Lund University, Faculty of Engineering

Master thesis
PHYM01

Fuel meter of the future

Author
David Dahlgren
M.Sc. student in Electrical Engineering, LTH
abt10dda@student.lu.se

Supervisors
Mikkel Brydegaard
Combustion Physics, LTH
mikkel.brydegaard@forbrf.lth.se

Gustaf Gustafsson
Dover Fueling Solutions
gustaf.gustafsson@doverfs.com

In collaboration with

Dover fueling solutions

June 11, 2019

Abstract

The purpose of this master thesis is to evaluate technologies that could measure parameters of interest to Dover Fueling Solutions, a fuel pump company. A list of interesting measuring technologies has been compiled and compared. Spectrometry was chosen as extra interesting, as it had the potential to differentiate fuels by different octane ratings, but also measure concentrations of different contents. A simplified spectrometer circuit setup was constructed and tested on different types of fuels. However, the results did not unambiguously show that different octane rated fuels could be differentiated. This was probably due to construction flaws. The project has shown the simplicity of the technology, but needs further testing and evaluation. The technology is definitely relevant to Dover Fueling Solutions and has potential to generate positive value for the company and future costumers.

Acknowledgements

A special thanks to Gustaf Gustafsson for being a great mentor during the project. Also thanks to Mikkel Brydegaard for providing his special skills and knowledge, it would not have been possible without him. Also a very special thanks to Helena Sletten and our son Uno for making rainy days shine bright.

Contents

1

Introduction

1.1 Background

Dover Fueling Solution (DFS) is a fuel pump conglomerate with it's base in Austin, Texas. Their products, which can be seen in Figure 1.1, can be found all over the world. At it's Malmö subsidiary, they research new technologies. Currently, the company sells pumps with great volume flow measuring ability using mechanical discretization of the flow (Positive Displacement Flow), they can measure volume flow for several months without deviation. The preciseness is important, due to the liquids worth: any long term deviation could prove costly for gas station owners. In fact, the mechanical technique used today to measure the volume flow is difficult to develop any further, and DFS is looking to measure the flow using other technologies, and at the same time look at other parameters that could be of interest to their customers. This is the base of this master thesis.

Figure 1.1: Fuel pumps - products of Dover Fueling Solutions.

Dover Fueling Solutions has customers all over the world, and each market has their own regulations and directives. Most markets have certain regulations concerning explosive risks, spillage risks, temperature operating ranges etc. This places many demands on the fuel pumps. The fuel itself can also come with many variations: it could be diesel, biofuel, ethanol and gasoline with varying octane rating. The fuel flow has many properties: density, water content, mass flow, volume flow, flow velocity, octane rating, air bubbles content and viscosity among others.

These properties can be of interest to customers. Relevant questions for the customers could be if the fuel liquid volume is as expected? Is the octane rating correct? The value of the liquid attracts people who want to tamper with the pumps, both those who buy it and those who sell it. Adulteration of fuel is also something to be aware of, particularly in developing countries. Adulterated fuel can damage motors and results in an increase of emissions [1]. This calls for a desire to validate the fuel content.

1.2 Purpose and aim

The purpose of this Master Thesis is to investigate potential parameters of interest for Dover Fueling Solutions and their customers. Important factors will be feasibility, cost and life expectancy of different measuring technologies. A literature study will be done, and the research will result in a matrix, consisting of measuring techniques on one axis, and features on another.

When the matrix has been completed, one or two techniques will be chosen depending on what potential worth they can give. Factors that will be taken into account when deciding technique to implement are primarily if they can measure more properties than one, if they are expensive and feasibility. The chosen technique will be studied closer and implemented if possible.

1.3 Limitations

When researching different measuring technologies, some physical quantities of interest mentioned by Dover Fueling Solutions was *mass flow, water content, air bubbles, octane rating, density* and *liquid flow velocity*. These quantities was mentioned that could have an potential interest to customers. Some of them indirectly, such as liquid flow velocity which can be used to find the *volume flow* using properties of the pipe and the liquid.

The idea was that the measurements should happen in real time, measurements should be taken on flowing liquid. This further limited the techniques.

1.4 Thesis disposition

The following part of this thesis, Section 2, Comparing technologies, is a small literature study which contains information about different types of technologies. The technologies are summed up in a table in Section 2.2. One of the technologies is selected and focused on. Section 3, Technology implementation, explains how the technology is implemented. It contains information about schematics, simulation, construction and testing. The results can be found in Section 4 and they will be discussed in Section 5. Finally, conclusions will be drawn in Section 6. References and appendix can be found at the end of the thesis.

2

Comparing technologies

In the search for different ways to measure the quantities mentioned in Section 1.3, primarily special topic books about sensors were used. Also some important sources were found using internet searches and studies of articles. Reading through special topic books about sensors is a good way to acquire an overview of many relevant techniques. Sensor technologies is a field in constant development, and therefore newer sources of sensor knowledge would be preferred, but could not always be found. Sources 10-15 years old are common. There is also no guarantee that the collected information about sensors is comprehensive enough to cover them all, and some measuring technologies were left out because they were not applicable to this project due to irrelevance or obvious difficulty to apply, such as titration. Titration can yield information about the content of a liquid, but would be to slow a process.

When measuring flow of a liquid, you either measure mass flow (kg/s) or volume flow (m^3/s). Mass gives a better picture of the liquid, since it is independent of pressure and temperature. Volume on the other hand is larger if the temperature is high. The energy content of a liquid, which is what is interesting when it comes to fuel, is proportional to the mass. Therefore, one might believe that when trading with expensive liquids such as fuels, they would be sold per kg, but are as a matter of fact sold by the volume. This is mostly due to historical reasons. The volume is however usually compensated to a reference temperature of 15 °C [2]. Mass flow measurement could still be interesting and has therefore been included.

Dover Fueling Solutions currently measures the volume flow of the liquid using Positive Displacement Flow meters, its principle is described in Figure 2.1. They do this with great accuracy and durability. It is difficult to compete with the accuracy of this measurement technique using other techniques, however, DFS wants to investigate other technologies to measure volume flow as a way to stay competitive. Is there a way to make the measuring in a cheaper way than with their current pumps?

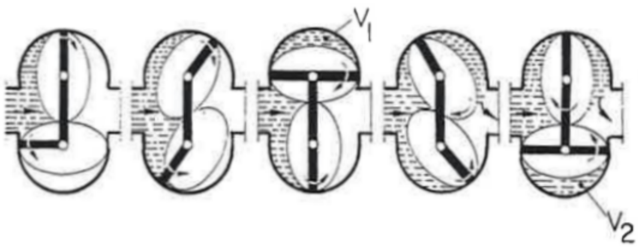


Figure 2.1: The Positive Displacement Flow meter is used to measure the volume flow of a liquid. The technique can be implemented in many ways, but the principle is that the liquid is discretized and counted. This technique has been refined by Dover Fueling Solutions to measure with great accuracy. Image source: [3], used with permission.

2.1 Technologies

The technologies in this section is listed in alphabetical order, and has been summed up Table 2.1.

2.1.1 Angular momentum meter for mass flow

This is a way of measuring mass flow. By forcing a tangential movement on a flowing liquid, for instance by letting the liquid pass through a rotating wheel as in Figure 2.2, an expression with the flow of mass can be acquired:

$$T = G\left(v_{ti} \cdot r_i - v_{tu} \cdot r_u\right) \tag{2.1}$$

where T is driving momentum, G is the flow of mass, v_{ti} is tangential velocity of the liquid at the entrance of the wheel, v_{tu} is tangential velocity of the liquid at the exit of the wheel and r_i and r_u are the distance of the liquid to the center of the pipe. In the case where v_{ti} is zero and the wheel is long enough for v_{tu} to become ωr_u, Equation 2.1 deflates to

$$|T| = G \cdot \omega \cdot r_u^2$$

To acquire G you need to measure T and ω, which can be difficult. Usually these types of mass flow meters are therefore implemented differently than as in Figure 2.2 [3].

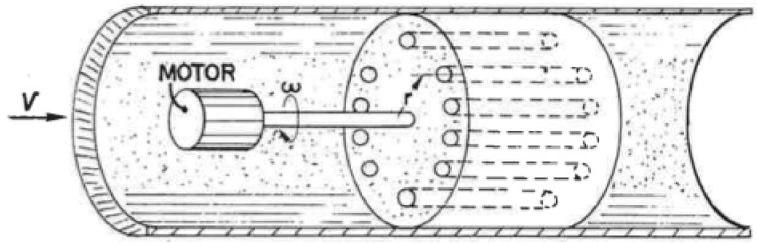


Figure 2.2: By forcing a tangential movement on a flowing liquid, the mass flow can be acquired. Image source: [3], used with permission.

2.1.2 Capacitance measuring

Capacitance can be used to measure water content in liquids, but can also be used to detect bubbles. The expression for capacitance in a capacitor is

$$C = \epsilon_r \epsilon_0 \frac{A}{d}$$

where ϵ_0 is the permittivity in vacuum, ϵ_r is the relative permittivity for the material between the capacitor plates, A is the plate area and d is the distance between the plates. The varying term in this case is ϵ_r. Imagine if the material between the plates in a capacitor was a flow of pure gasoline, the capacitance would be a certain value. If the flow instead changed to a gasoline diluted with water, the relative permittivity would change and therefore also the capacitance [4]. However, if an air bubble (or other pollutant) passed in the capacitor, the capacitance would also change [5]. Possibly both water content and bubbles could be detected by measuring the capacitance, if it's well understood how much bubbles of different sizes affect the capacitance combined with different water contents.

2.1.3 Coriolis meter

A Coriolis meter (Figure 2.3) utilizes the Coriolis effect, and is the dominating way to directly measure mass flow rate. The liquid runs through one or two tubes with certain shapes, typically U-shape, and the tubes are set in vibration by some sort of driver. The flowing liquid forces the tubes to wobble (deflect) in a measurable way. The mass flow can then be acquired from the following equation:

$$d = kfR \tag{2.2}$$

where d is the relative net deflection of one tube compared to the other, k is a constant, f is the vibration frequency and R is the mass flow rate. The main drawback of the Coriolis meter is that it is expensive compared to other technologies. It's vibration also limits is life time [6].

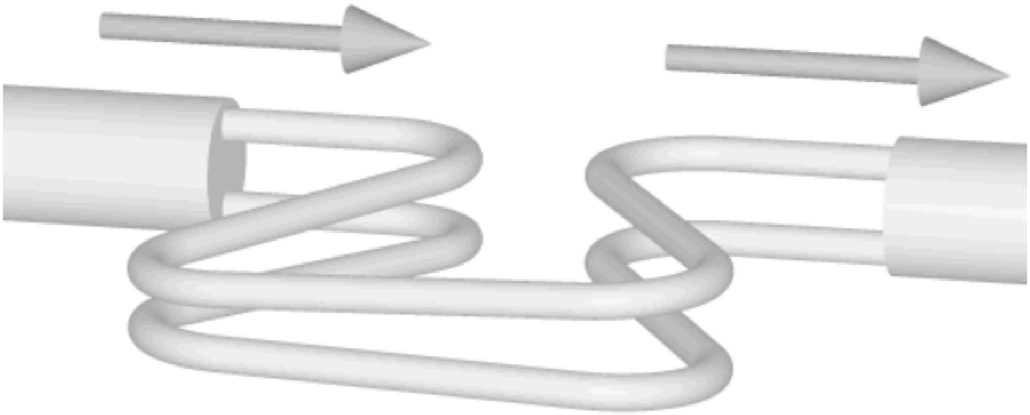


Figure 2.3: The Coriolis meter. The flowing liquid is directed through the vibrating U-shaped tubes, which forces the tubes to wobble. The flow of mass can then be acquired from Equation 2.2. Image source: [7].

2.1.4 Drag Force Flow Sensors

If an object is inserted in a tube of flow, forces will act on it. If the object is connected to the tube by a flexible beam, the acting force can be measured using strain gauges, and the velocity of liquid acquired using the following formula:

$$\epsilon = \frac{3C_D \rho A V^2 (L - x)}{E a^2 b} \tag{2.3}$$

where ϵ is the strain of the strain gauges, C_D is a drag force coefficient, ρ is the density of the liquid, A is the area of the object projected on the flow, V is the velocity of the liquid, L is the length of the beam, x is the where on the beam the strain gauge is located, E is Young's modulus of elasticity and a and b are some geometry target factors. The object could have different geometries, such as flat och spherical [8]. See Figure 2.4. A drawback is could be that you have to know much about the system in advance to have all the variables in Equation 2.3.

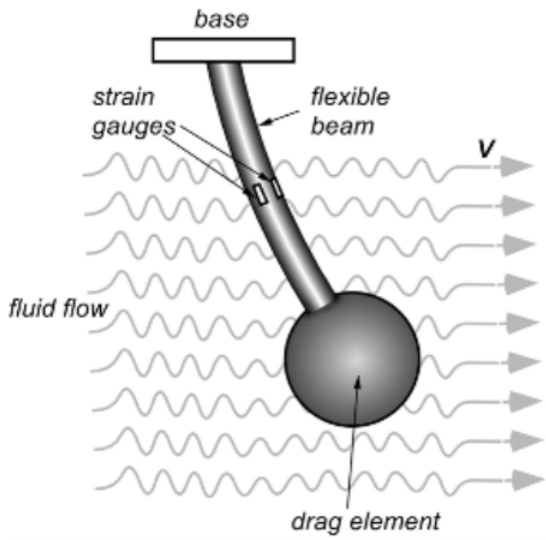


Figure 2.4: A Drag Force Flow Sensor used to measure flow velocity. From "Handbook of Modern Sensors" by Jacob Fraden. Used with permission.

2.1.5 Electrical conductivity

The electrical conductivity of gasoline with ethanol changes linearly with the concentration of ethanol, at concentrations larger than about 25 %. The conductivity also changes with the concentrations of water [9]. In other word it should be possible the measure the content of water or ethanol using anode and cathode. Although it might not be worth the risk, putting an electrical charge in highly flammable liquid could be risky and might not even be allowed by safety standards.

2.1.6 Electromagnetic flow Sensors

When a conductor moves through an magnetic field, it will induce a voltage according to Faraday's law. The induced voltage can be used to acquire the flow rate, however, the liquid should be a good conductor, which is not the case for gasoline (conductivity should be larger than 100 μS/m, but is a mere 25 pS/m for gasoline [3, 10]). But if the fuel contains ethanol the conductivity goes up, as mentioned in the previous section, and this method might then be applicable. The magnetic flow sensor is generally expensive, but could be very suitable for certain applications. For instance, it can tell in what direction the flow is moving [11]. A sketch of principle can be seen in Figure 2.5. The velocity can be acquired using

$$v = e - e' = 2a\mathbf{B}v$$

where v is the velocity of liquid, a is the radius of the tube, e and e' are induced currents and $\mathbf{B}$ is the magnetic flow.

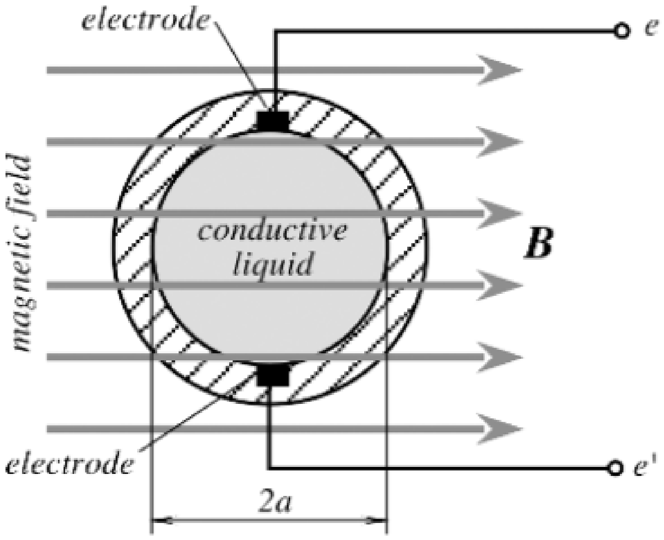


Figure 2.5: The principle of an electromagnetic flow sensor. The voltage will be induced in the electrodes. ***B*** *is the magnetic field and e and e' are induced currents. From "Handbook of Modern Sensors" by Jacob Fraden. Used with permission.*

2.1.7 Laser-doppler-anemometer, LDA

Laser-doppler-anemometers sends a beams of light into a flow, where some of the light will be reflected from particles in the flow. The particles could be bubbles or tracer particles. When the laser bounces on the moving particles, a doppler shift will be induced. This can be utilized to extract the velocity of the particles, and thus the flow rate. Generally, the LDA is expensive but reliable [3].

2.1.8 Microwave Absorbency

Microwave Absorbency can be used to measure water content. Water absorbs microwaves in the frequency of around 1-2 and 9-10 GHz. It can be detect water from 1-70% with an accuracy of $\pm$ 0.5% [12].

2.1.9 NIR-field Spectrometry

Spectroscopy is a discipline which studies hows matter and light interacts. It can be used to determine content of substances by studying how they reflect or absorb light with different wavelengths. Depending on how the substance absorbs or reflect energy in the light, conclusions can be drawn about the content of the substance. In terms of fuel, it can be used to determine octane number and water content. It can also be used to predict viscosity and density among other things [13]. While spectrometry can refer to lights with any wavelength, fuels generally has their interesting characteristics in the Near-infrared (NIR) field. NIR refers to the region of 780 nm to 2500 nm in the electromagnetic spectrum [14]. The spectrum for three different octane rated fuels can be seen in Figure 2.6. The differences for the fuels can be used to predict their octane rating. NIR-spectrums can be complicated, but can be used to identify substances and quantities of i.e. water. Figure 2.7 shows how the spectrum varies for ethanol with different contents of water. This measurement can be made very cost-efficient with LEDs as sources of light [15].

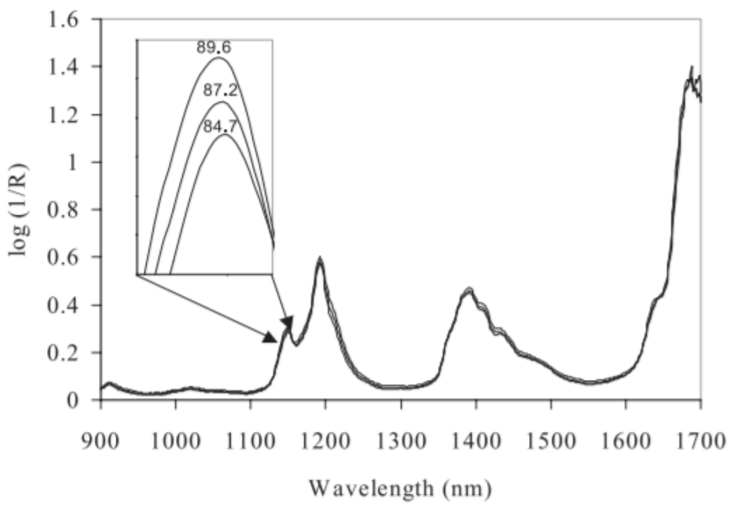


Figure 2.6: NIR-spectra for three different octane rated fuels. The R in the y-axis scale is reflectance. The curves for the three fuels are very alike, but differs slightly, and has been magnified between 1140 and 1155 nm. Image source: [16].

Octane rating is a property for a fuel, which tells how much pressure it can withstand before igniting. A higher octane number generally means higher quality of the fuel. A low octane rated fuel can lead to problems with engine knocking [18]. The true octane number for a fuel is determined using a standardized motor, and cannot be done quickly. Therefore, spectrometry is interesting as a way to predict octane rating faster and cheaper. It can be used in real time and with good precision. You can also look at specific wavelength of interest using laser diodes with the right wavelength, for instance in Figure 2.6, the magnified peak could be looked at. In order to avoid sample dependant variations such as turbidity, a comparison can be made between one measured intensity at a wavelength of interest and a normalized intensity, such as another wavelength in the same sample wavelength or pure water [19, 15].

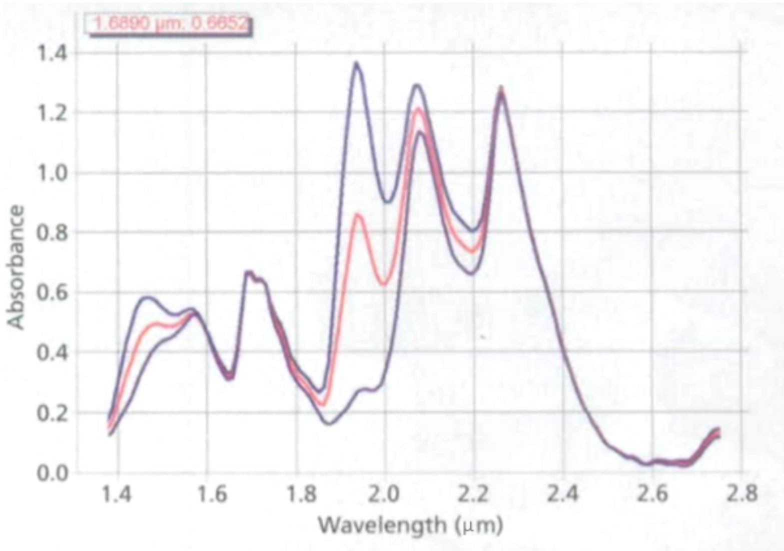


Figure 2.7: NIR-spectra for ethanol with differents contents of water. Blue line (uppermost) 90% ethanol, red line (middle) 95% ethanol and purple line (lowermost) 100% ethanol. Image source: [17].

2.1.10 Nuclear Magnetic Resonance

Electromagnetic radiation can be applied to a liquid and the water molecules set in resonance, if the frequency of the radiation is correct. The resonance in the molecules causes a loss in frequency power. This loss can be translated to water content. However, other substances can also be set resonance the therefore disturb the measurement [12].

2.1.11 Pressure Gradient Technique

Pressure gradient technique is a relatively common way to measure the volume flow rate. The flow enters some kind of contraction and the change in pressure is measured. An expression for the flow can then be derived using Bernoulli's principle, resulting in

$$q = \frac{A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \cdot \sqrt{\frac{2 \cdot (p_1 - p_2)}{\rho}}$$

where q is the volume flow, A_1 and A_2 are the tube flow area at the pressure sensors, p_1 and p_2 are pressures and ρ is the density of the flow. The contraction can designed in several ways for different characteristics, one such can be seen in Figure 2.8 [3].

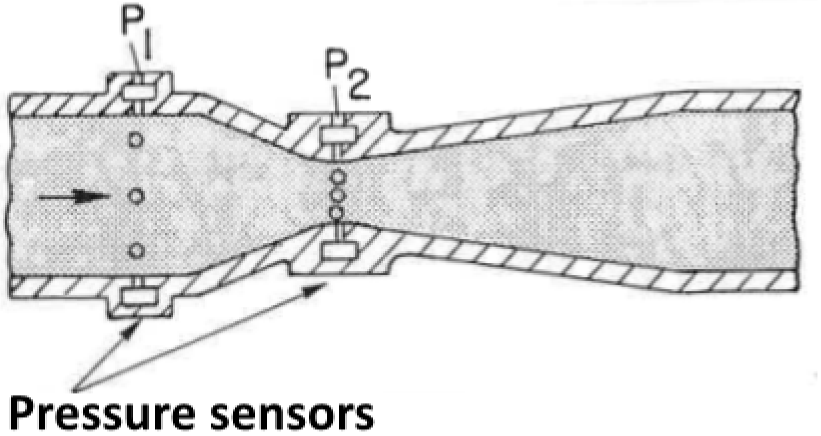


Figure 2.8: One design of the Pressure Gradient Technique. The change in pressure can be measured and the volume flow acquired. Image source: Modern Industriell Mätteknik: GIVARE, used with permission.

2.1.12 Thermal Transport Sensors

One way to measure the mass flow is to see how fast heat disperses. The principle is simple. At one point in the flow, put a heater, at another point slightly further down the flow, put a thermometer, as in Figure 2.9. Depending on what temperature is sensed, you can get an idea of how fast the flow is going. The faster the flow, the lower the temperature - the heat will dissipate faster.

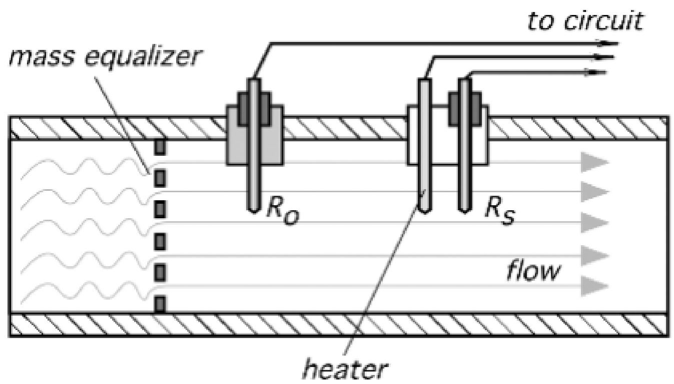


Figure 2.9: Thermal transport sensor. The heat dissipates with the flow, and the dissipation can be measured with a thermometer, R_S. This way, you can get a sense of the flow rate. R_0 is also a thermometer, and is used to know the temperature before heating. From "Handbook of Modern Sensors" by Jacob Fraden. Used with permission.

2.1.13 Turbine-Based Flow Sensors

The turbine-based flow sensor is also simple in principle: allow the liquid flow to move propeller blades, and use hall sensors to measure how fast the blades are rotating. The rotational speed of the turbine is proportional to the speed of the liquid. The faster the turbine is allowed to spin, the greater the resolution, but also shorter life time due to wear. If the turbine is designed to spin slower it leads to a lower resolution but greater life expectancy. See Figure 2.10.

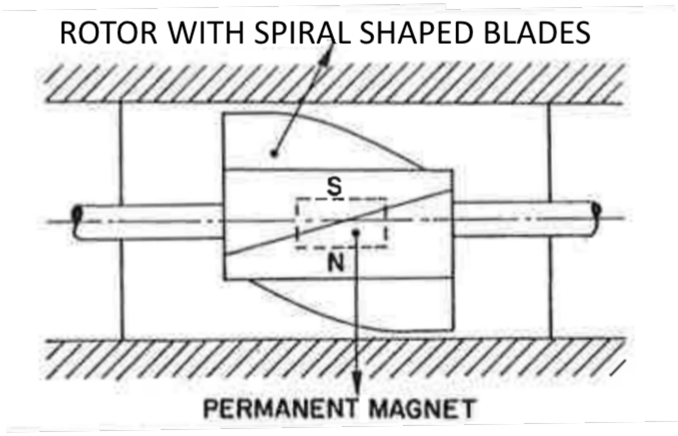


Figure 2.10: A turbine can be used to measure the velocity of a liquid. Image source: Modern Industriell Mätteknik: GIVARE, used with permission.

2.1.14 Ultrasound

Ultrasound is a technique that can be used to obtain many different parameters of a liquid. It is also a relatively cheap and reliable technique. By sending sound waves in the same direction as the flow, the speed of the liquid is added to the speed of the sound. And by sending the sound waves in the opposite direction of the flow, the speed of the liquid is subtracted from the speed of the sound. Therefore, by measuring the difference in time it takes the sound to traverse the both directions, you can extract the velocity of the flow. A typical setup can be seen in Figure 2.11.

As with LDA, ultrasound can also be used to measure a doppler shift, and therefore get a velocity of flowing particles, [8].

If the sound does not reach a microphone from the speaker, something must be obstructing the path. This could be utilized to detect air bubbles for instance [20].

Ultrasound can also be used to determine the density of the liquid. The speed of sound in liquid is

$$v = \sqrt{\frac{K_s}{\rho}}$$

where K_s is a coefficient of stiffness in the medium and ρ is the density. In other words, if K_s is known and v is measured, ρ can calculated, [21].

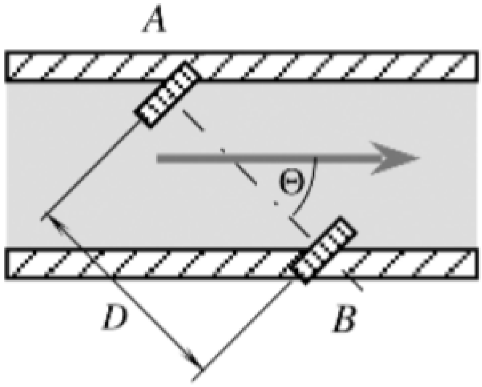


Figure 2.11: A typical setup for ultrasound flow meter. A and B are both transmitters and receivers of sound. The sound from A to B is faster than in the reversed direction due to flow of the liquid. The difference in the speed of sound upstream and downstream is proportional to the speed of the flow. From "Handbook of Modern Sensors" by Jacob Fraden. Used with permission.

2.1.15 Vortex-Shedding flow meters

By obstructing the flow of a liquid with an object, vortex or eddies occur in the flow. The vertices are alternating, or shedding, on each side of the obstructing body, as depicted in Figure 2.12. The alternating vertices has a frequency proportional to the velocity of the flow. So by measuring the alternating vertices, you can get an idea of the flow velocity. The measuring of the vertices can for example be made by ultrasound, thermal detection or pressure sensing, [3].

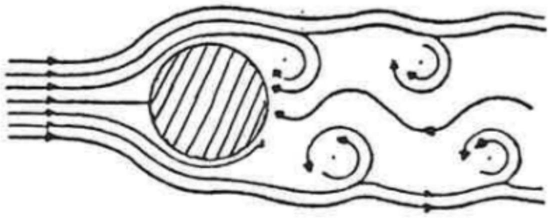


Figure 2.12: A vertex-shedding meter can be used to measure the flow velocity. The vertices on each side of the obstructing body are alternating with a frequency proportional to the flow velocity. Image source: Modern Industriell Mätteknik: GIVARE, used with permission.

2.2 Technology compilation table

Technology	Mass flow	Water content	Bubbles	Octane rating	Density	Flow velocity
Angular Momentum Flow Meter	X					
Capacitance measuring		X	X			
Coriolis meter	X					
Drag Force Flow Sensors						X
Electrical Conductivity Meters		X				
Electromagnetic Flow Sensors		X				X
Laser-doppler-anemometer LDA						X
Microwave Absorbency		X				
NIR-field Spectrometry		X		X		
Nuclear Magnetic Resonance		X				
Pressure Gradient Technique						X
Thermal Transport Senors	X	X				X
Turbine-Based Flow Sensors						X
Ultrasound			X		X	X
Vortex-Shedding flow meters						X

Table 2.1: A table showing the examined technologies that could be of interest to Dover Fueling Solutions.

2.3 Technology selection

As can be seen in Table 2.1, some technologies can measure several quantities, and some quantities can only be measured by one technology. For instance Ultrasound could be used to detect bubbles, but also to measure density and flow velocity. Initially, NIR-field Spectrometry and Ultrasound was viewed as extra interesting. Spectrometry because it would be a great advantage for the company if they could sell real time octane measuring to their customers, which would be something new to their market. At this point it was not clear if NIR-field spectrometry would turn out to be expensive and the feasibility of it. Ultrasound on the other hand is a well established technique with better known pros and cons. It's cheap and can measure several quantities, although not necessarily with the same setup.

For the spectroscopy, one idea was to look at a single wavelength of interest instead of an entire spectra, specifically a wavelength where the difference between different octane rated fuels are the greatest. This would simplify the implementation. For gasoline, some potential wavelengths of interest could be around 1150 nm, 1200 nm and 1400 nm, which can be seen as peaks in Figure 2.6. Two wavelengths needs to be measured for it to work. The other is used as a reference and should be somewhere where the amplitude does not vary that much, such as around 1300 nm in Figure 2.6, this is known as differential absorption [15, 19]. By dividing the acquired value at one wavelength by the value at the other wavelength, variations in turbidity would be reduced. Looking at only a couple of wavelengths instead of an entire spectra would largely simplify the technology, and make it cheaper and easier to construct.

Ultrasound is a well established technology, and several manufacturers and products exists on the market. There are several companies that supplies industrial process instrumentation and solutions.

The choice of technology to focus on ultimately fell on NIR-spectrometry. The main reason being it's a technology that could measure something difficult, octane rating, in a fast way. Dover Fueling Solutions expressed it has potential to attract new customers.

3

Technology implementation

As discussed in section 2.1.9 and 2.3, a simplified spectrometer can be made that would only look at two different wavelengths. To construct this simplified spectrometer three main parts are crucial: two light emitting sources with the right wavelength and a photodiode sensitive to light in this region. The medium of interest, the fuel, is in a container between the light source and the photodiode.

If the difference in spectra for different octane rated fuels are as small as in Figure 2.6, then the light sources would have to emit light at in very short spectra. Laser diodes can have this property, and has therefore been used in this project.

3.1 Circuit

The circuit for this project contains of a sender part and a receiver part. The circuits were sketched in the schematic editor Eagle (free version 9.3.0). The sender contains two light sources, while only one photodiode is used in the receiver. This means that the light sources are angled, as depicted in Figure 3.1.

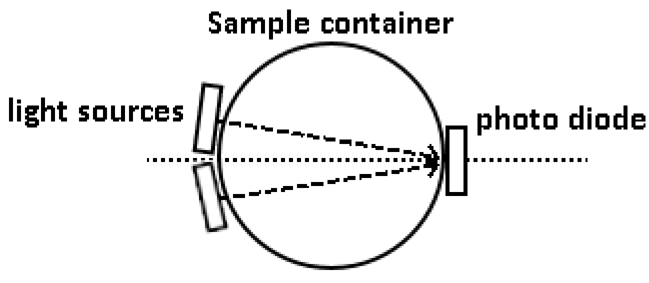


Figure 3.1: Principle setup of the spectrometer.

3.1.1 Sender

Using a time-division multiplexing (TDM) scheme, the lasers alternated in emitting light with a selectable frequency. This is achieved using a counter (CD4017) that enables current to flow through the laser diodes by opening the transistor, as can be seen in Figure 3.2. The counter puts all of its outputs in an on/off state one by one. First, the counter opens one of the transistor, activating its connected laser, second the other transistor, third a "black output" and finally it resets itself. The purpose of the "black output" is to record the dark current from the background level. Some specifications of the used lasers can be found in Table 3.1. More can be found the Appendix A.0.1 and A.0.3.

	Laser 1	**Laser 2**
Peak wavelength [nm]	1172	1317
Operating power [mW]	20	10
Operation current [mA]	89	54
Threshold current [mA]	48	27
Model number	FB-S1170-20SOT148	FB-S1300-10SOT148
Supplier	Fibercom Ltd	Fibercom Ltd

Table 3.1: Some specifications of the lasers used.

The laser diodes are supplied with a constant current source, using the setup seen in the Figure with the LM317 voltage regulator. The flowing current will be 1.25 volts divided by the size of the resistor, i.e. 15 Ω, resulting in 83.3 mA.

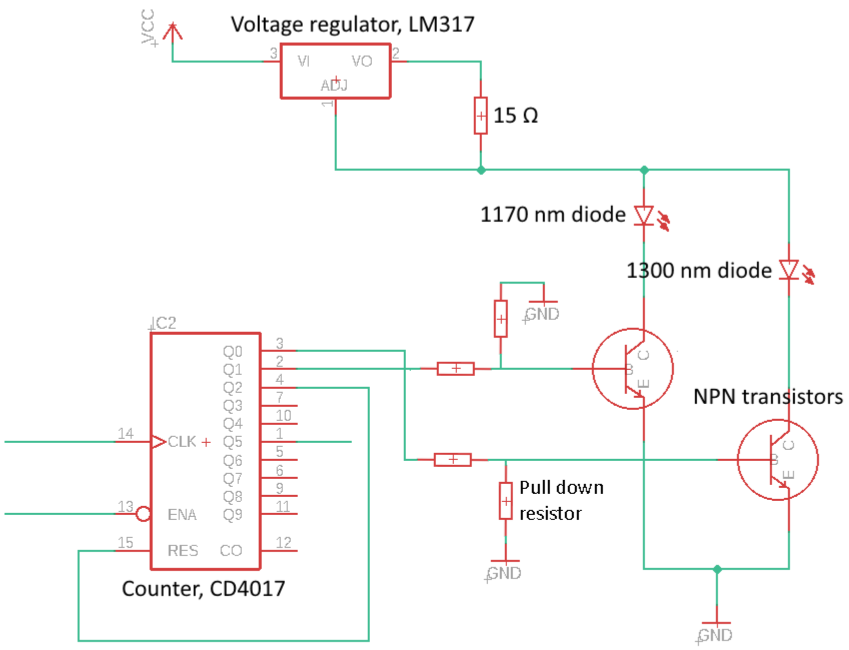


Figure 3.2: Schematics of the sender part. Two laser diodes alternating their transmissions with the help of the counter and the transistors.

3.1.2 Receiver

A photodiode will produce a small current when illuminated, which will need to be amplified. This is the basics of the receiver. It consists of a photodiode and amplification steps. In the schematics (Figure 3.3) two amplification steps were made, with the possibility to add or remove steps if needed. The acquired photodiode is of the type InGaAs, which is necessary since it is sensitive in the NIR-area (800–2600 nm). Photodiodes are commonly made out of silicon, and are sensitive only up to about 1100 nm [22]. The used photodiode also has a lower responsitivity in the lower end of the sensing range according to the data sheet (0.90 A/W at 1310 nm compared to 0.95 A/W at 1550 nm), see Appendix A.0.5 for more information. It does not state the sensitivity at 1170 nm, which is the interesting part.

The first step is a transimpedance amplifier with a reverse biased photodiode, meaning it amplifies a current to an inverted voltage. The amplification is a factor of the size of the resistor, R1, using the notations in Figure 3.3. The second step is an inverting amplifying step, with the amplification of $-\frac{R22}{R21}$. The data sheet shows that the Maximum forward current is 8 mA, meaning the total amplification could be at least 1 V/mA. The net voltage is 12 volts, meaning the amplification should be max 1.5 V/mA. However, the photodiode was never excited enough to produce that level of current, and an amplification of 50 V/mA was used.

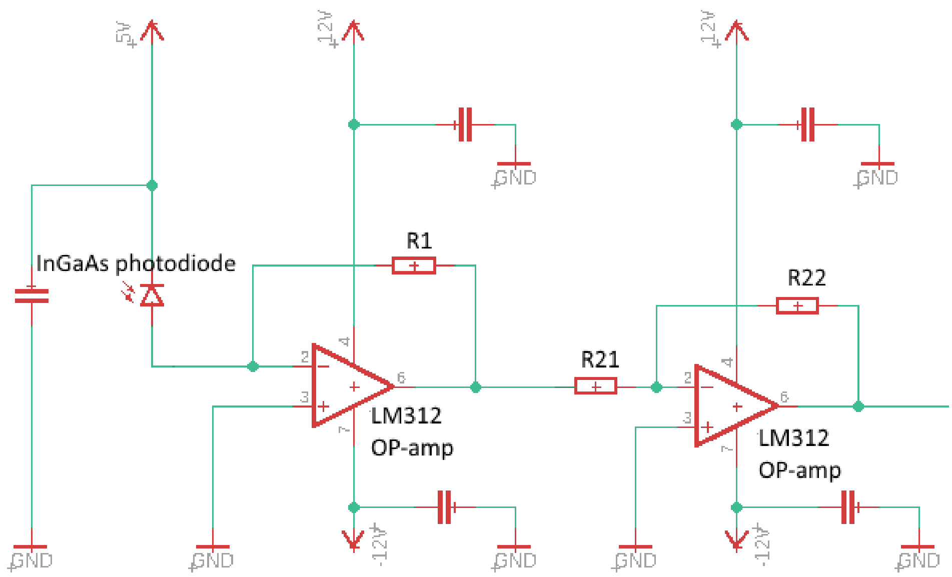


Figure 3.3: Schematics of the receiver part, with 2 amplification steps.

3.2 Simulation

The simulation was made in the software LTspice XVII, see Figure 3.4. The simulation was made with two amplification steps and a total amplification of 6 V/mA. The photodiode was simulated with a current signal generator. The simulation showed that the circuit was correctly designed, the voltage of the resistor R6 in Figure 3.4 was 6 times that of the current from I1.

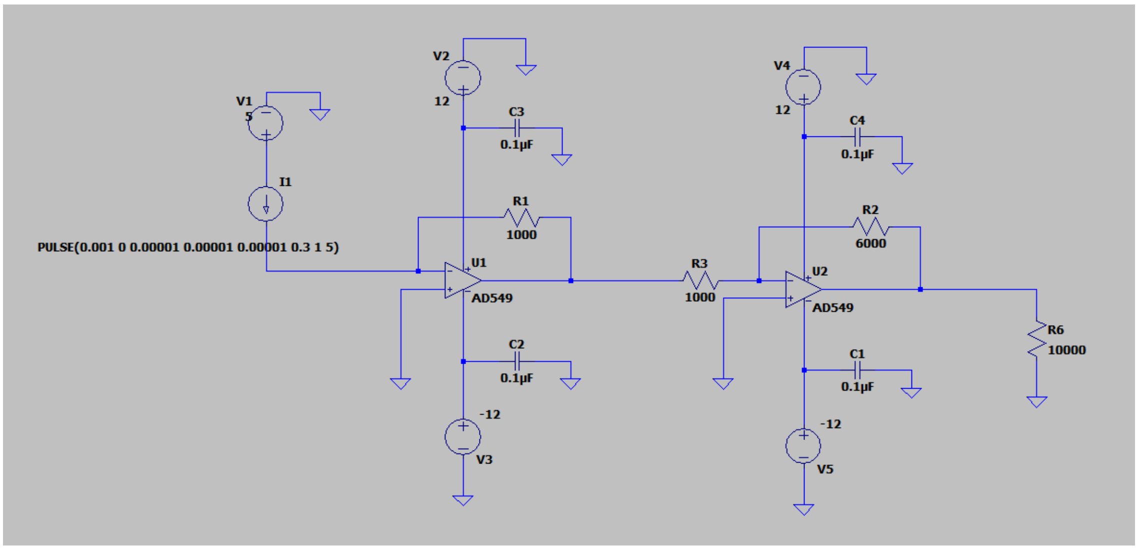


Figure 3.4: Simulation in LTspice of the receiver circuit with two amplification steps. The photodiode was simulated with a current signal.

3.3 Construction

The construction of the circuits were made using stripboard prototype cards, which has parallel strips of copper coating. The physical layout was designed using stripboard CAD program StripCAD 1.00. The designs can be seen in Figure 3.5 and 3.6. When it was finished, it was simply printed and put on the stripboard, then all the components and wires were soldered in place. Some minor design changes were made after the CAD-design.

The fuels were contained in glass test tubes with corks, and the holder for the test tubes was a simple rubber ring with the right hole size. This rubber ring held the laser diodes and the photodiode in place according to Figure 3.1. Therefore three holes with correct sizes were drilled in the rubber ring.

The constructed setup can be seen in Figure 3.7

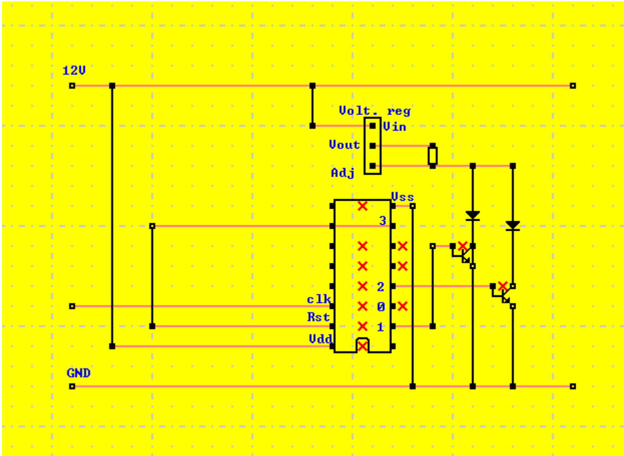


Figure 3.5: StripCAD design of the sender.

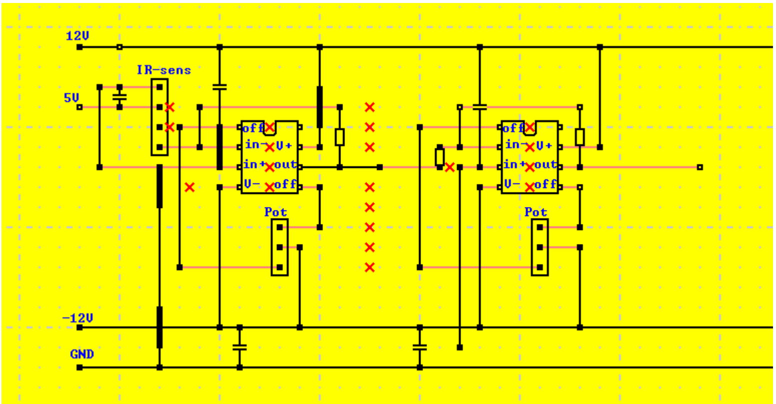


Figure 3.6: StripCAD design of the sender.

3.4 Testing

In Sweden, fuels are usually 95 or 98 octane rated. Diesel is also common. It was decided that tests should be made on diesel, 95 and 98 rated fuel. Samples were collected from three different retailers: OKQ8, Preem and Ingo around Malmö, at a total of nine samples. The reason for multiple retailers is that there are many different fuel refineries, meaning the fuel can have different turbidity and other optical properties. To make sure any findings of difference is of significance, several different samples are important to use.

It was assumed that the spectra of acquired samples are the same as in Figure 2.6. Other papers shows that the general structure of gasoline spectra is the same. Figure 3.8 shows the spectra of several different octane rated fuels, it's similar to Figure 2.6.

The samples were put in test tubes and the testing could commence. A function generator with variable frequency was used as input to the counter. The frequency determines how long a counter output will be high before switching to the next output, meaning the lasers will emit light with a period of the

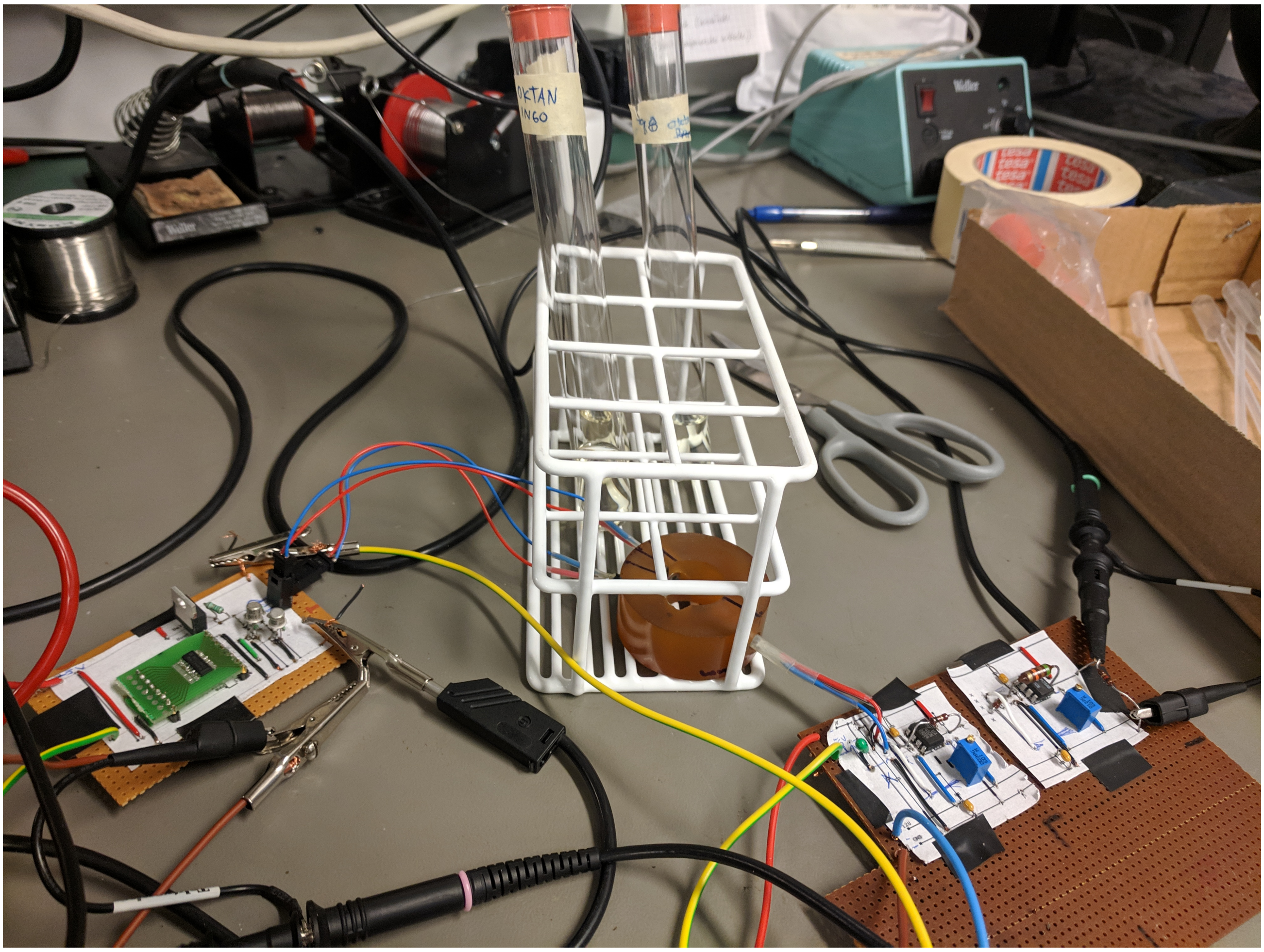


Figure 3.7: The actual final setup. No sample in the rubber ring. The diameter of the holder hole is 21 mm. The outer diameter of the test tubes are 20 mm and the glass has a thickness of 1.25 mm.

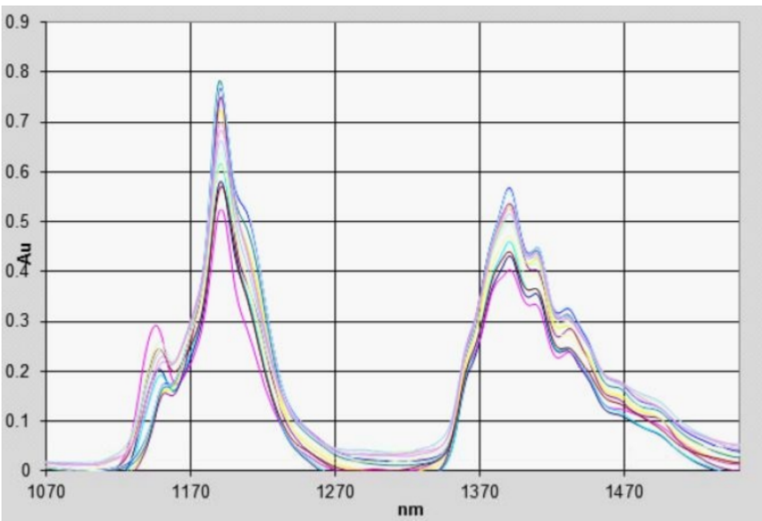


Figure 3.8: The spectra of fuels with different octane ratings. Image source: [23]

inverse of this frequency.

The amplified signal was visualized with an Tektronix DPO 5104 oscilloscope. All nine samples was tested, and also an empty sample and a sample with tap water.A division between the 1170 nm amplified signal and the 1300 nm amplified signal will be calculated. The goal is to see if there is a difference of significant between the three types of fuel. If that is the case, it would show that technology could be of interest to Dover Fueling Solutions.

The reading of the values was done with the help of the oscilloscope. See Figure 3.9 as an example. In the Figure: a) The amplified signal when no lasers emits light (dark current), b) the amplified signal when the 1170 nm laser emits light, c) the amplified signal when the 1300 nm laser emits light and d) the counter switches. The oscilloscope was paused and a mean were taken between two points. This was done with the help of the oscilloscope mean function, which calculates the mean between two lines; the green a and b in the figure. This was done on a), b) and c) in the Figure, and a mean of three different cycles was calculated. The lower levels, a) and b) were zoomed in with the help of the oscilloscope, for a better resolution. The image serves as an example and the values in it did not make it to the final results.

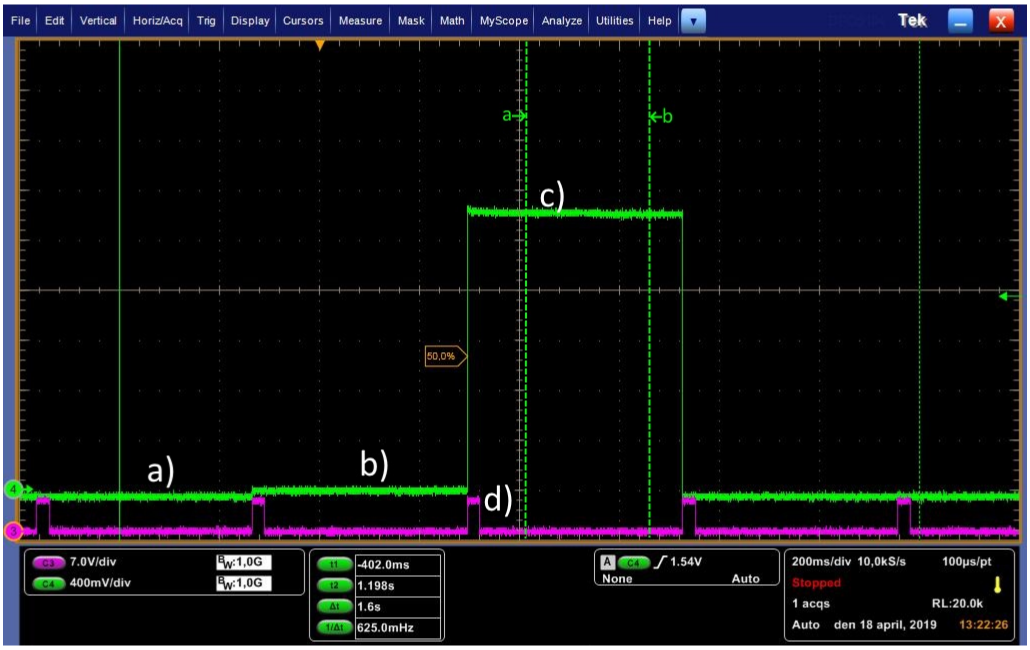


Figure 3.9: Oscilloscope screenshot of a measurement. a) The amplified signal when no lasers emits light, b) the amplified signal when the 1170 nm laser emits light, c) the amplified signal when the 1300 nm laser emits light and d) the counter switches. This screenshot is an example and these values does not appear in the results.

When the values had been acquired, the dark current amplified signal was subtracted and a division was calculated between the 1170 nm laser and the 1300 nm laser amplified signal, according to Equation 3.1.

$$absorbance\ ratio = \frac{1170\ nm}{1300\ nm} = \frac{V_{1170} - V_{dark\ current}}{V_{1300\ nm} - V_{dark\ current}} \tag{3.1}$$

where V_{1170} is the amplified signal of the 1170 nm signal, V_{1300} is the amplified signal of the 1300 nm signal and $V_{dark\ current}$ is the amplified signal of the dark current.

Then the mean was calculated for each type of fuel. The standard deviation was calculated using the Matlab-function `std`, which uses Equation 3.2. The distribution of the values was assumed to be a normal distribution, and was plotted using Matlab. The code can be found in Appendix B.

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \mu)^2} \tag{3.2}$$

where N is the number of samples, and X_i is the sample Absorption ratio of sample i.

4

Result

The collected values were compiled in the Table 4.1.

Type	**Origin**	**No laser**	**1170 nm laser [mv]**	**1300 nm laser [mv]**	**Absorption ratio**	**Type average**
empty		-0.26	36.4	234.4		
water		-0.27	1.7	14.4		
	Preem	-0.27	2.4	314.4	0.0085	
Diesel	OKQ8	-0.26	2.4	298.4	0.0089	
	INGO	-0.36	2.1	318.1	0.0078	0.0084
	Preem	-0.35	3.7	258.1	0.0158	
98 octane	OKQ8	-0.36	3.3	259.8	0.0142	
	INGO	-0.33	4.6	196.5	0.0249	0.0183
	Preem	-0.31	2.2	294.8	0.0084	
95 octane	OKQ8	-0.25	2.7	209.8	0.0139	
	INGO	-0.32	3.9	287.3	0.0146	0.0123

*Table 4.1: The columns **No laser 1170 nm laser** and **1300 nm laser** contains the observed values of the amplified signal for the respective state. The values under **Absorption ratio** has been calculated using Equation 3.1, that is, dividing the absorption of the 1170 nm signal with the 1300 nm signal. Finally the right most columns are average values of the type.*

The expected (mean) values and standard variation has been calculated and can be seen in Table 4.2.

	Diesel	**98 octane**	**95 octane**
μ	0.0084	0.0183	0.0123
σ	0.0006	0.0058	0.0034

Table 4.2: Expected value (μ) and standard deviation (σ) of the three fuel types.

The normal distribution plots using the values in Table 4.2 can be seen in Figure 4.1 and 4.2.

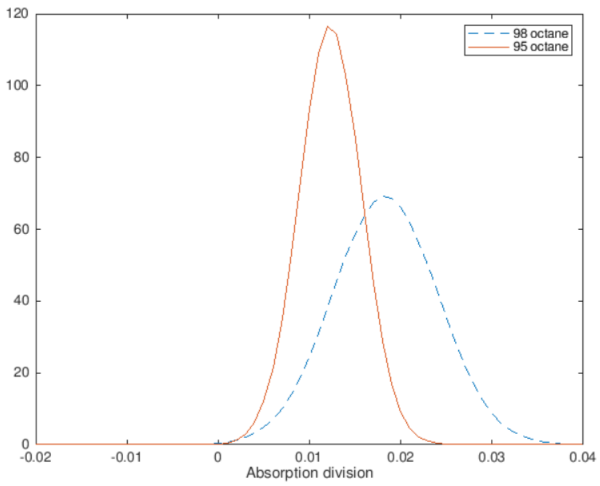


Figure 4.1: Using the values in Table 4.2, the normal distribution curves has been plotted for 95 and 98 octane fuel.

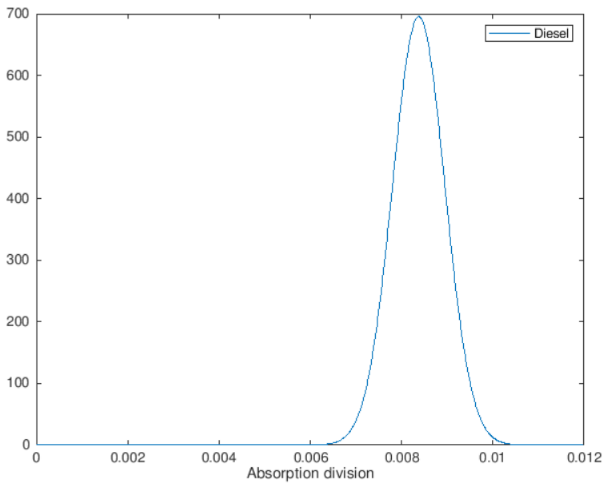


Figure 4.2: Using the values in Table 4.2, the normal distribution curves has been plotted for diesel. Note that the x-axis is much smaller than in Figure 4.1.

5

Discussion

The empty sample in Table 4.1 shows that the photodiode is much less sensitive to the 1170 nm laser than the 1300 nm laser. According to the datasheet, A.0.5, the photodiode is slightly less sensitive in the lower region, but this does not explain the vast differences between the 1170 nm laser and the 1300 nm laser that also can be seen in the table. This is unfortunate, since that is the most important part for this study. It does not mean however, that the values are not interesting.

Looking at the Absorption ratio values shows that the values are somewhat consistent. In both 95 and 98 octane two of the three values are close to each other, while the third is a bit off. This explains why the standard deviation is relatively high and the why Normal Distribution curves overlap as can be seen in Figure 4.1. The diesel samples shows a more consistent result, and the standard deviation is lower, which also shows in the Normal Distribution curve in Figure 4.2. The peaks of the curves for 98 and 95 octane rated fuels are located at different expected values, however since they overlap too much, it can't be said that the difference between them is of a statistical significance.

It's important to note, however, that the curves in Figure 4.1 and 4.2 are based on only three samples. For a clearer result, more samples might be required. The hope was that all curves would be similar in width as the one with diesel, it would be much easier to say that the fuels can with a certainty be differentiated using this technology.

Something important to comment on is the fact that the amplified 1300 nm signal values of the fuels are in most cases larger than the empty sample. This indicates that more light gets through if there is a fuel in place, which could mean that the liquid and the curved glass focuses the light against the photodiode. With only air in the test tube the differences in refractive indexes could diverge the beam.

The major reason for unclear results however, are probably due to flaws in the construction and testing setup. For one, the fuel container should not have been circular, but rather flat. The laser light is bent and could be refracted by the round glass in an undesired way. Also, the laser don't have lenses. According to the datasheet, the beam divergence of the lasers are 45° and 8° on each axis and 30° and 10° on each axis respectively (meaning they have an elliptical beam divergence). The lasers could be equipped with lenses to focus the light for a better effect transfer. No care was taken about the orientation of the lasers. No shielding was done to the amplification circuit, which could reduce the noise in the amplification.

During the measurements, it was noticed that the signal was very sensitive to movements. During all readings and measurements the test tubes were held as straight and similar as possible, to reduce differences. Even very small differences however, made relatively large changes in the amplified signal. This of course means there is a large variation from reading to reading. Using a better built setup could improve the results greatly.

5.1 Future work

If Dover Fueling Solution chooses to continue with this technology, they should start by designing the test setup in a better way. Use glass containers with flat surfaces. Build away sources of error and shield the construction from disturbances. Also, further amplifying steps could be added, such as ones that zooms in on the signal levels and amplifies them. Noise reduction amplifiers could also be added. It could also be considered if different lasers should be used, are there better suited wavelengths to look at?

A spectrometer reading should be made on fuels of interest. It would be useful if the spectra in Figure 2.6 could be verified. Do the local fuel differ much or anything? In an end product, the fuel would probably be in a flowing state. This might require the flow to be laminar. Also, since the lasers have a elliptical beam divergence, their orientation should be considered.

The lasers are sensitive to heat, and in a future iteration of this technology, it might be important to add a heat control. Also, instead of using an oscilloscope to manually read the results, it would probably be useful to have some sort of dedicated data acquisition system, such as a Data Acquisition Card (DAQ) or an audio input.

6

Conclusion

The spectrometry technology has great potential for Dover Fueling Solutions. It has the possibility to verify the product - fuel - which is important for customers at all levels. Although the testings and measurements in this project was not as unambiguous as hoped, the result seem to indicate there is a difference. It's not unlikely a better prototype would show a clearer difference. The construction is relatively simple. It could relatively simply be integrated in future versions of the fuel pumps, and would be a good sales argument.

Bibliography

[1] Bhanu Prasad Vempatapu and Pankaj K. Kanaujia. Monitoring petroleum fuel adulteration: A review of analytical methods. https://www.sciencedirect.com/science/article/abs/pii/S0165993616304174, 2017. Accessed 2019/02/05.

[2] Wikipedia. Fuel dispenser. https://en.wikipedia.org/wiki/Fuel_dispenser#The_metrology_of_gasoline, . Accessed 2019/02/19.

[3] Lennart Grahm, Hans-Gunnar Jubring, and Alexander Lauber. *Modern Industriell Mätteknik : GIVARE*. Bokförlaget Teknikinformation, forth edition, 2007. Chapter 11.

[4] Shatha K. Jawad, Samah Z. Al-Rahamnah, Samir M. Said, Ayah A. Muwafi, and Ghada H. Al-Issawi. Capacitor meter to measure the percentage of water in home diesel tank. https://www.researchgate.net/publication/287021991_Capacitor_meter_to_measure_the_percentage_of_water_in_home_diesel_tank, 2011. Accessed 2019/02/19.

[5] T. Vu Quoc, T. Pham Quoc, T. Chu Duc, T.T. Bui, K. Kikuchi, and M. Aoyagi. Capacitive sensor based on pcb technology for air bubble inside fluidic flow detection. https://ieeexplore.ieee.org/document/6984977, 2014. Accessed 2019/02/19.

[6] Alan S. Morris and Reza Langari. *Measurement and Instrumentation Theory and Application*. Academic Press, second edition, 2016. Section 16.2.2.

[7] Wikipedia user Cleontuni. The vibration pattern with mass flow. double sized version. https://en.wikipedia.org/wiki/Mass_flow_meter#/media/File:Coriolis_meter_vibrating_flow_512x512.gif. Accessed 2019/02/19.

[8] Jacob Fraden. *Handbook of Modern Sensors, Physics, Designs and applications*. Springer-Verlag, third edition, 2003. Section 11.

[9] Michael Kass, Timothy J Theiss, Chris Janke, and Steven J Pawel. Analysis of underground storage tanks system materials to increased leak

potential associated with e15 fuel. https://www.researchgate.net/publication/255001707_Analysis_of_Underground_Storage_Tanks_System_Materials_to_Increased_Leak_Potential_Associated_with_E15_Fuel, 2012. Accessed 2019/02/21.

[10] R Roberts, Roberts, and Roberts. Using properties to manage flammable liquid hazards. http://www.roberts-roberts.com/documents/Using%20Properties%20to%20Manage%20Flammable%20Liquid%20Hazards.pdf#page=3&zoom=100,0,600, 2011. Accessed 2019/02/22.

[11] William Hennessy. *Sensor Technology Handbook. Chapter 10: Flow and Level Sensors*. Elsevier, first edition, 2005. Section *Electromagnetic Flow Sensors*.

[12] Gert J.W. Visscher. *Measurement, Instrumentation and Sensors Handbook. Electromagnetic, Optical, Radiation, Chemical and Biomedical Measurement*. CRC Press, second edition, 2014. Section 80.2.

[13] Guided wave. Why nir is better than gc. https://sales.guided-wave.com/nir-vs-gc/. Accessed 2019/03/04.

[14] Wikipedia. Near-infrared spectroscopy. https://en.wikipedia.org/wiki/Near-infrared_spectroscopy, . Accessed 2019/03/04.

[15] Jesper Borggren. Combinatorial light path spectrometer for turbid liquids. https://lup.lub.lu.se/student-papers/search/publication/2260053, 2011. Accessed 2019/05/28.

[16] Durmuş Özdemir. Determination of octane number of gasoline using near infrared spectroscopy and genetic multivariate calibration methods. https://doi.org/10.1081/LFT-200035547, 2005. Accessed 2019/03/04.

[17] John Beauchaine and Jenni Briggs. Measurement of water in ethanol using encoded photometric nir spectroscopy. http://eds.a.ebscohost.com.ludwig.lub.lu.se/eds/pdfviewer/pdfviewer?vid=3&sid=9854ce08-c3f8-40d0-966b-5408399e9f26%40sessionmgr4010, 2007. Accessed 2019/05/07.

[18] Wikipedia. Octane rating. https://en.wikipedia.org/wiki/Octane_rating, . Accessed 2019/03/04.

[19] Liang Mei and Mikkel Brydegaard. Continuous-wave differential absorption lidar. https://onlinelibrary-wiley-com.ludwig.lub.lu.se/doi/epdf/10.1002/lpor.201400419, 2015. Accessed 2019/05/28.

[20] Antonin Povolny, Hiroshige Kikura, and Tomonori Ihara. Ultrasound pulse-echo coupled with a tracking technique for simultaneous measurement of multiple bubbles. https://www.ncbi.nlm.nih.gov/pubmed/29693582, 2018. Accessed 2019/04/02.

[21] Wikipedia. Speed of sound. https://en.wikipedia.org/wiki/Speed_of_sound#Equations, . Accessed 2019/04/02.

[22] Wikipedia. Photodiode. https://en.wikipedia.org/wiki/Photodiode#Materials, . Accessed 2019/05/09.

[23] www.azom.com. Determining the octane number using nir spectroscopy. https://www.azom.com/article.aspx?ArticleID=17517. Accessed 2019/05/13.

Appendix A

Data sheets

A.0.1 Laser diode 1170 nm

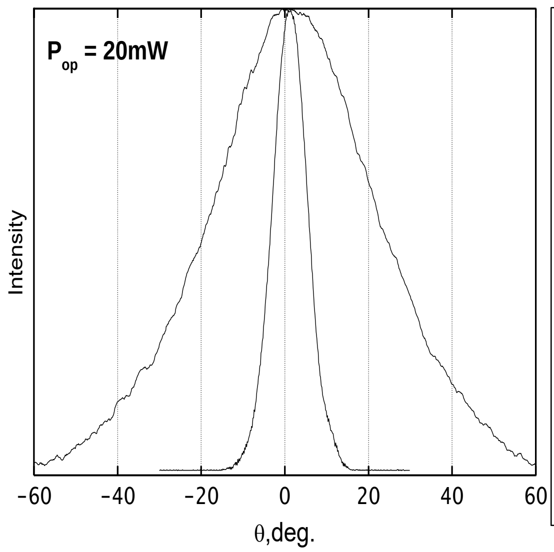
Diode laser in SOT-148 package
Model FB-S1170-20SOT148

Typical characteristics:

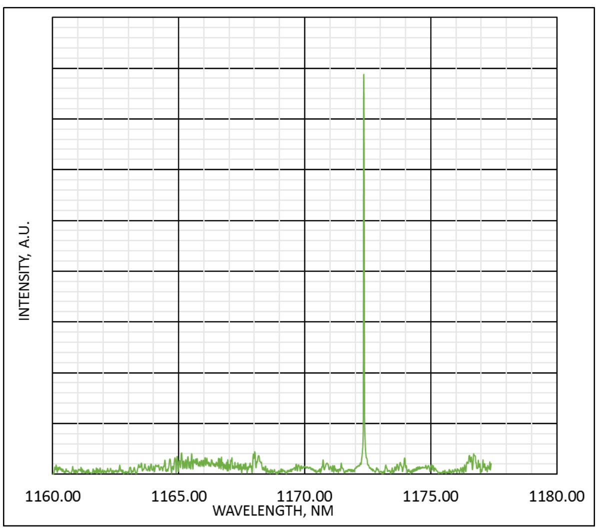
Sample № 37-999

Parameter	Value	Unit
Threshold current, I_{th}	**48**	mA
Operating current, I_{op}	**89**	mA
Operating optical power, P_{op}	**20**	mW
Peak wavelength at P_{op}, λ	**1172**	nm
Beam divergence, $\theta_{\|\|}$(FWHM)	**9**	deg
Beam divergence, $\theta_{\perp}$ (FWHM)	**30±3**	deg
Feedback PD current ,I_{PD},	**30**	μA
Feedback PD voltage	**<5**	V
Operating regime	**CW**	
Operating temperature, T_{op}	**25**	^{o}C
Package	**SOT-148**	

Beam divergence:



Emitting spectra:



A.0.2 Laser diode 1170 nm

Fibercom Ltd.

PRODUCT DATA SHEET

Laser Diode

Model FB-S1170-20SOT148

Specification	Symbol	Typical	Unit
		Laser Emitter	
Peak Wavelength	λop	1170±20	nm
CW Optical Output Power	Pop	20	mW
Operation Current	Iop	<110	mA
Operation Voltage	Uld	1.3±0.3	V
Threshold Current	Ith	<60	mA
Beam Divergence (FWHM)	$\theta_{\parallel}$	10±1	degree
Beam Divergence (FWHM)	$\theta_{\perp}$	30±5	degree
Spectrum Half-Width (FWHM)	$\Delta\lambda$	<5	nm
Emitting Area	Wxd	4x1	µmxµm
Wavelength Temperature Coefficient	$\Delta\lambda/\Delta T$	3±0.2	Å/degree
Operation Power Temperature Coefficient	$\Delta P/\Delta T$	0.25±0.05	mW/degree
Operation Current Temperature Coefficient	$\Delta I/\Delta T$	0.3±0.05	mA/degree
Mode Structure	SM	TE_{00}	-
Operation Temperature	Top	25	degree
Operation Temperature Range		-40… +50	degree
Storage Temperature Range		-40… +80	degree
Operation Mode	CW Pulse	Continuous Wave Pulse, τ>5 ns	-
		Photo Diode Monitor	
Monitor Current		1-1000	µA
PD Reverse Voltage		<5	V

Note: To guarantee reliable operation of laser diode SOT-148 package must be mounted onto copper carrier with TEC (Peltier element) keeping constant temperature.

Fibercom LTD., Address: 2-nd Hutorskaya Str., 19, bld.2, Moscow, 127287, Russia
Tel./Fax:+7 495 1070578, E-mail: zakaz@fbcom.ru, WEB: http://fbcom.ru

A.0.3 Laser diode 1300 nm

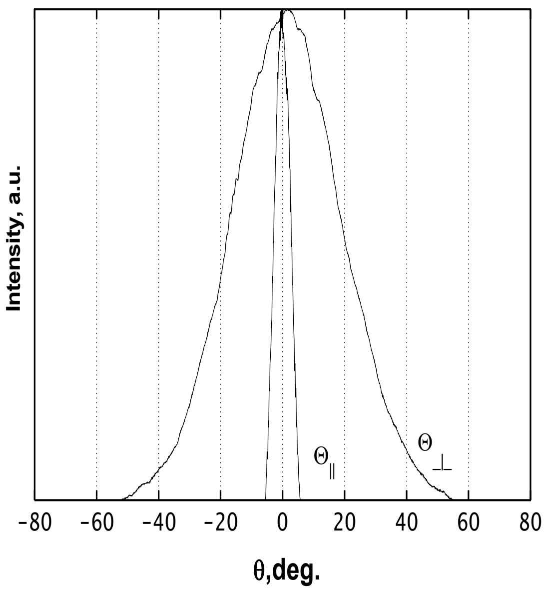
Diode laser in SOT-148 package
Model FB-S1300-10SOT148

Typical characteristics:

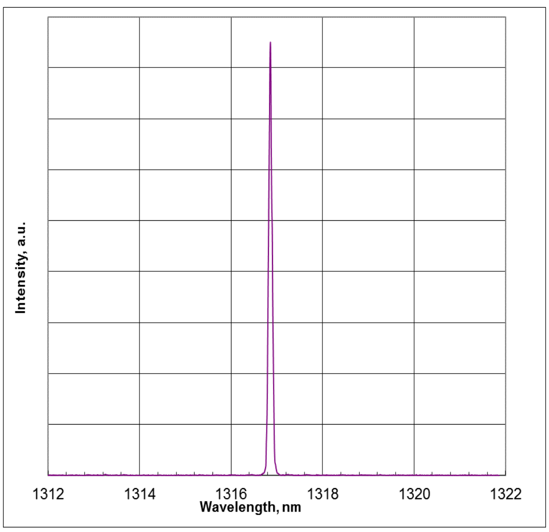
Sample № 347-69

Parameter	Value	Unit
Threshold current, I_{th}	**27**	mA
Operating current, I_{op}	**54**	mA
Operating optical power, P_{op}	**10**	mW
Peak wavelength at P_{op}, λ	**1317**	nm
Beam divergence, $\theta_{\parallel}$ (FWHM)	**6**	deg
Beam divergence, $\theta_{\perp}$ (FWHM)	**43**	deg
Feedback PD current, I_{PD},	**82**	μA
Feedback PD voltage	**<5**	V
Operating regime	**CW**	
Operating temperature, T_{op}	**25**	^oC
Package	**SOT-148**	

Beam divergence:



Emitting spectra:



A.0.4 Laser diode 1300 nm

Fibercom Ltd.

PRODUCT DATA SHEET

Laser Diode

Model FB-S1300-10SOT148

Specification	Symbol	Typical	Unit
Laser Emitter			
Peak Wavelength	λop	1300±30	nm
CW Optical Output Power	Pop	10	mW
Operation Current	Iop	<80	mA
Operation Voltage	Uld	1.1±0.2	V
Threshold Current	Ith	<40	mA
Beam Divergence (FWHM)	$\theta_{\parallel}$	8±2	degree
Beam Divergence (FWHM)	$\theta_{\perp}$	45±5	degree
Spectrum Half-Width (FWHM)	Δλ	<2.5	nm
Emitting Area	Wxd	5x1	μmxμm
Wavelength Temperature Coefficient	Δλ/ΔT	4±0.5	Å/degree
Operation Power Temperature Coefficient	ΔP/ΔT	0.15±0.05	mW/degree
Operation Current Temperature Coefficient	ΔI/ΔT	0.4±0.05	mA/degree
Mode Structure	SM	TE_{00}	-
Operation Temperature	Top	25	degree
Operation Temperature Range		-40… +50	degree
Storage Temperature Range		-40… +80	degree
Operation Mode	CW Pulse	Continuous Wave Pulse, τ>5 ns	-
Photo Diode Monitor			
Monitor Current		1-1000	μA
PD Reverse Voltage		<5	V

Note: To guarantee reliable operation of laser diode SOT-148 package must be mounted onto copper carrier with TEC (Peltier element) keeping constant temperature.

Fibercom LTD., Address: 2-nd Hutorskaya Str., 19, bld.2, Moscow, 127287, Russia
Tel./Fax:+7 495 1070578, E-mail: zakaz@fbcom.ru, WEB: http://fbcom.ru

A.0.5 FCI-InGaAs-500 photodiode nm

▪ 155Mbps/622Mbps/1.25Gbps/2.5Gbps

High Speed InGaAs Photodiodes

FCI-InGaAs-XXX series with active area sizes of 55µm, 70µm, 120µm, 300µm, 400µm and 500µm, exhibit the characteristics need for Datacom and Telecom applications. Low capacitance, low dark current and high responsivity from 1100nm to 1620nm make these devices ideal for high-bit rate receivers used in LAN, MAN, WAN, and other high speed communication systems. The photodiodes are packaged in 3 lead isolated TO-46 cans or in 1 pin pill packages with AR coated flat windows or micro lenses to enhance coupling efficiency. FCI-InGaAs-XXX series is also offered with FC, SC, ST and SMA receptacles.

▪ APPLICATIONS

- High Speed Optical Communications
- Single/Multi-Mode Fiber Optic Receiver
- Gigabit Ethernet/Fibre Channel
- SONET/SDH, ATM
- Optical Taps

▪ FEATURES

- High Speed
- High Responsivity
- Low Noise
- Spectral Range 900nm to 1700nm

Absolute Maximum Ratings

PARAMETERS	SYMBOL	MIN	MAX	UNITS
Storage Temperature	T_{stg}	-55	+125	°C
Operating Temperature	T_{op}	-40	+75	°C
Soldering Temperature	T_{sld}	---	+260	°C

Electro-Optical Characteristics T_A=23°C

PARAMETERS	SYMBOL	CONDITIONS	FCI-InGaAs-55			FCI-InGaAs-70			FCI-InGaAs-120			FCI-InGaAs-300			FCI-InGaAs-400			FCI-InGaAs-500			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Active Area Diameter	AA_ϕ	---	---	55	---	---	70	---	---	120	---	---	300	---	---	400	---	---	500	---	µm
Responsivity (Flat Window Package)	R_λ	λ=1310nm	0.80	0.90	---	0.80	0.90	---	0.80	0.90	---	0.80	0.90	---	0.80	0.90	---	0.80	0.90	---	A/W
		λ=1550nm	0.90	0.95	---	0.90	0.95	---	0.90	0.95	---	0.90	0.95	---	0.90	0.95	---	0.90	0.95	---	
Capacitance	C_j	V_R = 5.0V	---	1.0	---	---	1.5	---	---	2.0	---	---	10.0	---	---	14.0	---	---	20.0	---	pF
Dark Current	I_d	V_R = 5.0V	---	0.02	2	---	0.03	2	---	0.05	2	---	0.30	5	---	0.40	5	---	0.50	20	nA
Rise Time/ Fall Time	t_r/t_f	V_R = 5.0V, R_L=50Ω 10% to 90%	---	---	0.20	---	---	0.20	---	---	0.30	---	---	1.5	---	---	3.0	---	---	10.0	ns
Max. Revervse Voltage	---	---	---	---	20	---	---	20	---	---	20	---	---	15	---	---	15	---	---	15	V
Max. Reverse Current	---	---	---	---	0.5	---	---	1	---	---	2	---	---	2	---	---	2	---	---	2	mA
Max. Forward Current	---	---	---	---	5	---	---	5	---	---	5	---	---	8	---	---	8	---	---	8	mA
NEP	---	---	---	2.66E-15	---	---	3.44E-15	---	---	4.50E-15	---	---	6.28E-15	---	---	7.69E-15	---	---	8.42E-15	---	W/√Hz

Appendix B

Matlab code

```
close all
clear all

res_diesel = [0.008469009, 0.008894502, 0.007758978];
res_98_octane = [0.015779945, 0.014197599, 0.024874141];
res_95_octane = [0.008359595, 0.013901452, 0.014582222];

std_dies = std(res_diesel);
mean_dies = mean(res_diesel);

std_98 = std(res_98_octane);
mean_98 = mean(res_98_octane);

std_95 = std(res_95_octane);
mean_95 = mean(res_95_octane);

x = [-3:.001:3];
y_diesel = normpdf(x,mean_dies , std_dies);

figure(1)
plot(x,y_diesel)
legend('Diesel')
xlabel('Absorption division')

y_98octane = normpdf(x, mean_98 , std_98);
y_95octane = normpdf(x, mean_95 , std_95);

figure(2)
plot(x,y_98octane,'--')
hold on
plot(x,y_95octane)
```

```
legend('98 octane', '95 octane')
xlabel('Absorption division')
```