

# **Developing an improved Fuel Level Sensor concept for the evolving automotive industry**

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## **Abstract**

The twenty first century is characterised by the ubiquitous rise of developments throughout the globe's industries. With accelerating changes in the fields of technology, energy and computing, the automotive industry is home to a wide range of developments. Through research, the main trends giving rise to such developments within the industry, have been identified as: sustainable mobility, market proliferation, and vehicle space & safety optimisation.

The traditional Fuel Level Sensor is one of the vehicle components that will need to adapt, to remain suitable for these industry changes that lie ahead.

This research paper presents an exploration and understanding of the current Future Level Sensor developed by Robert BOSCH GmbH, together with an overview of the trends occurring throughout the automotive industry and how these will impact the changing requirements that the Fuel Level Sensor needs to fulfil.

To determine these requirements, several interviews, discussions, and co-creation sessions were conducted with industry experts, and extensive literature was reviewed. Thorough analysis of the data gathered enabled the future of the automotive industry to be depicted and presented in the form of a timeline. Moreover, the problems faced with traditional Fuel Level Sensors were identified. This allowed for the depiction of requirements to develop an improved Fuel Level Sensor concept that will be suitable for the evolving market, and will eliminate the issues faced with traditional Fuel Level Sensors.

*Keywords:* automotive Industry, fuel level sensor, future.



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## **Abbreviations**

AV	Autonomous Vehicle
BAS	Break Assist System
ECU	Electric Control Unit
EV	Electric Vehicle
FLS	Fuel Level Sensor
FSM	Fuel Supply Module
HV	Hybrid Vehicle
ICE	Internal Combustion Engine
RC	Resistor Card
WA	Wire arm

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# 1. Introduction

## 1.1 Overview of Paper

Sensors are the essential organs of a vehicle, providing drivers with safety and crucial information. While driving a vehicle, it is important for the driver to be aware of its vehicles fuel consumption so that informed decisions can be made regarding refuelling needs. In order for this information to be made available to the driver, a product called the Fuel Level Sensor is used.

As the name suggests, the Fuel Level Sensor is an instrument used to measure the amount of fuel in a vehicles' tank (Divakar, 2014).

While the automotive industry is rapidly evolving, and as a result vehicles are increasingly undergoing change, fuel level sensors, however, remain somewhat unchanged. As a result, research was undertaken on the traditional angular position Fuel Level Sensor used in the majority of vehicles, and its potential future amid the developing industry.

The main aim lied upon determining: How will the requirements of the Future Level Sensor be shaped by the rapidly evolving automotive industry?

This paper shows the insights gathered from the research conducted. The analysis of the results served as a basis to extract design requirements for the future development of a new Fuel Level Sensor concept.

This project was carried out at the Robert BOSCH R&D Automotive Centre, Vietnam, as part of the graduation project of the Industrial Design Engineering program, at The Hague University of Applied Sciences.

## 1.2 The Fuel Level Sensor

The Fuel Level Sensor (FLS) informs the driver about how much fuel is present in the vehicles tank via two systems, the sensing and the indicating unit.

The sensing unit is the part of the FLS that actually measures the amount of fuel. The indicating unit, on the other hand, as Divakar (2014) suggests, indicates the quantity of fuel to the driver by relaying the information collected by the sensing unit. It is most commonly known as the 'fuel gauge', and is located on the dashboard, where a needle fluctuates according to the data collected by the sensing unit (FLS).

There are different methods that can be used by the sensing unit to determine the amount of fuel in a vehicle's tank. Consequently, different types of fuel level sensors have been developed for various applications, differing in their measurement techniques.

Of these sensors however, there is one that prevails in the market: the angular-position fuel level sensor, with floater. It's low cost due to it being a mechanical sensor, makes for its wide adoption by auto makers.

Such a fuel level sensor is currently developed and provided by Bosch to various customers (automakers) such as BMW and Ford. It works by using the buoyant properties of a float which moves as the fuel level fluctuates. As this float is connected to a wire arm, the motion of the float will result in the rotation of a contact within a resistor, whose varying resistance value enables the amount of fuel in the tank to be determined. *(See section 4 for a detailed description of the FLS's working principle).*



Fig1. Bosch's Fuel Level Sensor.

## 2. Literature Review

### 2.1 Introduction

To investigate the future of fuel level sensing, research into the different methods capable of measuring fluid levels, as well as how the automobile industry will evolve over the next years has been conducted.

A substantial amount of literature was reviewed, by reading and analysing different reports and articles about liquid level sensing. Consequently, many different ways of determining liquid level were discovered. The level sensing methods appropriate for fuel level determination have been selected and presented. In addition, the trends that the automobile industry is facing have been identified. Scrutinising numerous reports and forecast analyses enabled the depiction of the context in which future Fuel Level Sensors will operate.

### 2.2 Liquid level measuring principles

#### 1. Traditional angular position sensor with floater

A well-established measurement method for liquid level sensing is that of angular position sensors, with floater. Fleming (2011) highlights that such sensors have reached mainstream adoption across fuel level sensing applications due to their low cost. Such sensors are traditional ones, working with a float that lies on the surface of the liquid.

When the level of the liquid changes, the float will move up/down accordingly. As Divakar (2014) explains, the float is connected to a metal arm which is mounted on a resistor. The resistor is composed of tracks on which the wire arm exerts contact. Following which, as the position of the float changes, a contact will move along the

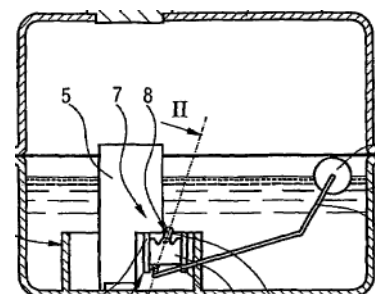


Fig 2. Traditional Float-type Sensor.

resistor card tracks, changing the resistance and current flow accordingly. Indeed, Nice (2001) highlights that the more resistance experienced across the resistor, the lower the flow of current will be. As a result, with an electrical output, the level of liquid can be measured with values of voltage corresponding to liquid level heights.

## II. Hydrostatic Pressure Transmitter

According to Muth (2014), hydrostatic pressure transmitters operate by measuring the pressure exerted by a liquid, at a certain depth towards the bottom of the container, as a result of the liquid's weight.

Expressing pressure as a product of density, height and gravity ( $P=\rho*h*g$ ), we can determine liquid level height. As Muth (2014) highlights, atmospheric pressure should also be considered as this is also acting on the liquid. As a result, we get:

$$\text{Eq1.} \quad h = \frac{(P_2 - P_1)}{\rho * g}$$

Where:

$h$  = height of the liquid

$P_1$  = pressure exerted by the liquid

$P_2$  = atmospheric pressure

$g$  = gravitational acceleration ( $9.8 \text{ ms}^{-2}$ )

$\rho$  = density of the liquid

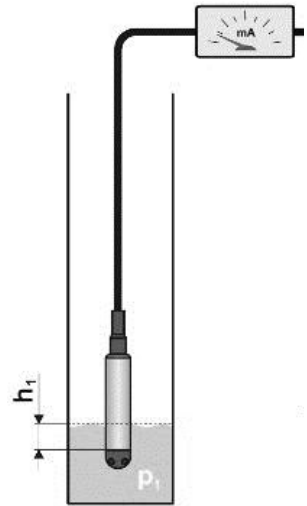


Fig3. Hydrostatic Pressure Transmitter.

## III. Ultrasonic, Radar & Laser Transmitters

These transmitters are time domain-reflectometry sensors, which work by sending a pulse from the top of the tank, down to the liquid. As described by Hambrice (2004), this pulse is then reflected on the surface of the liquid back to the transmitter. The time required for the pulse to travel to the liquid and back to the transmitter, is measured. This will be used by the control unit to determine the distance from the transmitter to the liquid surface, based on the predefined height and capacity of the container.

Ultrasonic transmitters use sound waves as their pulse, while radar and laser transmitters send microwaves and pulses of light, respectively.

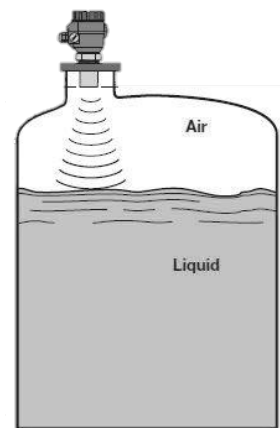


Fig4. Ultrasonic Level Transmitter.

Emerson (2013) suggests that to calculate the distance from the transmitter to the surface of the liquid, the control unit uses the following formula:

Eq2.  $Distance = (speed\ of\ pulse \times time\ delay)/2$

Breaking down the formula, we get

Eq3.  $d = \frac{c*t}{2}$

Where:

$d$  = the distance between the transmitter and liquid surface

$c$  = the speed of pulse (sound:  $330ms^{-1}$  , or light:  $340ms^{-1}$ )

$t$  = time taken for the pulse to travel from the transmitter to the liquid and back

#### IV. Capacitive sensors

Capacitors are devices that have two conducting plates (electrodes), separated by a dielectric material (insulator). Each dielectric material has a constant, for gasoline this is 2.2, and air, 1.0.

Fuel systems can use capacitors to measure fuel levels in vehicle tanks. Terzic et al. (2012) explains that during fuel level measurement, the distance between the two conductors is fixed and the level of the liquid is found by measuring the capacitance value between them.

As the amount of dielectric material fluctuates, the capacitance value will change accordingly. Webster (1999) confirms that since Gasoline has a dielectric constant higher than that of air, the capacitance value will increase when the amount of fuel present is increased.

The following formula can therefore be used to determine the capacitance value:

Eq4.  $C = E_r * C_0$

With  $E_r$  being the dielectric constant, and  $C_0$  = the capacitance when there is no dielectric material, we can find the value of the capacitance, ( $C$ ).

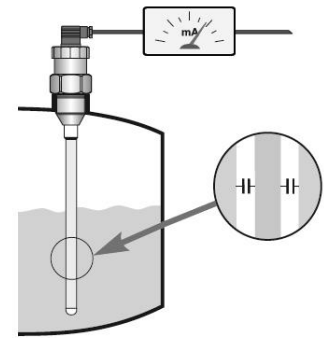


Fig5. Capacitive Sensor.

## V. Magnetostrictive sensors

Magnetostrictive level sensors are composed of a float (containing magnets) that moves along a wire when the level of the liquid fluctuates. Emerson (2013) explains that during its operation, two magnetic fields are generated: one when current is pulsed along the guiding wire, and a second one in the float, as a result of its vertical movement along the guiding wire. When the pulse causes the intersection of the two magnetic fields, according to Fine tek (2015), a 'twist' effect is created. This reflects the pulse as a sonic wave which travels along the guiding wire until it reaches the sensing element. The time between the sending out of the initial pulse that generated the magnetic fields, and the arrival of the sonic wave, is recorded. Hambrice (2004) further clarifies that the time taken for the pulse to travel along the guide rod until the floater and return, is converted into an output of current that allows for the position of the float, and in consequence the level of the liquid to be determined.

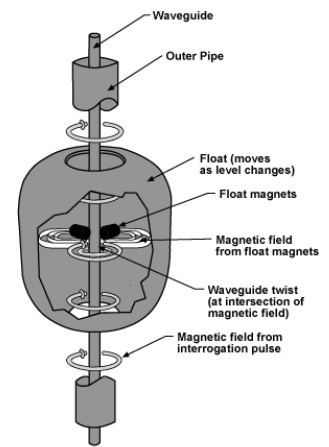


Fig6. Magnetostrictive working principle.

## VI. Magnetic float level indicator

Magnetic float level sensors make use of an auxiliary chamber, connected to the main liquid container by pipes as shown in Fig.11. In this chamber, a float with internal magnets lies on the surface of the liquid and moves up/down as the level of the liquid fluctuates. Emerson (2013) describes that as the level of the liquid changes, the magnets in the float trigger a set of flippers that are flipped as the float reaches their level. These flippers indicate how much liquid is present in the container.

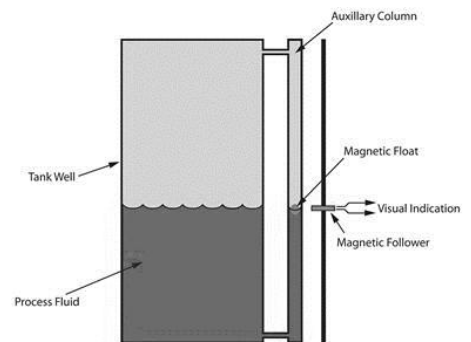


Fig7. Magnetic Float level Indicator.

## 2.3 Trends in the automotive industry

### Overview

The main forces driving the automotive industry such as electrification and the shift to autonomous vehicles are quite evident. However, it is unclear to what extent each of these forces will dictate the future of the industry. Indeed, although the trends in the automotive industry are identifiable, there are mixed perspectives towards which of the trends will prevail.

The megatrends characterizing the future of the automotive industry have been identified as the following: sustainable mobility, optimization (of vehicle system and components), and market proliferation. These are explored and detailed in this section of the literature review.

### ***I. Sustainable Mobility***

The internal combustion engine (ICE) has been predominant in the industry for almost 100 years. (Brown, Pyke and Steenhof 2010). In light of the recent hype about climate change, many developments are occurring across all fields to introduce products that generate a significantly lower impact on the environment than their predecessors.

The International Energy Agency (2007) projects that the automotive industry is expected to contribute to 50% of the greenhouse gases generated by 2030, coupled with the growing depletion of fossil fuels. To address this, Truckenbrodt (2004) portrays the automotive industry as shifting towards more sustainable power train technologies. Indeed, the need for 'greener' vehicles has resulted in the development of alternatives to gasoline and diesel, for vehicle powering. Consequently, we are presented with alternative bio fuels, and the electrification of vehicles.

While bio fuels have been developed since the inception of cars, Timilsina (2011) mentions that we may rely more and more on these due to the increasingly stringent environmental regulations regarding vehicle emissions. The use of biofuels in vehicles will not be restricted to ethanol or biodiesel but rather, in the future, a large choice will be available. Indeed, it is expected that the biofuel share for global transportation is projected to be at 10% by 2020 and 20% by 2040.

On the other hand, as Egbue and Long (2012) highlight, the use of Hybrid vehicles (HV's) and electric vehicles (EV's) will result in a reduction in dependence on fossil fuels and a decrease in harmful greenhouse gas emissions. The benefits of EV's are clear, they can reduce our environmental footprint. However, certain barriers restrict the mainstream adoption of electric vehicles, following which Mohr et al. (2013) state that by 2020, conventional vehicle systems will still dominate over 90% of the market.

While HV's seem to have found their trusted place in the consumer vehicle market, EV's are facing certain obstacles. Indeed, as Demont (2011) puts forward, while conventional cars have a driving range of 300-400 miles, the majority of electric vehicles on the other hand have a range of only 80-100 miles (Berman 2016). Moreover the time needed to charge EV's is considerably longer than it takes to refuel at a gas station. Also, issues of driving range and charging time are of great concern when driving long distances or using the EV's frequently. As Ford (2011) advances, consumer needs do not match what the majority of EV's currently deliver. In fact, Ford (2011) states that three quarters of European consumers expect an EV to be able to drive 300 miles and be charged in less than two hours. Access to charging infrastructure is also a concern.

Beyond technological limitations, another barrier is that of an EV's purchasing cost. TNAOS (2013) supports this, by explaining that most electric vehicles on the market, cost more than buying a conventional vehicle, and customers are reluctant to paying more for something that they have not experienced beforehand.

Looking at the history of electric vehicles, it can be noticed that although EV's can be developed, introduced to the market, mass manufactured and even experience widespread adoption, external influencers have the potential to tamper with its popularity.

Indeed, back in the 1800s, the first electric vehicle was developed, following which in the early 1900s, EV's were prevailing in the market (Anderson, 2012). Only 30 years later however, with a drop in petrol price, the market quickly switched back to ICE vehicles, leaving the EV to become extinct by 1935, before recently resurfacing in today's market.

While shifting to electric vehicles could be the most effective in reducing carbon emissions, it is uncertain when and if EV's will completely replace conventional vehicles in the market. In the meantime, the increasing adoption of biofuels will provide a quicker and less costly solution to decarbonisation together with the increasing adoption of Hybrid vehicles, which seem to be subject to less barriers in the market, than EV's.

## ***II. Optimization***

To remain active in the market, auto manufacturers are constantly looking to improve and optimize their products, so that the 'best possible' solution can be made available to their customers.

Size - Urbanization has led to the increasing use of smaller vehicles to easily navigate through narrow streets and around traffic congestion. Mohr et.al (2013) predict that by 2020, more than 30 million vehicles will be smaller vehicles, also known as microcars and subcompacts. With a reduction in size of a vehicle, this means that its components will have to be altered to fit in the smaller vehicles' support structures.

On the other hand, the automotive industry is readapting and designing vehicle components to take up 'unused space' in a vehicle's structure and provide more space and greater comfort for its passengers. As a result, Beecham (2012) advances that fuel tanks are being designed in peculiar forms to take up this unused space. Mohr et al. (2013), support this, by predicting that over the next years, fuel tanks will have more and more complex shapes.

Safety - Within the automotive sector, focus is increasingly being laid on improving the safety of vehicles and driving experience. As Lance (2016) suggests, this trend is perpetuated as a result of customer demands and regulations to decrease accident rates.

As a result, the increasing adoption of smart safety systems (such as BAS), and further development of semi-autonomous and autonomous driving systems can be seen.

Shifting towards autonomous vehicle's will enable people to have more time and accident rates to be dropped. Bertonecello and Wee (2015) predict that with the widespread development of autonomous vehicles, deployment of fully autonomous vehicles will commence by 2030, following which AV's will be mainstream by 2050. The use of autonomous vehicles could give rise to shared mobility and greater accessibility in the future.

### **III. Market proliferation**

The automobile industry can be categorized into established and emerging markets.

Emerging markets typically refer to developing economies that have a rapid growth potential. As advanced by the Foreign Economic and Trade University Press (2010), the most prominent countries that form the emerging markets, are the 'BRIC' (Brazil, Russia, India and China).

With a high growth-rate, such markets lead to an increase in the demand of vehicles and vehicle components, suitable for their operating environments. This increase in demand from emerging markets is likely to continue over the next years. Indeed, Mohr et al. (2013) predicts that by 2020, emerging markets will contribute to 67% of the profits generated in the automotive industry. With a rising demand from emerging markets, the automotive industry will have to increase their supply and provide products suitable to operate in the conditions that characterize such markets. Indeed, these differ significantly from standard established markets. *(See section 5.4 for defining characteristics of emerging markets).*

Established markets are those found in developed countries. Seldom growth is expected in such markets. Ling and Wang (2004) advocate that throughout the next years, it is expected that such markets will be congested with over-capacity. This will result in the automakers having to fight for market shares. Indeed, for these companies to expand in the future and gain further market share, Ling and Wang (2004) further stress that it will only be possible to do so, by taking over their competitors shares. Increased competitiveness in established markets will mean that automakers will need resort to certain practices to remain or become market leaders. According to Mohr et al. (2013), this implies that cost pressure will be at a high, with typically flat prices experienced across established markets. As a result, auto manufacturers will need to make sure they can match these prices by reducing surplus costs associated with their products.

## **2.4 Conclusion**

Several trends are serving as catalysts for the development of vehicle systems and concepts. However, it is unknown which of these will prevail within the automotive future. With the rise of demand in emerging markets, different needs and conditions need to be considered as the environment at hand differs from the conventional. Moreover, with the shift towards electrification, together with the optimization of vehicles, the need to adapt existing vehicle components to fit such systems arises.

Existing literature covers the obvious trends that are shaping the automotive world. However, it is not clear how vehicles components such as the Fuel Level Sensor will need to adapt to be suitable for the future. Research on liquid level measurement methods has pointed out that the traditional fuel level sensor has certain issues in terms of accuracy, component life and its mechanical nature *(see Appendix 5&6 for comparison of level measurement methods)*. It is therefore becoming increasingly challenging for such a sensor to remain pervasive in the market, in times where the rapidly changing industry, coupled with many developments are bound to influence the requirements of automotive products.

### 3. Research Design

#### 3.1 Research Question

How will the requirements of the Future Level Sensor be shaped by the rapidly evolving automotive industry?

#### 3.2 Research Goal

The aim of the research is to depict the requirements that the Future Level sensor will need to fulfill, in order to be useful in the future automotive industry. This has been achieved by analysing the trends and future predictions of the automotive industry.

The research question is an explorative one in which primary research of qualitative nature has been conducted, together with a thorough analysis of existing literature. To achieve this, it was crucial to explore the current Fuel Level Sensor developed at Bosch so as to understand its working principle, context of operation and current customer and market requirements. Moreover, an overview of the different methods of liquid level measurement have allowed for a conscientious understanding of the potential technologies available for fuel level sensing.

Sub Questions:

1. What are the current requirements of the FLS and how does it work?
2. Which trends occurring in the automotive industry have the potential to impact the FLS?
3. What are the characteristics of the customers and markets for which the FLS has been developed?

#### 3.3 Methodology

In order to collect the relevant data for this research assignment, the following methods have been used:

##### 1. Interviews & Discussions

*Participants: experts, researchers & engineers.*

- To understand the current requirements of the Fuel Level Sensor, and gain insights into its working principle and factors that can influence its operation.
- To depict and analyze the current problems faced with the traditional angular position Fuel Level Sensor.
- To identify the different markets the FLS is used in and understand their characteristics and implications.

- To gain an overview of the customers for which the FLS is developed and their requirements.

## 2. Literature Review

- To gather existing information about the different types of liquid level measuring techniques developed, together with the trends that are occurring in the automotive industry.

## 3. Co-creation sessions

*Participants: Design Engineers at Bosch.*

- To brainstorm and identify the trends in the automotive industry that have the potential to impact the Fuel Level Sensor and the nature of these impacts.

## 4. Explorations sessions

*Self-exploration and exploration with FLS experts.*

- To understand the FLS, its components, their assembly, its functioning system, working principle, assembly into tank, etc...

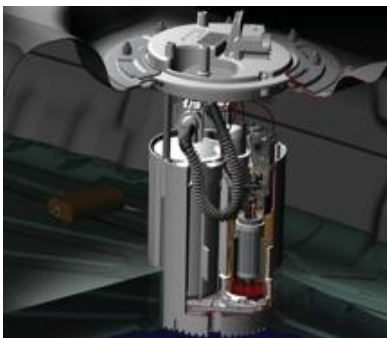
## 4. Results

### 4.1 Context

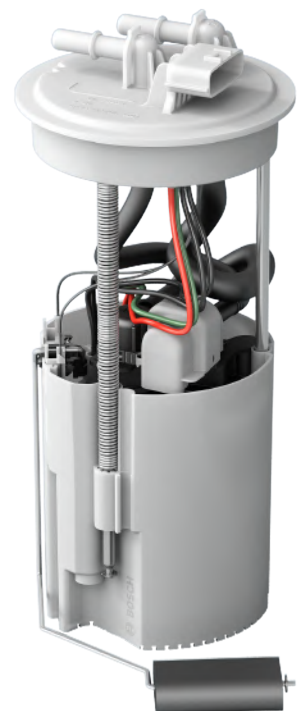
The Fuel Level sensor (FLS) currently developed at BOSCH is an integral part of the Fuel Supply Module (FSM).

The Fuel Supply Module (FSM), as shown in *Fig 8&9*. is an in-tank unit, which has the function of pumping the right amount of fuel to the engine at an appropriate pressure and constant rate. It is a crucial part of a vehicle, as it ensures the smooth running of the engine, and consists of the following components: Electric Pump, Fuel Filter, Fuel Pressure Regulator Valve, and the Fuel Level Sensor. The latter, is the focus of this research and assignment.

Since the FLS is an integral part of the FSM and is placed within a fixed structure, certain context limitations need to be considered when designing the Fuel Level Sensor (*see Section 5.6*).



*Fig9. FSM in-tank.*



*Fig8. Fuel Supply Module.*

The FLS measures the fuel level using a bottom-to-top measurement approach. Walleback (2008) suggests that such an approach is preferred because environmental factors such

as temperature variation can influence the tank geometry, and as a result its volume can be changed. An increase in temperature may cause the tank to expand. With the sensor measuring fuel level from bottom to top, the temperature increase will not affect the fuel level measurement as although the tank may be getting bigger, the fuel will always touch the bottom of the tank due to gravity.

## 4.2 Components of FLS

Bosch's Fuel Level Sensor consists of the following components. These are further modified and suited according to the FLS's application and the requirements established by the customer.

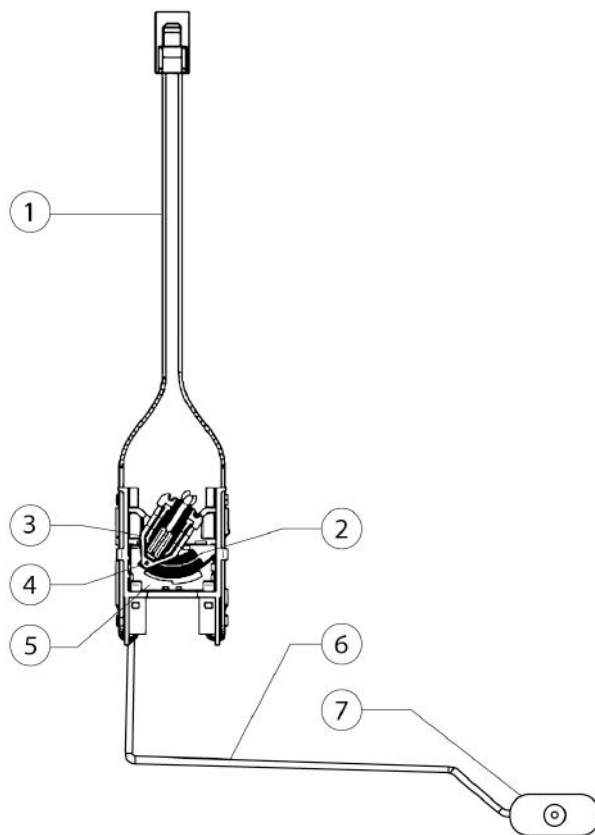


Fig10. Fuel Level Sensor Components.

**1. Cable Set** - Connects the FLS to the ECU and electric system of the vehicle.

**2. Resistor Card** - Converts the movement of the wire arm to an electrical output (mechanical signal to electrical signal).

**3. Wiper** - Moves the contact along the resistor card and holds the contact system in place.

**4. Contact system** - Applies force on the tracks of the resistor card. The contact forms a bridge between the conductive and restive track, closing the electric circuit.

**5. Housing** - Attaches the FLS to the FSM and holds the resistor card and cable set in place. Design features of the housing also allow for mechanical stops of the wiper and wire arm to be designed according to the angle of rotation devised per FLS.

**6. Wire Arm** - Connected on one side to the floater and the other side to the wiper, the wire arm moves with the floater, translating the displacement as the fuel rises/decreases to the sliding of the wiper on the resistor card.

**7. Floater** - 'floats' on the surface of the fuel and moves as the level of liquid in the tank fluctuates. Rotating and non-rotating floater types exist. Rotating floaters are able to rotate around the axle of the wire arm, while non-rotating floaters are fixed. Floaters also come in different shapes, ranging from spherical to rectangular.

### 4.3 Electronic scheme & working principle

A grounded variable resistor is used in the Fuel Level Sensor mechanism to identify the changes in fuel level. As the amount of fuel in the tank fluctuates, the floater moves up/down, causing the wiper to slide along the tracks of the resistor card.

As the fuel level decreases, the wiper moves away from the grounded part of the resistive track. Increased resistance is therefore experienced, resulting in a reduced current flow through the circuit. The position of fuel levels correspond to values of voltage output. The control unit interprets these output values and translates them into indications on the fuel gauge which the driver can understand.

For example, the following voltage outputs could correspond to distinct fuel level heights:  
 0 volts = empty tank                      6 volts = tank half full                      12 volts = full tank

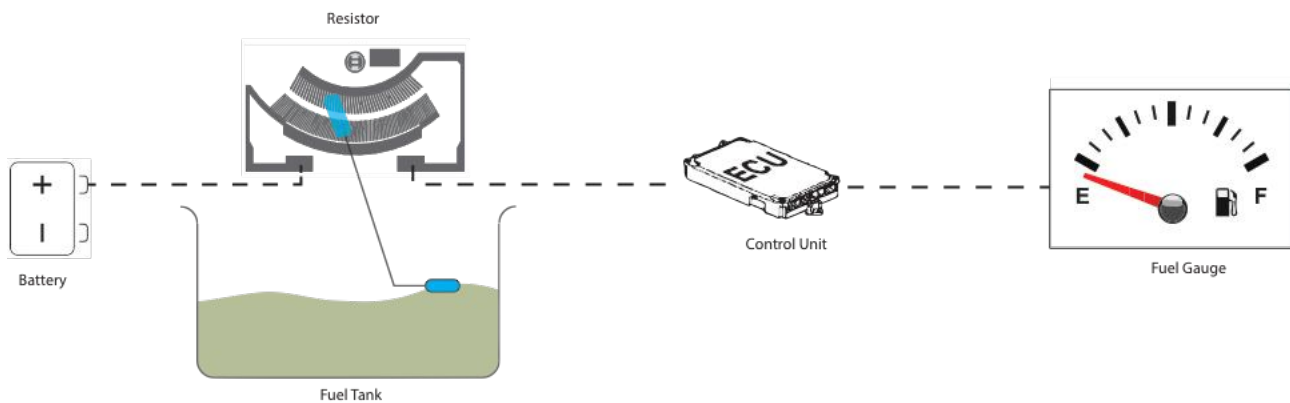


Fig11. Electrical component layout.

The resistor card is composed of two tracks, named the conductive and resistive tracks respectively, as shown in Fig12. The contact system displaced by the wiper along the tracks of the resistor card, links the conductive and resistive tracks allowing the current to flow through the circuit.

The vehicles battery supplies one end of the resistor with a power that commonly lies within ranges 12V and 13.5V. Depending on the application this value may vary.

A Commonly used variable resistor for this system is a two-wire connection one. Fig13. shows the circuit diagram of such a system, from which the voltage output (input to the control unit) can be determined via the readings of the resistors present in the circuit.

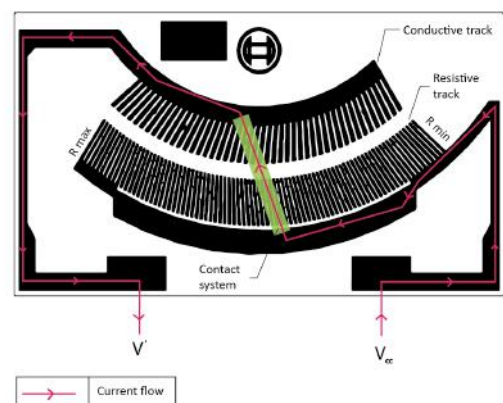


Fig12. Resistor Card.

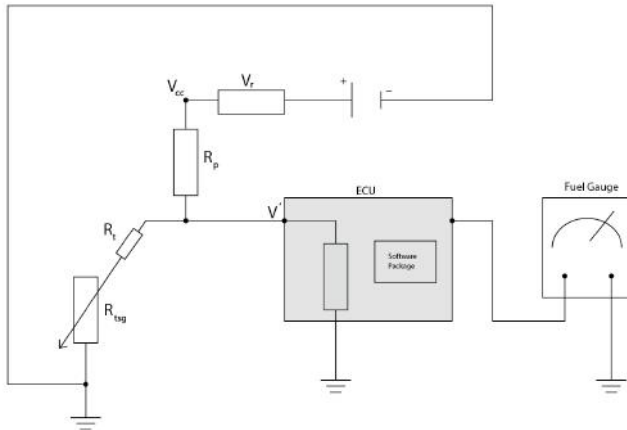


Fig13. FLS electronic circuit diagram.

$$Eq5. \quad V' = V_{cc} \frac{R_{tsq} + R_t}{(R_{tsq} + R_t + R_p)}$$

Where:

$V'$  : the measured output voltage  
 $V_{cc}$  : the voltage provided by the battery

$V_r$  : the voltage regulator

$R_p$  : the pull – up resistance

$R_t$  : the transition resistance

$R_{tsq}$  : the resistance across the FLS

#### 4.4 Market Description

The Fuel Level Sensor is used in established and emerging markets, however, the operating conditions in these markets differ considerably.

The FLS has direct contact with the fuel, whose composition in emerging markets is subsequently inferior to that of established markets. As a result, corrosion of the FLS's components and electrical interference of the system are risks that are prone to occur. Indeed, Springer et al. (2014) portray emerging markets as characterized by their 'bad fuels' and challenging environments (high amount of dust, uneven roads, etc.).

Fuel in such markets often contains water (causing the fuel to become conductive), and sulphur. If a fuel level sensor contains metal parts, and is used in such fuels, Pauls (2010) emphasizes that it is highly likely that such parts will experience sulphur deposits and in consequence be corroded. This will tinker with the ability of the fuel level sensor to produce accurate readings, and may even cut off the signal from the sensor to the control unit, as often seen with float type sensors. Moreover, in certain areas, uneven roads will increase the shocks and vibrations absorbed by the vehicle, causing them to experience turbulence or certain disturbances.

The sealing of the FLS housing has proven to protect the electrical components and prevent unwanted substances from contaminating the resistor card and contact. However, such sealing affects the torque of the wire arm, as more force is required to lift the floater up due to increased friction/resistance with the rubber sealing.

## 4.5 Customer Requirements

Bosch's customers for Fuel Level Sensors typically consist of auto manufacturers such as BMW, Ford and Renault. They provide BOSCH with the fuel tank in which the FLS will be used and submit a table of corresponding resistance values to height levels based on the tank's volume.

The following specifications are also provided by the customer:

- **MRA (Module Reservoir Assembly):** should the FLS be connected to the Fuel Supply Module or not?
- **Float type:** rotating or fixed?
- **Float shape:** customer has the possibility to specify a certain shape, if not the standard floater will be used.
- **Fuel type:** gasoline or diesel  
Ethanol content (in %)
- **The Clearance** between moving parts and tank (mm)
- **The Clearance** between nonmoving parts and tank (mm)

Based on the customer requirements, the type of FLS to be used and the selection of components is then chosen by the engineers at BOSCH. The market in which the FLS will be used is also considered, together with the fuel composition in which it will operate.

Based on the fuel level sensors BOSCH has developed for various vehicle tanks, a common value for the maximum fuel level measured is that of 190mm. In addition, records of max. fuel level at 460 mm have been noted. The height of max. fuel level will depend on the morphology of the tank in which it will be used.

While the most common fuel tanks for vehicles operating on internal combustion engines have a capacity usually ranging between 35-60 liters, certain vehicles can carry considerably different amount of fuel than these. Indeed, with small compact vehicles for example, a typical fuel tank will carry only 16L of fuel. On the other hand, larger vehicles such as SUV's can hold up to 80+ liters.

## 4.6 In-vehicle context considerations

When designing or adapting a Fuel Level Sensor for a vehicle, the morphology of the fuel tank has great influence over the position of the fuel level sensor within the tank, its range, and its shape.

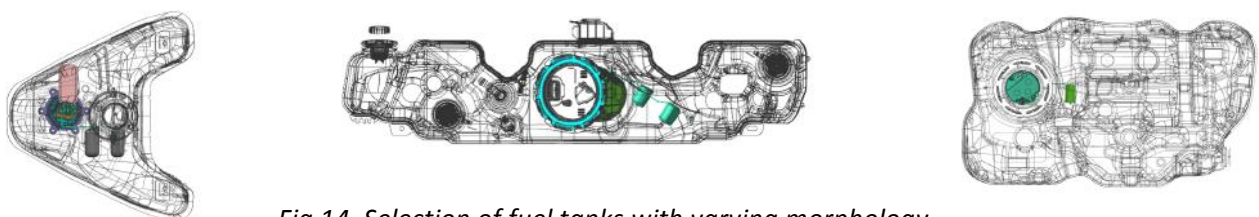


Fig 14. Selection of fuel tanks with varying morphology.

As Fig14. shows, fuel tanks can come in many different shapes and capacities. As a result, an accurate measurement of how much fuel is actually present in the tank can be challenging. The sensor needs to be adapted and its components perhaps redesigned so as to reach minimum and maximum fuel heights, and not collide with tank walls or other inner tank ‘obstacles’.

Such obstacles refer to the inner tank geometries which could be an obstacle with sensors with moving components. It is crucial to take these into account as the fuel level sensor should not collide with them, else it can get damaged. Fig15.on the right, shows a cross section of a fuel tank with these ‘inner obstacles’ highlighted in pink.

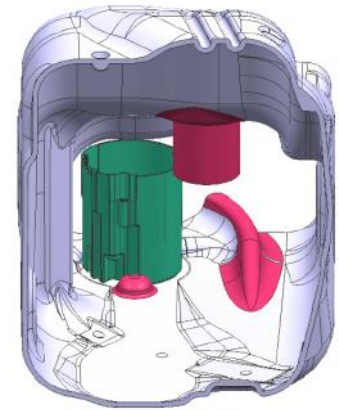


Fig15. Inner Tank obstacles.

Most sensors that are not in contact with the fuel such as ultrasonic, radar and laser transmitters, require only a change in the algorithms used by the control unit to adapt to the specific shape and dimensions of the tank.

Capacitive transmitters or float-based sensors on the other hand, require a greater adjustment to be suitable for use in tanks of different shapes and sizes. Indeed, this adjustment usually involves the redesigning of their physical components so that these fit into the required tank.

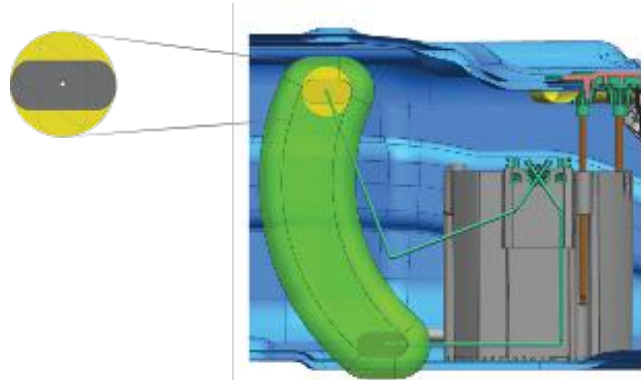


Fig16. FLS clearance with tank walls.

With ‘moving-type’ sensors it is also deemed important to ensure a certain clearance between the sensors moving components and the walls of the fuel tank so that the float does not get stuck to the bottom or top of the tank, and that the FLS does not collide with the tank walls and get damaged. With traditional float-type sensors, this wall clearance is usually between 15mm and 25 mm.

### **Product Turbulence**

Vehicle movements will cause the fuel to fluctuate within tank. Terzic et.al (2012) describe that when accelerating or driving up a hill, the movement of the fuel will produce waves, which can impact with the fuel level sensor. This phenomenon is called sloshing, and can result in the turbulence of the FLS. Consequently, a deterioration in the accuracy of the level measurement can be noted, due to the fuel surface being uneven during measurement. The lower the amount of fuel present in the tank, the more likely sloshing is to occur. Walleback (2008) raises the concern that this can be particularly alarming, as the fuel level sensor is most needed when fuel levels are low. Moreover, depending on the force and frequency of the waves, sloshing may even physically deform the fuel level sensor.

### Assembly

As previously mentioned, the Fuel Level sensor usually forms an integral part of the Fuel Supply Module. As a result, it is placed in the tank through the FSM opening along with the Fuel Supply Module. Since fuel tank designs are usually pre-determined prior to the development of the Fuel supply module and Fuel Level sensors, the Fuel Level Sensor is restricted by the size of the tank opening to fit the Fuel Level module and sensor in accordingly.

It is therefore essential to take into account this opening so as to make sure that the Fuel Level sensor can be assembled into the tank without damaging it, or the tank. The tank opening in which the FSM is placed usually has a diameter of  $\varnothing 120\text{mm}$  or  $130\text{mm}$  in conventional ICE vehicles.

### Tank morphology

Depending on the vehicle application, fuel tank geometries can usually take the form of regular profiles where the fuel disposition is not affected by inner tank structures.

Saddle tanks on the other hand, are tanks in which the fuel may not be evenly displaced throughout the tank due to inner tank 'obstacles'. As shown in fig 17. the fuel is unable to flow from one part of the tank to the other due to a separation in the middle causing the tank to have a 'saddle-like' shape.

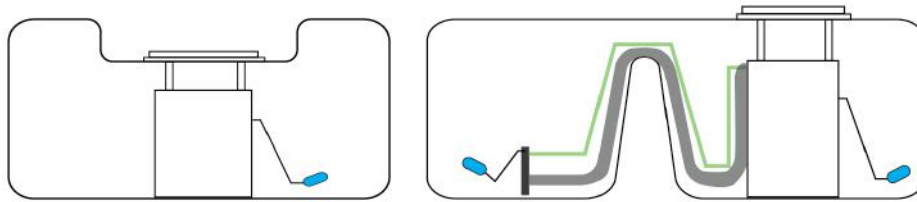


Fig17. Standard & Saddle tank profile with FSM & FLS.

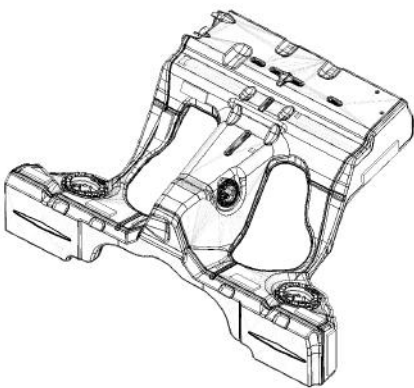


Fig18. Ferrari complex tank.

As a result, a single fuel level sensor is unable to measure the amount of fuel present throughout the tank. Consequently, several sensors are mounted and their readings calibrated according to the tank geometry to provide an accurate fuel level measurement.

Section 2.4 explored the trend of space optimization within vehicles, which is leading to the increasing adoption of tanks with complex shapes. These tanks will result in the profiles such as the saddle tank, with uneven bases and complex inner tank geometries. Henceforth, making it more and more complex to measure fuel levels accordingly.

An example of a fuel tank with complex morphology is one used in a Ferrari car. As shown in Fig18. The fuel will be at different levels depending on where it is placed within the tank. Hence, it was necessary in this case for BOSCH to install multiple fuel level sensors and calibrate the results to provide the driver with the actual fuel level height present throughout the tank.

## 5. Problem Description

### 5.1 FLS development at Bosch

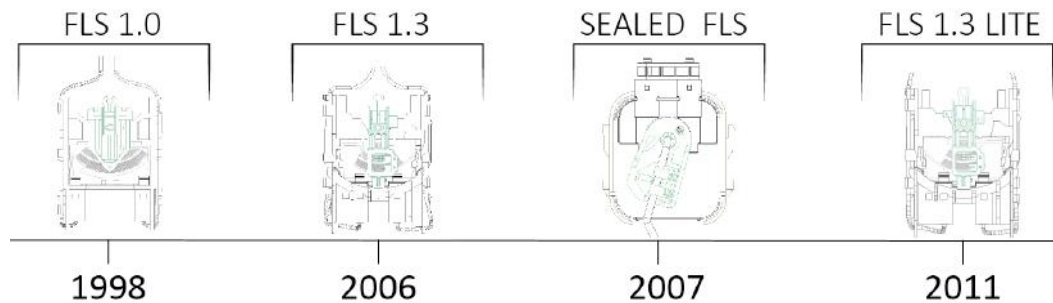


Fig19. Bosch FLS timeline.

The timeline above shows the development of the Fuel Level sensor at Bosch, since its inception in 1998. Over the past 20 years, the sensor has been modified and improved resulting in a product portfolio composed of four FLS generations. The difference between each generation mainly lies in incremental changes within the contact system of the FLS or the materials of its components. Overall, it can be noted that no radical changes have been made to the FLS since its development. The principle used to measure fuel levels, the traditional angular-position float sensor, has remain unchanged.

Current and Future Trends in the market, have given rise to a change in requirements for the FLS. The current FLS concept developed and produced by BOSCH for various auto manufacturers could therefore pose a challenge to meet the future needs of the automotive industry. For BOSCH to be ready for the changes that lie ahead and to remain a leader in the market, it is necessary to address these developments and adapt, to 'fix' the issues experienced with using the traditional level sensors and provide accurate and reliable fuel level sensing device for automakers.

### 5.2 Issues with traditional Fuel Level Sensors

General Issues experienced with the traditional Fuel Level Sensor include the many moving components that the FLS has, making it prone to wear. Moreover, the inability to be used in considerably small tanks due to the high torque required to lift the floater, and the challenging conditions of emerging markets in which the FLS is affected by the fuel composition, are also common issues faced with the traditional FLS. Moreover, issues specific to the FLS's contact, mechanical and electrical systems are presented in Fig20. Below. Refer to Appendix 7 for a more detailed description of these problems.


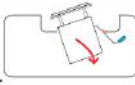




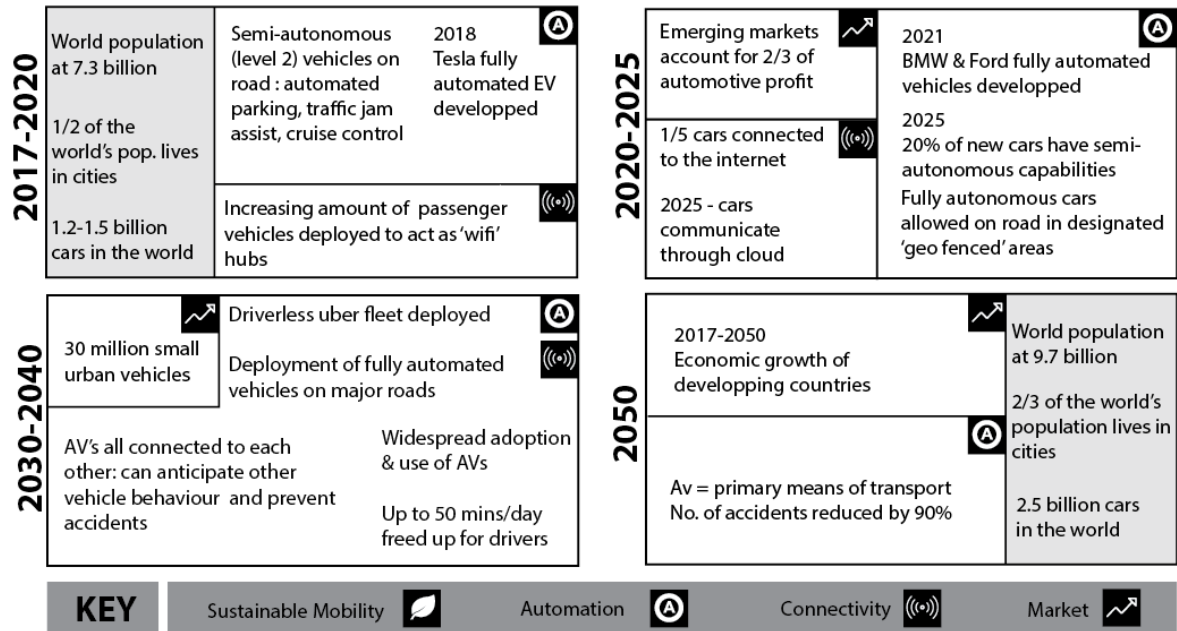
<b>DIRT</b> Dirt particles in fuel deposit on the resistor card. 	<b>ASSEMBLY</b> Wire Arm gets bent during FSM-tank assembly. 	<b>CORROSION</b> of metal components due to fuel composition (sulphur, water, etc..). 
<b>WEAR</b> of contact system : friction with resistor card. 	<b>SLOSHING</b> causes product turbulence and damages product. 	<b>PACKAGING</b> Wire arm creates wasted space in packaging & transport. 

Fig20. Main issues with traditional FLS.

## 6. Conclusion

### 6.1 Future Automotive Industry Timeline



### POWER TRAIN DIVERSIFICATION

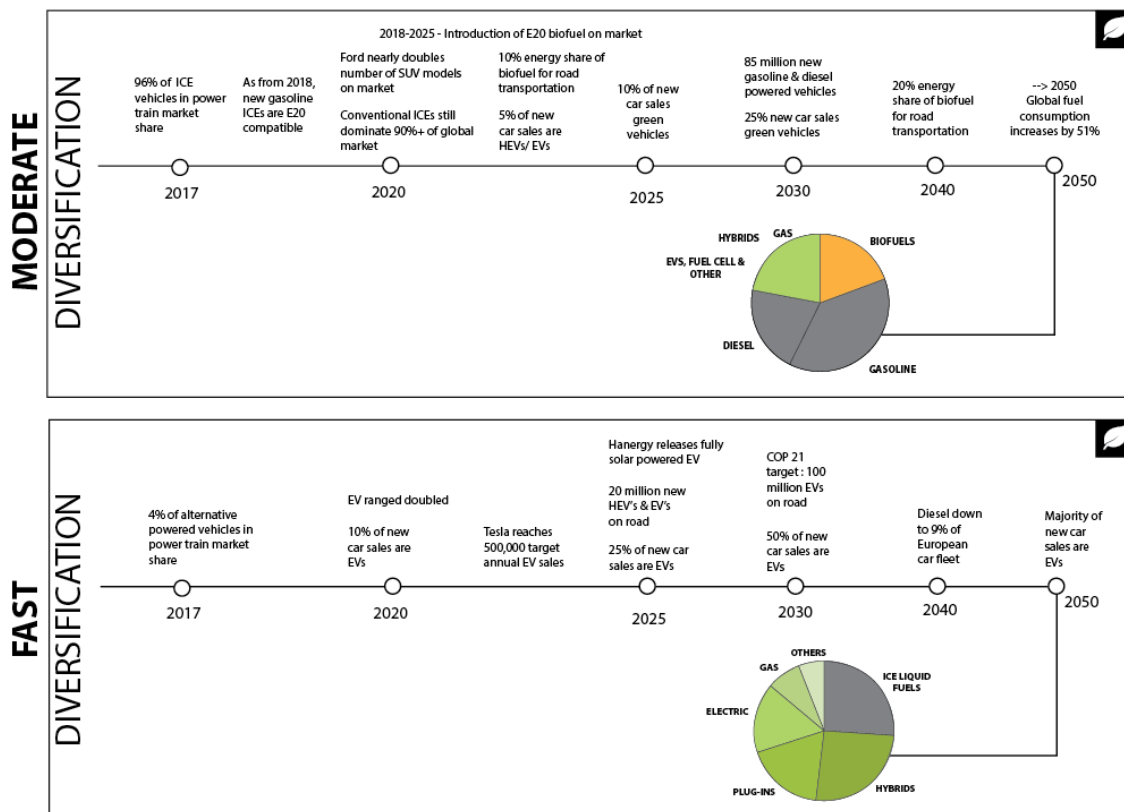


Fig21. Future automotive industry timeline.

## **6.2 Conclusion**

In this research paper, the need for an improved Fuel Level Sensor was explored. The aim of the research lied upon determining what trends are occurring and will occur in the automotive market, and how these will influence the requirements of the FLS.

During the research, experts from the initial development team of BOSCH's FLS highlighted substantial issues faced over the product lifecycle of the FLS. These issues are focused upon the corrosion of FLS components from submersion in fuel when in use, the dust particles affecting the resistor card due to use in 'bad quality' fuel, and the wear of components due to frequent contact with each other and tank sloshing. Moreover, the shape of the wire arm proved to pose problems in assembly, packaging, and the ease at which the sensor can be adapted to each customer.

In addition, the research has outlined the trends occurring in the automotive industry. The ones that have the potential to impact the FLS and its requirements were further explored and discussed through co-creation sessions. The exploration of these trends, together with the outlining of the current problems faced with traditional sensors have raised the need for an improved Fuel Level Sensor concept to be developed.

Indeed, this is needed in order to adapt to use in emerging markets, fix issues with the current FLS so as to remain competitive in market, adapt to changing vehicle/tank size and morphology, and prepare for the shift to sustainable mobility, where vehicles are bound to operate on different types of fuels and alternative powertrain systems.

Out of the requirements devised, certain base requirements have been carried on from the current FLS. The other requirements have been defined to allow for the problems faced with the traditional angular position sensor to be eliminated and for the FLS to be suitable for the changing automotive market.

The outcomes of the research highlighted the recurring request from BOSCH to have an improved FLS concept that will generate as less change as possible to the products to which it is connected such as the FSM, and the ECU, and that the FLS should continue to be at a competitive price in the market. As a result, it was decided that the sensor should remain a mechanical one and should output the same type of electrical resistance output as the current FLS, in order for it to be easily integrated into the vehicle and its affected sub-assemblies, without imposing much disruption/change to the current system.

One concern raised by certain stakeholders during the course of this research, is the need to develop a new FLS if the market is shifting to sustainable power train systems such as electric vehicles. Secondary research was conducted, focusing on reputable articles, reports and future scenarios which were analysed accordingly. What was found, was that much of the literature available presents views towards the total shift to electrification in the future and equal views against this occurring.

Indeed, whether the future power train market will still be dominated by ICE liquid powered vehicles or if alternative power train systems will prevail the market in the next 30 years is unknown. Many sources predict that ICE vehicles will maintain predominant in the market for still quite some time, while equally other sources predict the opposite. Indeed, while the U.S. Energy Information Administration predicts that vehicles powered with gasoline and diesel *“will still represent some 95% of the international car market”<sup>i</sup>* in 2040, the World energy council on the other hand, predicts that 50% of new car sales in 2030 will be electric vehicles. Many factors will affect whether we will experience a fast diversification in the power train technologies driving the global fleet, or if this will be more moderate.

BOSCH has recently informed in a press release that it is still unsure which powertrain will prevail the market in the future. As a result, Bosch is investing heavily in electro mobility while at the same time working on optimizing and improving combustion-engine technology. Bosch also predicts that *“In addition to the 20 million new hybrids and electric vehicles on the world’s roads in 2025, there will be some 85 million new gasoline and diesel-powered vehicles”<sup>ii</sup>*.

The philosophy of Bosch is to deliver innovative solutions to their customers (automakers) that are reliable and of high quality, allowing them to be market leaders in the field. Moreover, with the global trend of optimization to remain competitive in the market, improving vehicles and their components regardless of their power train technology is a practice most of companies in the field are undergoing. As a result, the need arises for the improvement of the FLS to be adapted and developed based on the requirements defined through the research results presented in this paper.

The requirements derived from this research will be the ‘starting point’ for the designing of an improved Fuel Level concept.

### 6.3 Design Brief

#### **Project Goal**

Develop an improved Fuel Level Sensor concept to meet the needs of the rapidly changing automobile industry.

#### **Design Challenge**

The suitability of the traditional Fuel Level Sensor for the rapidly changing automotive industry poses a challenge.

There is a need to eliminate the issues faced with the current traditional sensor, and develop an improved fuel level sensor concept to meet future requirements arising from the trends and developments occurring in the automotive industry, as explored in *sections 2.3 and 6.1*

## Scope/Boundaries

### 1. Target

The FLS will be designed for fuel tanks used in passenger vehicles as these are the most of BOSCH's customers.

### 2. Electrical system

The electrical system of the current FLS will be maintained to avoid having to change the whole system from the FLS to the fuel gauge, including the vehicle electrical connection to the FLS and the ECU, as these are already established by the automakers.

As a result, the electrical output signal will be kept identical, using the existing cable harness and a variable resistor with equal output specifications. There is however room to change the form of the variable resistor and resistor tracks from the arc-like shape currently used. These possibilities are further explored in the Design report.

## Design Requirements

How will the requirements of the Future Level Sensor be shaped by the rapidly evolving automotive industry?

Based on the insights gathered through research on the future of the automotive industry, the function of the fuel level sensor and its working principle, the following requirements were determined for the fuel level sensor to be developed in the next part of this project. Refer to appendix 8 for detailed descriptions of certain requirements.

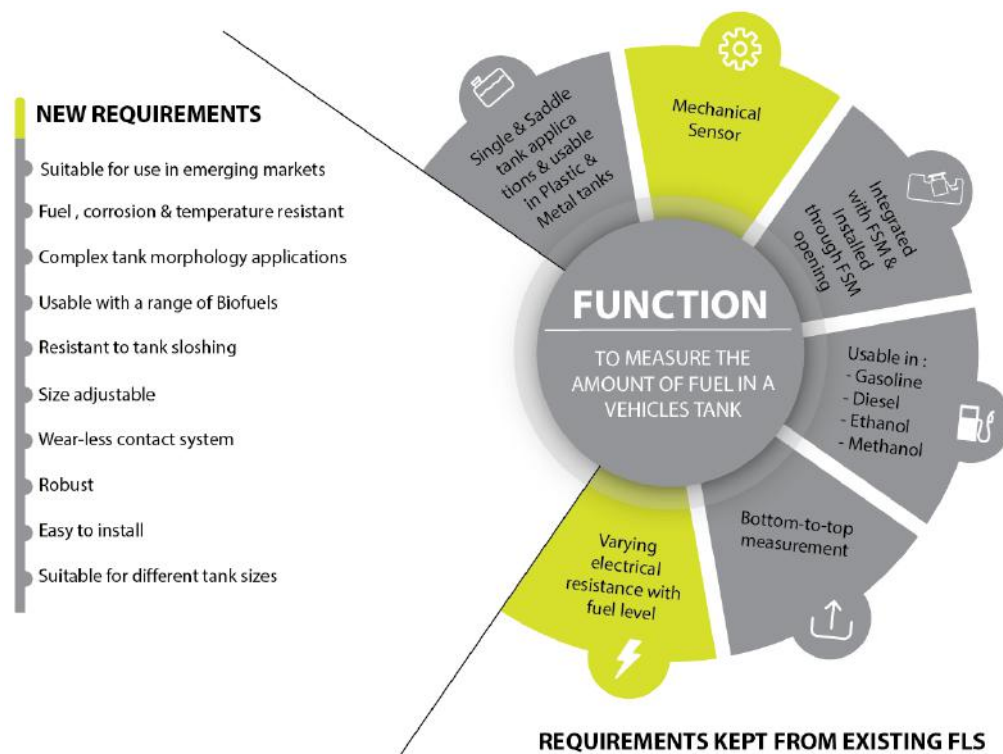


Fig22. Overview of Requirements.

## PRIMARY REQUIREMENTS

**General**

- The FLS should be of mechanical nature.
- The FLS should be suitable for use in emerging markets.
- The FLS should be suitable for fuel tanks with a capacity of 15L to 80+ L.
- The FLS should not be influencable by fuel composition.
- The FLS should be usable in single & saddle tanks, and tanks with complex morphology.
- The FLS should measure fuel levels using a bottom-to-top measurement approach.
- The FLS should be usable in plastic & metal tanks.
- The FLS should be usable with gasoline, diesel, ethanol, methanol, and a wide range of bio fuels.

**Assembly**

- The FLS should fit into the fuel tank through the FSM tank opening ( $\varnothing$  120mm or 130mm).
- The FLS should be easy to install.
- The FLS should be available as an integrated components of the FSM and a stand-alone product.

**Material**

- The FLS should be temperature resistant for a temperature range of -40 to +70 °C.
- The FLS component materials (if in contact with the fuel) should be corrosion resistant and be unaffected by the fuel composition.

**Electrical**

- The FLS should maintain the electrical output type/ output signal of the current FLS.
- The FLS should operate at a voltage ranging from 6V to 16V DC (varies with application).

**Mechanical**

- The FLS should resist tank sloshing.
- If the FLS contains moving parts, these should respect a clearance of 15 to 25 mm with the tank walls.

## SECONDARY REQUIREMENTS

- The components of the FLS should come as little as possible in contact with the fuel.
- The FLS should have as less moving parts as possible.
- The FLS should opt for a wear-less contact on the resistor card.

# **APPENDIX**

## APPENDIX 1: Sources

### Images

**Fig1.** © BOSCH Internal Media Library.

**Fig2. Traditional Float-type Sensor** [Online image]. (2009).Retrieved December 6, 2016  
from: <http://www.google.co.ug/patents/US7490514>

**Fig3. Hydrostatic Pressure Transmitter** [Online image]. (2016).Retrieved December 6, 2016  
from: <http://www.pvl.co.uk/hydrostatic-level-sensors.html>

**Fig4. Ultrasonic Level Transmitter** [Online image]. (2016).Retrieved December 6, 2016  
from: <http://www.directindustry.com/prod/magnetrol/product-6020-1633245.html>

**Fig5. Capacitive Sensor** [Online image]. (2016).Retrieved December 6, 2016  
from: <http://www.pvl.co.uk/capacitive-level-sensors.html>

**Fig6. Magnetostrictive working principle** [Online image].Retrieved December 6, 2016  
from: <http://www.ddc-online.org/Input-Output-Tutorial/Liquid-Level.aspx>

**Fig7. Magnetic Float level Indicator** [Online image]. (2015).Retrieved December 6, 2016  
from: <http://www.azom.com/article.aspx?ArticleID=12457>

**Fig8.** © BOSCH Internal Media Library.

**Fig9.** © BOSCH Internal Media Library.

**Fig10.** © BOSCH Internal Media Library.

**Fig14.** © BOSCH Internal Media Library.

**Fig16.** © BOSCH Internal Media Library.

**Fig18.** © BOSCH Internal Media Library.

### **Equations**

**Eq1.** Muth, M., Fundamentals of hydrostatic level measurement, Industrial Process Products & Technology, (2014).Retrieved from:  
[http://www.wika.us/upload/TA\\_0414IPPT\\_en\\_ca\\_67743.pdf](http://www.wika.us/upload/TA_0414IPPT_en_ca_67743.pdf)

**Eq2.** Emerson, R. (2013) *The Engineer's Guide to Level Measurement*. Chanhassen, MN: Rosemount, Inc.

**Eq3.** Emerson, R. (2013) *The Engineer's Guide to Level Measurement*. Chanhassen, MN: Rosemount, Inc.

**Eq4.** Terzic, E., Terzic, J., Nagarajah, R., Alamgir, M. (2012) *A Neural Network Approach to Fluid Quantity Measurement in Dynamic Environments*. London: Springer-Verlag

**Eq5.** © Bosch Internal database.

## APPENDIX 2: References

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## APPENDIX 4: Keywords

**Brake assist system** – braking technology for vehicles in which the force of the brake is increased by systems within the vehicle in the case of an emergency.

**Automakers/manufacturers** – Companies that manufacture and sell vehicles within the automotive industry. These include: Toyota, BMW Ferrari, Peugeot, and many more.

**Autonomous vehicle** – Vehicle that can drive without the need of human input. Such a vehicle senses its environment and detects surrounding objects.

**Bad/dirty fuel** – Fuel containing considerable amount of water, dirt, or other unwanted substances that make it affect its purity and quality. Such fuels are often found in emerging markets and are prone to damage components that come into contact with it.

**Biofuel** – Fuels derived from organic matter such as plants and other agricultural produce.

**Bottom-to-top measurement** – Measurement approach in which the level of the fuel in a tank is measured from the bottom of the tank, to the surface of the fuel.

**Complex morphology** – Refers to the intricate geometry and profile of a fuel tank. Often includes bases of different levels causing the fuel to be dispersed around segments of the tank, and making it difficult to measure total fuel amount in tank with a single apparatus.

**Conventional vehicle/car** – Vehicles that operate on internal combustion engines through gasoline or diesel, are currently predominant in the automotive industry and have been used since the 1880s.

**Electric vehicle** – Vehicle that operates on an electric motor.

**Electrification** – refers to the trend of adopting electric vehicles and other vehicles that make use of electricity to operate such as HV's.

**Fuel Gauge** - used to display the fuel level in a vehicles tank. The fuel gauge is usually located on the dashboard of the vehicle.

**Fuel Supply Module** – contains several crucial components for the functioning of a vehicle. Its main task is to pump the right amount of fuel to the engine at an appropriate pressure and constant rate.

**Fuel tank** – Container which holds the fuel to power a vehicle, usually located towards the back of the vehicle.

**Hybrid vehicle** – Vehicle that operates on more than one type of motor/engine. In this paper, HV's refer to vehicles in which an electric motor and internal combustion engine are used to power the vehicle either alternatively or conjunctively.

**Internal combustion engine** – Vehicle engine used by conventional vehicles in which the fuel is burnt in a combustion chamber resulting in the release of gases that have high pressure and temperature, enabling the engine to be powered.

**Market proliferation** – The spreading and growing of markets.

**Megatrends** – Global trends that are shaping certain industries and generating significant impact.

**Microcar/subcompact** – smaller sized vehicles than the average passenger vehicle.

**Operating voltage** – The voltage level of an electric system when it is in use.

**Optimisation** – The improvement of something to make it more efficient or better.

**Output voltage** - The voltage leaving an electric component or system.

**Power train** – Refers to the components that transmit the power from the engine to the rest of the vehicle to enable it to be to move.

**Resistance** – The ability to prohibit of a certain amount of current to travel through an electric system.

**Sloshing** – the movement of fuel within the fuel tank. When the vehicle is in motion, the fuel in the tank and form waves and as a result damage certain components located within the tank.

**Sulphur** – a chemical element (S16) that is known to react with near to all elements, with the exception of noble materials such as gold.

**Transmitter** – devices that transmit electromagnetic waves carrying certain signals.<sup>1</sup>

**Variable resistor** – controls current flow through altering amounts of resistance that are manipulatable.

**Voltage regulator** – is used to maintain a certain voltage level in an electric circuit.

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<sup>1</sup> <https://www.google.com/search?q=trasnmitterasisted+braking+system&ie=utf-8&oe=utf-8#q=trasnmitter>

## APPENDIX 5: Classification of liquid level measuring principles

	OPERATING PRINCIPLE		CONTACT WITH FUEL		LEVEL MEASUREMENT		MEASUREMENT APPROACH	
SENSOR	Mechanical	Electrical	Contact	Contactless	Continuous	Point	Bottom-up	Top-down
Traditional Float type								
Hydrostatic Pressure								
Ultrasonic								
Laser								
Radar								
Capacitive								
Magneto resistive (AMR)								
Magnetostrictive								
Magnetic float level								

*APPENDIX 6: Advantages and limitations of measuring principles*

Sensor	Advantages	Limitations
Traditional Float level sensor	<ul style="list-style-type: none"> <li>- Cheap Cost</li> <li>- Well-established in market</li> </ul>	<ul style="list-style-type: none"> <li>Mechanical nature</li> <li>Accuracy &amp; reliability issues</li> <li>Influenceable by fuel composition</li> </ul>
Pressure sensor	<ul style="list-style-type: none"> <li>- Unaffected by fuel composition, quality, or properties such as conductiveness and dielectric value.</li> <li>- Unaffected by tank geometry or other present objects within the tank.</li> <li>- Easy to install.</li> </ul>	<ul style="list-style-type: none"> <li>- Density of the fuel needs to be constant so that measurements are accurate.</li> </ul>
Ultrasonic transmitter (Ultrasound)	<ul style="list-style-type: none"> <li>- Easy to mount in the fuel tank</li> <li>- Non-mechanical nature: no moving parts (reduced need for maintenance &amp; increased robustness)</li> <li>- Contactless (doesn't get affected by fuel composition, or change in fuel properties)</li> </ul>	<ul style="list-style-type: none"> <li>- The pulse needs to be uninterrupted during the time it is sent, reflected, and received. (Fuels that form vapour wouldn't be suitable).</li> <li>- The liquid surface should be stable. (sloshing will result in inaccurate measurements)</li> <li>- Other components in the tank could cause "false echoes" of the ultrasound pulse.</li> </ul>
Radar level transmitter	<ul style="list-style-type: none"> <li>- Unaffected by changes in temperature, pressure, dielectric constant of fuel, fuel conductivity, or fuel composition.</li> </ul>	<ul style="list-style-type: none"> <li>- Not suitable for fuel contaminated with large amount of dust or foam, as the radar will detect the foam or dust instead of the fuel to be measured.</li> </ul>

Laser transmitter	<ul style="list-style-type: none"> <li>- Usable in small tanks and deep tanks.</li> <li>- Signal less prone to be diverged or deflected.</li> <li>- Not affected by fuel dielectric or conductive properties.</li> </ul>	<ul style="list-style-type: none"> <li>- Expensive</li> <li>- Not suitable for transparent liquids or liquids with considerable dust particles or foam.</li> </ul>
Capacitive	<ul style="list-style-type: none"> <li>- Cheap cost</li> <li>- Electrical nature</li> <li>- Adaptable to different sizes and shapes</li> <li>- Alamgir et al. (2013) depict the traditional level sensors as having a limit to their functional life, due to their mechanical nature. Using the capacitance principle for level sensing applications can eliminate issues of component wear faced by such sensors.</li> </ul>	<ul style="list-style-type: none"> <li>- Dielectric constant should remain stable.</li> <li>- Need to calibrate the ECU for each different tank application</li> <li>- Dielectric constant of used fuel must be calculated each time</li> <li>- Needs a grounded</li> </ul>
Magnetostrictive	<ul style="list-style-type: none"> <li>- Precise measurements as a result of the use of magnets</li> <li>- Limited moving parts (only float), guided by the inner rod.</li> </ul>	<p>Attracts metal particles present in the tank/fuel</p> <p>Change in fuel density will result in erroneous measurements</p>
Magnetic float level sensor	<ul style="list-style-type: none"> <li>- Floater is prone to get stuck or affected by fuel composition</li> <li>- Electrical system is isolated from fuel (sealed).</li> <li>- Float is guided.</li> <li>- Contains minimal moving parts</li> </ul>	<ul style="list-style-type: none"> <li>- Reed switches do not allow for continuous measurement.</li> <li>- Mostly used in on/off applications.</li> <li>- Application in passenger vehicle fuel measurement unseen.</li> </ul>

## APPENDIX 7: Problems with traditional FLS

*(Results from interview with FLS development expert in Bosch Czech Republic , discussion with FLS engineers in Bosch Vietnam & Literature Review)*

### **I. Contact System**

- *Dirt particles in fuel*

Dirt (even in very small amounts) can deposit on the resistor card - when the wiper (contact) touches the resistor card and in consequence if dirt present, touches the dirt, then signal is lost/disturbed because the contact is not directly touching the resistive tracks on the resistor card.

This problem is partly eliminated with the development of the 'multi-finger' wiper so the contact touches the resistor card at several locations (not just one contact). However, fuel Level sensors with only one contact point like rivets may cause a complete loss of signal if this contact touches the dirt.

- *'Wear' of the wiper*

Due to frequent contact with the resistor card, the wiper/ contact system is bound to wear off after a certain time. The material of this wiper will wear off and therefore less and less contact will be made with the resistor card , and in time there will be no more contact , causing mis readings at first and in the end no reading from the Fuel Level Sensor causing the driver to not know how much fuel is present in the tank.

- *Electrochemical corrosion*

When the FLS is used in conductive fuel ( fuel with water or high ethanol content), then electrochemical corrosion can occur. This results in some material present on the resistor card (silver) to corrode (come off) - also known as 'silver migration'.

- *Sulphur content*

Fuel Level Sensors with materials such as Silver present on the wiper contact & resistor card will oxidise when used in fuel where Sulphur is present. This occurs mostly in emerging markets. When oxidation of the metal occurs, signal quality decreases/is lost.

This problem can be eliminated by using contacts made of other materials such as gold . Using gold will protect the resistor card from Sulphur but results in a higher cost of producing the Fuel Level Sensor

## **II. Mechanical system**

- *Wire*

The wire is made of stainless steel and during manipulation & installation of the FSM into the tank, it can get bent causing mistakes in fuel height measurements.

- *Float*

The hole present in rotating floaters gets bigger during use due to fuel sloshing and general rotary movement of the float around the wire arm. Fuel sloshing is more observable in smaller tanks. As a result, when the hole gets bigger, the float can end up getting off the wire arm. At this stage, the FLS can no longer measure fuel height.

## **III. Electrical System**

- *Electrical Corrosion*

Electrical corrosion caused by direct constant current. However, the FLS is not permanently with current (when it is not moving). Therefore pulse-feeding limits the degree to which there is electrical corrosion. Pulse feeding is a good solution to protect the contact system & the material on the resistor card.

## *APPENDIX 8: Further detailing of certain requirements*

### **The FLS should be suitable for use in emerging markets.**

With the rapid expansion of the automotive industry to emerging markets, the FLS needs to be usable in such markets which have different operation environment than emerged markets (for which the current FLS is designed for). Indeed, the fuel quality, composition and vehicle operating conditions are different.

### **The FLS should be usable in single & saddle tanks, and tanks with complex morphology.**

As explored in the future trends developing the automotive market, it has been noted that tank shapes will become more complex as automakers want to use as much 'unused' space as possible within the vehicle and to also give more passenger space to vehicle users.

### **The FLS should be usable with a wide range of bio fuels.**

Due to the sustainable mobility trend, an increasing amount of biofuels will be used, also the variety of biofuels available will grow. The organic nature of biofuels are why they contain higher concentrations of water. As a result, they are more likely to corrode materials in which they are used. They are more chemically active than the conventional gasoline or diesel and can therefore be more aggressive to certain materials.

### **The FLS should be available as an integrated components of the FSM and a stand-alone product.**

Bosch sells their FLS as part of the FSM (package). Therefore, the FLS is connected to the ECU and electronic circuit of the vehicle through the flange electrical connectors which are located within the FSM. In certain applications however, several FLS's need to be mounted within the tank. This is common in tanks with complex shapes/morphologies. As a result, in order to install several FLS's without having to use several FSM's it is important that the FLS is available as a stand-alone product too.

### **The FLS should fit into the fuel tank through the FSM tank opening ( $\varnothing 120\text{mm}$ or $130\text{mm}$ ).**

Fuel Supply Modules produced by Bosch fit into two standard tank openings of either 120mm or 130mm. Since the FLS is to be fixed into the tank with the FSM/through the FSM tank opening, it is important that it can fit through these set dimensions as it is very costly to have to make additional holes into the tank.

### **The FLS should be temperature resistant for a temperature range of -40 to +70 °C.**

Vehicles are used globally, in different climates where temperatures can reach both extremes of the spectrum. In addition, when the fuel returns from the engine through the 'return port', it is very hot. As a result, it is crucial for vehicle components located within the tank to be able to resist low and high temperatures.

## APPENDIX 9: Results from Co-creation session 1

**Aim:** To brainstorm and identify the trends in the automotive industry that have the potential to impact the Fuel Level Sensor. A look into what the FLS may look like in the future.

**Participants:** 6 x Design Engineers at Bosch

**Themes focused on :** Sustainable Mobility, Optimisation of space and performance, Rise of Emerging markets.

Useful insights gathered:

### 1. Sustainable Mobility & Electrification

- The type of fuel used will change therefore chemical composition of fuel will differ. This can affect the components of the Fuel Level Sensor based on their material (corrosion and oxidation can occur).
- Substance used to power vehicles could change - gas, solar energy, etc..
- The increasing development of Hybrid vehicles will result in smaller tanks used in such vehicles. The Fuel Level Sensor should therefore be able to operate in a smaller confinement of space. (Especially with Hybrid vehicles that are not 50% electric and 50% fuel based, but rather 90% electric with 10% fuel for emergency or backup)
- The shape of the FLS could differ to be more optimised with the possible reduction of number of components and be made more compact.
- The Fuel Level Sensor could be placed outside of the tank so that it does not come in contact with the fuel.
- The Fuel Level Sensor may not be used anymore in the future, if we completely shift towards electrification.

### 2. Optimisation

- Other methods to measure liquid levels could be applied in the context of fuel level measurement.
- Shape change of FLS & Material alterations

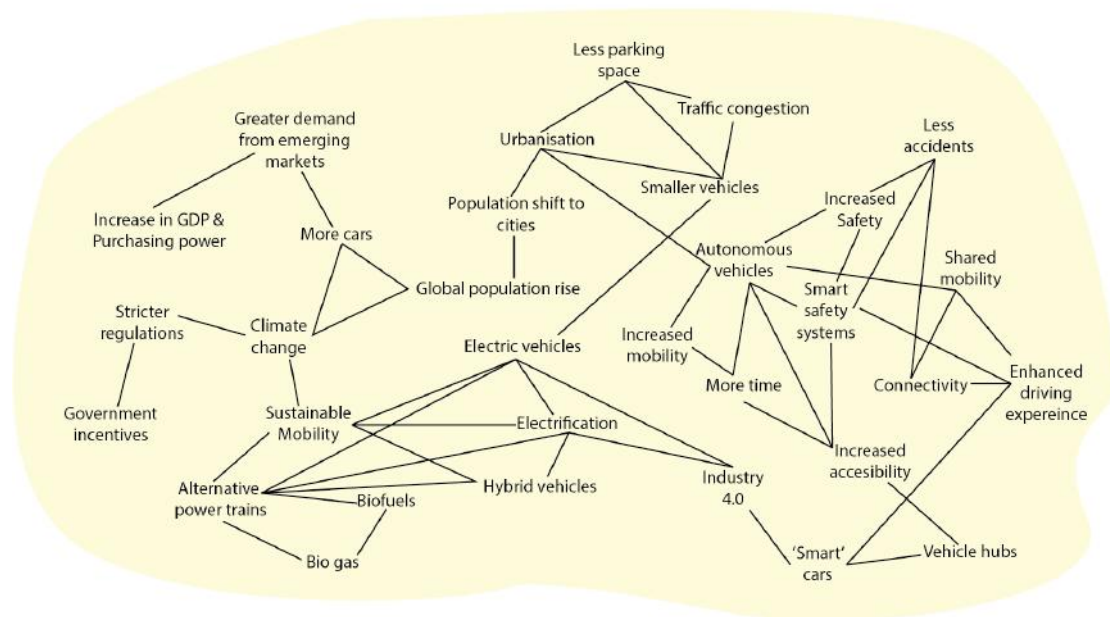
- Tank sizes will change
- A different way to place the Fuel Level Sensor within the tank - another assembly point in the reservoir or on other components.
- Shift to smaller Fuel Level Sensors but more of them within the tank

### 3. Rise of Emerging markets

- Shift in market , therefore need to design for a different type of market by taking into account the influential factors and context
- Material change in components to be more resistant to bad fuels, corrosion,dust,etc..
- Use a different mechanism more adapted to a lot of movement & tank sloshing
- Good sealing of components

## APPENDIX 10: Trends in the automotive industry

## WEB OF CONNECTED TRENDS



## END NOTES

<sup>i</sup> <https://epic.uchicago.edu/news-events/news/car-future-may-run-gasoline>

<sup>ii</sup> [http://www.bosch.com.tw/media/tw/news\\_room/2017/02\\_1/powertrain/PI\\_Power\\_2017\\_02\\_01\\_E\\_final\\_GFS.pdf](http://www.bosch.com.tw/media/tw/news_room/2017/02_1/powertrain/PI_Power_2017_02_01_E_final_GFS.pdf)

# Design Report

Emilie Langlois



# Acknowledgments

The past 6 months working on this project have enabled me to develop diverse skills and gain a lot of knowledge. It has been a great learning curve from which many memories and unforgettable experiences will remain. The process and the journey through which this project has brought me have enriched me and taught me numerous things.

I'd like to thank all the wonderful colleagues at Bosch for always being here to answer all my questions and being willing to involve me in their daily work tasks so that I could learn as much as possible during my time there. Without them, undertaking and finishing this project would not have been possible.

Thanks to my tutors for supporting me throughout the project and for being here when needed despite the 9000+ km separating us. Thanks to my family without which this great learning experience abroad, and the opportunity to take part in the Industrial Design Engineering program at THUAS would not have been possible.

If I had to sum up the different elements that make up my project, this pie chart below would represent it best.

I hope you enjoy the read !  
-Emilie



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# CHAPTER 1

## *Introduction*

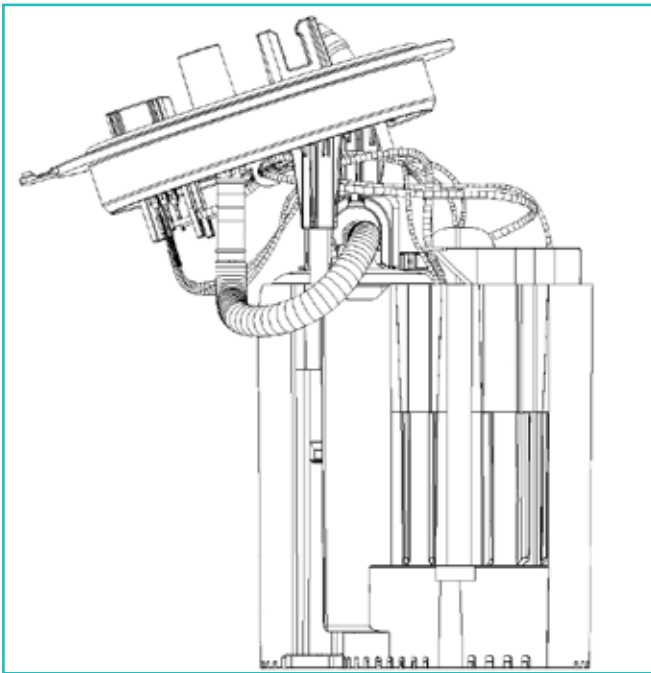


## Prior knowledge needed

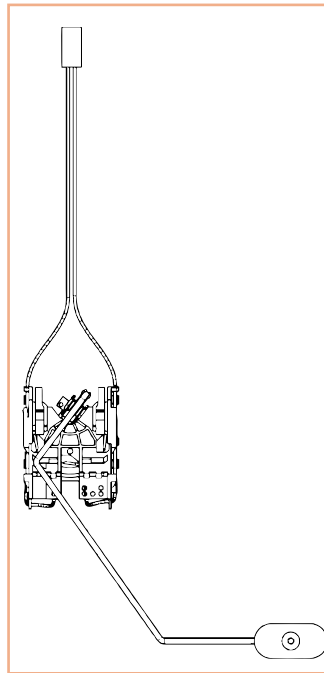
**FLS** = Fuel Level Sensor

**FSM** = Fuel Supply Module

The FLS is a component of the Fuel Supply Module and measures the amount of fuel in a vehicle's tank.



Fuel Supply Module



Fuel Level Sensor

# SUMMARY

This design project was conducted as part of my graduation project as an Industrial Design Engineering student at The Hague University of Applied Sciences.

Partnering with the Robert BOSCH Automotive R&D Centre in Vietnam, I was assigned to work on the Fuel Level Sensor; a device used to measure the amount of fuel in a vehicle's tank.

Through the research conducted and presented in the paper "Developing an improved Fuel Level Sensor concept for the evolving automotive industry", requirements were derived for the development of a new Fuel Level Sensor concept for BOSCH.

The proposed concept is a vertically mounted FLS which measures the fuel level using a floater that magnetically triggers a set of fingers on a comb to apply contact on a resistor card. Using a bottom-to-top measurement approach the proposed FLS concept eliminates most of the issues experienced with the traditional level sensors, and provides a good solution to accommodate for the industry changes that lie ahead.

This report provides an overview of the process followed and results obtained during the course of the project to reach the proposed FLS concept.

# COMPANY BACKGROUND

Robert BOSCH GmbH is a German multinational engineering corporation, headquartered in Stuttgart with over 440 branches distributed over roughly 60 countries worldwide.

BOSCH offers technological services in four areas of operation: Consumer goods, Energy and Building Technology, Mobility solutions and Industrial Technology, delivering technology and services that are "invented for life".

One of the subsidiaries of Robert BOSCH GmbH is the Automotive R&D Centre in Vietnam. The Automotive R&D Centre was established in 2014 focusing on mobility solutions with regards to connectors, push belts, fuel injection valves and fuel supply. It is in this location that I conducted my graduation project through my internship as part of the Fuel Supply team.

The Fuel Supply team works with the Fuel Supply Module and its components (Fuel Pump, Flange, Pot, Fuel filter, Fuel Level Sensor, etc..)

Together with the Fuel Supply team, it was chosen that I would focus on the Fuel Level Sensor for my project.



# BOSCH

# PROCESS OVERVIEW

The process used throughout this project was inspired from the 'double diamond design model' by the Design Council UK. The model was adapted to the project and requirements from the Industrial Design Engineering Program. As a result, there are four main stages covered throughout the project: **DISCOVER**, **DEFINE**, **DEVELOP** and **DELIVER**.

Fig1. on the right, shows an overview of the stages and the tasks performed throughout each stage. The converging and diverging processes are also illustrated accordingly. The 'Discover' and 'Define' stage have been covered in the research report "Developing an improved Fuel Level Sensor concept for the evolving automotive industry". This design report documents the two last stages of the process.

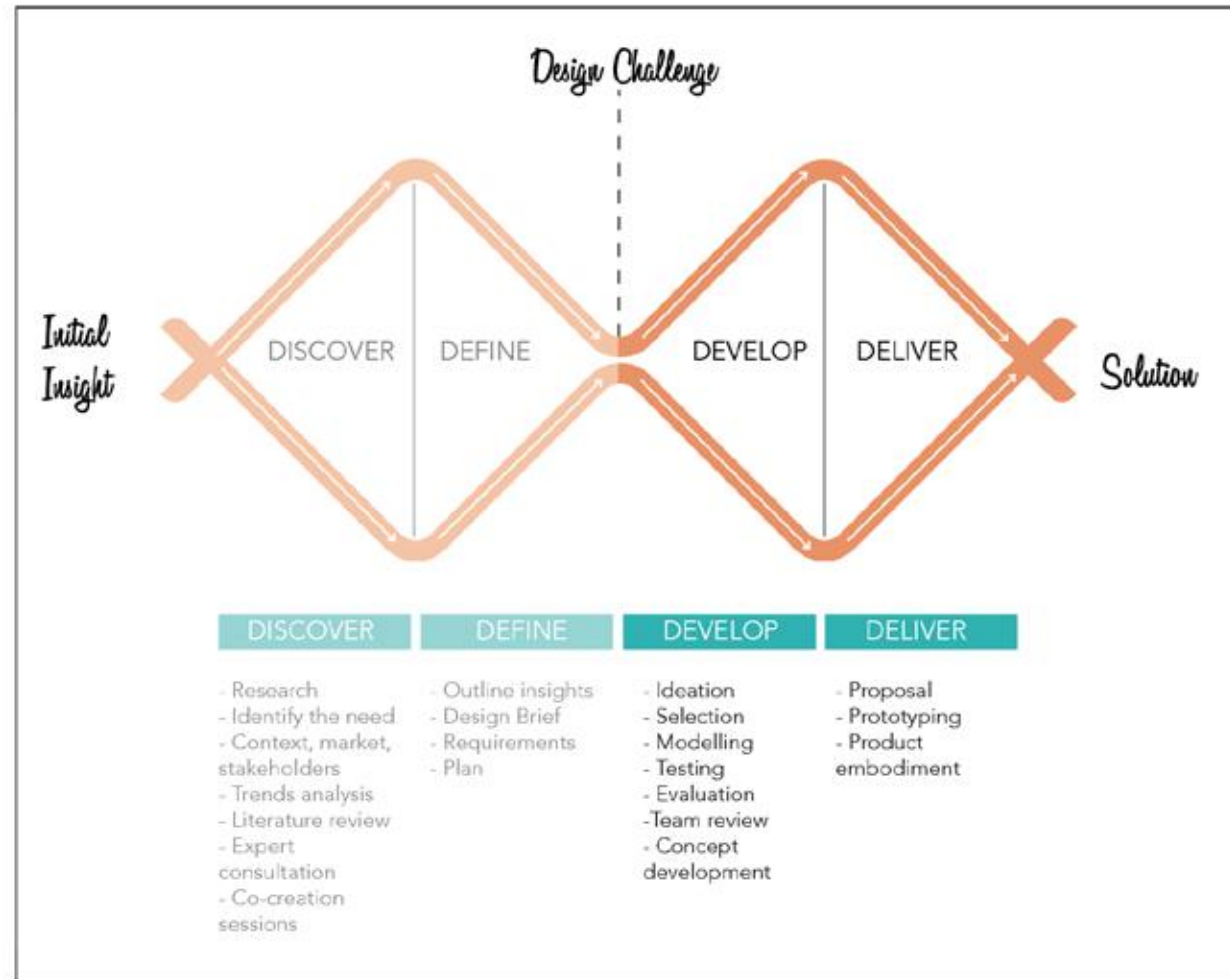


Fig1. Overview of Process

# DESIGN BRIEF

## Problem Statement

Several issues with the use of traditional type Fuel Level Sensors in vehicles have been identified. These include the packaging, assembly, corrosion and wearing out of the product and its components.

Moreover, with the rapidly developing automotive industry, vehicle systems are undergoing changes that will have an effect on the future of the current components used in vehicles.

The Fuel Level Sensor is no exception to this. Indeed, the increasing shift to emerging markets, the change in vehicle and tank, size and morphologies, and the shift to sustainable mobility are trends that have been identified as carrying future impact on the FLS and its requirements.

## Design challenge

The suitability of the traditional fuel level sensor for the rapidly changing automotive industry poses a challenge. In order for BOSCH to maintain its market leader position it is necessary to innovate and consider other improved FLS concepts of enhanced suitability for the market than the current one developed.

**Challenge :** Develop an improved Fuel Level Sensor concept to meet the needs of the rapidly changing automobile industry and eliminate as much as possible the issues faced with traditional type Fuel Level Sensors.

## Company Requirements

**1. Mechanical sensor :** The FLS should remain a sensor of mechanical nature in order to keep the cost low and enable production with existing plant capabilities.

**2. Electrical output :** The FLS should maintain the same type of electrical output as the current one used (varying resistance with fuel level heights).

## Deliverables

The final deliverables agreed upon with the company are to:

- 1) Propose an improved FLS concept
- 2) Build a physical prototype of the concept, as well as a CAD model to illustrate its working principle
- 3) Detail the costs, assembly process and manufacturing process of the product

# REQUIREMENTS



## General

- The FLS should be of mechanical nature.
- The FLS should be suitable for use in emerging markets.
- The FLS should be suitable for fuel tanks with a capacity of 15L to 80+ L.
- The FLS should not be influencable by fuel composition.
- The FLS should be usable in single & saddle tanks, and tanks with complex morphology.
- The FLS should measure fuel levels using a bottom-to-top measurement approach.
- The FLS should be usable in plastic & metal tanks.
- The FLS should be usable with gasoline, diesel, ethanol, methanol, and a wide range of bio fuels.



## Mechanical

- The FLS should resist tank sloshing.
- If the FLS contains moving parts, these should respect a clearance of 15 to 25 mm with the tank walls



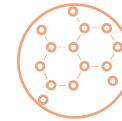
## Assembly

- The FLS should fit into the fuel tank through the FSM tank opening (Ø120mm - Ø130mm).
- The FLS should be easy to install.
- The FLS should be available as an integrated component of the FSM and a stand-alone product.



## Electrical

- The FLS should maintain the electrical output type/ output signal of the current FLS.
- The FLS should operate at a voltage ranging from 6V to 16V DC (varies with application).



## Material

- The FLS should be temperature resistant for a temperature range of -40 to +70 °C.
- The FLS component materials (if in contact with the fuel) should be corrosion resistant and be unaffected by the fuel composition.



## Secondary

- The components of the FLS should come as little as possible in contact with the fuel.
- The FLS should have as less moving parts as possible.
- The FLS should opt for a wear-less contact on the resistor card.

# STAKEHOLDERS

Want to:

- deliver vehicles of decent quality with components that are reliable and long lasting , providing a safe and comfortable driving experience
- offer 'the best' to their customers at an acceptable price to remain competitive in the market

- purchase the Fuel Level Sensor (FLS) from Bosch
- assemble the FLS & FSM into the vehicles
- replace faulty FLS's
- sell 'whole' vehicle to drivers

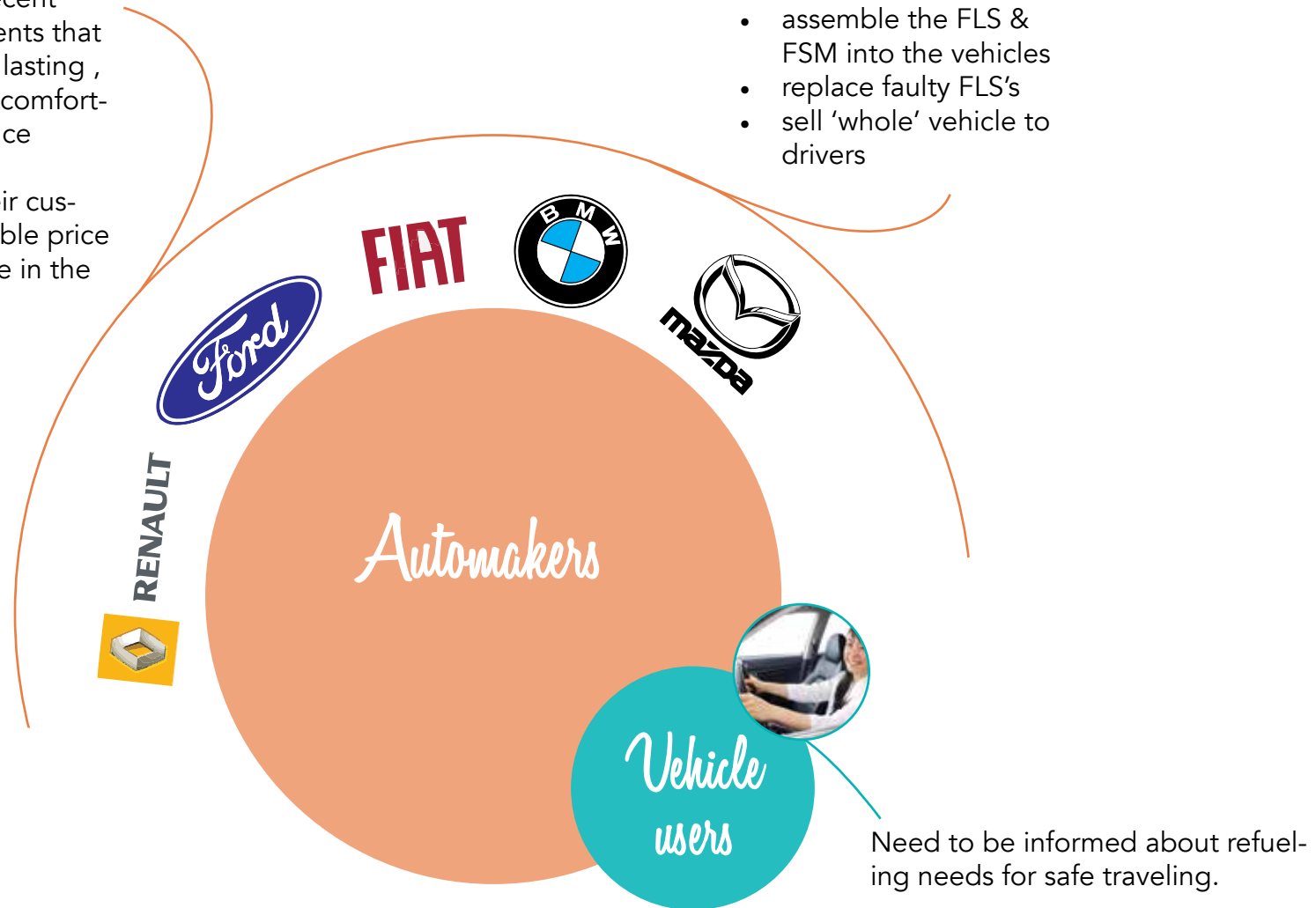


Fig2. Stakeholders

# CONTEXT OF USE

## Fuel Supply Module

The Fuel Level Sensor is a component that is part of the Fuel Supply Module and thus has to fit in its assembly.

Two types of Fuel Supply Modules exist: concentric and eccentric. The eccentric FSM was chosen for this project as it is most suitable for tanks of complex morphology (trending in the future of the automotive industry). It also allows for more space to attach the FLS without having to create much disruption or change in design to the main components of the FSM.

Eccentric FSM's have flanges and pots that are not centered one above each other. As seen on the right, the flange is not located directly above the pot, and in some cases may be tilted.

Fig4. shows the main components and dimensions of the Fuel Supply Module, these are essential in determining where the FLS can be attached to the FSM.

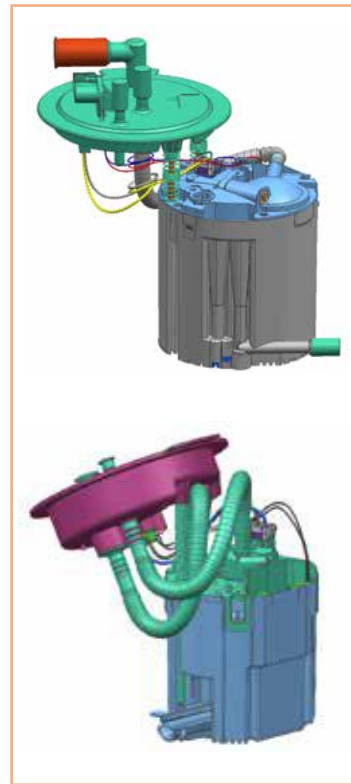


Fig3. Eccentric FSM

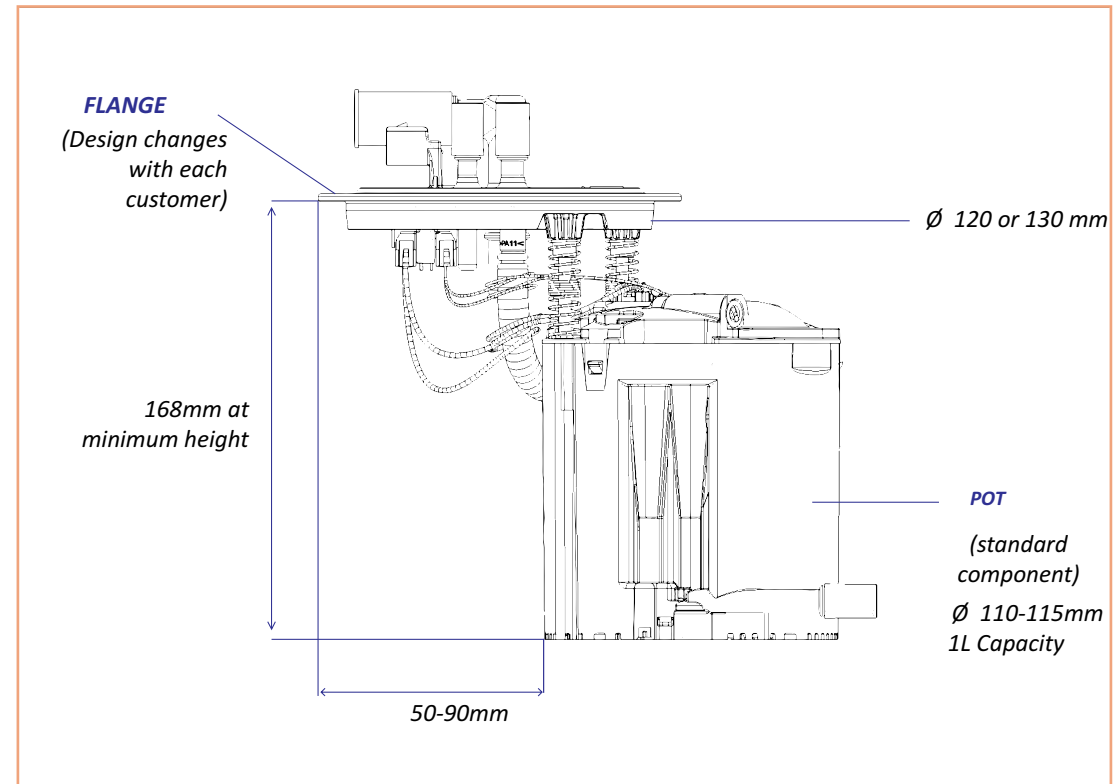


Fig4. FSM dimensions

## FSM - Tank Assembly

The FSM is currently assembled into the fuel tank through the four simple steps shown below.

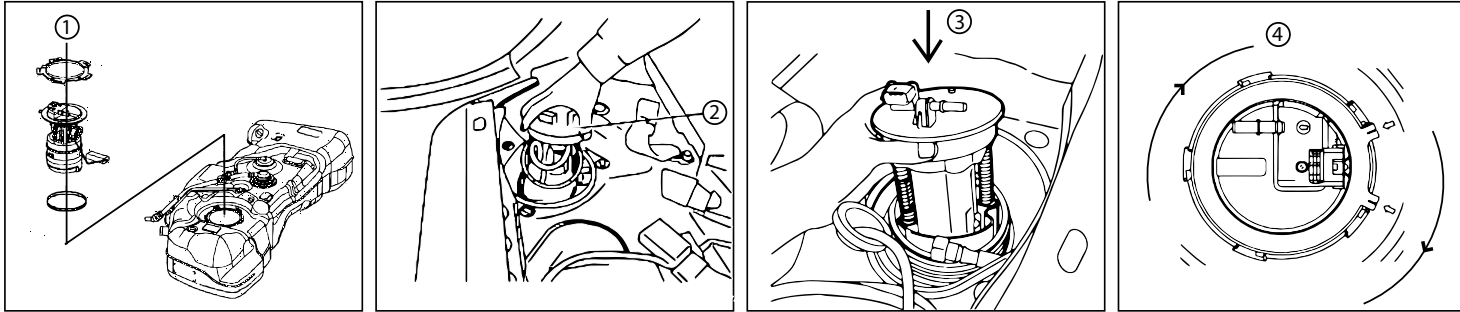


Fig5. FSM Assembly

The FSM is placed in the tank through the opening.

It is rotated in the right direction according to the arrow symbols on the flange.

The FSM is pressed down on the guide rods & springs.

The FSM is locked in place by rotating the screw lock.

## Tank Morphology

Tanks come in various shapes and sizes. What they all have in common however, is the opening in which the FSM is inserted. This opening is usually  $\varnothing 120$  or  $\varnothing 130$  mm depending on the size of the flange. Moreover, all tanks have 'placement borders' on their bottom surface, in order to keep the FSM stabilised within the tank.

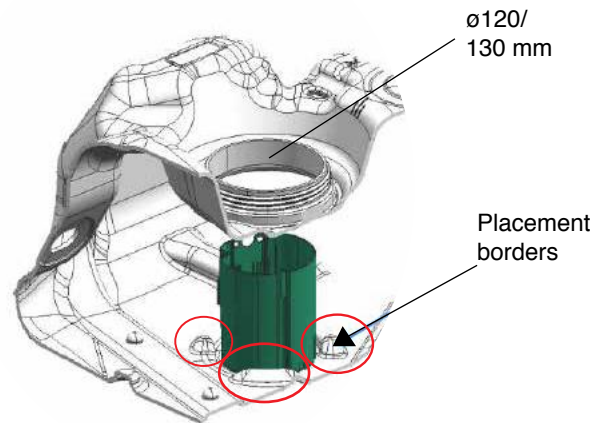
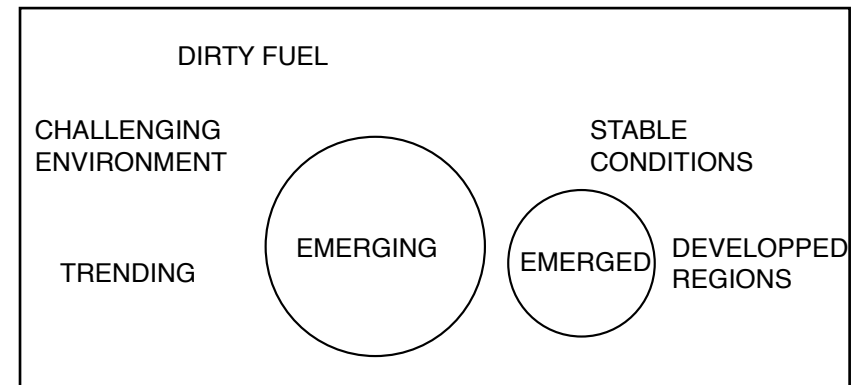


Fig6. FSM tank placement

## Market & Conditions



# RECAP

*what*

measure the amount of fuel in a vehicle's tank.

*why*

to provide drivers with reliable information regarding refueling needs.

*who*

driver of vehicle(to be informed), Bosch (to remain market leader) & automakers to provide 'the best' to their customers.

*when*

on a daily basis.

*where*

focus is in passenger vehicles, in emerging and emerged markets.

*how*

by providing an enhanced fuel level sensor with reduced issues and therefore improved reliability, that is suitable for the developments occurring in the automotive industry.



## CHAPTER 2

*Ideation*

# IDEA GENERATION

For Ideation, two directions were chosen:

1. Adapting existing level measurement techniques to passenger vehicle fuel tank applications.
2. Exploring how different properties of liquid and fuel change with volume, and coming up with ideas on how this change can be measured and embodied into a product.

Following which, a mind map was created as inspiration (see Fig7.), and a dozen ideas were generated.

These were then quickly filtered down using an evaluation matrix which judged the ideas based on two criteria: Their suitability for the trends occurring in the automotive industry, and their ability to solve the issues faced with the traditional Fuel Level Sensor.

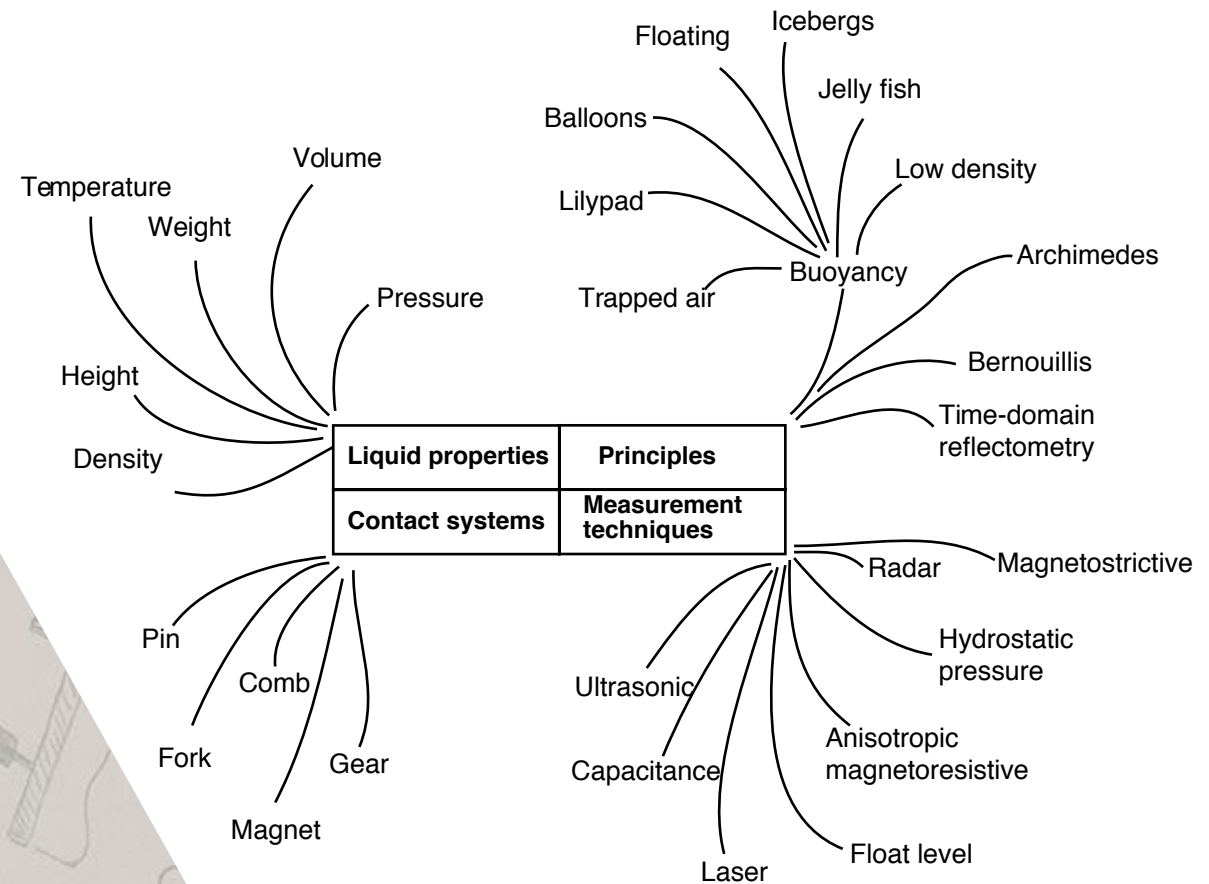
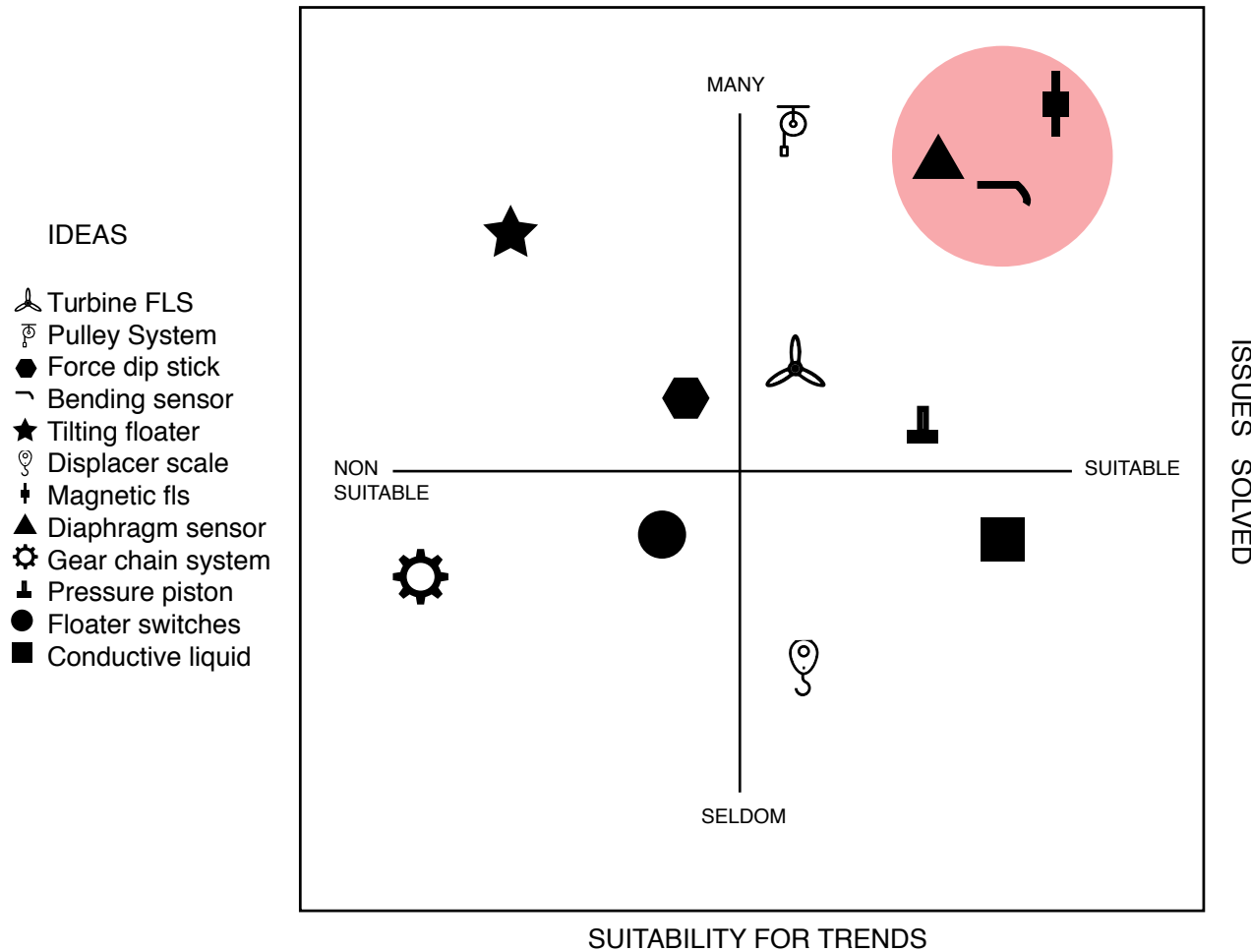


Fig7. Ideation Mind map

# IDEA EVALUATION MATRIX



From the evaluation matrix, three ideas were chosen to be further detailed into concepts. They have been chosen based on their ability and potential to solve issues with the traditional FLS and be suitable for use in the developing automotive industry.

These ideas are the Magnetic floater level sensor, Diaphragm pressure sensor, and Bending force sensor.

Fig8. Evaluation matrix

# CONCEPT 1

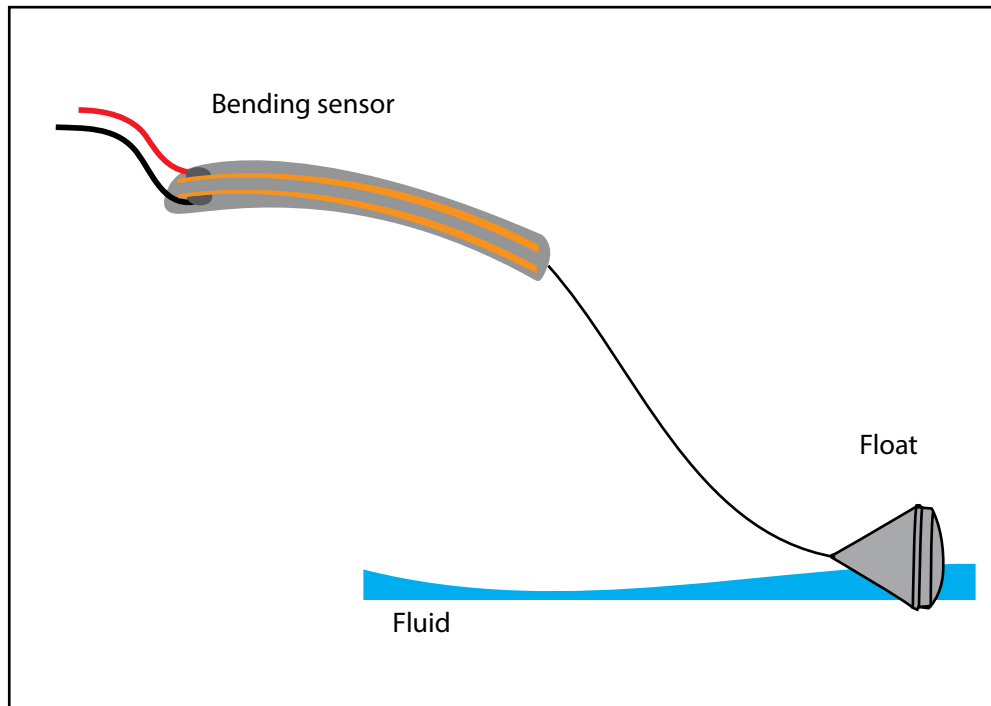


Fig9. Illustration of Concept 1

The first concept was inspired by a balloon. Coupled with a force based resistor, as the 'balloon looking' floater moves up and down with the fluctuation of the fuel level in the tank, the resistor to which it is connected bends. As a result, resistance values change with the degree to which the sensor is bent.

The more fuel is present in the tank, the greater the upthrust force acting on the floater will be, thus the bending moment experienced by the sensor will decrease.

The sensor contains conductive particles separated by gaps whose sizes vary with bending moment. Thus, the greater the bending moment, the greater the gaps between the particles and the greater the resistance.

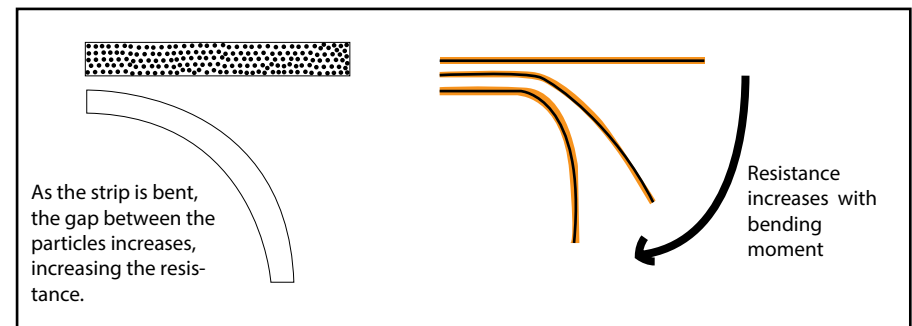
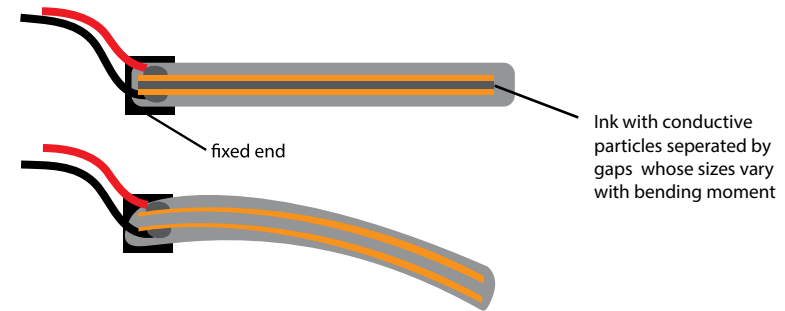


Fig10. Concept 1 Working principle

## Advantages:

- Insulated electrical components.
- Sensitive float: higher range of readings.

## Issues:

- Durability : wear of sensor from constantly varying bending moment.
- In tank assembly :flexible balloon attachment can get tangled around/interfere with other components.

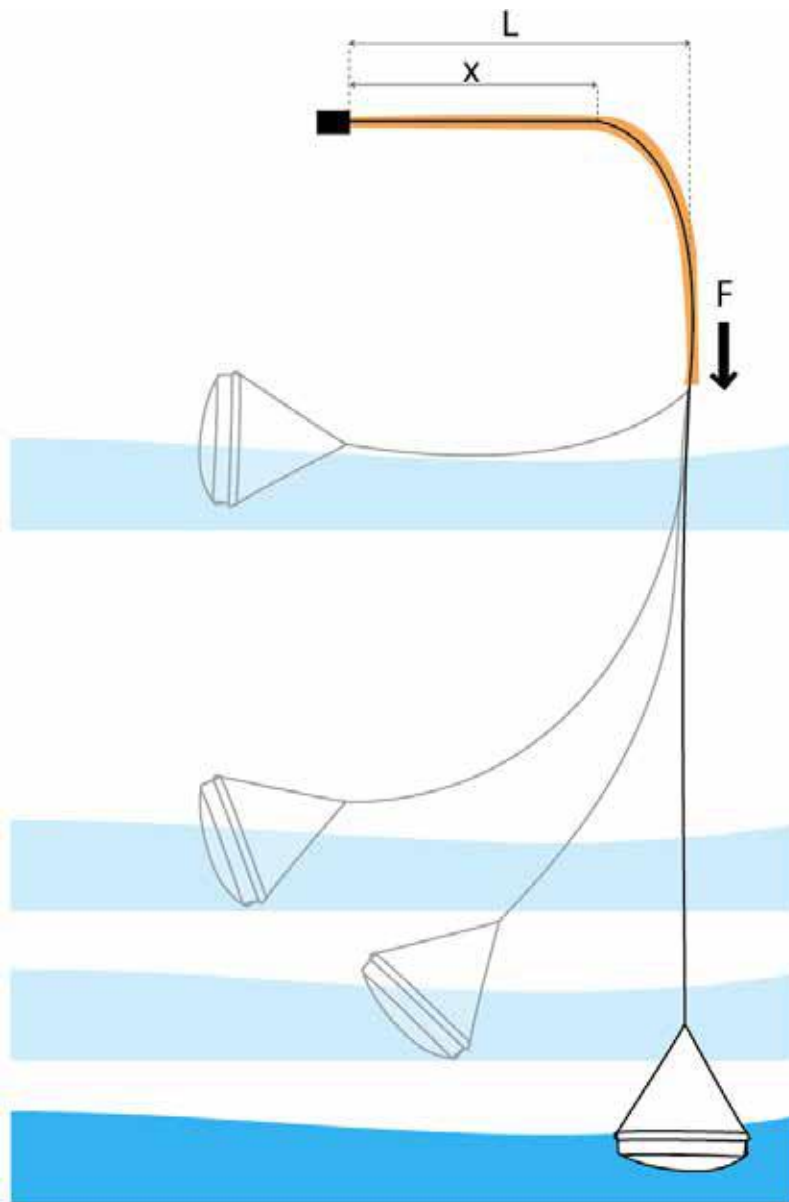


Fig11. Theoretical Principle

## Theory

The downward force acting on the floater stays the same regardless of fuel level. It is the upthrust force that varies.

As the amount of fluid decreases, the upthrust force decreases, causing the strip to bend and the resistance to increase.

$$M = F(L-x)$$

Where:

M = Bending Moment

F = Force causing the strip to bend

L = distance between fixed end and position of Force applied

x = distance between fixed end and start of bending

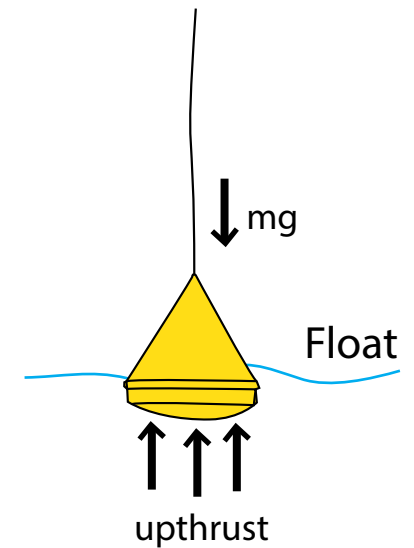


Fig12. Acting forces

# CONCEPT 2

Concept 2 is based on the principle of altering resistance due to the deformation of a material.

This deformation can be induced by the pressure exerted by fuel in a tank. The greater the volume of fuel present in the tank, the higher the pressure will be at the bottom of the tank.

A diaphragm is used to measure this change in pressure. It is placed at the bottom of the tank, attached to the FSM. As the pressure exerted on the diaphragm varies with the amount of fuel present in the tank, the diaphragm material changes shape causing the piezoelectric elements to bend. This results in a change in resistance.

## Advantages:

- Doesn't take up a lot of space.
- Easily inserted into tank.
- Bottom-to-top measurement approach.

## Issues:

- Lost space at bottom to measure low fuel heights.
- Could pose problem for complex tank shapes.
- Challenging to adapt to each tank as sensor has to be recalibrated.

Piezoelectric elements induce a change in resistance based on material deformation.

With the sensor placed at the bottom of the tank, it will be under the influence of the hydraulic pressure that is exerting a downward force on it, causing the diaphragm to deflect. In consequence, the resistance will be varied.

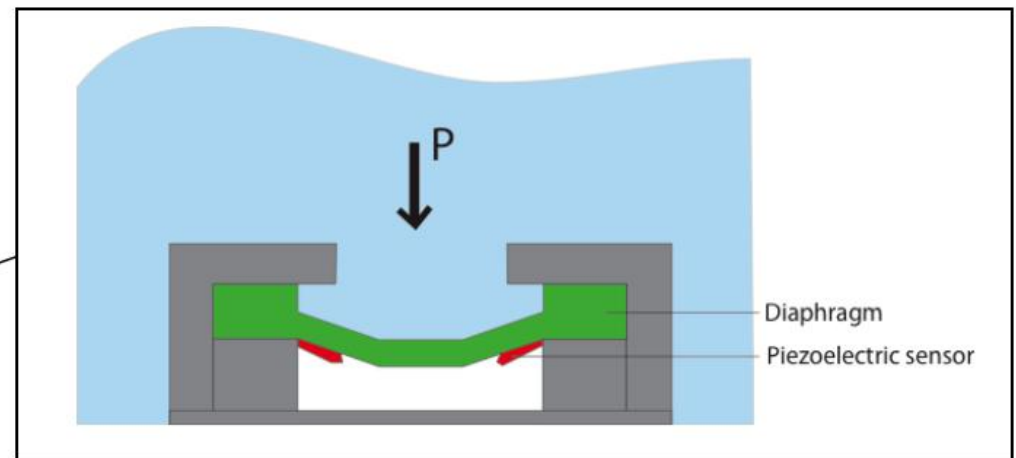
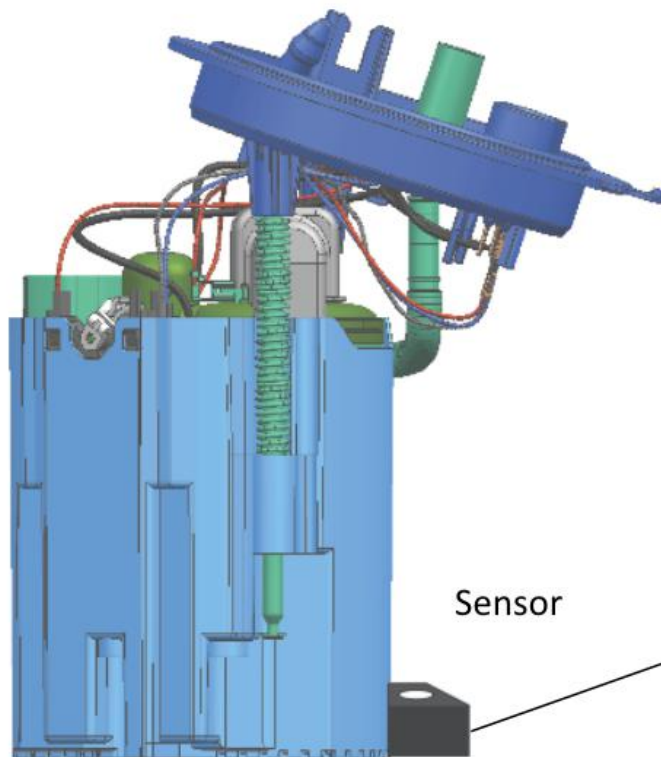


Fig13. Concept 2 model

# CONCEPT 3

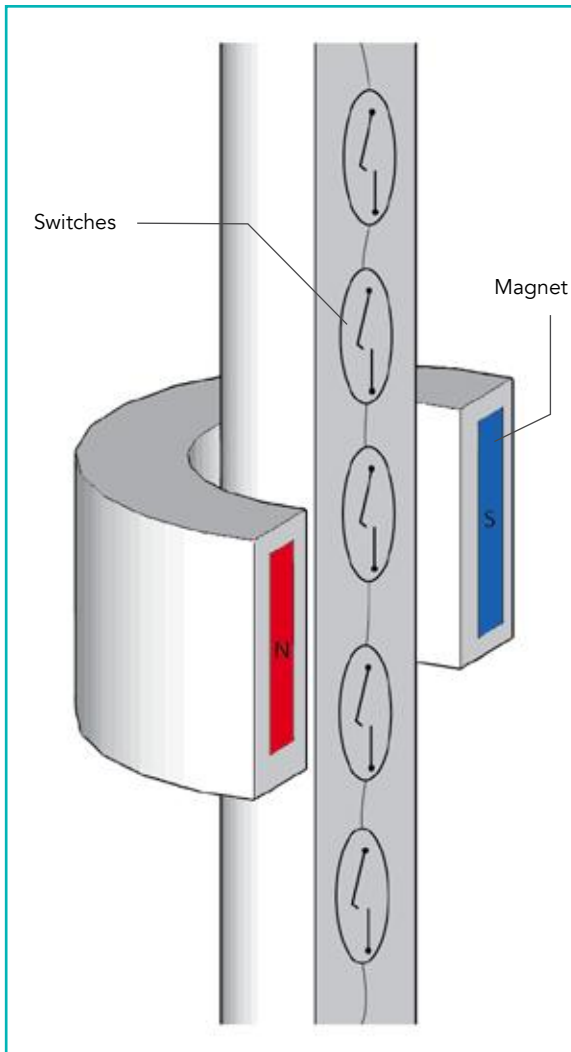


Fig14. Concept 3 Working principle

This concept is inspired by a level sensing technique used in liquid level measurement of static tanks in other fields. Common applications are in on/off systems.

The float moves with fuel level vertically. There is a magnet inside the float which activates a series of switches, allowing the fuel level to be determined. As the magnet moves past each switch, they 'close' allowing the current to pass through the circuit.

The switches are sealed inside the middle tube and are therefore unaffected by the fuel.

The magnet allows for a 'contactless' solution.

## Advantages:

- Insulated : good for emerging markets & non affected by fuel composition.
- Potential to be manufactured using existing plant capabilities.

## Issues :

- Non-continuous level measurement (point level measurement).
- Float rotation: magnet.

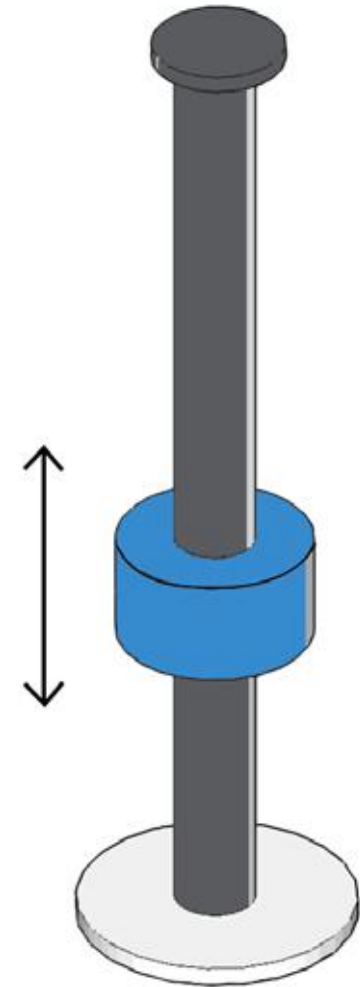


Fig15. Illustration of Concept 3

# EVALUATION OF CONCEPTS

## 1.) Against Requirements

The 3 concepts were evaluated against the requirements set during the research phase. Three criteria were set to perform this evaluation.

✓ = the concept meets the requirement (+1),

X = the concept does not meet the requirement (-1),

and

P = the concept has the potential to be developed to meet the requirement (0).

Based on these, the evaluations were tallied and totaled as shown on the right.

	BENDING			MAGNETIC			DIAPHRAGM		
THE FLS SHOULD:	✓	X	P	✓	X	P	✓	X	P
be of mechanical nature.									
be suitable for use in emerging markets.									
be suitable for fuel tanks with a capacity of 15L to 80+ L									
not be influencable by fuel composition									
be usable in single & saddle tanks, and tanks with complex morphology									
measure fuel levels using a bottom-to-top measurement approach									
be usable in plastic & metal tanks.									
be usable with gasoline, diesel, ethanol, methanol, and a wide range of bio fuels									
maintain the electrical output type/ output signal of the current FLS.									
operate at a voltage ranging from 6V to 16V DC (varies with application)									
resist tank sloshing									
moving parts should respect a clearance of 15 to 25 mm with the tank walls									
be temperature resistant for a temperature range of -40 to +70 °C.									
component materials in contact with the fuel should be corrosion and fuel resistant									
fit into the fuel tank through the FSM tank opening									
be easy to install									
be available as an integrated components of the FSM and a stand-alone product									
<b>TOTAL</b>	6	-3	8	12	-1	4	8	0	9
	3			11			3		

Fig16. Table of Evaluation against Requirements

## 2). Evaluation by team review & co-creation session

The 3 concepts were also presented to a team of design engineers at BOSCH, following which they expressed their opinions of each concept and voiced out which concept they thought was best to further develop.







The magnetic level sensor was chosen by the vast majority of the review team as they believed that it has the potential to meet the requirements set and solve the issues faced with the traditional Fuel Level Sensor. It was also put forward by several of the review members that this concept involved less product disruption in terms of the FSM and tank assembly. It would therefore be more suitable for BOSCH to implement with its existing products and production capabilities.

The evaluation conducted by the team review together with the evaluation matrix against the requirements allowed me to come to the conclusion that the magnetic level sensor concept is the most suitable out of the three concepts to move forward with for the project.

As a result, together with the review team, a list of improvements to be made to this concept was developed. This would enable the concept to later fulfill the requirements, eliminate the issues faced by the traditional FLS and be suitable for the industry changes happening in the automotive world.

These are presented on the left and are to be worked on during the next stage of the project (see *Chapter 3: Concept Development*).

### Improvements to be made:

-  Enable a more fluid/continuous measurement of the fuel level
-  Protect the product against tank sloshing
-  Product resistance to fuel
-  Attachment of the product to the FSM
-  Limiting the rotation of the float
-  Assembly of the product into the tank



## CHAPTER 3

# Concept Development

# FLS TO FSM ASSEMBLY

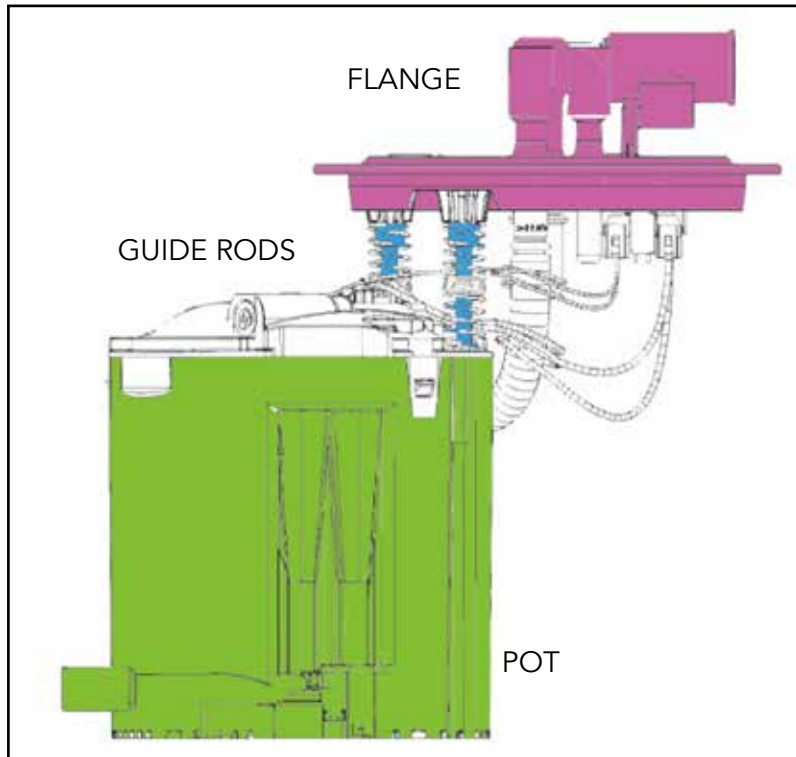


Fig17. Attachment possibilities

The Flange was chosen as the attachment point of the FLS to FSM because the Pot has a standard design and is therefore not adaptable accordingly. Moreover, the guide rods are not static and could therefore make it troublesome to ensure a stable attachment of the FLS.

The Flange is custom designed per customer., allowing for alterations and additions for the FLS to be secured. It is also possible to move the flange components around during the design phase so as to ensure there is enough space for the FLS fitting within the flange base.

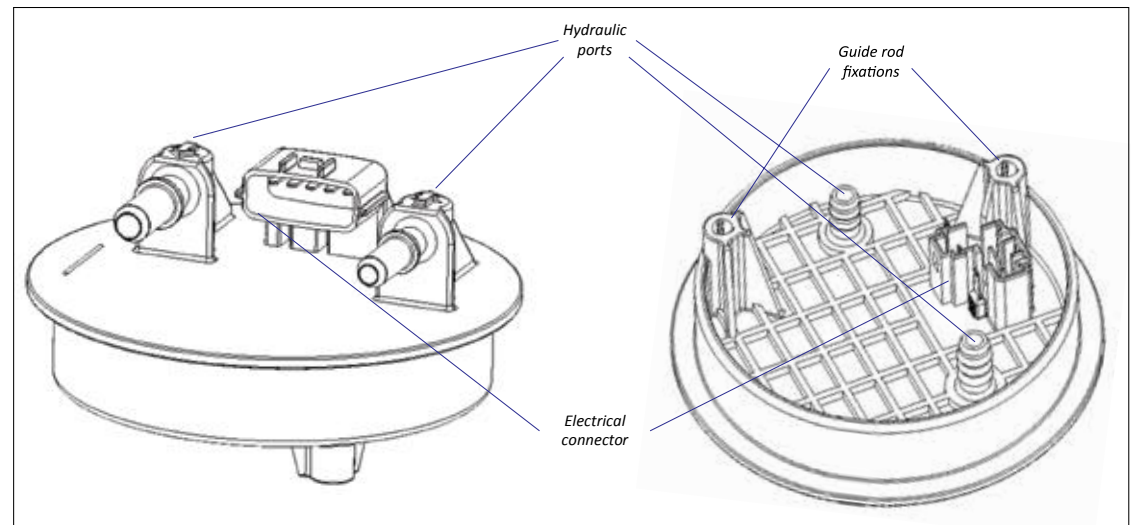


Fig18. Flange components

# FLANGE PLACEMENT

The FLS can be attached to the flange in the space available (see orange highlight).

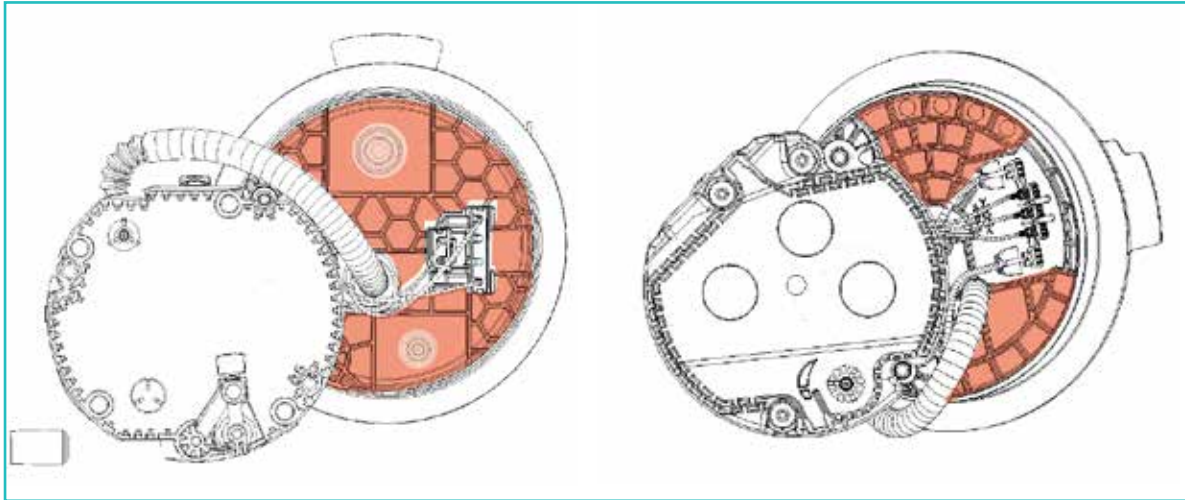


Fig19. Attachment area

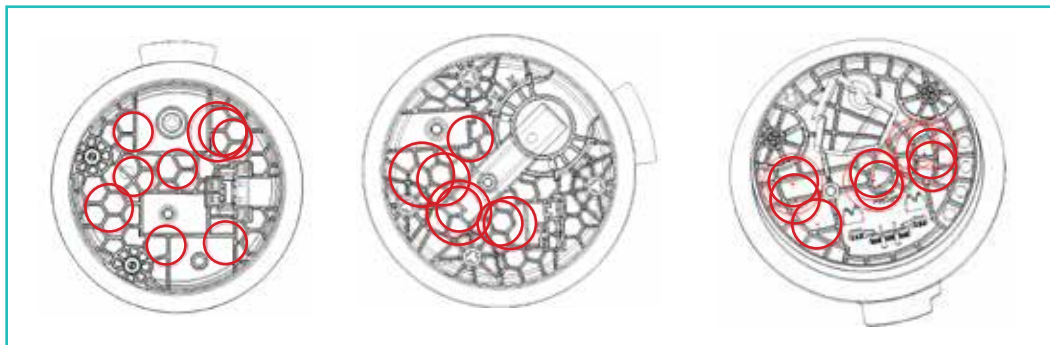


Fig20. Study with Trials of 25,30 and 35mm diameter placements.

## Distance Flange-Pot

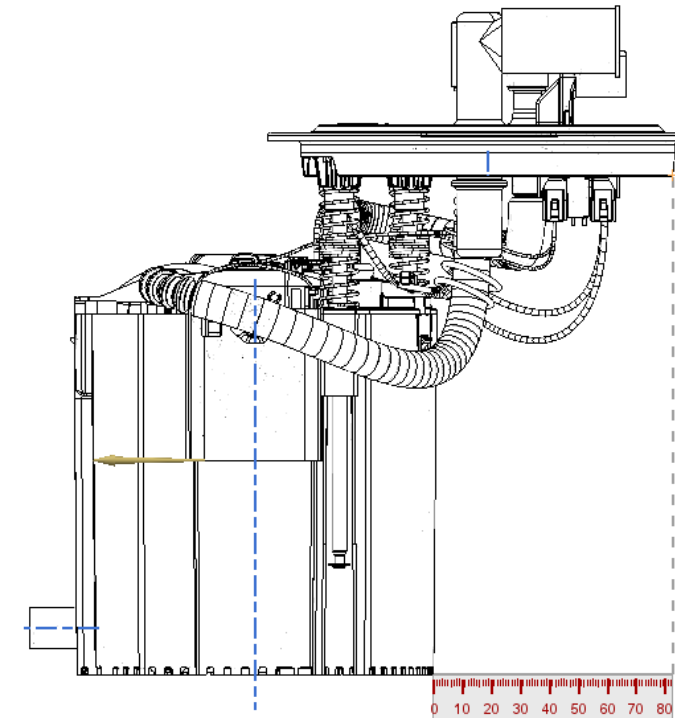


Fig21. Measurement Flange-pot

### Conditions

- The FLS should not touch the pot or be placed within it.
- The FLS should not surpass the FSM size as its needs to fit through the designated FSM tank opening which has a fixed size.

### Findings

Available space between pot and end of flange :

Minimum = 50mm  
Range : 50mm to 80+mm

# WORKING PRINCIPLE

One of the features to be developed with the magnetic floater level sensor idea was improving the fluidness of the measurements. The initial idea worked on a series of switches placed vertically along the inside of the tube, connected to one another. As the magnet went pass a switch it closed the two contacts, letting current pass through the system at a certain point. The level of the fuel was therefore able to be determined.

To enable continuous measurement of fuel levels, the working principle was ameliorated by using a vertically mounted resistor card with a magnetic contact system. This increased the range of measurement, with more frequent readings being taken than with the initial switch system.

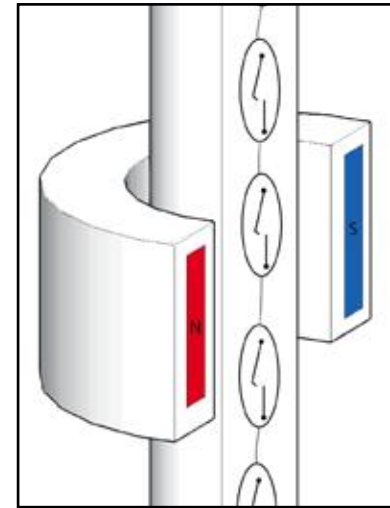


Fig22. Initial system

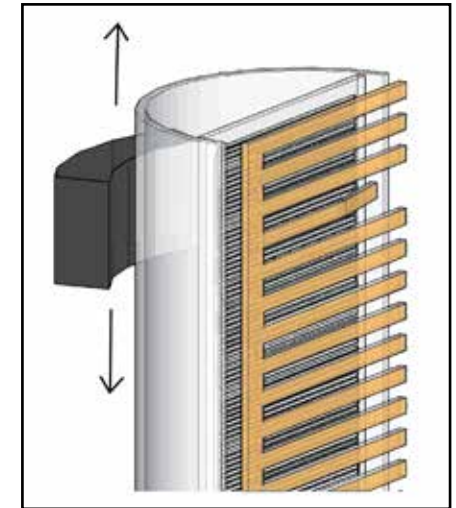


Fig23. Improved system

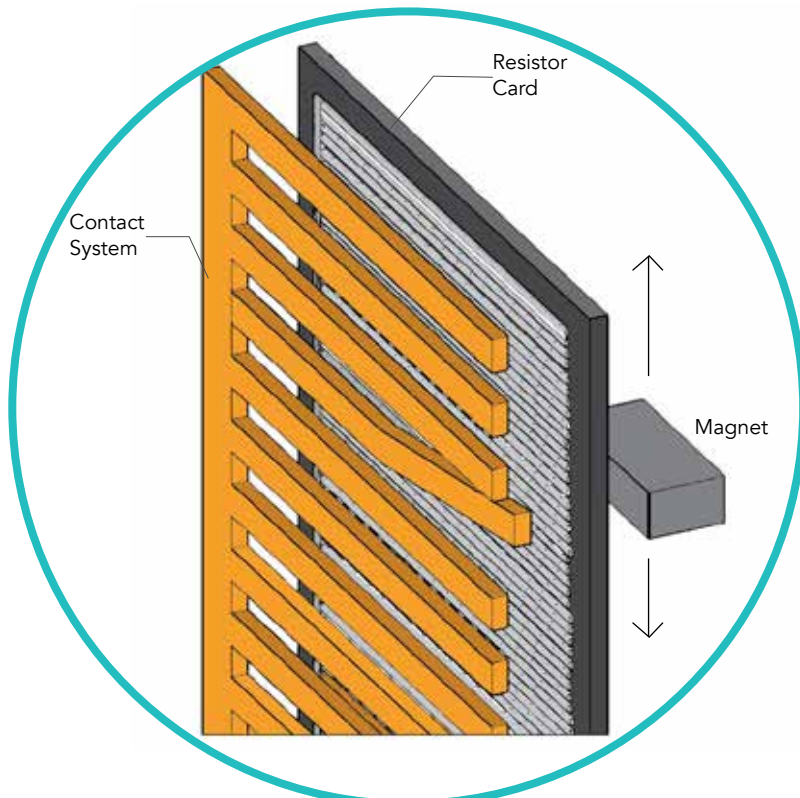


Fig24. Improved system working principle

## Explanation of improved system

Fig24. on the left shows an enlarged and exploded view of the inside working system of the FLS concept being developed.

The system consists of a magnetically sensitive contact system (shaped like a comb with fingers). When the magnet moves vertically along the tube with the floater, it pulls the fingers of the contact system towards it. These 'fingers' touch the tracks on the resistor card, alternating the amount of resistance in the electric system. The 'comb-like' contact system is flexible and easily moves towards the magnet, touching the resistor card. The magnet is placed on the under side of the resistor card.

## Attachment to Flange

### - Annular snap fit

Snap fit chosen as connecting method of FLS to FSM because of cheap cost, easiness of assembly and high strength.

Reinforcement mesh makes the snap fit stronger so as to bear the load of the FLS.



Fig25. CAD model



Fig26. 3D printed model

## Slosh Guard

*"The FLS should resist tank sloshing"*

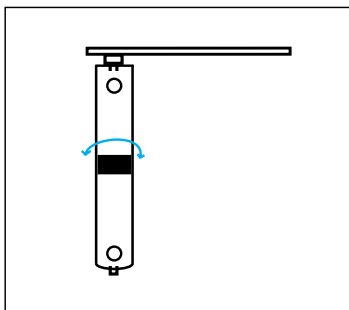


Fig27. Slosh Guard

Slosh Guard:

- 1) Protects FLS from tank sloshing and product turbulence as fuel in the column is stabilised.
- 2) Limits the floater from over tilting when the vehicle is driving on a slope.
- 3) Prevents the magnetic field from affecting other components in the tank.

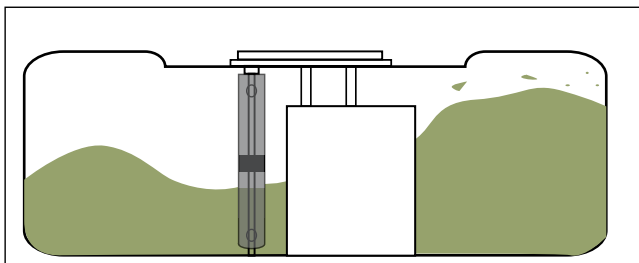


Fig28. Tank sloshing application

## Stand-alone & FSM attachment

*"The FLS should be usable in single & saddle tanks, and tanks with complex morphology"*

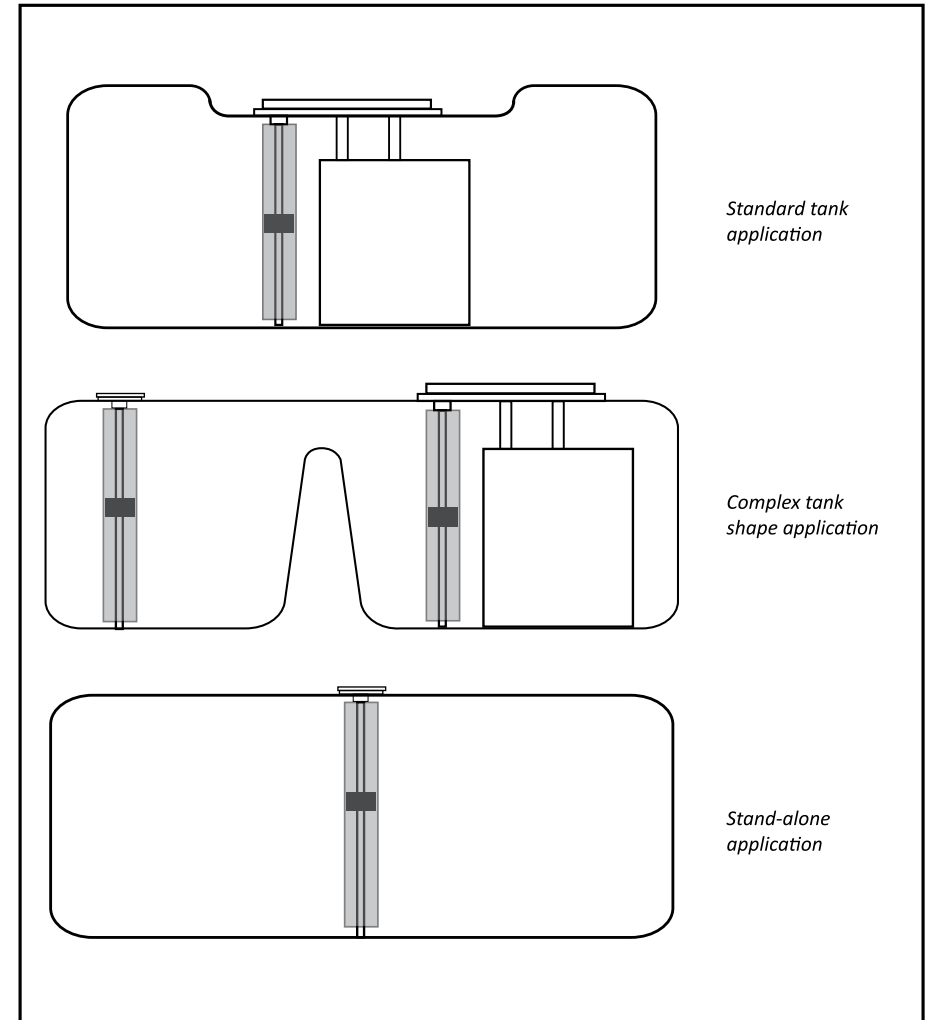


Fig29. FLS Application possibilities

# FLOATER BUOYANCY

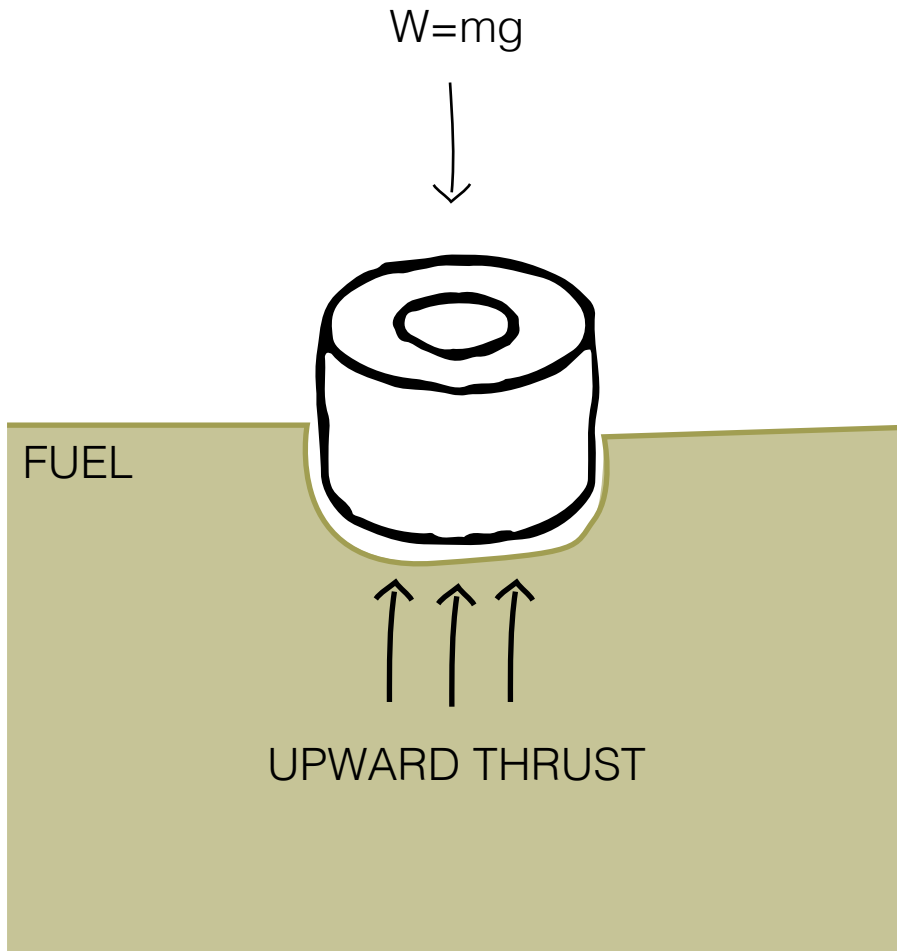


Fig30. Forces acting on floater

## FLOATER INFORMATION

Diameter = 28mm      Material = Low-density Nitrophyl  
Height = 20mm      Density = 0.2g/cm<sup>3</sup>

## THEORY

Fig30. shows two forces acting on the floater. In order for the floater to be buoyant, the upward thrust force needs to be greater than the downward force (weight).

When an object floats it is buoyant and therefore has positive buoyancy.

Positive buoyancy occurs when the density of the floater is less than that of the fluid in which it is immersed/floating.

FLUID = Fuel (Gasoline/Diesel/Biofuel)

FLOAT MATERIAL= Low-density Nitrophyl

## DENSITY

### FUEL

Gasoline: 0.72 g/cm<sup>3</sup>

Diesel: 0.83 g/cm<sup>3</sup>

Biodiesel: 0.88 g/cm<sup>3</sup>

Ethanol & Methanol: 0.79 g/cm<sup>3</sup>

**Range of fuel density = 0.72 g/cm<sup>3</sup> – 0.88 g/cm<sup>3</sup>**

### FLOAT

Nitrophyl = 0.2 g/cm<sup>3</sup>

**Density of float material < Density of fuel**  
**(0.2 g/cm<sup>3</sup> < 0.72 – 0.88 g/cm<sup>3</sup>) = positive buoyancy**

## SUBMERSION OF FLOATER

Calculating the submersion extent of the floater under the surface of the fuel will determine whether it will sufficiently float.

Generally submersion extents of floaters used at Bosch range between 20 and 30%. Thus, if the submersion extent calculated lies within that range it is suitable.

To calculate the floater submersion, we explore Force as a product of density and gravity.

$$F_b = \rho_f V_f g$$

$$F = mg$$

$$mg = \rho_f V_f g$$

$$m = \rho_f V_f$$

Finding  $V_f$

$$V_{\text{displaced fluid}} = V_{\text{floater}}$$

$$V_{\text{floater}} = \pi r^2 h$$

$$= \pi * 1.4^2 * 2$$

$$= 12.30 \text{ cm}^3$$

$$m = \rho_f V_f$$

$$m = 0.2 * 12.3 = 2.46\text{g}$$

$$\rho_f = \frac{V}{m}$$

$$\text{Average fuel density} = 0.8 \text{ g/cm}^3$$

$$2.46 = V * 0.8$$

$$V = \frac{2.46}{0.8} = 3.075 \text{ cm}^3$$

$$\text{Percentage of floater submerged} = \frac{3.075}{12.3} * 100 = 25 \%$$

# MODELLING & TESTING

Various parts of the concept were modeled and tested. Of them, the three main tests performed are presented in this section of the report.

## Test 1: Assembly & installation into the tank

This test involved participants attaching the FLS to the FSM and inserting the assembly into the tank. The test was performed in order to explore whether it was easy and logical for someone to assemble the product and place it into the tank accordingly, and if the product fits easily into the tank without damaging the tank, FSM, or FLS.

## Test 2: Slosh guard

The slosh guard test involved testing three variations of slosh guard tubes. These differed in the type and placement of holes they had (to allow the fuel in).

They were evaluated based on two criteria :

1. If the fuel level in the container equaled the fuel level within the slosh guard tube .
2. The degree to which fuel disturbance occurred within the slosh guard when the container was moved and fuel waves were created.

## Test 3: Product features , assembly & working principle

In this test, the assembly of the product components was performed and their dimensions were checked to see if the components fit correctly in the assembly. Several features of the FLS product were also tested to see if they generally worked in a physical 3d model. These include : the anti-rotation feature of the guide rod, the snap fit to the flange, the stabilization of the cap to the bottom of the tank, the slosh guard, and the impermeability of the guide rod.



# RESULTS

## Test 1: Assembly & installation into the tank

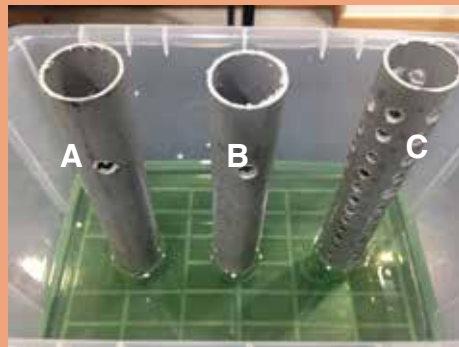
**Outcome :** All respondents managed to insert the FSM with the FLS into the tank with ease and without colliding the FLS with tank walls or inner tank obstacles.

### Improvements to be made :

- a).It should be informed that the FLS should be attached to the FSM before it is inserted into the tank.
- b.) It would be useful to inform the assembler about the angular placement of the FSM/flange in order to avoid the rotation of this during insertion, and eliminate the risk of collision between the FLS and the inner tank obstacles. This could be done through the handbook/manual delivered with the FSM or by adding a mark on the flange or FLS.



## Test 2: Slosh Guard



**Outcome :** Each slosh guard has fuel in holes and a vent hole to let the fumes out. Following the slosh test, slosh guard B was chosen as it was the least affected by the fuel waves movement and allowed the fuel to enter the guard while maintaining the same fuel height as in the tank



## Test 3: Product features , assembly & working principle

### Outcome:

#### 1. Product Assembly & dimensions

The product components easily fit in the FLS assembly in a logical manner.

Improvements to be made: Dimensional tolerances should be added for production to ensure that moving and connecting components fit together correctly.

Proposal:

coaxial tolerance:

- slosh guard to guide rod
- float to guide rod
- cap to guide rod

#### 2. Guide rod anti rotation feature

The float was able to move up and down the rod without rotating. Tank sloshing was also simulated through movement of the tank - the float remained in the right position on the guide rod.

#### 3. Slosh guard

The level inside the slosh guard and the level of fuel in the tank were matching.

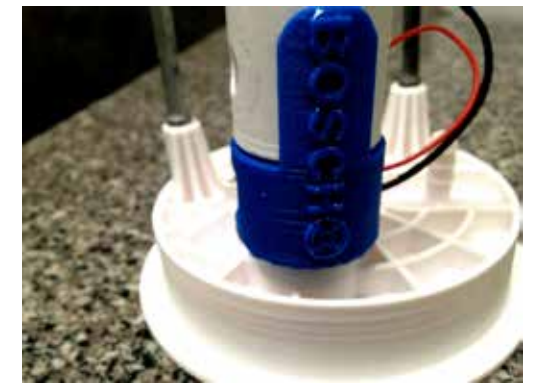
#### 4. Impermeability

After testing of the product in fuel and water for over an hour, the cap was removed to check if it was dry inside the guide rod (where the electric components are to be stored). No signs of humidity or liquid were found.

#### 5. Connection to Flange

The snap fit took a lot of human force and effort to fit in , but once it was in it was impossible to remove, deeming it strong enough to be used as a connection means to the FSM.

In serial production, force machines exist to press the male part of the snap fit into the female part accordingly.





## CHAPTER 4

Proposal

# DESCRIPTION

## Working Principle

The Fuel Level Sensor is a cylindrically shaped product which measures the amount of a fuel in a vehicle's tank using magnetic contact-less technology.

As the level of the fuel fluctuates, a float moves along a guide in which a magnetically activated comb and a resistor card is located. The float contains a magnet. Thus, as it moves along the guide, it pulls the fingers of the comb to apply contact onto the resistor card tracks. Each fuel height value therefore corresponds to a certain amount of resistance and in consequence to a specific electrical output value. As a result, the fuel level can be determined.

As the fuel level decreases, the resistance increases as the contact being made on the tracks is moving away from the grounded part of the resistor.

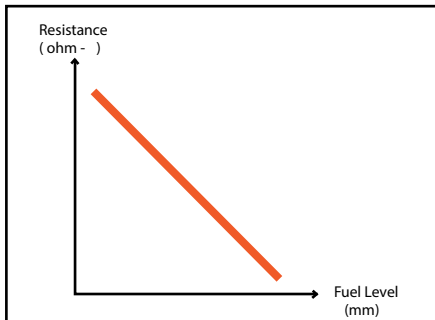


Fig32. Correlation: resistance & fuel level

## Assembly

The fuel level sensor is attached to the FSM through the flange, and functions using a bottom-to-top measurement approach. It is also available as a stand-alone product that is inserted into the tank separate from the FSM.

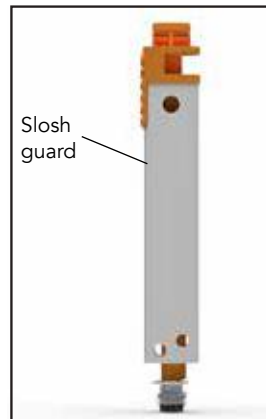


Fig33. FLS side view

## Market

The FLS is suitable for emerging and emerged markets.

Its electrical components are sealed inside the main body, making it unaffected by fuel type, quality or composition, and resistant to corrosion.

## Tanks

The FLS is suitable for single, saddle and complex tanks. Since it is also available in stand-alone, it can be placed in several areas of the tank alongside being attached to the FSM.

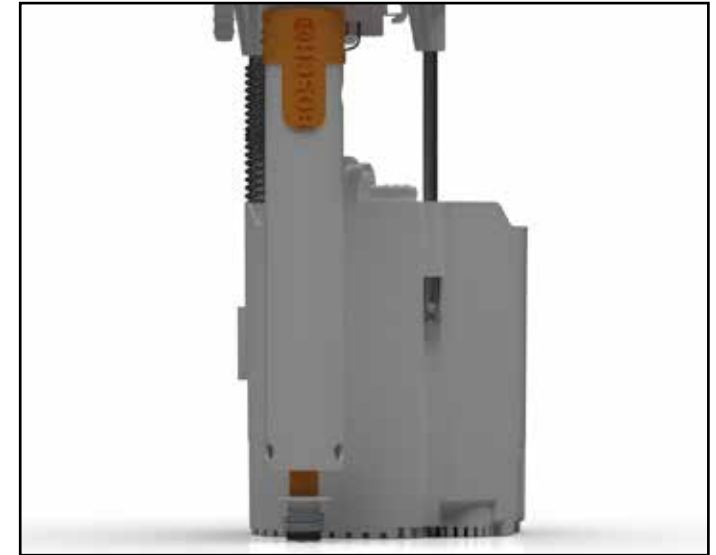


Fig31. Concept proposal

## Customer adaptation

The product is easy to adapt to different customers and tanks as all that is needed is to adjust the length of the slosh guard, guide tube and resistor card. There is no need to redesign the whole product each time. This extension/retraction per customer can be achieved through the use of adjustable molds during production. As a result, new molds do not have to be created for each customer.

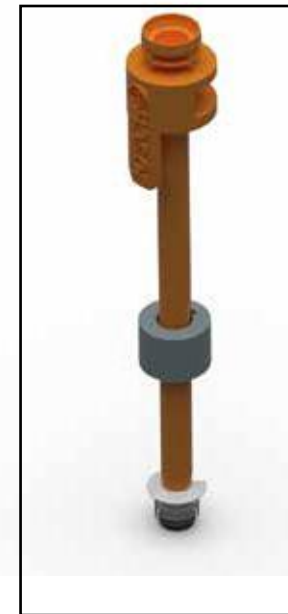


Fig34. FLS without slosh guard

# ISOMETRIC VIEW



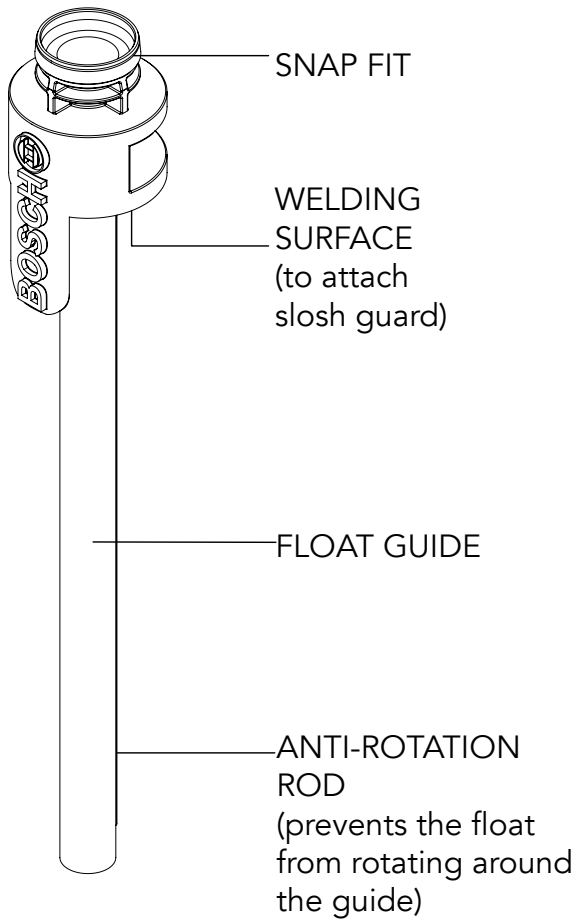
# COMPONENT DESCRIPTION



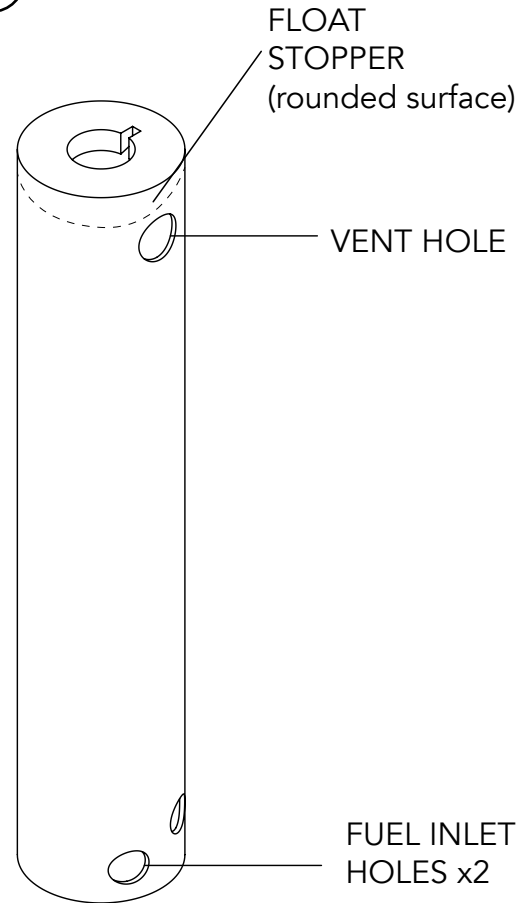
Fig35. Cross-section of FLS

# MAIN FEATURES

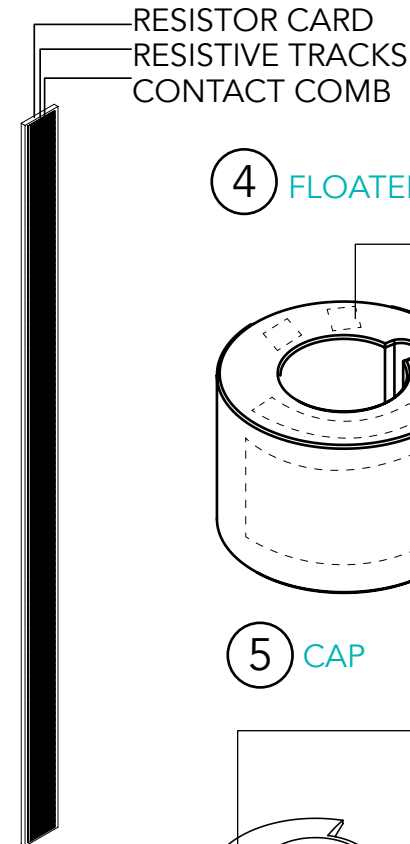
## 1 MAIN BODY



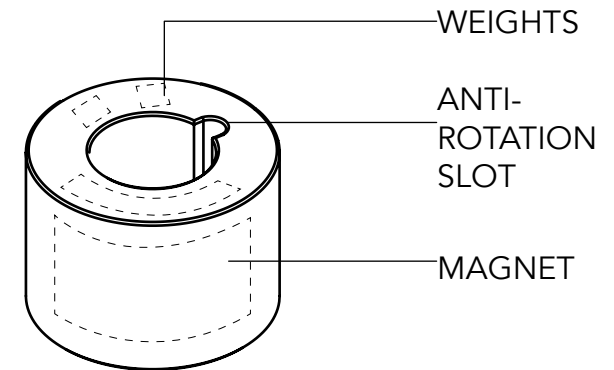
## 2 SLOSH GUARD



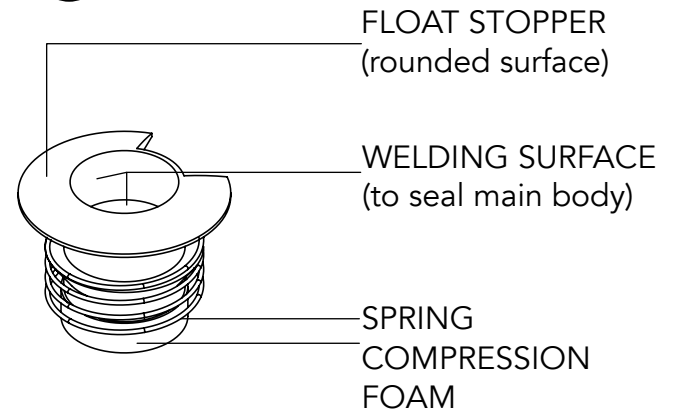
## 3 RESISTOR CARD



## 4 FLOATER



## 5 CAP



# CONTEXT

The Fuel Level Sensor is typically assembled to the FSM and placed in the vehicle fuel tank. The illustrations below show the FLS to FSM assembly and the in-tank position of the FLS accordingly.

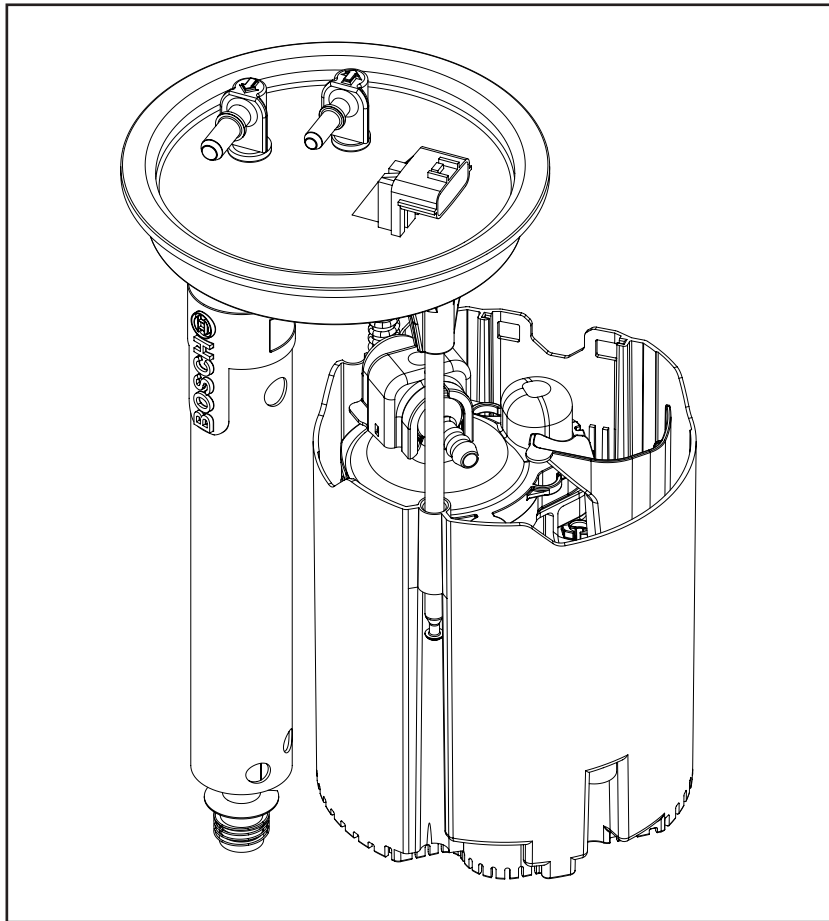


Fig36. FLS to FSM assembly

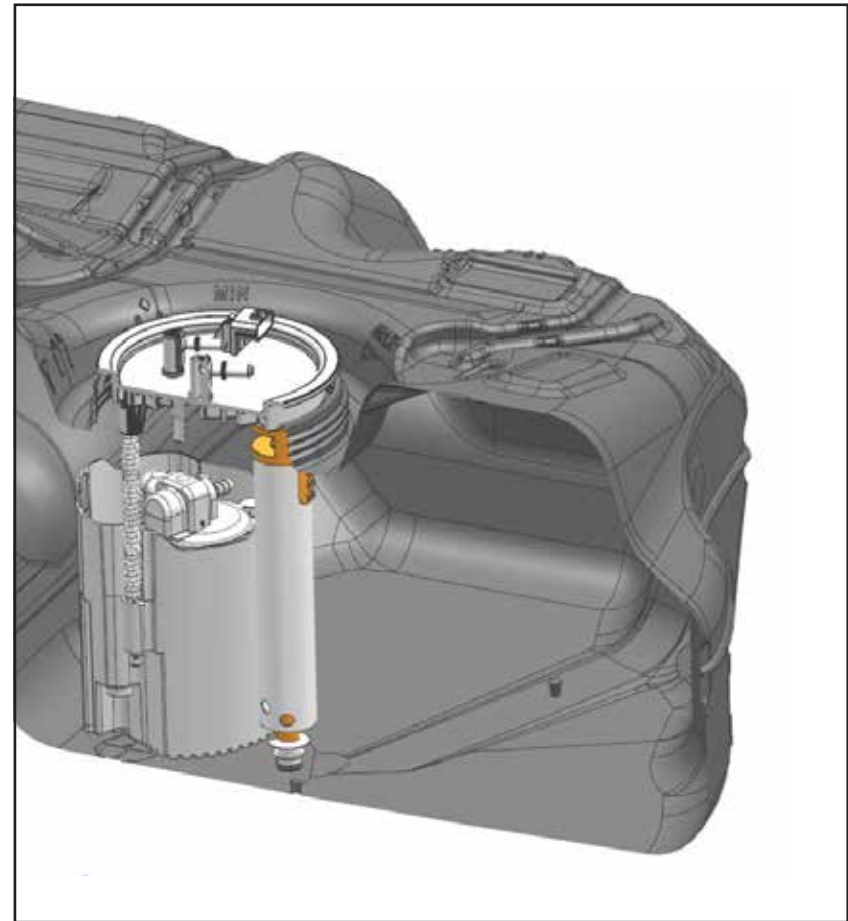


Fig37.FLS in-tank placement

# STAND-ALONE APPLICATION

As mentioned in the requirements, the FLS should be available as an integrated component of the FSM, and a stand-alone component.

In order to be used as a stand-alone component, the FLS is assembled to a flange as shown in the figures below. The flange contains the electrical connector from which the electrical output of the FLS will transfer to the vehicle's ECU.

The Flange, connected to the FLS through snap fit connection, is mounted onto the tank and can be used alone within the tank or as a support of the FSM in complex tank morphology applications.



Fig38. Stand-alone FLS

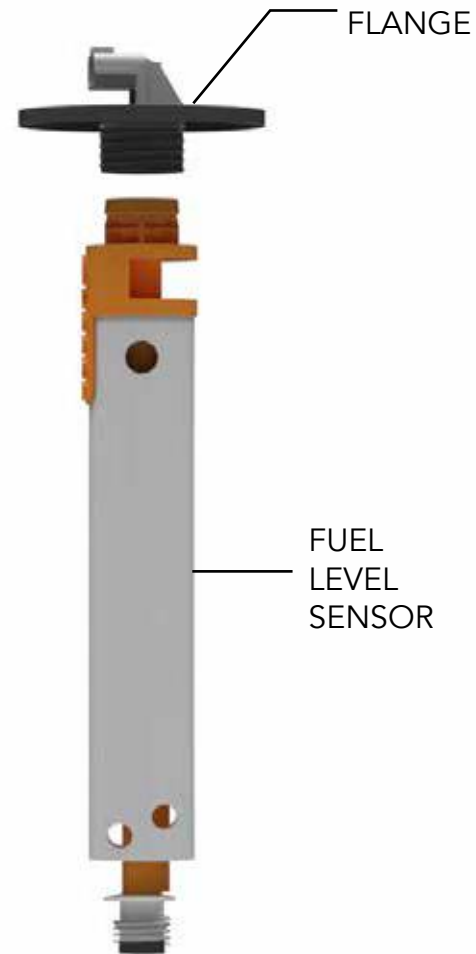


Fig39. Stand-alone FLS components

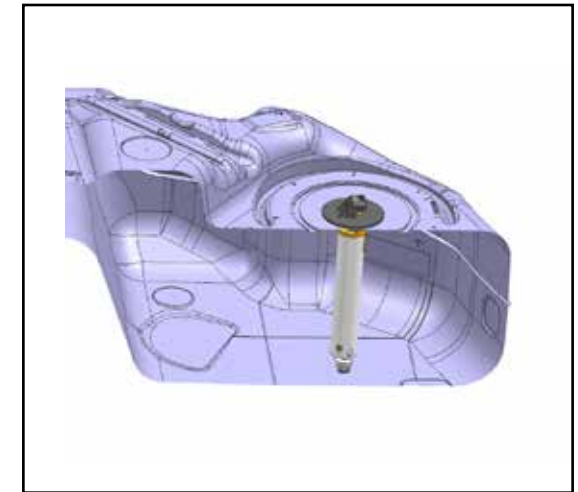


Fig40. Stand-alone FLS in tank

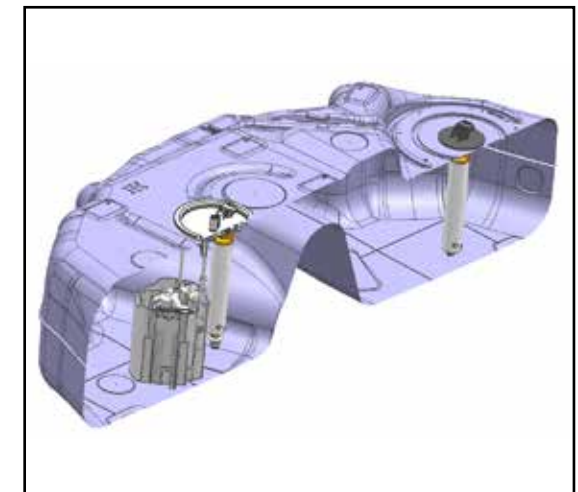
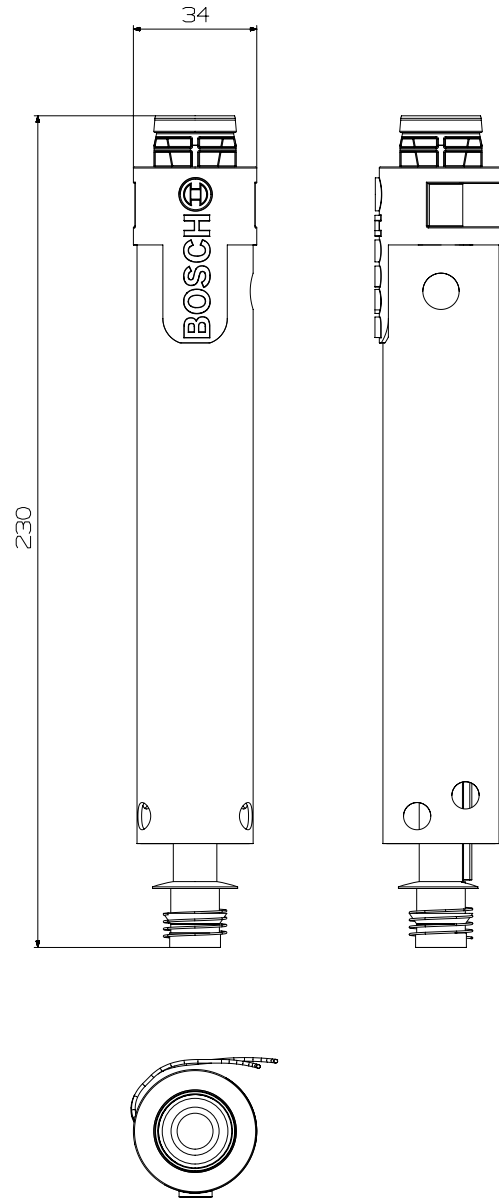


Fig41. Two variations of FLS assembly

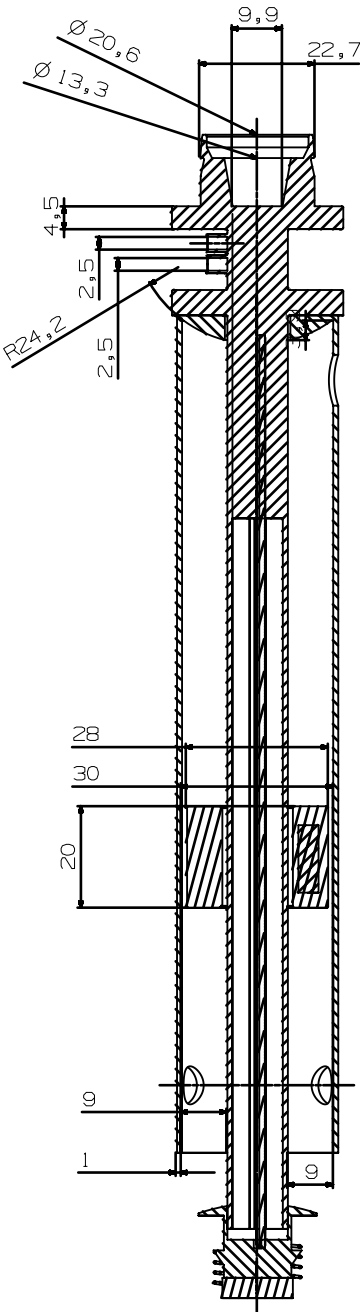
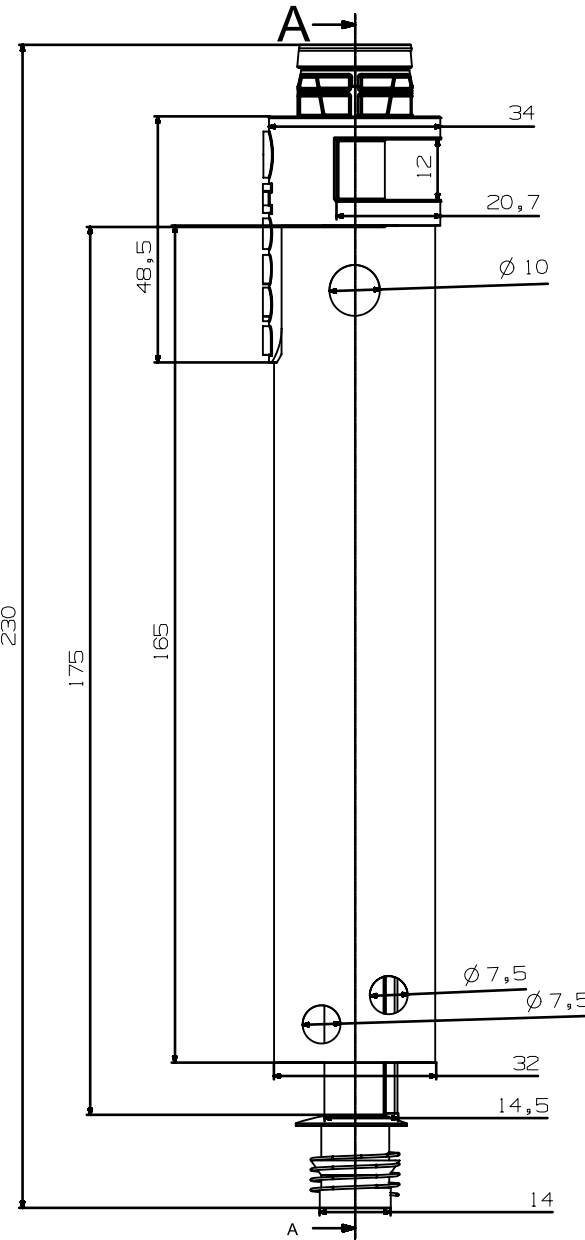
# ORTHOGRAPHIC VIEW



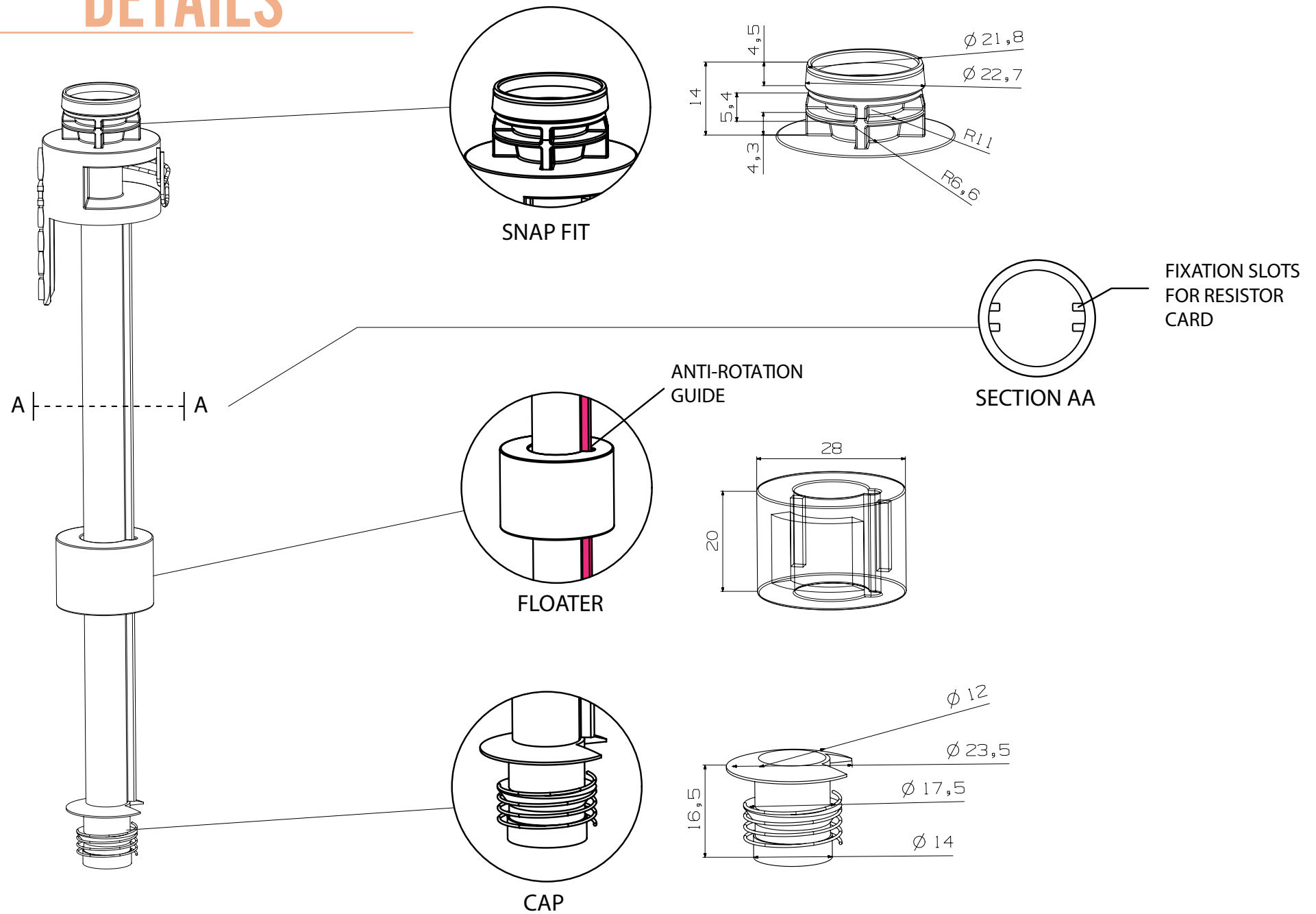
# EXPLODED VIEW



## DIMENSIONS



# DETAILS



# FSM ATTACHMENT

The FLS is attached to the FSM through the Flange. A snap fit connection is used. This snap fit is of angular type, the male part is located on the top part of the FLS, and the female part is found on the bottom of the flange.

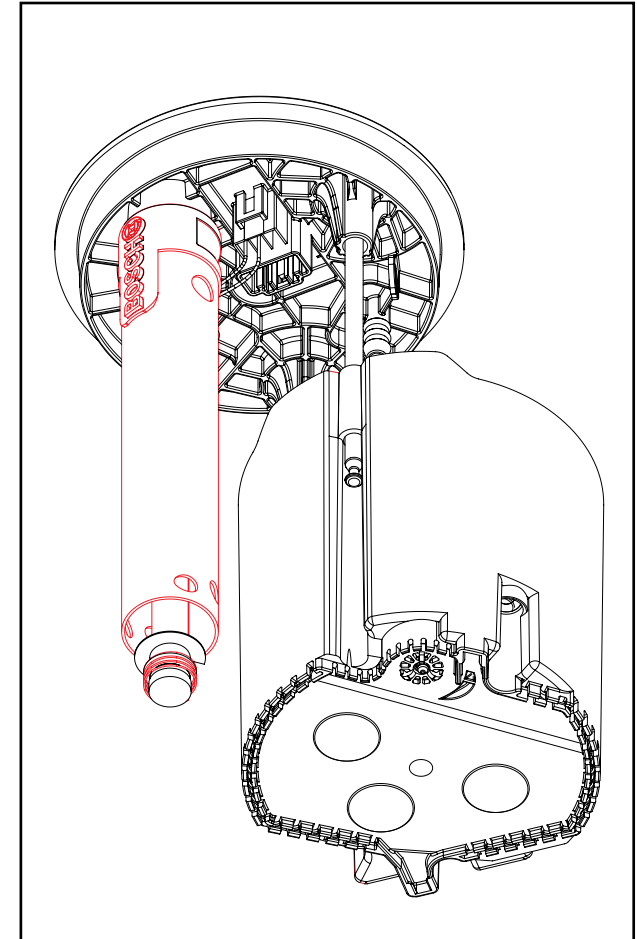
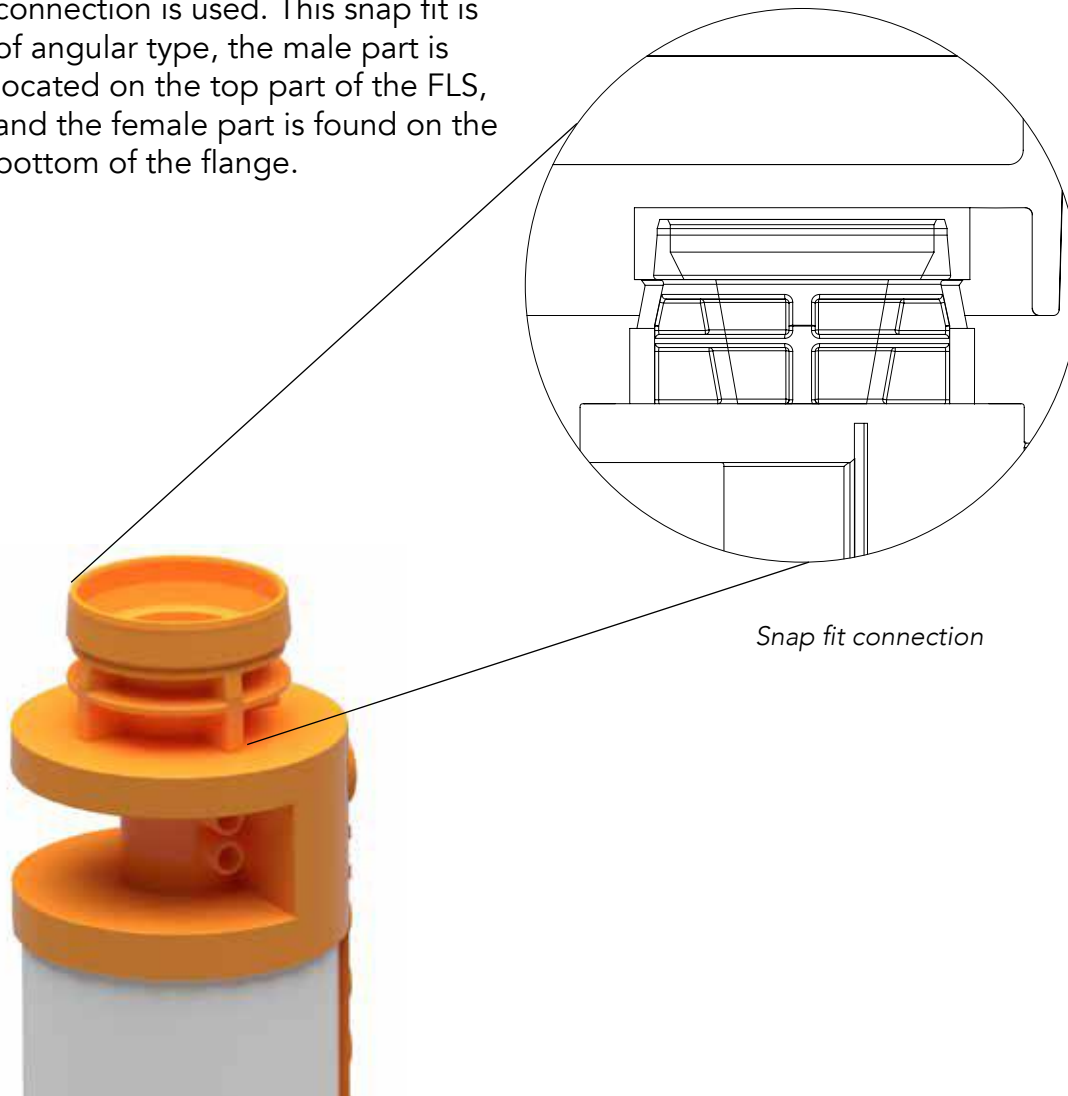


Fig42. 3D model detail view



# ATTRIBUTES



*Sealed electrical components*



*Unaffected by fuel type & composition*



*Easy installation  
Snap on connection*



*Suitable for different sized tanks*



*Contactless system*



*Protected from tank sloshing*



*Can connect to FSM or stand-alone*



*Suitable for diverse tank shapes*



# CHAPTER 5

## Implementation



# PROTOTYPES



FLS Assembly



Fuel Level Sensor



FLS Cross section

# FEASIBILITY

## Materials



Component	Material	Details
<b>Main body</b>	Polyoxymethylene	Unaffected by fuel, currently used for FSM, allows easy joining of different components, temperature & corrosion resistant.
<b>Slosh guard</b>	Polyoxymethylene	
<b>Float</b>	Nitrophyl (0.2-0.3 g/cm <sup>3</sup> )	Enables high buoyancy, easily mouldable into different shapes , operating temperature = -40 - 21 degrees, inserts can be moulded into float during production (magnet).
<b>Magnet</b>	Nickel Iron Alloy	Ferromagnetic element
<b>Resistor card plate</b>	ceramic substrate (Al <sub>2</sub> O <sub>3</sub> )	
<b>Resistive track</b>	Copper	Since the resistive tracks will not be in contact with the fuel, a precious metal such as silver and gold current used, is not needed to be printed on the resistor card. Copper is suitable as an alternative and is significantly cheaper.
<b>Comb</b>	Iron alloy	Ductile, able to be drawn out into thin flexible strips for the comb, attracted by magnets.
<b>Spring</b>	Nickel coated steel	Excellent chemical and corrosion resistance , durable.
<b>Compress</b>	EPDM (ethylene propylene diene monomer) Rubber sponge	Impermeable, compressible and can withstand high pressure/load.

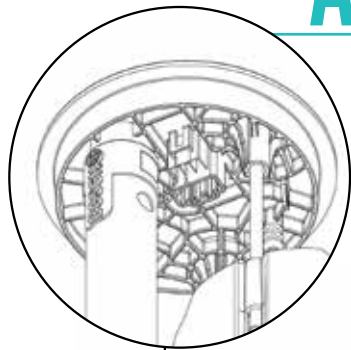
## Manufacturing process

Component	Manufacturing Method	Supplier
<b>Main body</b>	Injection Molding (with mold of extendable length)*	Internal production
<b>Slosh guard</b>	Injection Molding (with mold of extendable length)*	Internal production
<b>Float</b>	Injection Molding	Rogers Corporation
<b>Magnet</b>	Purchased	NA
<b>Resistor card &amp; tracks</b>	The tracks are printed on the ceramic base as a paste, following which it is placed in a furnace for firing. Firing sinters the conductive particles together and sticks the track onto the ceramic card.	Internal production
<b>Comb</b>	Stamping	Internal production
<b>Spring</b>	Auto-coiler (for coil winding), hardening, applying nickel coating	Internal production
<b>Compress</b>	Purchased	NA

\* The main body and slosh guard components are injection molded with special molds. These molds are adjustable according to the height of the tank in which it will be used so that the same mold can be used for different tanks, and that a new mold does not have to be manufactured each time due to high cost reasons. As a result, depending on the height of the tank, part of the mold is extended/retracted and injection molding is then performed.

# ASSEMBLY

	ULTRASONIC WELDING
	GLUING



① Snap FLS to flange



② Fix slosh guard to main body



③ Insert floater through float guide



④ Connect electrical wires to resistor card terminals

⑤ Fix resistor card in cap



⑥ Insert cap containing resistor into float guide and seal it

⑦ Connect electrical wires to connector



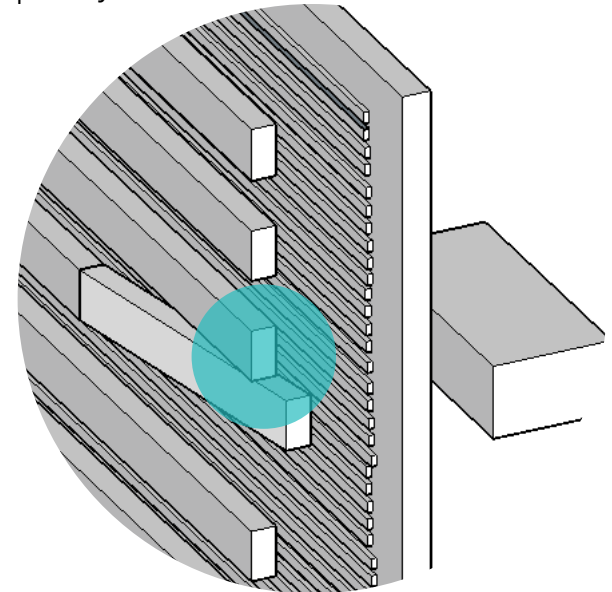
## ISSUES with traditional FLS

### PROPOSED FLS CONCEPT :

- ~~Deposits from fuel on resistor card~~
- ~~Product damage during assembly~~
- ~~Corrosion of metal components~~
- Wear of contact system
- ~~Product turbulence due to sloshing~~
- ~~Difficult to package & transport~~
- ~~Unsuitable for emerging market~~
- ~~Difficult to use in small tanks~~

## Wear of contact system

The proposed FLS concept has less moving components and less wear of the contact system as it does not slide on the resistor card but rather applies pressure at certain points. Thus, the wear of the contact system will be much less than the traditional FLS. However, we cannot prove that the issue has not been completely eliminated.


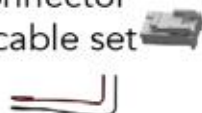
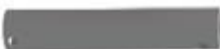







# COST

The Cost has been calculated per product, per batch of 100,000 parts, using existing production line, machinery and labour.

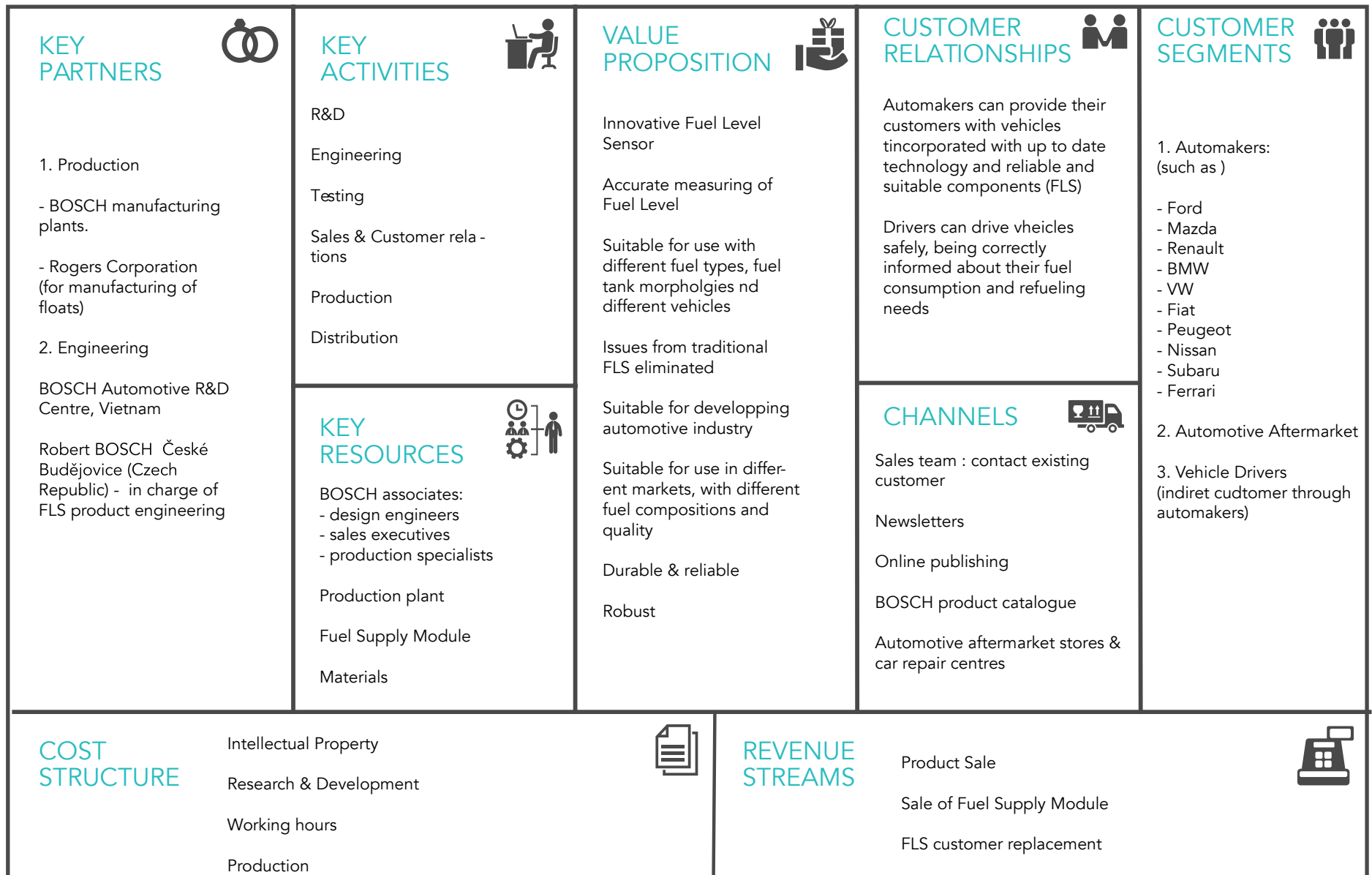
The product costs excludes the one-off mold costs for injection moulding. (3-50,000\$ fixed costs per mold) .

Cost per product for 100,000products:

Component	Cost (€)	Component	Cost (€)
Main body 	0.6	Connector & cable set 	0.2
Slosh Guard 	0.4	Cap Body 	0.2
Floater 	0.2	Spring 	0.2
Resistor card & Contact system 	0.8	Magnet 	0.3
<b>Total cost = 2.9 €</b>			

**Cost Review :** Total cost per product lies within acceptable limits of cost price of traditional fuel level sensor and company requirements.

# BUSINESS MODEL CANVAS



# EVALUATION

The proposed concept has been evaluated using the SWOT model, as shown below. FLS experts at BOSCH also gave their advice on the concept, from which I have been able to set recommendations for the improvement of the product and further developments.

## Strengths

- Sealed components
- Market suitability
- Bottom-to-top measurement
- Easily adaptable for different customers and tanks
- Solves issues with traditional FLS
- Suitable for trends identified in the industry

## Weakness

- Mechanical system: moving parts
- Not entirely wearless contact system
- Measurement of very low levels not possible due to space taken up by stabilisation cap

## Opportunities

- Space to add different sensors such as fuel temperature, ethanol composition, etc..
- Could be adapted for use in other vehicle fluids level measurement such as oil

## Threats

- Fast growing industry
- Technology development
- Customer power train system change



- Le Tuan Thanh  
Fuel Level Sensor Product Design Engineer



The biggest problem faced by traditional Fuel Level Sensors is the robustness of contacts in the fuel, especially in bad fuel markets.

This new concept has solved this problem and can also be applied into small tanks which are popular in emerging markets - where traditional FLS's have difficulty with space for the floater arm.



## Comparison between traditional FLS and proposed concept

### Tank morphology



The stand-alone application of the FLS allows it to be easily inserted into tanks, unlike the traditional FLS which requires a supporting flange and guides to be held in place.

### Contact system



The magnetic system enables less wear of the components as they are not constantly rubbing against one another like with traditional FLS's. Moreover, since the contact system is sealed, issues of deposits on the resistor card are eliminated as well as corrosion of the resistive tracks and contact system, as these are made of metal.

### Customer adaptation



The traditional FLS requires the whole wire arm and resistor card to be redesigned per customer application, according to the tank structure. With this proposed FLS concept, it is only the length of the FLS that needs to be adjusted per application according to the tank depth. With the use of extendable molds during production, it is much quicker and easier to adapt the FLS for different customers and tanks.

### Moving components



With the proposed FLS concept, considerably less moving components are used in the system. The traditional FLS has the wire arm, contact system, and floater that are in movement.

### Tank sloshing



With the slosh guard, the FLS is protected from product turbulence due to tank sloshing. This also allows for a more stable measurement of the fuel, unlike the traditional FLS which is operating freely in the tank.

### Installation



The traditional FLS had the problem of the wire arm getting deformed during installation into the fuel tank. With the proposed FLS concept, this issue is eliminated, the FLS fits within the FSM geometrical boundaries and is simply snapped on underneath the flange then inserted with the FSM.

### Logistics



With the angular wire arm, the traditional FLS was difficult to package and transport, resulting in a great waste of unused space. The geometric modular shape of the proposed FLS concept will allow for easier packaging and transportation.

### Market suitability



The FLS is suitable for use in emerging markets as its electric system is sealed and not in contact with the fuel. This prevents the 'bad' or 'dirty' fuel found in emerging markets to tamper with the electric system or create deposits of dirt or sulphur accordingly. Moreover, the use of a slosh guard protects the inner components from getting damaged when the vehicle is riding on uneven roads.

# REQUIREMENTS CHECK

## DETAILS

### GENERAL

Mechanical nature

Suitable for use in emerging markets.

Suitable for fuel tanks with a capacity of 15L to 80+ L

Not influencable by fuel composition.

Usable in single & saddle tanks, and tanks with complex morphology.

Uses a bottom-to-top measurement approach

Usable in plastic & metal tanks.

Usable with different fuels

### ASSEMBLY

Fits into the fuel tank through the FSM tank opening

Easy to install.

Available as FSM component and a stand-alone product.

Floater moving system

Components protected

Length of FLS extendable in production

Sealed components

Vertical Measurement

Floater rises with fuel level

NA

Electrical components sealed

Snap fits onto flange and fits in unused space

Snap fits onto flange

FSM component and available as stand-alone with flange

### MATERIAL

Temperature resistant

Component materials corrosion resistant & unaffected by the fuel

### ELECTRICAL

Maintain the electrical output type/ output signal of the current FLS

Operate at a voltage ranging from 6V to 16V DC (varies with application).

### MECHANICAL

Resists tank sloshing

Moving parts respect clearance of 15 to 25 mm with tank walls

### SECONDARY REQUIREMENTS

The components of the FLS should come as little as possible in contact with the fuel.

The FLS should have as less moving parts as possible.

The FLS should opt for a wearless contact on the resistor card.

## DETAILS

Materials used have been used for rest of FSM which operates in the same conditions as FLS

Varying resistance with fuel level height

Was not able to test this

Slosh guard component

Only float moves along guide rod

Critical components are sealed

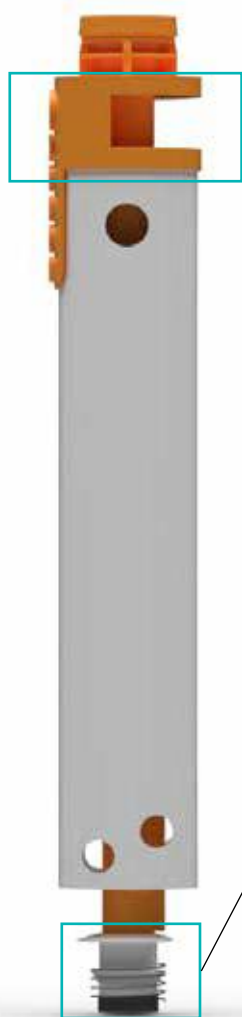
Number of moving parts reduced

Contact system is not completely wearless



# RECOMMENDATIONS

*for further development*



## 1. Reduce lost measurement space

Measurement of the fuel level in the entirety of the tank is not possible as some space is lost due to components. Indeed, the bottom stabilisation cap prevents the last few mm of fuel level to be determined. This is also the case with the top of the tank.

## 2. Adapt the FLS for use in concentric FSMs

This FLS has been designed for use with eccentric type Fuel Supply Modules. If the concept proves to be accepted and produced, adapting it for use in concentric flanges too would enable the use of the FLS throughout the whole FSM range at Bosch.

## 3. Have a wearless contact system

One of the requirements that was not entirely met was using a 'wearless' contact system in the product. Having a completely wearless contact system would improve the product and make it even more durable.



Appendix

# FINALISED ASSIGNMENT DESCRIPTION

## ADAPTING THE FUEL LEVEL SENSOR FOR THE FUTURE

*[Graduation Project focused on proposing an adapted/new Fuel Level Sensor concept to meet the future requirements of the rapidly developing automobile industry].*

## INTRODUCTION

### COMPANY BACKGROUND

Robert Bosch is a multinational company specialized in engineering and electronics. With its expertise in many fields, including power tools, home appliances, automotive components, security systems and packaging technology, Bosch is composed of over 440 subsidiaries worldwide.

One of these subsidiaries, is the Robert Bosch Automotive R&D center, in Vietnam. It is at this location that the assignment will be conducted, more specifically, as part of the Fuel Supply team.

### THE FUEL SUPPLY MODULE

One of the products developed at the R&D center in Vietnam, is the Fuel Supply Module.

*The Fuel Supply Module (FSM) is an in-tank unit, which has the function of pumping the right amount of fuel to the engine at an appropriate pressure and constant rate. It is a crucial part of a vehicle, as it ensures the smooth running of the engine.*

The main components that make up the Fuel Supply Module (FSM) are as follows:

- The electric Pump
- The fuel Filter
- The fuel pressure regulator valve
- The fuel level sensor

The latter, is the focus of this assignment.



## PRODUCT

### The Fuel Level Sensor

The *fuel level sensor (FLS)* is an essential part of a vehicle. Its crucial function, is to measure the amount of fuel present in the vehicles tank, allowing the driver to know when it is needed to fill up their tank.

Different Methods exist to measure the amount of fuel present in a tank. Existing FLS technologies used in vehicles, consist mainly of traditional float-type potentiometric level sensors.<sup>1</sup> Such Fuel Level Sensors operate with a float that moves up/down as the level of the fuel in the tank changes. This float is attached to a level arm, which is connected on its other end to a wiper, applying contact on a resistor card.

As the level of the fuel changes, the level arm moves, causing the wiper to move a contact along the resistor card, and varying the resistance accordingly. Each level of fuel corresponds to an electric value, and this electric value is the output signal that is transmitted to the fuel gauge (on the dashboard), so that the car driver is able to know how much fuel is present in his/her car tank.

Although many different methods and products exist to measure the amount of fuel present in a tank, the FLS with floaters are the most common on the market. This is mainly because they are mechanical sensors, and are therefore low cost compared to other types of sensors.



<sup>1</sup> Terzio, E., Terzio, J., Nagarsjah, R., Alamgir, M. (2012) *A Neural Network Approach to Fluid Quantity Measurement in Dynamic Environments*. London: Springer-Verlag.

## ASSIGNMENT

The Assignment incorporates the two spheres of Futuring and Product design. Together, they will be the catalyst for the redesign and development of the Fuel Level Sensor, to meet the future requirements of the rapidly developing automobile industry.

### PROBLEM STATEMENT

The current FLS concept developed and produced by Bosch for various auto manufacturers, will pose a challenge to meet the future needs of the automotive industry.

Current and Future Trends in the market, such as the increasing use of hybrid cars, the rise in competition, and the expansion towards emerging markets, will give rise to a change in requirements which the FLS will have to be able to fulfill.

The current FLS produced by Bosch, has been used since the late 1990s. The past and present requirements for the FLS will not resemble those of the future. Thus, there is a need to redesign and develop the current FLS, if Bosch wants to remain a leader in the market.

### PROJECT GOAL

*Develop a concept for the Fuel Level Sensor to meet the needs of the rapidly changing automobile industry.*

### DESIGN CHALLENGE

Redesign the Fuel Level Sensor so that it will meet the future requirements shaped by the rapidly changing automobile industry, whilst being able to accurately and reliably measure the amount of fuel in a vehicles' tank.

**Requirements** are to be defined by the results, interpretation and analysis of the research conducted regarding the future trends of the market. This will be conducted in the 'research part' of the assignment.

In the meantime, the following examples of requirements can be used for reference.

1. Trend: Increasingly complex tank shapes and geometries.<sup>2</sup>

Requirement: The FLS should be able to measure fuel levels in tanks with obstructions and geometries that cause unequal fuel dispersion.

<sup>2</sup> Infineon, (2009) *Liquid Level Sensing: Measuring Liquid Levels Using Hall Effect Sensors*. Munich: Infineon Technologies AG. Retrieved from: [www.infineon.com/dgdl/0appnote\\_Liquid\\_Level\\_Sensing\\_Rev\\_1\\_0.pdf?fileId=693a30c437311ff5a0123a386f8a2c63d](http://www.infineon.com/dgdl/0appnote_Liquid_Level_Sensing_Rev_1_0.pdf?fileId=693a30c437311ff5a0123a386f8a2c63d)

2. Trend: Increase in demand from emerging markets<sup>3</sup> (such as Brazil, India, etc...).

Requirement: The FLS should work effectively in 'dirty' and 'aggressive' fuels, and the associated challenging environment that characterizes emerging markets.

### BOUNDARIES

In order to bring focus to the assignment, boundaries have been set regarding what elements of the current FLS should be kept. This is needed, as, in the time frame during which the assignment will be worked on, it is not possible to redesign the whole FLS product.

These boundaries are:

#### 1. Output Signal

The signal collected from the resistor card and transferred to the fuel gauge is to be kept the same.

#### 2. Working Principle: Mechanical Sensor

The sensor should remain a mechanical one as it is cheaper to produce. However, the mechanism used to measure the amount of the fuel in the tank (how the product measures the fuel) is to be different from the current product.

### EFFORT

Estimated. 20 hours/week

Support from BOSCH associates: Estimated. 2hours/week

### SUPPORTING TOOLS

Software: Unigraphics NX, ANSYS Mechanical.

Literature Databases: IEEE Xplore Digital Library, ScienceDirect, SAE Mobilus, Google Scholar.

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Requirement: The FLS should work effectively in 'dirty' and 'aggressive' fuels, and the associated challenging environment that characterizes emerging markets.

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<sup>3</sup> Mohr, D., Muller, N., Alexander, K., Gao, P., Kass, H K., Kreiger, A., Hensley, K., (2013) The road to 2020 and beyond: what's driving the global automotive industry? McKinsey & Company, Advanced Industries.

## ACTIVITIES

The journey from Insight to Impact (see 4 /s), will follow the Design Process, as illustrated on the right.

The Design Process to be undertaken combines the standard iterative design process and the converging and diverging characteristics of each stage<sup>4</sup>.

The last stage, 'Proposal', is custom to the assignment and involves the 'end delivery'. In this case, the end delivery is not a ready to manufacture product, but rather a Proposal of the redesigned Fuel Level Sensor / change of FLS concept.

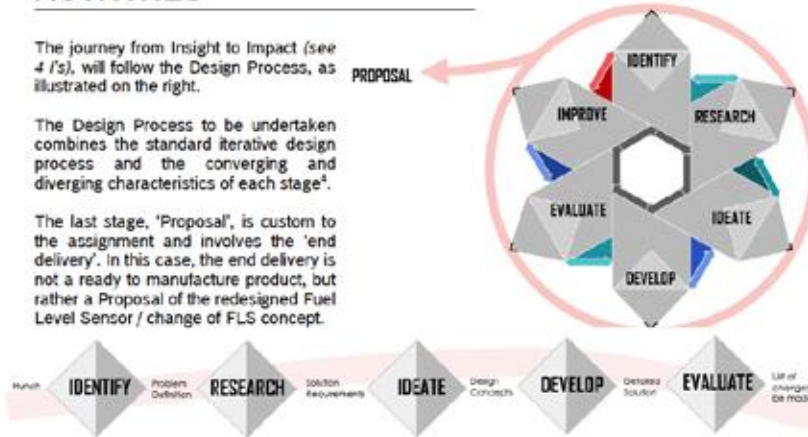


Fig 2: Converging & Diverging outcomes of each stage

### STAGE DESCRIPTIONS

**STAGE 1: IDENTIFY** - the need/problem to be worked on.

**STAGE 2: RESEARCH** - the problem, context, stakeholders, market, competition, and influential factors.

The Research will be focused on looking further into the need to redesign and develop the FLS and what the requirements of the new FLS will be.

During the research, the following will be identified and analyzed:

#### GENERAL

<sup>4</sup>See the 'Double Diamond Process Model' explained in: A study of the design process by the Design Council. Available at: [www.designcouncil.org.uk/files/asset/document/ThreeLessons\\_Design\\_Council%20%282%29.pdf](http://www.designcouncil.org.uk/files/asset/document/ThreeLessons_Design_Council%20%282%29.pdf)

<sup>5</sup> Modified Design Process from 'Discover Design Handbook'. Available at: <https://www.discoverdesign.org/handbook>

- Explanation of FLS & application
- Keywords

### LITERATURE REVIEW

- Fuel measuring principles
- Trends in Automobile Industry

### FLS of BOSCH

- Description of Product
- Working principle
- Theory behind FLS (electronic scheme, height to angle relationship)
- Components & Function descriptions
- Context:
  - FLS as part of FSM, FLS in the tank
  - Overview of FSM & FLS assembly to FSM
  - Tank specifications & measurements, tank types
  - Fuel behavior & conditions in the tank

### MARKET DESCRIPTION & REQUIREMENTS

- Emerging markets
- 1st world markets
- Fuel types & effect on FLS
- Competition: Competitors products & comparison with BOSCH product

### CUSTOMER PROFILE & REQUIREMENTS

- Customer needs & requirements
- Customer type
- Current process of taking customer request and adapting FLS accordingly

### PROBLEM DESCRIPTION / ASSIGNMENT

- Why is there the need to develop a new FLS?
- Past - present - future of Bosch's FLS
- Problems/faults of current FLS used at BOSCH
- Problem Description & Design Challenge

### FUTURING

- Trends in Automobile & Sensor Industry
- Future Scenarios
- Effect of these on FLS
- How will the FLS have to adapt?

### OUTPUT

Research Report (findings, analyses & conclusions)

Future scenario showing how the automobile industry will look like in the future, and therefore the changes that the FLS will need to adapt to.

List of requirements the 'new' FLS should fulfill.

Updated Design Brief & Challenge

#### **STAGE 3: IDEATION** - *Idea Generation & Selection*

- Translating Product Requirement into Product functions.
- Ideation of solutions to address the problem through creative processes & methods.
- 3d modelling & prototyping throughout this stage of the Design Process.
- Solution selection

#### **STAGE 4: DEVELOP** - *selected design concept into a detailed solution.*

- Further development, detailing and finalization of the solution chosen.
- Testing/evaluating through simulation, prototypes, animation.

#### **STAGE 5: EVALUATE** - *the solution against initial requirements company wishes.*

- Comparison to initial product (how significant/good/bad is the change) & analysis of feasibility
- Evaluation against requirements (to what extent is each requirement fulfilled? )
- Comparison of solution to competitor products and to future market needs

#### **OUTPUT**

- Based on results of evaluation, list of things to keep in new product and list of 'concerns' to be worked back upon again & go back to Idea generation / solution development

- Recommendations for further development of product in future.

#### **STAGE 6: IMPROVE** - *the solution by applying required changes according to needs from Evaluation.*

This stage will involve going back to stages 2, 3, and improving/re-adjusting the concept accordingly.

## **PRACTICAL END RESULTS**

The end result of the assignment will be a proposal of a new or redesigned FLS concept. A 3D CAD model will be created to illustrate the proposed concept. This will be substantiated by a prototype showing the sensors working principle, together with a digital animation if possible. Furthermore, the proposal will be supported by the creation of a future scenario of the trends in the automobile industry that have the ability to influence the future of the FLS.

In addition, a research report and a design report will be delivered. The research report will include the results and analysis of the data collected, together with the interpretation of these to be used for the development of the FLS. The design report on the other hand, will show the process and development of the product from the initial 'problem' described to the solution proposed.

