CHALMERS

Implementation of a network system

An analysis of different network types for tough environments

Master thesis in Master's Program Product Development

JONAS ERIKSSON & JOSEF SAID

Department of Product and Production Development
Division of Product Development
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
The Giraffe AMB covered with camouflage

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ABSTRACT

This master thesis was carried out for Saab AB and the department of Electronic Defence Systems. It presents an investigation of the possibility to implement a network system in Saab's ground based radar Giraffe AMB. Currently, the system is characterized by extensive parallel wiring and different units communicating with each other using simple pulses. The pros and cons of the implementation of a new system are considered.

The Giraffe AMB has harsh environmental requirements and the requirements that are to be considered in this project are shock, vibration, temperature, relative humidity and EMC. Furthermore it is important that the system is mature with many suppliers and that it is future safe, in the aspect that its life-time on the market does not end in the near future.

In parallel with a study of the current system, several different network systems are studied and examined. Different network systems, developed for tough environment, are analyzed after their maturity and future prospects. The focus is set on Industrial Ethernet and CAN-bus networks. Different suppliers are contacted and visited for the purpose to look at their products. All the suppliers' solutions and systems are considered and examined after their ability to fulfill the set requirements. Later, all the solutions are screened with the use of a Pugh matrix to get a final solution.

Two different CAN-bus based solutions are chosen, one that is possible to implement in a shorter perspective and one that is better suited for the future. A cost analysis for the short term solution is performed, the programmability is investigated and an Failure Mode Effect Analysis is also made.

Key words: CAN, Controller Area Network, Industrial Ethernet, Fieldbus, Saab, Giraffe AMB.

Implementering av ett nätverkssystem
En undersökning av olika nätverkssystem gjorda för tuffa miljöer
Examensarbete inom produktutveckling
JONAS ERIKSSON & JOSEF SAID
Institutionen för produkt och produktionsutveckling
Avdelningen för produktutveckling
Chalmers tekniska högskola

SAMMANFATTNING

Detta examensarbete är utfört för Saab ABs räkning och avdelningen Electronic Defence systems. Den här rapporten redogör en undersökning av möjligheten att implementera ett nätverkssystem i Saabs markradar Giraffe AMB. Det nuvarande systemet karaktäriseras av omfattande parallellt kablage, där olika enheter kommunicerar med varandra genom enkla pulser. För- och nackdelar med en implementation av ett nätverkssystem är avvägda.

Giraffe AMB har väldigt höga miljökrav och kraven som är behandlade i detta projekt är shock, vibration, temperatur, relativ luftfuktighet och EMC. Vidare är det viktigt att systemet är framtidssäkert, moget och har många leverantörer. Det är viktigt för Saab att produkten inte försvinner från marknaden inom kort.

Flera olika nätverkssystem är studerade och undersökta, parallellt med studien av nuvarande system. Dessa nätverkssystem, utvecklade för tuffa miljöer, är analyserade efter deras mognad och framtidsutsikter. Fokus sätts efter det på industriellt Ethernet och CAN-bussar. Produkter från olika leverantörer undersöks sedan efter deras förmåga att uppfylla de satta kraven. Med hjälp av en Pugh matris gallras sedan lösningarna för att få fram en slutlösning.

Två olika CAN-lösningar väljs; en som är möjlig att implementera i närtid och en som är bättre i det långa loppet. En kostnadsanalys för utförs, programmeringsmiljön undersöks och även en FMEA analys.

Nyckelord: CAN, Controller Area Network, Industriellt Ethernet, fältbuss, Saab, Giraffe AMB.

Contents

Preface

This report covers a master thesis for Saab AB and is carried out by two students from Chalmers University of Technology. The report is aimed to give an insight in the methodology and results that came out from this project. It presents some digital networks, designed for harsh environment, along with their future prospects. Products that are built on these networks are also presented and evaluated according to Saab's needs.

We would like to thank our supervisor Sven Olsson at Saab for his coaching and expertise. Thank you Göran Brännare, who was our supervisor at Chalmers and supported us with methodology and contacts. Other staff at Saab we would like to thank: Jan Rydén, Åke Lindbeck, Rolf Nilsson and Torgny Hansson.

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Lastly, thank you Roger Johansson, lector at the Computer and Networks department, Chalmers, for the insight in network technologies.

Göteborg June 2010

Jonas S. Eriksson, Josef Said

Terminology

This section contains terms and abbreviations that will be present in the report.

Table 1: Terminology

Term	**Explanation of abbreviation**	**Description**
Baud		Symbols per second or pulses per second. The baud rate is related to but should not be confused with gross bit rate expressed in bit/s.
CAN	Controller Area Network	
EMC	Electro Magnetic Compatibility	
Full-Duplex		Communication is possible in both directions, simultaneously
Half-Duplex		Communication is possible in both directions, but only in one direction at a time.
I/O	Input/output	Devices used to read the signals from the control units and translate them to the network
LIN	Local Interconnect Network	
MOST	Media Oriented System Transport	
OSI-model	Open System Interconnect Model	
PLC	Programmable Logic Controller.	It is a digital computer designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact.
Switch		A network switch allows you to have dedicated bandwidth on point-to-point connections with every computer and to therefore run in Full duplex with no collisions in contrast to a hub.
TCP	Transmission Control Protocol	
Transducers		It commonly implies use as a sensor/detector but any device which converts energy can be considered a transducer.
TTP	Time-Triggered Protocol	
UDP	User Datagram Protocol	

1 Introduction

1.1 Saab AB

Saab, Svenska Aeroplan Aktiebolaget, was founded in 1937. The goal was to meet the current need of a domestic military aircraft industry in Sweden. Today, Saab has about 13 200 employees and provides the global market with services and solutions from military defence to civil security. They currently have operations on every continent but their most important markets are Europe, South Africa, Australia and the US. Since the beginning of 2010 Saab is divided into five business areas: Aeronautics, Dynamics, Electronic Defence Systems, Security and Defence Solutions, and Support and Services.

Saab has not only produced military products. In the 1940's they also began producing cars. In 1990 the automobile division became an independent company, Saab Automobile which was later sold to General Motors. Saab helped to create Sweden's computer, missile and space industries in the 1960's. In 1969 Saab also produced trucks, when they merged with Scania. Saab-Scania was separated again in 1995. *(Saab AB, 2010)*

Figure 1.1 Saab has developed many products things since it was founded.

1.2 Saab Electronic Defence Systems

Saab Electronic Defence Systems' focus is within Electronic Warfare with key elements like radar, UV and laser sensors as well as jammers, decoys and counter-measures dispenser systems. These systems have been developed with experience of over 50 years and are available for airborne, naval and ground vehicle applications. Saab Electronic Defence Systems is a merger between the former business units Saab Avitronics and Saab Microwave Systems. *(Saab AB, 2010)*

Saab Microwave Systems was formerly owned by Ericsson and known as Ericsson Microwave Systems, but was in 2006 bought by Saab. The take-over came natural as Saab and Ericsson already had co operations with the radar system Erieye and the radar system used in JAS Gripen. *(Karlberg, 2006)*

1.2.1 Giraffe AMB

The Giraffe Agile Multi-Beam, figure 1.2, is a surveillance radar system used for short and medium range air defence systems. With its 3D radar and 360° coverage the Giraffe AMB also detects rockets, artillery and mortar projectiles, and will pinpoint the weapon position as well as predict the impact point well in advance. It is developed under the Electronic Defence Systems business area. *(Saab AB, 2010)*

Due to the small production series of the Giraffe AMB and the high requirements that are set on the system, in terms of for example reliability, temperatures, electromagnetic compatibility and safety, distributed network systems have never been implemented. Instead the traditional architecture with centralized control and discrete cables to each corresponding unit has been prevalent.

Though the current architecture is extensively tested and reliable, it is characterized by extensive wiring and lack of additional features such as diagnostics or distance control.

Figure 1.2 The Giraffe AMB (Saab AB, 2010)

1.3 Purpose

The purpose with this report is to present an analysis of the possibility to implement a distributed network system into Saab's Giraffe AMB. Saab is interested to see if there are cable or cost savings to earn. They are also curious to know what added functions from a distributed network might do for the Giraffe. It is of great importance for Saab that the investigated technology is mature, well tested, and will stay on the market for a long time. This is because the Giraffe AMB has long development time and is a low volume product.

1.4 Aim

The goal for this project is to investigate if there is a possible alternative to Saab's current signal distribution in the Giraffe AMB before 1th of June 2010. This alternative should be presented both in a report and orally, at Chalmers as well as Saab, in June 2010.

1.5 Delimitation

The purpose of the project is not to develop new technology but rather to investigate the implementation of an already existing technology, used in other systems.

Because of the project members' background in Mechanical Engineering and Product Development, the focus will not be set on electrical technology, software, signal processing or programming.

The development and implementation of signal-busses into the Giraffe AMB would take years. This project does therefore not have the intent to implement a finished solution, but rather give a recommendation that can be investigated further.

1.6 Methodology

To begin with, the current system is investigated in terms of included components, requirements and functionality. This is carried out in cooperation with Saab employees and with assistance of internal documents at Saab.

In parallel with this investigation an extensive research including education of different network systems and the technology they are based on is performed. In this research the networks functionality, application area, maturity and future prospects are considered. Different sources are used; both from literature and expert help from Chalmers and suppliers. The research is followed by an evaluation, using the S-curve, of the different networks and their ability to fulfill the functional demands set on them.

After selecting two promising networks, further investigations are made. They are studied on a deeper level to give a clear view of their functionality. During this stage many suppliers are visited for the purpose of learning about the different systems and to see what products they could offer. The systems from the different suppliers are then compared to the environmental requirements handed by Saab, followed by a comparison between the different systems with the use of a Pugh-matrix.

The selected system is evaluated in the aspects of its up- and down sides, programming and cost. In the end a Failure Mode Effect Analysis is made to predict the new system’s possible failure areas.

2 Current Design

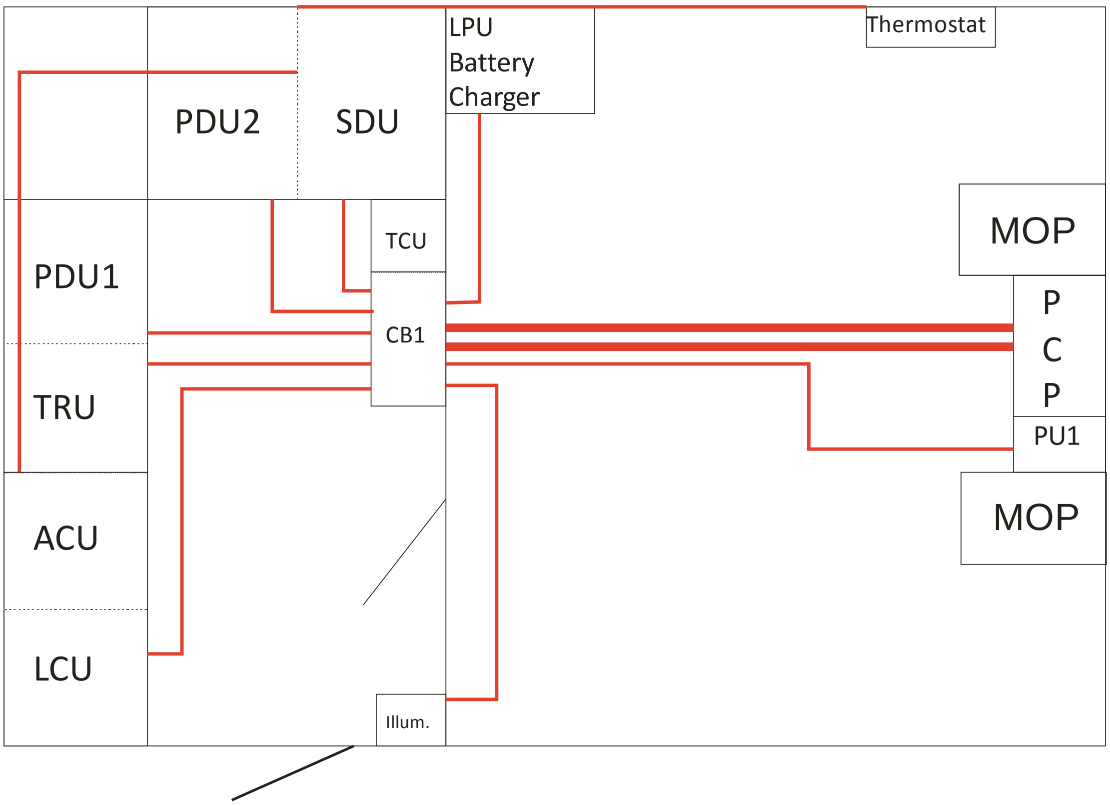
The main parts of the Giraffe AMB are the primary radar, secondary radar and the navigation system. These parts are all installed in a 6 m container that is provided with supporting legs to hold it in a horizontal position and to stabilize it. Additionally it for example contains power supply, climate units and communication equipment.

The Giraffe AMB has two places for operators, MOP in figure 2.1. In between them is a Power Control Panel, PCP, which has an interface towards the operators with on/off-switches and indicator lights. The indicator lights are used for fault indications and to indicate the status of the switches. There are 10 switches and 20 indicator lights on the PCP.

Inside the PCP, a Switch On Logic card, SOL, is mounted. It is used to control a sequential automatic start of the system and to control a shut down during intentional or unintentional power loss. The SOL card also controls climate units, different functions and presentation equipment. The switches and indicator lights are input and output signals to the SOL card.

Further input signals to the SOL card come from the thermostat, error signals and operation indications from different units. Output signals from the SOL are distributed to different units for power distribution, climate units, control panels and the data processing's fault manager.

Figure 2.1 illustrates the layout of the inside of the Giraffe AMB with the different units this project concerns. The PCP is with two cables connected to a connection box, CB1, which connects the PCP to the other units.



Figur 2.1 The system with the different control units inside the container and the connection between them with the cables.

The units in figure 2.1 are named below.

- **ACU:** Air Conditioning Unit,
- **CB1:** Connection Box 1
- **ECU:** Electronic Cooling Unit
- **Illum.**: Illumination unit
- **LCU:** Liquid Cooling Unit,
- **LPU:** Low voltages Power Unit including a battery unit
- **MOP:** Manöver Och Presentation (Operating places)
- **PCP:** Power Control Unit
- **PDU 1:** Power Distribution Unit 1,
- **PDU 2:** Power Distribution Unit 2,
- **SDU:** Signal and Data Processing Unit
- **SOL:** Switch On Logic
- **TCU:** Turntable Control Unit
- **Thermo.:** Thermostat
- **TRU:** Transceiver Unit

This system requires an extensive wiring and the communication is carried out through pulses. The signals going from and to the SOL card are 28V except the signals that goes from the SOL to the SDU where the voltage ranges from 0 to 5V.

Communication between the SOL and SDU is of the more simple nature with one way communication of simple pulses. The SDU instead communicates with other units, not treated in this project, and consists of a computer connected to an Ethernet network. Because SOL only communicate with simple pulses the information sent is limited. If it is possible to extend this information flow, it would be beneficial.

3 Requirements

The requirements for the Giraffe AMB depend on the environment it is to operate in and is often set by the customer. The requirements used in this project are based on customer requirements from another Giraffe AMB project. They are suitable for most environments that the Giraffe AMB is exposed to.

Many of the requirements are based on international standards, providing a tool to overcome barriers caused by different certification criteria. The standards concerning this project are the American military standard, MIL-STD, the NATO standardization agreement, STANAG and the standards set by the International Electrotechnical commission, IEC.

The mechanical requirements concerning shock and vibration are each stated according to two different test methods. Shock is defined according to a saw-tooth pulse and a half-sine pulse, while the vibration is specified according to random vibration and sinusoidal vibration. The reason for the different specifications is because the suppliers state their requirements according to the half-sine pulse and sinusoidal vibration, while Saab in their latest projects uses the saw-tooth pulse and random vibration. Requirements according to the latter mentioned tests are more coherent with how they occur in reality, there is however no clear equivalence between the two different tests. This is why older test specifications are used to specify shock and vibration. In addition the requirements concern temperature, relative humidity, Electromagnetic Compatibility and supply voltage.

For more information about the effects of the environmental requirements and the different test methods, see Appendix A.

There are also some desired properties described in section 3.2. These properties do not have to be fulfilled, but it would give a higher customer value if they did.

3.1 Set requirements

The requirements put on the system are divided into environmental conditions, mechanical environment and electromagnetic compatibility.

3.1.1 Environmental conditions

The system need to be designed to operate in the climate zones A1, C1, C2, B2 and B3 according to STANAG 2895.

3.1.1.1 Temperature

Storage temperature	-46°C to +71°C
Operating temperature	-46°C to +49°C

As design criteria -40°C shall apply as the lower limit.

3.1.1.2 Relative humidity

Relative humidity	<95% at 30°C

This environment is an example of extreme events and is only achieved a few times during life time.

3.1.2 Mechanical environment

3.1.2.1 Vibrations

To be able to compare Saab's requirements with requirements from suppliers, vibrations need to be specified as sinusoidal. The random vibration requirements are also stated because it is the requirements Saab currently use.

Random vibration
According to MIL-STD 810F fig 514.5C-3

Frequency range	**Auto Spectral Density, ASD**
5-20 Hz	0.5 g^2/Hz
20-500 Hz	0.05 g^2/Hz

Sinusoidal vibration
According to MIL-STD 810C method 514.2, procedure VIII, modified from 4.2g above 50 Hz in standard.

Acceleration	1.5g
Frequency	5-500Hz
Time	1 octave/min, 6 sweep/direction, 3 directions

3.1.2.2 Shock

To be able to compare Saab's requirements with requirements from suppliers, shocks need to be specified as half-sine pulse. The saw tooth pulse shocks are the currently used requirement by Saab and is therefore specified.

Saw tooth pulse
According to MIL-STD 810F fig 516.5-II.

The saw tooth requirement is an acceleration of 20g for 11ms.

Half-sine pulse
According to MIL-STD 810C, method 516.2 procedure I. Modified from 30g in standard.

Acceleration	15g
Time	11msec
Number of shocks	3 shocks in ±3 directions (totally 18 shocks)

3.1.3 Electromagnetic compatibility, EMC

The EMC requirements are according to MIL-STD-461F, with additions from MIL-STD-464A and IEC-61000.

3.1.4 Supply voltage

The supply voltage system provides a nominal voltage of 28VDC with voltage limits 24-32 V. It is therefore required that the components can handle 32V.

3.2 Desired properties

Table 3.1 lists and describes desired properties a system can have. Each property is weighted from 1-5, depending on its importance, with 5 as most important.

Table 3.1 The desired properties with weighting

Criteria	Weight
Stand-alone supplier: One supplier that can deliver a complete system is favorable.	4
Compatibility with future Saab protocols: If a protocol is used in Giraffe AMB or at another project within Saab, it may be favorable to use this.	3
Freedom when adding functions: When using a network system it is often compatible with some kind of higher-layer protocol. This criterion is set to compare the flexibility of the different systems.	2
Programmability: It is a spoken wish from Saab that the system should be easy to program.	3
Required cabling: A purpose of this project is to reduce the number or size of the system cabling, this is why this criterion is set.	4
Possibility for development: The product's ability to adapt for upcoming development of the Giraffe AMB is of importance.	3

4 Networks

Before selecting a network, a thorough investigation is made. The networks of interest are those developed for applications that are exposed to tough environments. Network systems exposed to these kinds of environments are possibly the ones used in military, railway, aerospace, marine, industrial applications and in the automotive industry, including heavy-duty vehicles. Most network types that are in these areas are similar and therefore referred to as Industrial Networks and Automotive Networks.

Serial fieldbuses, Industrial Ethernet and CAN are the dominant technologies in the industry. The automotive industry makes use of CAN, LIN, MOST and FlexRay networks. Furthermore, network systems also have a higher layer protocol that is applied on top of these networks. The meaning of higher layer protocol is explained below.

4.1 Network theory

This chapter presents some background theory regarding networks. Firstly the OSI-model is presented, which describes the guideline model for communicating between computers. The OSI-model and its layers are referred to many times in this report. Collision detection techniques are used by the different networks, and network topologies are also covered.

4.1.1 The OSI-model – The Open System Interconnect model

In 1977 the OSI reference model was developed by the International Organization for Standardization (ISO). It was designed to promote the interoperability by creating a guideline for network data transmission between different hardware vendors, software, operating systems and protocols. The model is considered the primary architectural model for communication between computers and provides a platform when describing network protocols.

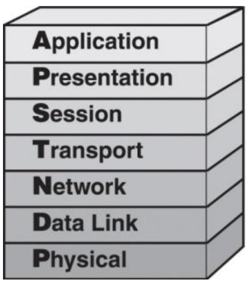


Figure 4.1 The OSI model with its seven layers. (Groth et al, 2003)

As shown in figure 4.1 the OSI-model has seven layers where each layer has a specific function that it performs before passing it on to the next layer. It is perceived that the layers communicate with the corresponding layer on the other side, while in reality they communicate with the layers above and below them. This is shown in figure 4.2 where the red arrow represents the actual way for the communication. When a message is to be sent from one layer to its corresponding layer on the other side it starts at the top of the transmitter, each layer ads information and sends it down one step until it has reached the bottom where it is sent to the receiver's bottom layer.

The receiver's bottom layer sends the information up the layers and each layer process the information given to it and removes it before it is sent to the next layer.

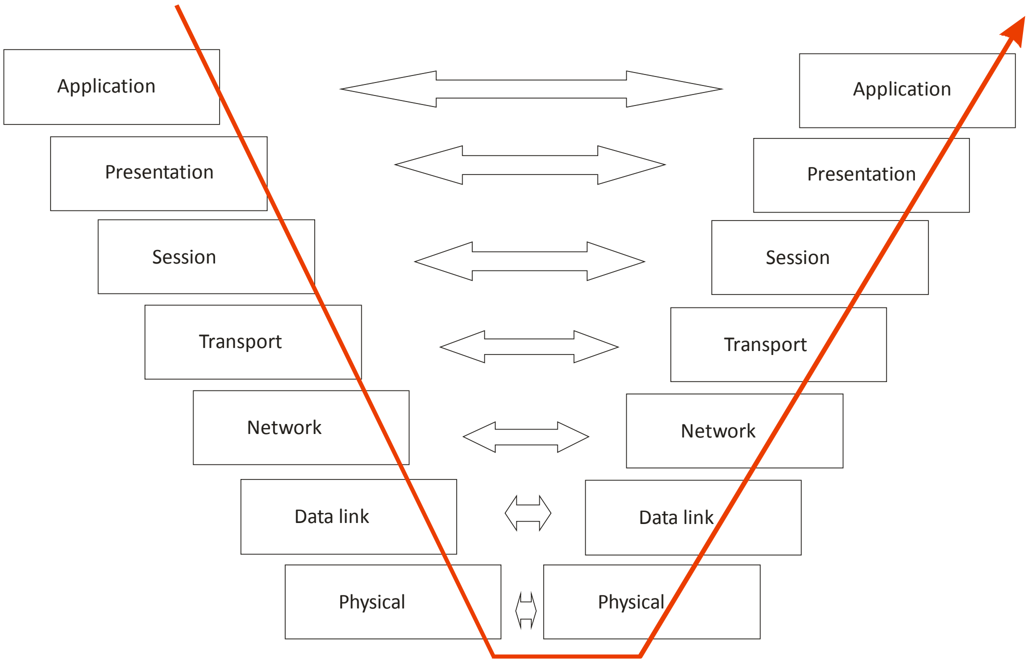


Figure 4.2 The OSI-model's way of transportation. The left side represent the transmitter and the right side is the receiver.

4.1.1.1 The different layers

1. **The Physical layer:** Describes the physical parts of the network media such as the cabling.
2. **The Data Link layer:** The Data link layer gives the raw data provided by the Physical layer and gives it a logical structure. It also provides reliable deliveries across the physical link and contains different access methods for example CSMA/CA which is used in CAN.
3. **The Network layer:** The Network layer handles the logical addressing and translation of logical names into physical addresses. An important function in this layer is called Quality of Service, QoS, which handles the prioritization of the data. Additionally, the layer controls congestion, routes data and builds and tears down packages.
4. **The Transport layer:** Data is divided into smaller packages here so that the network layer can process it easier. The small packages must later be correctly reassembled. It provides end-to-end error detection and correction.
5. **The Session layer:** Defines how computers establish, synchronize, maintain and end a session. A session could be a program that has some connection to a terminal or database.
6. **The Presentation layer:** This layer formats data exchange. Characters are converted and data is encrypted. The data may be compressed and data streams redirected.
7. **The Application layer:** The top layer and also the layer closest to the user. It consists of tools that applications can use to accomplish tasks. The application layer is responsible for defining how interactions occur between applications and the network.

Higher layer protcols make use of the upper layers of the OSI model. *(Groth et al, 2003)*

4.1.2 Master techniques

Network systems can be divided into two main categories; multi-master and master-slave.

Multi-master:
In a multi-master network all the nodes have equal rights and work independently according to their programmed tasks. The multi-master technique assures direct communication between nodes which gives maximum speed and reliability. *(Holtmoen, 2007)* The dependency of one master node is removed and it is possible to have master nodes in different physical sites. *(Voss, 2005)*

Master-slave:
The master-slave network uses the approach to have one master node controlling the access to the other nodes, the slaves. A slave must wait for a control message from the master after a sent data message and causes delays. The use of a master-slave technique will therefore lead to an under exploitation of the network bandwidth. *(Willig & Woesner, 2005)*

4.1.3 CSMA protocols

The carrier-sense multiple-access protocols, CSMA, listen to the medium before transmitting a frame. They do this in order to find out if it is available or busy, if it is free the frame is transmitted, if it is busy the frame transmission is postponed. Different CSMA protocols exist and the two techniques that are covered here are called CSMA/CD and CSMA/CA. *(Willig & Woesner, 2005)*

CSMA with Collision Detection, CSMA/CD:

By reading back the signal from the cable during the transmission and comparing it to the transmitted signal a signal collision can be detected. If the signal is changed a collision has occurred. The reason for using collision detection is that if two or more stations collide without detection, the transmitted frames would have been transmitted uselessly. But if the collision is detected, the transmission can be aborted and less bandwidth is used. *(Willig & Woesner, 2005)*

CSMA Protocols with Collision Avoidance, CSMA/CA:

Sometimes it is not possible to detect collisions before they occur, at these times it is preferable to avoid them instead. Different protocols do this in different ways. *(Willig & Woesner, 2005)*

4.1.4 Topology

Topology is the arrangement of a network and can be divided into a physical topology and a logical topology. The physical topology is the layout of the cables and nodes. It is determined by the mapping of the physical or logical connections between nodes. The logical topology defines how information and data flow within the network. Even if both topology types often are similar, it is important to notice that they can differ. The most common topologies are; bus, line, star, ring and mesh. These are illustrated in figure 4.3. *(Groth et al, 2003)*

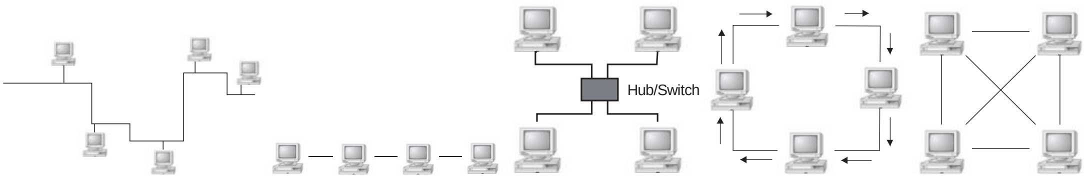


Figure 4.3 Bus, line, star, ring and mesh topology.

4.2 Industrial networks

Industrial Networks are networks designed for tough industrial surroundings with tough mechanical environments and sometimes even severe temperatures and humidity conditions. They are used within for example production and automation to communicate between devices. What defines an industrial network and separates it from for example an office network is shown below:

- **Temperature** – The system should be able to "cold start" in winter conditions as well as withstand the desert sun with added stress of the heat generated by the equipment itself.
- **Humidity** – They are often specified to be able to operate in 90+ percent humidity, non-condensing.
- **EMI/RFI** – The industrial environment often include frequency drives, high voltage lines, among others, and therefore need to withstand Electromagnetic interference/Radio frequency interference.
- **Installation/Mounting** – Industrial network components need to be mounted on for example DIN rails, cabinet racks or fiberglass enclosures.
- **Redundancy** – This is a method to provide high levels of reliability. This is done by using more than one route from the component, so called redundant media. This can also be used to power (if one fails, the other immediately takes the full load).
- **Area Classification** – Industrial components need to be installed in all areas, even in the zones where vapor, gas and dust occur.
- **Fault Notification** – Industrial systems also need to have a fault notification if a component fails in order to utilize the redundancy. *(Verhappen & Agostin, 2009)*

Traditionally different applications in the industry make use of different types of technology. Figure 4.4 shows how the different levels in an industrial automation system use different technologies. The higher level applications in plant management, plant control and process control make use of Ethernet, while in the lower levels of the hierarchy different fieldbuses and CAN is a common network type.

The bottom of the pyramid, the sensor and actuator level, has input and output elements reading things such as current speed and temperatures. These elements are of high quantity and therefore price sensitive. Using a high cost network such as Ethernet might not be preferable because of the large quantity needed.

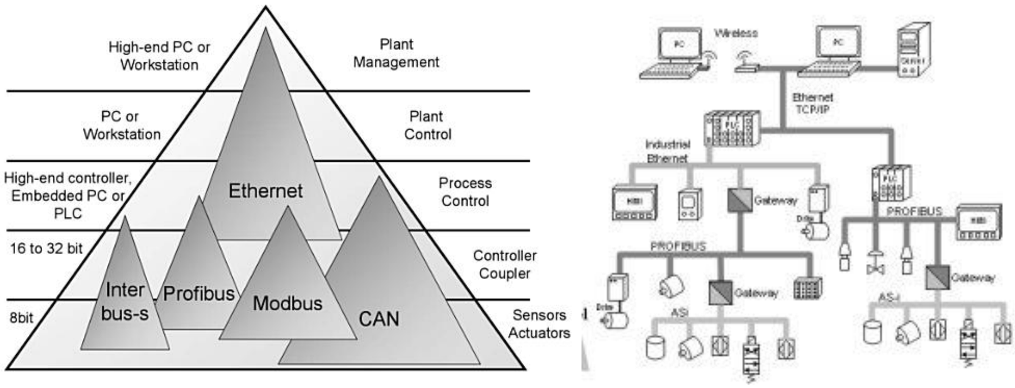


Figure 4.4 Communication in the Automation Pyramid (Pfeiffer et al 2003) & (Verwer Training and Consultancy, 2010)

The development of cheap and effective microcontrollers has however changed this fact and nowadays the trend is to introduce more and more networking interface even at the very bottom of the pyramid. CAN is one of the network types in this segment, but its main application area is in automotive. More information about CAN in sections 4.3.1 and 7.

Next above the bottom layer is the Controller level. What separates this level from the bottom one is that it, besides collecting the inputs, has some sort of control algorithm that transmits the appropriate commands back to the actuators, the outputs.

The top layers are suited for Plant Control and Plant Management. The high performance needed from these networks come from the bandwidth required to handle all the information from all the layers below. *(Pfeiffer et al, 2003)*

This view of the industrial automation system as a hierarchy is however likely to change. There are trends to install Ethernet further and further down in the hierarchy, even at the very bottom. The higher bandwidth and homogenous network from the factory floor all the way up to the offices are two of the driving factors for introducing Ethernet instead of the previously used fieldbuses. More about these trends in section 5. *(Cisco Systems Inc, 2010)*

4.2.1 Industrial fieldbuses

Fieldbus is an industrial communication system connecting distributed field devices such as sensors, actuators and transducers to a central control or management system. The aim with developing this technology was to reduce cabling by replacing the used central parallel wiring and analog signal transmission with digital technology. Due to the different demands from the industry, different bus systems with varying principles and properties were established in the market.

The main application area for the fieldbus is the process and factory automation, but it is also used in areas such as building automation, railway applications and avionics.

With a fieldbus installation it will be possible to extend the system much more easy than it is for a centralized system. It is also possible to monitor devices and apply updates via a network. Industrial fieldbuses use several different topologies. *(Jecht et al, 2005)*

The industrial networking system is under constant evolution and is adopting ideas from other areas such telecommunication and other networking technologies. *(Sauter, 2005)*

The most commonly used protocols are Modbus, Profibus and InterBus except from the CAN-based DeviceNet and CANopen. (H. Kuhnke Ltd, 2007)

4.2.1.1 Protocols

Modbus is a layer seven protocol and one of the leading network protocols in the industrial manufacturing environment. It uses a master-slave communication which makes it easy to implement. Its simplicity and robustness has made it a very popular protocol. *(Intellicom Innovation AB, 2010) & (Buchanan, 2000)*

Profibus is the world leading fieldbus, with a greater installed-base than all the other fieldbuses combined. In contrast to Modbus, Profibus does not only provide a protocol for the seventh layer but is a complete system having its own protocol for all the used layers. *(Jecht et al, 2005)*

Interbus is a protocol just as Profibus, describing the entire system. However, it is restricted to a ring topology and is designed for a fast sensor/actuator network with cyclic or periodic data. It is targeted to remote input and output for time-triggered applications. *(Decotignie, 2005)*

4.2.2 Industrial Ethernet

Ethernet is a commonly known and recognized network that is used in both the office and at home. The Industrial Ethernet is built around the same principle but recognizes the different demands from the factory floor that are put on the network. Because of the high demands from the industry, Industrial Ethernet is designed to avoid downtimes and has a reliable communication because of the use of CSMA/CD. *(Cisco Systems Inc, 2010)*

Further it should withstand tough environments with high temperature ranges, chemicals, UV radiation, vibrations and factory noise in form of electric and magnetic noise generated from for example large motors and high voltage devices.

While office Ethernet is almost always configured in a star topology, Industrial Ethernet on the other hand supports many different topologies, including star-, tree-, line-, and ring topologies. The cables and connectors are often more robust as regular Ethernet cables does have weak cables and connectors. *(Rinaldi, 2010)*

The development of Industrial Ethernet is driven from the need to connect the administrative, control-level and device-level networks to run over a single network infrastructure. In an Industrial Ethernet network, the fieldbus specific information is embedded into Ethernet frames. *(Cisco Systems Inc, 2010)*

4.2.2.1 Protocols

The protocols used by Industrial Ethernet are based on the fieldbus protocols. This is because the industry already has the fieldbus protocols implemented into their systems. Fieldbus protocol information is embedded into Ethernet frames and the implementation of the Industrial Ethernet on the previously fieldbus technology becomes easier. The most popular protocols are ProfiNet, Modbus TCP/IP, Ethernet IP and EtherCAT. *(Cisco Systems Inc, 2010)*

ProfiNet is a further development of Profibus but runs over the physical layer Ethernet. It has full TCP/IP, Internet and web compatibility, with real-time determinism. *(Profibus International, 2010)*

Modbus TCP/IP is an open standard protocol with a master-slave architecture running over regular Ethernet hardware, which enables hardware from different vendors. Just as the Modbus fieldbus protocol it is simple and easy to implement. *(Modbus International, 2010)*

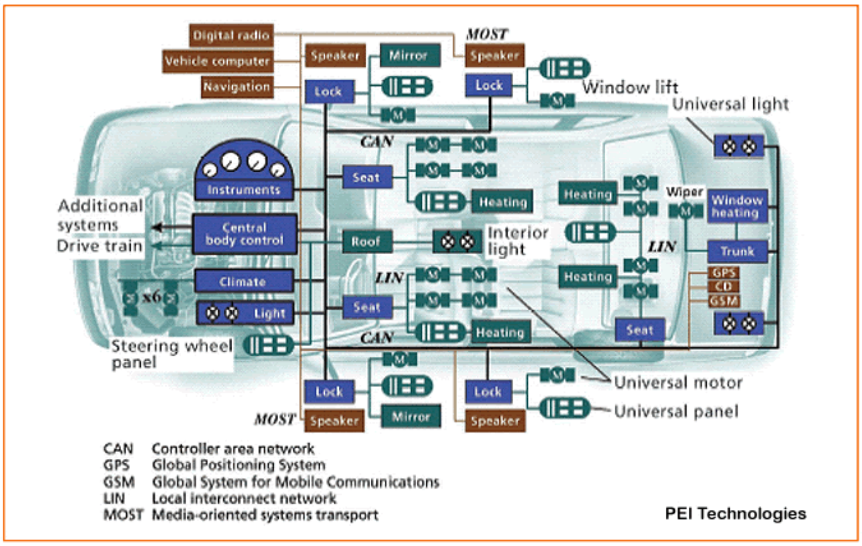
Ethernet/IP is an application layer protocol that uses TCP for general messages and UDP for I/O messaging and control. It is based on Common Industrial Protocol, CIP, which DeviceNet, CompoNet, and ControlNet also utilize. It runs over regular Ethernet and is deterministic and real-time. (*ODVA, Inc, 2010*)

EtherCAT is an open standard and is a shortened word for Ethernet for Control Automation Technology. It is built for speed and determinism with its main target application of single-point applications such as machine control and motion. It has master-slave architecture with predictable timing and precise synchronization. *(National Instrument Corporation, 2009)*

4.3 Automotive networks

Before network systems were introduced into cars, they could contain up to 5 km of wire. Driven mainly by the weight aspect, this introduced the bus network. It was not only the weight aspect however that was a problem. Diagnosing a truck with several kilometers of cables can be time consuming if not almost impossible in some cases. Therefore, faults diagnostics together with making minor modifications was also improved with a network system. The commonly used networks in the automotive industry are CAN, LIN and MOST. FlexRay is also used but not in the same extent as the other networks. *(Murphy, 2003)*

Figure 4.5 shows a common automobile and its different networks. As it can be seen, several different networks are used, which is because of the varying cost of the networks. LIN is the cheapest and MOST is the most expensive network. In between CAN and FlexRay, the former is cheapest. *(LIN Administration, 2010)*



Figur 4.5 The automotive networks and their applications in a car.

4.3.1 Controller Area Network, CAN

CAN is a serial network technology that provides fast and robust communication up to real time requirements in electromagnetically noisy environment. It is primarily used in embedded systems and is a two-wired, half-duplex, high-speed network, running at speeds up to 1 Mbps. CAN has excellent error detection and fault confinement capabilities. *(Voss, 2008)*

In cars, it can be found in window and seat operation, engine management, brake control, climate control among many others. *(The Clemson Vehicular Electronics Laboratory, 2010)*

Due to the fact that the CAN system originally was designed for the automotive industry and its demanding environment, it is robust, reliable and has the ability to function in difficult electrical environments. Because of its characteristics it is suitable for other high precision and demanding applications, for example the medical engineering with their strict safety demands has applied CAN. Additionally it is used in areas such as industrial applications, maritime, space and aviation, and even down to household appliances. *(Voss, 2008)*

4.3.2 FlexRay

FlexRay was founded in 2001 by the FlexRay consortium. The aim was to establish one standard for high-performance communication technology in the automotive industry. *(Millinger & Nossal, 2005)*

The FlexRay consortium consists of several companies but the core partners are BMW, DaimlerChrysler, General Motors, Volkswagen as well as Bosch, Freescale and NXP (Philips). *(IXXAT Automation GmbH, 2010)*

FlexRay was first used commercially as late as in 2007. It was installed in the BMW X5 for its active roll stabilization feature (Dynamic Drive). *(Electrobit, 2010)*

FlexRay offers better speed and higher security than CAN. Because of its redundant transmission channels and fault-tolerant synchronization mechanism it is aimed for active safety systems such as X-by-wire, which include steer-by-wire and brake-by-wire. It supports simultaneous time triggered and event triggered communication at speeds up to 10 Mbps. *(The Clemson Vehicular Electronics Laboratory, 2010)*

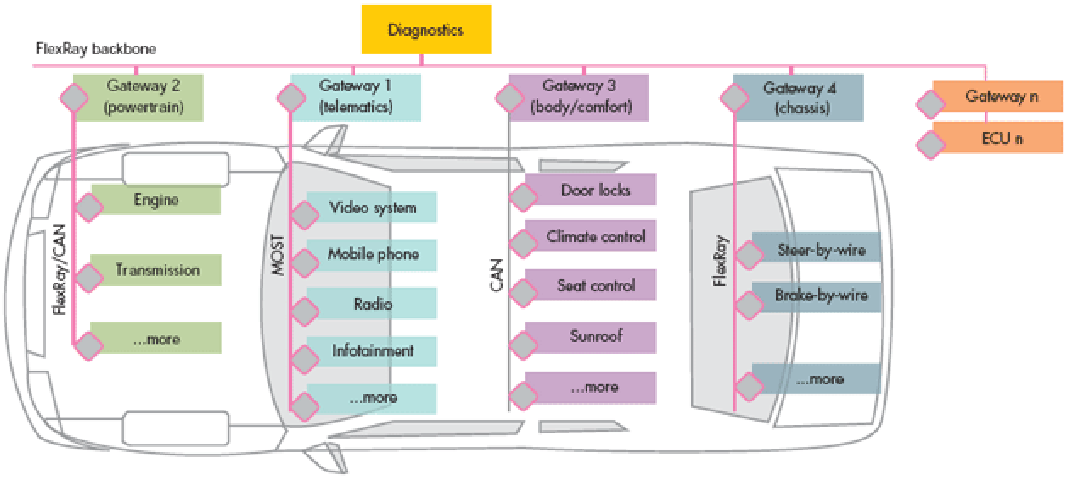


Figure 4.6 FlexRay serving as the backbone of the system (Electronic design, 2010)

In figure 4.6, it can be seen that FlexRay is dealing with the X-by-wire systems and other chassis systems but is also functioning as a backbone instead of the present commonly used CAN bus.

4.3.3 MOST

Media Oriented Systems Transport (MOST) was released in 1997. The company behind it was originally SMSC (formerly Oasis SiliconSystems AG) in cooperation with BMW, Becker Radio, and DaimlerChrysler. MOST is aimed for multimedia applications in the automotive environment and enables communication with and between multimedia devices such as car radios, CD and DVD players, and GPS navigation systems. *(The Clemson Vehicular Electronics Laboratory, 2010)*

The most commonly used version has a bandwidth of 24.8 Mbps, but there is also a second version with the double bandwidth. A third version is to come and has an expected bandwidth of 150 Mbps. As just a regular audio stream takes about 9.8 Mbps, the high bandwidth is needed for these multimedia purposes. *(Henricsson, 2006)*

Only about 768 kBaud is available transmitting control messages as most of the bandwidth is dedicated to multimedia. But in other words, this means that almost 3000 control messages can be transmitted per second. *(Vector, 2009)*

4.3.4 LIN

LIN, Local Interconnect Network, and version 1.1 was released in 1999. It is developed by the LIN consortium and is a small and relatively slow (19.2 kBaud) in-vehicle communication and networking bus system used to connect intelligent sensors and actuators. *(The Clemson Vehicular Electronics Laboratory, 2010)*

The primary advantage with LIN, except the price, is that it can be implemented with a single wire by using the vehicle chassis as a current return path. It is also possible for LIN to communicate over a vehicle's power distribution system with a DC-LIN transceiver. *(The Clemson Vehicular Electronics Laboratory, 2010)*

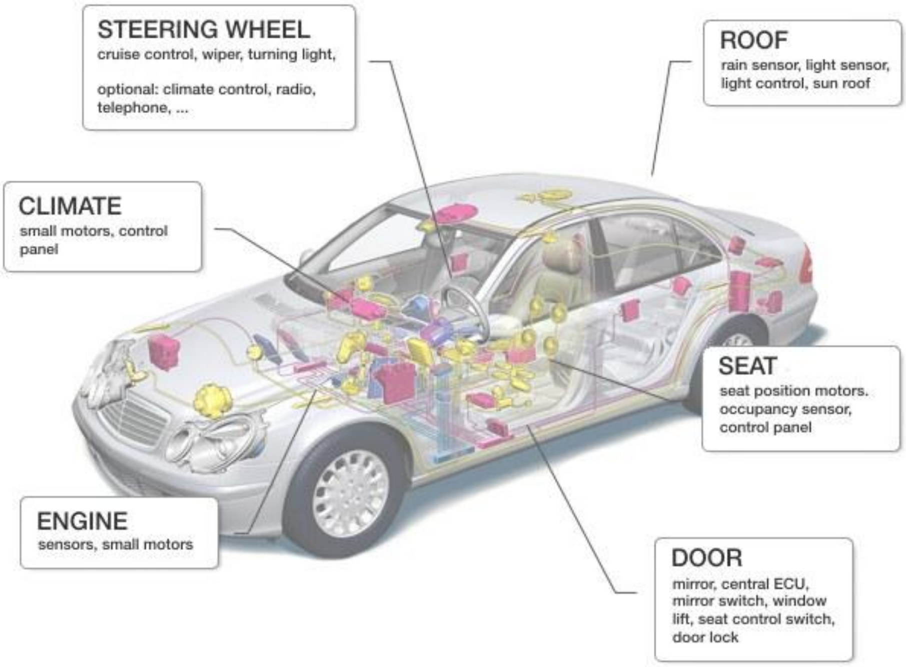


Figure 4.7 Typical LIN applications (LIN Administration, 2010)

Figure 4.7 shows where LIN is commonly implemented in an automobile. This is mainly simple devices such as electric mirrors and switches.

4.3.5 TTP

The Time-Triggered Protocol TTP is a mature data communication system that is relatively low-cost and designed to handle safety-critical applications. TTP has been used in commercial applications since 1998 but has been under development for more than 25 years. The reason for its long development time is the ongoing discussion about its safety features. Formal proofs, prototype implementation, and multi-million fault injection experiments have been carried out to validate the protocol. *(TTA-Group, 2010)*

TTP runs at speeds of up to 25 Mbps per channel. It targets cross-industry applications but especially the aerospace market and can be found in modular and distributed control systems in aerospace programs such as the Airbus A380, Lockheed Martin F-16 and in the Boeing 787 Dreamliner. *(Mobile Dev & Design, 2008)*

Table 4.1 The difference between Time-Triggered and Event-Triggered protocols (Hur Yerang, Zhou Jiaxiang Lee Insup, 2001)

	TT	**ET**
Sporadic message		YES
Periodic message	YES	
Flexibility		YES
Predictability	YES	

As can be seen in table 4.1, time triggered networks has some safety benefits over event-driven networks but lacks in sporadic messages and flexibility.

One major drawback of TTP is its lack of suppliers. Until recently there was only one supplier, TTTech, but now there are two as Austriamicrosystems also has released a controller supporting TTP. *(TTA-Group, 2010)*

5 Future prospects

Before being able to determine which network that is most suitable for implementation, it is important to know its maturity and if the technology is threatened by newer technology that will replace it. It is of great importance for Saab that the technique is well proven and has a bright future. This is because the Giraffe AMB has long development time and is a low volume product. Therefore any investments or changes in the design must be able to be implemented over a long time. Any technique that cannot meet these criteria will not be further investigated. A tool to estimate the maturity of a product group is the S-curve.

A product generation goes through a life cycle on the market. This life cycle is exemplified through the S-curve and is illustrated in figure 5.1. A product generation's lifetime can be split up into four stages:

1. A new product based on a new revolutionary technology is introduced. This technology enhances the performance greatly compared to its predecessor. During this stage the sales volume is low and expenses are dominating.
2. The next phase is the growth phase, which is reached if the product becomes a success. The volume increases and the investments are returned.
3. After a while, the volumes will stagnate as the market becomes saturated. At this time the product generates steady cash flow with relatively low cost. Further development focus mainly on small improvements, so called evolutionary developments.
4. The profits per units will finally reach zero and the product is phased out on behalf of a new revolutionary products. *(Johannesson et al, 2004)*

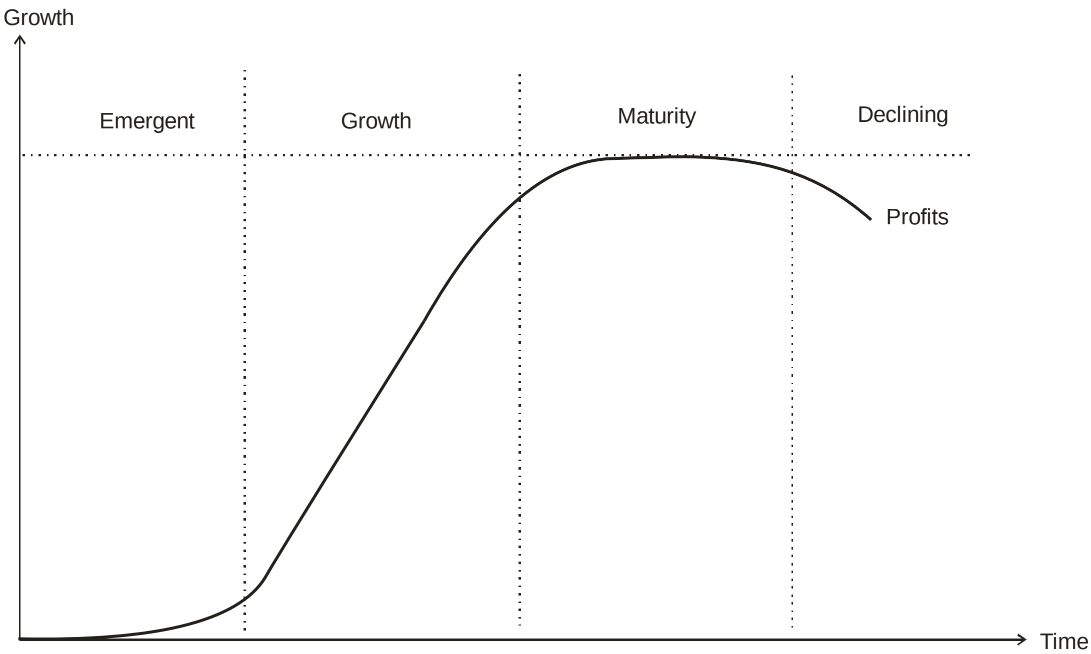


Figure 5.1 The S-curve

The different networks will be evaluated using the S-curve to get a clear view on what technology is worth investing in. It is important that the product has gained wide-spread with many users and suppliers. Furthermore it is important to know that the product will have a long life-time on the market which requires an investigation on new competing technologies that are threatening to replace other mature technologies.

To perform this stage, projections and analyses have been read. Many conclusions from this stage must be made based on information gathered without knowing if it is the real outcome. For example it is difficult to know if a new technology will gain a wide spread or not.

The estimation of where on the S-curve the different networks are in their life-cycle is an estimation based on several different sources. It is important to take into consideration that it is a prediction made by the authors'.

5.1 Industrial networks

In the industrial market many suppliers provide fieldbus solutions. For these solutions, there is often an ad-on available enabling Industrial Ethernet or CAN protocols. The trends concerning CAN are presented in section 5.2. By investigating the market trends in the industry, there is a tendency that can be seen amongst the different protocols. Fieldbuses have been used for a long time and the market is mature with several suppliers and users, but it is also saturated. However, Industrial Ethernet is a somewhat new technology enabling a connection between the field devices and the administrative level. There is a tendency that fieldbuses are to be replaced by Industrial Ethernet. *(Cisco Systems Inc, 2010) & (Sauter, 2005)*

The shift from fieldbuses to Ethernet however does not seem to be straight forward. Fieldbuses are most commonly still used, but with Ethernet as backbone to connect the fieldbus devices together. *(Advantech Co, 2008)*

Even if Ethernet may be the superior network between the two, it is still young in industrial contexts. It is still more expensive for basic field devices and still lacks the comprehensive support and list of resellers that fieldbuses currently have. *(INTERBUS Club, 2010)*

In a survey, 263 respondents were asked how they currently use or plan to use Industrial Ethernet. It should however be noted that this is a relatively small amount of respondents, but can still be used as a small hint if not looked at too blindly. 88% of the respondents are already using Ethernet or are planning to use it for monitoring or data acquisition but only 63% are using it or plan to use it down at the sensor level. (*Control Engineering, 2010*)

Another reason for the relatively slow adaption could be the fact that the current industries have already invested in fully working fieldbuses, and therefore are not too keen on upgrading the whole network at once. *(Profibus International, 2010)* The existing fieldbuses meet the industrial requirements and are more mature and stable than Industrial Ethernet. Because of this, hybrid systems where Ethernet co-exists with fieldbuses seems to be the trend in near future. This is exemplified in Figure 5.3. *(INTERBUS Club, 2010) & (IMS Research, 2009)*

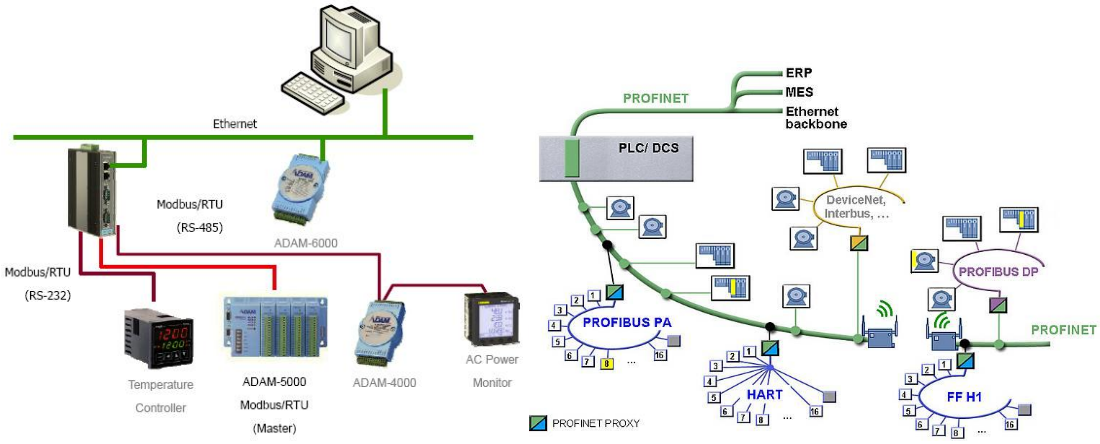


Figure 5.3 To the left, Modbus/RTU fieldbus connected to a Ethernet backbone (Advantech Co, 2008) and to the right different fieldbuses connected to PROFINET (Profibus International, 2010)

The migration of Ethernet further down into the device or sensor level of the automation network hierarchy is however likely to continue. *(ARC Advisory Group Inc., 2008)*

The world financial crisis did however slow down the installations in 2009. The percentage for Industrial Ethernet did however decline less than for industrial automation as a whole. Reports predict that Industrial Ethernet networking installations will grow by over 10% a year from 2011. Within the next 5 years dramatic changes will occur in the way Ethernet is used in industrial automation. *(IMS Research, 2009)*

There are more than one study that predicts the same growth rate. “Recent studies by ARC Advisory Group, VDC Research Group, and others, indicate that the Industrial Ethernet market will grow at a compound annual rate (CAGR) in the range of 30 percent over the next three years.”*(Verhappen & Agostin, 2009)*

Here is a quotation that sums up this section: “There is no doubt that Ethernet is fast becoming the dominant force in every area of data communication, and that the industrial applications of Ethernet are gradually taking the place of conventional fieldbus systems in the automation sector.” *(Babb, 2009)*

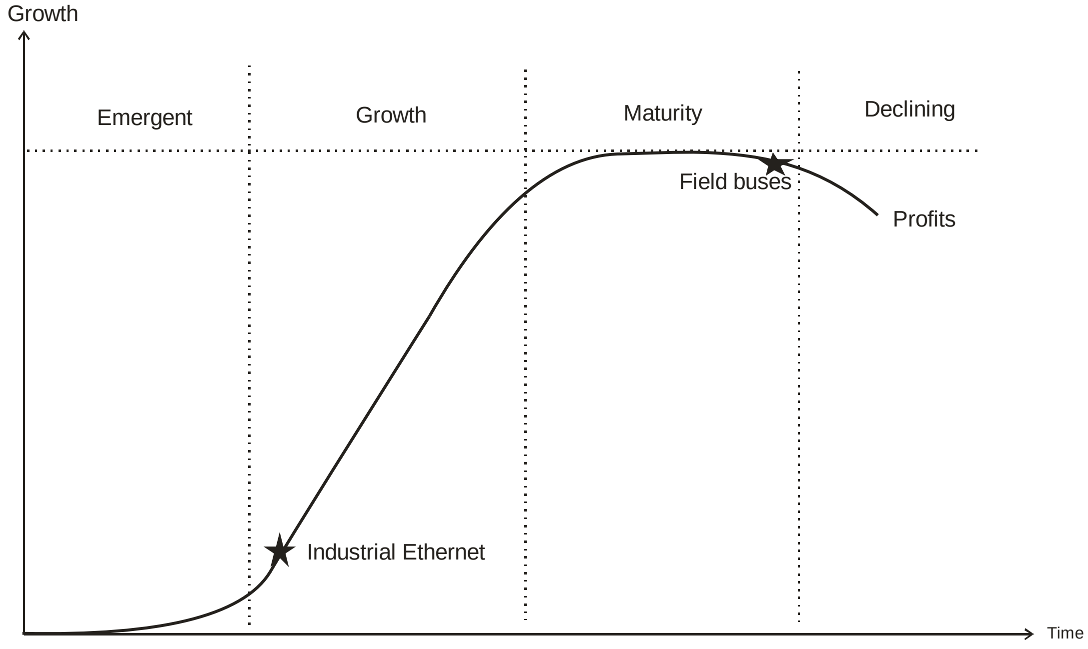


Figure 5.4 The S-curve for two industrial networks

Figure 5.4 shows the estimated position of the two technologies on the S-curve. Industrial Ethernet is seen as the upcoming technology while fieldbus is a mature technology on its way to be replaced. In the future the fieldbus technology will probably be replaced by Industrial Ethernet, connecting all the levels of the industry.

5.2 Automotive networks

TTP is a well proven technology but is not supported by a satisfying amount of suppliers and is therefore not included in the future analysis.

CAN is the dominating network system in the automotive industry. In contrast to the previously mentioned tendencies concerning the industrial networks, there are no strong indications that CAN will be completely replaced by any technique in the near future. Some say it could be replaced by FlexRay. Others say FlexRay will only be a complement to CAN in order to enable X-by-wire in automobiles. *(Electrobit, 2010)*

There are however some trends saying that FlexRay is beginning to replace CAN in certain applications. These are mainly applications that are safety critical, but also applications that do not require the safety FlexRay offers, but instead the increased bandwidth. *(Day, 2008)*

Figure 5.5 below, shows that the adaption of FlexRay is not that rapid yet, even though the growth path is virtually assured through 2020. *(de Regt, 2007)*

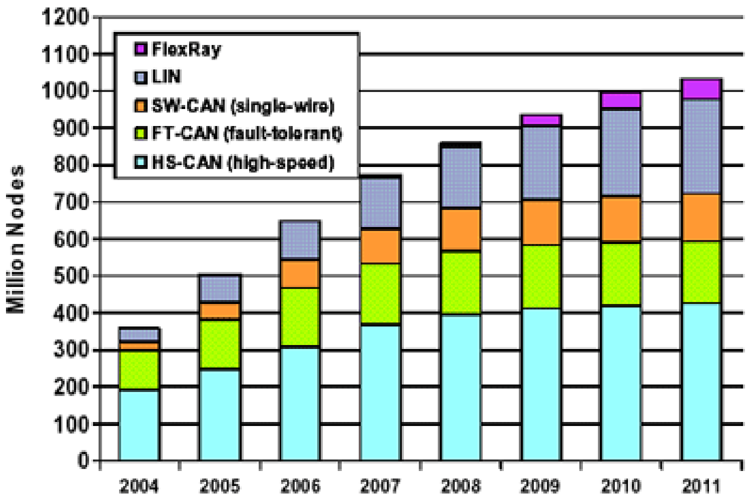


Figure 5.5 2007 year's projected outcome (de Regt, 2007)

Another technology that may be implemented in automotives in the future is Ethernet. If it will replace FlexRay is doubtful but possible. FlexRay however still has safety and weight benefits over Ethernet. *(de Regt, 2007)*

The rumors instead speculate that Ethernet is under consideration instead of MOST and similar multimedia areas, such as a camera-based driver assistant system. The main incentive behind this is the performance need. *(Hammerschmidt, 2009)*

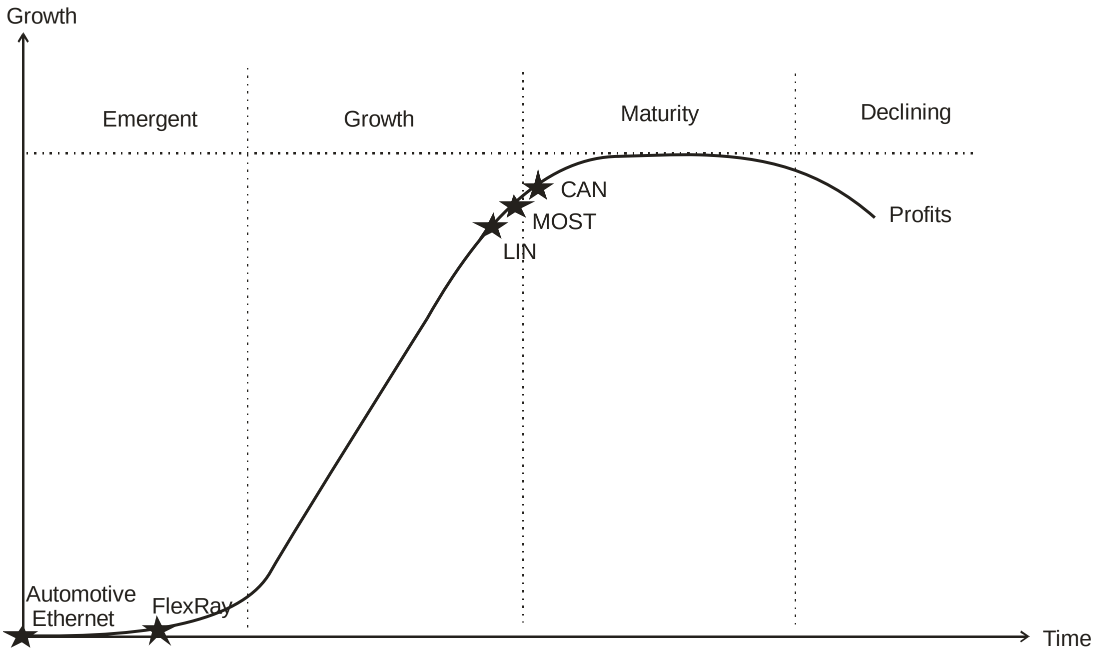


Figure 5.6 An S-curve for Automotive networks

With all this in mind, the positions are pointed out in an S-figure, figure 5.6. FlexRay is in the beginning of the curve and is far from mature. CAN is very mature, but has still not declined as it still finds itself to new business areas. With this in mind, is positioned just before the stagnating point in figure 5.6. LIN is probably in the same area as CAN or just below. MOST is probably near LIN as well but can be replaced by a superior technique as discussed above. In that case, the S-curve for MOST will not rise any further.

6 Network selection

As previously stated the selected network should be mature, and be based on a proven technology that has many users and is provided by several suppliers. Furthermore it needs to be future safe in the aspect that it is not threatened to be replaced by a new revolutionary technology. From the previous section, where each technology is placed on an S-curve, a decision of which networks that are worth further investigation can be made.

Looking at the industry, it is dominated by fieldbuses and Industrial Ethernet. Both technologies are proven and will be able to replace the parallel wiring that is used in the Giraffe AMB. However, there are some aspects making Industrial Ethernet a better option for further investigation. The fieldbus technology has reached its saturation point on the market and is already being replaced by Industrial Ethernet, making its future uncertain. The gained benefits from replacing fieldbuses with Industrial Ethernet are strong enough to predict that this technology will replace fieldbuses. The use of Industrial Ethernet will provide an opportunity to connect the SDU with the other units, making more information available for the operators.

In the automotive industry, more network types are used in the same product. Depending on the application's need for bandwidth and reliability, different networks can be chosen. MOST is a multimedia network and is not aimed for other user areas than that. In addition, it is not future safe because of some predictions say that it might be replaced by other networks. It is therefore not investigated further.

LIN is a mature network with a predicted safe future. It is however only used for simple applications and is too basic for any further investigation. FlexRay on the other hand is used for safety critical applications and is the most advanced network in the automotive industry. It has however not gained any spread in the industry and it is uncertain if it will in the future. Additionally it does not have enough suppliers.

The automotive network with the most mature technology is CAN. It has been on the market for a long time, has many users and suppliers, and it seems as it still finds new application areas to be used in. It will probably reach a saturation point in a near future, but for the technology to be replaced a new technology need to be accepted by the industry and used instead of the CAN bus. The only technology capable of this from the current networks available is FlexRay, which still has not been gained any major recognition by the market. This is why CAN is chosen for further investigation.

Two networks are decided to use for further investigation, one from the automation and process industry and one from the automative industry. Industrial Ethernet and CAN will be investigated further.

7 Controller Area Network, CAN

Throughout the years, the amount of electrical control units has increased in vehicles, where the development has focused on optimizing the collaboration between the new functions. This has led to the development of a network system with a serial data bus topology that increases the communication speed between the control units. *(Holtmoen, 2007)*

Controller Area Network, CAN, was introduced 1986 by Robert Bosch GmbH with help from Mercedes-Benz, Intel and several German universities. During 1987 the first CAN controller chips, the Intel 82526 and Phillips 82C200, were introduced. It was first intended as an automotive network and was in 1992 introduced into a car from Mercedes-Benz. *(Voss, 2008)*

The electrical parameters for the CAN-system are specified according to ISO 11898, the standard for high speed communication, up to 1Mbit/s. However, such a speed can only be obtained with a network that has a maximum length of 40 meters. With longer cables, the speed is reduced and as an example the maximum speed at a length of 500m is 125kbit/s. At these low speeds below 125kbps there is another standard called ISO 11519. *(Holtmoen, 2007)*

An important milestone for the CAN system's success is the foundation of the establishment CAN-in-Automation, CiA, in 1992, which is the international users' and manufacturers' organization. This organization develops and supports standards and higher layer protocols for CAN. Everything they are participated in is based on the members' interest, participation and initiative. *(Voss, 2008)*

7.1 How a CAN network works

To provide a direct communication between nodes, CAN use the multi-master bus access, which provides maximum speed and reliability. All nodes in the network have equal rights as the transmitting node will act as a master during the actual transmission. To avoid collisions between nodes, CAN use Carrier Sense Multiple Access Collision Avoidance, CSMA/CA. With the help from each message's identifier a possible bus conflict is resolved. *(Voss, 2008)*

Using the multi-master network, all the control units work independently in accordance to their programmed instructions. This makes CAN very flexible and new control units can easily be added without changing hardware or software for the other control units. However, the newly added unit cannot work as a transmitter, only as a receiver, because such function would require a change in software. Because of the bus-structure and multi-master technique, CAN is not sensitive to node failure. If for example one node fails, the others can still communicate with each other.

In a CAN system, one control unit transmits a frame to all the other units, and every unit decides for itself if it wants to receive it or not. When a frame is transmitted through the CAN-network, no control units are addressed. Instead the message contains a unique identifier. This identifier is valid throughout the whole network and gives the message an identity and a priority. *(Holtmoen, 2007)*

When a control unit wants to send a message to the bus its microcontroller puts it together and places it in an interim storage memory. The part of the control unit which is called CAN-controller checks this memory on regular basis and when it detects an outgoing message it checks if the data bus is available for use. If the bus is available, the controller tries to pass forward the message. With the help from the bus arbitration, which handles the priority of the messages, the most important messages get access to the bus. All the control units receive the message and with the help of an acceptance test in order to check if the message is destined for them. Every control unit must hence filter every message. *(Holtmoen, 2007)*

The most important parts in a control unit for it to be able to communicate with the bus are; the microcontroller, the CAN-controller and the transceiver, which are exemplified in figure 7.1. *(Holtmoen, 2007)*

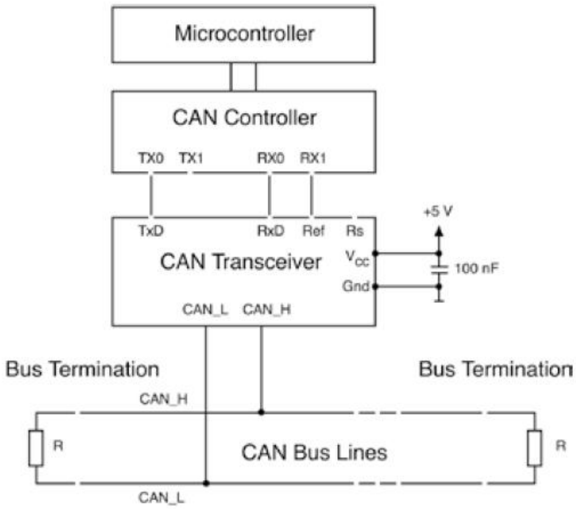


Figure 7.1 Physical CAN connection according to ISO 11898-2, CAN high-speed physical layer. (CAN in Automation)

7.1.1 Microcontroller

A microcontroller can be described as a small computer. While computers can run thousands of programs, microcontrollers are "special purpose computers" and do one thing well. They are aimed for low-cost and low-power performance. *(Brain, 2010)*

The microcontroller has components for communication with other control units and for processing information. The program in the memory is the software with the instructions that control the operation of the control unit. It has a set of setting values and known specifications for functions that the control unit handles. Values from sensors are read and compared to the preprogrammed values. After that the control unit sends out signals for the actuators. *(Holtmoen, 2007)*

7.1.2 CAN-controller

The CAN-controller is an integrated part of the microcontroller. Incoming messages from the CAN bus are sorted in the control unit as incoming and outgoing messages and through the transceiver sent to the controller. It is the CAN-controller that sorts out the messages the control unit reads. Accepted messages, together with the messages that the microcontroller wants to send, goes through an interim storage memory. When the controller reads a message from the bus it is first controlled by the supervision level that makes sure that the message does not contain any errors. If it does, it is not passed forward to the next level. If the message does not contain any faults it is sent to the acceptance level in which the message is read and determined if it is suitable for its control unit. If the message is of importance it is sent to the microcontrollers inbox where it will be read when the microcontroller is available otherwise no action is taken. When the microcontroller wants to send a message it is placed in the "out-going" box between the microcontroller and the CAN-controller. The controller then decides when to send the message depending on when the bus is free. If a message would be sent to a bus from two control units at the same time the message with the highest priority gets the access while the other message has to wait. *(Holtmoen, 2007)*

7.1.3 Transceiver

The transceiver is a transmitter and a receiver. The bus can only transmit voltage pulses and not a current of bits. Every bit in a message on the bus can have two logic conditions; a dominant bit can correspond to logic 0, a recessive bit can correspond to a logic 1.

When the transceiver works as a transmitter it receives the serial bit current from the CAN controller and sends the message to the bus as voltage pulses. In contrast, when it works as a receiver it reads the voltage pulses distributed by the bus and pass it forward to the CAN controller. *(Holtmoen, 2007)*

7.2 Higher layer protocols

CAN is effective for most automotive applications but is alone not suitable for areas like machine automation because of its limitation to communicate with only 8 bytes. Higher layer protocols have therefore been introduced, examples of these are; CANopen, DeviceNet and SAE J1939. Shortly CANopen is used in machine control, DeviceNet in factory automation and J1939 is used in heavy-duty vehicles. They support messages of unlimited length and a master/slave configuration.

7.3 Frames

According to the CAN 2.0A standard, CAN frames use an 11-bit identifier in the Arbitration field. An identifier describes the content of a frame, where its most important function is to set the priority of it. This length is fully sufficient for use in the automotive industry and in industrial application. However, for the off-road industry this was not sufficient. Customer demands forced an extension of the standard called CAN 2.0B and the higher layer protocol SAE J1939 was created. The new standard has an 18-bit extension and consists of a 29-bit identifier. Figure 7.2 and 7.3 illustrates the composition of the different frames where the shaded area shows the extended part.

SOF	11 bit CAN ID	RTR	6 Bit Control Field	0…8 byte Data Field	16 Bit CRC Field	2 Bit Ack	7 Bit End of Frame

Figure 7.2 Frame with an 11 bit identifier

S O F	11 bit CAN ID	S R R	I D E	18 Bit CAN ID	R T R	6 Bit Control Field	0…8 byte Data Field	16 Bit CRC Field	2 Bit Ack	7 Bit End of Frame

Figure 7.3 Frame with a 29-bit identifier, the shaded part is the extension

As a standard, all the messages are referred to as frames, such as data frame, error frame et cetera. Any control unit connected to the bus can transmit a message when the bus is idle and its consistency must be accepted by all units in the CAN network. CAN has four different types of frames; data frame, remote frame, error frame and overload frame.

- **Data frame:** The most common data type and is the data transferred from one node to one or several receiving nodes.
- **Remote frame:** The requested data, any node can request data from another node. A remote frame is followed by a data frame containing the requested data.
- **Error frame:** An error frame is a message that violates the framing rules of a message. If a node detects an error it sends the error frame. All the other nodes will detect the fault and also send an error frame. This will make the transmitting node to retransmit the message. All the participants in the CAN-bus system may report an error during a data or remote frame transfer.
- **Overload frame:** The overload frame can occur between a data and remote frame transmission. This means that a unit can request a delay between two data or remote frames. The Overload Frame is rarely used and today's CAN controllers are clever enough not to use it. *(Voss, 2008)*

A standard data frame consists of the following components:

- **SOF, Start of Frame:** marks the beginning of data and remote frames
- **Arbitration Field:** includes the ID and RTR (Remote Transmission Request) bit, which distinguishes data and remote frames
- **Control Field:** Used to determine data size and message ID length
- **Data Field:** The actual data, which only applies for a data frame.
- **CRC Field:** Checksum
- **EOF, End of Frame:** Marks the end of data and remote frames.

(Voss, 2008)

7.4 Bus rationing

Some data that need to get to the CAN-bus is more important than other data. It is therefore vital that the more important information gets access to the bus first, for example a signal from a collision sensor is much more important than signal carrying information about motor load. The control unit that sends the important message puts high demands that the message does not get stalled by other units that try to send out their data. Messages should not stall each other. Therefore CAN utilize the arbitrary collision avoidance system CSMA/CA. This system means that a control unit needs to check if the network is available before sending any message. *(Holtmoen, 2007)*

8 Industrial Ethernet

In the industry more manufacturers are starting to use Industrial Ethernet to get a high performance, reliable, secure and real-time communication. Industrial Ethernet make use of the Ethernet and IP suite of standards already developed for corporate network environment.

8.1 Separate networks

Today companies have separate networks supporting their factory floor operations and business operations, figure 8.1. They have throughout the years been developed for different types of information flows and for these networks to exchange information gateways are needed to translate the application-specific protocols to Ethernet-based protocols. This limits the functionality and bandwidth, and requires significant effort to keep up to date.

Traditionally, the device-level network links together the different I/O devices such as sensors, transducers and motion equipment with a variety of fieldbuses such as Profibus and Modbus. Each type has its own requirement concerning power, cabling and communication leading to a multiple of networks in the same space. The different sets need several different skills and support programs within the same company. With Industrial Ethernet a company is able to connect its administrative, control-level and device-level networks to run over a single network infrastructure. When using the Industrial Ethernet network, the fieldbus specific information is embedded into Ethernet frames.

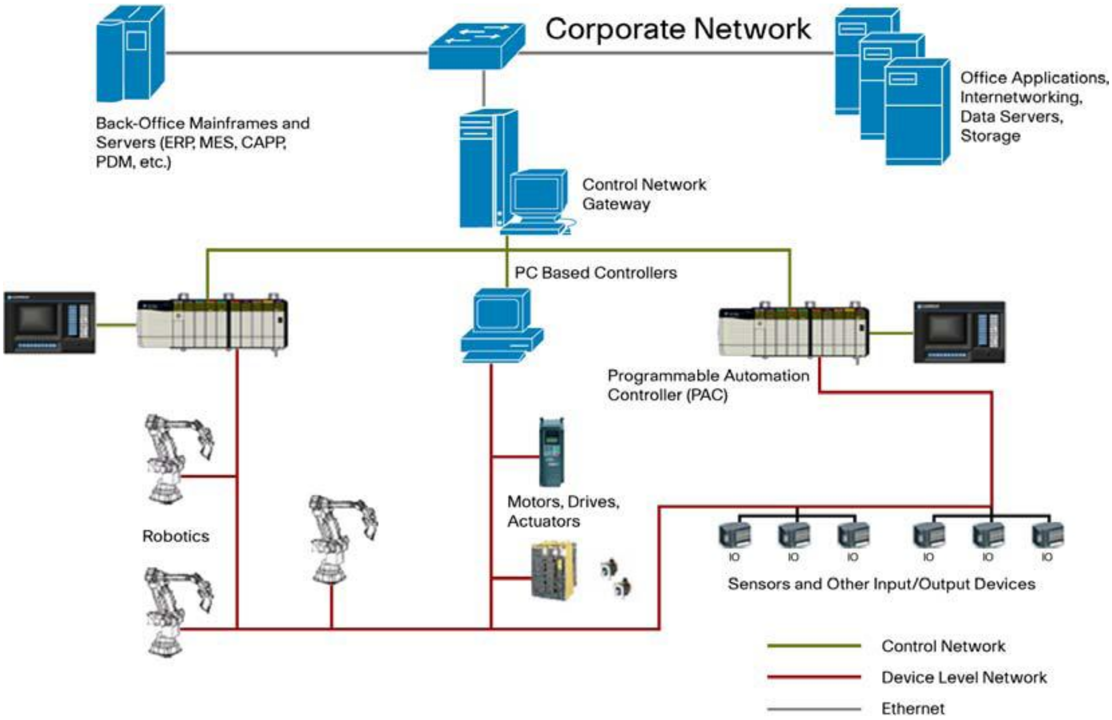


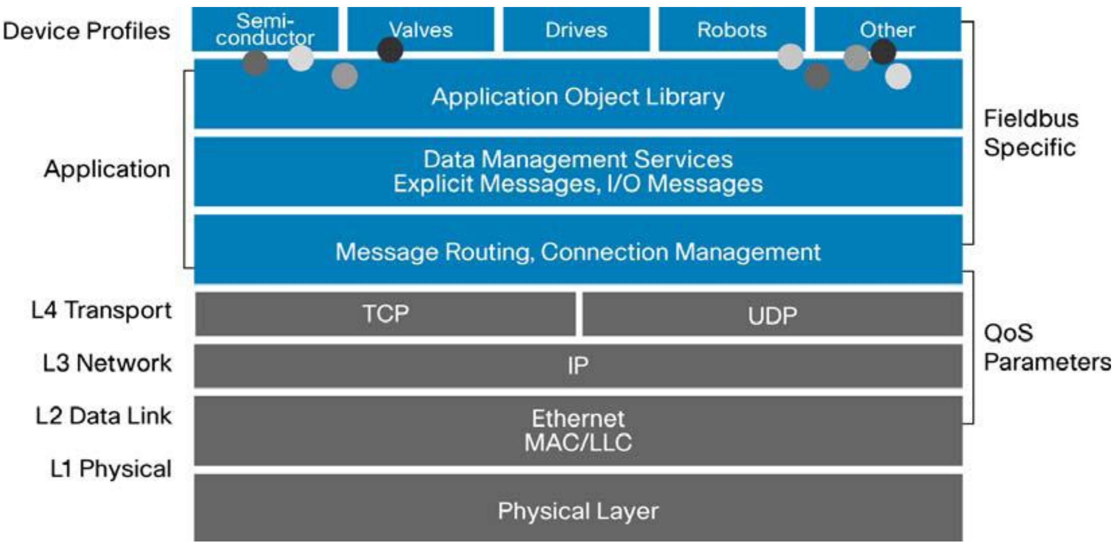
Figure 8.1 The traditional fieldbus architecture

Referring to the OSI-model, the traditional Ethernet resides in layer 1 and 2 while Industrial Ethernet is broader also encompassing layers 3 and 4. In layer 3, IP addressing is used. In layer 4, Transmission Control Protocol, TCP, and User Datagram Protocol, UDP, which is referred to as the IP suite, are utilized.

8.2 Industrial Ethernet vs. regular Ethernet

Industrial Ethernet is derived from the same industry standard as traditional Ethernet but their implementation is still not identical. The main difference is that Industrial Ethernet requires equipment that is able to handle severe environmental conditions, flexible node counts, varieties of media, very predictable real-time data-traffic performance, and increased levels of segmentation. Environmental requirements have led to a difference in hardware used. Industrial Ethernet include industrial-grade components, convection cooling, and relay output signaling. The harsh environmental conditions require modules that are able to operate under tough conditions such as extreme temperatures and under extreme vibration and shock. Furthermore the equipment needs to be able to operate using 24 volts of DC power.

With Ethernet as the leading network solution more companies are porting traditional fieldbus architectures to Industrial Ethernet. Industrial Ethernet applies the Ethernet standard to the factory floor. The great advantage with this is that organizations and devices can continue using their tools and applications but now over a more efficient network infrastructure. Users can connect the devices to each other without requiring separate gateways and a faster communication is achieved. In figure 8.2 it can be seen that the higher layers are fieldbus specific, built on the lower layer Ethernet protocol. *(Cisco Systems Inc, 2010)*



Figur 8.2 Ethernet for automation control

9 Alternative solutions

Here are the toughest products with the highest environmental requirements presented from different suppliers. The suppliers can be divided into suppliers providing solutions for the industry, and suppliers that supply CAN-bus solutions for heavy duty vehicles. The industry solutions support the use of several different protocols for fieldbuses, Industrial Ethernet and CAN. There is also a solution concerning an integrated CAN interface which is also investigated.

9.1 Plus+1 by Sauer-Danfoss

Sauer-Danfoss has a product called Plus+1, which is a CAN bus system typically used by off-road vehicles. The Plus+1 product line consists of different controllers and input/output expansion modules communicating over a CAN bus. In a distributed CAN system each product‘s hardware is equally effective with intelligence in every node. It is also possible to expand the system with additional modules.

The programming of the system is made in Sauer-Danfoss own graphical environment GUIDE (Graphical User Integrated Development Environment).

Plus+1 does originally not follow any pre-defined higher layer protocol as its functions are free to program. However, functions from the protocols SAE J1939 and CANopen are available to put in if desired.

9.1.1 Controller units

The controllers, or microcontrollers, are the programmable members of the system. Sauer-Danfoss have different controllers available consisting of five standard housings, 12, 24, 38, 50 and 88 pin. The amount of inputs vary from 4-46 and the amount of outputs vary from 2-32. The PCP requires a module with 10 inputs and 20 outputs. Only one controller can match this requirement alone. And it is the Controller called MC088-01X. However, it is possible to expand a controller with an I/O module to get the right amount of inputs/outputs.

One downside with MC088-01X controller is that the pins are placed on the top, in contrast to the other controllers, where the pins are placed in at the front. This might lead to difficulties in connecting wires to it because the signal wires in the PCP are placed in front of where a microcontroller would be placed. Figure 9.1 illustrates the controllers. *(Sauer-Danfoss, 2010)*

Figure 9.1 The Microcontrollers with MC088-01X to the far right

9.1.2 I/O units

Beside the microcontrollers different I/O modules will be needed, either to increase the amount of inputs/outputs for the microcontroller or to be placed at a control unit physically placed at another location. *(Sauer-Danfoss, 2010)*

9.1.3 Requirement fulfillment

The Plus+1 system fulfils the requirements fairly good but further testing is still needed for shock, vibration and EMC. The shock and vibration tests are should be performed in order to see if they fulfill the random vibration and saw-tooth pulse requirements. Table 9.1 specifies the requirements.

Table 9.1 Environmental requirements for Plus+1 (Sauer-Danfoss, 2010)

Requirement	Value
Storage temperature	-40°C to +85°C
Operating temperature	-40°C to +70°C
Voltage limit	36 VDC
Shock	15g/11ms, half-sine
Vibration	1g, 24-2000 Hz
Relative humidity	95%
EMC requirements	Not tested for military req.

9.2 Twido Extreme by Schneider Electrics

The Twido Extreme controller is made for severe environmental conditions for example in terms of temperature, vibration, oil splashing, and impact. Originally it was designed for Caterpillar and is now used for heavy-duty vehicles such as garbage and fire trucks.

Schneider Electrics only offers this controller and they do not have any suitable I/O-modules. In order to implement a network system in the Giraffe AMB I/O-modules are needed. For this solution to work I/O-units from other suppliers are needed.

Twido is available with three different communication ports for different protocols. Two of the ports are for the one CAN protocol each, CANopen and J1939, and the third is for the fieldbus protocol Modbus.

To program and debug the Twido Extreme the TwidoSuite software is used.

Figure 9.2 Twido Extreme Controller

9.2.1 Requirement fulfillment

Twido Extreme fulfils the requirements fairly well. However, both shock and vibration requirements need further testing because they are not tested as saw tooth pulses or random vibrations. The controller is not tested for EMC according to military standards and will need to be tested in accordance.

Table 9.2 Environmental requirement for Twido Extreme (Schneider Electrics, 2009)

Requirement	Value
Storage temperature	-55°C to +155°C
Operating temperature	-40°C to +110°C
Voltage limit	Max 32V
Shock	15g/11ms, half-sine
Vibration	1g, 24-2000 Hz
Relative humidity	90%
EMC requirements	Not tested for military req.

9.3 SIPlus S7-300 by Siemens

The SIPlus S7-300 is a PLC using the Industrial Ethernet technology with the ProfiNet protocol. Developed for harsh environments, it is protected against moisture, corrosive vapors, salts, dusts et cetera. Additionally it is constructed to be used under conditions of condensation and in saline atmospheres, and in the combined presence of moisture and corrosive gases.

Special adaptations to tailor the PLC after individual requirements is possible, these requirements might for example be; different voltage/current ranges, higher voltage strength, higher mechanical strength and following special standards, including declaration of conformity. *(Siemens AG, 2008)*

Figure 9.3 The SIPlus S7-300 PLC

9.3.1 Requirement fulfillment

The SIPlus PLC might not fulfill the lower temperature limit for operation, but during drift the temperature can be regulated, and the -25°C limit could work. It is important that the storage temperature limits fulfil the temperature requirements because no heating or cooling device is used when the system is shut down. Another point is that the voltage limit is not good enough. However, according to Siemens, it should be able to handle a voltage of 32 V. Otherwise the PLC can be adapted for other current ranges. Tests for EMC, shock and vibration are needed to get conformity with Saab's requirement.

Table 9.3 Environmental requirements for SIPlus S7-300 (Siemens AG, 2010)

Requirement	**Value**
Storage temperature	-40°C to 70°C
Operating temperature	-25°C to 70°C horizontal mounting -25°C to 60°C vertical mounting
Voltage limit	28,8 V
Shock	15g/11ms, half-sine
Vibration	1g, 24-2000 Hz
Relative humidity	5-100%
EMC requirements	Not tested for military req.

9.3.2 I/O modules, SIMATIC ET 200eco PN

The SIMATIC ET 200eco PN is an I/O-module designed to be used outside a control cabinet into a machine gap, a tough environment with for example a lot of vibrations. Its housing is made out of a fully sealed zinc die-cast, which makes it mechanically rugged and resistant to vibrations, dust, oil and humidity.

Its ProfiNet connection has a 2-port switch in each module and can be used in other both star and line topologies. Both the power and the bus are connected to the I/O module via a M12 connection.

It is available in two different housings, illustrated in figure 9.4:

- A long and narrow 4 x M12 connection with the dimensions 30 x 200 x 37 mm.
- A shorter and wider 8 x M12 connection with the dimensions 60 x 175 x 37 mm.

The ET 200eco PN modules can be mounted horizontally or vertically. *(Siemens AG, 2009)*

Figure 9.4 The different ET 200ecoPN modules (Siemens AG, 2009)

9.3.3 Requirement fulfillment

The I/O modules have great mechanical capabilities except for the temperature requirements that have the same problem as the PLC during operation. There is no specification for the storage temperature and the operating temperature is worse than Saab's requirements. Even if the drift temperature can be regulated during operation, it needs to be heated during extreme cold and chilled during extreme heat. Furthermore, the voltage range needs to be expanded and the product needs to be EMC tested for military requirements. The ET 200eco PN handles vibration and shock very good, even though they it is not specified according to the random vibration and saw-tooth pulse tests it is an indication that it probably will handle them well.

Table 9.4 Environmental requirements for ET 200eco PN (Siemens AG, 2009)

Requirement	**Value**
Storage temperature	
Operating temperature	-25°C to +60°C
Voltage limit	28,8 V
Shock	30g/18ms
Vibration	40g, 10-58 Hz
Relative humidity	5-100%
EMC requirements	Not tested for military req.

9.4 Programmable gateway, BL67-PG-EN-DN by Turck

The programmable gateway can be used as a PLC and is the head component of a BL67 station. I/O-modules connected to the gateway can communicate with each other independently of the protocol. Many industrial protocols are supported but the protocols that are of interest for Saab's application are the CAN protocols: DeviceNet and CANopen. The module is illustrated in figure 9.5.

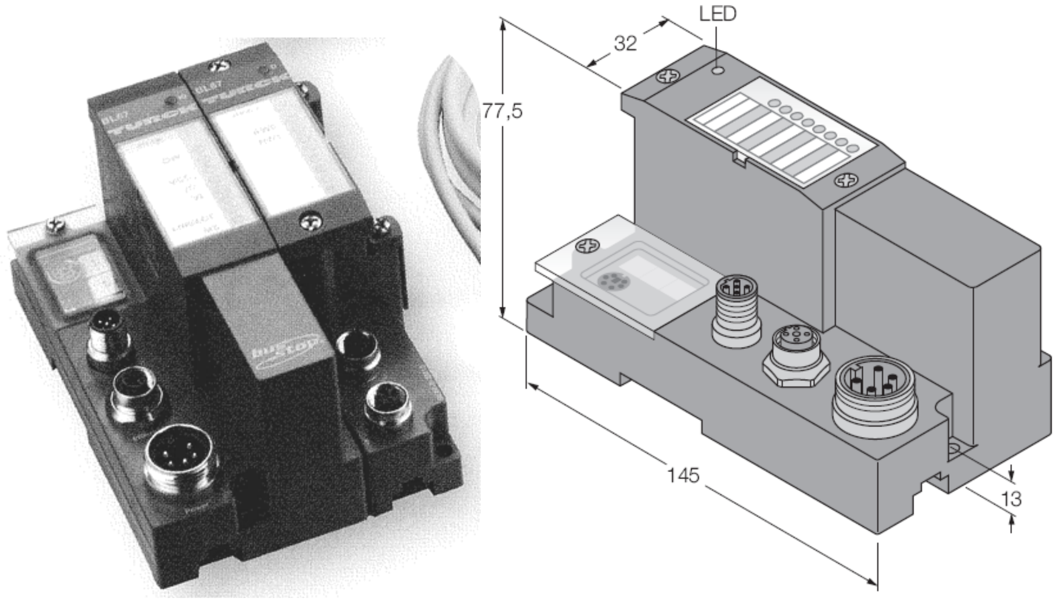


Figure 9.5 BL67-PG-EN-DN programmable gateway

9.4.1 Requirement fulfillment

This master unit does not fulfil all environmental requirements. The lower temperature range is only tested for a limit of -25°C and the required limit is -40°C. This might not be critical because a heating fan can sometimes be used. However, the storage temperature will need further testing. As for the other products the vibration, shock and EMC requirements need further testing.

Table 9.5 Environmental requirement for BL67-PG-EN-DN programmable gateway (TURCK, 2009)

Requirement	**Value**
Storage temperature	-25°C to +85°C
Operating temperature	-25°C to +70°C
Voltage limit	30 VDC
Shock	15g/11ms
Vibration	1g 24-2000 Hz. Extended 20g 10-150Hz
Relative humidity	95%
EMC requirements	Not tested for military req.

9.4.2 I/O modules, BLCXX-4M12S-8DI-P

Turck's I/O-module is designed to allow direct mounting onto a machine without any other housing or enclosure. They can be connected to the master unit and to each other via M12 connectors. Figure 9.6 illustrates the I/O-modules.

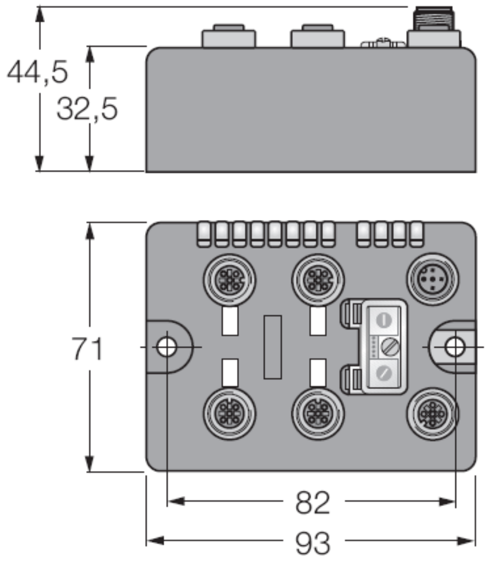


Figure 9.6 The I/O-modules, BLCXX-4M12S-8DI-P

9.4.3 Requirement fulfillment

The I/O-modules fulfill almost all the requirements but there are some uncertainties for the voltage tolerance. If they cannot tolerate 32V they will not be possible to use. Further testing needs to be made for the voltage tolerances, EMC, shock and vibration.

Table 9.6 Environmental requirement for BLCXX-4M12S-8DI-P (TURCK, 2009)

Requirement	**Value**
Storage temperature	-40°C to +70°C
Operating temperature	-40°C to +85°C
Voltage limit	30 VDC
Shock	15g/11ms
Vibration	20g 10-150Hz
Relative humidity	95%
EMC requirements	Not tested for military req.

9.5 Integrated CAN

Instead of having separate units, such as I/O units, that translate the signals from the control units to CAN signals, it is possible to integrate the CAN bus directly to the control unit. This could be the best solution over time as it will be the most cost effective and space saving solution.

As previously mentioned in section 7 the most important parts in a control unit to make it able to communicate on a CAN-bus are; the microcontroller, the CAN-controller and the transceiver. The CAN-controller is often integrated within the microcontroller which leads to only two main components to integrate CAN: a microcontroller with integrated CAN-controller and a transceiver.

Figure 9.7 shows a circuit layout for a simple CAN node. This example node has 2 analog inputs and 2 digital outputs. It consists of one CAN transceiver and two microcontrollers.

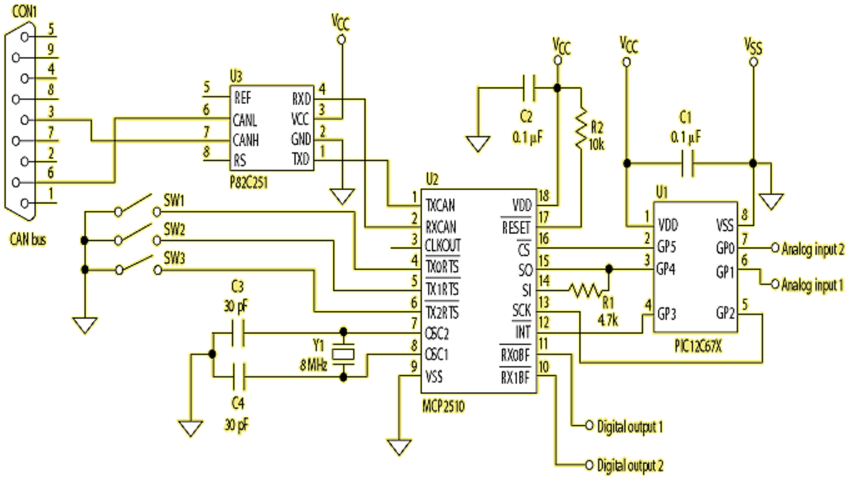
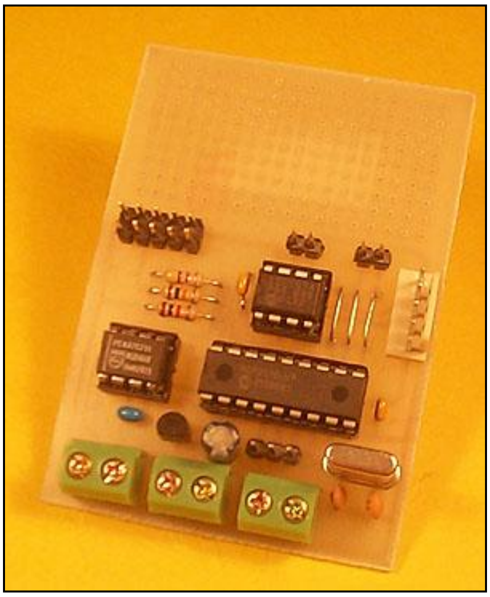


Figure 9.7 An example of a simple CAN node (Electronic design, 2001)

As seen in figure 9.8, a CAN node can be built with few, small components. This set of components offer 2 analog inputs, 3 Digital Inputs and 2 Digital Outputs. It operates with a 9-24 Vdc Power Supply and cost only USD$19.50. *(Futurlec, 2010)*



Figur 9.8 Example of a CAN node (Futurlec, 2010)

9.5.1 Microcontroller

There are many manufacturers to choose from when it comes to microcontrollers with integrated CAN-controllers. The manufacturers include ASIX, Atmel, Dallas Semiconductors, Freescale Semiconductors, Infineon, Luminary Micro, Nuvoton, NXP (founded by Philips), Samsung, Silicon Laboratories, Inc., STMicroelectronics, Texas Instruments and Toshiba. *(Keil, 2010)*

One relatively newly released microcontroller chip with integrated CAN, that is already brought into Saab, is the LM3S9B96 from Texas Instruments (formerly Luminary Micro). It is a 32-bit ARM®Cortex™-M3 based Microcontroller running at 80MHz and has a 256KB Flash ROM. It has two CAN controllers of CAN version 2.0A/B and a temperature range of -40 to 85°C. It supports up to 65 General Purpose

Input/Outputs, depending on configuration as well as two 10-bit Analog-to-Digital Converters (ADC) with sixteen analog input channels and sample rate of one million samples/second. It has Ultra-low power consumption and integrated sleep/standby modes. *(Texas Instruments, 2010)*

9.5.2 Transceiver

The transceiver SN65HVD1040-Q1 from Texas Instruments could be used to ensure compatibility with the proposed microcontroller. This is a 5V transceiver that has a Bus-Fault Protection of -27 V to 40 and withstands voltage transients from –200 V to 200 V. Other characteristics are High Electromagnetic Immunity (EMI), Low Electromagnetic Emissions (EME), temperature range of –40°C to 125°C and Low-Current Standby Mode (<12 mA Max) with Bus Wake-Up. *(Texas Instruments, 2010)*

10 Selection of system

When selecting a winning system from the investigated suppliers they are compared against each other with help of a Pugh matrix. A Pugh matrix is a relative comparing matrix where the suppliers are compared through selection criteria's. These criteria's are not critical criteria's but more wishes that can be "over-fulfilled". The used criteria's are the desired properties stated in section 3.2:

- **Req. fulfillment:** All the suppliers fulfilled the set requirements differently, some requirements where not even tested for. It would be preferable to avoid performing too many additional tests as these are expensive.
- **Stand-alone supplier:** This wish is because some of the solutions require a mix of two suppliers. One supplier that can deliver a complete system is favorable.
- **Compatibility with future Saab protocols:** At other departments and other modules, CAN interfaces are starting to be implemented. It can be a good idea for the future if the same interface is used for all the control units, especially if integrated CAN is something to strive for.
- **Freedom when adding functions:** When using a network system it is often compatible with some kind of higher-layer protocol. This criterion is set to compare the flexibility of the different systems.
- **Programmability:** It is a spoken wish from Saab that the system should be easy to program.
- **Required cabling:** A big purpose of this project is to reduce the cabling of the system, this is why this criterion is set.
- **Possibility for development:** The products' ability to adapt for upcoming developments of the Giraffe AMB is of importance.

Notable is that because the Twido Extreme from Schneider Electrics is only a controller, one of the concepts is a mix of the Twido Extreme and the I/O-modules by Turck.

Table 10.1 Pugh matrix

Criteria	Siemens	Turck	Sauer-Danfoss	Schneider/Turck
Req. fulfilment		-	+	+
Stand-alone supplier		-	+	-
Compatibility with future Saab protocols	R	0	+	0
Freedom when adding functions	E	0	+	0
Programmability	F	0	0	0
Required cabling		0	0	0
Possibility for development		-	+	+
Total	**0**	**-2**	**+5**	**+1**

As a result from the Pugh matrix the selected supplier is the Plus+1 from Sauer-Danfoss. Usually the solution is weighed several times with different references but because Sauer-Danfoss won with relatively great margin, it is not necessary for any further weighing.

Plus+1 by Sauer-Danfoss is the system that is chosen. However, integrated CAN is also a good solution with many shared benefits together with the Plus+1. It is also possible to use these systems together. Because integrated CAN is not a feasible solution in the shorter perspective it is seen as a solution for the future while Plus+1 is the system chosen for implementation in the nearer future.

11 Selected system

The chosen concept is the Plus+1 system by Sauer-Danfoss. It is a modern CAN system with a high degree of freedom for the user.

11.1 Plus+1

The system needs a microcontroller that will replace the Switch On Logic Card and I/O-units, spread out at different control units. To fit our system the microcontroller will need 10 inputs and 20 outputs. The best suited controller is the MC038-010 together with an OX024-10 expansion module.

The microcontroller has 15 inputs and 13 outputs and the I/O-expansion module has 16 outputs. Both modules are illustrated in figure 11.1.

Figure 11.1 MC038-010 and OX024-010 Expansion Module

The IOX024-020 I/O-module is used at the different control units in order for them to be able to communicate with the CAN bus. It has 8 Inputs and 8 outputs and notable is that it requires a separate power cord with separate safety plugs.

Figure 11.2 IOX024-020 Expansion Module

Figure 11.2 illustrates potential layout of a system where the cabling through the CB1 is removed and replaced by a communication through a CAN-bus. The I/O-modules are placed in control units with free space. Their cover will also need to be removed in order for them to fit a card rack.

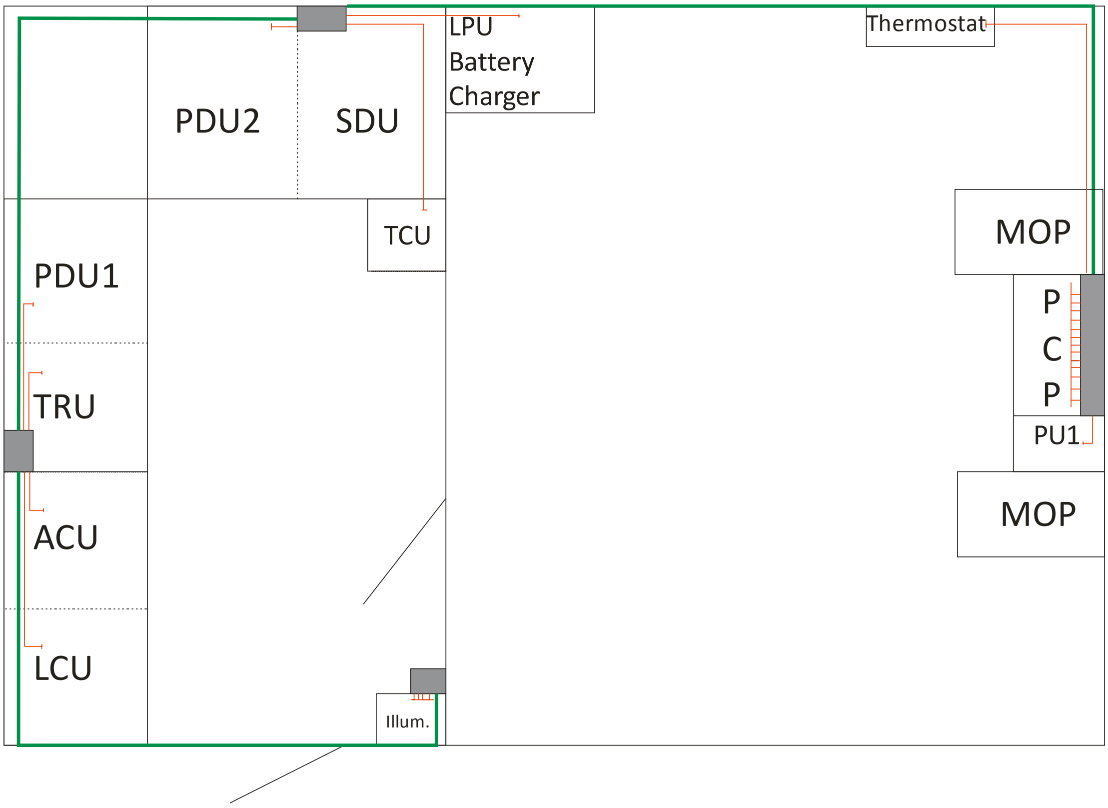


Figure 11.3 An illustration of the Sauer-Danfoss CAN system in the Giraffe AMB

11.2 Communication with SDU

As mentioned in section 2 it would be beneficial for the different units to communicate with the SDU. In order to do this, a gateway or CAN-interface is needed. The SDU a free cPCI slots at which a board with CAN functionality can be installed. Emtrion Gmbh is a german based company that offers a cPCI CAN controller called HiCO.CAN-CPCI, shown in figure 11.4.

Figure 11.4 The HiCO.CAN-CPCI

The HiCO.CAN-CPCI has 1-2 CAN interfaces built on the SJA1000 CAN controller with CAN 2.0B. It has a storage temperature range of -40 to +85°C and operating temperature range of 0 to +70°C. They do however offer extended temperature range on request. The relative humidity is 0 to 95%, non-condensing. It does also support Linux which is a demand from Saab. *(Emtrion, 2008)*

11.3 Highlights with the Plus+1 system

Implementing CAN to the system will bring several advantages. CAN enables diagnostics of the system, so it is easy to find faults. Compared with the current system, where this possibility does not exist, a lot of time will be saved leading to improved service towards customers. One observable benefit when implementing a network system is that the CB1 box is no longer needed. This is cost beneficial but also space saving.

With the use of a gateway or CAN-interface installed in the SDU, it will be possible for the operators to see faults or other information that might be of interest that is routed through the bus. This information could be displayed directly on the operators' screens. With this information they could try to fix the problem themselves, by for example rebooting a device. If they cannot fix it themselves, they could call the support with information of failing source. The support could then send assistance and spare parts immediately as they know which units that are failing.

Distance control is something that is improved as well. Today the Giraffe AMB can be remotely controlled by the operators. They can sit from a distance and control several units at the same time. What they control is everything that is controlled by the SDU and displayed on the screens. By implementing CAN, more control units can be remotely controlled, as everything that is controlled by the PCP also becomes available.

CAN is a flexible system where new nodes can be implemented easily. This is because it supports all available protocols as well as self compiled protocols. It is possible to connect the Plus+1 system to arbitrary nodes, as long as they have a CAN interface. This means that CAN nodes from other suppliers can be added without greater complications. Furthermore it is easier during development of a new Giraffe AMB to customize it in the aspect of adding or modifying functions.

12 Programming

Sauer-Danfoss programming is called GUIDE (Graphical User Integrated Development Environment) and has a graphical user interface. The Plus+1 system only follows the physical and data link layers, which enables the user to freely program.

For programming in GUIDE drag and drop building blocks are used. The pre-tested blocks or modules can be basic components or operation-ready solutions with the ability to be implemented at all levels. When chosen, the block can be compiled and downloaded to the controller at once or if it needs to be customized it can be reprogrammed.

On the right hand side of the programming environment components and functions can be dragged to the work space. To work in GUIDE there are no requirements for previous software programming skills.

With the eLearning that is free to use on Sauer-Danfoss webpage it is possible to get comprehensive training in the program. As long as the programmer is acquainted with his own system there should not be any difficulty to learn the program even after some absence.

In the near future the possibility to program in C will be possible. This is very good because programmers might want to use C-programming instead because they are more comfortable with this.

Figure 12.1 and 12.2 shows some screen shots of the program where the interface can seen. The first picture shows a blank work space with a hardware list on the right hand side that can be dragged in to the work space. The second picture illustrates the dragged in hardware and its connections and the third picture is the work space of the inputs for the hardware. A fourth picture is also illustrated as an example of how to program the functions.

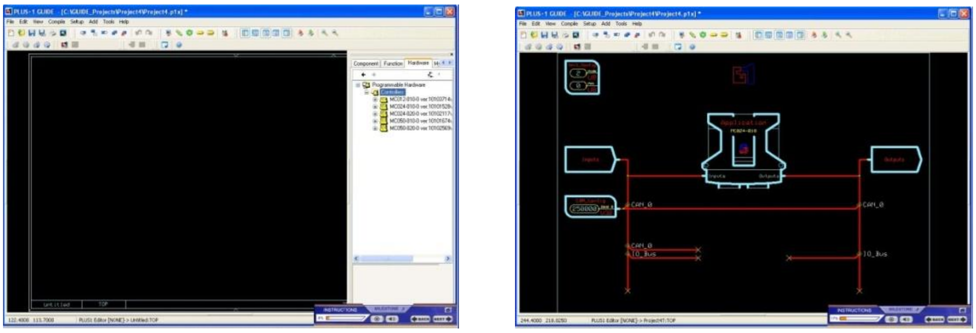


Figure 12.1 Screen shots from GUIDE

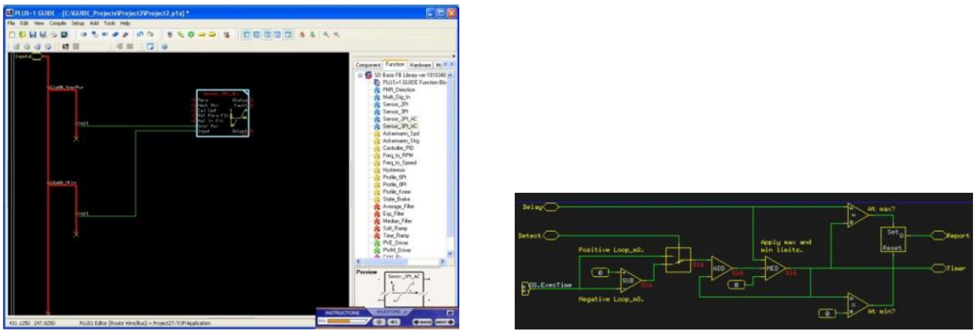


Figure 12.2 Screen shots from GUIDE

13 Cost analysis

When making a cost analysis for implementation of the new system, several factors need to be considered. Before the system is ready for installation an investigation needs to be made, employees need to be trained, a productification needs to be made, as well as a system design and functional verification. Furthermore the system needs further testing and production methods have to be developed. These costs together with materiel costs are considered as initial costs.

Because the new system requires a change in modules and cabling, new tests are needed. The Plus+1 system is not tested to the desired extent which requires further testing of vibration, shock and EMC. As temperature and humidity tests are relatively cheap it is decided that these will be performed while testing the other requirements as well.

Because of the sensitivity of this information, the calculations will only be available for Saab AB in appendix D.

13.1 Starting expenses

The initial costs will mostly concern engineering and testing of the new system. Other starting expenses will be purchase of licenses and creating production methods. The expected engineering hours are divided into a worst and best case scenario. The worst case scenario requires about 2700 engineering hours while the best case scenario will require about 1800 engineering hours.

Testing the products for the environmental requirements will include testing for EMC, vibration, shock, temperature and relative humidity. Furthermore there is a need to purchase a set of test products as well as license fees.

Before the system is ready for production a method for production needs to be made and the production staff needs to be trained. This is estimated to require 100 engineering hours in order to develop a method and 40 production personnel hours for the training.

With all these expenses considered, this will give an initial cost of the worst case scenario that is 33% higher than the best case scenario.

13.2 Cost per Giraffe AMB

When investigating the cost changes for every produced Giraffe, the idea is to take the scenario where the current system with CB1 and SOL card is removed and replaced with a microcontroller and I/O-units. The cabling will also be changed and the estimation is performed by removing the existing cabling that is led through the CB1 and replaced by a simpler wire leading to the use of cheaper connectors.

The assembling cost will be a big part of the cost reduction. Today the SOL card has many cables connected to it, while in the Plus+1 system only two cables will handle the communication between the PCP and control units. However, the signal connections that are removed from the SOL card are moved to the I/O-units, which will not lower the handling costs noteworthy. But there is the possibility that the reduction of big cables will make the assembling part easier. Today the labor cost of manufacturing the PCP is about 60% of the total PCP cost, where most of this cost is placed on the SOL card.

Furthermore there will be some costs concerning purchasing of components. This is something that the sale representatives need to negotiate but is not a significant part of the cost.

There are parts of the cost analysis that are very difficult to estimate. One concern the savings from improved flexibility in the system in terms of adding or removing functions can save a significant amount of development time, especially if an order is customized. Savings from easier implementation of new functions is estimated to save about 300 engineering hours for each Giraffe AMB, which in some cases can be much more.

Concerning improved functionality through diagnostic time it is also difficult to make an estimation of how much money this will save. The customers are vey keen on having their Giraffe’s running as much time as possible and an estimation based on the rental costs of a system is made. An estimation of the how much saved diagnostic time is needed to gain the initial cost back is made. It is estimated to about 500 hours for the worst case scenario (not including other savings).

14 Failure Modes and Effects Analysis, FMEA

Quality issues can, generally speaking, in worst case lead to deaths, injuries, or large-scale economical losses. Trivial quality issues that are not safety critical is still perceived as annoying for the customer and is affecting the product image negatively. *(Johannesson et al, 2004)*

Saab wants to avoid quality issues or failures to a very high degree. A failure in operation may in worst case lead to deaths as the radar may not function properly in operation. It can also lead to high costs, as large resources will be used to solve the problem. For example the need for a diagnostic engineer to be shipped to the location and after that a replacement part. Time is also of importance when something needs to be solved.

Failure Modes and Effects Analysis, or FMEA, is a tool to ensure quality during the product development stage. It is built on subjective judgments from the developer team, of what things that can go wrong, the likelihood and what consequences this has. *(Johannesson et al, 2004)*

The FMEA analysis shows that the areas of most concern for the development of the system are EMC, software, financial, and future. The EMC is a concern as it may not be fully detected during the development and testing stage. It may also be discovered when the system is assembled wrong. The software is a concern as a faulty programming may lead to system failure after a long time. As the software will be developed by personal without any experience in CAN this will lead to an even greater risk. Extensive software testing and assistance from experienced personal with the programming will minimize this risk.

There is a financial risk is due to unexpected development issues. To minimize the surprise of an unexpected high cost, a worst case scenario cost analysis is made which needs to be considered. Lastly the future concern is due to the fact that CAN may decline because of upcoming techniques such as FlexRay. There is nothing to date that suggest a total conversion from CAN to FlexRay but FlexRay will probably take some of the market shares from CAN in the future.

The FMEA analysis made is shown in Appendix C.

15 Conclusions

Several different network types have been investigated throughout this project. The network types of interest are the ones developed for tough environmental conditions, especially temperature, relative humidity, vibration, shock and Electro Magnetic Compatibility. Systems used to operate in these kinds of environments are those used in the automation industry and in automobiles. After an investigation of the network types used in these industries the most promising types showed to be fieldbuses, Industrial Ethernet and CAN-bus.

However, a big part of this project is to choose a network type that is mature and will be on the market for a long time. With this aspect taken into consideration, the traditional fieldbus technology used in the industry is eliminated. This is due to the fact that it is starting to be replaced with the Industrial Ethernet technology, enabling the connection with the automation floor and the office. As can be seen in the chapter 5, maturity comes with a drawback. If the technology is too mature, the profits will go down and force the companies to develop a new revolutionary technology. There in lays a contradiction, as Saab requires a mature technology, but also requires that the technology will be available for a long time. Industrial Ethernet is however considered satisfyingly mature even though it is not as mature as CAN. One worrying aspect with CAN is that it perhaps is too mature and can be replaced by a revolutionary technology, such as FlexRay.

Suppliers providing solutions for Industrial Ethernet and CAN networks were visited for educational purpose and to see what products they have to offer. Different promising products were chosen for further investigation. With the use of a Pugh matrix the Sauer-Danfoss Plus+1 system was chosen. This is a CAN system that provides a high degree of freedom, because it does not follow any specific higher layer protocol. It does however have the ability to use functions from the two higher layer protocols SAE J1939 and CANopen. In addition to the solutions from the suppliers an alternative solution with integrated CAN was looked at. With simple CAN interface the different control units are able to communicate through a CAN-bus excluding all the large modules that otherwise are needed. However, because of long contracts with suppliers manufacturing several subsystems and long lead times for implementing the CAN interface into the units this solution is not suitable in a short perspective.

The Plus+1 system is further analyzed from a cost perspective and its programmability. The cost analysis results in a high implementation cost but without any greater in cost savings concerning the purchase of the modules and assembly. Instead the greatest savings will come from the CAN systems upsides with great diagnostic ability and flexibility, helping Saab to find errors in their products much faster and enabling faster development time. These savings will be great and through time save much more money than the cost to implement the new system.

Furthermore the system will need some further testing concerning vibration, shock and EMC. This is because the system is not tested for the requirements Saab requires for their products. Programming the system is made through a graphical interface and is straight forward to learn with tutorials available online.

16 Recommendations

To decide if to implement a new system there will be a need for a further investigation off aspects that are not included in this project. The system has been investigated in the sense of suitable technology, environmental requirements fulfillment, suitable suppliers, cost and programming. Things that have not been investigated are the signal handling and other electrical properties (concerning how the connections should be made).

It is recommended to start of investigating the Sauer-Danfoss Plus+1 system and its suitability for implementation. It will need further testing for EMC, vibrations and shock. As described earlier the tests for vibration and shock that have been performed are not sufficient for the Giraffe AMB.

Integrated CAN is something that should be strived for. Because a lot of units are made by subcontractors it might be difficult to get a completely integrated system. However, some parts can get a CAN interface and it is our recommendation to implement this interface into those components. The Sauer-Danfoss+1 system can work together with these units if they have a CAN interface.

The personnel need to be trained and educated. Both engineers and staff from the production need to be involved, engineers need to learn how to design and program the system, while the production staff needs to learn how the system is used and assembled. Concepts also need to be developed, for both the physical parts and the logic. This step is followed by a design process and later by a functional verification. Further, the system needs to be productified, where all the parts of this system need to be drawn and tested in order to be added into Saab's system. When all these steps are carried out, a production method needs to be made.

The greatest implementation improvement will be gained if integrated CAN is implemented. Knowing that this cannot be made right away, it should be kept in mind that when making new modules there should also be a CAN interface, enabling them to be connected to a CAN bus. Their size is small and the cost is low. With integrated CAN, all the advantages that are available from the Sauer-Danfoss system will be present but the purchase cost will be lower. It is possible to use the Plus+1 modules in combination with integrated CAN. That means that when a module is about to be replaced, it can be implemented to the CAN-bus without connecting it to an I/O-module.

17 References

Advantech Co. *Flexible Modbus Solutions*. September 24 2008.Available: < http://www.advantech.com/eautomation/remote-io/news.aspx?doc_id=%7B5FC3E97D-B571-40CB-A968-3B6C4E857C7> (2010-05-30)

American Meteorological Society. (1959). *Glossary of Meteorology*. Boston: AMS Relative humidity (RH) indicates the degree of saturation of the air.

ARC Advisory Group Inc. (2008). *Continued Rapid Growth Seen for Industrial Ethernet.*January 30 2008. Available: < http://www.automationworld.com/webonly-3878> (2010-05-30)

Babb, M (2009). Profinet gains another major PLC supporter. *Control Engineering UK.* September 05 2009. Available: < http://www.controlenguk.com/article.aspx?ArticleID=24656> (2010-05-30)

Brain, Marshall (2010). How Microcontrollers *Work. How Stuff Works.* Available: < http://electronics.howstuffworks.com/microcontroller1.htm> (2010-06-04)

Buchanan, William (2000). *Computer busses: design and application.* London: Arnold.

CAN in Automation. *CAN made easy*. Available: <http://www.can-cia.org/pg/can/additional/can_basics_print.pdf> (2010-05-30)

Cisco Systems Inc. (2010). *Industrial Ethernet: A Control Engineer's Guide* (Electronic). PDF format. Available: < https://www.cisco.com/web/strategy/docs/manufacturing/industrial_ethernet.pdf > (2010-05-30)

Control Engineering (2010). *Industrial Ethernet Protocols Survey results show who's winning and why.* Available: < http://www.controleng.com/article/265257-Industrial_Ethernet_Protocols_Survey_results_show_who_s_winning_and_why.php> (2010-04-27)

Day, John (2008). Kicking CAN. *Auto Electronics.* May 01 2008. Available: < http://autoelectronics.com/mag/flexray_replaces_controller_area_network-0508/index2.html> (2010-05-30)

De Regt, Hans (2007). Back to Basics & Future Trends: Automotive networking. December 07 2007. *Automotive Design Line.* Available: <http://www.automotivedesignline.com/howto/204702733> (2010-05-30)

Decotignie, Jean-Dominique (2005). *Which Network for Which Application.* In Zurawski, Richard (editor). *The Industrial Communication Handbook.* PDF format. Available: < http://old.engnetbase.com/books/4682/3077ch19.pdf> (2010-05-30). Boca Raton : Taylor & Francis

Electrobit (2010). *The FlexRay Protocol – A New Communications System.* Available: < http://www.elektrobit.com/what_we_deliver/automotive_software/technologies_and_standards/flexray> (2010-05-30)

Electronic design (2001). Build a simple and inexpensive Controller Area Network Node. April 1 2001. *Electronic design.* Available: <

http://electronicdesign.com/article/communications/build-a-simple-and-inexpensive-controller-area-net.aspx > (2010-05-30)

Electronic design (2010). Available: <http://archive.electronicdesign.com/files/29/21886/fig_01.gif> (2010-05-30)

Emtrion GmbH. *HiCOCAN Technical Informations* (2008). PDF format. Available: <http://www.emtrion.de/doc/HICOCAN_technical_V03en_edi2089.pdf> (2010-05-30)

Futurlec (2010). Available: <http://www.futurlec.com/CANNode.shtml> (2010-05-30)

Groth, David, Lammle, Todd & Tedder, William. (2003). *Network + Study Guide, Deluxe Edition*. (Electronic) Alameda, CA: SYBEX Inc. Available: books24x7 (2010-05-28)

H. Kuhnke Ltd (2007). *Fieldbus System* Available: http://www.thetimerandcountercompany.com/fieldbus.php (2010-05-30)

Hammerschmidt, Christoph (2009). Ethernet no threat to FlexRay, NXP says. 27 August 2009. *Industrial Design Line.* Available: < http://www.industrialcontroldesignline.com/news/219501141;jsessionid=41DXLCAENQDXZQE1GHPSKHWATMY32JVN> (2010-05-31)

Henricsson, Per (2006). En buss för multimedia I fordon (Electronic). December 12 2006. *Elektronik Tidningen.* Available: <http://www.etn.se/index.php?option=com_content&view=article&id=20418> (2010-05-30)

Holtmoen, Sigbjörn (2007). *Prestanda CAN.* Malmö: Gleerups Utbildning AB

Hur Yerang, Zhou Jiaxiang Lee Insup (2001). *Time-Triggered Protocol.* PPT format. Available: <http://www.cis.upenn.edu/~lee/01cis642/slides/Time-Triggered%20Protocol.ppt> (2010-05-30)

International Electrotechnical Commission (2010). *Electromagnetic compatibility and the IEC.* Availabe: <http://www.iec.ch/zone/emc/> (2010-06-04)

International Electrotechnical Commission (2010). Availabe: < http://www.iec.ch/about/mission-e.htm> (2010-04-1)

IMS Research (2009). *Ethernet and Fieldbus Networks Destined to Co-exist in Industry in China.* August 31 2009. Available: < http://www.imsresearch.com/press_release_details.html&press_id=1307> (2010-05-30)

IMS Research (2009). *Industrial Ethernet Riding out the Storm.* September 3 2009. Available: < http://www.imsresearch.com/press_release_details.html&press_id=1083> (2010-05-30)

Intellicom Innovation AB *(2010). Modbus RTU overview.* Available: < http://www.intellicom.se/solutions_modbus_rtu.cfm > (2010-05-30)

INTERBUS Club (2010). Available: <http://www.interbusclub.com/> (2010-05-30)

IXXAT Automation GmbH (2010). *FlexRay Introduction*. Available: < http://www.ixxat.com/introduction_flexray_en.html> (2010-05-30)

Jecht, Ulrich, Stripf, Wolfgang & Wenzel, Peter (2005). *Profibus: Open Solutions for the World of Automation.* In Zurawski, Richard (editor). *The Industrial Communication Handbook.* PDF format. Available: < http://old.engnetbase.com/books/4682/3077ch10.pdf> (2010-05-30). Boca Raton : Taylor & Francis

Johannesson, Hans, Persson, Jan-Gunnar & Pettersson, Dennis (2004). *Produktutveckling: effektiva metoder för konstruktion och design.* Stockholm: Liber

Karlberg, Lars (2006). Saab köper Ericssons radarbolag Microwave (Electronic). *Ny Teknik*, June 12 2006. Available:< http://www.nyteknik.se/nyheter/fordon_motor/rymden/article39997.ece> (2010-05-28)

Keil (2010). *CAN-based Microcontrollers.* Available : <http://www.keil.com/can/chips.asp> (2010-05-30)

LIN Administration (2010). *Technical Overview, Target applications* Available : <http://www.lin-subbus.org/index.php?pid=4&lang=en&sid=daeaee4aba7c09e1f57930c90b2bc300> (2010-05-30)

Millinger, Dietmar & Nossal, Roman (2005). *FlexRay Communication Technology*. In Zurawski, Richard (editor). *The Industrial Communication Handbook.* PDF format. Available: < http://old.engnetbase.com/books/4682/3077ch30.pdf> (2010-05-30)

Mobile Dev & Design (2008). *Time-triggered protocol controller targets aerospace applications.* March 25 2008. Available <http://mobiledevdesign.com/hardware_news/controller_targets_applications_0326/> (2010-05-30)

Modbus Organization (2010). *Modbus FAQ : About the Protocol.* Available : <http://www.modbus.org/faq.php> (2010-05-30)

North Atlantic Treaty Organization. Standardization Agreements. Available: < http://www.nato.int/cps/en/SID-8BF0F167-D3248540/natolive/stanag.htm> (2010-04-20)

National Instruments Corporation (2009). *Industrial Networking Based on Ethernet.* July 20 2009. Available : < http://zone.ni.com/devzone/cda/tut/p/id/8834 > (2010-05-30)

Niall, Murphy (2003). A short trip on the CAN bus. August 11 2003 *Embedded.com.* Available : < http://www.embedded.com/columns/murphyslaw/13000304?_requestid=689820 > (2010-05-30)

ODVA, Inc (2010). *Multi-axis synchronized motion over EtherNet/IP* (Electronic). PDF format. Available: < http://www.odva.org/Portals/0/Library/Publications_Numbered/PUB00112R0_CIP_Motion_Brochure_ENGLISH.pdf > (2010-05-31)

Pfeiffer, Olaf, Ayre, Andrew & Keydel, Christian (2003). *Embedded networking with CAN and CANopen.* San Clemente, CA : RTC

Profibus International (2010). *A Rich Powerful Ethernet Solution for Automation.* Available : <http://www.profibus.com/technology/profinet> (2010-05-30)

Profibus International (2010). *Embracing the Best of Fieldbuses.* Available : < http://www.profibus.com/technology/profinet/for-pa/> (2010-05-30)

Profibus International (2010). *The All-Encompassing Industrial Ethernet.* Available : < http://www.profibus.com/technology/profinet/overview/> (2010-05-30)

Rinaldi, John (2010). Industrial Ethernet all the rage (Electronic). *InTech.* March/April 2010. Available : < http://www.isa.org/InTechTemplate.cfm?template=/ContentManagement/ContentDisplay.cfm&ContentID=81666> (2010-05-30)

Saab AB (2010). Available :<http://www.saabgroup.com/en/About-Saab/Company-profile/> (2010-05-29) & <http://saabgroup.com/NR/exeres/7317FA22-F4A9-4B6D-AF41-4842C45AA990.htm> (2010-05-29) & <http://www.saabgroup.com/en/Land/GBAD/Ground-Based-Surveillance/Giraffe-AMB/Features/> (2010-05-29)

Sauer-Danfoss (2009). *Plus+1 Controller Family Technical Information.* PDF format. Available : <http://www.sauer-danfoss.com/stellent/groups/publications/documents/product_literature/520l0719.pdf> (2010-05-30)

Sauer-Danfoss (2009). *Plus+1 CAN I/O Module Communications Technical Information.* PDF format. Available : < http://www.sauer-danfoss.com/stellent/groups/publications/documents/product_literature/520l1029.pdf> (2010-05-30)

Sauter, Thilo (2005). *Fieldbus System : History and Evolution.* In Zurawski, Richard (editor). *The Industrial Communication Handbook.* PDF format. Available: < http://old.engnetbase.com/books/4682/3077ch7.pdf> (2010-05-30). Boca Raton : Taylor & Francis

Schneider Electric (2009). Hardware Guide. *Twido Extreme Programmable Controller.* 35013462.04 05/2009. PDF document provided by Schneider Electrics.

Siemens AG (2008). *SIPlus extreme*. PDF format. Available< http://www.automation.siemens.com/mcms/topics/en/siplus/extreme/information-material/Documents/siplus_extreme_flyer_en.pdf> (2010-05-30). Germany

Siemens AG (2009). *SIMATIC ET 200 For distributed automation solutions.*PDF format. Available: <http://www.automation.siemens.com/mcms/topics/en/siplus/extreme/technical-documentation/s7-300/Documents/SIPLUS_S7-300_CPU_A9.pdf> (2010-05-30)

Siemens AG (2010). *Zentralbaugruppen CPU modules*.PDF format. Available: <http://www.automation.siemens.com/mcms/topics/en/siplus/extreme/technical-documentation/s7-300/Documents/SIPLUS_S7-300_CPU_A9.pdf> (2010-05-30)

Teas Instruments (2010). Available: < http://focus.ti.com/docs/prod/folders/print/sn65hvd1040-q1.html> (2010-05-30)

Teas Instruments (2010). *Stellaris LM3S9B96 Microcontroller Data Sheet.* PDF format. Available: <http://focus.ti.com/lit/ds/symlink/lm3s9b96.pdf> (2010-05-30)

The ClemsonVehicular Electronics Laboratory (2010). *Automotive buses.* Available: <http://www.cvel.clemson.edu/auto/auto_buses01.html> (2010-05-30)

TTA-Group (2010). *FAQ*. Available: <http://www.ttagroup.org/ttp/faq.htm> (2010-05-30)

TTA-Group (2010). *Products.* Available*:* <http://www.ttagroup.org/ttp/products.htm> (2010-05-30)

Vector (2009). *Media Oriented Systems Transport (MOST)*. Available: <http://www.vector.com/vi_most_en,,223.html> (2010-05-30)

Verhappen, Ian & Agostin, Andreas (2009). The Question of Ethernet: *Control Engineering Asia*, March 1 2009. Available: <http://www.ceasiamag.com/article-5083-thequestionofethernet-LogisticsAsia.html> (2010-05-28)

Verwer Training and Consultancy Ltd. (2010). *Tutorial – introduction to Fieldbus*. Available<http://verwertraining.com/tutorals/tutorial-introduction-to-fieldbus-and-profibus/> (2010-05-31)

Voss, Wilfried (2005). *Comprehensible Guide to Controller Area Network*. Greenfield, MA: Copperhill media.

Willig, Andreas & Woesner, Hagen (2005). *Principles of Lower-Layer Protocols for Data Communications in Industrial Communication Networks.* In Zurawski, Richard (editor). *The Industrial Communication Handbook.* PDF format. Available: <http://old.engnetbase.com.proxy.lib.chalmers.se/books/4682/3077ch1.pdf> (2010-05-28). Boca Raton : Taylor & Francis.

Appendix A - Requirement clarification

A.1 Shock

Mechanical shock can produce unfavorable effects on materials, both physically and functionally. Both the magnitude and the duration of the shock are affecting the results. If the duration of the shock corresponds with the natural frequency periods of the material and/or periods of major frequency components, the adverse effects will be magnified. *(MIL-STD-810G)*

Shock is a moderately high level force impulse (above even extreme vibration levels) over a relatively short time (usually much less than the period of the fundamental frequency of the material). *(MIL-STD-810G)*

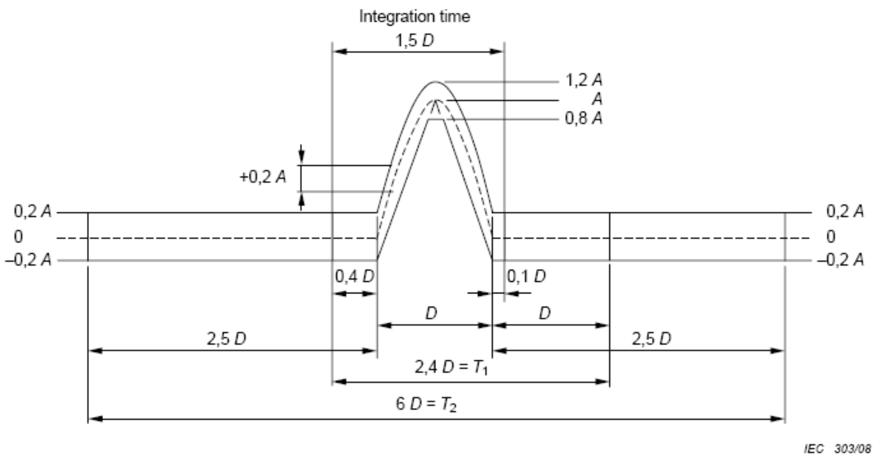
Basic pulse shapes

The choice of pulse shape for shock depends on a number of factors and there are no straight on answer which pulse shape to use.

The specified basic pulse shapes are given below

- half-sine: one half-cycle of a sine wave, as shown in Figure B.1;
- final-peak saw-tooth: asymmetrical triangle with short fall time, as shown in Figure B.2;
- trapezoidal: symmetrical trapezoid with short rise and fall times.

The true value of the actual pulse shall be within the limits of tolerance shown by the solid lines in the relevant figure. *(SS-EN_60068-2-27)*



Key (applicable for all three Figures 1 to 3)

– – – nominal pulse

—— limits of tolerance

D = duration of nominal pulse

A = peak acceleration of nominal pulse

T_1 = minimum time during which the pulse shall be monitored for shocks produced using a conventional shock-testing machine

T_2 = minimum time during which the pulse shall be monitored for shocks produced using a vibration generator

Figure B.1

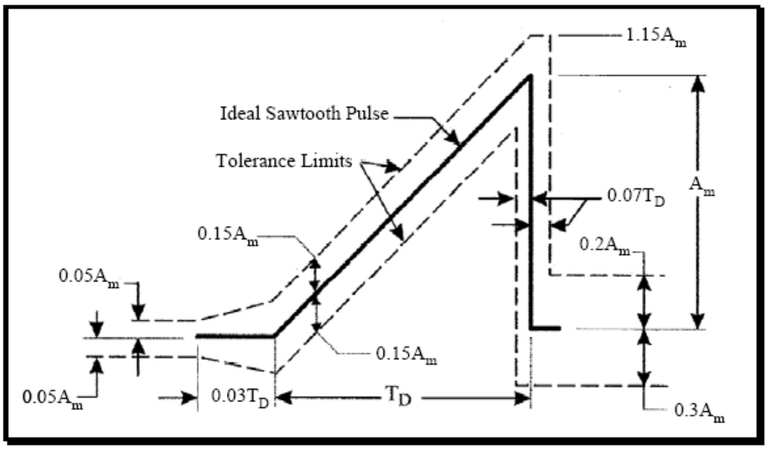


Figure B.2

The saw-tooth pulse shape is an alternative for testing in Procedure I – Functional Shock and Procedure V – Crash Hazard Shock test described in MIL-STD-810G. Saab AB has previously used half-sine pulse in their specifications, but has now switched to saw-tooth pulse instead. However, as the industry still uses the half-sine pulse, the older Saab specifications are used in order to compare.

A.2 Vibrations

Vibration is present at all frequencies with a varying range of intensities. The amplitudes vary randomly, periodically or as a combination of both.

A.2.1 Random vibration

Random vibration or auto spectral density, ASD, is the square of the root mean square, rms, value of the acceleration divided by the bandwidth of the measurement, g^2/Hz.

The ASD is defined over a frequency range containing the lowest and highest frequencies in where the product is exited by mechanical vibration. The lowest level is typically half the frequency of the lowest frequency at which significant vibration exists and the highest frequency is two times the highest materiel resonant frequency. The highest frequency has for a long time been limited to 2 kHz, but this limitation has changed and tests are now performed at levels of 3-4 kHz.

When specifying the vibration it is not sufficient to only give the rms value because it does not contain any spectral information, the frequency range must also be given.

A.2.2 Sinusoidal vibration

Sinusoidal vibration is expressed as acceleration over a frequency range. Environments exposed to this kind of vibration are characterized by a fundamental frequency and harmonics of that fundamental. Each present fundamental generates harmonics. The environments that should be tested with this kind of vibration are environments that contain sinusoidal excitation in nature for example propeller and turbine blade passage.

A.2.3 Equivalence between random and sinusoidal vibration

Vibrations have historically been defined as sinusoidal vibrations. However, most vibrations are in nature random and now that is how they should be characterized. This has made a need for an equivalent between them.

Sine vibrations and random vibrations are based on different sets of mathematics and to compare the effects of given vibrations the materials dynamic response is needed. Therefore it is not feasible to define a general equivalence.

Attempts have been made to compare the peak acceleration of sine vibrations to the rms acceleration of random vibrations. Both vibrations use the same dimensional units which is acceleration in standard gravity. The difference is that the peak sine acceleration is the maximum acceleration at one frequency while the random rms is the square root of the area under a spectral density curve. These are to different measurements and therefore not equivalent.

Saab's vibration requirements have previously been specified as sine vibrations but are now more correctly defined as random vibrations. However, it is still more common among suppliers to define the vibrations as sinusoidal. To get a comparable value older specifications from Saab have been used. *(MIL-STD-810G, ANNEX A)*

A.3 Relative humidity

Relative humidity is defined as the ratio of the actual vapor pressure of the air to the saturation vapor pressure. *(American Meteorolical Society, 1959)*

Hereby follows some physical phenomena associated with humidity.

A.3.1 Absorbtion

Absorption is gathering of water within the material, where the quantity absorbed depends, in part, on the water quantity of the air. Material absorbs water in a continuous matter until equilibrium is reached. Absorption is also dependent on the temperature because the penetration speed of the water molecules increases with temperature.

A.3.2 Adsorbtion

Adsorption is the adherence of water vapor to a surface whose temperature is higher than the dew point. Depending on the type of material, the surface condition, and vapor pressure different quantity of moisture adhere to the surface.

A.3.3 Condensation

Water vapor that comes in contact with a surface whose temperature is lower than the dew point of the ambient air will transform from vapor to liquid. The air may have varying dew point, because it is dependent on the amount of water vapor in the air. Additionally, the dew point, the absolute humidity[1] and the vapor pressure are directly interdependent.

1

Absolute humidity. The density of water in a particular volume of air. The most common units are grams per cubic meter, although any mass unit and any volume unit could be used. Warm air can hold more water vapour than cold air. *(MIL-STD-810G)*

A.3.4 Diffusion

Due to a difference in partial pressures diffusion is caused, which is the movement of water molecules through material. Diffusion is often encountered in electronics where water vapor penetrates the organic coating of capacitors or semiconductors.

A.3.5 Effects of warm, humid environments

There are both physical and chemical effects on materiel as a consequence to temperature-humidity conditions. The variations of temperature and humidity can trigger synergistic effects or condensation inside materiel. Some typical problems are:

- Surface effects, such as:
    - Oxidation and/or corrosion of metals
    - Increased chemical reactions
    - Chemical or electrochemical breakdown of organic and inorganic surface coatings.
    - Interaction of surface moisture with deposits from external sources to produce a corrosive film.
    - Changes in friction coefficients, resulting in binding or sticking
- Change in material properties, such as:
    - Swelling of materials due to sorption[2] effects
    - Loss of physical strength
    - Electrical and thermal insulating characteristics
    - De-lamination of composite materials
    - Change in elasticity or plasticity
    - Degradation of lubricants
- Condensation and free water, such as:
    - Electrical short circuits
    - Fogging of optical surfaces
    - Changes in thermal transfer characteristics

These effects are not all the possible problems, more problems exist.

A.4 Electromagnetic Compatibility, EMC

EMC describes the ability of an electronic device or system to work in its electromagnetic environment. Disturbances from each component must be limited and also, each component need to be immune to certain levels of disturbances from the environment.

EMC is used to ensure the reliability and safety of all types of systems exposed to electromagnetic environments. This is why there are many test and standards to ensure this. The International Electrotechnical Commission prepares and publishes standards for electronically related technologies are and their tests are commonly used to define systems EMC. For military applications military standards are often used. (IEC, 2010)

[2] the process in which one substance takes up or holds another (by either absorption or adsorption)

A.5 Standards

As technology is becoming more complex, it is gets more difficult to understand different constructions and how they fulfill different requirements. Customers need be reassured that the product is reliable and meet their expectations in terms of performance, safety, durability and other criteria. With international standards it becomes much easier to for the industry to reduce barriers caused by certification criteria's.

Standards is an important tool when designing, testing and verifying products. The standards concerning this project are MIL-STD, STANAG and IEC.

A.5.1 MIL-STD

MIL-STD is an American military defence standard. It is often called "*MilSpecs*" and is used to help achieve standardization objectives by the U.S. Department of Defense.

A.5.2 STANAG

"NATO Standardization Agreements for procedures and systems and equipment components, known as STANAGs, are developed and promulgated by the NATO Standardization Agency in conjunction with the Conference of National Armaments Directors and other authorities concerned." (NATO, 2010-04-20)

A.5.3 IEC

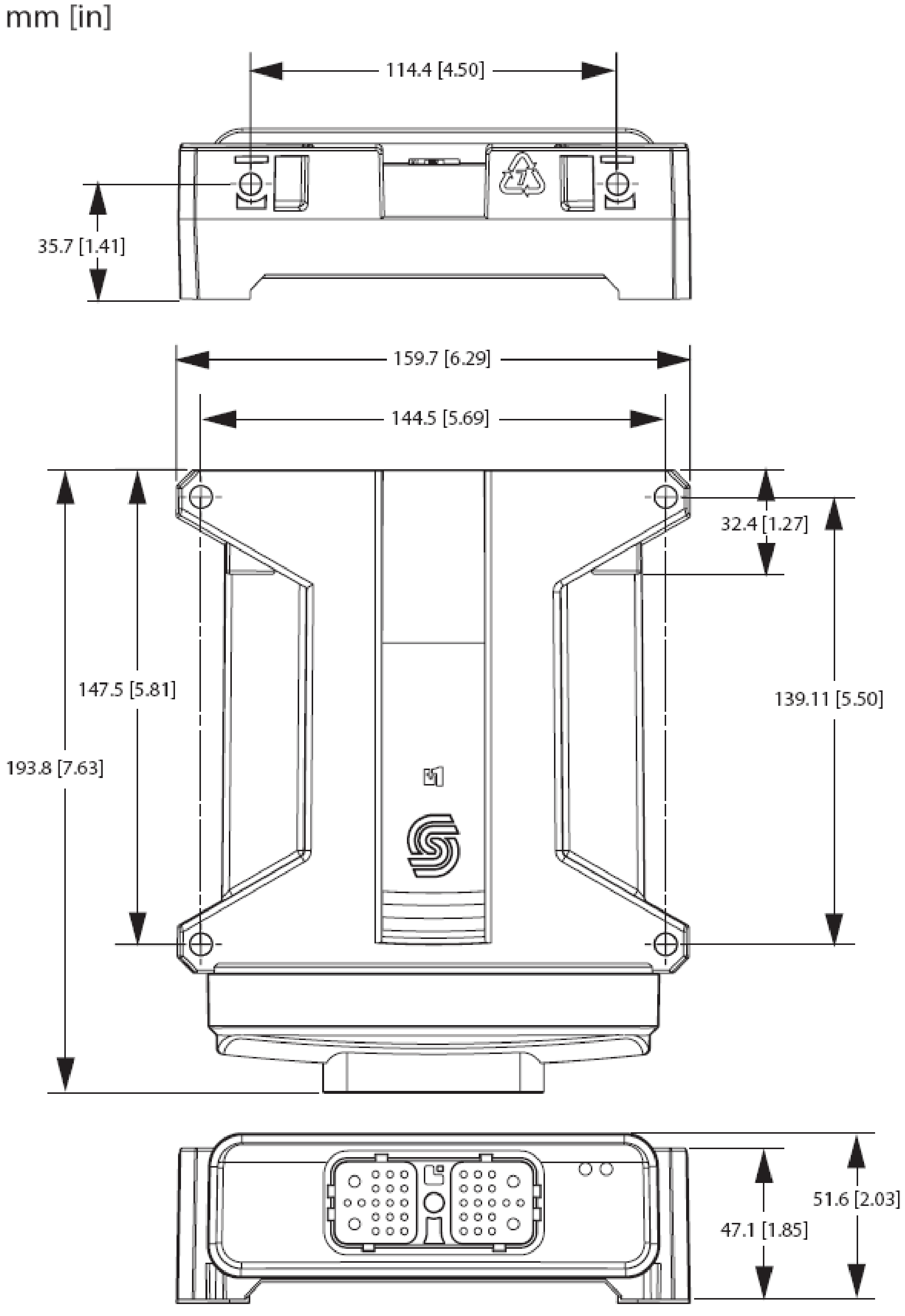
"The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes international standards for all electrical, electronic and related technologies. These serve as a basis for international standardization and as references when drafting international tenders and contracts.

Through its members, the IEC promotes international cooperation on all questions of electrotechnical standardization and related matters, such as the assessment of conformity to standards, in the fields of electricity, electronics and related technologies.

The IEC charter embraces all electrotechnologies including electronics, magnetics and electromagnetics, electroacoustics, multimedia, telecommunication, and energy production and distribution, as well as associated general disciplines such as terminology and symbols, electromagnetic compatibility, measurement and performance, dependability, design and development, safety and the environment."(IEC, 2010-04-21)

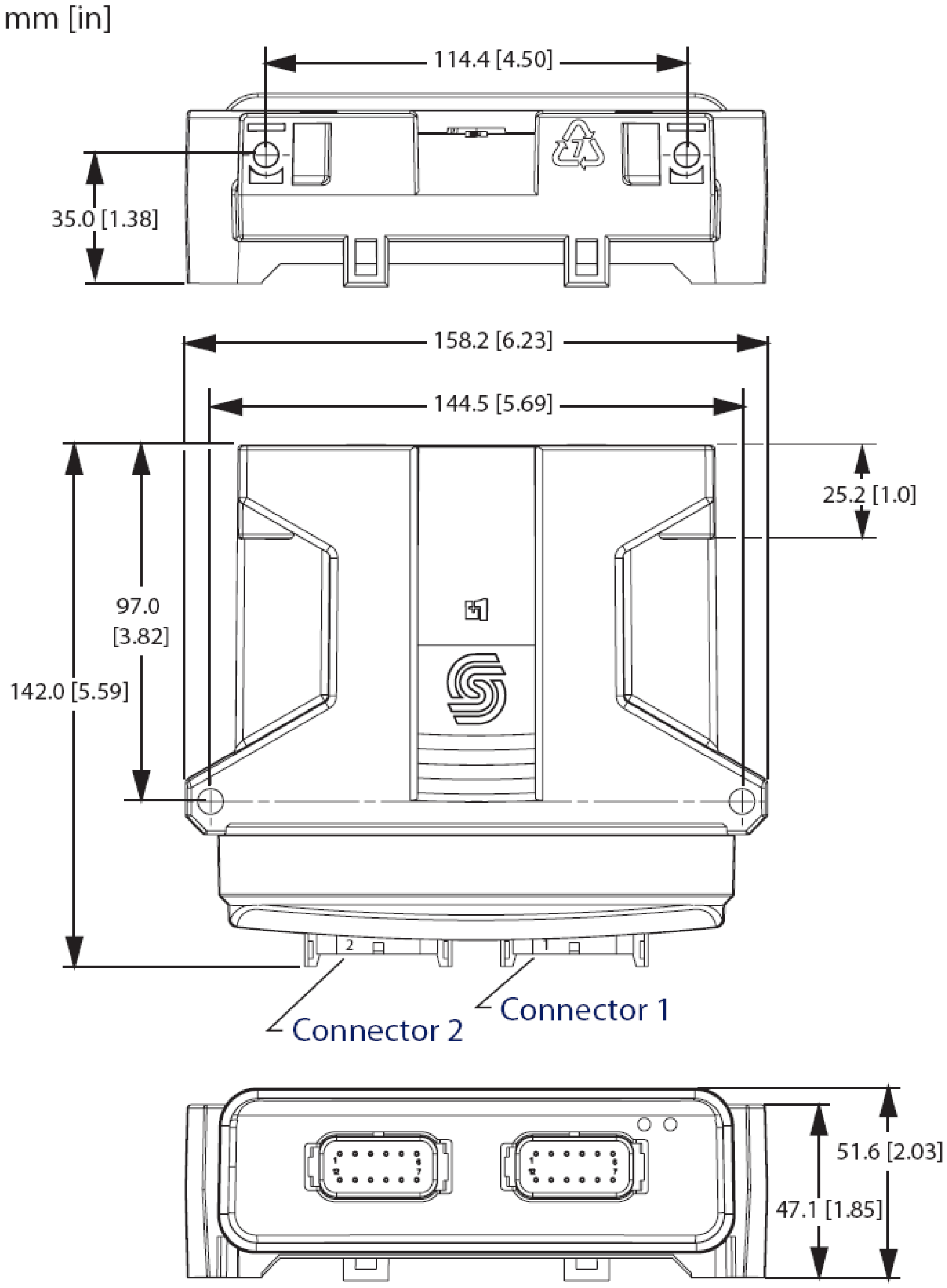
Appendix B – Detailed drawing

The MC038-10 microcontroller.



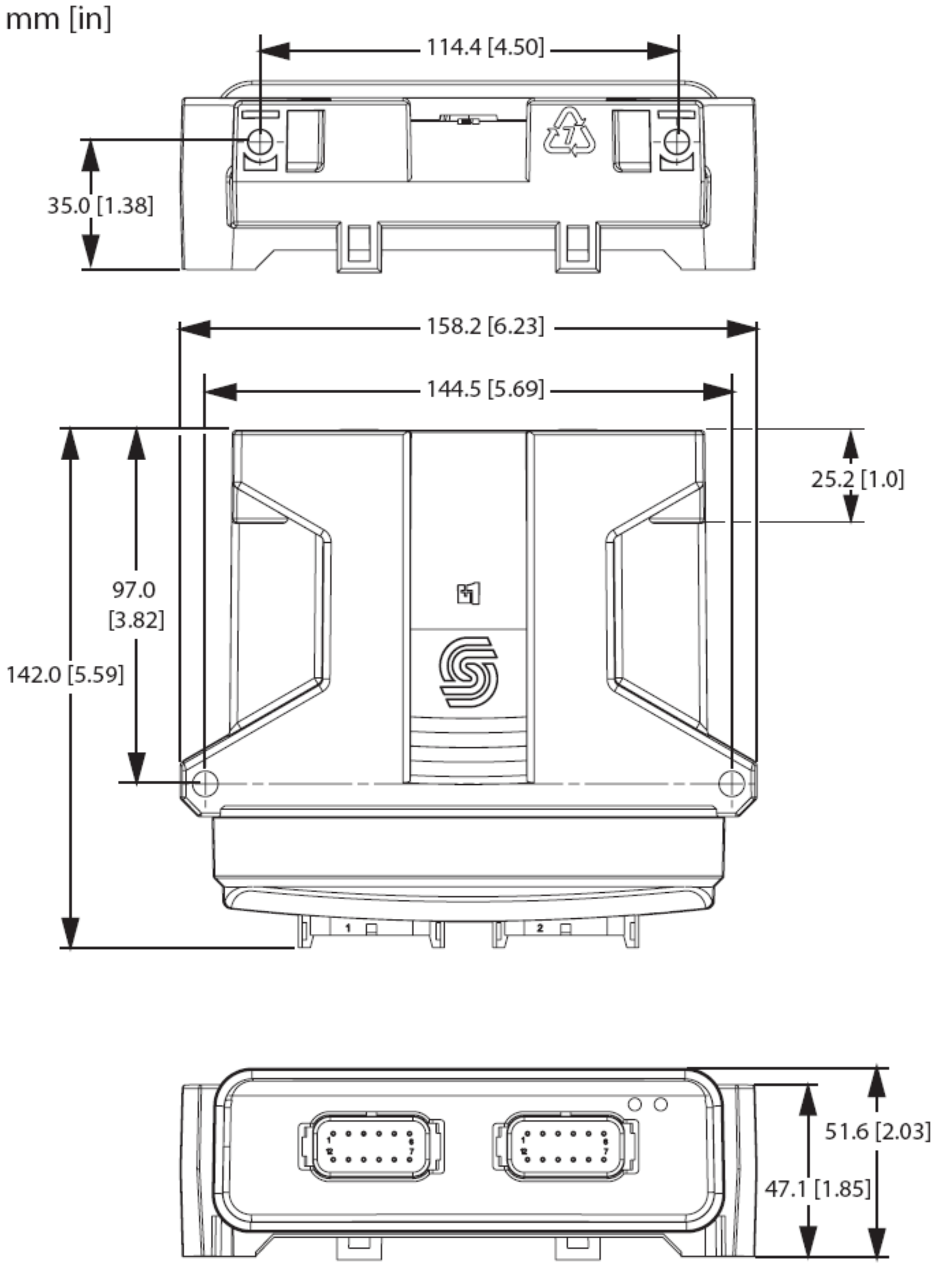
http://www.sauer-danfoss.com/stellent/groups/publications/documents/product_literature/11051653.pdf

The IOXO24-020 expansion module.



http://www.sauer-danfoss.com/stellent/groups/publications/documents/product_literature/11063057.pdf

The IOXO24-10 expansion module.



http://www.sauer-danfoss.com/stellent/groups/publications/documents/product_literature/520l0717.pdf

Appendix C – FMEA

Product Name:	Sauer-Danfoss CAN system	Prepared by:	Jonas Eriksson Josef Said	Page :	1 of 1
Project Manager:		FMEA Date (Orig):	2010-04-22	Rev. A	

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
Component/Main function	In what ways can the Component or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **often** does cause or FM **occur?**	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	Likelyhood of **NOT detecting** the Cause or the Failure Mode?		What are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?	Note the actions taken. Include dates of completion.				
Control Unit	System Hang	User can no longer start or stop the system	10	Too much traffic	1	Surveillance program	2	20	Test for highest possible traffic and design for this			10	1	2	20
			10	Software	3		2	60	Use skilled programmers in the beginning			10	3	2	60
	Electrical failure	User can no longer start or stop the system	10	Wrong power input	1	Current surveillance	4	40	Design for a correct current			10	1	4	40
			10	Power cables attached wrongly	1	Current surveillance	2	20	Correct training			10	1	2	20
	Detach	User can no longer start or stop the system / no longer start or stop units	8	Control unit wrongly attached	2		4	64				8	2	4	64
	EMC/EMI	Interfere with other equipment and jam those	8		2	Measurement of EMC	5	80	Design for EMC			8	2	5	80
I/O unit	Unit System Hang	User can no longer start or stop the unit	8	Software	3		2	48	Use skilled programmers in the beginning			8	3	2	48
	Electrical failure	User can no longer start or stop the unit	7	Wrong power input	1	Current surveillance	4	28	Design for a correct current			7	1	4	28
			7	Power cables attached wrongly	1	Current surveillance	2	14	Correct training			7	1	2	14
	Detach	User can no longer start or stop the unit	5	I/O unit wrongly attached	2		4	40				5	2	4	40
	EMC/EMI	Interfere with other equipment and jam those	8		2	Measurement of EMC	5	80	Design for EMC			8	2	5	80
CAN cable	Loosen / Detach	User can no longer start or stop one or more unit	9	Wrongly attached	3		1	27	Investigate it under assemble			8	3	1	24
	Corrode	One or more units can be difficult communicate	6	Wrong cable	3		2	36	Design against corrosion			6	3	2	36
	Break	One or more units can be difficult communicate	8	Wrong cable that cannot withstand too low temperature	1		1	8	Design for low temperature			8	1	1	8
			8	Outer mechanical factor	1		1	8	Design for hidden cables			8	1	1	8
	EMC	Interfere with other equipment and jam those / The information can be read from outside of Giraffe	8		2	Measurement of EMC	5	80	Design for EMC			8	2	5	80
Financial	Higher development cost than expected	Saab will abort the project	10	More engineering costs than expected	4	Cost analysis	5	200	Worst case scenario cost analysis			10	4	5	200
Testing	EMC testing does not meet the criteria	Saab will abort the project	10	Bad EMC properties	2	Measurement of EMC	1	20	Test at the beginning of the project			10	2	1	20
Future	CAN fades away from the market	Delayed delivery and high development costs	8	Another technique such as FlexRay competes with CAN and possibly eliminates it	2	Close relationship with the supplier	5	80	Close relationship with the supplier			8	2	5	80