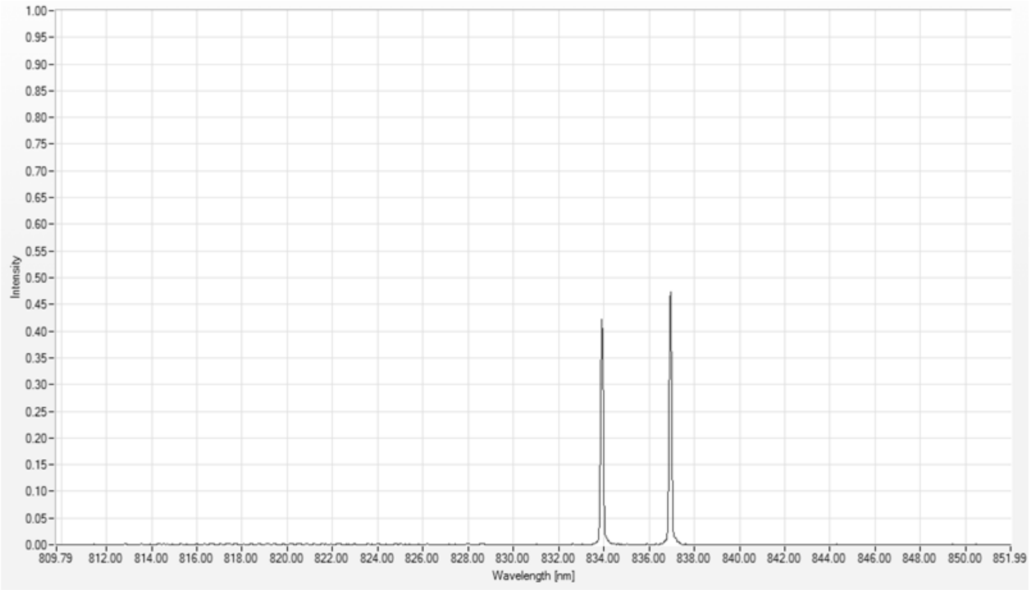


Figure 27. A screen shot from the program Splicco with the two wavelengths of the two FBGs woven into the safety belt.

5.2.2 OUTPUT POWER

The minimum required output power read from the power meter was 2.5 µW, which means that the effective coupled power into the fiber, before the coupler was twice as big, 5 µW. To be on the safe side, a minimum coupled power of 10 µW is preferable. Figure 27 shows the result with the minimum required output power. The test procedure was the same as the one with different layers of clothes described earlier. Two layers of clothes were used.

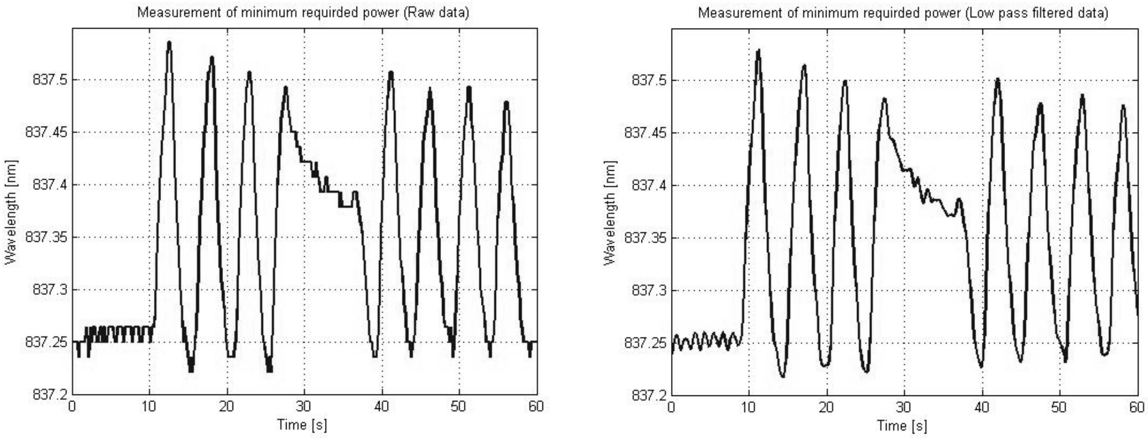
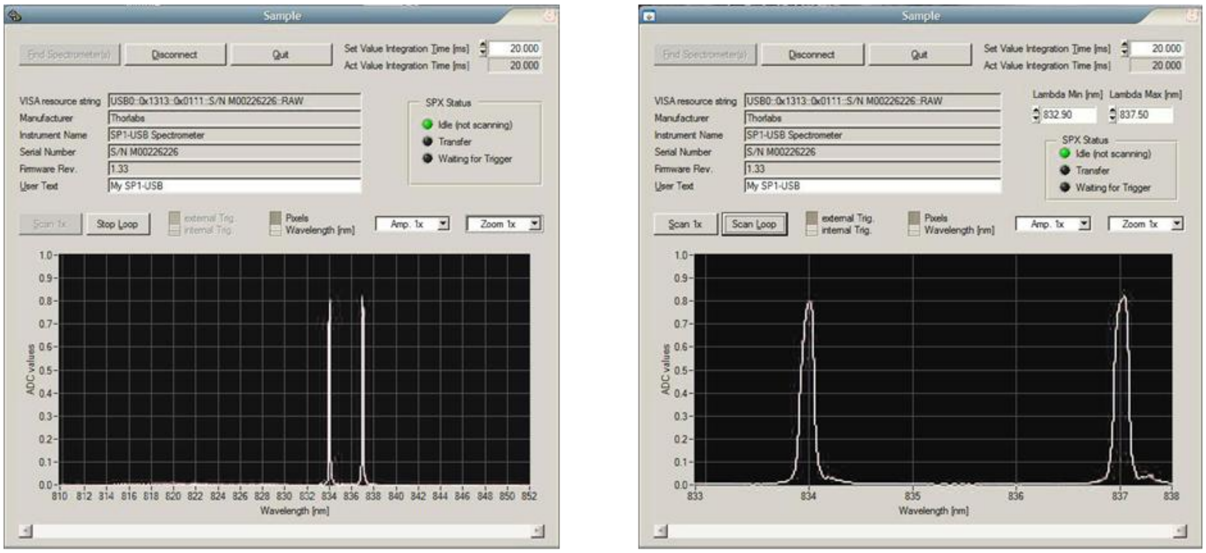


Figure 28. The minimum required coupled fiber power, Left) The plotted taw data, Right) Low pass filtered data

5.2.3 DATA ACQUISITION

From the beginning the sample software could only display the wavelength range the spectrometer was calibrated with (810 - 851 nm). Functions to log data and to choose the specific wavelength range presented was implemented in the modified software. The data from the spectrometer was saved in three text files, log_intesity.txt, log_wavelength.txt and log_info.txt. The log_intesity file logged the intensity from the peaks, log_wavelength corresponding wavelength and log_info saved the setting for the spectrometer, e.g. integration time, manufacturer, Serial number etc. Figure 29 shows a screenshot from the original sample source code and the modified one.



Set Value Integration Time [ms]: 20.000
Act Value Integration Time [ms]: 20.000
VISA resource string: USB0::0x1313::0x0111::S/N M00226226::RAW
Manufacturer: Thorlabs
Instrument Name: SP1-USB Spectrometer
Serial Number: S/N M00226226
Firmware Rev.: 1.33
User Text: My SP1-USB

Set Value Integration Time [ms]: 20.000
Act Value Integration Time [ms]: 20.000
Lambda Min [nm]: 832.90
Lambda Max [nm]: 837.50
VISA resource string: USB0::0x1313::0x0111::S/N M00226226::RAW
Manufacturer: Thorlabs
Instrument Name: SP1-USB Spectrometer
Serial Number: S/N M00226226
Firmware Rev.: 1.33
User Text: My SP1-USB

Figure 29. Screenshots from Left) The original and Right) The modified.

An m-file was created that imported the saved text files; log_intesity and log_wavelength respectively created by the modified Sample program. The saved data is stored as a vector where every row in the vector is one set of data (screen dump) and corresponding columns is the absolute intensity for the log_intesity.txt file. The m-file is then finding the maximum values of the intensity (y-axis) and the positions of those maximum values are saved it in another vector. Corresponding wavelengths at those positions are then found and saved and plotted against the elapsed time.

5.2.4 HEART- AND BREATHING RATE

The different clothing test described earlier was done and Figure 30 -Figure 33 show the results.

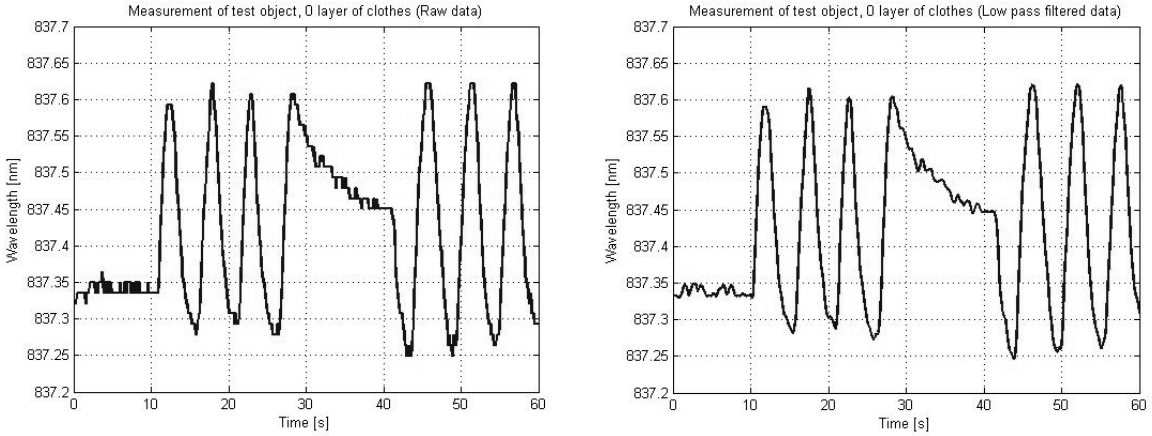


Figure 30. With zero layer of clothes. Left) The plotted raw data, right) Low pass filtered data.

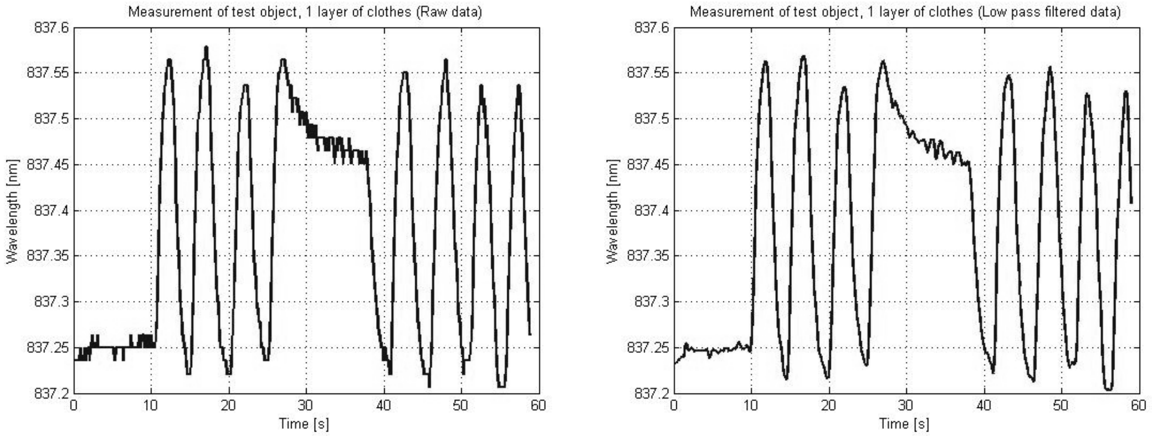


Figure 31. With one layer of clothes, Left) The plotted raw data, right) Low pass filtered data.

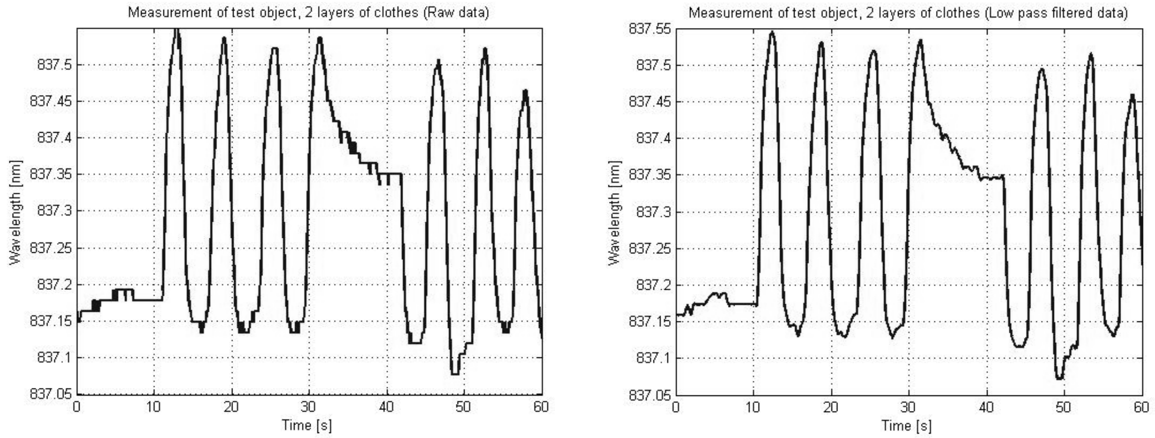


Figure 32. With two layers of clothes, Left) The plotted raw data, right) Low pass filtered data.

The breathing rate can easily be determined and an indication of the heart beat can be shown, even with a winter coat which is demonstrated in Figure 33.

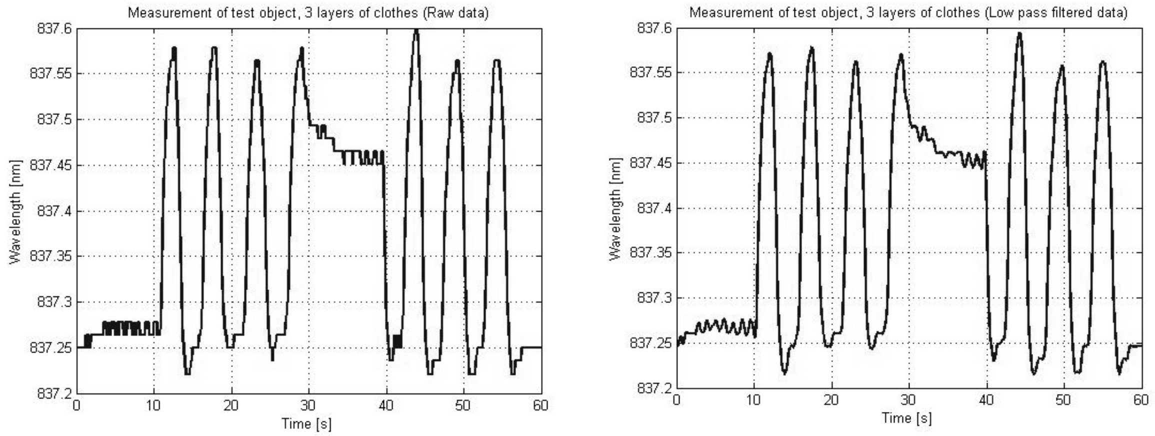


Figure 33. With three layer of clothes, Left) The plotted raw data, right) Low pass filtered data.

Figure 34 is a plot from the test when the test object is having a normal dialogue to simulate a conversation with another passenger in the car.

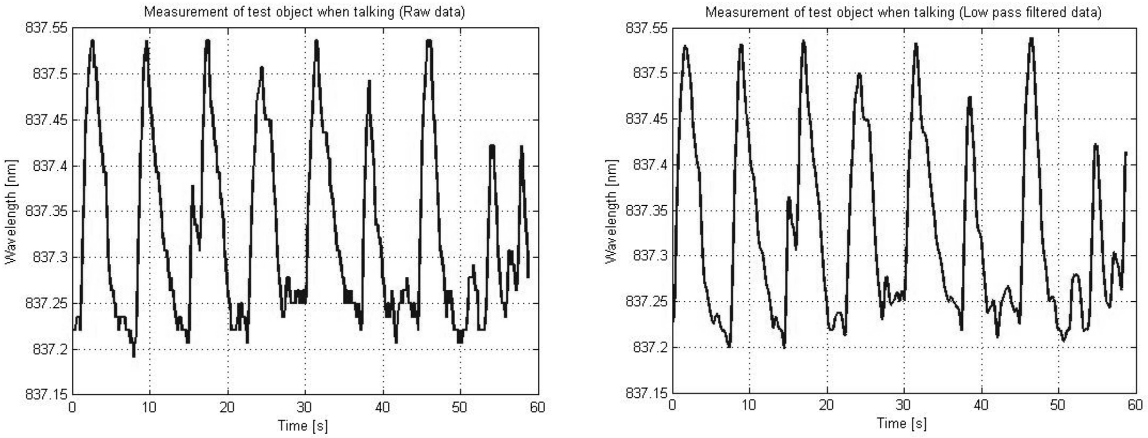


Figure 34. Test object talking and breathing normally for one minute, Left) The plotted raw data, right) Low pass filtered data.

Following plot, Figure 35 shows the result when the test object is moving heavily in the chair. The right picture is low pass filtered hard.

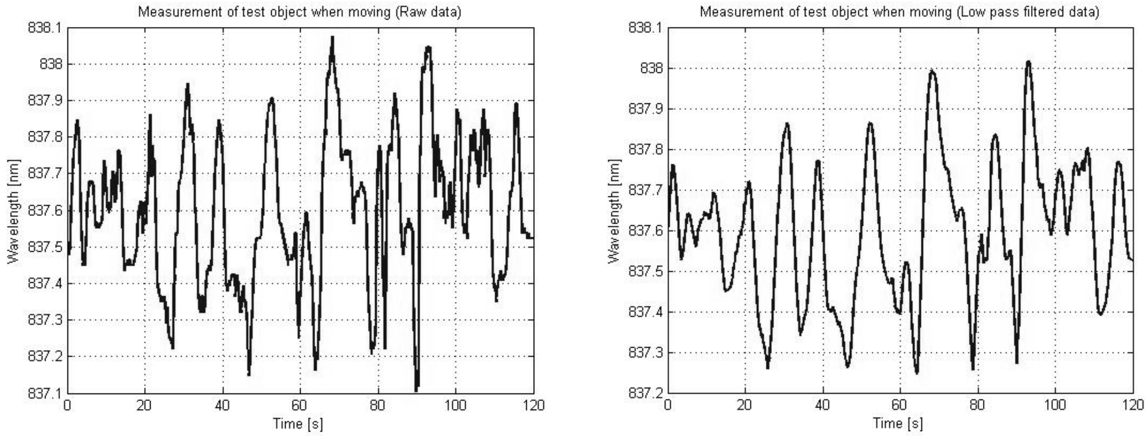


Figure 35. Test object is breathing normally but moving back and forth and left and right, Left) The plotted raw data, right) Low pass filtered data (hard).

Figure 36 shows the result when the test object exhaled all air from the lungs and held his breath for 20 seconds. The heart beats can be seen. The change in wavelength is though only one pixel.

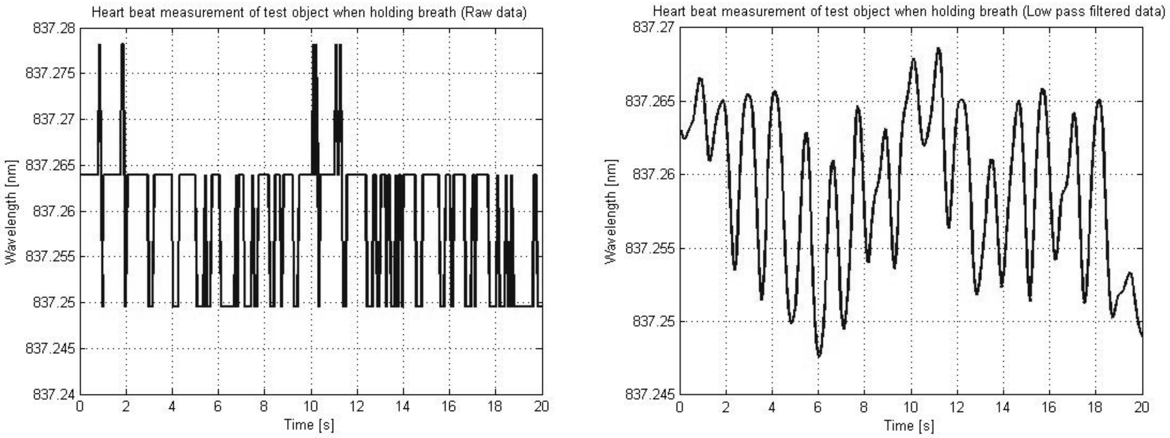


Figure 36. Test object has exhaled all air from the lungs and held his breath for 20 seconds, Left) The plotted raw data, right) Low pass filtered data.

The test object measured his heart rate during the whole test procedure, 17 beats. When counting the peaks from the right picture in Figure 36, there result is 17.

The fifth test done was to determine if there were any differences between two test objects.

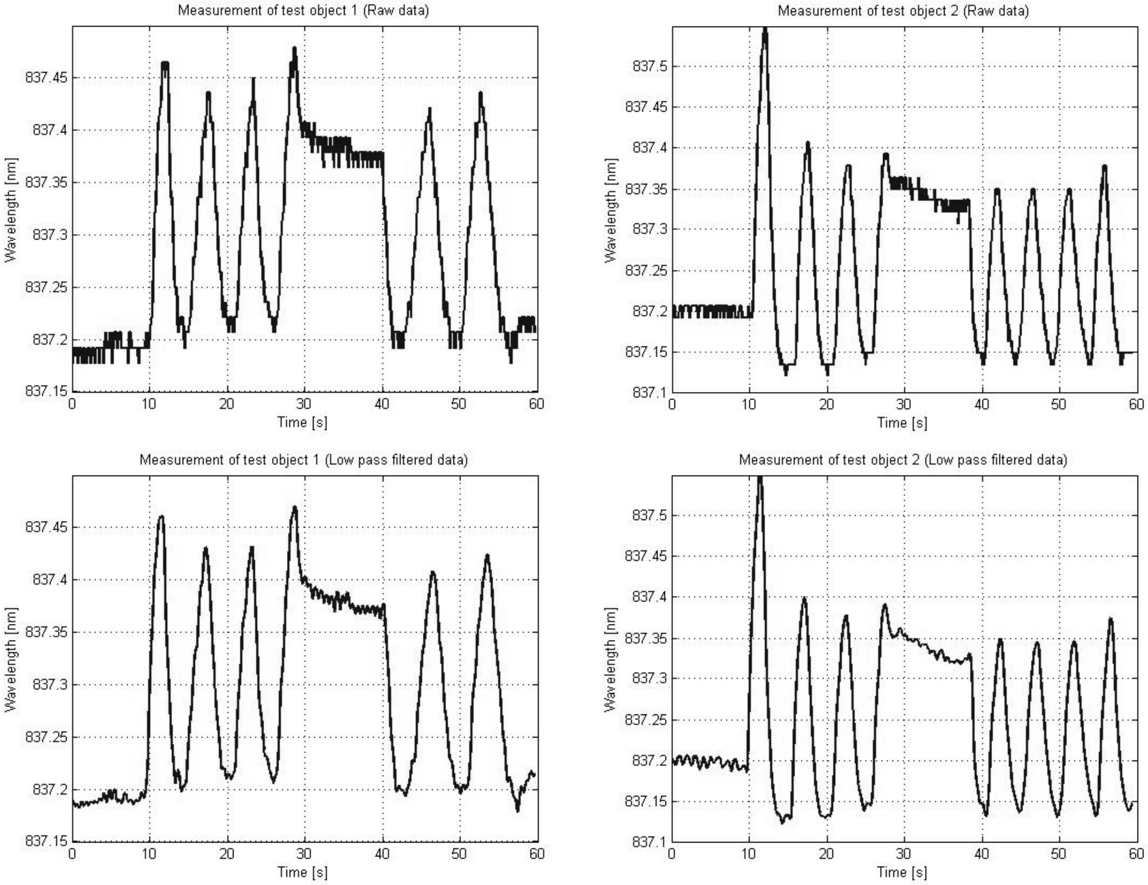


Figure 37. Differences between two test objects, Upper left corner) Raw data from test object 1, Upper right corner) Raw data from test object 2, Lower left corner) Low pass filtered data from test object 1 and the Lower right corner) Low pass filtered data from test object 2.

It can bee shown that there are individual differences between one person and another regarding the ability to discover the heart rate.

As Figure 38 shows, there is an indication of the heart beats when the test object was breathing slowly.

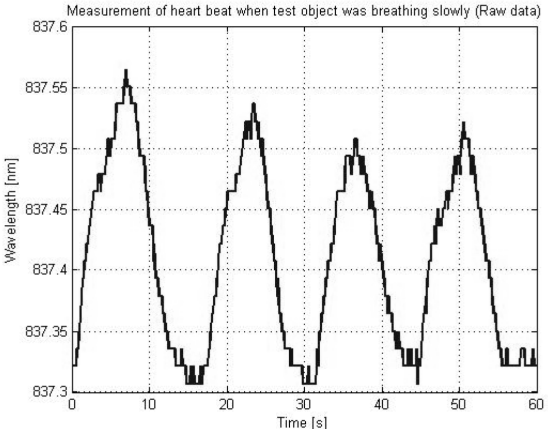


Figure 38. Detection of heart beats when test object was breathing slowly.

6. DISCUSSION

The prototype is able to detect the breathing rate at a not moving person without any problems. It can also find the breathing rate at person talking without any signal processing. When the person starts moving during the tests, it fast becomes harder to detect which signals generated that can be correlated to the breathing.

The first initial tests with Splicco showed a large lack of resolution of the spectrometer, but this indication was hard to verify when no data logging was possible with the program. A lot of time was instead spent on getting time sets of the data with other programs, which resulted in a modified source code of the sample software with possibilities to only look at small parts of the spectrum and exporting time sets of that spectra. LabView was also used to do some small tests and to verify the data from the constructed program. Before the modifications were done to the source code, large efforts were made to implement the instrument directly to Matlab using Instrument Control Toolbox. Unfortunately, this toolbox did not support the whole VISA standard and an interface could not be made. The implementation of the instrument to LabView did also cause problems because of the interface between the instrument and the software. This problem was later solved by using an older version of the driver to the instrument.

At the first test, the belt retractor was not correctly fixed which gave poor results. At these test, even the breathing rate was hard to detect. When the test setup later was arranged in a way similar to a car seat and the retractor was fixed, the results significantly improved, but no heart beat could be detected. At both these test setups, the fiber end was loose (see Figure 17) which caused some slack. When the fiber later was stretched and the end attached to the safety belt, better results were collected. At some of these tests, even the heart beats were detected. At tests focusing on identify the heart beat, different layers of clothes were used. Among these tests with zero, one, two and three layers of clothes (bare-chested, polo shirt, polo shirt and slip-over, polo shirt, slip-over and winter coat) we could see no major differences between zero, one and two layers. Surprisingly, when testing the winter outfit (three layers of clothes) the heart beat could be found at a higher rate. The reason for this could be the texture of the fabric or that the pressure against the heart rises.

A couple of tests where the FBG was placed over the collar bone were done. At these tests the heart rate was much harder to detect. The required power from the SLD was lower than we had expected and so low that further investigations about using a LED should be done. The frame construction used to lead the light into the fiber core in this prototype was first used with a LED, but was not practicable. Instead a pigtailed LED where the light already is directed into the fiber and that can be found on the market should be investigated. In comparison, the SLD used had a cost of about 8 000 SEK and the LED 36 SEK. We had large problems of finding the right components, to the right price and with an acceptable delivery time. Most manufacturers of the different components have a delivery time of about one month. We also had to wait for the different quotes in order to find as good price as possible. This was finally solved by using a local distributor with shorter delivery time and with prices matching their competitors. The problems of finding and getting a good quote delayed the project more than one month.

7. CONCLUSIONS

The power from SLD is more than enough to get a good signal from the spectrometer. Due to the fact that the power is the largest cost parameter when looking at SLDs, a much cheaper light source should be able to find. The tests showed that the breathing rate was easily detectable with the spectrometer when the person did not move too much. By holding the breath and not move the heart rate could be detected. To be able too detect the heart rate better, a spectrometer with higher resolution is needed. At the tests that gave the heart rate, the change in wavelength between peak and bottom value was 14 pm (a few peaks were 28 pm) which corresponds to the smallest change in wavelength possible to detect (i.e. one pixel shift and maximum resolution). In order to detect the heart rate with certainty, the resolution must get higher.

The test where the test object was breathing gently, indications of the heart beat could be shown. With that in mind and with a better spectrometer, it should be possible to detect the heart beats. As the resolution increases and the heart beats can be detected, a more advanced signal processing is required and to be able to detect rapid changes of the rate some sort of adaptive algorithm could be necessary. The test with different clothing did not show that large differences when looking at detecting the heart rate. This was an unexpected result especially that the winter clothing gave one of the best results. The conclusion from this was that as long as the clothing the person is wearing does not have a lot of air between the layers which damps the signal, the heart rate can be detected (with a spectrometer with higher resolution). One indication that also could explain the unexpected result is that the measurement seems to be a little sensitive to friction between the clothes and safety belt where the FBG is located. Tests with tape between belt and clothing gave the heart rate better than without, but more tests with different friction need to be done to verify that result. Another indication is that the pressure against the heart seems to be larger when wearing winter clothes.

The position of the FBG is important to get as good signals as possible. The heart rate or “pulse” at an injured person is measured at the neck or hip where the signal is the strongest. Some tests with the FBG placed over the collar bone next to the neck to identify the heart rate showed poor results. Additional tests showed that the closer the FBG is placed to the heart, the better result.

The prototype is fully functional if only the breathing rate is considered and the minimum fiber coupled output power from the light source is at least 5 µW. If the heart rate also must be shown a spectrometer with higher resolution would be needed.

8. RECOMMENDATIONS, CONSIDERATIONS AND FUTURE WORK

During the development of the prototype different aspects were found that must be considered. Some of the aspects are price, durability and design. Other aspects for future work with the prototype that were found are shown. During the interviews and the initial medical study, a lot of different needs and desires were identified which also is brought out.

8.1 COSTS

The total cost of the prototype is about 40 000 SEK, a cost that can be compared with Autoliv's goal of 200 SEK/ea. in a series of 100 000 – 1 million. The two most expensive components in the system which must be considerably reduced are the spectrometer and the light source. In the prototype, a spectrometer with a cost of 21 000 SEK and a light source with a cost of about 18 000 SEK are used. Large cost factors with both these components are the series they are manufactured in. Both the spectrometer and SLD are manufactured after an order of the costumer and none of the components are usually found in stock. When an order is placed, the spectrometers are manufactured and manually configured after the costumer's demands and specifications. The spectrometer used in the prototype was assembled in Sweden, sent to Germany for calibration and then back to Sweden. It was calibrated to meet the requirements of resolution and centre wavelength. Which components of the mirrors, diffraction grating, CCD and electronics that are of highest costs has not been identified at this stage, but price seems to raise with better resolution at most manufacturers. The spectrometer used in the prototype originally had a diffraction grating of 600 slits/mm, but was at order changed to one with 1200 slits/mm. This was before delivery changed, to their best with 1800 slits/mm in order to get as good resolution as possible. These changes increased the resolution significantly, but no extra charge was added by the manufacturer. The manufacturer has a diffraction grating with 3600 slits/mm, but they can not give an answer today whether this could be implemented in the spectrometer used or not. Such a change might increase the resolution with a factor 2. Tries have been done to get an estimation of price at a very large order from different manufacturers, but unfortunately has no one been forthcoming in this matter.

If the spectrometer would be specially designed for the application, the components necessary could be optimised and parameters not of interest could be removed. If an automation of the manufacture process also would be implemented, we believe that the price would be significantly lowered.

The SLD is a modified laser diode with properties of a LED, but with much higher output power, which is the main cost factor. In order to identify cost cuts, Dr. Vladimir Shidlovski at Superlum Diods Moscow, Russia was consulted. The company is one of the largest in the business and he estimated that a 1 mW SLD with cost of €750/ea today could cost €270/ea with an order quantity of their maximum production capability of 10 000/year. If the output power instead would be 300 µW, the estimated price would go down to €240/ea. With essential production investments, the price of €750 today could go down to €100/ea. Lower cost cuts is only possible by changing technical data, e.g.:

- Packaging style.
- Output power.
- Necessity of wavelengths.
- Others.

In order to cut large costs, the least power necessary must be found and calculated for a total system via further tests.

8.2 DURABILITY

Problems with spectrometers that must be considered are that they can be sensitive to mechanical disturbance [28], a problem that could be avoided by the fact that the measuring is done after the collision where no mechanical disturbances are found. Two other problems that are of interest is the fact that they commonly are sensitive to high jolts and temperature changes [12]. The construction inside the spectrometer with mirrors, diffraction grating and CCD with picometre precision must be robust to handle the high force at a collision. Rapid temperature changes, that could occur must also be considered and tested.

The SLD is very sensitive to voltage and current spikes. To operate it a controller is necessary that erase these spikes and that give a steady voltage and current. The setup used for the SLD in the prototype is very sensitive to movements where just touching it decreases the output power with a couple of micro Watts. In a real application, a pigtailed light source must instead be used.

8.3 POSSIBLE DESIGNS

In most cars today, it is possible to fit five people, two in the front and three in the back. Using the prototype at all five seats in the car will be too expensive. With the FBG technology and when using different correlated wavelengths in the different safety belts, only one light source and one spectrometer would be needed. This will decrease the costs five times for the whole system. Two ideas will be presented, one with parallel coupler (2:5) and one with serial coupled FBGs. The parallel solution is easier to implement, but the output power from the light source is divided into five equal parts and must therefore be higher. It will also be more robust, if one of the fibers is failing, the other four are still working. This can be shown in Figure 39.

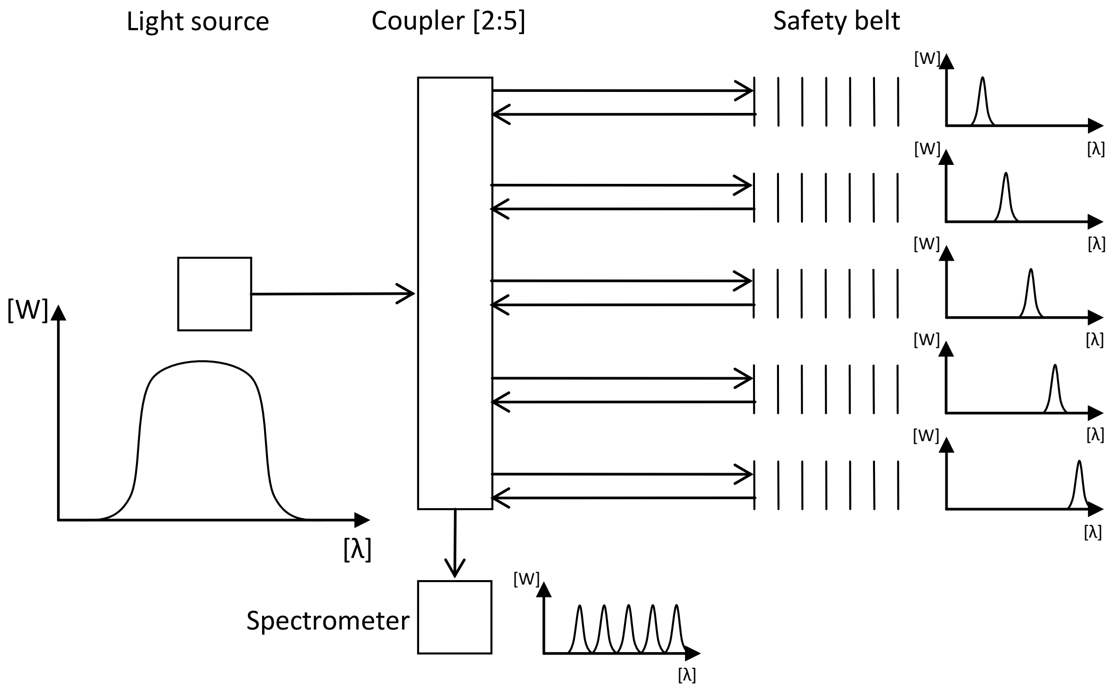


Figure 39. Solution with parallel coupled safety belts.

The other solution with serial coupled FBGs is harder to implement, but a smaller output power from the light source would be needed, see Figure 40. If the pervading fiber is broken, the whole chain will be broken and the following FBGs after the break will no longer be in use. Both ideas will not be further investigated and only mentioned.

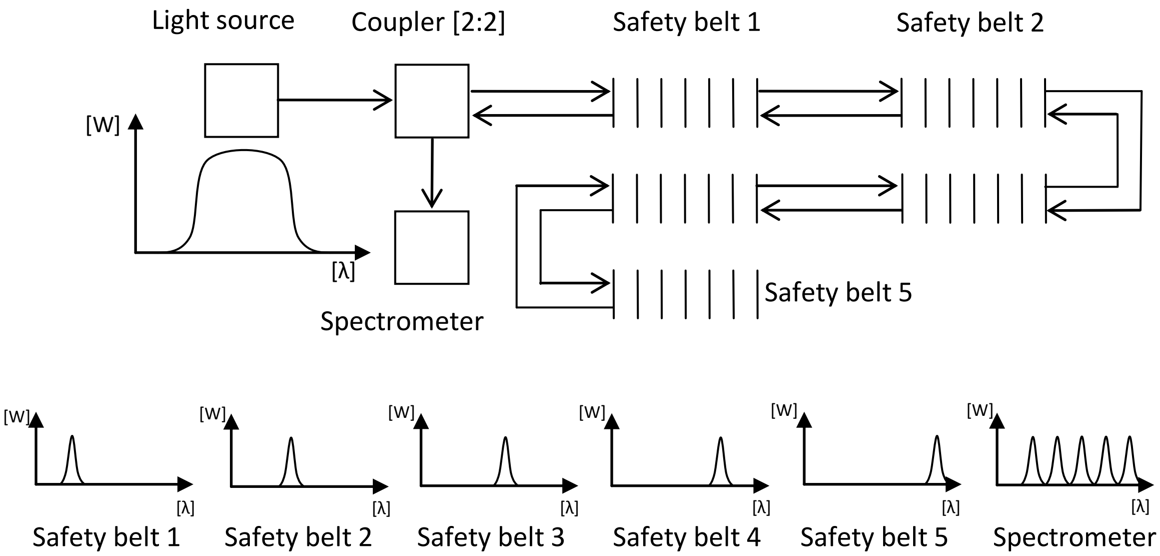


Figure 40. Solution with serial coupled safety belts.

8.4 FUTURE WORK MEDICAL

When interviewing the personnel in the so called “Golden Hour-chain” we saw a need of many things that could be investigated throughout different master theses. For Autoliv as a company, a couple of ideas regarding new products came up and are listed below:

- How many people are actually sitting in the car?
- The age of the occupants?
- Is anyone jammed inside the car?
- What is the velocity of the car just before the actual crash?
- What is the energy absorbed by the car during the crash?
- From which direction was the car hit?
- Is it possible to supervise the occupants’ wakefulness after a crash?
- Has the car been involved in a multi hit crash?
- Is it possible to install a camera in the rear-view mirror?
- Has the car done a roll-over?

8.5 FUTURE WORK PROTOTYPE

Some indications found during the work are worth further investigations. Some of these investigations are:

- Use of a wavelength dependent filter to lower the costs of the spectrometer.
- Use of a LED instead of a SLD.
- A microprocessor for the data acquisition.
- Rubber band attached to stretch the fiber.
- Position of FBG automatically over heart.

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Appendix A

Fiber in-woven in the safety belt

Manufacturer	OFS Denmark
Item #	Single mode fiber CF04246-04
Type	Clearlite 820-16
Core	Ø 4.8µm
Cladding	Ø 125µm
Acrylate coating	Ø 250µm

Connector welded onto open fiber

APC-style connector utilizes a ferrule that has an 8° end and the best option for systems that are sensitive to back reflections.

Manufacturer	Thorlabs
Item #	P3-830A-FC-5
Fiber	SM800-5.6-125
Operating Wavelength	830nm
Mode Field Diameter (MFD)	5.6µm(1)
Cladding Diameter	125µm ± 1µm
Coating Diameter	245 ± 5%
Cut-off Wavelength	730nm ± 70nm
Attenuation, Max.	≤5dB/km @830nm
NA	0.12(2)
Protective Jacketing	Ø3mm, Yellow
Insertion loss	<0.3dB Loss (Connector to Connector)
Length	5m

Notes:

1) MFD is nominal, calculated value, estimated at the operating wavelength(s)

2) 0.10<NA<0.14

Ericsson FSU 925 Fiber Splicer

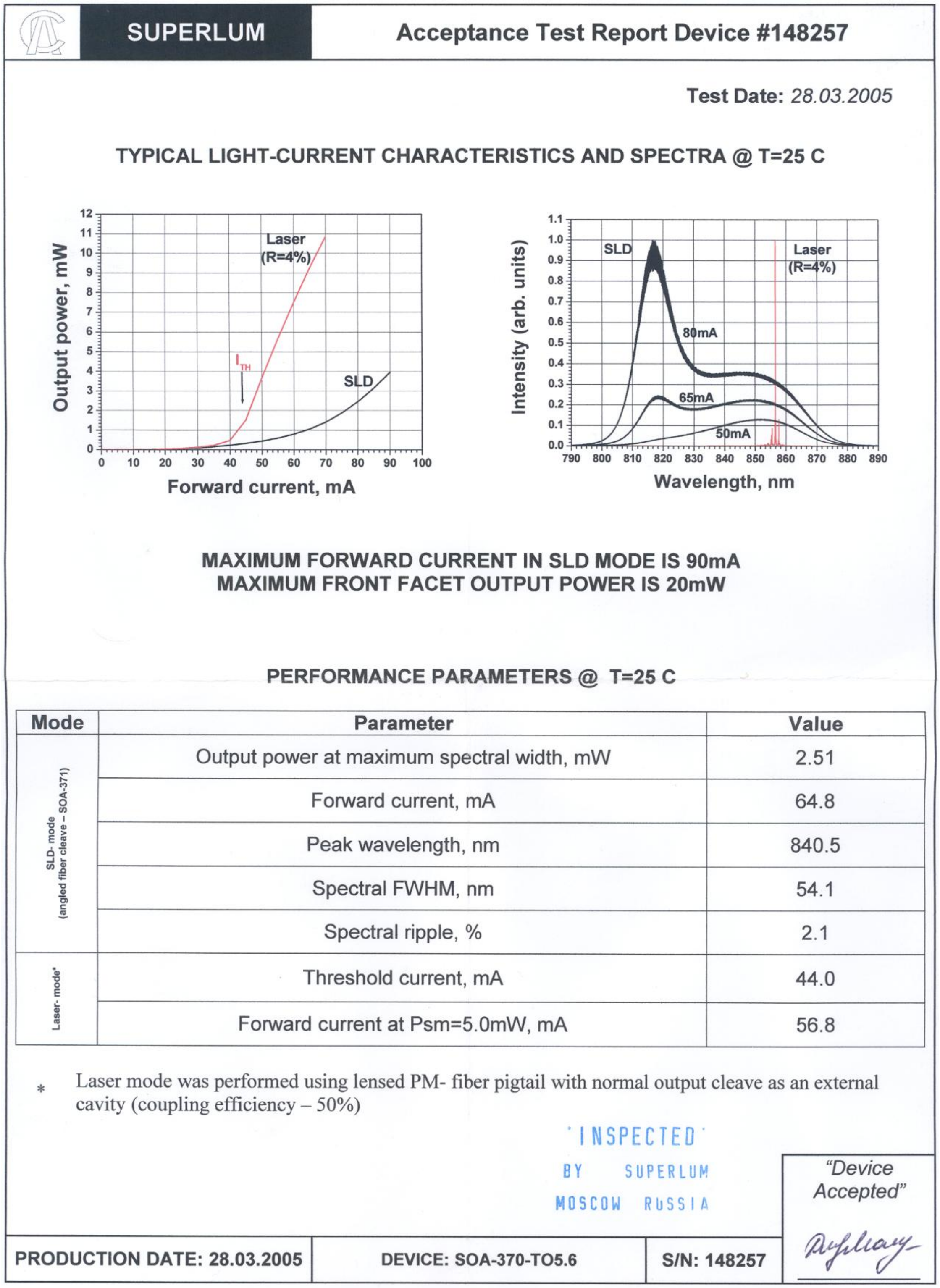
Located at MC2 department,Chalmers. Operated by Henrik Sunnerud, Scientist

Singlemode Fiber Optic Coupler

Special version of FC830-50B-FC, with 3 FC/APC and 1 SMA-SP connector instead of the usual FC connectors

Manufacturer	Thorlabs
Item #	FC830-50B 3FC/APC-1SMA-SP
Center Wavelength (nm)	830
Δλ (nm)	± 15
Coupling Ratio (%)	50/50
Insertion Loss(dB)	3.1-3.5 / 3.1-3.5
Excess Loss (dB)	0.15
PDL (dB)	<0.2
Directivity(dB)	>55
Termination	FC/APC

Light source



SUPERLUM **Acceptance Test Report Device #148257**

Test Date: *28.03.2005*

TYPICAL LIGHT-CURRENT CHARACTERISTICS AND SPECTRA @ T=25 C

MAXIMUM FORWARD CURRENT IN SLD MODE IS 90mA
MAXIMUM FRONT FACET OUTPUT POWER IS 20mW

PERFORMANCE PARAMETERS @ T=25 C

Mode	Parameter	Value
SLD- mode (angled fiber cleave – SOA-371)	Output power at maximum spectral width, mW	2.51
	Forward current, mA	64.8
	Peak wavelength, nm	840.5
	Spectral FWHM, nm	54.1
	Spectral ripple, %	2.1
Laser- mode*	Threshold current, mA	44.0
	Forward current at Psm=5.0mW, mA	56.8

* Laser mode was performed using lensed PM- fiber pigtail with normal output cleave as an external cavity (coupling efficiency – 50%)

INSPECTED
BY SUPERLUM
MOSCOW RUSSIA

"Device Accepted"

PRODUCTION DATE: 28.03.2005 | **DEVICE: SOA-370-TO5.6** | **S/N: 148257**

Fiber Launch System: Laser Diode to Fiber, 5.6 & 9mm, Metric

Item	KT112/M

Fiber Optic Power Meters with Internal Sensor

Manufacturer	Thorlabs
Item #	PM20A
Optical Power Range	-60 dBm to +16 dBm (1 nW - 40 mW)
Spectral Range	400 - 1100 nm
Detector Type	Silicon
Sensor Size	3.6 mm²
Input Aperture	3.6 mm²
Aperture Thread	0.535-40 (SM05 compatible) for Fiber Adapters Fiber Adapter included for FC/PC & FC/APC
Measurement Uncertainty	± 5%
Measurement Standard	NIST Traceable
Optical Damage Threshold	50 W/cm²
General Console Specifications	
Detector Compatibility	-
Display Type	Alphanumeric 8-Digits LCD
Display Format	4 Digit Read Out with Units and Symbols
Power Units	dBm, dB, nW, µW, mW
Resolution	14bit
Sample Rate	10 Hz
Dimensions (H x W x D) w/ Holster	125 mm x 80 mm x 39 mm (4.9" x 3.1" x 1.5")
Weight	0.2 kg (0.44 lbs)
Operating Temperature	5°C - 40°C
Storage Temperature	-20°C - 70°C
Power Management	
Battery Operation	Internal NiMH Battery Pack, 150mAh, 6V
Operating Time	50+ hours
Shutdown	Manual / Auto
Charger	3-Hour Battery Charger Included
Charger Power Supply:	Input: 85 - 265 VAC, 50 - 60 Hz; Output: 12VDC @ 0.85A

Spectrometer

The spectrometer is based on a compact Czerny-Turner grating with a fiber SMA input and a linear CCD array

Manufacturer	Thorlabs
Item #	SP4-USB (Custom made version of SP2-USB)
Spectral Range	800 -900nm
Spectral Resolution	< 1nm FWHM @ 633nm
Slit	10µm Wide x 20mm High
Grating	600 Lines/mm, 500nm Blaze
Dimensions	Approximately 112 x 91 x 51mm³
Weight	700g
Integration Time	1µs - 200ms
Scan Rate	190 Scans Per Second (Maximum)
Dynamic Range	2000:01:00
Fiber Connector	SMA 905
Trigger Input	BNC
Trigger Signal	TTL
Max. Trigger Frequency	500kHz
Min. Trigger Puls Length	1µs
CCD Integration Time	1µs to 200ms
CCD Sensitivity	300V / (lx · s)
CCD Pixel Size	7 x 200µm (7µm pitch)

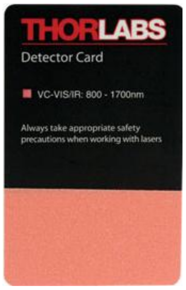
Power Source

Manufacturer	Thorlabs
Item #	LDC2000
Current Control	
Control Range (continuous)	0 to ±2 A
Compliance Voltage	>4
Resolution	<5 µA
Accuracy	100 µA
Noise(10 Hz to 10 MHz, RMS)	<20 µA
Ripple (50 Hz, RMS)	<5 µA
Transients, typical	<2 mA
Drift (30 min, 0 to 10 Hz)	<200 µA
Temperature Coefficient	<50 ppm/°
Power Control	
Control Range Photo Current	5 µA to 2 mA
Resolution Photo Current	0.1 µA
Accuracy	0.1 µA
Current Limit	
Setting Range	0 to =100 mA
Resolution	100 µA
Accuracy	±5 mA
Modulation, Analog Control Input	
Input Resistance	10 kΩ
Modulation Coefficient, CC	200 mA/V
3 dB Bandwidth DC	50 kHz DC
Modulation Coefficient, CP	0.2 mA/V ±5%
Control Output for Laser Current	
Load Resistance	>10 k
Transmission Coefficient	100 V/A ±5%
Connectors	
Laser Diode, Photodiode, LASER ON signal	DB9 Female
Modulation Input	BNC
Control Output Laser Current	BNC
Chassis Ground	4 mm banana
General Data	
Line Voltage	110 V ±10%, 115 V ±10%, 230 V ±10%
Line Frequency	50 to 60 Hz
Maximum Power Consumption	60 W
Operating Temperature	0 to +40 °C
Storage Temperature	–40 °C to +70 °C

Warm-up Time for Rated Accuracy	10 min
Weight	<3 kg
Dimensions (W x H x D)*2	5.8 x 2.8 x 12.5" 146 x 66 x 290 mm

Viewing Card

IR and VIS Absorption Bands



Item #	VC-VIS/IR
Absorption Band	400 - 640 nm and 800 - 1700 nm
Emission Band	~580 - 750 nm
Active Region Dimensions	31.8 mm x 54 mm
Requires Optical Charging	No

APPENDIX B

QUOTES

A major part of the prototype development was to find suitable components to a reasonable price and which could be delivered in time. A lot of different manufacturers and companies have been investigated in this process. The two main and most expensive components in the system are the light source and the spectrometer. These components have special requirements which some of the different manufacturers couldn't satisfy. To get a small view over the range of different manufactures contacted are some of the quotes of the two main components received summarized below:

Product	Manufacturer	Price (SEK)	Lead time (weeks)
SLD	EXALOS	10 000 – 17 275	> 5
SLD	Opto-Link Corp.	50 000	8 – 12
SLD	Superlum	24 000 – 27 000	3
LED	Thorlabs	12 650	1
Spectrometer	Hamamatsu	15 200 – 35 000	>4
Spectrometer	Lightspeed Tech.*	13 500	>3
Spectrometer	Thorlabs	21 450	3

(* The Lightspeed spectrometer did not satisfy the resolution requirements)

Costs

Main Components		Qty	Price/ea	Price
SP4-USB	USB2.0 Spectrometer, 800-900nm	1	21,437.00	21,437.00
FC830-50B	3FC/APC-1SMA-SP FC830-50B-3FC/APC-1SMA-SP	1	2,724.15	2,724.15
P3-830A-FC-5	Singlemode Fiber Patch Cable, 830nm, FC/APC	2	880.90	1,761.80
ADAFC3	APC FC to APC FC Mating Sleeve	3	176.00	528.00
KT112/M	9mm Laser Diode to Single/Multi Mode Fiber Coupler	1	8,207.00	8,207.00
PM20A	Digital Fiber Power Meter,400-1100nm, +16dBm	1	3,901.50	3,901.50
PM20-SMA	SMA Fiber Adapter for PM20 Series	1	225.40	225.40
VC-VIS/IR	Viewing Card for 400-640nm & 800-1700nm	1	624.20	624.20
LED equipment				
LED851W	LED, 850nm, 8mW w/ Glass Window, TO-18	1	32.95	32.95
LED851L	LED, 850nm, 18mW w/ Glass lens, TO-18	1	32.51	32.51
S1LEDM	LED Mount for SM1	1	225.42	225.42
C230TM-B	600-1050nm Moderate NA Optic	1	771.60	771.60
C220TME-B	600-1050nm Collimating Optic	1	771.60	771.60
SM1FCA	SM1 FC/APC Adapter	1	260.10	260.10
LEDD1	LED driver in a T cube	1	2,158.80	2,158.80
TPS001	T-CUBE 15V POWER SUPPLY	1	221.10	221.10
SLED equipment				
OLE 101 2224	Gain element 830 nm SAF 90% TO56	1	8,487.90	8,487.90
LD1255R	RoHS version of LD1255	1	1,031.73	1,031.73
LD1255P	Laser Driver Mounting Plate for LD1255	1	130.10	130.10
PS-12DC-EU	220-240VAC, 50-60Hz, Desk Top European	1	518.50	518.50
LD1255-CAB	LD1255 Power Supply Cable	1	121.40	121.40
				54,172.76
Shipping		4	223.07	892.28
				55,065.04

APPENDIX C

```
clear all
close all

%Put in the path where the data files lies
addpath('C:\Documents and Settings\Administrator\Desktop\Collect data')
%Put in the name of files
log_intesity=importdata('log_intensity_Coffe_Slowly.txt');
log_wavelength=importdata('log_wavelength_Coffe_Slowly.txt');

%Init variables to the right sizes
mean_wave_raw = zeros(1,length(log_intesity(:,1)));
max_val_int = zeros(length(log_intesity(:,1)),1);
max_val_pos = zeros(length(log_intesity(:,1)),1);
time = 60;
fs = time/length(mean_wave_raw);
time_length = length(log_intesity(:,1))* fs;
x = fs:fs:time_length;

 %Find intesity peaks and save their positions in mean_wave_raw
for i = 1:length(log_intesity(:,1))
    [max_val_int(i),max_val_pos(i)] = max(log_intesity(i,:));
    mean_wave_raw(i) = log_wavelength(i,max_val_pos(i));
end

%------------------------Creating a low pass filter--------------------------
%Init filter parameters

freq = 1/fs;
nyq = freq/2;
Fl = 1/nyq;
Fh = 2/nyq;

%FIRPM; 1 equals nyqvist which is Fs/2
f_spec=[0 Fl Fh 1];
a_spec=[1 1 0 0];
filter_spec = firpm(30,f_spec,a_spec);
filtered_data = conv(filter_spec,mean_wave_raw);
filtered_data(1:(length(filter_spec)-1)) = [];
filtered_data(end-(length(filter_spec)-1)+1 : end) = [];

%Normalize data
b=sum(filtered_data)/length(filtered_data);
c=sum(mean_wave_raw)/length(mean_wave_raw);
d=b/c;

x2=[(time_length/length(filtered_data)):...
   (time_length/length(filtered_data)):time_length];
```

```
%-------------------------------------Plot-----------------------------------
figure(1),plot(x,mean_wave_raw,'LineWidth',2)
grid on
ylabel('Wavelength [nm]');
xlabel('Time [s]');
% XLim([0 60])
Ylim([837.3 837.60])
title('Measurement of heart beat when test object was breathing slowly (Raw
data)')

figure(2), plot(x2,filtered_data/d,'LineWidth',2)
grid on
ylabel('Wavelength [nm]');
xlabel('Time [s]');
% XLim([0 60])
Ylim([837.2 837.55])
title('Measurement of minimum requirded power (Low pass filtered data)')

figure(3),plot(log_wavelength(1,:),log_intesity(1,:))
grid on
ylabel('Intesity');
xlabel('Wavelength [nm]');
%XLim([837.0 837.6])
title('Total wavelength movement of minimum requirded power')
hold on
for i=2:length(log_wavelength(:,1))
    plot(log_wavelength(i,:),log_intesity(i,:))
end
hold off
```