Dissertation

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THE DESIGN OF A DATA ACQUISITION SYSTEM FOR A MITSUBISHI MIRAGE RX SUPERCAR

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Declaration of Authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: Date:

Acknowledgments

Firstly, I would like to thank Spencer Sport for the opportunity to undertake this project.

Secondly thanks to Tim Tudor for being my supervisor over the duration of this project and for sharing your data acquisition knowledge with myself.

Thirdly I would like to thank my friends and family for all your support over the past three years, with special thanks to Tiegen Lillicrap for all your motivation and continued support since meeting at UWTSD.

Finally, my daughter Izzy - This is all for you, kiddo.

Abstract

This report contains the design of a bespoke data acquisition system for Spencer Sport to obtain valuable chassis parameter data from their Mitsubishi Mirage RX Supercar.

To achieve this task, extensive research was undertaken on data acquisition and the hardware required to create the DAS, the benefits of which are discussed during this report.

The final design concept will allow Spencer Sport to create the DAS and install it within the race vehicle, as such the data recorded by the system can then be utilized by Spencer Sport to improve the performance of the Mirage.

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i. Table of Abbreviations

Table 1: Table of Abbreviations

Abbreviation	Definition
AC	Alternating Current
AS	Autosport
AV	Analogue Voltage
AWG	American Wire Gauge
CAE	Computer-Aided Engineering
CAN	Control Area Network
CAN_H	Control Area Network High
CAN_L	Control Area Network Low
CRC	Cyclic Redundancy Check
DAS	Data Acquisition System
DC	Direct Current
ECU	Electronic Control Unit
EMI	Electromagnetic Interference
F/L	Front Left
F/R	Front Right
FIA	Federation Internationale de l'Automobile
G_{lat}	Lateral G Force
G_{long}	Longitudinal G Force
GPS	Global Positioning System
G_{vert}	Vertical G Force
Hz	Hertz
IP Rating	Ingress Protection Rating
Kbits	Kilobits
L/H/S	Left-Hand Side
MAU	Medium Access Unit
MB	Megabyte
Mbits	Megabits
NVH	Noise, Vibration and Harshness
P-P	Peak to Peak
R/H/S	Right-Hand Side
R/L	Rear Left
R/R	Rear Right
RFI	Radio Frequency Interference
RMS	Root Mean Squared
RTR	Remote Transmission Request
RX	Rallycross
SVIM	Synchronous Versatile Input Module
V	Voltage

1 Introduction

The use of data acquisition within motorsport has given race teams the ability to increase the likelihood of winning within a competition by producing valuable vehicle feedback, thus allowing vehicle modifications to be made to increase performance (Lopez & Seaber, 2009). Before the introduction of DAS, race engineers would acquire vehicle feedback through discussions with the driver along with experience and intuition (Segers, 2008) and therefore apply a trial-and-error method to improve vehicle performance. The advancements in vehicle technologies mean that data acquisition systems have endless possibilities, with newer models boasting more channels and sophisticated sensors that allow a wider range of vehicle parameters to be monitored.

A common misconception is that data acquisition and telemetry are both the same thing, although similar, this is not the case. Data acquisition refers to the logging of data to be analysed at a later time, whereas telemetry is the term used to describe the live transfer of data via radio or remote receiver, giving vehicle information immediately (McBeath, 2008).

There are six reasons why a race team should use data acquisition, as outlined by Rodrigo de Oliveira Santos, a performance engineer specialising in data analysis (Santos, 2014):

- Vehicle performance analysis
- Driver performance analysis
- To aid with vehicle development
- To allow the monitoring of safety and reliability
- To determine vehicle parameters for simulation
- The benefit of maintenance logs

For this project, the DAS will be used to analyse the performance of Spencer Sports Mitsubishi Mirage RX Supercar to aid Spencer Sport with further vehicle development.

Spencer Sport are a motorsport team located in Ceredigion, who compete in both the British and European Rally Championships along with Rallycross Championships. Founded in 2014, the company first began competing in 2016, beginning with the MSA British Rally Championship and achieved second place. The team now competes regularly both in rally and rallycross and in 2015, became the official distributor of the Mitsubishi Mirage rally car for the UK and Ireland (Spencer Sport, 2019).

1.1 Aims & Objectives

The aims of the project are outlined below:

- To identify the requirements for a data acquisition system for the Mitsubishi Mirage RX Supercar and the analysis which could be performed to develop the rallycross vehicle further.
- Identify the capabilities of the Motec C187 and supporting SVIMs belonging to UWTSD.
- Design a loom specific to the Mitsubishi Mirage RX utilising the Motec C187 logger belonging to UWTSD, which is currently in use on the MCR.
- Identify and source the materials and sensors required to create the data acquisition loom.

These aims will be achieved through extensive research into the application of the data acquisition system followed by hardware research to gain an understanding of DAS for a motorsport application. Vehicle parameters and choice of sensors will be selected and justified to ensure that the best information will be obtained for vehicle development. The design of the DAS will focus on reliability and accuracy thus producing a high specification system with the capability of withstanding the rallycross environment.

2 Timing Plan

Section 2.1 shows the October 2018 provisional timing plan for the project as submitted under the Project Proposal, with expectations of completing the loom manufacture along with testing by the April 2019 deadline. As seen in Figure 1, the project follows these timings up to December 2018, where finalising a design took longer than originally expected. The reasoning for this is due to a combination of system re-designing, the introduction of further sensors to the system as suggested in the Interim Viva and personal underestimation of the timings required to complete a final design concept.

The DAS was re-designed three times during this project to accommodate input from Spencer Sport along with the addition and removal of certain sensors. This is described in detail in Section 4.3 of this report. Input during the Interim Viva encouraged further research to be undertaken on vehicle testing and the DAS application and deeper knowledge to be obtained on sensor theory.

Due to re-design, it was crucial that the final proposed design had covered all aspects of the brief outlined by Spencer Sport, therefore a month was undertaken to perfect the design concept and produce schematics and supporting pin data for ease of manufacture. With each re-design the bill of materials was altered to accommodate the changes and could not be completed until design has been finalised, thus manufacturing of the system could not be completed due to the finalised system design not being confirmed until March 2019.

Both manufacturing of the loom and DAS testing has been recommended for further work, as described in detail in Section 7 of this report.

2.1 Provisional Timing Plan

- **October - November 2018:** Initial research and gain an understanding of the Motec C187 system. Arrange and meet with Spencer Sports to discuss the project and view the Mitsubishi Mirage RX Supercar.
- **November - December 2018:** Begin designing the loom, specifying the relevant wires, connectors and other consumables required along with the sensors needed to create a working data acquisition loom. Commence work on interim viva.
- **December - January 2019:** Complete the loom design along with a relevant wiring schematic/diagram. Confirm the pin data and finish the fitment diagram.
- **January - March 2019:** Complete manufacturing of the loom.
- **March - April 2019:** Installing the loom to the Mitsubishi Mirage RX Super car and testing.

2.2 Final Timing Plan

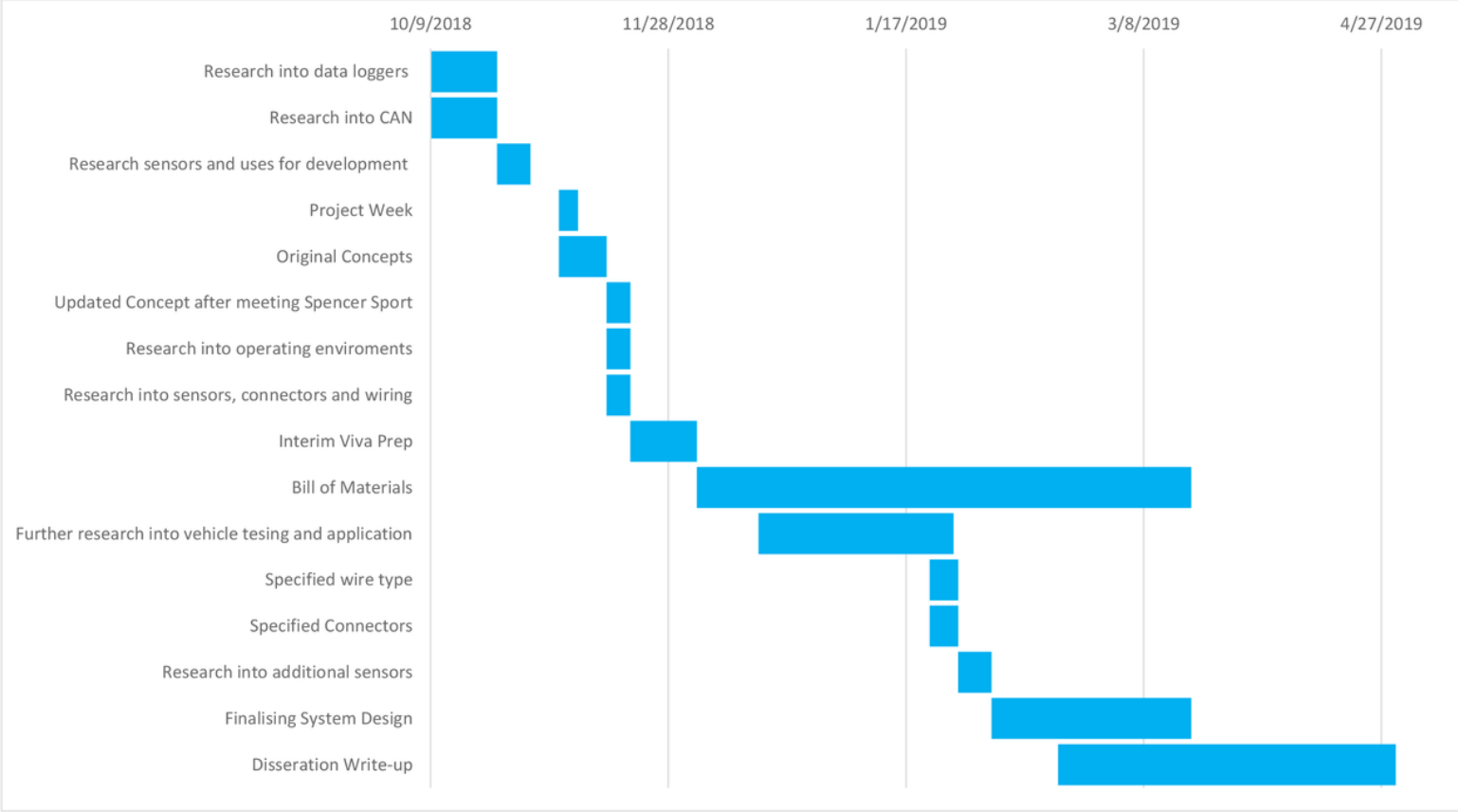


Figure 1: Final Timing Plan Gantt Chart (Bartram, 2019)

3 Research

3.1 Data Acquisition Systems (DAS)

Data acquisition has become a crucial part of vehicle development, allowing for the analysis of vehicle behaviour through the means of data logging. During the testing element of the development process, data logging is used to obtain several vehicle parameters such as engine and chassis system behaviour to give developers feedback on how a vehicle reacts under a real-world application. The capabilities of data acquisition have increased due to the advancement in vehicle technology and has played a significant role in improving the safety and handling of vehicles as well as reducing emissions and NVH (Millbrook Proving Ground, 2019).

At the heart of every data acquisition system is the logging device commonly known as the data logger. A compact device with the ability to process and store various real-time input data, which can be accessed and analysed at a later time by connecting the data logger to a computer with the relevant software installed. Data logging devices have physically benefitted from technology advancement, from large bulky systems weighing 150lbs (68kg) as seen in 1972 (Doty & Olejnik, 1972) which measured performance and emissions, to present day compact systems weighing as little as 670g (MoTeC Pty Ltd, 2018). The capabilities of the data logger are usually dependent on cost, as the number of channels available, logging frequencies and as additional specifications increase so does the cost of the data logger (Race Technology, 2019). Many modern data logging devices benefit from internal sensors integrated into the logger unit. In turn this reduces the overall number of sensors required yet increases the number of channels available (MoTeC Pty Ltd, 2018).

Data from various parameters is recorded using sensors, carefully selected for the application to give the most accurate data for analysis. The earliest fully functioning sensor was a Manifold Absolute Pressure (MAP) senor developed by Gulton in 1973 (Grace, 1991). Since its development, the capability of sensors has dramatically increased due to the sophistication of modern technology. On average, modern road vehicles in 2017 had between 60 and 100 sensors (MEMSJournal, 2017) which feedback vehicle information to various electronic control units (ECUs) to aid with engine management, safety and comfort systems. Sensors are the most significant component of any data acquisition system as the data logger is rendered useless without parameter data. Poor or incorrect data supplied by the sensors can be detrimental during analysis thus quality of sensors and parameter data must be ensured.

3.2 Data Acquisition Systems in Motorsport

Data acquisition has proven to be a vital development tool within all areas of motorsport, allowing race teams to achieve maximum performance from both the vehicle and the driver. Sensors must be of a high specification to withstand the harsh environments during a motorsport application whilst maintaining a high level of reliability (Barnes, et al., 2000) to allow for an accurate representation of both vehicle and driver behaviour.

For analysis, data is commonly broken down into the following three sub-categories as outlined by (Lopez & Seaber, 2009) and justified by (Segers, 2008):

- Vital functions of the vehicle
- Chassis parameters
- Driver behaviour

3.2.1 Vital Functions of the vehicle

Data obtained on the vital functions of the vehicle relates to the critical areas of the engine, such as engine pressures and temperatures, these are used to ensure the hardware limitations of the engine are not being reached and that the engine is functioning correctly and safely (Santos, 2014). By monitoring the vehicles vital functions modifications can be made to certain powertrain areas, such as the cooling system, whilst still retaining high levels of reliability and function.

3.2.2 Chassis Parameters

Chassis behaviour data can give an indication of suspension, handling and aerodynamic issues, thus allowing modifications to be made to optimise performance in these areas. As suspension, handling and aerodynamic properties of a vehicle are all related (Uffelmann, 1986) it is important to understand the dynamics relating to the latter in conjunction with the chassis parameter data provided by the data acquisition system when making modifications. Several chassis parameters such as damper travel and ride height can be recorded, dependent on data logger capabilities and budget. Wheel speed along with Global Positioning System (GPS) are typically used as reference points, allowing chassis behaviour at both varying speed and track position to be analysed (McBeath, 2008). With the introduction of non-contact infra-red sensors, analysis of tyre behaviour can be undertaken, giving the ability to compare tyres performance along with grip when tyre data is used in conjunction with suspension data (Callea, 2004).

3.2.3 Driver Behaviour

Unlike vehicle behaviour, driver behaviour is unpredictable and driving styles varies from driver to driver. As (Andria, et al., 2016) states, an overall driver profile formed using data from a combination of sensors relating to throttle position, steering wheel angle, braking and gear shifting. An advantage of measuring driver behaviour is the ability to distinguish between poor handling issues due to problems with the vehicle or poor handling issues due to driver behaviour through the comparison of chassis parameter data. As (Kegelman, et al., 2017) explains a competent driver can sometimes be more important to any race team than a high-performance vehicle and can supply vital information on vehicle control to aid with development.

3.3 DAS Application: Rallycross (RX) & The Mitsubishi Mirage RX Supercar

3.3.1 Rallycross (RX)

In 1967, rallying and circuit racing were combined to create the sport known as Rallycross, where up to eight vehicles participate on a circuit consisting of both gravel and asphalt for a maximum of three minutes, winning is achieved by completing the required laps in the shortest time (Motorsport UK, 2019). Vehicles used in World Rallycross, RX Supercars, have the ability to accelerate from 0 to 60 in under two seconds and produce a power output in excess of 600bhp (FIA World Rallycross Championship, 2017). Regulations published in 2019 by the (Fédération Internationale de l'Automobile, 2019) (FIA), the organisers of both the World Rallycross Championships and European Rallycross Championships, state in Appendix J - Article 279 Section 3.6 that the use of on-board data recorders are allowed within the competition. The MSA British Rallycross Championships also permits the use of on-board data recorders, as outlined in Section 5.3.1 of the Sporting and Technical Regulations published by (TOYO TIRES MSA BRITISH RALLYCROSS CHAMPIONSHIP, 2018). Although data acquisition is permitted, both regulations state that the use of telemetry is prohibited.

In March 2019, Yas Marina Circuit unveiled the circuit for the opening round of the FIA World Rallycross Championship 2019. The 1.2km circuit consists of 63% asphalt and 37% gravel along with the addition of wide areas for overtaking, a jump section and a hairpin bend (FIA, 2019). Despite being short in both length and lap time, rallycross circuits tend to be highly complex hence data acquisition can provide vital information to increase both speed and vehicle handling through the several crucial bend sections with the changes in terrain.

Due to the mixed terrain the vehicle will be subject to during a rallycross event, the data acquisition system must have the capability to withstand these conditions. Section 3.5 of this report will detail the necessary specifications of the hardware in relation to application.

3.3.2 Mitsubishi Mirage RX Supercar



Figure 2: Mitsubishi Mirage RX Supercar (Spencer Sport, 2018)

The vehicle specified by Spencer Sport which the data acquisition system will be created for is the Mitsubishi Mirage RX Supercar. The two litre, 16 valve turbo charged engine built by Julian Godfrey Engineering produces approximately 600bhp and 650lb/ft of torque and is mounted longitudinally down the chassis, a process which was undertaken by Mparts located in Orebro, Sweden (Spencer Sport, 2019).

Developed in 2017 by Spencer Sport, the left-hand drive Mirage boasts several high specification components, each component carefully selected to gain an advantage over the other competitors whilst still conforming to the rallycross regulations outlined by the FIA. Data acquisition provides Spencer Sport with the ability to gather important information on the Mirage in a real-world application, thus allowing the team to increase the capabilities of the vehicle further which should give the team an advantage during racing.

The Mitsubishi Mirage RX Supercar has had an excellent start to the 2019 rallycross season, competing in round 1 of the Toyo Tires British Rallycross Championship in March and successfully winning all heats and the final, finishing 2.5 seconds ahead of the second place competitor (Spencer Sport, 2019).

3.4 Controller Area Network (CAN)

In 1985, Robert Bosch GmbH in collaboration with the Intel Corporation began development on a method of vehicle multiplexing to allow for the rapid transfer of electronic vehicle data in real time, known as networking. By 1987 Bosch had succeeded in this task and released his in-vehicle real-time networking solution, the Controller Area Network bus (PhaillIntel, 1988). By 1991 this method of multiplexing was set as the standard across all motor vehicles due to its low cost and high reliability of data transfer (Bosch, 2014).

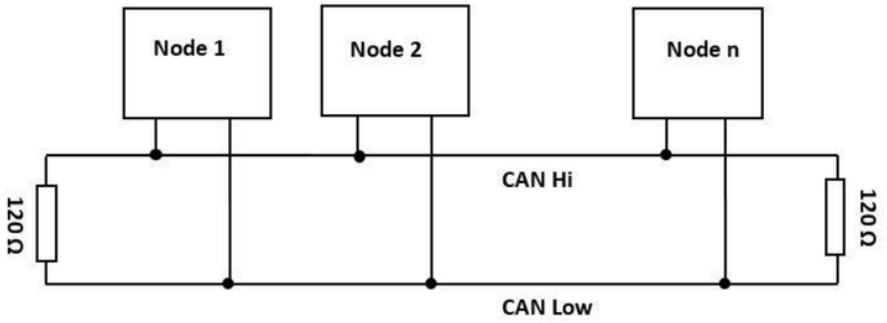


Figure 3: CANbus Schematic (pico technology, 2019)

Each connection on a single CANbus system are known as nodes, with all nodes having access to the entire CANbus information simultaneously, should one node cease to function all other nodes on the bus are unaffected and continue to operate (Hillier, 2014). The name "bus" is given due to each node being connected in parallel to the CAN system, seen in Figure 3. Communication across the CANbus is conducted in binary, where the dominant state is represented by "Logic 0" and the recessive by "Logic 1" (Bosch, 2014). These logic states are converted into voltage levels by the CAN receiver, with CAN High (CAN_H) and CAN Low (CAN_L) producing different voltage levels dependent on state (Bosch, 2007). When in dominant state, CAN_L produces a lower voltage than in the recessive state whereas CAN_H produces a higher voltage when in the dominant state (ISO, 2006).

Messages are transferred across the CAN using frames. There are four unique frame formats as described by both (Voss, 2005) and (Bosch, 2007):

- *Data Frame*: The transfer of data from a single node to one or several receiving nodes.

- *Remote Frame*: The request of data from a single node. The node responds by sending a Data Frame containing the relevant information.
- *Error Frame*: Should a node suffer a malfunction the node will produce an Error Frame, informing all other nodes on the CAN of the error.
- *Overload Frame*: Should a node require a delay between a Data and Remote Frame an Overload Frame is used to inform the system that it currently cannot process an additional frame.

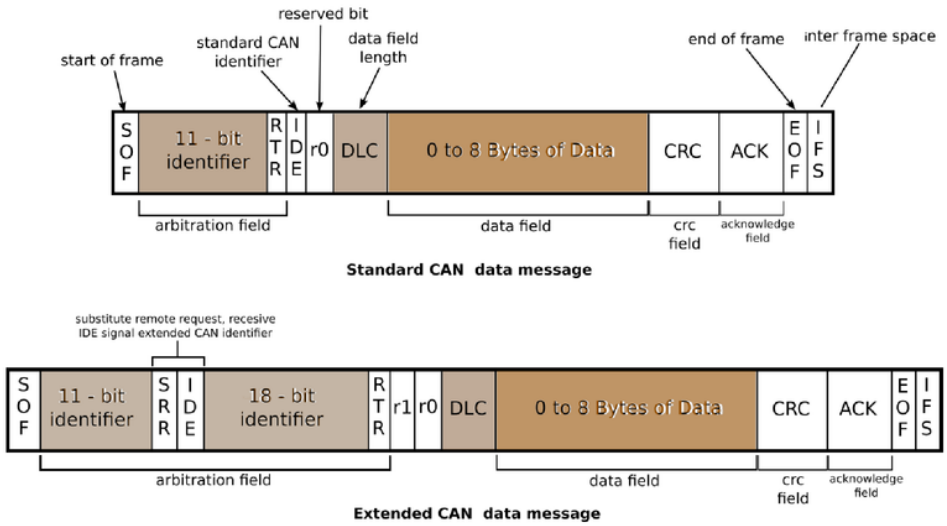


Figure 4: Architecture of a Data Frame (Dewesoft, 2019)

A data frame consists of either a standard 11-bit identifier (CAN 2.0A) or an extended 29-bit identifier (CAN 2.0B). The architecture of a data frame, seen in Figure 4, shows that although the standard and extended data frames differ in the arbitration field, following r0 (Reserved Bit) both data frames are identical in content. Each standard data frame consists of the following fields as outlined by (Bosch, 1991) in his CAN Specification Version 2.0 document:

- *Arbitration Field*: A combination of both the identifier and Remote Transmission Request (RTR). The identifier is 11-bits in length with bit ID-10 being the most significant bit and ID-0 being the least significant. For data frames, the RTR bit must be dominant whereas in a remote frame this bit is recessive.

- *Data Field*: Consisting of 0 to 8 bytes, with each byte containing 8 bits, the data field is what contains the information which is transferred between nodes.
- *CRC Field*: Used to indicate whether any errors occurred during data transfer and is calculated applying polynomial equations, the Cyclic Redundancy Check (CRC) field is followed by an individual recessive bit.
- *Acknowledgement Field*: Consisting of two bits, if the message is received correctly one of the two bits will be transformed from a recessive bit to a dominant bit to indicate the successful transfer of data.

The advantage of the extended data frame over the standard data frame is the increase of the identifier from 11-bits to 29-bits, which increases the different message types from the standard 2032 to in excess of 500 billion message types (Reuss, 1993).

Physically, the CANbus consists of two twisted wires, one transmitting the CAN_H data, whilst the other transmits CAN_L data. The twisting of the wires allows for the filtering of interference by creating the difference between the CAN_H voltage and CAN_L voltage (Bosch, 2014). Bit transfer rates are dependent on CANbus length, with ISO 11898 specifying 1 Mbits per second for 40m on high-speed CAN, as CANbus length increases bit transfer rates decrease (Bosch, 2007).

3.4.1 High-Speed CAN (CAN-C)

ISO Standard 11898-2 defines high-speed CAN as a medium access unit (MAU) which operates with transmission rates up to 1Mbits per second (ISO, 2003). This rapid transfer of data has made CAN-C the networking choice for engine management systems along with vehicle safety systems. When in the recessive state, a voltage of 2.5V is seen on both CAN High and CAN Low of CAN-C, when in the dominant state the CAN_H voltage increases to 3.5V where as CAN_L decreases to 1.5V (Bosch, 2007).

CAN-C is the typical communication protocol used for data acquisition due to the higher data transfer speeds and real-time networking in comparison to the low-speed CAN-B, which is limited to data transfer speeds of a maximum of 125 kbits per second (Bosch, 2014).

3.5 Hardware

3.5.1 MOTEC C187

The Motec C187 is a high specification data logger created by Motec for use in motorsport data acquisition. This display logger has the capability to store up to 250MB of data, logging frequencies up to 1000Hz and the ability to collect data from a mixture of analogue and digital inputs. Internally, the Motec C187 is capable of measuring battery voltage, device temperature and can record G Force in three axes. The five input types available on the Motec C187 are as follows:

- Analogue Voltage Inputs
- Analogue Voltage Temperatures
- Switch Inputs
- Digital Inputs
- Wheel Speed Inputs

For the purpose of this project where the focus is on chassis-based parameters, the channels utilised will be Analogue Voltage Inputs along with the Wheel Speed Inputs.

Analogue Voltage Inputs:

Table 2: Analogue Voltage Input Specifications

Measure Voltage Range	Resolution	Update Rate
Inputs 1-4 & 11-14: 0 to 5.46V	Inputs 1-4 & 11-14: 1.33mV	1000 times/sec
All other Inputs: 0 to 15.0V	All other Inputs: 3.66mV	1000 times/sec

Analogue Voltage inputs on the Motec C187 can be used for potentiometers, voltage output sensors or with sensors with variable resistance. They are capable of logging frequencies of 1000Hz and voltage ranges from 0V up to 15V. Most chassis-based sensors require the analogue voltage input channel as the sensors supply an analogue signal rather than a digital signal. The reasoning for the use of analogue signal sensors is that unlike a digital signal, which reads information in binary and can only give a finite range of 0 and 1, an analogue signal is capable of giving readings of a variable quantity and can be processed in real-time (TechDifferences, 2016). The Motec C187 has a total of 20 Analogue Voltage Inputs available for use as such these will be the main channels used for the data acquisition in this project.

Wheel Speed Inputs:

Table 3: Wheel Speed Input Specifications

Voltage Range	Update Rate	Resolution	Maximum Frequency
Hall: 0V to 15V	100 times/sec	0.1Hz	3200Hz
Magnetic: -80V to +80V	100 times/sec	0.1Hz	3200Hz

(MoTeC Pty Ltd, 2018)

The Motec C187 gives the option of logging two types of wheel speed sensors, Hall effect or Magnetic. Magnetic mode refers to speed sensors that generate an analogue pulse, such as a variable reluctance sensor or inductive sensor, whereas hall effect sensors generate a digital pulse. The two types of wheel speed sensors are discussed further in Section 4.2.2.1 of this report.

3.5.2 Synchronous Versatile Input Module (SVIM)

SVIMs are used in as an expansion to the Motec C187 to allow further vehicle parameters to be logged, communicating with the Motec C187 via CAN. These expanders have an advantage over the Motec C187 system as they are capable of logging frequencies up to 5000Hz therefore are advantageous for chassis and suspension analysis. The SVIMs also have the capability of a 10V sensor supply, rather than the 8V maximum supply the Motec C187 has to offer. The inputs available on the SVIMs are as follows:

- 6 × Fast Analogue Voltage Inputs
- 10 × High Resolution Analogue Voltage Inputs
- 8 × High Resolution Differential Analogue Voltage Inputs
- 2 × Speed Inputs

Specifications of each channel:

Table 4: SVIM Channel Specifications

Type	Update Rate	Bits	Range	Resolution
AV F	5000Hz	12	0-5V	1.2mV/step
AV H	1000Hz	15	At Gain = 1: 0-5V	At Gain = 1: 0.153 mV/step

			At Gain = 64: 0-78mV	At Gain = 64: 0.00238 mV/step
AV D	1000Hz	15+Sign	At Gain=1: –5 to 5 V differential 0 to 5 V absolute	at Gain=1: 0.153 mV/step
			At Gain=64: –78 to +78 mV differential 0 to 3 V absolute	at Gain=64: 0.00238 mV/step
AV SPD	100Hz	12	0-10.3V	2.5 mV/step

(MoTeC Pty. Ltd, 2018)

SVIMs when used in multiples can synchronise all 18 high-resolution analogue voltages due to the fact that all inputs are sampled at the same instance in time. This is a crucial detail for analysis of suspension behaviour across all four corners of the vehicle along with other chassis perimeters.

When utilising these SVIMs considerations must be taken to prevent the system exceeding 90% of the total available CAN bandwidth which in this case the total bandwidth is 1Mbit/sec, therefore 90% of the total is equivalent to 900,000bits/sec.

Approximate Bandwidth being utilised can be calculated by Equation 1:

$$\boldsymbol{Approximate\ Bandwidth} = \boldsymbol{Total\ Measurement\ rate\ (Samples\ per\ Sec)} \times \boldsymbol{30\ (bits\ per\ sample)} \qquad \textbf{Equation 1}$$

(MoTeC Pty. Ltd, 2018)

3.5.3 Sensors

When selecting sensors for any automotive application, careful consideration must be made when selecting the correct type of sensor for each application, along with what data that sensor will have to ability to supply in order to aid with vehicle development. For this project Spencer Sports have supplied a list of chassis parameters they wish to be recorded on the Mitsubishi Mirage Rallycross vehicle, these parameters and their uses for development are outlined in Table 5:

Table 5: Vehicle Parameters and uses for development

Vehicle Parameter	Uses for development
Wheel Speed	Wheel speed is used as a reference point to compare with other logged data allowing vehicle/driver behaviour comparisons over a range of speeds. Wheel speed also gives an indication of whether modifications to the vehicle have allowed for an increase in speed which is critical in a motorsport application.
Damper Travel	Gives a reading of suspension behaviour and allows for modifications to be made to improve cornering and handling by identifying any current handling problems.
Steering Angle	A measure of driver behaviour through a track, by comparing the steering angle with suspension data driver handling issues can pin pointed.
Brake Pressure	A measure of driver behaviour. Data logged can give an indication of braking consistency, reaction times and the braking force applied by the driver.
Air Flow	By reading the airflow above the vehicle the aerodynamic properties of the roof of the vehicle can be obtained thus allowing for modifications to increase air flow and decrease drag.
Ride Height	By recording ride height and comparing it with the damper travel information, the best suspension set up can be determined.
Tyre Temperature	By logging tyre temperature, a reading of tyre behaviour and performance can be analysed around a track along with comparison between different makes of tyres.
Brake Temperature	Brake temperature data gives an indication on how efficiently the brake discs are performing. This information will allow modifications to be made to the braking system to maximise performance.

3.5.4 Additional Sensors

In addition to the sensors specified by Spencer Sport, research has been conducted into additional chassis-based parameters that would aid with vehicle development on the Mitsubishi Mirage RX Supercar.

Global Positioning System (GPS): The accuracy of GPS has increased over the years, with automotive GPS achieving an accuracy between 3 to 5 meters (Reif & Dietsche, 2014). In motorsport, as GPS can be a vital development tool further accuracy is required due to the speeds achieved during racing, thus GPS has been developed to increase accuracy to approximately 2cm (VBOX Automotive, 2007). In order to increase accuracy commonly more than one GPS is used across a vehicle, with one at the front of the vehicle and one to the rear at a fixed distance. In additional to increasing the accuracy by using two GPS antennas, GPS can also aid with determining the Pitch and Yaw of a vehicle (Segers, 2008).

Yaw Sensor: When in motion, a vehicle is subjected to three degrees of rotation - Roll, Pitch & Yaw. Yaw is defined as the rotation of an object about the vertical axis which runs through the centre of mass (the z axis), the centre of mass on a vehicle being the centre of gravity (Simcraft, 2019). In rallying the ability to increase the capability of yaw acceleration is advantageous due to the mixture of terrain and hairpin bends that the rally car is subjected to during the competition (Blundell & Harty, 2015) thus information on the yaw characteristics of the vehicle is desired. Yaw can be broken down into two measurable parameters - Yaw Rate and Yaw angle, where Yaw rate is the degree of Yaw over time and the Yaw angle is the angle the vehicle has rotated from the centre line. Yaw rate in conjunction with steering angle can be used to further understand the handling of the vehicle such as oversteer and understeer behaviours. Methods of estimating Yaw Rate have been investigated due to the previously high cost of Yaw Sensors, these methods implement information obtained from steering wheel angle, wheel speed and lateral acceleration (Hac & Simpson, 2000). Although as technology has advanced Yaw Rate sensors are now readily available and are commonly used in automotive applications in conjunction with Electronic Stability Control/Programmes (ESC/ESP) thus the cost has reduced. Yaw Rate sensors can either be purchased for Yaw individually or a combination of Roll, Pitch & Yaw in order to acquire data on the three degrees of rotation.

3.5.5 SPEEDBOX RTK

As discussed in Section 3.5.4, both GPS and Yaw are valuable chassis parameters for a rallycross application. The Motec C187 is limited to logging data from a singular GPS,

therefore, to allow for the two GPS as desired within the DAS a Speedbox is required, provided by the university.

Designed by Race Technology, the Speedbox RTK is an additional component to a DAS, allowing for further channels such as GPS, yaw and pitch to be measured. By including two GPS antennas, which are provided with the Speedbox RTK, the need to purchase separate antennas is eliminated and therefore reduces sensor cost. The Speedbox RTK communicates with the Motec C187 via CAN allowing for the rapid transfer of data with programable bit rates up to 1Mbits per second (Race Technology, 2008).

3.5.6 Resolution, Linearity & Accuracy

Three important factors with sensor selection are the resolution, linearity and accuracy of the sensor data. All three relate to the quality of the data that can be obtained during testing therefore it is desirable to have this knowledge for each sensor in order to ensure the best quality of data can be achieved for analysis.

3.5.6.1 Resolution

Resolution is defined as the smallest measurement that a sensor is capable of reliably indicating (Measurement Computing, 2017) and is dependent on the electrical noise produced by the sensor when operated, therefore it must be ensured when selecting a sensor that the resolution is considerably less that the measurement that is required. At high frequencies this electrical noise is increased, due to this a low-pass filter can be introduced in order to minimise electrical noise thus the resolution quality improves. If the low-pass filter is applied manufacturers will give a static resolution specification, whereas a non-filtered sensor will be given a dynamic resolution specification (Lion Precision, 2014). The units of resolution can be given in dimensional units, volts or bits, in the case of displacement dimensional units are desired. The specification of resolution can be given in two formats, RMS (Root Mean Square) or Peak to Peak (P-P) where RMS is equivalent to the power from a Direct Current (DC) source and P-P is the average between the maximum and minimum peaks of the electrical noise over a set period of time. P-P will always be at least six times greater than the given RMS value (Lion Precision, 2014).

3.5.6.2 Linearity

Linearity is the maximum deviation between the ideal straight-line measurement and the actual measurement that is obtained (Banner Engineering, 2018). Theoretically it is assumed that a sensor output will give a linear result when graphed, realistically this is not the case with pressure transducers, due to the construction of the sensors (i.e. materials & geometry)

therefore information regarding the linearity is desired (AZO Sensors, 2018). In sensor specifications, linearity is given as a percentage of the measurement range and recorded as Full Scale (FS) Linearity where the worse deviation is given (Sedgwick, 2013).

3.5.6.3 Accuracy

To obtain the best information to aid with vehicle development, the accuracy of the data obtained is critical. The accuracy of the recorded data is given as a range in which the true value lies, due to the impossibility of achieving exact accuracy. Factors that influence the accuracy of a sensor include the environment which it is subject to along with the deterioration of both the sensor and measured object over time (Segers, 2008). Accuracy is recorded within specification sheets as a percentage of the measurement with plus or minus the value in order to give a range.

3.5.7 Connectors

When selecting connectors in motorsport, three major factors in relation to operating environment are considered:

- IP Ratings
- Vibrations
- Heat Sources

3.5.7.1 IP Ratings

IP rating (Ingress protection rating) relates to the working environments of electrical equipment and how they fair against the elements. The IP rating consists of two numbers, the first number relates to the protection level against to solid objects whilst the second number relates to the protection against liquids. The higher the number the more the connector can withstand the elements (Active Sensors, 2015). Within motorsport, specifically a rallycross application, it is vital for the electrical connectors used to have the highest IP rating possible to be able to survive the rugged and harsh environment that they are exposed to. A common IP rating used in motorsport connectors is IP67, where the number 6 is reference to the highest protection of solids available by completely preventing the ingress of dust. The number 7, refers to the protection against liquids and allows the connecters to be protected from immersion up to 1m. The highest liquid protection number is 8, although this level of protection is used for electricals that are continuously submerged in water, thus this level of protection is not required within motorsport (DSMT, 2018).

3.5.7.2 Vibrations

In motorsport the electrical system is put under hard vibrations due to the environment the vehicle is expected to function under. These vibrations put a higher tension onto the electrical connectors generating component failure along with fretting corrosion as described by (Morello, 2014). used in motorsport are placed under vigorous tests to ensure they possess the qualities necessary for working correctly under these situations. These tests consist of testing the connecters in the X, Y and Z axes under various vibration intensities and frequencies for various time periods and monitoring how the connectors withstand these conditions. (Mroczkowski, 2008) states that these tests check the connectors ability to work whilst exposed to both vibrations and external mechanical stresses whilst also checking for any fretting corrosion that may occur when subject to such vibration. Connectors in motorsport are given vibration ratings along with IP ratings, these vibration ratings are measured by the amount of G force the connector can withstand at a rate of Hertz. These ratings can be paired with the knowledge of the terrain that the vehicle will be driving on to create a wiring loom that has the ability to withstand the vibrations that the electrical system will be exposed to.

3.5.7.3 Heat Sources

Heat sources can be detrimental to electrical wiring and sensors, with heat having the ability to melt wiring along with the plastic-based housing of sensors this results in the temperature of the copper wiring within the insulated outer layer increasing. Sources of heat on a vehicle are normally contained to the engine bay, heat dispersed by the brake discs and pads and the exhaust system. When creating a wiring loom is it important to avoid as much as possible these areas of heat, keeping wiring to a minimum in these areas, or in the case of engine management electronics, routing the wiring in the best possible way along with making sure the wiring is correctly insulated to avoid any heat damage. Specifications for sensors typically include the operating temperature ranges that the sensors can safely operate under.

Taking these three factors into account, Deutsch AS Standard Series Connectors have been selected for the DAS. These lightweight, high specification connects are popular for use in the motorsport industry with specifications as follows:

- IP Rating — IP67
- Operating Temperatures — -55°C up to 175°C
- High density arrangements up to 128 options
- 5 keyway orientations

- Accepts wire gauges 16, 20 & 22

(Deutsch Industrial, 2012)

As Deutsch Autosport connectors are required for both the Motec & SVIMs, with the Motec requiring the 79 pin Autosport connector and the SVIMs each requiring one 55 pin Autosport connector for sensors and one 5 pin Autosport connector for CAN communications with the Motec. A further advantage of using only the Deutsch AS Standard Series would be a uniform high standard of connectors across the Data Acquisition System.

3.5.8 Wiring

As with connectors, operating environment is a major factor with wire selection on a motorsport vehicle, particularly a rallycross vehicle. Should the wiring deteriorate rapidly due to incorrect wiring selection for the application in question, complete loss of data will occur hence selecting the correct wiring is a crucial design factor within the design of the DAS.

Wiring, like connectors, carry a temperature rating, with PVC at the lower end of operating temperatures of up to 80°C. Crosslinked wire has a higher resistance to temperature, being rated up to temperatures of 125°C, this is due to the way cross linked wiring is produced, where the molecules of insulation are crosslinked in order to change the insulation to another state (Allied Wire & Cable, 2018). Due to the areas where data will be recorded being near these heat sources e.g. brakes, higher temperature rated wire is desirable.

Tefzel wire is the most popular type of wiring used within motorsport applications due to having the ability to survive high temperatures along with the flexibility required when routing vehicle wiring. Tefzel refers to the material coating the wiring, a fluoropolymer which allows for the wire to withstand temperatures up to 150°C (DuPont Fluoroproducts, 2003).

Along with the type of wiring, gauge of wiring is also an important factor which relates to the amount of electrical current that can safely pass through the wire. Incorrect wire gauges can cause a detrimental effect to an electrical system, using a wire whose diameter is too narrow to sufficiently carry the current travelling through the wire can result in the worst case, electrical fires.

The Motec C187 specifies an American Wire Gauge (AWG) of 22 to be used in order to accommodate the 79 Pin Autosport Connector and to not exceed the 5A current limit of the Motec C187 (MoTeC Pty Ltd, 2018). The specification of this wire gauge is outlined in Table 6:

Table 6: Wire Gauge AWG 22 Specifications (MoTeC Pty Ltd, 2018)

Wire Gauge (AWG)	Cross Sectional Area (mm^2)	Max Current at 100°C (A)	Resistance (Ohm/m)
22	0.38	5	0.045

Bundling of the wires through twisting under tension is suggested to increase flexibility and decrease the chance of electrical interference, this also ensures that all wires are under the same tension therefore maximising reliability of the loom (Perston, 2018).

3.6 Software

In order to analyse the data obtained by the combination of the hardware suitable software is required, in the case of the Motec C187 the required software is Motec i2 Pro. Data acquisition software is used to plot the data received from the various sensors giving a graphical representation of how a vehicle (and driver) is performing around a track.

3.6.1 Math Channels

Maths channels within Motec i2 Pro allow for deeper data analysis by allowing the data to be integrated with fixed vehicle parameters along with utilising vehicle dynamic equations in order to give further behaviour information of a vehicle without the need for additional sensors (McBeath, 2008). When outlining the specific chassis-bases parameters Spencer Sport required for the DAS, Propshaft Speed was listed as a requirement. Although propshaft speed can be recorded via Hall effect speed sensors, difficulty keeping the sensors within the temperature working range was found due to the close proximity of the exhaust system to the propshaft therefore propshaft speed can be calculated through the use of maths channels and Equation 2:

$$\frac{(Wheel\ Speed\ Left + Wheel\ Speed\ Right)}{2 \times Final\ Drive\ Ratio} \qquad \text{Equation 2}$$

With the use of the data provided from the sensors, along with maths channels and vehicle specifications, further vehicle behaviours can be accounted for, a selection of these behaviours and equations used are outlined as follows:

Brake Bias (Front):

$$\frac{Brake\ Line\ Pressure\ Front}{Brake\ Line\ Pressure\ Front + Brake\ Line\ Pressure\ Rear} \times 100\% \qquad \text{Equation 3}$$

(Segers, 2008)

Brake bias, calculated by Equation 3, can be an overall indication of a vehicles breaking performance by giving a ratio of front and rear breaking force. Brake bias can be affected by numerous contributing factors unrelated to the braking system such as the centre of gravity along with how the weight of the vehicle is distributed across the axles, therefore adjusting the suspension set up can affect the brake bias (Toma, 2016). As a rallycross vehicle is subject to harsh braking, brake bias can give an indication of the best braking set up in order to avoid wheel locking during a circuit.

Combined G's:

$$\sqrt{{G_{lat}}^2 + {G_{long}}^2} \qquad \text{Equation 4}$$

(Fey, 1993)

The Motec C187 has the capability of measuring G force in the three axes, lateral, longitudinal & vertical. Combined G's is a display of a vehicles total acceleration and is used to indicate where during corner entry the tyres are underused (Fey, 1993). As longitude and latitude G's are measured at right angles to each other, Pythagoras Theorem can be used to calculate the combined G's as seen in Equation 4.

Banking Angle (α):

$$Arc\tan\left[\frac{{G_{vert}}^{-1}}{G_{lat}}\right] \qquad \text{Equation 5}$$

(Segers, 2008)

During rallycross competitions a vehicle is expected to travel across numerous types of uneven terrain, this uneven terrain can cause banking to occur. By knowing the banking angle (also known as Road Camber) over a track a comparison can be made with the roll angle of the vehicle to determine how the suspension reacts to the change and adjust accordingly.

Aerodynamic Analysis:

$$Air\ Speed = \sqrt{\frac{2 \times Dynamic\ Pressure\ (Pa)}{Air\ Density\ (kg/m^3)}} \qquad \text{Equation 6}$$

$$Headwind = Airspeed\ (m/s) - Car\ Speed\ (m/s) \qquad \text{Equation 7}$$

(Racecar Engineering, 2019)

$$Drag\ Coefficient\ C_D = \frac{Mass\ of\ vehicle\ and\ driver \times G_{long}}{Dynamic\ Pressure \times Frontal\ Area\ (A)} \qquad \text{Equation 8}$$

(Segers, 2008)

With the use of pitot tubes within the DAS, dynamic pressure information can be obtained and used to calculate further aerodynamic characteristics of the vehicle. By calculating air speed (Equation 6), head wind can be calculated (Equation 7) and used to justify downforce behaviour by informing whether the wind around the vehicle is working with or against the

vehicle (Racecar Engineering, 2019). Dynamic pressure information can also be used to calculate the Drag Coefficient of the vehicle (Equation 8), this allows modifications to be made to the aerodynamic properties of the vehicle to decrease drag and thus increase overall performance.

The DAS system will not be limited to these maths channels, as more channels are calculated these new parameters can be used in further equations giving a deeper understanding of vehicle and driver behaviour.

3.6.2 Logging Frequencies (Sampling Rate)

The most important factor to consider with a data acquisition system is the frequency at which data is logged, should the frequency be too low important data could be lost, whereas if logged too frequently it can take up unnecessary memory within the Data Logger unit (McBeath, 2008). Frequency is measured in Hertz (Hz) and indicates how many samples are recorded per second. When selecting frequencies two factors are considered, how frequently the data should be recorded along with the memory capacity of the DAS, with the Motec having 250MB of storage. In order to achieve accurate data, the recording frequency should be at least twice the vibration frequency, this is critical in order to accurately read the cyclic variation peaks & valleys (Fey, 1993).

Frequency guidelines by (Segers, 2008) are outlined below:

- Fluid Temperatures & Pressures 1-5 Hz
- Chassis & Driver Activity 20 Hz
- Suspension Motion 100 - 200 Hz

Taking Sergers guidelines into consideration, although dated, along with the sensor specified frequencies, channel frequencies and the terrain and movement the vehicle will be subject to, the frequencies selected for each sensor can be seen in Table 7:

Table 7: Selected Sensor Frequencies

Sensor	Frequency (Hz)
Wheel Speed	100
Damper Travel	750
Steering Angle	20
Brake Pressure	5

Pitot Tube	100
Ride Height	750
Tyre Temperature	100
Brake Temperature	100
SPEEDBOX GPS	20
SPEEDBOX Yaw/Pitch/Body Slip Angle	20

With frequencies, considerations must be taken in order to not exceed 90% of the total CAN bandwidth per CAN bus as seen in Section 3.5.2, 90% of the total CAN bandwidth being 900,000bits/sec. Using Equation 1, seen in Section 3.5.2, the total approximate bandwidth being used can be calculated, where the measuring rate is equivalent to the logging rate, unless the logging rate is lower than 50 Hz, then the logging rate = 50 Hz. Channels which are not logged are also considered at 50 Hz. (MoTeC Pty. Ltd, 2018)

CAN Bus 1: SVIM Left

$$(2 \times 100) + (2 \times 750) + (1 \times 50) + (4 \times 50) + (9 \times 50) + (8 \times 50) = 2600\ Samples\ per\ Second$$

$$2600 \times 30 = 78{,}000\ bits\ per\ second\ (7.8\%\ of\ Total\ CAN\ Bandwidth)$$

CAN Bus 2: SVIM Right

$$(2 \times 100) + (2 \times 750) + (2 \times 100) + (2 \times 50) + (4 \times 50) + (6 \times 50) + (8 \times 50) = 2900\ Samples\ per\ Second$$

$$2900 \times 30 = 87{,}000\ bits\ per\ second\ (8.7\%\ of\ Total\ CAN\ Bandwidth)$$

CAN Bus 3: Speedbox RTK

$$(2 \times 50) + (3 \times 50) = 250\ Samples\ per\ Second$$

$$250 \times 30 = 7{,}500\ bits\ per\ second\ (0.75\%\ of\ Total\ CAN\ Bandwidth)$$

CAN Bus 4: Tyre & Brake Temperatures

$$(4 \times 100) + (4 \times 100) = 800\ Samples\ per\ Second$$

$$800 \times 30 = 24{,}000\ bit\ per\ second\ (2.4\%\ of\ Total\ CAN\ Bandwidth)$$

These calculations show that the entire data logging system will only use approximately 19.65% of the total CAN bandwidth available, therefore plenty of additional CAN bandwidth is available if more sensors were added to the system or if the increasing in logging frequencies was needed. Both the Speedbox and Tyre/Brake Temperatures take up minimal CAN bandwidth due to the lower frequencies and minimal channels used by both systems in comparison to the SVIMs.

With the bits per second that the data acquisition system will be generating calculated, along with the total Motec C187 Memory (250MB), this can be used to calculate the total amount of time that the data logger will be able to record for:

$$Total\ Bits\ per\ Sec\ = 78{,}000 + 87{,}000 + 7{,}500 + 24{,}000$$

$$196{,}500\ bits/sec\ =\ 0.02456\ megabytes/sec$$

$$\frac{250}{0.02456} = 10179.15\ seconds$$

$$\frac{10179.15}{3600} = 2.83 = 2.49\ Hours$$

Therefore, running the DAS system with the sensors required along with the selected frequencies gives 2.49 hours of testing before the Motec C187 memory reaches maximum capacity.

During DAS testing, the selected frequencies can be tested and increased should need be, specifically damper travel due to the frequencies suggested by both (Segers, 2008) and (Fey, 1993) being dated in comparison to modern data logger and sensor capabilities.

4 Design

4.1 The Design Process

The Design Process is the method which engineers follow when developing a product. Although there are several different models outlining the design process, such as Pahl & Baitz and their systematic approach (Kannengiesser & Gero, 2017), all consist of a variant of the five steps of the design process. These five steps are as follows:

- Identify the Problem
- Research
- Generate Solution
- Analyse and select a solution
- Test selected Solution

4.1.1 Identify the Problem

The objective, as outlined in Section 1 of this report, is to design a data acquisition system to be used by Spencer Sports on their Mitsubishi Mirage RX Supercar in order to aid with development. The University will be supplying the data logger (Motec C187) along with supporting SVIMs therefore focus will be on relevant sensor selection along with loom design. As described in Section 3, considerations must be made for the environment which the Mitsubishi Mirage RX will be operating within.

4.1.2 Research

With any project, gathering an understanding of the subject in hand is vital, allowing for decisions to be made based on acquired knowledge through the means of researching the relevant topic. For this project several areas have been researched to gain an understanding of both the application of the DAS and the specifications required for the components, ensuring reliability and high accuracy of data for data analysis. Section 3 of this report covers in depth all relevant research undertaken for the project.

4.1.3 Generate Multiple Solutions

Selecting the correct layout for application and efficiency is an important design factor for the DAS, therefore multiple layout solutions must be considered before a decision is made.

With the university supplying the Motec C187 along with two SVIMs, a decision must be made on which combination of these three hardware components will be used for the DAS. The three possible combinations along with the advantages and disadvantages of each are outlined on the following page:

4.1.3.1 MOTEC C187 Only

Table 8: Advantages and Disadvantages of a MOTEC C187 only DAS

Advantages	Disadvantages
SVIMs not required	Lack of specified pins for sensor function
Input direct from sensors rather than third party through the SVIMs	Large amount of wiring to be used to return to the Motec C187
	Additional wiring allowing more areas susceptible to damage
	Cluttered wiring and various sensors sharing supply along with earthing
	8V supply rather than the 10V supply that the SVIMs offer
	Larger amount of wiring to remove and refit in order to log data for testing

The advantages and disadvantages of using the Motec C187 alone for the data acquisition system has shown that the disadvantages greatly outweigh the advantages therefore, in the case of this data acquisition system, the Motec C187 alone is not a viable option.

4.1.3.2 MOTEC C187 and one SVIM located on left hand side (L/H/S) of vehicle

Table 9: Advantages and Disadvantages of a DAS consisting of both the MOTEC C187 and one SVIM

Advantages	Disadvantages
Pins available on SVIM for further sensors on the L/H/S of vehicle	Requires six additional wires running from the right-hand side of the vehicle to the Motec C187 directly (11 wires in total, SVIM if fitted requires 4 from Motec)
Pins available on Motec for further sensors if required	Right-hand side wheel speed sensors would be supplied by 8V rather than the 10V supply from SVIMs as on the left-hand side
Allows for a single loom for the L/H/S of the vehicle connecting direct to Motec	

The reasoning for the location of a single SVIM to the left hand side of the vehicle, rather than the right hand side is primarily due to the vehicle being left-hand drive, therefore the drivers cockpit is located on the left and by using the SVIM, minimal wiring would be required to cross from the L/H/S of the vehicle to the location of the Motec C187 on the R/H/S of the vehicle.

4.1.3.3 MOTEC C187 and both SVIMs

Table 10: Advantages and Disadvantages of a DAS consisting of the MOTEC C187 and both SVIMs

Advantages	Disadvantages
Several spare pins if further sensors are required on both SVIM's along with Motec C187	Should any SVIMs fail to function correctly loss of all data at L/H & R/H sides of vehicle
Minimal wiring required across the vehicle	
10V sensor supply available on SVIM's	
SVIMs have high resolution capabilities in comparison to the Motec C187	
Several Supply and Ground Pins available	
Loom can be split L/H/S & R/H/S for simple fitment and removal	

The advantages of utilising both the Motec C187 along with both SVIMs greatly outweighs the disadvantages and thus proves that the best combination of hardware for the data acquisition system is to use the Motec C187 along with both SVIMs, located at the L/H/S and R/H/S of the vehicle.

4.1.4 Analysis and Select a Solution

Throughout this project the DAS has been adapted several times to meet the projects objectives as a result of hardware limitations, input from spencer sport and the addition of further chassis parameters. This is discussed further in Section 4.3. The selected solution for the DAS is discussed throughout this report and detailed from Section 4.2 onwards.

4.1.5 Test Selected Solution

After loom design and manufacture is completed the data acquisition system will undergo testing to ensure reliability and functionality.

4.2 System Architecture

4.2.1 MOTEC C187 and SVIM Locations

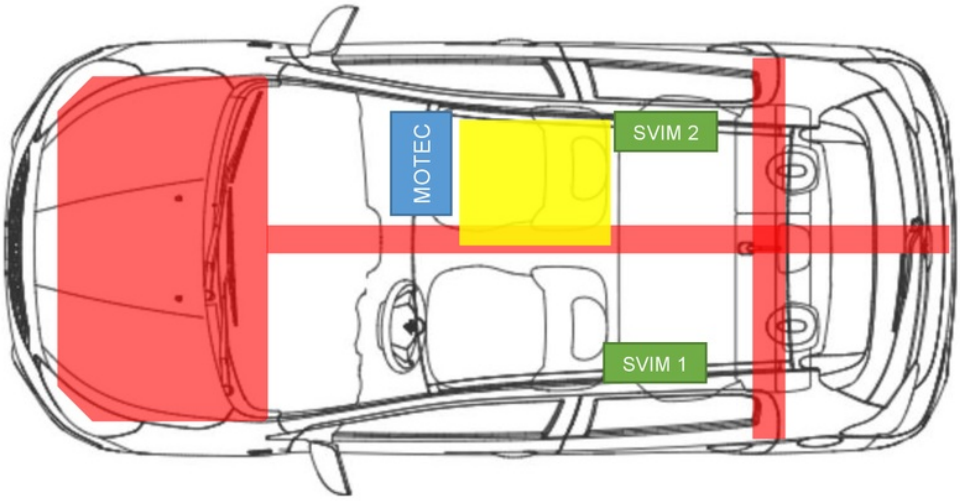


Figure 5: MOTEC C187 & SVIM Locations, Mitsubishi Mirage Blueprint from (MITSUBISHI MOTORS CORPORATION, 2019)

When designing a vehicle electrical system, it is crucial to avoid if possible, areas of external heat sources and areas of electrical interference.

Figure 5 shows these areas where:

- External Heat Sources: Indicated in Red
- Areas of Electrical Interference: Indicated in Yellow

External heat sources can be detrimental to electrical components, from effecting the performance to complete failure. (Almubarak, 2017) states that external temperatures can influence internal electrical overheating due to the decrease in the efficiency of internal heat distribution in a hot environment. The effect of external heat sources on connectors and wiring is described in Section 3.5.6.3 of this report. The Mitsubishi Mirage RX Supercar has three concentrated areas of heat, the engine, exhaust system and finally the radiator which is located in the rear of the vehicle. During the design of the data acquisition system high priority has been given to avoid these areas with all hardware components to ensure reliability and prolonged function.



Figure 6: Area of Electrical Interference on the Mitsubishi Mirage RX Supercar (Bartram, 2018)

On the Mitsubishi Mirage all major electrical hardware such as the ECU along with Spencer Sports engine parameter data logger and battery (Photographed in Figure 6) are located in the indicated yellow area of Figure 5. Electromagnetic Interference (EMI), also known as Radio Frequency Interference (RFI), is the name given to the interference caused by an electronic devices' electromagnetic field during operation, as such this impacts the operation of other nearby electronic devices (Electronics Notes, 2019). Due to the advancement in vehicle technology and the implementation of several electronic control devices, during vehicle development manufacturers must ensure vehicles comply to the EMC standards. The ability to predict and therefore minimise EMI during the development stage of a vehicle can be achieved through the use of Computer-Aided Engineering (CAE), the benefits of which are discussed by (Mologni, et al., 2010).

The ignition system is the primary source of electrical interference across a vehicle due to the fluctuating and spikes of the voltage across the primary circuit (Deng, et al., 2008) therefore mounting all hardware for the data acquisition system out of this area must be achieved to produce reliable data.

Taking both these factors into consideration, the Motec C187 will be located on the right-hand side of the vehicle, placed forward from the area of electrical interference to ensure accurate data whilst minimising errors due to interference. SVIM 1 will be located on the left-hand side of the vehicle, behind the driver's seat to eliminate the need for wiring to cross over the driver's cockpit. Finally, SVIM 2 will be located behind the area of electrical interference on the right-hand side of the vehicle with wiring between the SVIM and Motec C187 being kept as far as possible away from the area of electrical interference.

4.2.2 Sensor Selection and Locations

4.2.2.1 Wheel Speed

As wheel speed is used as a reference point in data acquisition in conjunction with GPS data, accuracy must be ensured. Considerations must be taken due to the close proximity with the wheels of the vehicle and thus the sensor is permanently exposed to the harsh rallycross terrain.

There are two types of sensor technology available to record wheel speed for a motorsport application:

- Hall Effect
- Inductive (Magnetic Pickup)

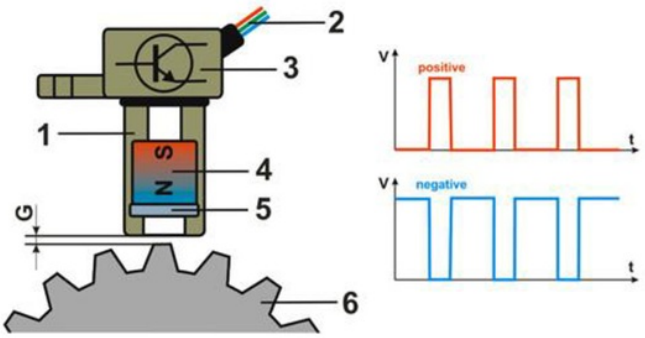


Figure 7: Hall Effect Sensor (Mucevski, 2015)

Table 11: Figure 7 Hall Effect Sensor Supporting Information

Number/Letter	Component
1	Sensor Housing
2	Output Wires
3	Integrated Electronics
4	Permanent Magnet
5	Hall Effect Device
6	Trigger Wheel
G	Air Gap

The definition of the Hall effect principle, given by its discoverer Edwin Hall in 1879 is that when a magnetic field is applied perpendicular to the current flow of an electrical conductor, a voltage difference is produced across the electrical conductor, perpendicular to both the magnetic field and current flow (Hall, 1879).

The Hall Effect sensor, seen in Figure 7 applies this principle by applying an electrical current through the Hall Effect device, the permanent magnet deflects the flow of electrons as current flows through the Hall Effect device thus creating a potential difference. The trigger wheel is used as a means of switching off the Hall Effect, as the teeth of the wheel pass the sensor the magnetic flux is diverted. It is this on/off method which produces the digital output signal (Hillier, 2014).

Hall Effect wheel speed sensors are a popular choice in both automotive and motorsport applications due to being cost effective in comparison to inductive sensors, which require an excessive amount of wire during construction in order to gain accurate measurements (AZO Sensors, 2017).

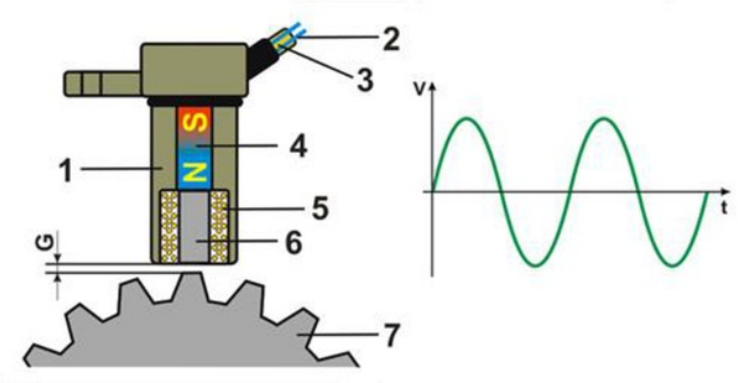


Figure 8: Inductive Sensor (Mucevski, 2015)

Table 12: Figure 8 Inductive Sensor Supporting Information

Number/Letter	Component
1	Sensor Housing
2	Output Wires
3	Coaxial Coated Protection
4	Permanent Magnet
5	Inductive Coil
6	Pole Pin
7	Trigger Wheel
G	Air Gap

An inductive sensor, shown in Figure 8, produces an analogue voltage signal through the use of a permanent magnet and an inductive coil wrapped around the pole pin. As the trigger wheel rotates and the teeth pass through the magnetic field produced by the sensor the flux density is modulated thus generating an AC voltage in the coil (Daytronic, 2019).

Disadvantages of the inductive sensor are that at lower speeds the generated analogue signal causes the AC output signal to be low, and that the magnitude of the signal varies during operation (Hillier, 2014).

Out of the option of the two types of wheel speed sensors, the DAS wheel speed will be recorded with Hall Effect sensors. This is due to disadvantages of the inductive sensor outlined by (Hillier, 2014) where during the reduced speeds that occur through the tight bends of a rallycross circuit, wheel speed accuracy is required.

The Hall Effect sensor selected for the DAS is the SP Series Wheel Speed Sensor, produced by KA Sensors which can withstand high temperatures along with a robust design. Full technical specifications can be found in Appendix A-3.

4.2.2.2 Damper Travel

Damper travel is measured by linear potentiometers, which are fitted to each suspension strut and cover the entire extension and retraction of the damper. The output is proportional to the stroke length of the damper and due to infinite resolution, are the most common device used to measure linear position.

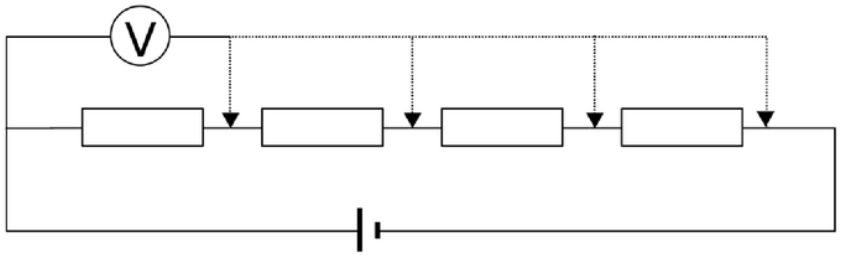


Figure 9: Linear Potentiometer (Legg, 2008)

With linear potentiometers (also known as potential dividers), resistance varies according to slider position as seen in Figure 9. The slider moves between two fixed terminals at each end along a resistive strip and as the distance between the two terminals decreases, the resistance increases thus creating a voltage decrease (Engineering 360, 2018), explained by Ohms Law (See Equation 9).

$$Voltage\ (V) = Current\ (I) \times Resistance\ (R) \qquad \text{Equation 9}$$

For a rallycross application where a vehicles suspension system is subjected to vigorous changes, the linear potentiometer must be able to withstand these changes whilst producing accurate results for data analysis.

Taking this into consideration, the KP Series KP193 Standard Heavy-Duty Linear Position Sensor, produced by KA Sensors has been selected. Designed specifically for harsh motorsport applications and boasting a linearity of equal to or less than 0.5% this makes the sensor ideal for the application. Full technical specifications can be found in Appendix A-4

4.2.2.3 Steering Angle

To record steering angle, rotary potentiometers are commonly used due to the long service life with being non-contact (McBeath, 2008), such as the case with linear potentiometers.

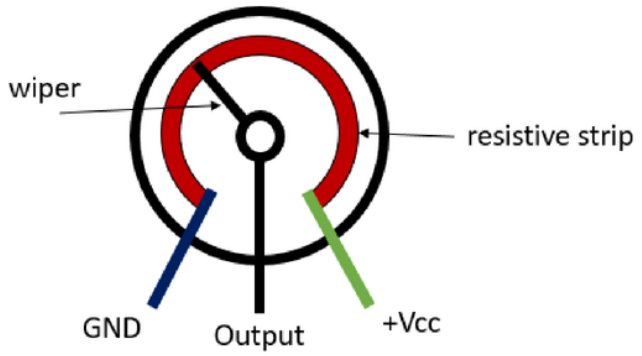


Figure 10: Rotary Potentiometer (Santos, 2016)

The mechanics of a rotary potentiometer are identical to a linear potentiometer, although rather than following a linear resistive strip, the slider (or wiper) follows a circular resistive strip, seen in Figure 10.

The rotary potentiometer selected for the DAS is the KH Series KH21 Non-Contact Rotary Position Sensor. With the option of custom programmable angles this will allow for data to be acquired from lock to lock, which due to the rallycross application is desirable. Full technical specifications can be found in Appendix A-5.

4.2.2.4 Brake Pressure

Measuring brake pressure can be achieved through the use of strain gages, typically in conjunction with a diaphragm to create a pressure transducer, allowing for high pressure such as seen in the brake system to be accurately recorded (Hitchcox, 2013)

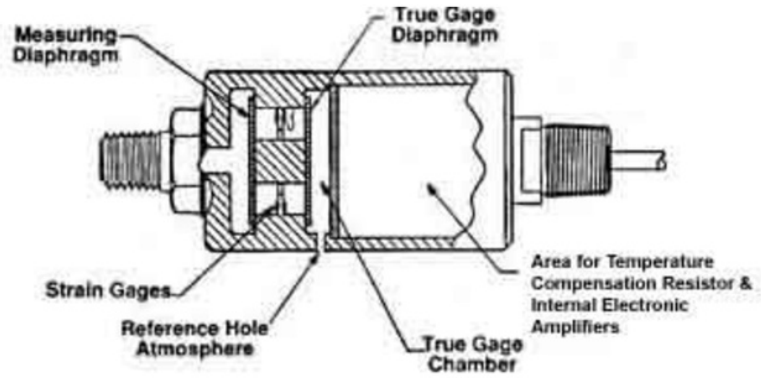


Figure 11: Pressure Transducer (Industrial Electronics, 2018)

A strain gauge consists of a solid-state semiconductor between two silicon dioxide layers which are fitted with four pressure-sensitive resistors (Hillier, 2014). The strain gauge is bonded to a diaphragm, as seen in Figure 11, which is exposed to the pressurised brake fluid, as the diaphragm is deflected strain is applied to the strain gauges and by the use of a Wheatstone full bridge circuit, two resistors are compressed whilst the other two are stretched, altering the resistance and thus the measured voltage (Bosch, 2014). The change in resistance is directly proportional to the pressure that the sensor is exposed to.

With brake pressure reaching pressure of approximately 200bar (Bosch, 2014) it is vital for the pressure transducer to be robust enough to function in excess of this pressure, therefore the ASL Series Standard Pressure Transducer by KA Sensors has been selected. Giving an accuracy of ±0.5% and the ability to withstand high temperatures make this sensor ideal for the recording of brake pressure data. Full technical specifications can be found in Appendix A-6.

4.2.2.5 Air Flow

The standard method of recording air flow around a vehicle is through the use of pitot tubes.

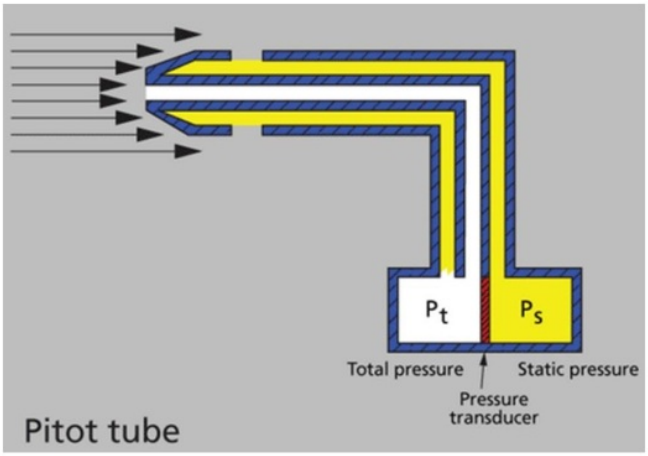


Figure 12: Pitot Tube (Denizen, 2017)

The Pitot tube, seen in Figure 12, measures air speed around a vehicle by recording both static and total pressure. Holes on the outside of the tube are connected to one side of a pressure transducer to give the static pressure whilst the centre hole is connected to the other side of the pressure transducer to give total pressure. The difference between the two pressures is measured by an electronic strain gauge, giving the dynamic pressure (Benson, 2017).

By re-arranging Bernoulli's aerodynamic equation seen in Equation 10, air velocity can be calculated as shown in Equation 11:

$$P_{STATIC} + \frac{1}{2}\rho V^2 = P_{TOTAL}\,(Constant) \qquad \text{Equation 10}$$

$$V = \sqrt{\frac{2 \times (P_{TOTAL} - P_{STATIC})}{\rho}} \qquad \text{Equation 11}$$

The Pitot tubes selected for the DAS are produced by Motec and provide an accuracy of ±0.25%. Two Pitot tubes are required to aid with the aerodynamic development of the Mirage, one located on the roof at the rear of the vehicle and a secondary Pitot tube located in the air vent located on the right hand side of the vehicle, which channels air directly to the radiator located at the rear of the vehicle. Full technical specifications can be found in Appendix A-7.

4.2.2.6 Ride Height

Ride Height is measured using a laser transducer, operating on the principle of triangulation, seen in Figure 13.

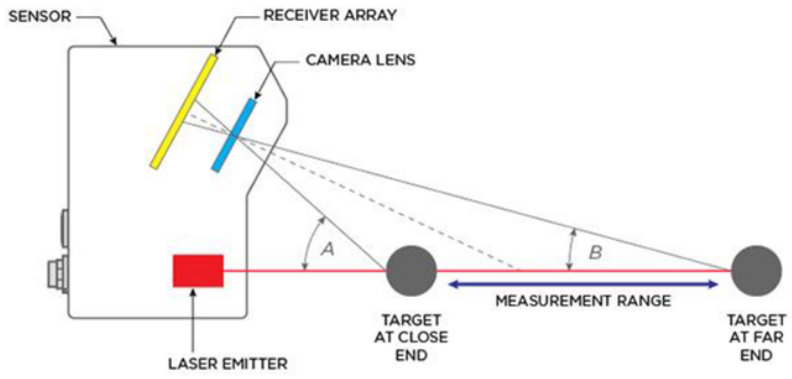


Figure 13: Laser Transducer (Pastorius, 2014)

A visible laser is emitted from the sensor, which reflects off the target surface and returns to the sensors receiver array, commonly a charge coupled device (CCD) to produce a more accurate result (AZO Sensors, 2014). As the distance increases and decreases the angle between the laser and emitter alters as seen in Figure 13, this change in angle is processed though the microcontroller embedded within the sensor and thus produces a distance relative to the change of angle (Segers, 2008).

As the accuracy of data obtained from the laser transducer is dependent on lens cleanliness, and the application of the sensor in this case recording the vehicle ride height it is crucial for the sensor to be constructed for a motorsport application. Therefore, the sensor selected for this application is the RHL 3 Laser Ride Height Sensor produced by KA Sensors, which is commonly the choice for a rally environment due to high speed logging capabilities, high accuracy and a construction designed to withstand both high temperatures and vibrations. Two ride height sensors are required for the DAS to measure the ride height at both the front and rear of the vehicle and were specified to be included by Spencer Sport, due to damper travel not accounting for tyre deflection. Full technical specifications can be found in Appendix A-8.

4.2.2.7 Tyre & Brake Temperature

Tyre and brake temperatures will both be recorded using infra-red temperature sensor technology due to the requirement of a non-contact sensor as in both cases the sensors will be recording a rotational target subject to high temperatures.

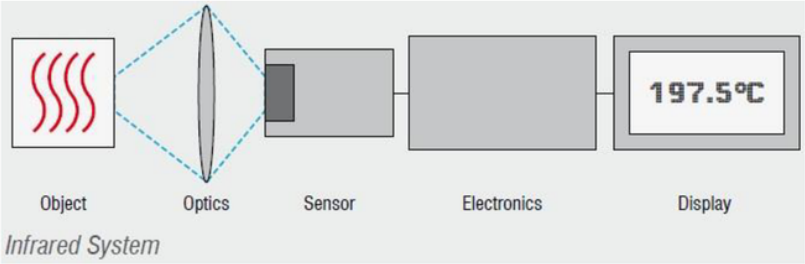


Figure 14: Infra-Red Temperature Sensor (Bestech Australia, 2019)

The construction of an Infra-red temperature sensor, as seen in simplicity in Figure 14, includes a lens to capture the heat energy produced by the target and a detector to allow the conversion of the energy to an electrical signal. Emissivity is adjusted to match that of the material of the target and the ensure accurate data is produced due to the changes in ambient temperature, a compensation circuit is used to halt the ambient temperature, modifying the sensor output (Merchant, 2017).

The DAS will include both tyre and brake temperatures recorded by high specification infra-red temperature sensors produced by Izze Racing, which communicate with the Motec C187 via CAN. Both Infra-red temperature sensors can record temperature at 16 points allowing the thorough analysis of both brakes and tyres. Full technical specifications for both tyre and brake temperature sensors can be found in Appendix A-9 and A-10 respectively.

4.2.2.8 SPEEDBOX RTK (GPS, Yaw & Pitch)

As outlined in Section 3.5.5 of this report, the Speedbox RTK will be used within the DAS to record both GPS along with Yaw and Pitch of the vehicle.

For GPS locations, Race Technology specify the mounting when using the magnetic strip provides with the Speedbox RTK, seen in Figure 15, with an 80cm baseline for the antenna strip. Figure 15 suggests minimising the distance between the Speedbox RTK and the base antenna located at the rear to ensure accurate data (Race Technology, 2012). Taking this into consideration, the Speedbox RTK will be positioned by SVIM 2 (Right), the location of which is shown in Figure 5.

Specifications are given for the correct mounting of the Speedbox base unit, the unit must be mounted as level as possible and positioned in the direction of travel, which is indicated on the unit with arrows (Race Technology, 2008). Supporting information for the Speedbox RTK can be found in Appendix A-11.

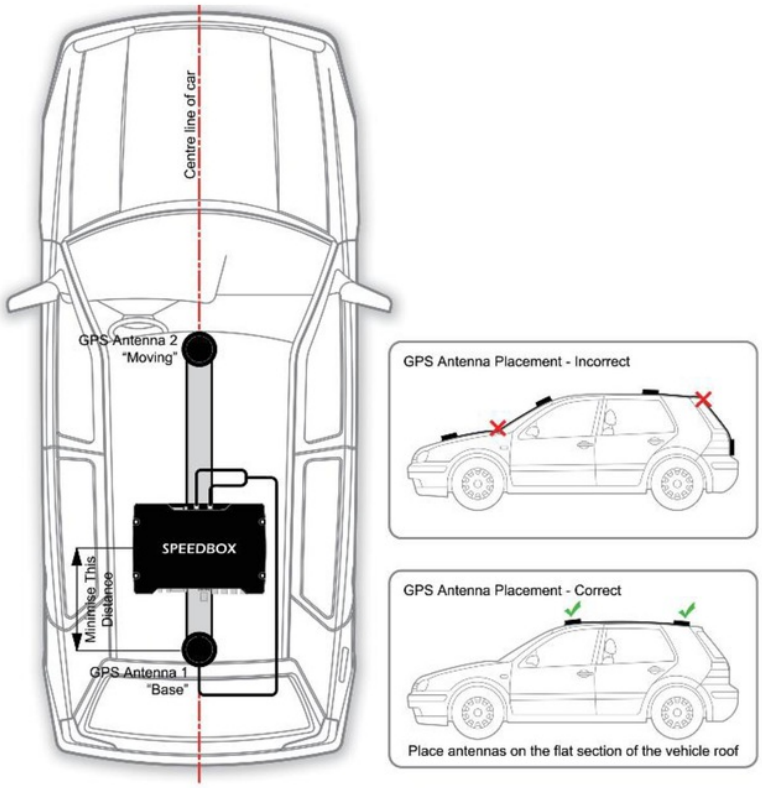


Figure 15: Mounting arrangement for the magnetic antenna strip (Race Technology, 2012)

4.2.3 Hardware Mounting

When mounting the hardware, (Yang L., 2015) states that it is crucial to minimise the vibrations which the hardware will be exposed to during usage as vibrations can produce inaccurate data along with electrical component failure due to vibration fatigue. The most popular method of isolating vibrations in a vehicle is through the use of rubber bushes, seen in vehicle engine mounts and suspension mounts, and according to (Roncen, et al., 2019) widely recognised as the best material for the absorbing vibrations. For sensor mounting, brackets must be constructed from robust enough material to withstand the environment whilst minimising the vibrations transferred from the vehicle body to the sensor.

Several components of the DAS have specific mounting details to ensure reliability and to maximise capabilities, these details can be found within the specification sheets in Appendix A. Finalising all hardware mounting in detail is recommended for further work.

4.2.3.1 Suggested Wheel Area Sensor Mounting

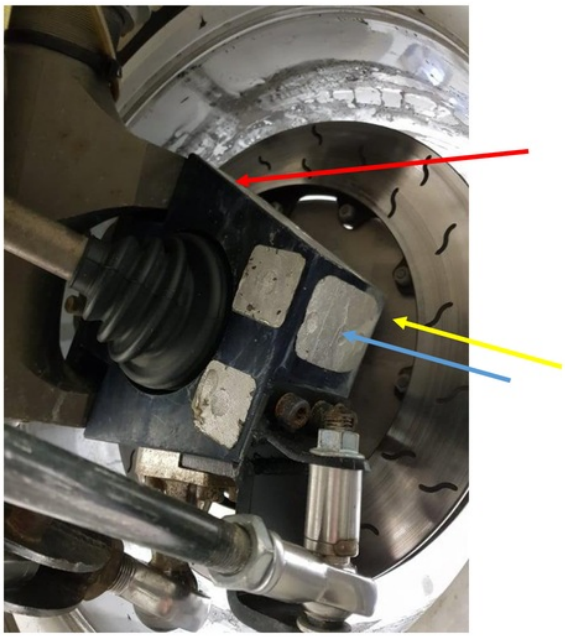


Figure 16: Mitsubishi Mirage Wheel Hub Area (Bartram, 2018)

Figure 16 shows the suggested mounting areas of the wheel speed sensors and brake temperature sensor, indicated by blue and red arrows respectively. As the wheel speed sensor requires a trigger wheel to function, this wheel can be fitted to the surface indicated by a yellow arrow. The wheel speed sensor then has the option of either being mounted to the side of the hub by a bracket or be fitted into the hub directly through the drilling of a sensor sized hole to decrease vibration. Technical specifications for the required trigger wheel dimensions can be found in Appendix A-3.

By placing the brake temperature sensor on the top of the hub, this gives the sensor a good view of the entire brake disc width. The advantage of fixing to the hub is that the sensor will have a constant view of the disc due to the hub and discs synchronised motion under suspension travel.

Wiring for both sensors will travel upwards and merge with the wiring required for the damper travel linear potentiometer, ensuring that the wiring is kept away from moving components.



Figure 17: Mitsubishi Mirage Wheel Arch Area (Bartram, 2018)

Figure 17 shows the suggested mounting points for the damper travel linear potentiometer. The red arrows represent suggested fixing points for the mounting brackets to allow the recording of data throughout the entire damper stroke. The linear potentiometer must be orientated to account for the lock to lock rotation which occurs though the MacPherson strut, along with ensuring that the potentiometer does not affect the suspension in any way and that there is enough clearance between the mounted potentiometer and surrounding components.

For tyre temperature sensors, it is suggested that they are fitted within the front of the wheel arch to allow for entire coverage of tyre surface as seen in Figure 18.



Figure 18: Izze Racing Tyre Temperature Sensor (Izze Racing, 2019)

4.3 Early Designs

Prior to meeting with Spencer Sport on the 16th of November 2018 three basic concepts were developed based on the brief provided to the university for the data acquisition project in October 2018. Each concept outlined the three hardware options has described in Section 4.1.3 of these report, where in place of the SVIMs being located at the left and right-hand sides of the vehicles the SVIMs were located front and rear of the vehicle to accommodate engine parameters. These basic concepts and supporting Pin data are included in Appendix B.

After discussions with Spencer Sport the project brief was altered to specify that the data acquisition system was required to acquire data on chassis and driver parameters only, due to the engine parameters on the Mitsubishi Mirage RX Supercar currently being logged by a separate data acquisition system. By examining the Mirage, the location of the Motec C187 was decided upon along with the relocation of the SVIMs from the front and rear of the vehicle to the left and right-hand sides of the vehicle. An updated data acquisition schematic along with supporting Pin data was designed to reflect these changed and are included in Appendix B.

Further research and the introduction of CAN based sensors, along with additional chassis parameter sensors allowed progression to be made to the final data acquisition design proposal as discussed in this report.

4.4 Final Concept

The final concept of the DAS can be seen in the schematic diagrams shown in Section 4.5 along with the supporting pin data in Section 4.6. Figure 19 shows the layout and wiring schematic for the Motec C187 direct and CAN systems. Each sensor on the DAS has a connector to ease replacement should one fail, and each corner of the vehicle is given a connector to allow the easy removal and re-fitting of the system. Another connector is used to separate the loom travelling to the rear of the vehicle from the Motec C187 and each side of the Tyre and Brake Temperature CAN system is separated through the use of connectors, as specified by Izze Racing (Izze Racing, 2019) with each side containing a 120Ω terminating resistor. Due to the Speedbox, SVIMs and Ride Height sensors requiring at minimum a 12V supply to function, the supply is taken directly from the Motec C187 supply. The two Speedbox GPS have not been included in this schematic due to cabling supplied by Race Technology and direct fitment to the Speedbox base unit.

Figure 21 shows the entire schematic for the sensors which will be directly connected to the SVIMs. As with Figure 19 each sensor has a connector, as does each corner of the vehicle.

Each side of the vehicle is fitted with a connector for easy removal of the SVIMs whilst leaving the wiring intact, hence minimising the time required to remove and refit the system.

The complete hardware list for the finalised DAS concept is as follows:

- Motec C187
- Supporting SVIMs (2)
- Speedbox RTK
- SP Series Wheel Speed Sensor (4)
- KP Series KP193 Standard Heavy-Duty Linear Position Sensor (4)
- KH Series KH21 Non-Contact Rotary Position Sensor
- ASL Series Standard Pressure Transducer (2)
- Motec Pitot Tube (2)
- RHL 3 Laser Ride Height Sensor (2)
- Izze Racing Brake Temperature Sensor (4)
- Izze Racing Tyre Temperature Sensor (4)

The required connectors, wiring and consumables can be found in Section 4.7. To ensure a high standard of connectors across the DAS, sensors should be purchased with wiring rather than the option of pre-fitted connectors. This has been accounted for when specifying the number of connectors and all sensors have been priced without pre-fitted connectors.

4.5 Wiring Diagrams

4.5.1 MOTEC C187 & CAN Schematic

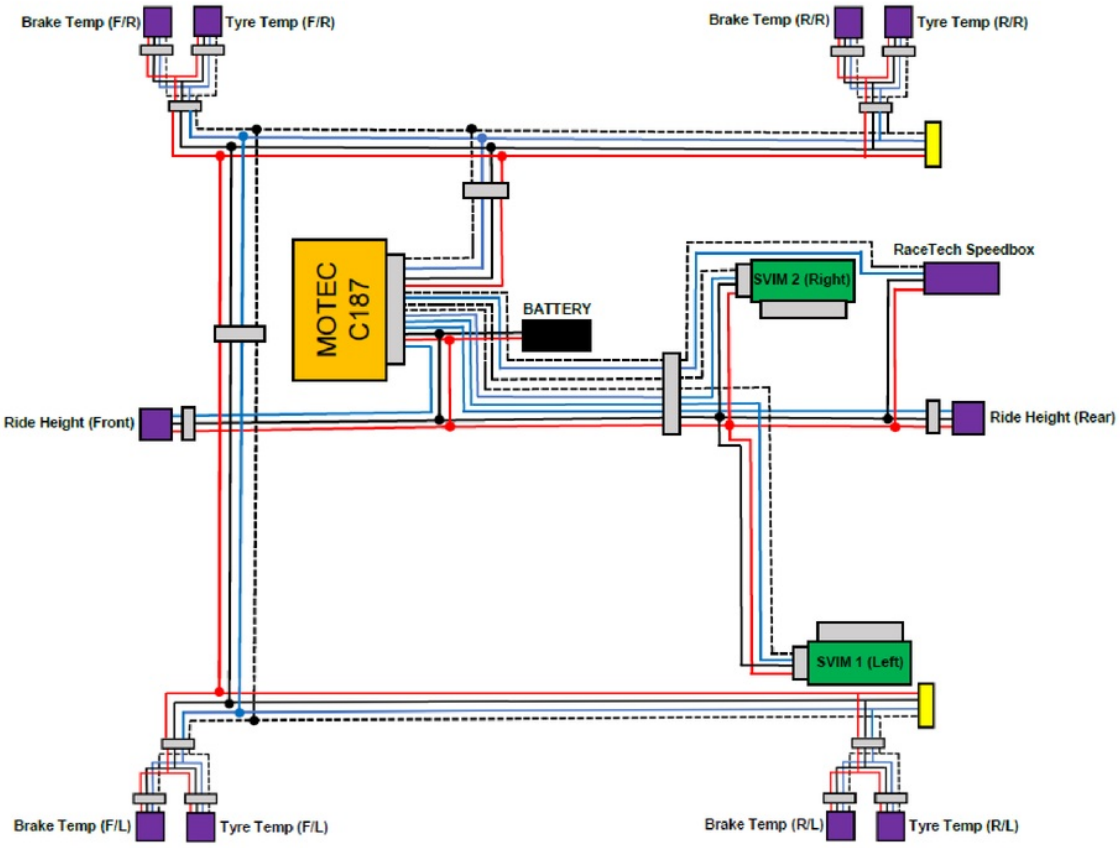


Figure 19: MOTEC C187 & CAN Schematic

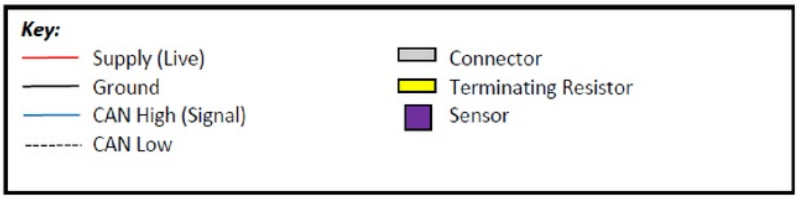


Figure 20: MOTEC C187 & CAN Schematic Key

4.5.2 SVIM Schematic

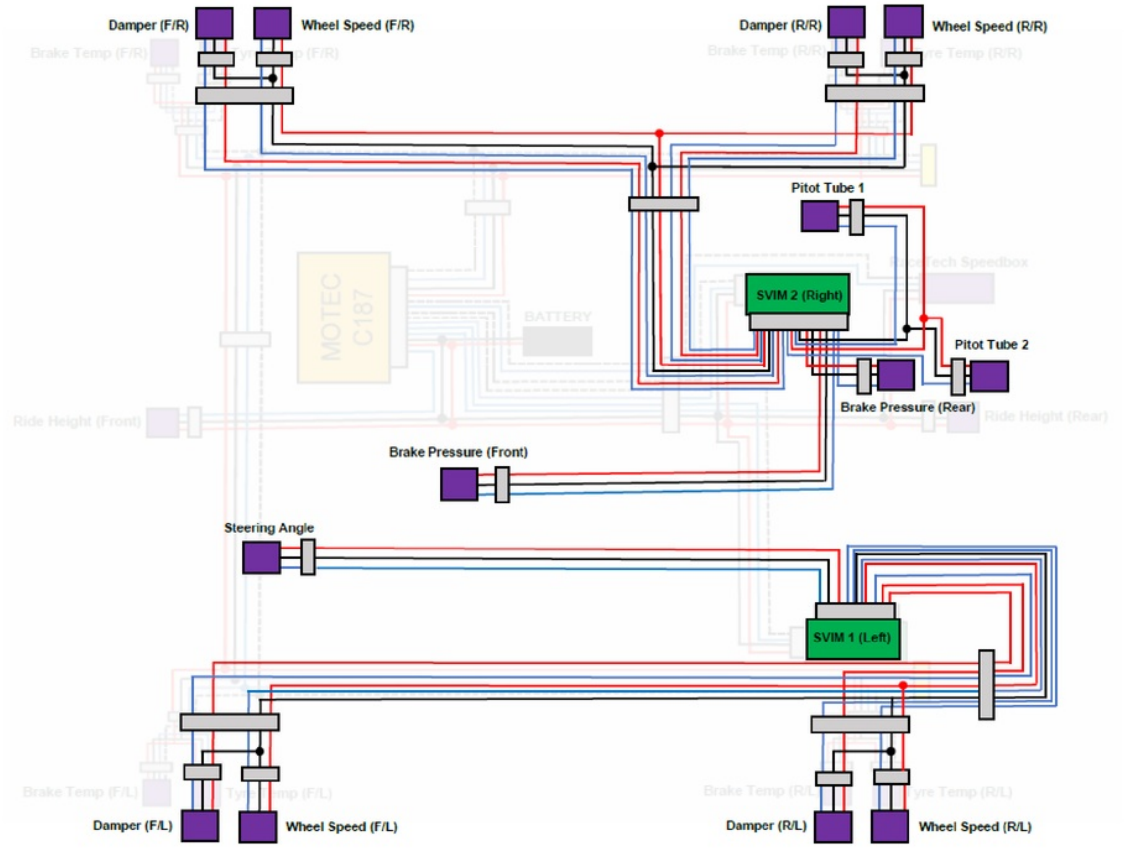


Figure 22: SVIM Schematic

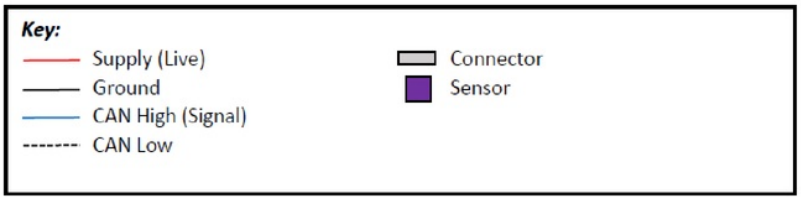


Figure 21: SVIM Schematic Key

4.6 Supporting Pin Data

Table 13: Pin Data for MOTEC C187 Direct

Sensor	CAN High (3)	Ground (1)	CAN Low (2)	Supply Motec +VE (4)
Speedbox	72	7	71	8
SVIM 1 (Left)	74	7	73	8
SVIM 2 (Right)	76	7	75	8
Tyre & Brake Temperatures	60	6	59	18
	Motec Signal (3)	**Ground (2)**	**Supply Motec +VE (1)**	
Ride Height Front	49	7	8	
Ride Height Rear	50	7	8	

Table 14: Pin Data for SVIM 1 (Left)

Sensor	SVIM Signal (3)	SVIM Ground (1)	SVIM 5V (2)	SVIM 10V (2)	Pin (3) Function
Wheel Speed F/L	41	4		53	Speed 1
Wheel Speed R/L	42	10		53	Speed 2
Damper Travel F/L	47	4	26		Analogue Volt Fast 1
Damper Travel R/L	48	10	27		Analogue Volt Fast 2
Steering Angle	8	17	44		Analogue Volt High Res 5

Table 15: Pin Data for SVIM 2 (Right)

Sensor	SVIM Signal (3)	SVIM Ground (1)	SVIM 5V (2)	SVIM 10V (2)	Pin (3) Function
Wheel Speed F/R	41	4		53	Speed 1
Wheel Speed R/R	42	10		53	Speed 2
Damper Travel F/R	47	4	26		Analogue Volt Fast 1
Damper Travel R/R	48	10	27		Analogue Volt Fast 2
Pitot Tube 1	8	17	18		Analogue Volt High Res 5
Pitot Tube 2	9	17	18		Analogue Volt High Res 6
Brake Pressure 1 (Rear)	13	17	18		Analogue Volt High Res 7
Brake Pressure 2 (Centre)	14	25	35		Analogue Volt High Res 8

4.7 Bill of Materials

4.7.1 Sensors

Table 16: Sensor Price List

Sensor	Quantity	Price	Vat Included	Total (Inc VAT)	Brand	Supplier
Wheel Speed Sensor	4	£75	Yes	£300.00	Ka Sensors	Electronic Performance Systems (EPS)
Linear Potentiometer	4	£200	Yes	£800.00	Ka Sensors	Electronic Performance Systems (EPS)
100Bar Brake Pressure	2	£90	Yes	£180.00	Ka Sensors	Electronic Performance Systems (EPS)
Rotary Potentiometer	1	£145	Yes	£145.00	Ka Sensors	Electronic Performance Systems (EPS)
Brake Temperature	4	£232.63	Yes	£930.52	Izze Racing	Izze Racing
Tyre Temperature	4	£232.63	Yes	£930.52	Izze Racing	Izze Racing
Pitot Tube	2	£651.48	No	£1,563.55	Motec	M-Cal.com
Ride Height	2	£1,632.28	Yes	£3,264.56	Ka Sensors	Milspec Wiring

4.7.2 Connectors

Table 17: Connector Price List

Connector	Quantity	Price	VAT Included	Total (Inc. VAT)	Brand	Supplier
Motec & SVIMS:						
Motec 79 Pin Autosport Connector	1	£157.34	No	£188.81	Deutsch Autosport AS	M-Cal.com
Motec 55 Pin Autosport Connector	2	£126.68	No	£304.03	Deutsch Autosport AS	M-Cal.com
Motec 5 Pin Autosport Connector	2	£54.75	No	£131.40	Deutsch Autosport AS	Kempower Motorsport
Wheel Area Sensors:						
Deutsch Autosport ASU 3 Pin Connector #22 Contacts	8	£33.32	Yes	£266.56	Deutsch Autosport ASU	Racespec

Deutsch Autosport ASU 3 Socket Connector #22 Contacts	8	£39.37	Yes	£314.96	Deutsch Autosport ASU	Racespec
Deutsch Autosport Size 8 Pin Connectors #22 Contacts	18	£53.50	Yes	£963.00	Deutsch Autosport AS	Racespec
Deutsch Autosport Size 8 Socket Connectors #22 Contacts	18	£58.93	Yes	£1,060.74	Deutsch Autosport AS	Racespec
Pitot Tubes & Brake Pressures:						
Deutsch Autosport ASU 3 Pin Connector #22 Contacts	4	£33.32	Yes	£133.28	Deutsch Autosport AS	Racespec
Deutsch Autosport ASU 3 Socket Connector #22 Contacts	4	£39.37	Yes	£157.48	Deutsch Autosport AS	Racespec
Ride Height:						
Deutsch Autosport ASU 3 Pin Connector #22 Contacts	2	£33.32	Yes	£66.64	Deutsch Autosport AS	Racespec
Deutsch Autosport ASU 3 Socket Connector #22 Contacts	2	£39.37	Yes	£78.74	Deutsch Autosport AS	Racespec
SVIMS to Motec:						
Deutsch Autosport Size 10 Pin Connectors #22 Contacts	1	£53.67	Yes	£53.67	Deutsch Autosport AS	Racespec
Deutsch Autosport Size 10 Socket Connectors #22 Contacts	1	£60.48	Yes	£60.48	Deutsch Autosport AS	Racespec
Terminating Resistor Connector:						
Deutsch Autosport ASL Socket Connector	2	£37.59	Yes	£75.18	Deutsch Autosport ASL	RaceSpec
Pins/Sockets:						
Deutsch Autosport Size 22 Pin Terminal	144	£0.93	Yes	£133.92	Deutsch Autosport AS	Racespec

Deutsch Autosport Size 22 Socket Terminal	144	£0.93	Yes	£133.92	Deutsch Autosport AS	Racespec
Deutsch Autosport ASL Size 23 Socket Terminal	4	£2.26	Yes	£9.04	Deutsch Autosport ASL	Racespec
Deutsch Autosport Size 23 ASC/ASU 3 Way Pin Terminal	42	£1.82	Yes	£76.44	Deutsch Autosport ASU	Racespec
Deutsch Autosport Size 23 ASC/ASU 3 Way Socket Terminal	42	£2.12	Yes	£89.04	Deutsch Autosport ASU	Racespec

4.7.3 Wiring

Table 18: Wiring Price List

Wire	AWG	Colour	Length Required (m)	Length in Feet	Price Per Foot	VAT Included	Total (Inc. VAT)	Brand	Supplier
Tefzel	#22	Red	40	131.2	0.15	Yes	£19.68	Tefzel	OHM Racing
Tefzel	#22	Black	40	131.2	0.15	Yes	£19.68	Tefzel	OHM Racing
Tefzel	#22	Blue	39	128	0.15	Yes	£19.20	Tefzel	OHM Racing
Tefzel	#22	White	14	46	0.15	Yes	£6.90	Tefzel	OHM Racing

4.7.4 Consumables

Table 19: Consumables Price List

Consumable	Quantity Required	Price	VAT Included	Total (Inc. VAT)	Brand	Supplier
Wheel Arch Grommets	4	£3.50	No	£16.80	RaceTech	RaceTech Direct
Body Grommets for Ride Height Sensors	2	£3.50	No	£8.40	RaceTech	RaceTech Direct
Roof Pitot Tube & GPS Grommets	2	£3.50	No	£8.40	RaceTech	RaceTech Direct
Cable Sheathing	40	£1.26	Yes	£50.40	N/A	RaceSpec
Terminating Resistors	2	£71.43	Yes	£142.86	ASL	RaceSpec

4.7.5 Bill of Materials Summary

Table 20: Bill of Materials Summary

Item	Total Cost
Sensors	£8,114.15
Connectors	£4,297.33
Wiring	£65.46
Consumables	£226.86
Total: £12,261.44	

A bill of materials is used during the design process to give an overview of the materials and components required to manufacturer a product. For this project, the bill of materials has been extended to include the prices of the required components. No budget was specified by Spencer Sport therefore components specifically for a motorsport application have been selected due to high specification and reliability.

Table 16 shows all required sensors to produce the DAS. As specified by Spencer Sport, KA Sensors have been selected where possible due to the maintained relationship between Spencer Sport and KA Sensors. Had a budget for the DAS been given, several sensors could be swapped for a cheaper alternative, although reliability and quality would be compromised, thus increasing over all DAS cost in the long run due to the additional cost of replacing failed sensors. All sensors required for the DAS comes to a total of £8,114.15, as outlined in Table 20.

All connectors required are shown in Table 17. As stated in Section 3.5.7, Deutsch Autosport connectors have been selected, with the ASU variant being used for sensors (excluding CAN based sensors) due to the smaller keyway sizes provided. Additional connectors have been included to ease fitment and removal of the system, locations of which can be seen in Section 4.5. Table 20 shows that the total investment required to purchase all connectors is £4,297.33.

To differentiate between each wire exiting the sensors, colour coded wiring has been selected where:

- Red: Supply (Live)
- Black: Ground
- Blue: CAN High
- White: CAN Low

The advantage of using colour coded wiring is by matching the wiring diagram, the electrical system will be simple to follow should any failure occur, Table 18 shows that each coloured

wire is priced identically, therefore colour coding does not increase the DAS cost in any way. To correctly suggest the lengths of wire required, during visiting Spencer Sport in November several areas of the vehicle were measured by a flexible measuring tape in relation to the Motec C187 location. The breakdown of distances can be seen in Appendix C. Table 20 shows that the wiring is the cheapest element of the DAS, costing a total of £65.46.

Finally, Table 19 contains a list of all consumables required for the DAS. Grommets will be used to allow wiring to cross through the bodywork, firstly to seal the holes required to eliminate the chance of environmental factors travelling into the vehicle and secondly to eliminate the chance of the wires rubbing against any sharp edges due to the drilled holes. Cable Sheathing has been selected to protect the wiring further, whilst still retaining the flexibility required during wire routing. As specified by Izze Racing, two terminating resistors have been included, a requirement for the tyre and brake temperature sensor CAN circuit. The total for all consumables is £226.86 as seen in Table 20.

The total cost for all materials and components required to manufacture the DAS is £12,261.44. It must be noted that this total does not include any specialist tools required for manufacturing nor any component which the university will be supplying (Motec C187, SVIMs and Speedbox).

Although a high cost system, the benefits of the DAS as a development tool to improve the performance of a vehicle could be seen as outweighing the cost, thus raising the question of how much is a race team willing to pay to win?

As with any race team, Spencer Sport benefit from several commercial partnerships along with sponsors (Spencer Sport, 2019) whose investments could be used to fund the DAS. Spencer Sport could fund the system themselves, with the reasoning that an increased performance vehicle can lead to an increase in competition wins, which could lead to further partnerships and sponsors.

5 Design Limitations

As with any DAS, the system is limited to the capabilities of the hardware used throughout the system. One DAS limitation as described by (Dunnicliff & Green, 1993) is the blind acceptance of recorded data, whether correct or not although a skilled data analysis engineer would be capable of recognising any unusual data trends.

Limitations of a DAS are typically dependent on cost, but as described in Section 4.7, no budget was specified by Spencer Sport for the design of the DAS thus allowing freedom for the selection of high specification sensors and connectors.

The limitations of the proposed design are as follows:

- *Chassis Parameter Based:* Should Spencer Sport want to expand the system to account for engine parameters the locations of the SVIMs would need to be relocated and the system re-designed to compensate for the additional parameters.

- *Available Testing Time:* As described in Section 3.6.2, the Motec C187 memory will reach maximum capacity after 2 hours and 49 minutes of testing under the specified frequencies. As race teams often spend a whole day vehicle testing, the Motec C187 would require data to be downloaded from the system frequently. Should the DAS testing prove that these frequencies are insufficient and require increasing, maximum capacity would be achieved much earlier.

- *Specifically designed for the Motec C187:* The main limitation of the proposed design is that the system is unfortunately not universal to all data loggers, although it could be argued that with the relevant pin data and by changing the data logger connector the system could fit a different logger, however, the SVIMs are only compatible with Motec data loggers (MoTeC Pty. Ltd, 2018).

6 Discussions & Conclusion

6.1 Discussions

6.1.1 Sensors

As discussed in Section 3 and 4 of this report, selecting the correct sensors for application is vital whilst ensuring that they produce accurate and reliable information for data analysis. (Barnes, et al., 2000) describe the importance of ensuring that sensors in a motorsport environment can withstand both high temperatures and high levels of vibration and thus has influenced the choice of sensors selected during this project. Due to a budget not specified, as outlined in Section 4.7.5, this has allowed for the selection of high specification sensors for the DAS to ensure the highest quality of data to be achieved. The advantage of utilising software maths channels as described in Section 3.6.1 was the elimination of recording propshaft speed though sensors, which due to close proximity with the exhaust system would cause mounting and sensor issues and the possibility of inaccurate data due to heat exposure, the effects of which are outlined in Section 3.5.7.3 and 4.2.1.

6.1.2 Connectors

Section 3.5.7 discusses the factors which must be considered when selecting connectors for a motorsport application. Taking these factors into consideration, the Deutsch AS Standard Series Connectors were selected for the DAS, due to their high specifications and popularity within the motorsport industry. During design, as seen in Section 4, connectors have been used to allow the removal and refitting of the system to occur with ease. Allowing the easy removal of the Motec C187 and SVIMs whilst leaving the bulk of the DAS intact make it simple for Spencer Sport to remove the system should the university require the return of these DAS elements. A further advantage of the use of additional connectors is that the sensors can stay attached to the vehicle at all times, eliminating the need to remove the entire system if maintenance is required to just one particular area. Each sensor is fitted with a connector to allow for easy replacement should failure occur.

6.1.3 Wire Selection

Quality of wiring is a crucial factor to any DAS as all data transfer occurs through the wiring, this is discussed in Section 3.5.8. Tefzel wiring has been selected due to its high temperature rating and flexibility, an important factor for wire routing. Motec specifies that the wire should be AWG 22 for two specific reasons, firstly to accommodate the 79 Pin Autosport Connector and secondly not to exceed the 5A current rating of Motec C187 as AWG 22 Tefzel wire also has a maximum current rating of 5A (MoTeC Pty Ltd, 2018). As

described in Section 3.5.8, bunding of the wires is suggested to ensure reliability with the added advantage of reducing electrical interference.

6.1.4 System Design

During DAS design, as described in Section 4, it has been crucial to relate back to application during the whole process, whilst achieving the aims outlined in Section 1.1. The proposed system design ensures high quality and reliability of data by using high specification sensors, connectors and wiring. Considerations have been made for working environment and other performance-effecting factors to prolong the life of the DAS.

By utilising only 19.65% of the available CAN bandwidth, the option is available to add further sensors should they be required thus increasing the capabilities of the system, as additional parameters are recorded more maths channels can be incorporated to achieve an increased understanding of the vehicles behaviour.

The cost of each component as outlined in Section 4.7.5 has been justified, with higher quality components the reliability and accuracy of data easily outweighs the future cost that may occur with failure of cheaper components.

6.2 Conclusion

The design of a DAS for a rallycross application has proven to be a substantial task due to the extensive research required to justify and produce a high quality and reliable system. The advantage of having no budget limitation has meant that the focus has entirely been on creating a system with the best technology available to ensure the data obtained can aid Spencer Sport with the development of the Mitsubishi Mirage RX Supercar and increase vehicle performance. The requirement to re-design the system meant that the design was not finalised until March 2019, therefore manufacturing the system unfortunately could not begin as originally hoped for.

This report contains all the necessary information required to begin the manufacturing process, with all sensors, connectors, wiring and consumables accounted for along with system schematics and supporting pin data. Each component selected has been thoroughly researched and justified throughout this report to ensure the finest custom DAS for Spencer Sport.

To conclude:

- The aims of the project as outlined in Section 1.1 have been achieved with a finalised design concept contained within this report.
- The manufacture and testing of the DAS are recommended for further work.

7 Recommendations for further work

As discussed in Section 5.2.3, firstly all hardware mounting is recommended for further work due to the design of the DAS being the primary focus of the project. By finalising all mounting, all required materials can be added to the Bill of Material thus giving the final overall cost of the DAS. To finalise the exact mounting positions, it is suggested that further visits to Spencer Sport be undertaken to see the Mitsubishi Mirage, thus allowing the required measurements can be taken and the correct clearances between the mounted sensors and any surrounding moving components to be determined.

With hardware mounting finalised, all materials can then be purchased, and the manufacturing of the loom can commence. As outlined in Section 2, the continuous re-design of the system, along with personal underestimation of the time required to finalise a DAS design concept meant that manufacturing of the loom did not occur as the final system design was not achieved until March 2019. The design outlined in this report should ease the manufacturing process as both the schematics and supporting pin data are supplied in Sections 4.5 and 4.6 respectively.

After manufacturing has taken place, the DAS should be subjected to rigorous testing to ensure reliability across the system. Once testing is complete and Spencer Sport are happy with the system, the addition of further maths channels within Motec i2 Pro can be applied if required as discussed in Section 3.6.

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11 Appendices

Appendix A: Hardware Technical Specifications

A-1: MOTEC C187 Pin Data

Pin List by Pin Number

Pin	*Name*	*Function*
1	AV15	Analogue Voltage Input 15 (with 44 I/O upgrade)
2	AV16	Analogue Voltage Input 16 (with 44 I/O upgrade)
3	AV17	Analogue Voltage Input 17 (with 44 I/O upgrade)
4	AV18	Analogue Voltage Input 18 (with 44 I/O upgrade)
5	AV19	Analogue Voltage Input 19 (with 44 I/O upgrade)
6	0V	Sensor 0 V
7	BAT-	Battery Negative
8	BAT+	Battery Positive
9	AUX1	Auxiliary Output 1
10	AUX2	Auxiliary Output 2
11	AUX3	Auxiliary Output 3
12	AUX4	Auxiliary Output 4
13	AUX5	Auxiliary Output 5
14	AUX6 / LIN	Auxiliary Output 6 / LIN
15	RS232-2 TX	RS232-2 Transmit Output
16	RS232-2 RX	RS232-2 Receive Input
17	0V	Sensor 0 V
18	5V	Sensor 5 V
19	AV7	Analogue Voltage Input 7
20	AV8	Analogue Voltage Input 8
21	AV9	Analogue Voltage Input 9
22	AV10	Analogue Voltage Input 10
23	AV11	Analogue Voltage Input 11 (with 44 I/O upgrade)
24	AV12	Analogue Voltage Input 12 (with 44 I/O upgrade)
25	AV13	Analogue Voltage Input 13 (with 44 I/O upgrade)

Figure 23: Motec C187 Pin Data (MoTeC Pty Ltd, 2018)

Pin	Name	Function
26	AV14	Analogue Voltage Input 14 (with 44 I/O upgrade)
27	0V	Sensor 0 V
28	5V	Sensor 5 V
29	VID1	Video Input 1
30	VID0V	Video 0 V
31	VID2	Video Input 2
32	VID3	Video Input 3
33	0V	Sensor 0 V
34	AT1	Analogue Temp Input 1
35	AT2	Analogue Temp Input 2
36	AT3	Analogue Temp Input 3
37	AT4	Analogue Temp Input 4
38	AT5	Analogue Temp Input 5 (with 44 I/O upgrade)
39	AT6	Analogue Temp Input 6 (with 44 I/O upgrade)
40	0V	Sensor 0 V
41	AT7	Analogue Temp Input 7 (with 44 I/O upgrade)
42	AT8	Analogue Temp Input 8 (with 44 I/O upgrade)
43	0V	Sensor 0 V
44	5V	Sensor 5 V
45	AV1	Analogue Voltage Input 1
46	AV2	Analogue Voltage Input 2
47	AV3	Analogue Voltage Input 3
48	AV4	Analogue Voltage Input 4
49	AV5	Analogue Voltage Input 5
50	AV6	Analogue Voltage Input 6
51	0V	Sensor 0 V
52	DIG1	Digital Input 1

Figure 24: Motec C187 Pin Data Continued (MoTeC Pty Ltd, 2018)

Pin	Name	Function
53	DIG2	Digital Input 2
54	DIG3	Digital Input 3
55	DIG4	Digital Input 4
56	0V	Sensor 0 V
57	SW1	Switch Input 1
58	SW2	Switch Input 2
59	CAN4L	CAN 4 Low
60	CAN4H	CAN 4 High
61	0V	Sensor 0 V
62	8V	Sensor 8 V
63	SPD1	Speed Input 1
64	SPD2	Speed Input 2
65	SPD3	Speed Input 3
66	SPD4	Speed Input 4
67	E-TX+	Ethernet Transmit +
68	E-TX–	Ethernet Transmit –
69	AV20	Analogue Voltage Input 20 (with 44 I/O upgrade)
70	RS232-1 TX	RS232 Transmit Output
71	CAN3L	CAN 3 Low
72	CAN3H	CAN 3 High
73	CAN1L	CAN 1 Low
74	CAN1H	CAN 1 High
75	CAN2L	CAN 2 Low / RS232 Ground Input
76	CAN2H	CAN 2 High / RS232 Receive Input
77	E-RX+	Ethernet Receive +
78	E-RX–	Ethernet Receive –
79	RS232-1 RX	RS232 Receive Input

Figure 25: Motec C187 Pin Data Continued (MoTeC Pty Ltd, 2018)

A-2: SVIM Data Sheet

MoTeC ENGINE MANAGEMENT & DATA ACQUISITION SYSTEMS

PRODUCT DATASHEET
SVIM #18111 rev 4.0

SVIM Synchronous Versatile Input Module

Part Number #18111



Basic Specifications

Inputs

- 6 x Fast analogue voltage inputs
- 10 x High resolution analogue voltage inputs
- 8 x High resolution differential analogue voltage inputs
- 2 x Speed inputs

Internal sensors

- Battery voltage
- Internal temperature
- Internal voltages

Communications

- 1 x CAN

Power Supply

- Operating voltage 7 - 30 V
- Operating current 0.22 A excluding sensor currents
- Reverse battery protection
- Battery transient protection

Physical

- Case size 48 x 90 x 26.2 mm
- Weight 150 grams
- Connectors
  - 1 x 55 pin Autosport connector
  - 1 x 5 pin Autosport connector
- Internal temperature range –40 to 85 °C
- Ambient temperature range –40 to 70 °C

Other Information

Compatibility

- MoTeC Data Loggers: ACL and ADL3

The **SVIM (Synchronous Versatile Input Module)** is a compact expander that works in conjunction with the ACL and ADL3 Data Loggers to facilitate the synchronised logging of high speed, high resolution inputs.

The SVIM acquires data of the highest integrity for use in advanced chassis and suspension analysis. It samples 18 inputs at the same instant in time using 18 separate converters with 5th order anti-aliasing filters.

Multiple SVIMs are synchronised so that every SVIM in the vehicle samples its high resolution AV inputs at the same instant in time. This is important when looking at the relationships of signals collected from different sensors around the vehicle and useful for test rigs and real time simulations.

SVIMs are versatile in nature and can be located close to sensors, reducing the weight and complexity of wiring. When used in multiples, up to 200 sensor inputs are available. The SVIM supports many different types of sensors, including unamplified thermocouples and strain gauges.

The SVIM is configured and controlled using Data Logger Manager software, that has special programming functions for the SVIM.

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www.motec.com, Ph 61 3 9761 5050, Fax 61 3 9761 5051, support@motec.com.au
Product specifications are subject to change

Figure 26: SVIM Data Sheet (MoTeC Pty. Ltd, 2018)

Connectors and Pinout

Connector 1

55 pin Autosport connector
Mating connector: #68090

Pin	Name	Function
1	0V 1	Sensor 0 V 1
2	AV H1	Analogue Volt High Res 1
3	AV H2	Analogue Volt High Res 2
4	0V 4	Sensor 0 V 4
5	0V 1	Sensor 0 V 1
6	AV H3	Analogue Volt High Res 3
7	AV H4	Analogue Volt High Res 4
8	AV H5	Analogue Volt High Res 5
9	AV H6	Analogue Volt High Res 6
10	0V 4	Sensor 0 V 4
11	R1	Pull-up Resistor 1
12	R2	Pull-up Resistor 2
13	AV H7	Analogue Volt High Res 7
14	AV H8	Analogue Volt High Res 8
15	AV D1+	Analogue Volt Diff 1 +
16	AV D1−	Analogue Volt Diff 1 −
17	0V 3	Sensor 0 V 3
18	5V	Sensor 5 V
19	AV H9	Analogue Volt High Res 9
20	AV H10	Analogue Volt High Res 10
21	AV D8+	Analogue Volt Diff High Res 8 +
22	AV D8−	Analogue Volt Diff High Res 8 −
23	AV D2+	Analogue Volt Diff High Res 2 +
24	AV D2−	Analogue Volt Diff High Res 2 −
25	0V 3	Sensor 0 V 3
26	5V	Sensor 5 V
27	5V	Sensor 5 V
28	AV D7+	Analogue Volt Diff High Res 7 +
29	AV D7−	Analogue Volt Diff High Res 7 −
30	AV D5+	Analogue Volt Differ High Res 5 +
31	AV D5−	Analogue Volt Diff High Res 5 −
32	0V 2	Sensor 0 V 2
33	R3	Pull-up Resistor 3
34	R4	Pull-up Resistor 4
35	5V	Sensor 5 V
36	AV D4+	Analogue Volt Diff High Res 4 +
37	AV D4−	Analogue Volt Diff High Res 4 −
38	AV D6+	Analogue Volt Diff High Res 6 +
39	AV D6−	Analogue Volt Diff High Res 6 −
40	0V 2	Sensor 0 V 2
41	SPD1	Speed 1
42	SPD2	Speed 2
43	5V	Sensor 5 V
44	5V	Sensor 5 V
45	AV D3+	Analogue Volt Diff High Res 3 +
46	AV D3−	Analogue Volt Diff High Res 3 −
47	AV F1	Analogue Volt Fast 1
48	AV F2	Analogue Volt Fast 2
49	AV F3	Analogue Volt Fast 3
50	AV F4	Analogue Volt Fast 4
51	AV F5	Analogue Volt Fast 5
52	AV F6	Analogue Volt Fast 6
53	10V	Sensor 10 V
54		Not Used
55		Not Used

Connector 2

5 pin Autosport connector
Mating connector: #65033

Pin	Name	Function
1	BAT −	Battery −
2		Not Used
3	BAT +	Battery +
4	CAN LO	CAN Low
5	CAN HI	CAN High

Figure 27: SVIM Data Sheet Continued (MoTeC Pty. Ltd, 2018)

A-3: Wheel Speed Sensor Data Sheet

ka sensors
SENSE | ANALYSE | CONTROL

SP Series
Wheel Speed Sensor



Sensors For Motorsport

The SP Series of Wheel Speed Sensors have been designed as simple compact sensors suited to the demanding motorsport and automotive testing industries.

The main construction is stainless steel with a maximum operating temperature of 150°C, which provides for a robust sensor even in exposed areas such as the engine bay or wheel hub.

By using a proven 'Hall Effect' sensing technology, the SP detects a change in magnetic field as the target asses the sensors tip. The output transistor switches its state as the target passes, so giving a measurable pulse train which can be used within standard data logging equipment or ECU's.

Technical Specifications

Measurement Frequency	8KHz
Sensor Type	Hall Effect
Mounting	M12 x 1.25 or 7/16-20UNF-2A Thread, 2x Lock Nuts
Sensing Range (Air Gap)	2 to 3mm
Target Size (Width x Length)	8mm Wide x 1mm Long (Minimum)
Output	NPN. Internal Pullup Resistor Value 10KΩ
Max Load Current	25mA Max
Supply	5-24Vdc (10mA)
Operating Temperature Range	-40°C to +150°C
Construction	303 Grade Stainless Steel
Electrical Connection	50cm 22AWG 55Spec Cable + DR25 Sleeve
Thread Dimensions	Please See Mechanical Drawings
Protection Class	IP67
EMC Protection	EN 560947-5-2
Weight (Excluding Cable)	25g
Options	Cable Specifications and Labelling

KA Sensors adopts a continuous development program which sometimes necessitates specification changes without notice.

Features

- Miniature Size
- M12 or 7/16 Mounting
- NPN Output
- 5-24V Supply
- IP67 Sealed
- High Temperature

Applications

- Drive Shaft Speed
- Traction Control
- Launch Control
- Wheel Speed

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SP12 10.18

PRESSURE | TEMPERATURE | FORCE | TORQUE | POSITION | SPEED | ACCELERATION | GYRO

Figure 28: Wheel Speed Sensor Data Sheet (KA Sensors, 2019)

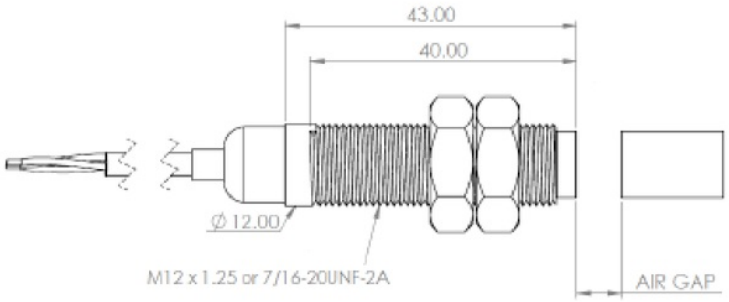
PART NUMBER CONFIGURATOR

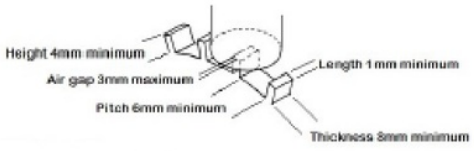
SP □ - □ - □ - □ - □

Thread Size	7/16-20 UNF-2A Male	71
	M12 x 1.25 Male	12
Output	NPN. Internal Pullup Resistor Value 10KΩ	NPN
Thread Length	40mm Long	40
Cable Length	50cm 22AWG 55Spec Cable + DR25 Sleeve	050
Special Code	None	000

The KA configuration tool is used to specify a standard KA Sensor, other options are available.

MECHANICAL DETAILS





CONNECTION DETAILS

+Ve Supply	0V Supply	Signal
Red	Black	White

Sense
Analyse
Control

Services for:

- Data Logging
- Telemetry
- Controls
- Wiring

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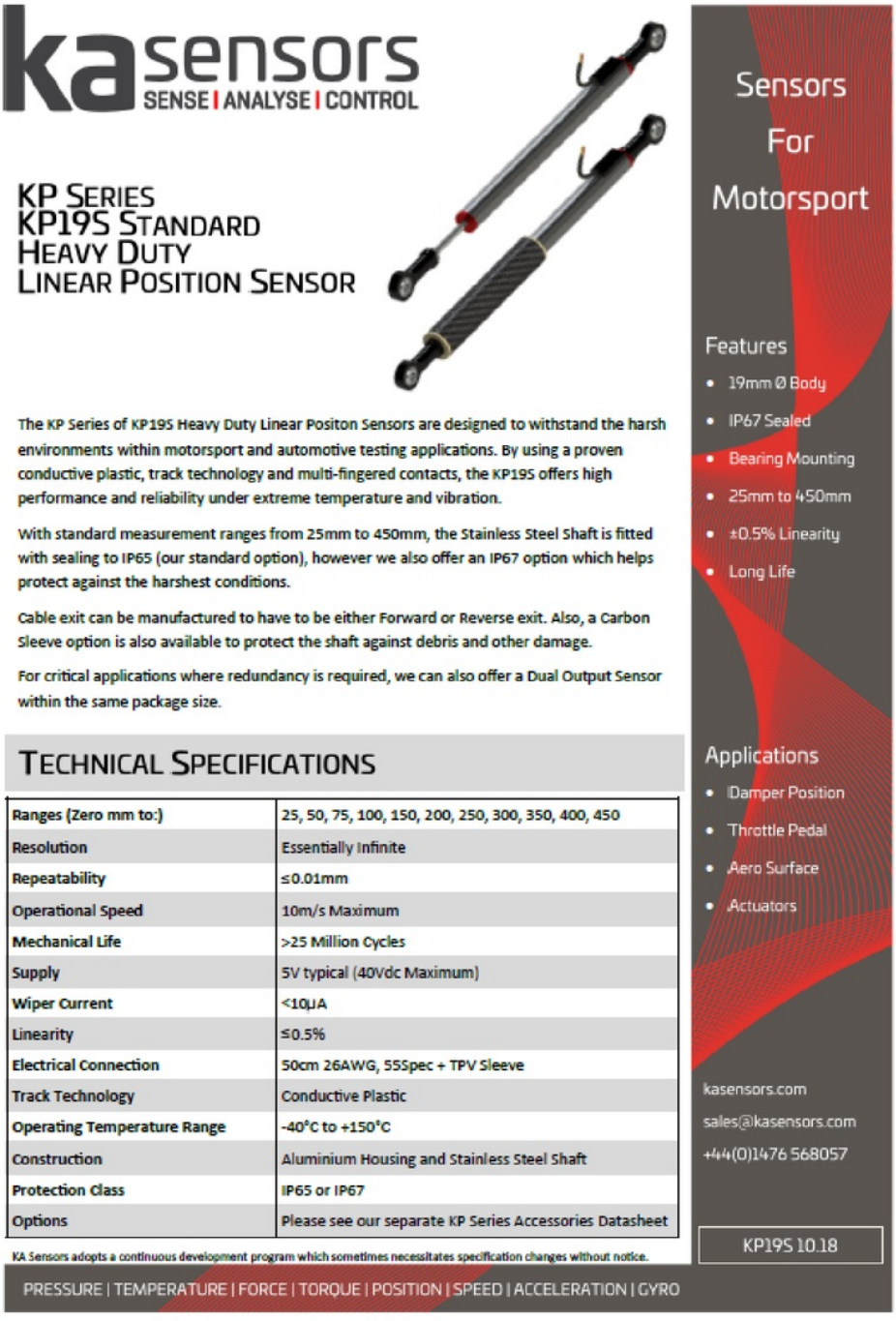
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Figure 29: Wheel Speed Sensor Data Sheet Continued (KA Sensors, 2019)

A-4: Linear Potentiometer Data Sheet



ka sensors
SENSE | ANALYSE | CONTROL

KP Series
KP19S Standard
Heavy Duty
Linear Position Sensor

The KP Series of KP19S Heavy Duty Linear Positon Sensors are designed to withstand the harsh environments within motorsport and automotive testing applications. By using a proven conductive plastic, track technology and multi-fingered contacts, the KP19S offers high performance and reliability under extreme temperature and vibration.

With standard measurement ranges from 25mm to 450mm, the Stainless Steel Shaft is fitted with sealing to IP65 (our standard option), however we also offer an IP67 option which helps protect against the harshest conditions.

Cable exit can be manufactured to have to be either Forward or Reverse exit. Also, a Carbon Sleeve option is also available to protect the shaft against debris and other damage.

For critical applications where redundancy is required, we can also offer a Dual Output Sensor within the same package size.

Technical Specifications

Ranges (Zero mm to:)	25, 50, 75, 100, 150, 200, 250, 300, 350, 400, 450
Resolution	Essentially Infinite
Repeatability	≤0.01mm
Operational Speed	10m/s Maximum
Mechanical Life	>25 Million Cycles
Supply	5V typical (40Vdc Maximum)
Wiper Current	<10µA
Linearity	≤0.5%
Electrical Connection	50cm 26AWG, 55Spec + TPV Sleeve
Track Technology	Conductive Plastic
Operating Temperature Range	-40°C to +150°C
Construction	Aluminium Housing and Stainless Steel Shaft
Protection Class	IP65 or IP67
Options	Please see our separate KP Series Accessories Datasheet

KA Sensors adopts a continuous development program which sometimes necessitates specification changes without notice.

Sensors For Motorsport

Features
- 19mm Ø Body
- IP67 Sealed
- Bearing Mounting
- 25mm to 450mm
- ±0.5% Linearity
- Long Life

Applications
- Damper Position
- Throttle Pedal
- Aero Surface
- Actuators

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KP19S 10.18

PRESSURE | TEMPERATURE | FORCE | TORQUE | POSITION | SPEED | ACCELERATION | GYRO

Figure 30: Linear Potentiometer Data Sheet (KA Sensors, 2019)

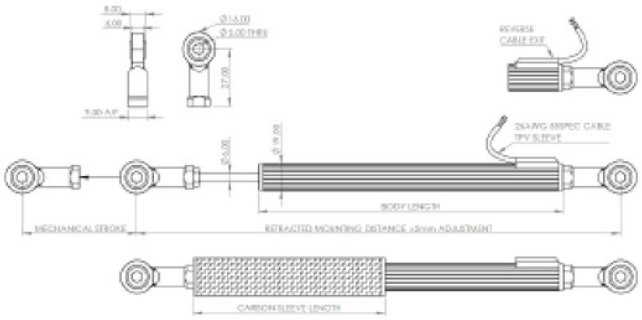
PART NUMBER CONFIGURATOR

KP19S - □ - □ - □ - □ - □ - □ - □

Range (Stroke)	25 mm	025
	50 mm	050
	75 mm	075
	100 mm	100
	150 mm	150
	200mm	200
	250mm	250
	300mm	300
	400mm	400
	450mm	450
Seal Rating	IP65	65
	IP67	67
Cable Exit	Forward	F
	Reverse	R
Dual Output	No	0
	Yes	1
Spring Return	No	0
	Yes	1
Flange Mount	No	0
	Yes	1
Special Code	None	000
	Carbon Fibre Sleeve	159

The KA configuration tool is used to specify a standard KA Sensor, other options are available.

MECHANICAL DETAILS



Active Electrical Stroke (mm)	25	50	75	100	150	200	250	300	350	400	450
Retracted Mounting Distance (mm)	173	198	223	248	298	348	398	448	498	548	598
Mechanical Stroke (mm)	27	52	77	102	152	202	252	302	352	402	452
Body Length (mm)	107	132	157	182	232	282	332	382	432	482	532
Weight Without Cable (g)	53	58	63	68	78	151	159	167	175	183	191
Resistance (KOhms±20%)	1.7	3.4	5	6.7	10	13.4	16.7	20	23.3	26.6	29.9
Carbon Sleeve Length (mm)	40	65	90	115	165	215	265	315	365	415	465

CONNECTION DETAILS

	+Ve Supply	0V Supply	Signal
Single Output	Red	Black	Yellow
Dual Output	Brown	Blue	White

Output signal may be reversed by swapping connections to the Red and Black wires.
DO NOT connect +Ve Supply to the Yellow wire as this will cause damage to the sensor element.

Sense
Analyse
Control

Services for:

- Data Logging
- Telemetry
- Controls
- Wiring

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Figure 31: Linear Potentiometer Data Sheet Continued (KA Sensors, 2019)

A-5: Rotary Potentiometer Data Sheet

ka sensors
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KH Series
KH21 & KH22
Non-Contact Rotary Position Sensor



The KH21/22 Series of Non-Contact Rotary Position Sensors are designed to withstand the harsh environments of motorsport and automotive testing applications.

By using a proven 'Hall Effect' technology, the KH21/22 offers high performance and reliability at temperatures up to +150°C. Alternatively, they are capable of operational excellence in cold environments down to –25°C.

With a small and lightweight 22.5mm diameter body, the KH21/22 Sensor is ideal for many applications within both motorsport and automotive testing and development programs. Typical applications include: throttle, gearbox and pedal position.

Available in either Single (3 wire) or Dual (6 wire) outputs, the modular design allows for various mounting arrangements with different Shaft/Drive types.

Technical Specifications

Electrical Angles (Degrees)	30°, 60°, 120°, 240°, 360°, Custom Angles Available
Supply	5V or 6-30V (Max 32mA) Reverse Polarity Protected
Output	Please See Part Number Configurator For Options
Output Centre Position (Voltage)	2.5V When Shaft Ident Is In Line With The Cable Exit
Resolution	12 Bit
Accuracy, Linearity	±0.1%
Accuracy, Hysteresis	<0.1°
Update Rate	5KHz
Mechanical Life	> 25 Million Cycles at Max 150RPM
Operating Temperature Range	-25°C to +150°C
Housing Material	Aluminium
Shaft Material	Stainless Steel
Track Technology	Hall Effect
Electrical Connection	50cm 26AWG, 3/6 Wire, 55spec, FDR 25 Sleeve
Protection Class	IP65 or IP67
Weight	20g
Options	Cable Length, Labelling, Mounting Flange & Shaft Drive

KA Sensors adopts a continuous development program which sometimes necessitates specification changes without notice.

Sensors For Motorsport

Features
- Compact Design
- Excellent Linearity
- High Temperature
- Lightweight
- IP65 or IP67 Sealing
- Rugged Construction

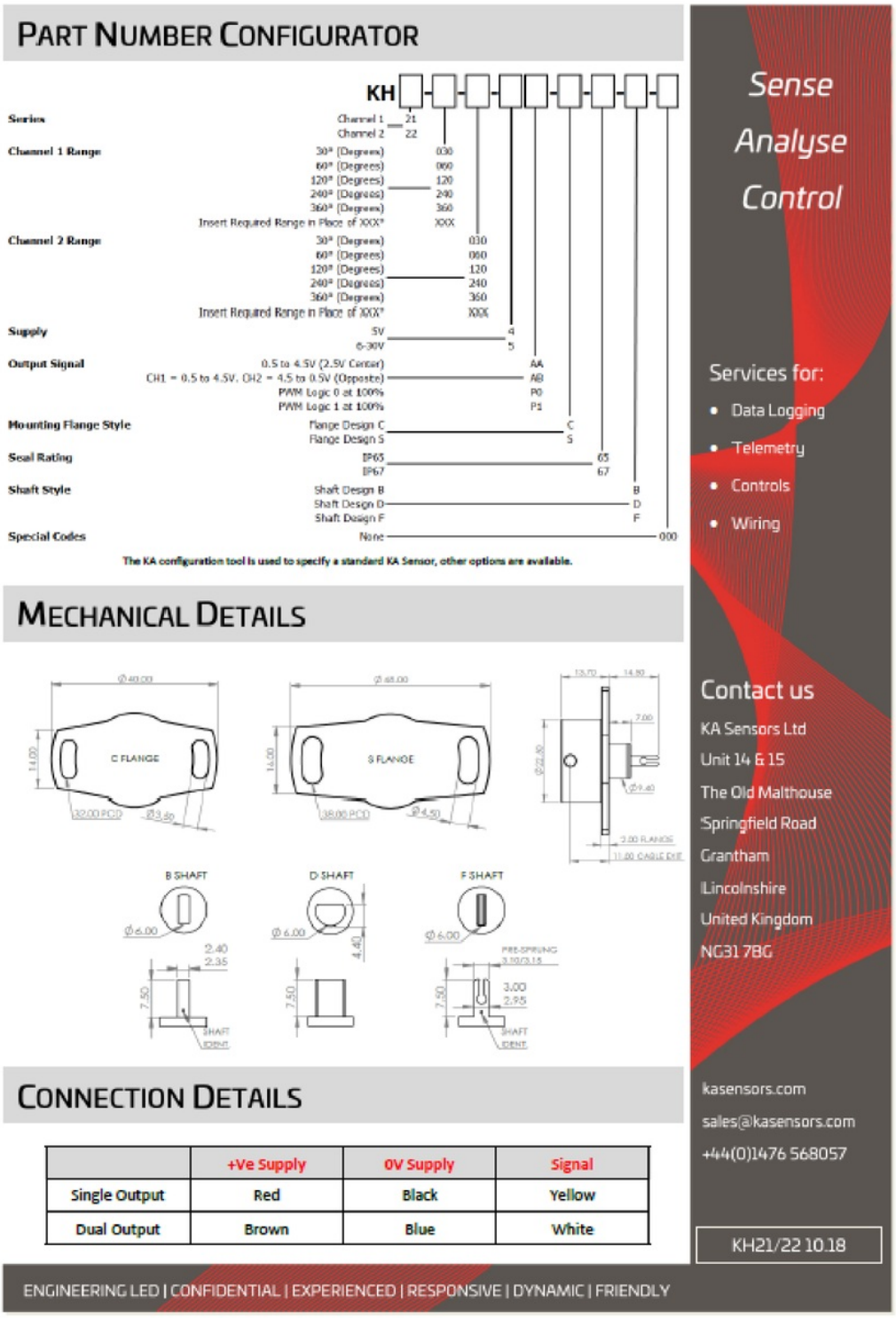
Applications
- Throttle Position
- Steering Angle
- Pedal Position
- Gear Position
- Aero Surfaces
- Actuators

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KH21/22 10.18

PRESSURE | TEMPERATURE | FORCE | TORQUE | POSITION | SPEED | ACCELERATION | GYRO

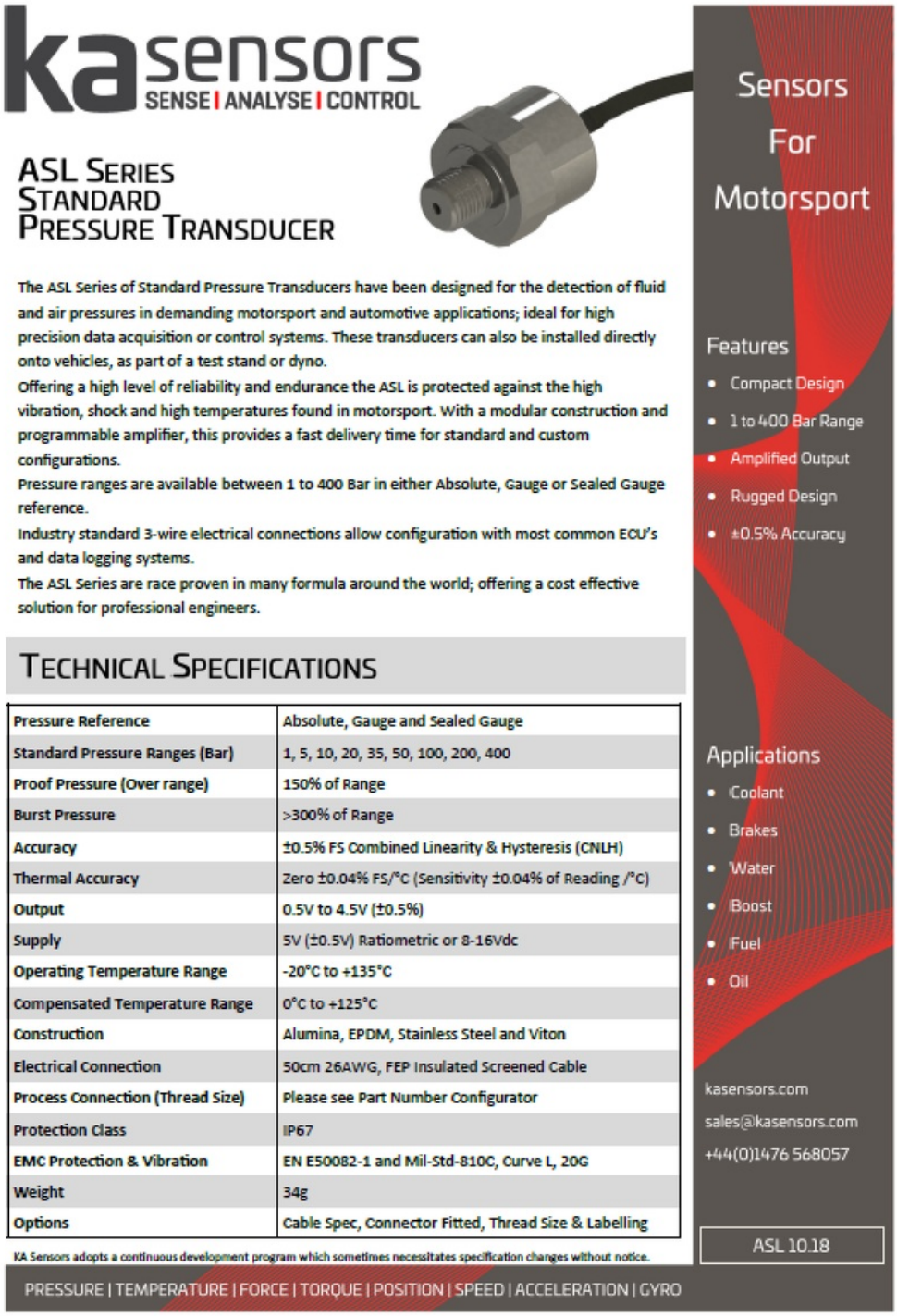
Figure 32: Rotary Potentiometer Data Sheet (KA Sensors, 2019)



	+Ve Supply	0V Supply	Signal
Single Output	Red	Black	Yellow
Dual Output	Brown	Blue	White

Figure 33: Rotary Potentiometer Data Sheet Continued (KA Sensors, 2019)

A-6: Pressure Transducer Data Sheet



ka sensors
SENSE | ANALYSE | CONTROL

ASL Series Standard Pressure Transducer

Sensors For Motorsport

The ASL Series of Standard Pressure Transducers have been designed for the detection of fluid and air pressures in demanding motorsport and automotive applications; ideal for high precision data acquisition or control systems. These transducers can also be installed directly onto vehicles, as part of a test stand or dyno.

Offering a high level of reliability and endurance the ASL is protected against the high vibration, shock and high temperatures found in motorsport. With a modular construction and programmable amplifier, this provides a fast delivery time for standard and custom configurations.

Pressure ranges are available between 1 to 400 Bar in either Absolute, Gauge or Sealed Gauge reference.

Industry standard 3-wire electrical connections allow configuration with most common ECU's and data logging systems.

The ASL Series are race proven in many formula around the world; offering a cost effective solution for professional engineers.

Technical Specifications

Pressure Reference	Absolute, Gauge and Sealed Gauge
Standard Pressure Ranges (Bar)	1, 5, 10, 20, 35, 50, 100, 200, 400
Proof Pressure (Over range)	150% of Range
Burst Pressure	>300% of Range
Accuracy	±0.5% FS Combined Linearity & Hysteresis (CNLH)
Thermal Accuracy	Zero ±0.04% FS/°C (Sensitivity ±0.04% of Reading /°C)
Output	0.5V to 4.5V (±0.5%)
Supply	5V (±0.5V) Ratiometric or 8-16Vdc
Operating Temperature Range	-20°C to +135°C
Compensated Temperature Range	0°C to +125°C
Construction	Alumina, EPDM, Stainless Steel and Viton
Electrical Connection	50cm 26AWG, FEP Insulated Screened Cable
Process Connection (Thread Size)	Please see Part Number Configurator
Protection Class	IP67
EMC Protection & Vibration	EN E50082-1 and Mil-Std-810C, Curve L, 20G
Weight	34g
Options	Cable Spec, Connector Fitted, Thread Size & Labelling

KA Sensors adopts a continuous development program which sometimes necessitates specification changes without notice.

Features
- Compact Design
- 1 to 400 Bar Range
- Amplified Output
- Rugged Design
- ±0.5% Accuracy

Applications
- Coolant
- Brakes
- Water
- Boost
- Fuel
- Oil

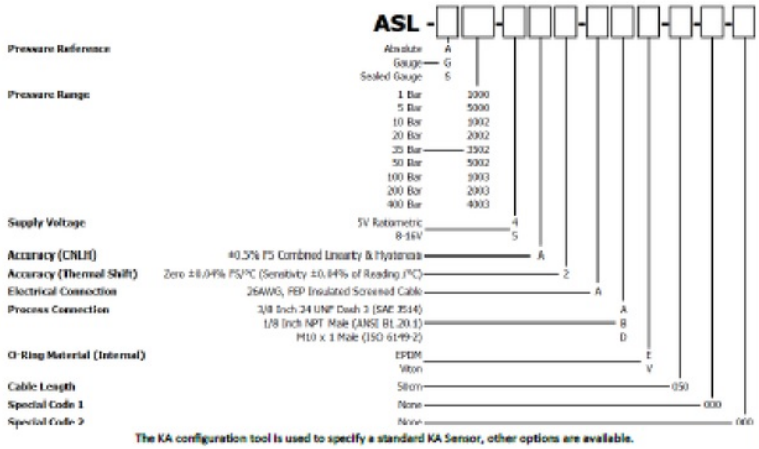
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ASL 10.18

PRESSURE | TEMPERATURE | FORCE | TORQUE | POSITION | SPEED | ACCELERATION | GYRO

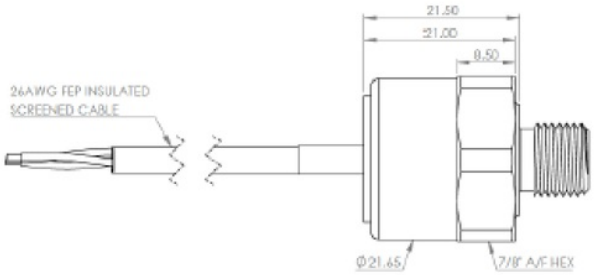
Figure 34: Pressure Transducer Data Sheet (KA Sensors, 2019)

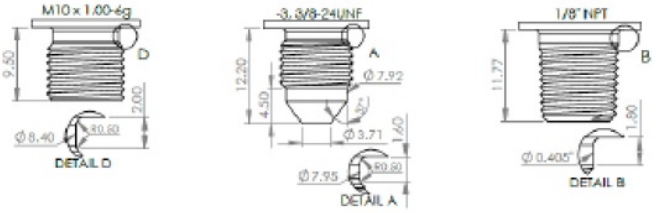
PART NUMBER CONFIGURATOR



The KA configuration tool is used to specify a standard KA Sensor, other options are available.

MECHANICAL DETAILS





CONNECTION DETAILS

+Ve Supply	0V Supply	Signal
Red	Blue	Yellow

Sense
Analyse
Control

Services for:

- Data Logging
- Telemetry
- Controls
- Wiring

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Figure 35: Pressure Transducer Data Sheet Continued (KA Sensors, 2019)

A-7: Pitot Tube Data Sheet

MoTeC Race smart.

PITOT TUBES

Pitot Tubes allow the measurement of differential air pressure, which can then be used to calculate Air Speed. This data can then be used for the analysis of aerodynamic performance, where the speed of the air over the vehicle's aerodynamic surfaces is the key factor, not the speed of the vehicle over the ground.

The Pitot Tubes are available with two different tube heights, and three different measurement ranges:

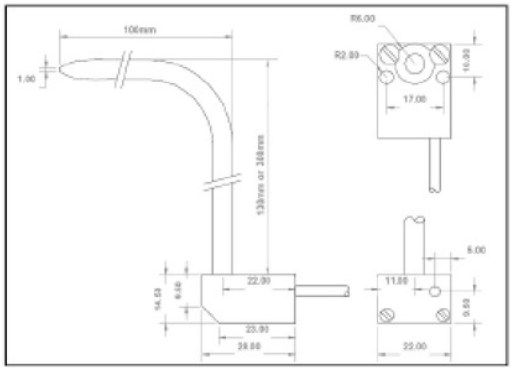
53204 — 130mm tube, 25mbar (up to ~230km/h)
53205 — 130mm tube, 50mbar (up to ~330km/h)
53206 — 130mm tube, 70mbar (up to ~390km/h)

53207 — 300mm tube, 25mbar (up to ~230km/h)
53208 — 300mm tube, 50mbar (up to ~330km/h)
53209 — 300mm tube, 70mbar (up to ~390km/h)



Specification:

Supply	5 to 16V
Signal	0-5V
Operating Temp Range	-40 to +85°C
Accuracy	±0.25%
Housing	Aluminium Alloy
Pitot Tube	Stainless Steel
Tube Diameter	6mm



Wiring:
Supplied with 1m PTFE 26AWG cable

- Red = Power
- White = Signal
- Blue = Ground

Mounting
The device should be mounted such that the top section is horizontal and therefore parallel to the oncoming air flow. The tube should be mounted so it sees free stream air speed, and is out of any areas where the air flow is affected by part of the vehicle itself.

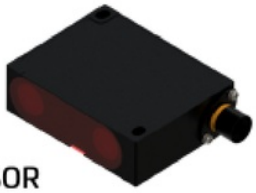
Calibration
Each sensor is calibrated individually so please refer to the calibration sheet supplied with the sensor.

MoTeC Europe Ltd, Unit 14 Twyford Mill Industrial Estate, Adderbury, Oxon, OX17 3HJ
Tel: 08700 119 100 Fax: 08700 111 922 www.motec.com.au sales@moteceurope.co.uk

Figure 36: Pitot Tube Data Sheet (Motec, 2019)

A-8: Laser Transducer Data Sheet

ka sensors
SENSE | ANALYSE | CONTROL



RHL Series
RHL3 Laser Ride Height Sensor

The RHL Series of Laser Ride Height Sensors are designed to withstand the harsh environments of industrial and motorsport applications.
Our RHL3 Sensor incorporates a small diameter visible laser that is reflected off the track surface to a precision CCD detector which determines the height from the ground.
Supplied in two standard measurement ranges of 200mm (60-260mm) or 500mm (200-700mm). With a measurement rate of 750Hz and linearity of 0.2 to 0.5%, this ensures a fast and accurate recording of real-time car data.
The RHL3's construction of anodized aluminium provides protection against high vibration and temperature. However, in the event of damage, the plastic lens can easily be replaced.
Also offered is a choice of electrical connection; either Deutsch Connector or a low profile Cable Exit can be selected.

Technical Specifications

Ranges	200mm (60-260) 500mm (200-700)
Resolution	200mm is 0.1mm 500mm is 0.6mm
Linearity	200mm is ±0.2% FS 500mm is ±0.5% FS
Measurement Range	750Hz
Thermal Effects	0.08% FS/°C
Output	1 to 5V
Ambient Light	<4000LX
Supply	11-30V (50mA)
Operating Temperature Range	0°C to +110°C
Storage Temperature Range	-20°C to +125°C
Construction	Black Anodized Aluminium Casing, Plastic Replacable Lens
Electrical Connection	Cable: 100cm 26AWG, 55Spec Wire + DR25 Sleeve Connector: Deutsch ASL Connector
Protection Class	IP67
Laser Type	1mW, 670nm, Class 2 (DIN EN 60825-1 2007)
Vibration and Shock	20G 10Hz-1kHz & 15G 6ms (IEC 68-2-29)
Weight	90g (Excluding Cable or Connector)
Options	AV Mounts, Cable Length, Connector and Labelling

KA Sensors adopts a continuous development program which sometimes necessitates specification changes without notice.

Sensors For Motorsport

Features
- 200 or 500mm Range
- 0-110°C Temp Range
- Rugged Construction
- ±0.2% Linearity
- Replaceable Lens

Applications
- Ride Height
- Suspension Setup
- Chassis Distortion
- Bodywork Deflection

kasensors.com
sales@kasensors.com
+44(0)1476 568057

RHL3 10.18

Figure 37: Laser Transducer Data Sheet (KA Sensors, 2019)

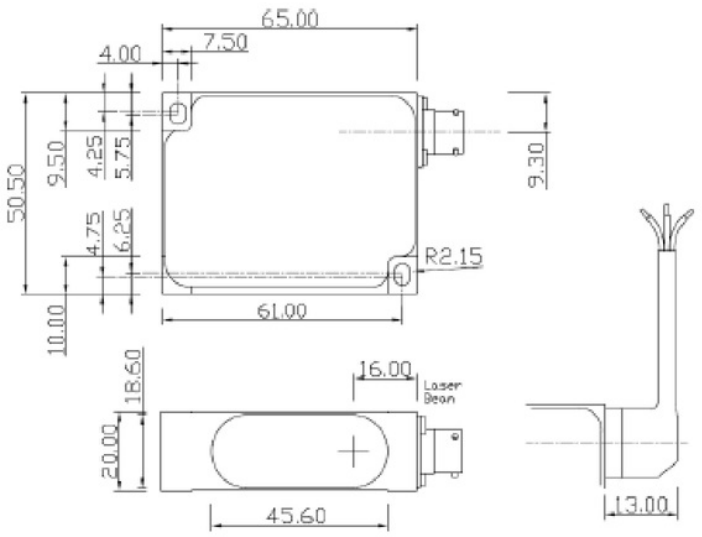
PART NUMBER CONFIGURATOR

RHL3 - □ - □ - □ - □ - □ - □

Range (mm)	200	200
	500	500
Electrical Connection	Deutsch ASL Connector	ASL
	Cable: 26AWG, 555pec Wire + DR25 Sleeve	CAB
Pin Type	Pins	P
	Sockets	S
	Not Applicable	0
Key Way	A Key Way (Yellow)	A
	C Keyway (Orange)	C
	N Key Way (Red)	N
	Not Applicable	0
Cable Length (If Applicable)	Not Applicable (Connector)	000
	100cm	100
Special Code	None	000

The KA configuration tool is used to specify a standard KA Sensor, other options are available.

MECHANICAL DETAILS



CONNECTION DETAILS

+Ve Supply	0V Supply	Signal	Not Connected
Red (Pin1)	Black (Pin2)	White (Pin3)	Pin 4 & 5

Sense
Analyse
Control

Services for:

- Data Logging
- Telemetry
- Controls
- Wiring

Contact us

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Unit 14 & 15
The Old Malthouse
Springfield Road
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NG31 7BG

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RHL3 10.18

ENGINEERING LED | CONFIDENTIAL | EXPERIENCED | RESPONSIVE | DYNAMIC | FRIENDLY

Figure 38: Laser Transducer Data Sheet Continued (KA Sensors, 2019)

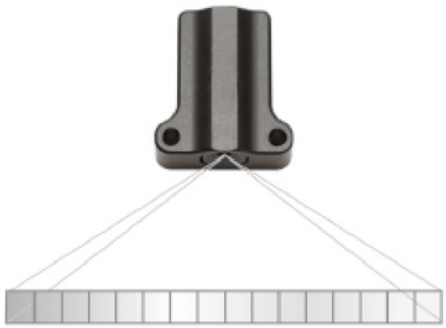
IZZE RACING

Infrared Tire Temperature Sensor, IRTS-V2 - Datasheet

The Izze-Racing tire temperature sensor is specifically designed to measure the highly transient surface temperature of a tire with spatial fidelity, providing invaluable information for chassis tuning, tire exploitation, compound selection, and driver development.

The sensor is capable of measuring temperature at 16, 8, or 4 laterally-spaced points, at a sampling frequency of up to 100Hz, object temperature between -20 to 300°C, using CAN 2.0A protocol, and enclosed in a compact IP66 rated aluminum enclosure.

The sensor is available with two field-of-views: ultra-wide (120°) or wide (60°).



SENSOR SPECIFICATIONS

Temperature Measurement Range, T_o	-20 to 300°C
Package Temperature Range, T_p	-20 to 85°C
Accuracy (Central 10 Channels, Nominal) (16-Ch Sensor)	±1.0°C for $0°C < T_p < 50°C$ ±2.0°C for $T_p < 0°C$ and $T_p > 50°C$
Accuracy (First & Last 3 Channels, Nominal) (16-Ch Sensor)	±2.0°C for $0°C < T_p < 50°C$ ±3.0°C for $T_p < 0°C$ and $T_p > 50°C$
Noise Equivalent Temperature Difference, NETD	0.5°C at 16Hz, $\varepsilon = 0.85$, $T_o = 25°C$
Field of View, FOV	60°x 8° (wide) 120°x 15° (ultra-wide)
Number of Channels	16, 8, or 4
Sampling Frequency	100[1], 64[1], 32, 16, 8, 4, 2, or 1Hz
Thermal Time Constant	2 ms
Effective Emissivity	0.01 to 1.00 (default = 0.78)
Spectral Range	8 to 14 µm

1 – Optional Extra, 64Hz limit for IRTS-120-V2, 100Hz limit for IRTS-60-V2

ELECTRICAL SPECIFICATIONS

Supply Voltage, V_s	5 to 8 V
Supply Current, I_s (typ)	30 mA
Features	• Reverse polarity protection • Over-temperature protection (125°C)

MECHANICAL SPECIFICATIONS

Weight	20 g
L x W x H (max, 60° FOV)	36.6 x 26.0 x 12.3 mm
L x W x H (max, 120° FOV)	31 x 29.0 x 12.3 mm
Protection Rating	IP66

© Izze-Racing 2018

Figure 39: Tyre Temperature Data Sheet (Izze Racing, 2019)

CAN SPECIFICATIONS

Standard	CAN 2.0A (11-bit identifier), ISO-11898
Bit Rate (Default)	1 Mbit/s
Byte Order	Big-Endian / Motorola
Data Conversion	0.1 °C per bit, -100 °C offset, unsigned
Base CAN ID's (Default)	LF Sensor: 1200 (Dec) / 0x4B0 (Hex) RF Sensor: 1204 (Dec) / 0x4B4 (Hex) LR Sensor: 1208 (Dec) / 0x4B8 (Hex) RR Sensor: 1212 (Dec) / 0x4BC (Hex)
Termination	None

CAN ID: Base ID

Channel 1		Channel 2		Channel 3		Channel 4	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

CAN ID: Base ID+1

Channel 5		Channel 6		Channel 7		Channel 8	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

CAN ID: Base ID+2

Channel 9		Channel 10		Channel 11		Channel 12	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

CAN ID: Base ID+3

Channel 13		Channel 14		Channel 15		Channel 16	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

WIRING SPECIFICATIONS:

Wire	26 AWG M22759/32, DR25 jacket (EPD49715A available upon request)
Cable Length (typ.)	500 mm
Connector	None

Supply Voltage, V_s	Red	(twisted)
Ground	Black	
CAN +	Blue	(twisted)
CAN -	White	

© Izze-Racing 2018

Figure 40: Tyre Temperature Data Sheet Continued (Izze Racing, 2019)

SENSOR CONFIGURATION:

To modify the sensor's configuration, send the following CAN message at 1Hz for at least 10 seconds and then reset the sensor by disconnecting power for 5 seconds:

CAN ID: Current Base ID

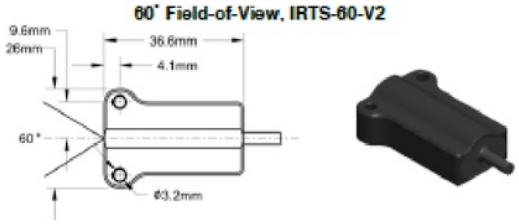
Programming Constant		New CAN Base ID (11-bit)		Emissivity	Sampling Frequency		Channels	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4	Byte 5		Byte 6	Byte 7
30000 = 0x7530		1 = 0x001 ⋮ 2047 = 0x7FF		1 = 0.01 ⋮ 100 = 1.00	1 = 1Hz 2 = 2Hz 3 = 4Hz 4 = 8Hz	5 = 16Hz 6 = 32Hz 7 = 64Hz[1] 8 = 100Hz[1]	40 = 4Ch 80 = 8Ch 160 = 16Ch	

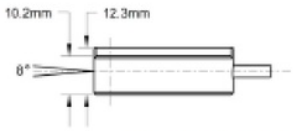
1 – Optional Extra, 64Hz limit for IRTS-120-V2, 100Hz limit for IRTS-60-V2

CAN messages should only be sent to the sensor during the configuration sequence.
DO NOT continuously send CAN messages to the sensor.

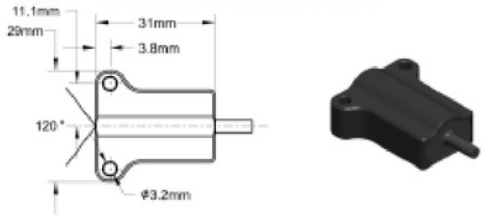
DIMENSIONS:

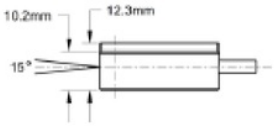
60˚ Field-of-View, IRTS-60-V2





120˚ Field-of-View, IRTS-120-V2

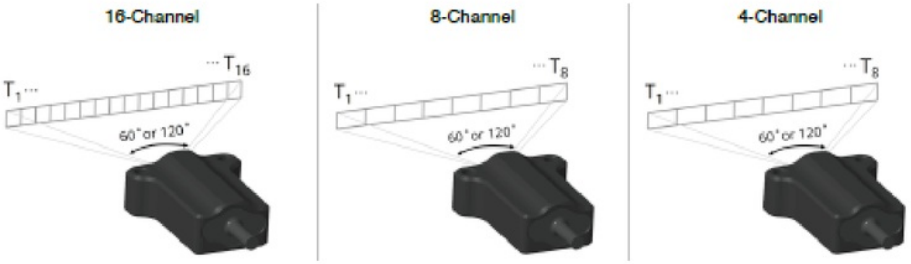




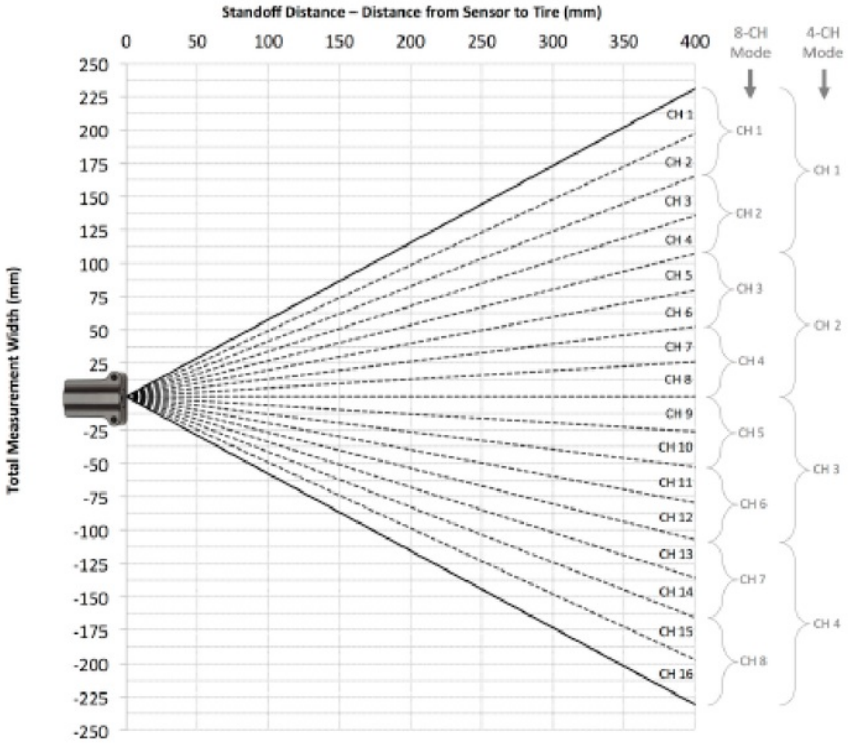
© Izze-Racing 2018

Figure 41: Tyre Temperature Data Sheet Continued (Izze Racing, 2019)

Field of View (FOV):



60° Field-of-View, IRTS-60-V2:



(Approximate. Angle offset (z-axis rotation) between -5° and +5°, mounts should allow adjustment accordingly)

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Figure 42: Tyre Temperature Data Sheet Continued (Izze Racing, 2019)

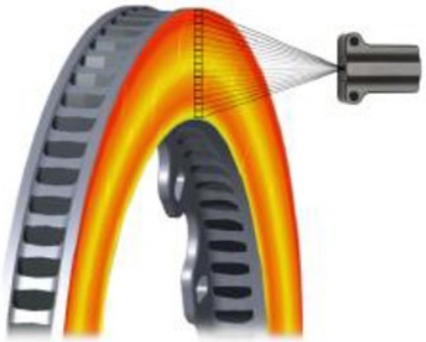
A-10: Brake Temperature Sensor Data Sheet

IZZE RACING

Multichannel Brake IR Temperature Sensor, IRTS-60-V2 - Datasheet

The Izze-Racing Multichannel Brake Infrared Temperature Sensor is specifically designed to measure the highly transient surface temperature of a brake rotor at multiple points, making it possible to acquire the time-based temperature distribution across a rotor's surface in order to evaluate & optimize the pad pressure distribution, cooling efficiency, braking efficiency, and hot spot formation from thermoelastic instabilities.

The sensor is capable of measuring temperature at 16, 8, or 4 points at a sampling frequency of up to 100Hz, object temperature between -20 to 950°C, using CAN 2.0A protocol, enclosed in a compact IP66 rated aluminum enclosure, and priced to be affordable to all tiers of motorsport.



SENSOR SPECIFICATIONS

Temperature Measurement Range, T_o	-20 to 950°C	
Package Temperature Range, T_p	-20 to 85°C	
Accuracy	< ±2.0% FS	
Uniformity	±1.0% FS for -20°C < T_p < 85°C	
Noise Equivalent Temperature Difference, NETD	0.8°C at 32Hz, ε = 0.85	
Field of View, FOV	60° x 8°	
Number of Channels	16, 8, 4, or 1	
Sampling Frequency	100, 64, 32, 16, 8, 4, 2, or 1Hz	
Thermal Time Constant	2 ms	
Emissivity	0.01 to 1.00	(default = 0.55)
Spectral Range	8 to 14 µm	

ELECTRICAL SPECIFICATIONS

Supply Voltage, V_s	5 to 8 V
Supply Current, I_s (typ)	30 mA
Features	• Reverse polarity protection • Over-temperature protection (125°C)

MECHANICAL SPECIFICATIONS

Weight	20 g
L x W x H (max)	36.6 x 26.0 x 12.3 mm
Protection Rating	IP66

© Izze-Racing 2018

Figure 43: Brake Temperature Data Sheet (Izze Racing, 2019)

CAN SPECIFICATIONS

Standard	CAN 2.0A (11-bit identifier), ISO-11898
Bit Rate	1 Mbit/s
Byte Order	Big-Endian / Motorola
Data Conversion	0.1°C per bit, -100°C offset, unsigned
Base CAN ID's (Default)	LF Sensor: 1220 (Dec) / 0x4C4 (Hex) RF Sensor: 1225 (Dec) / 0x4C9 (Hex) LR Sensor: 1230 (Dec) / 0x4CE (Hex) RR Sensor: 1235 (Dec) / 0x4D3 (Hex)
Termination	None

CAN ID: Base ID

Channel 1		Channel 2		Channel 3		Channel 4	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

CAN ID: Base ID+1

Channel 5		Channel 6		Channel 7		Channel 8	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

CAN ID: Base ID+2

Channel 9		Channel 10		Channel 11		Channel 12	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

CAN ID: Base ID+3

Channel 13		Channel 14		Channel 15		Channel 16	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

CAN ID: Base ID+4

Sensor Temperature		Unused		Unused		Unused	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

WIRING SPECIFICATIONS:

Wire	26 AWG M22759/32, DR25 jacket
Cable Length (typ.)	500 mm
Connector	None

Supply Voltage, V+	Red	(twisted)
Ground	Black	
CAN +	Blue	(twisted)
CAN -	White	

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Figure 44: Brake Temperature Data Sheet Continued (Izze Racing, 2019)

SENSOR CONFIGURATION:

To modify the sensor's configuration, send the following CAN message at 1Hz for at least 10 seconds and then reset the sensor by disconnecting power for 5 seconds:

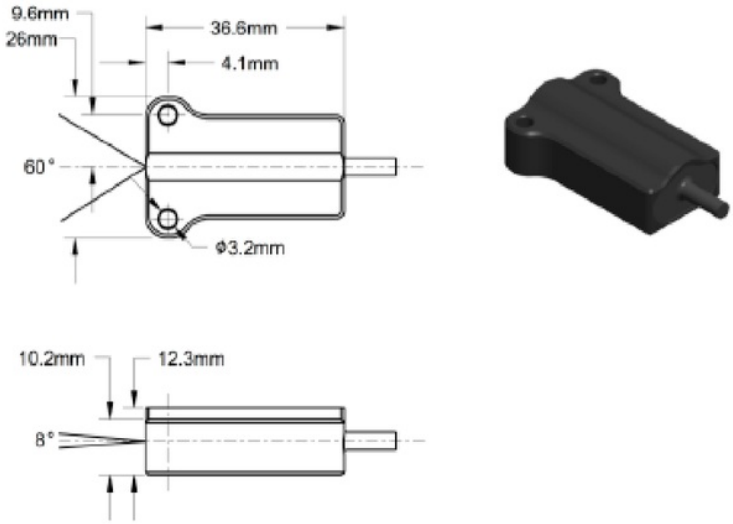
CAN ID: Current Base ID

Programming Constant		New CAN Base ID (11-bit)		Emissivity	Sampling Frequency		Channels	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4	Byte 5		Byte 6	Byte 7
30000 = 0x7530		1 = 0x001 ⋮ 2047 = 0x7FF		1 = 0.01 ⋮ 100 = 1.00	1 = 1Hz 2 = 2Hz 3 = 4Hz 4 = 8Hz	5 = 16Hz 6 = 32Hz 7 = 64Hz 8 = 100Hz	40 = 4Ch 80 = 8Ch 160 = 16Ch	

CAN messages should only be sent to the sensor during the configuration sequence.
DO NOT continuously send CAN messages to the sensor.

DIMENSIONS:

60° Field-of-View, IRTS-60-V2

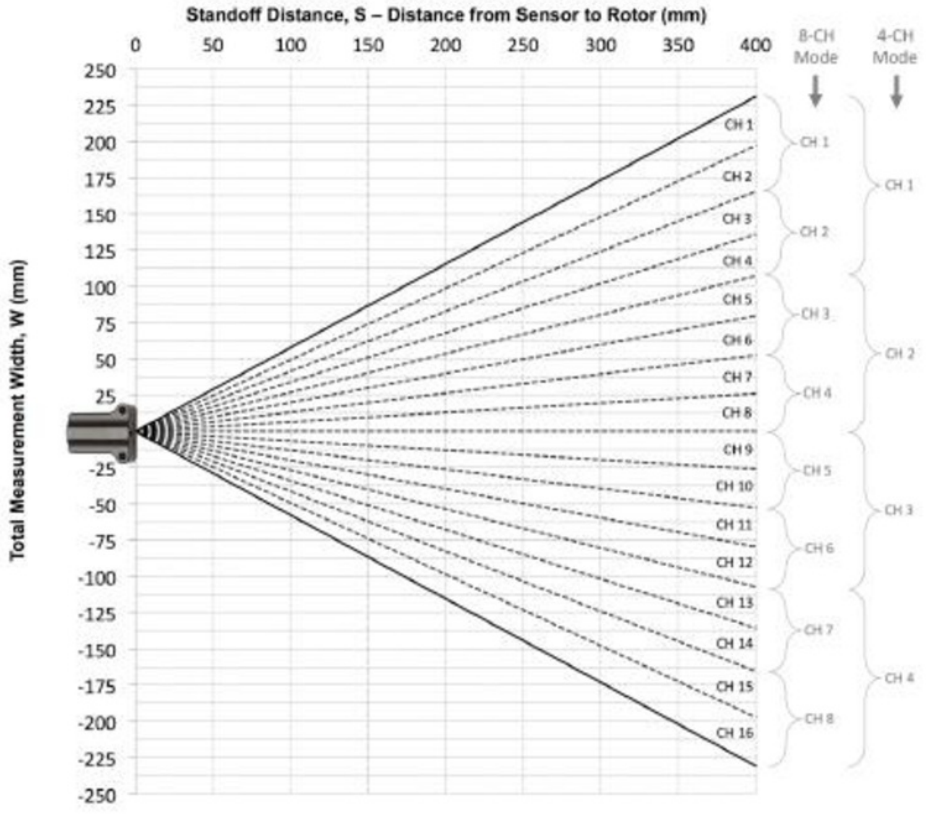


© Izze-Racing 2018

Figure 45: Brake Temperature Data Sheet Continued (Izze Racing, 2019)

Field of View (FOV):





(Approximate. Angle offset (z-axis rotation) between -5° and +5°, mounts should allow adjustment accordingly)

© Izze-Racing 2018

Figure 46: Brake Temperature Data Sheet Continued (Izze Racing, 2019)

7. Technical Specification

GPS	20Hz, no interpolation. Tracking loops optimised for applications up to 4g. Tracks all satellites in view.
GPS Antenna	Magnetic base, 3.3v active antenna with SMA connector.
Power Supply Requirements	DC, 9 to 36V. Current consumption approximately 200mA @ 12V.
Case Construction	Anodised aluminium.
Connector Type	SMA female bulkhead connector for GPS antenna 9 way d-type male connectors for RS232 9 way d-type male connector for CAN 9 way d-type male connector for expansion port LEMO 0B four pin socket for Analogue channels BNC socket for trigger input BNC socket for pulse output
Serial Output	Race Technology, UBLOX, and NMEA messages. Individually configurable for each port at speeds of up to 115.2kbaud.
CAN Output	Combined speed Longitudinal acceleration Lateral acceleration Vertical acceleration SPEEDBOX status GPS position (lat/long/altitude and ECEF X/Y/Z formats), GPS position accuracy, GPS velocity GPS velocity accuracy GPS time GPS heading and number of satellites used in GPS solution output at 20Hz. **With RTK option** yaw, pitch slip estimated baseline and estimated accuracy

Race Technology Ltd. VAT reg. 715 9671 09
After 12, King Street, Eastwood, Nottingham, NG16 3DA, UK
Tel: +44 (0) 1773 537620 Fax: +44 (0) 1773 537621
email: sales@race-technology.com

Figure 47: Speedbox RTK Supporting Information (Race Technology, 2008)

	With IMU option Yaw rate Pitch rate Roll rate Output at 3.3V level, 11 or 29-bit addressing, user configurable addressing and baud rate (125/250/500kbps/1Mbps).
Analogue Output	Combined speed Longitudinal acceleration Lateral acceleration Vertical acceleration GPS heading GPS gradient GPS speed GPS speed accuracy GPS number of satellites in solution GPS derived lateral acceleration GPS derived motorcycle lean angle **With RTK option:** RTK yaw RTK pitch RTK slip RTK baseline RTK accuracy **With IMU option:** Yaw rate Pitch rate Roll rate
Pulse Output	User configurable pulse rate: 1-400 pulses per metre pulse at 5V, high period user configurable from 10 to 1000µs, or 50% duty cycle. . Output impedence 50Ω, minimum recommended termination impedance 1kΩ.
Accelerometers	3-axis, precision digital output. 2g minimum full scale on both axes, 6g option available. Resolution of 0.001g.
Vibration	Factory tested at 25g, 50Hz sinusoid for 5 minutes
Temperature	Factory tested from -20°C to +70°C

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After 12, King Street, Eastwood, Nottingham, NG16 3DA, UK
Tel: +44 (0) 1773 537620 Fax: +44 (0) 1773 537621
email: sales@race-technology.com

Figure 48: Speedbox RTK Supporting Information Continued (Race Technology, 2008)

Appendix B: Early Designs

B-1: DAS Version 1 Schematic Options

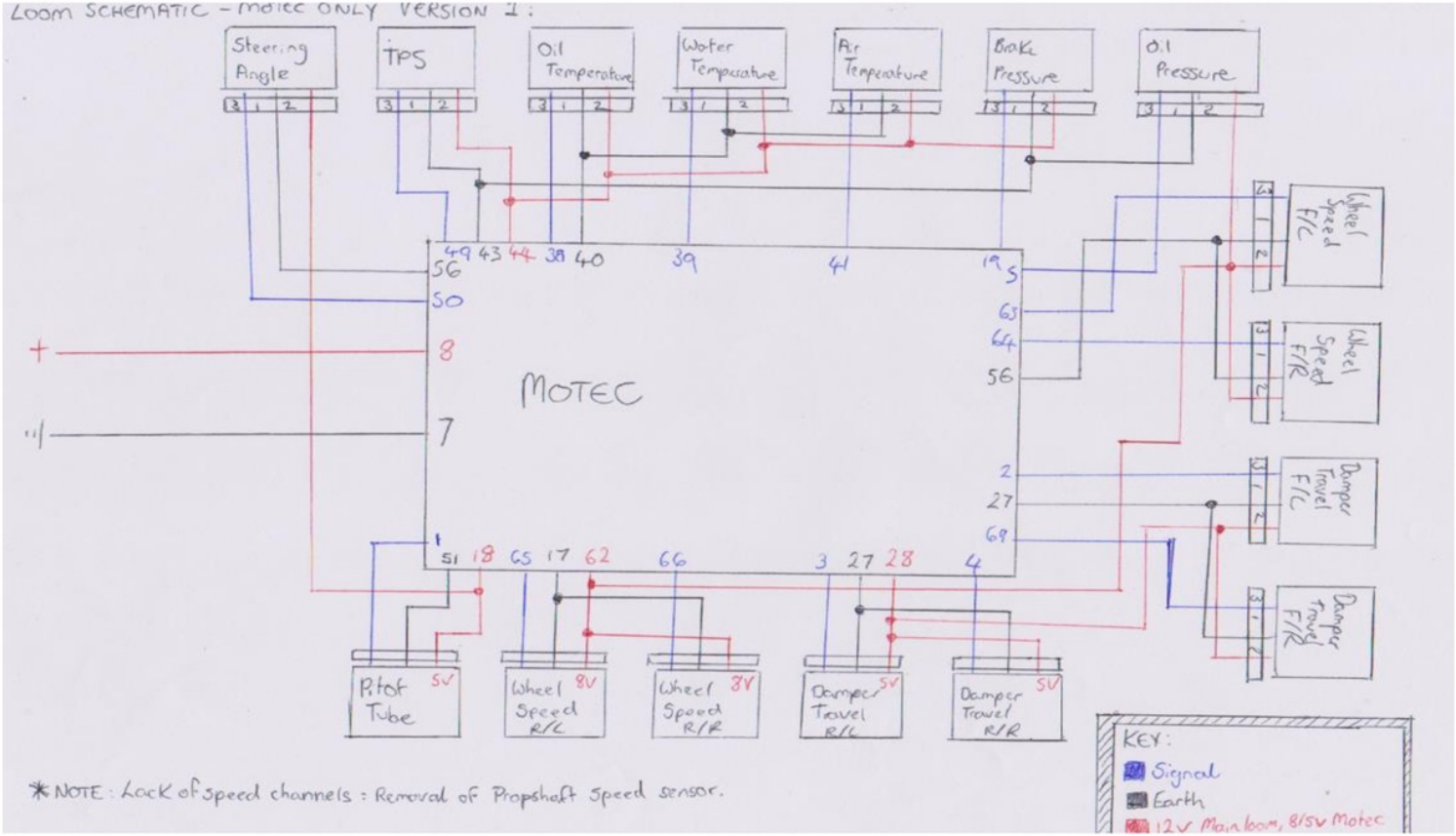


Figure 49: DAS Version 1: Motec Only Schematic (Bartram, 2018)

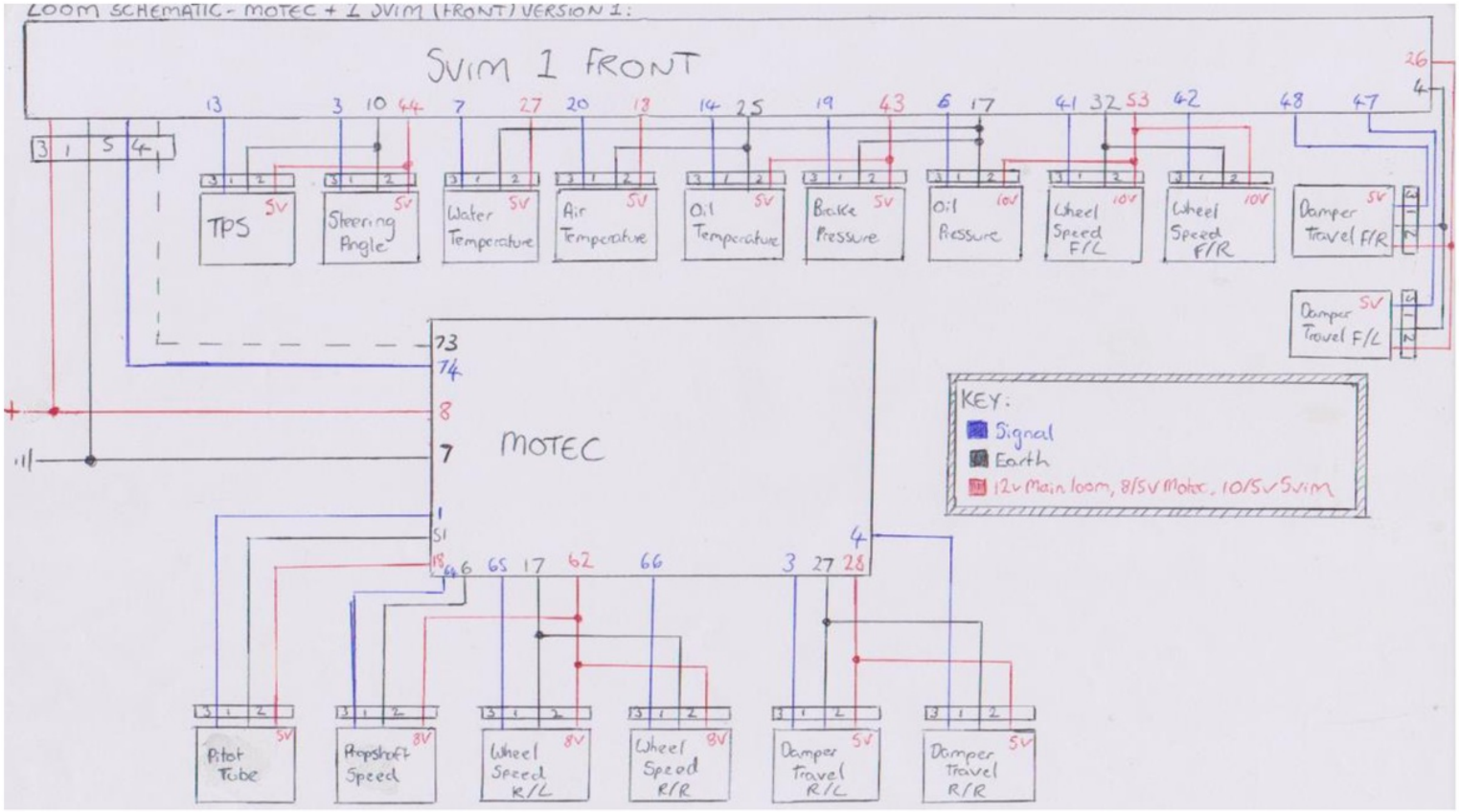


Figure 50: DAS Version 1: Motec and 1 SVIM Schematic (Bartram, 2018)

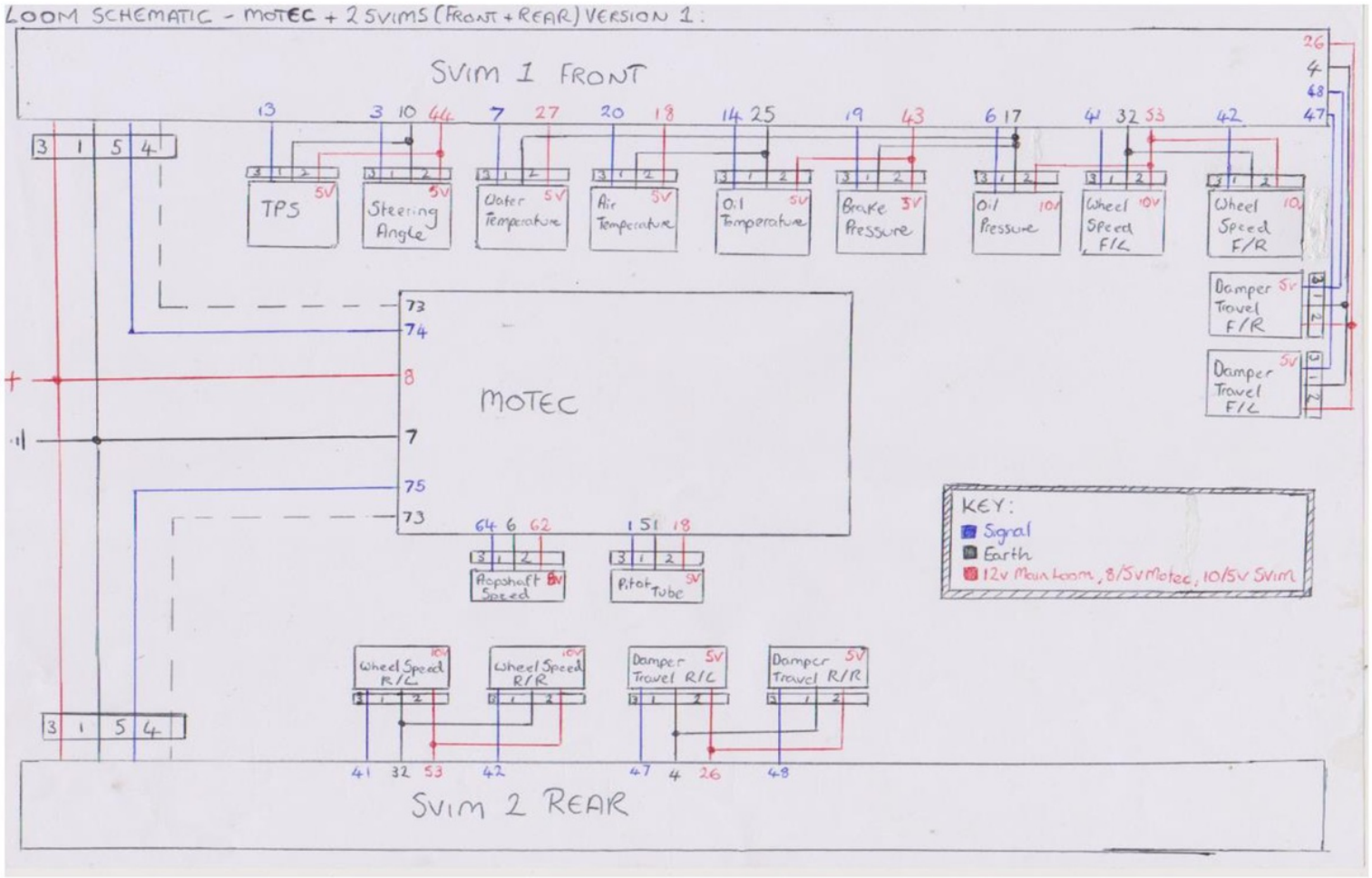


Figure 51: DAS Version 1: Motec and 2 SVIMs Schematic (Bartram, 2018)

B-2: DAS Version 1 Supporting Pin Data

Table 21: DAS Version 1: Motec Only Pin Data

Location	Sensor	Motec Signal (3)	Motec Ground (1)	Motec 5V (2)	Motec 8V (2)	Pin (3) Function
Engine:	Oil Pressure	5	43		62	Analogue Voltage Input 19
	Oil Temperature	38	40	44		Analogue Temp Input 5
	Water Temperature	39	40	44		Analogue Temp Input 6
	Air Temperature	41	40	44		Analogue Temp Input 7
	TPS	49	43	44		Analogue Voltage Input 5
Chassis:	Wheel Speed F/L	63	33		62	Speed Input 1
	Wheel Speed F/R	64	33		62	Speed Input 2
	Wheel Speed R/L	65	17		62	Speed Input 3
	Wheel Speed R/R	66	17		62	Speed Input 4
	Damper Travel F/L	2	56	28		Analogue Voltage Input 16
	Damper Travel F/R	69	56	28		Analogue Voltage Input 20
	Damper Travel R/L	3	27	28		Analogue Voltage Input 17
	Damper Travel R/R	4	27	28		Analogue Voltage Input 18
	Brake Pressure	19	43	44		Analogue Voltage Input 7
Additional Chassis:	Propshaft Speed					**No Speed Channels Available**
	Pitot Tubes	1	51	18		Analogue Voltage Input 15
	Ride Height					
Cabin:	Steering Angle	50	56	18		Analogue Voltage Input 6

Table 22: DAS Version 1: Motec and 1 SVIM (Motec Pin Data)

Location	Sensor	Motec Signal (3)	Motec Ground (1)	Motec 5V (2)	Motec 8V (2)	Pin (3) Function
Engine:	Oil Pressure					
	Oil Temperature					
	Water Temperature					
	Air Temperature					
	TPS					
Chassis:	Wheel Speed F/L					
	Wheel Speed F/R					
	Wheel Speed R/L	65	17		62	Speed Input 3
	Wheel Speed R/R	66	17		62	Speed Input 4
	Damper Travel F/L					
	Damper Travel F/R					
	Damper Travel R/L	3	27	28		Analogue Voltage Input 17
	Damper Travel R/R	4	27	28		Analogue Voltage Input 18
	Brake Pressure					
Additional Chassis:	Propshaft Speed	64	6		62	Speed Input 2
	Pitot Tubes	1	51	18		Analogue Voltage Input 15
	Ride Height					
Cabin:	Steering Angle					

Table 23: DAS Version 1: Motec and 1 SVIM (SVIM Pin Data)

Location	Sensor	SVIM 1 Signal (3)	SVIM 1 Ground (1)	SVIM 1 5V (2)	SVIM 1 10V (2)	Pin (3) Function
Engine:	Oil Pressure	6	17		53	Analogue Volt High Res 3
	Oil Temperature	14	25	43		Analogue Volt High Res 8
	Water Temperature	7	17	27		Analogue Volt High Res 4
	Air Temperature	20	25	18		Analogue Volt High Res 10
	TPS	13	10	44		Analogue Volt High Res 7
Chassis:	Wheel Speed F/L	41	32		53	Speed 1
	Wheel Speed F/R	42	32		53	Speed 2
	Wheel Speed R/L					
	Wheel Speed R/R					
	Damper Travel F/L	47	4	26		Analogue Volt Fast 1
	Damper Travel F/R	48	4	26		Analogue Volt Fast 2
	Damper Travel R/L					
	Damper Travel R/R					
	Brake Pressure	19	17	43		Analogue Volt High Res 9
Additional Chassis:	Propshaft Speed					
	Pitot Tubes					
	Ride Height					
Cabin:	Steering Angle	3	10	44		Analogue Volt High Res 2

Table 24: DAS Version 1: Motec and 2 SVIMs (Motec Pin Data)

Location	Sensor	Motec Signal (3)	Motec Ground (1)	Motec 5V (2)	Motec 8V (2)	Pin (3) Function
Engine:	Oil Pressure					
	Oil Temperature					
	Water Temperature					
	Air Temperature					
	TPS					
Chassis:	Wheel Speed F/L					
	Wheel Speed F/R					
	Wheel Speed R/L					
	Wheel Speed R/R					
	Damper Travel F/L					
	Damper Travel F/R					
	Damper Travel R/L					
	Damper Travel R/R					
	Brake Pressure					
Additional Chassis:	Propshaft Speed	64	6		62	Speed Input 2
	Pitot Tubes	1	51	18		Analogue Voltage Input 15
	Ride Height					
Cabin:	Steering Angle					

Table 25: DAS Version 1: Motec and 2 SVIMs (SVIM 1 Pin Data)

Location	Sensor	SVIM 1 Signal (3)	SVIM 1 Ground (1)	SVIM 1 5V (2)	SVIM 1 10V (2)	Pin (3) Function
Engine:	Oil Pressure	6	17		53	Analogue Volt High Res 3
	Oil Temperature	14	25	43		Analogue Volt High Res 8
	Water Temperature	7	17	27		Analogue Volt High Res 4
	Air Temperature	20	25	18		Analogue Volt High Res 10
	TPS	13	10	44		Analogue Volt High Res 7
Chassis:	Wheel Speed F/L	41	32		53	Speed 1
	Wheel Speed F/R	42	32		53	Speed 2
	Wheel Speed R/L					
	Wheel Speed R/R					
	Damper Travel F/L	47	4	26		Analogue Volt Fast 1
	Damper Travel F/R	48	4	26		Analogue Volt Fast 2
	Damper Travel R/L					
	Damper Travel R/R					
	Brake Pressure	19	17	43		Analogue Volt High Res 9
Additional Chassis:	Propshaft Speed					
	Pitot Tubes					
	Ride Height					
Cabin:	Steering Angle	3	10	44		Analogue Volt High Res 2

Table 26: DAS Version 1: Motec and 2 SVIMs (SVIM 2 Pin Data)

Location	Sensor	SVIM 2 Signal (3)	SVIM 2 Ground (1)	SVIM 2 5V (2)	SVIM 2 10V (2)	Pin (3) Function
Engine:	Oil Pressure					
	Oil Temperature					
	Water Temperature					
	Air Temperature					
	TPS					
Chassis:	Wheel Speed F/L					
	Wheel Speed F/R					
	Wheel Speed R/L	41	32		53	Speed 1
	Wheel Speed R/R	42	32		53	Speed 2
	Damper Travel F/L					
	Damper Travel F/R					
	Damper Travel R/L	47	4	26		Analogue Volt Fast 1
	Damper Travel R/R	48	4	26		Analogue Volt Fast 2
	Brake Pressure					
Additional Chassis:	Propshaft Speed					
	Pitot Tubes					
	Ride Height					
Cabin:	Steering Angle					

B-3: DAS Version 2 Schematic

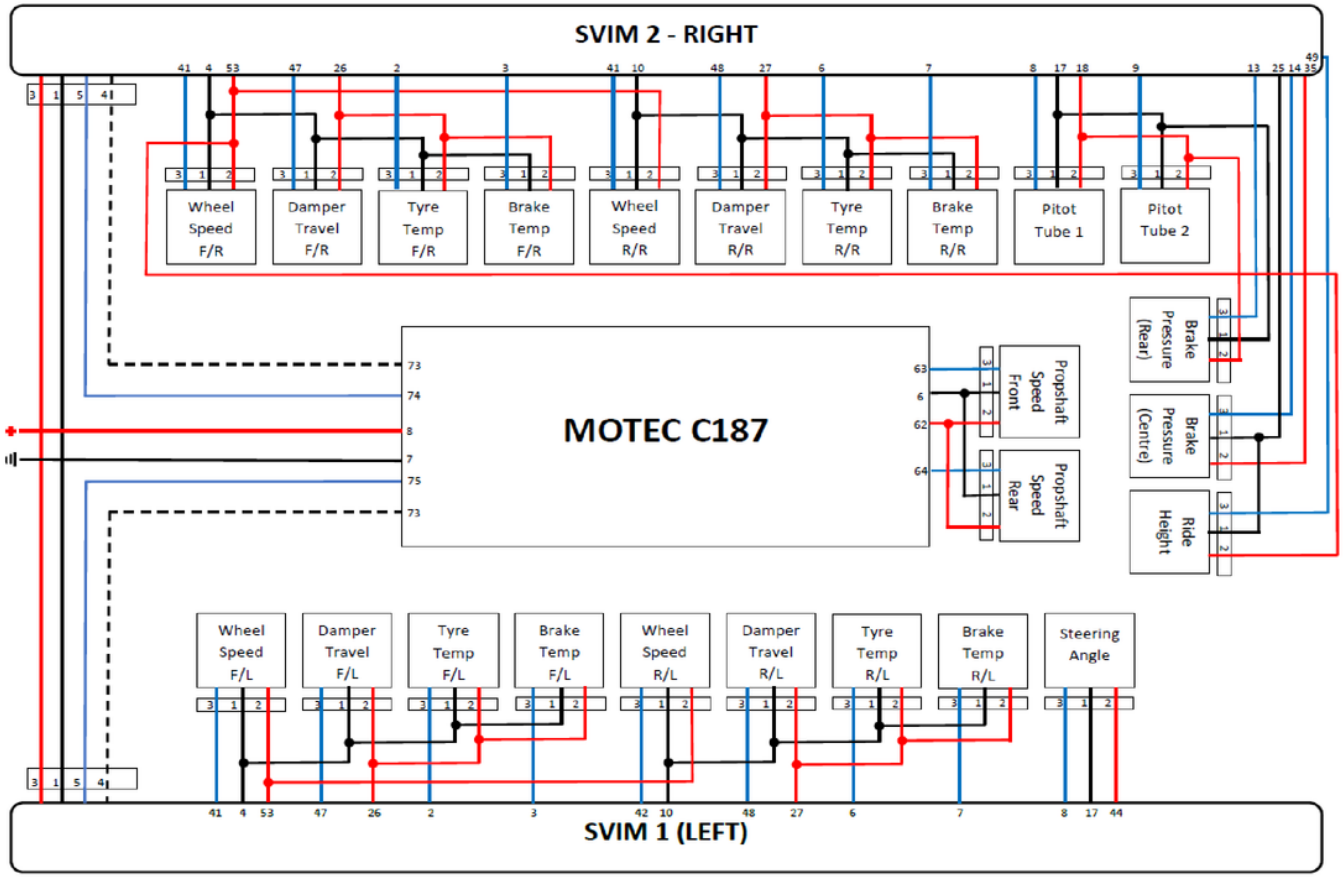


Figure 52: DAS Version 2: Motec and SVIM Schematic (Bartram, 2018)

B-4: DAS Version 2 Supporting Pin Data

Table 27: DAS Version 2: Motec Directly Pin Data

Location	Sensor	Motec Signal (3)	Motec Ground (1)	Motec 5V (2)	Motec 8V (2)	Pin (3) Function
Chassis:	Propshaft Speed (F)	63	6		62	Speed Input 1
	Propshaft Speed (R)	64	6		62	Speed Input 2

Table 28: DAS Version 2: SVIM 1 (Left) Pin Data

Sensor	SVIM Signal (3)	SVIM Ground (1)	SVIM 5V (2)	SVIM 10V (2)	Pin (3) Function
Wheel Speed F/L	41	4		53	Speed 1
Wheel Speed R/L	42	10		53	Speed 2
Damper Travel F/L	47	4	26		Analogue Volt Fast 1
Damper Travel R/L	48	10	27		Analogue Volt Fast 2
Tyre Temperature F/L	2	4	26		Analogue Volt High Res 1
Tyre Temperature R/L	6	10	27		Analogue Volt High Res 3
Brake Temperature F/L	3	4	26		Analogue Volt High Res 2
Brake Temperature R/L	7	10	27		Analogue Volt High Res 4
Steering Angle	8	17	44		Analogue Volt High Res 5

Table 29: DAS Version 2: SVIM 2 (Right) Pin Data

Sensor	SVIM Signal (3)	SVIM Ground (1)	SVIM 5V (2)	SVIM 10V (2)	Pin (3) Function
Wheel Speed F/R	41	4		53	Speed 1
Wheel Speed R/R	42	10		53	Speed 2
Damper Travel F/R	47	4	26		Analogue Volt Fast 1
Damper Travel R/R	48	10	27		Analogue Volt Fast 2
Tyre Temperature F/R	2	4	26		Analogue Volt High Res 1
Tyre Temperature R/R	6	10	27		Analogue Volt High Res 3
Brake Temperature F/R	3	4	26		Analogue Volt High Res 2
Brake Temperature R/R	7	10	27		Analogue Volt High Res 4
Pitot Tube 1	8	17	18		Analogue Volt High Res 5
Pitot Tube 2	9	17	18		Analogue Volt High Res 6
Brake Pressure 1 (Rear)	13	17	18		Analogue Volt High Res 7
Brake Pressure 2 (Centre)	14	25	35		Analogue Volt High Res 8
Ride Height	49	25		53	Analogue Volt Fast 3

Appendix C: Supporting Vehicle Information

Table 30: Hardware Distances to Motec & SVIMs

	Meters (m)
Wheelbase:	2.4
Width:	1.7
Total Length:	3.8
Motec to Battery:	1
Motec to SVIM 1 (Left):	2
Motec to SVIM 2 (Right):	1
Wheel Hubs to Motec:	
F/L	2.75
R/L	2.4
F/R	0.9
R/R	1.8
Wheel Hubs to SVIMs (Wheel Speeds & Dampers):	
F/L	0.75
R/L	0.4
F/R	1.9
R/R	1
Tyre & Brake Temps:	
Front to Rear	6.8
Left to Right	1.7
To Motec	1.5
Brake Pressures:	
Front	0.9
Rear	1.65
Front Axle Distance to Motec (Ride Height Front):	1
Rear Axle Distance to Motec (Ride Height Rear):	3.4
SVIM 2 to Pitot Tubes:	
Vent	0.7
Roof	3
Steering Angle to SVIM:	2