CHALMERS


# XCP OVER CAN AND ETHERNET ON AUTOSAR

## Calibration and Measurement Protocol

Master of Science Thesis in Computer Science and Automation and Mekatronics

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Cover: The McLaren Formula One team monitoring the car's embedded systems before the start of the race.

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# Abstract

New vehicles contain more and more electronic aides and control systems. As the number of functions increase, the complexity of the system increases at an even greater pace. AUTOSAR is an initiative that aims to bring order to embedded electrical systems in vehicles.

The ever larger software systems naturally generate ever larger amounts of data needing to be taken care of, analysed and checked for correctness during the development of the system itself. XCP is a network protocol that is mainly used for transferring measurement data and calibration parameters during the development process in the automotive industry. In order to utilize the complete capacity of the existing in-vehicle network, the protocol has been designed to be independent of the transport layer.

The aim of this thesis is to implement a subset of XCP for execution on a rapid prototyping platform developed by QRtech, a high-tech consulting company in Kallebäck, Gothenburg. In order to be compatible with the latest technology and methodology XCP has been implemented according to the requirements specified by AUTOSAR.

In the current implementation, all the mandatory requirements are met, have been verified and comply with the AUTOSAR standard. Even before completion, the project roused interest in parts of the local automotive industry.



Keywords: XCP, AUTOSAR, CAN Network, Ethernet, Measurement and Calibration, DAQ-list, QR5567.

# Sammanfattning

Nya fordon innehåller allt mer elektroniska hjälpmedel och styrsystem. I takt med att funktionerna blir fler och fler ökar komplexiteten hos systemet lavinartat. AUTOSAR är ett initiativ för att försöka skapa ordning inom de inbyggda fordonselektriska systemen. Genom att skapa standardiserade gränsytor mellan alla de funktionella applikationsdelarna och de hårdvarunära delarna är tanken att systemet ska vara skalbart och därmed undviks problemet med sambandet mellan komplexitet och storlek.

De allt större mjukvarusystemen generar naturligtvis också mer och mer datatrafik som måste kunna läsas och övervakas under framtagningen av systemet. XCP är ett nätverksprotokoll som i huvudsak används för att överföra mätdata och kalibreringsparametrar vid utvecklingsarbete inom bilindustrin. För att på ett enkelt och smidigt sätt kunna utnyttja hela bilens existerande inbyggda nätverkskapacitet är protokollet designat för att vara oberoende av vilket transportmedia som används.

Målet för examensarbetet är att implementera utvalda delar av XCP protokollet för exekvering på en prototyputvecklingsplattform framtagen av QRtech, ett teknikkonsultföretag i Kallebäck i Göteborg. För att var kompatibelt med de senaste teknikerna och metodikerna så har XCP implementerats enligt de krav som AUTOSAR specificerar.

Som implementationen ser ut idag är samtliga XCP – och AUTOSAR specifika krav uppfyllda, och verifierade. Även före fullbordandet visades visst intresse från lokala aktörer inom bilindustrin.

# Preface

We would like to thank the following people for aiding us during this thesis project:

Rolf Snedsböl our examiner who has provided us with a lot of suggestions and corrections of this report.

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The unnamed lady who every morning brought us breakfast at the office.

Finally we would like to thank all the fine men and women at QRtech for their moral support and for making us feel welcome and at home at QRtech.

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# Acronyms

| | |
|---|---|
| **ADC** | Analog Digital Converter |
| **API** | Application Programming Interface |
| **ASAM** | Association for Standardization of Automation and Measuring Systems |
| **AUTOSAR** | Automotive Open System Architecture |
| **BSW** | Basic Software |
| **CAN** | Controller Area Network |
| **CCP** | CAN Calibration Protocol |
| **CTO** | Control Transmission Object |
| **DAQ** | Data Acquisition List |
| **DIO** | Digital Input Output |
| **DTO** | Data Transmission Object |
| **ECU** | Electronic Control Unit |
| **E/E** | Electrics and Electronics |
| **GDB** | GNU Debugger |
| **GNU** | GNU's Not Linux |
| **MCAL** | Microcontroller Abstraction Layer |
| **ODT** | Object Descriptor Table |
| **PEEDI** | Powerful Embedded Ethernet Debug Interface |
| **PWM** | Pulse Width Modulator/Modulation |
| **RTE** | Run-Time Environment |
| **SWC** | Software Component |
| **STIM** | Data Stimulation List |
| **TFTP** | Trivial File Transfer Protocol |
| **USB** | Universal Serial Bus |
| **VFB** | Virtual Function Bus |
| **XCP** | Universal Measurement & Calibration Protocol |

# 1 Background

Vehicles are becoming increasingly more computerized with up to 90% of all new functionality falling into the E/E (Electrics/Electronics) category. As a result it is becoming progressively harder to maintain an overview of the E/E system in a vehicle. To counter this, the industry has united in an effort to create a single software architecture that can be followed by everyone from car manufacturers to suppliers of components and creators of tools. This initiative is known as AUTOSAR (Automotive Open System Architecture).

Because of the increasing amount of electronics and the amount of data traffic that they generate, the need to transfer larger amounts of data has arisen. For this purpose a special network protocol called XCP (Universal Measurement and Calibration Protocol) has been conceived and specified. Because it has the capability to run on different transport mediums it can utilize more of the technological progress that has been made within the automotive E/E area. As the name 'XCP' suggests, the protocol is an evolutionary continuation of CCP (CAN (Controller Area Network) Calibration Protocol), where the 'C' for 'CAN' has been replaced by 'X' to indicate an unknown or generic transport layer implementation. CCP was developed largely by ASAM (Association for Standardization of Automation and Measuring Systems), a consortium of German car manufacturers founded in 1998 that provides standards for data models, interfaces and syntax specifications for various uses, such as testing, simulation and evaluation. These standards are adhered to mainly by European car makers and to a lesser extent by the Japanese and American ditto.

## 1.1 Previous work

QRtech (Qualified Real-time technology) is an independent company that has their own in-house developed embedded prototyping platform called the QR5567. Its purpose is to be used for advanced engineering projects, mainly in the automotive area. Previous work at the company in regards to the QR5567 platform has consisted of implementation of necessary software infrastructure, such as start-up routines and programming tools.

## 1.2 Purpose

The purpose of this project is to make a 'Universal Measurement and Calibration Protocol' (XCP) implementation that complies with the AUTOSAR XCP module specification. This implementation is to be run on the Arctic Core AUTOSAR platform targeting the rapid prototyping board QR5567. The main communication protocols of interest are CAN (Controller Area Network) and Ethernet. The module should not be specific to a single embedded component, but be adaptable to different applications of embedded components. Since the size of the project is not fully known by QRtech, part of the task is to define which optional components of the protocol to include (see Appendix A for further details).

## 1.3 Significance

Having a standardized protocol for measurement and calibration allows for reusability of toolkits between different hardware and software vendors. A generic module for XCP with a configurable feature set eliminates the need for reimplementation of the protocol for each use case. Making it AUTOSAR compatible widens the area of use. For a company in the automotive sector of today, it is vital to be able to offer the latest technological solutions and to have staff with the right competence. As the industry surges forward towards the common AUTOSAR platform, expertise in the field becomes more and more sought after.

# 2 Scope

Implementing XCP in its entirety is a considerable task, too large to fit within the given timeframe for this project. Some features and functionality had to be excluded in order to ensure completion (see Appendix B). The following goals were set from the beginning:

- Selecting which XCP services to implement
- Implementing the selected XCP services
- Verifying the implementation

## 2.1 Limitation of Transport Protocols

XCP can be run on a number of different transport-layer protocols; the initial request from QRtech was to make an implementation for CAN (Controller Area Network) and for Ethernet. As work progressed it was discovered that some AUTOSAR modules necessary for an Ethernet implementation were not yet in place in Arctic Core. As a result Ethernet became of secondary importance. For development purposes an Ethernet version was implemented, because the possibility to test functionality without the need of reprogramming the device each time was considered worth the extra time and effort. The assumption was that it would prove worthwhile in the end, especially if the system would live on after the project was completed. It has however not been tested or verified while running on the target hardware and must therefore be considered as out of the project scope. If or when the necessary Ethernet modules in Arctic Core are implemented, XCP for Ethernet could probably be adapted quite easily.

## 2.2 Optional XCP features

XCP contains many features that are not strictly necessary in order to run the core functionality. Because of limited knowledge of time requirements for the various implementations, an open planning scheme was adopted. Instead of defining what to include or exclude, a prioritization order was made, adding optional features if time allowed. The prioritization was revised after input-meetings with QRtech management as depending on what other projects the company was running at the same time, the possible areas of application might vary.

# 3 AUTOSAR platform

More and more of the added value in vehicles falls within the electrics and electronics (E/E) area. Traditionally the way to develop E/E in vehicles is to have one unit for every service. Because of the increase in the number of services and the subsequent increased architectural complexity, E/E systems are becoming increasingly difficult to manage. This difficulty is of course also associated with higher costs for both further development and maintenance of the system already in place. In an effort to tackle this problem and move away from the 'one box, one service' mentality, a completely new approach was needed. Several automotive companies have decided to unite and develop a common platform. This initiative is known as AUTOSAR. The aim is to revolutionize the way automotive software is developed and also the way in which it is executed on the ECUs in the vehicle. The AUTOSAR consortium stipulates the goal of the initiative as follows:

> *"The primary goal of the AUTOSAR development cooperation is the standardization of basic system functions and functional interfaces, the ability to integrate, exchange and transfer functions within a car network and to substantially improve software updates and upgrades over the vehicle lifetime. Having this goal in mind, AUTOSAR pushes the paradigm shift from an ECU based to a function based system design attempt in automotive software development and enables the management of the growing E/E complexity with respect to technology and economics." – FAQ on AUTOSAR.org*

By decoupling hardware and software the AUTOSAR consortium hopes to make development more independent. As a way to assist this it was decided that the platform should handle all ECU access. This has the effect that a developer does not need specific knowledge about the ECU. (1)

## 3.1 Layered infrastructure

In order to provide an easy-to-read top-down description, the AUTOSAR platform has layered software architecture. It maps the basic software modules to the appropriate layers and shows their relationship. There are three main layers in the AUTOSAR software architecture, each with their own well defined purpose (see Figure 1 and Figure 3).

### 3.1.1 Basic Software Layer

The bottom layer is the Basic Software Layer (BSW). This is the only layer that can access the Microcontroller itself. It consists of a number of modules which are used by the Application layer via the Runtime Environment (RTE). Each module has an AUTOSAR specification that specifies the modules requirements, its data types and interfaces. The modules are grouped into the following sub layers:

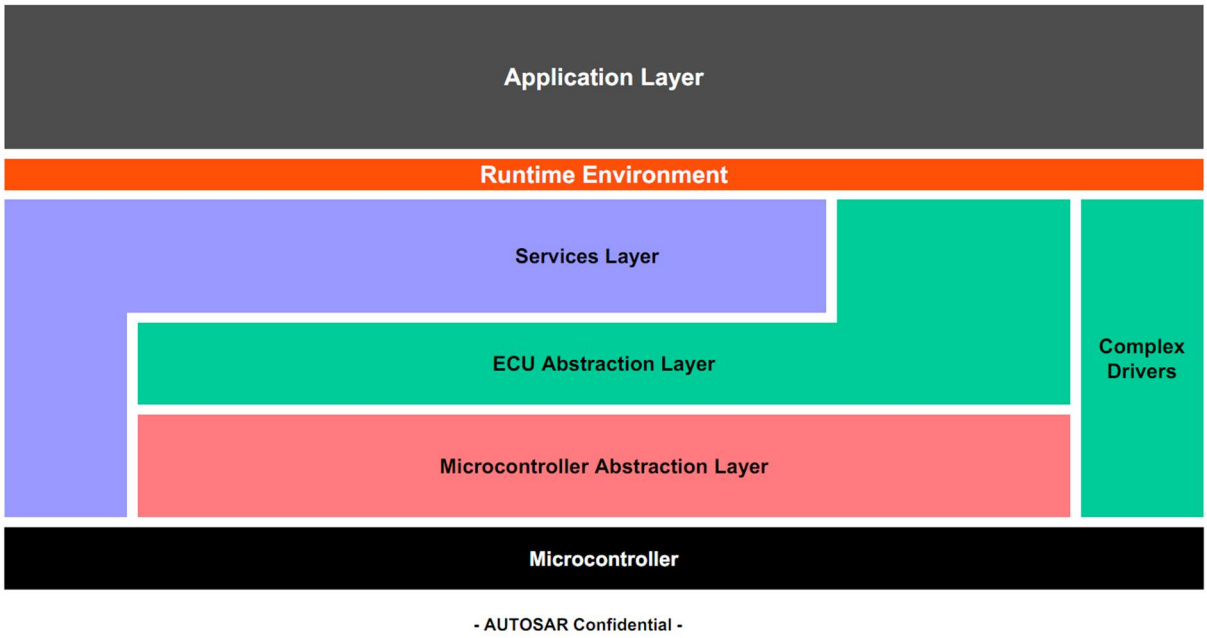


**Figure 1: Schematic view of the different architecture layers including the sub layers in the BSW layer.**

- Micro Controller Abstraction Layer (MCAL) – Contains internal drivers that have access to the microcontroller and internal peripherals. The MCAL makes the higher software layers independent of the microcontroller. This means that if for some reason the microcontroller needs to be replaced, the rest of the system can be left as it is. The only changes that are needed are to those modules concerning the MCAL. The modules of the MCAL are divided in to four different blocks (see Figure 2):

    - The Microcontroller drivers block consists of four drivers; the General Purpose Timer, the Watchdog Driver, the MCU driver and Core Test.

    - The Memory Drivers block contains drivers which provide services for memory handling, such as reading from, writing to or simply erasing memory devices. In terms of memory devices, the AUTOSAR standard supports internal and external Flash memory and internal EEPROM (Electrically Erasable Programmable Read-Only Memory).

    - The Communication Drivers block contain drivers for the different methods of communication supported in AUTOSAR such as CAN FlexRay and Ethernet (in AUTOSAR 4.0).

    - I/O Drivers block contain drivers for input and output modules, such as PWM (Pulse Width Modulation) and ADC (Analog Digital Converter).

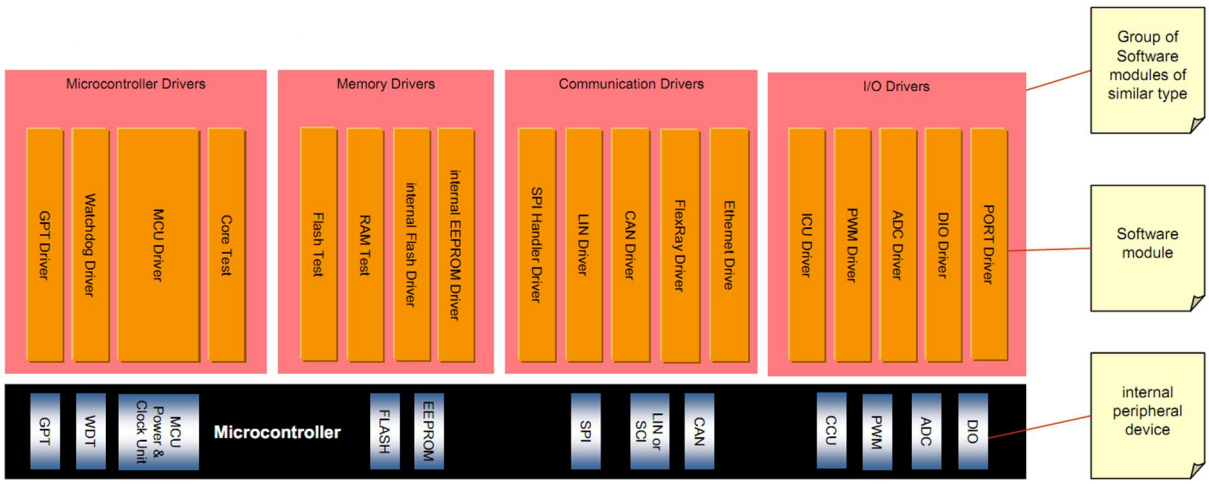


**Figure 2: The modules of the MCAL layer divided into blocks.**

- ECU Abstraction Layer - Makes the higher software layers independent of the hardware layout of the ECU. In order to achieve the desired independence the layer is divided into five blocks in an attempt to mimic an ECU.

    - The *I/O Hardware Abstraction* provides functionality for handling input and output to the system. This is the only block in the ECU abstraction layer that has access to the RTE directly, instead of through the system layer as is the case for the other blocks in the layer.

    - The *Communication Hardware Abstraction* is a collection of interfaces for each of the communication techniques of an AUTOSAR compliant ECU. These interfaces abstract the drivers for the specific communication technique and provide the upper layers with transmission functionality such as status information and send/receive-functions. Instead of having direct access to microcontroller hardware, the equivalent MCAL driver is used.

    - The *Memory Hardware Abstraction* is in function a lot like the communication hardware abstraction. It provides the upper layer with functionality required to access memory via the MCAL drivers.

    - The *Onboard Device Abstraction* is used for any devices that do not fit in anywhere else. The access to these devices is routed through the MCAL.

    - Any components that are not in the AUTOSAR specification but still need to access the hardware falls into the *Complex Driver Layer*. It provides the possibility to add extra functionality such as device drivers; some might argue that this isn't strictly part of the ECU abstraction layer.

- Services Layer – Provides services such as memory and OS functionality for the other BSW modules and the application layer.

    - The *System Services* module contains the AUTOSAR OS (Operating System) which handles scheduling and run-time resource protection and offers reasonable real-time performance. It is the scheduling functionality in the OS that executes the upper layer software components via the tasks that they are mapped to.

    - *Communication Services* provides the necessary functionality in order to run the vehicle network communication. This is done by providing an interface to the different vehicle techniques such as CAN and FlexRay, along with network management and diagnostics. This includes reworking the message frames and omitting transport layer specific data such as message headers and other various properties (hardware timestamps for example).

    - *Memory Services* consists of modules which are responsible for managing all non-volatile data. The purpose of the memory service block is to provide non-volatile data to upper layer applications in a uniform and well defined way, abstract memory from the corresponding locations and properties relevant to the application. It also provides mechanisms for saving, loading, for checksum protection and for verification.

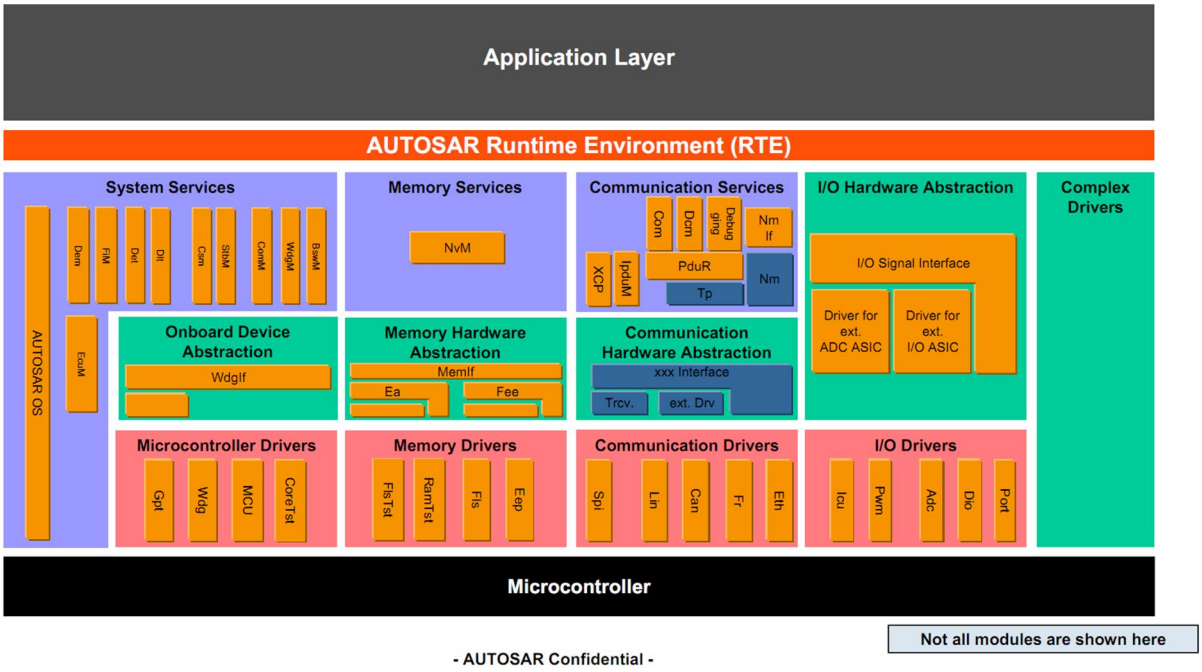


**Figure 3: A selection of modules organized into layers (colors) and blocks (large boxes).**

### 3.1.2 Runtime Environment

The RTE is responsible for mapping the components in the application layer and the basic software layer so that they can communicate and make use of each other's functionality. The way this is done in AUTOSAR is through the concept of ports. A port is either of type providing or requiring. A providing port in AUTOSAR is realized as an implemented function while a requiring port is realized as a function call. The ports can be configured in one of two ways; either as a sender-receiver interface or as a client-server interface. Depending on which interface is used and how it is configured the behaviour of the RTE may vary. If for instance a requiring port interface is configured as asynchronous the RTE will not block in order to call the providing port, instead it will schedule the call at a more convenient time and continue execution.

At the design level the RTE is abstracted to a Virtual Function Bus (VFB) through which all communication runs. This also alleviates the communication handling for application layer development. In a way the RTE is the heart of the architecture, the glue that binds all the other components. Since the entire system is not fully known at the time when the RTE is being developed some parts of it must be generated afterwards. This is done when the system is configured, i.e. when all the different components are known and their descriptions have been made. A schematic view of the connections the RTE provides is seen in Figure 4

### 3.1.3 Application Layer

The top layer is the application layer that consists of software components that provide various functionalities and services in the vehicle. The two most significant types are the application software component type and the sensor actuator type. The latter is a software representation of a hardware component (a sensor or an actuator) while the former can make use of sensor data to provide actuators with relevant input. The data that is sent to or received from application layer components use the port interface functionality as described in 8.1.2.

It is the development of application layer software components that the whole AUTOSAR initiative is based around and that justify its existence. The lower layers and the RTE have, in essence, the purpose of making the development of application layer software components easier and standardizing the development of said software components. Everything that *uses* the AUTOSAR platform is located in the application layer; this is the part of the system where the components actually do something useful in the vehicle.

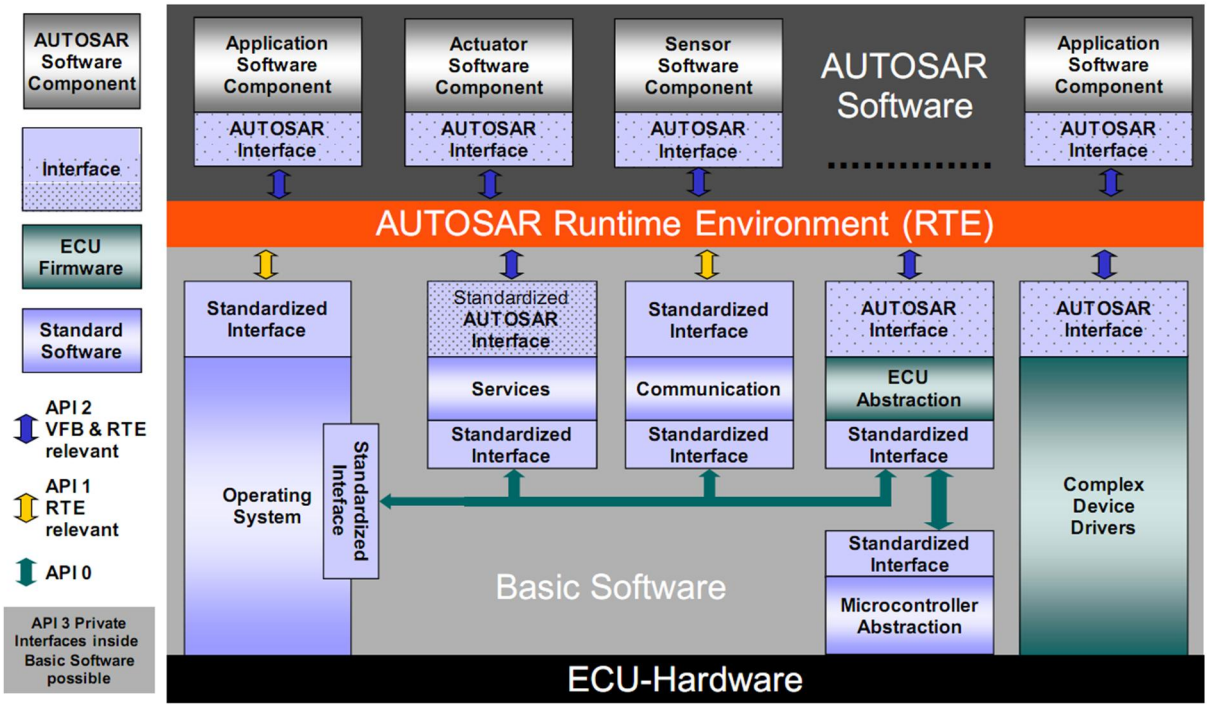


**Figure 4: An example of how the different components can be connected and what interfaces they use.**

## 3.2 Open Standard Cross car manufacturers

One advantage with a standardized platform is the increased exchangeability of hardware and software. This exchangeability is present on many different levels, between manufacturer's applications, vehicle platforms and so on. A hardware component manufactured by one company can easily be used in any vehicle as long as it has an AUTOSAR Software Components (SWC) that is delivered along with the component (e.g. a windscreen wiper motor which would have an actuator typed SWC). This means that the system integration phase of the vehicle design process will be easier and require less attention. As long as the standard is followed, by all who deliver components to the vehicle, they should be able to interact smoothly without any need for software rework apart from connecting the hardware's SWC with the functional SWCs that use them. This should also be a reasonably easy task thanks to the standardized API (More on this in chapter 8.3).

The problem is that in order to get the platform in place, much work is required with little financial return until it has been sufficiently utilized. A lot of the platform may not be used in every project and some parts might hardly ever be used. By implementing only the infrastructure that is to be used in the project at hand, development costs can of course be kept down. The drawback is that this makes software reuse very difficult if even possible (certainly impossible among different companies as sharing company code with outsiders is not very common). By standardizing the platform the initial cost can be motivated because it is shared not only by other car manufacturers but by the component manufacturers as well (e.g. Bosch and Continental deliver components to most vehicle manufacturers, especially those located in Europe). It is simply worth the extra effort if it means that further down the line the same software can be reused. It also opens up the possibility of switching components quickly and economically as long as they comply with the standard. The entire necessary

infrastructure is already in place and it should, in theory, just be a matter of snapping the new component (both hardware and software) into place.

In short; by using a standardized platform the automotive industry can; 'Cooperate on standards, compete on implementation' which has become something of a motto for the AUTOSAR initiative. If integration and infrastructure costs, both in terms of dollars & cents and man-hours, can be reduced the amount left for implementing functionality will be much greater than otherwise. This in turn will mean more functionality and/or higher quality software in terms of robustness, security and dependability.

## 3.3 Standardized API for application modules

In order to achieve some of the goals with the AUTOSAR initiative, *standardization of basic system functions and functional interfaces,* a standardized API is almost unavoidable. The AUTOSAR Application Programming Interface (API) defines all the functions and methods that are needed in order to utilize the AUTOSAR platform's functionality (see Figure 5). By following the structure and naming conventions of the API, developers can make their code compatible with it making it easier for other developers to use the functions implemented. The point is to ensure that all the different AUTOSAR implementations are compatible with one another. As a result there is no need for adaptation to OEM specific environments simply because there are none. If you know how to connect to the AUTOSAR interfaces you have all the knowledge needed to integrate the component to the system in question.

| | | |
|---|---|---|
| ***Service name:*** | Xcp_<module>RxIndication | |
| ***Syntax:*** | `void Xcp_<module>RxIndication(`<br>`  PduIdType XcpRxPduId,`<br>`  PduInfoType* XcpRxPduPtr`<br>`)` | |
| ***Service ID[hex]:*** | 0x03 | |
| ***Sync/Async:*** | Synchronous | |
| ***Reentrancy:*** | Reentrant for different XcpRxPduIds, non reentrant for the same XcpRxPduId | |
| ***Parameters (in):*** | XcpRxPduId | PDU-ID that has been received |
| | XcpRxPduPtr | Pointer to SDU (Buffer of received payload) |
| ***Parameters (inout):*** | None | |
| ***Parameters (out):*** | None | |
| ***Return value:*** | void | -- |
| ***Description:*** | This function is called by the lower layers (i.e. FlexRay Interface, TTCAN Interface and Socket Adaptor or CDD) when an AUTOSAR XCP PDU has been received | |

**Figure 5: An example from the AUTOSAR API.**

## 3.4 Drawbacks with AUTOSAR

There are of course some drawbacks with AUTOSAR. The layered infrastructure does lead to increased requirements in terms of available memory and computing power simply because the structure creates more overhead when direct access is denied. This is the price paid for better overview. Something that used to be simple to implement, might however become more difficult as everything must be done according to AUTOSAR methodology.

Standardized software can only be as good (in terms of resource use) as, or worse than, software that is written exclusively for its specific purpose. If the standardized software would be better, then the purpose-written software would be redundant and inferior. I.e. the situation should never occur because the standardized software could be used as a template and possibly (likely) be enhanced to increase performance. (2)

# 4 XCP - Calibration & Measurement Protocol

XCP is a generalization of a similar protocol called CCP with clear separation between transport layer and protocol layer. Whereas CCP was developed to support only CAN communication, its successor, XCP was designed to support a wide range of transport protocols. XCP was standardized by ASAM (Association for Standardization of Automation and Measuring Systems) (3) (4)

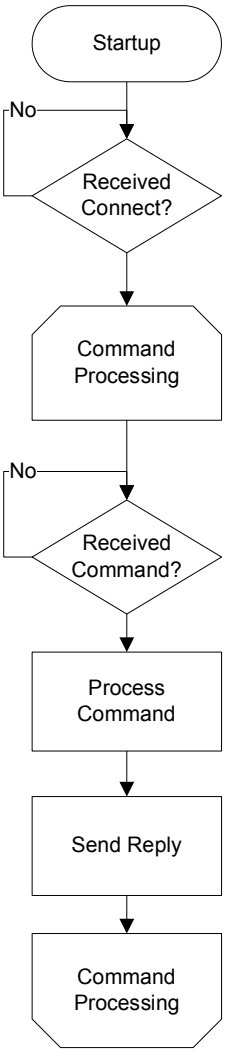


**Figure 6: Flow chart of the XCP protocol**

Both XCP and CCP have their roots in the need for calibrating Engine/Electronic Control Units (ECU) on the fly during the development phase of their lifespan. Today's vehicle control units often use quite complex internal algorithms to calculate output from any given input. The algorithms are more often than not parametric in that they have static controlling parameters to adjust the behaviour of a standard algorithm. A common day example of this could be the Traction Control Systems (TCU) and Anti-lock brake systems (ABS) of your normal car. The algorithms used in these types of system use input from various actuators (gyros, accelerometers, speed, steering angle and so on) to control the brakes and engine torque to avoid wheel lock and the car skidding out of control.

To keep costs down and to ensure proper behaviour, the algorithms used to do these types of controls are standardized and often identical between different models/manufactures of cars. To cope with the differences between vehicles (weight, wheelbase, tires, engine etc) the algorithms can be tuned through parameters. (5)

During the development process, a model of the vehicle is normally used to tune the algorithm at the start, but eventually you are forced to tune the controller when it is actually controlling the vehicle/system. This is where XCP (and its predecessor CCP) comes in. It allows communication over standard communication protocols like CAN/Ethernet/USB with the ability to accurately measure and modify variables in the running controller.

Figure 6 depicts the basic flow of command execution of the core XCP protocol.

## 4.1 Mode of operation

XCP is designed as a Single Master/Multi Slave system. A single master system, on a development PC, can be connected to multiple slaves running on embedded devices. This allows a complete view of a larger controlled system. An example situation could be in a vehicle where a single master is connected to the ECU handling engine control as well as another ECU controlling adaptive suspension. The master controller is then able to measure internal controller states, as well as tune parameters for the embedded system while evaluating performance.

## 4.2 Transport Layer (Ethernet, CAN, USB)

The XCP protocol was designed from the ground up to be transport layer agnostic and as such can support many different types of transport protocols. While each transport protocol puts some restrictions on the core protocol, it functions according to the same principles and with the same core packet syntax.

The XCP communication protocol is defined to use the slave's native byte-order. This implies that the master must be able to control two sets of byte orders for the XCP core protocol, but also simplifies the implementation of the slave. The byte-order the slave uses is sent as a reply to the master when the master connects to the slave for the first time.

The transport protocol sets limits on the possible throughput of data. A CAN network for example has a limit of 1 mbit transfer rate, this however is only possible with no other bus load and can be significantly lower if longer transmission cables are required. With Ethernet and USB this transmission cap is lifted and much larger throughput is possible. This allows for high speed sampling of large amount of data, while on a CAN network you may need to limit sampling speed and quantity to not overload the protocol.

### 4.2.1 Ethernet

XCP over Ethernet frames each core XCP packet with a header containing a packet number and length, but otherwise makes no changes to the underlying XCP core frame (see Figure 7). It allows for transport over both TCP and UDP where UDP imposes a limitation of packet size (DTO[1]/CTO[2]) defined by the maximum packet size of UDP. (4)

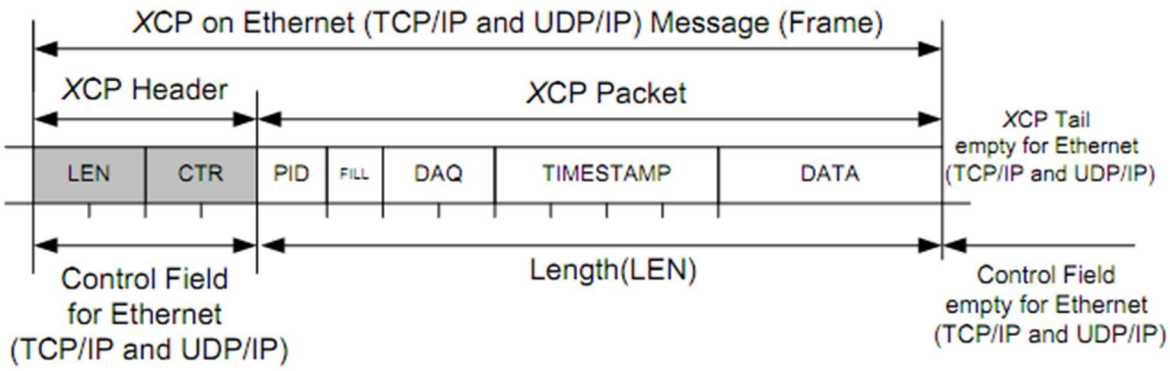


**Figure 7: Header and Tail for XCP on Ethernet.**

### 4.2.2 CAN

The CAN-bus (Controller-area network) is a serial communication bus originally constructed for communication between microcontrollers in automotive applications. It is a multi-master broadcast system without need for a controlling host computer. It has built in prioritization of messages with minimal delay in transmission and reception.

[1] DTO: Data Transfer Object
[2] CTO: Control Transfer Object

When the CAN-bus is free, any node on the bus is free to start transmitting. If two nodes start sending at the same time, the message with highest priority will be received by all nodes. The node transmitting the lower priority message will resend its message after a given delay. Priority of messages is defined by the message id, where a lower id has a higher priority than a numerically higher id.

The automatic prioritization of messages functions through a method of recessive and dominant bits. Where a logical 0 is considered dominant and a logical 1 is considered recessive. At the start of each transmission, nodes send their identifier starting with the most significant bit. After transmitting a recessive bit (1) on the serial bus, the node checks if the transmitted bit matches what is currently received on the bus. Should any other node have transmitted a dominant bit at the same time, the node will detect a dominant bit on the bus and stop transmission. After the full identifier has been transmitted, only one node will remain active on the bus and can begin sending its payload.

XCP over CAN limits packet size (DTO/CTO) to 8 bytes, but allows for transfer of data without identifier by leaving that up to the CAN packet identifier. The normal XCP frame over CAN can be seen in Figure 8. Interleaved communication[3] is not allowed. Each slave has at least two CAN id's reserved, one for receiving commands and one for sending. (4)

The XCP protocol has one extension when used over CAN which allows for automatic discovery of connected XCP slaves on the CAN-bus. If the master broadcasts a GET_SLAVE_ID message on the CAN-bus, all connected slaves will reply with a message signalling on which CAN packet id's they communicate.

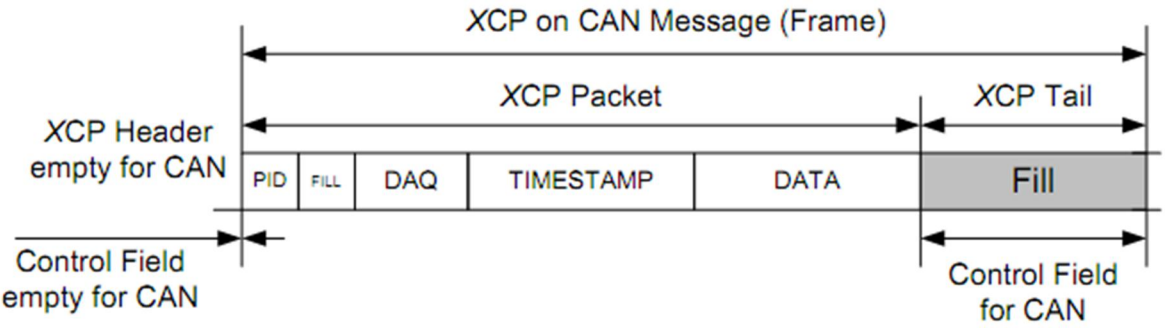


**Figure 8: Header and Tail for XCP on CAN.**

[3] Interleaved Communication: allows the master to send multiple commands to the slave without waiting for it to acknowledge them.

### 4.2.3 USB

XCP over USB frames each core XCP packet with a header containing data length and an optional packet number as can be seen in Figure 9. It also appends a tail which ensures that the following XCP packet follows a defined alignment. The communication model allows for either single XCP packets per USB packet, multiple complete packets in a single USB packet or streaming of XCP packets which allows XCP packets to cross USB packet borders. (4)

Depending on the chosen method of packaging of XCP packets in USB packets, XCP may be limited to the maximum size of an USB packet.

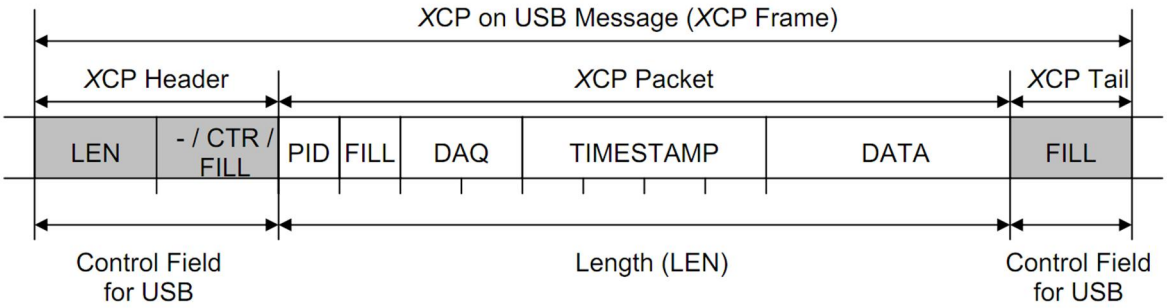


**Figure 9: Header and Tail for XCP on USB**

## 4.3 Online Calibration

Provides direct read and write access to memory of the ECU. It also allows for access of different memory areas with a XCP specific address extension. Each calibration segment of the devices may be divided into multiple pages. Each page is semantically identical in the device but allows the master to modify multiple parameters without them taking direct effect. When finished it can signal a page switch for the embedded device where it starts using all of the newly written parameters at the same time.

Each segment in the device has one ECU active page and one XCP active page. The page active for the ECU is the memory the ECU is currently using for its internal control loops. The XCP page is the memory area which the XCP master currently can read and write to. If the slave device allows it, the XCP and ECU may point to the same memory in which case modifications take effect directly.

## 4.4 DAQ Lists – Data Acquisition Lists

A core feature of the XCP protocol is the DAQ lists. In order to be able to send a large amount of data in a small amount of time and with low bandwidth load desirable, XCP offers the ability to configure lists that take care of transmitting requested data at a given interval. Each DAQ list (Figure 10) has a number of Object Descriptor Tables (ODTs) that in turn contains Object Descriptor Table Entries (ODT Entries) as described in Figure 11. Each ODT Entry has an address and a length, these make out the description of the parameter that it represents. When the DAQ list is processed the contents of the list is copied to the corresponding address of each entry in each ODT. The slave doesn't receive an acknowledgement that the master has received the data correctly.

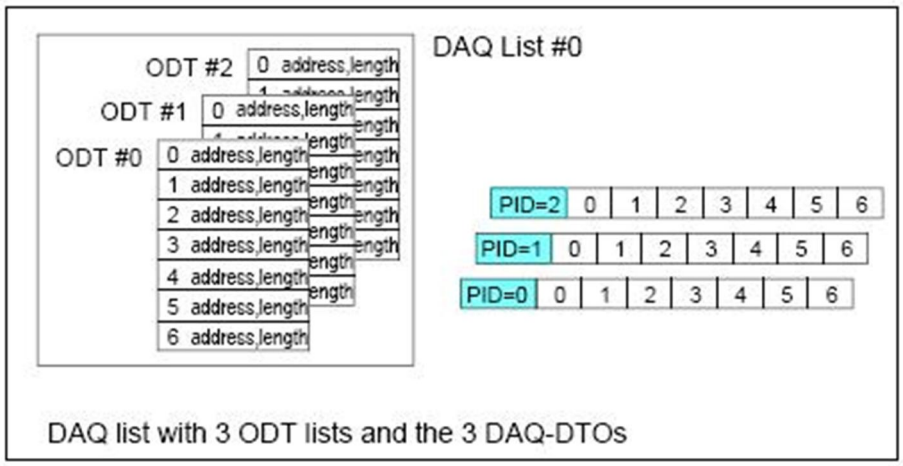


**Figure 10: For each DAQ-list configurations a number of ODT's are defined, each having a unique identifying PID.**

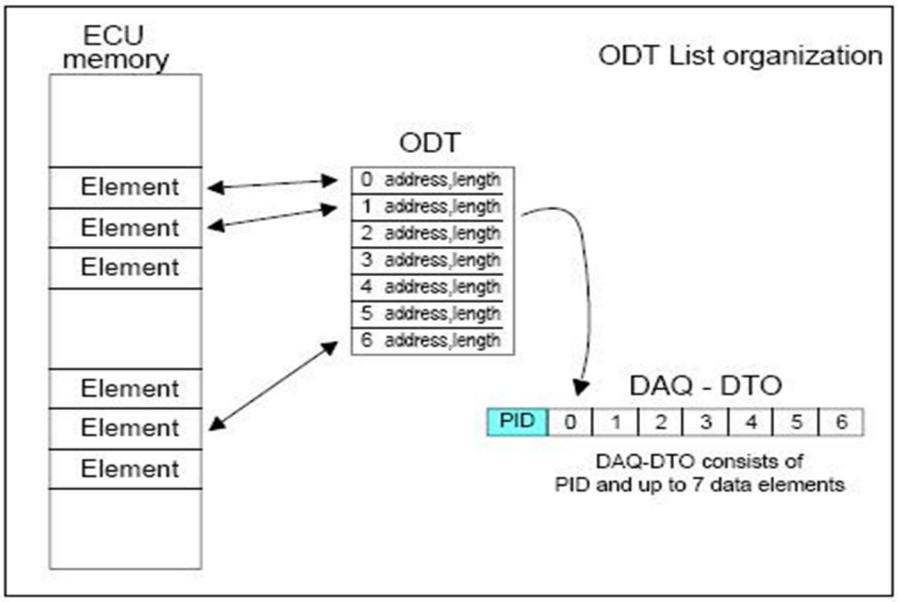


**Figure 11: Each ODT entry in a DAQ list points to a memory element with specified address and length.**

### 4.4.1 DAQ-list configuration

XCP has two different ways of configuring the DAQ-lists, static and dynamic. While static configuration is mandatory according to the specification, dynamic configuration seems to be the preferred way (as an example CANape only uses dynamic configuration in their examples). Which configuration method that is to be used is decided exclusively by the slave, there is no way for the master to request one or the other, nor can both be used in parallel. In addition to the configurable DAQ-list (static or dynamic) the slave can also have a number of predefined DAQ-lists. These lists cannot be altered in any way. Each ODT entry has a predefined address and size. The only thing the master is allowed to do is configure their direction, prescaler, priority and which event channel it should be connected to.

In static configuration the slave already has a structure of DAQ-lists with ODT's and the ODT's have entries. This configuration cannot be edited. If there is only one DAQ-list, that has three ODT's and the ODT's have 5 entries each, then this is all the master has got at its disposal. The entries can be edited, i.e. the address and address extension that maps it to a memory space can be changed. A lot of the DAQ-list's properties can also be changed just as in the case with the predefined list.

The dynamic configuration is, as the name suggests, less restricted. The master can request allocation of any number of DAQ-lists, each DAQ-list can have any number of ODT's and the ODT's can have any number of entries. There are some restrictions to the command sequence of the allocation, see Figure 12 and the following list:

- The allocation must always start with sending a command to clear the previous allocations; this is done with the FREE_DAQ. This will reduce the number of DAQ-lists to the predefined lists if any exists on the device.
- The next step is to allocate the DAQ-lists; this can either be done one at a time or by allocating all the lists at once. If a FREE_DAQ has not been executed before this step the device will return an error message.
- After allocating the DAQ-lists the master can start allocating ODT's to the different lists. All the ODT's in all the DAQ-lists need to be allocated before the first entry is allocated.
- Finally the entries are allocated.

| after | FREE_DAQ | ALLOC_DAQ | ALLOC_ODT | ALLOC_ODT_ENTRY |
|---|---|---|---|---|
| FREE_DAQ | ✓ | ✓ | ERR | ERR |
| ALLOC_DAQ | ✓ | ✓ | ✓ | ERR |
| ALLOC_ODT | ✓ | ERR | ✓ | ✓ |
| ALLOC_ODT_ENTRY | ✓ | ERR | ERR | ✓ |

**Figure 12: The allowed sequences when allocating a dynamic DAQ-list configuration.**

The parameter MAX_ODT is a defined in the AUTOSAR specification as maximum number of ODTs available on the *slave*, its range however suggests that it is instead the maximum number of ODTs available in the *DAQ-list***.** More about the different XCP parameters can be found in Appendix C – Readme for XCP AUTOSAR module.

### 4.4.2 STIM Lists – Data Stimulation Lists

The opposite of DAQ lists are STIM lists. They provide a means for the master to write to (stimulate) the slave in a controlled manner. When the master writes to a STIM list, the data is buffered in the slave until the STIM list is executed at which point the stimulation data is copied to specified memory addresses of the ECU.

STIM lists execute at a certain interval or at certain points in the program running on the ECU. This avoids the problems of directly modifying control parameters on the fly, mid execution of some control-loops. Instead it allows the ECU to apply new parameters at controlled points in time.

STIM lists are built up in the same fashion as DAQ lists. They consist of ODT's (object data descriptors) and ODT entries. Each ODT is transmitted in a single STIM packet from the master to the slave, and consists of multiple ODT elements. Each element has previously been configured to point to a memory address + extension with a specified length.

### 4.4.3 Processing Event Channel

Each DAQ-list is connected to an event channel that dictates how often the DAQ-list should be executed. The DAQ-list also has a parameter called a prescaler that states how many event channel executions that should occur between each time the DAQ-list is run. If this parameter is set to 1 the DAQ-list will be run each time the event channel is executed. The flow of the data acquisition can be seen in Figure 13.

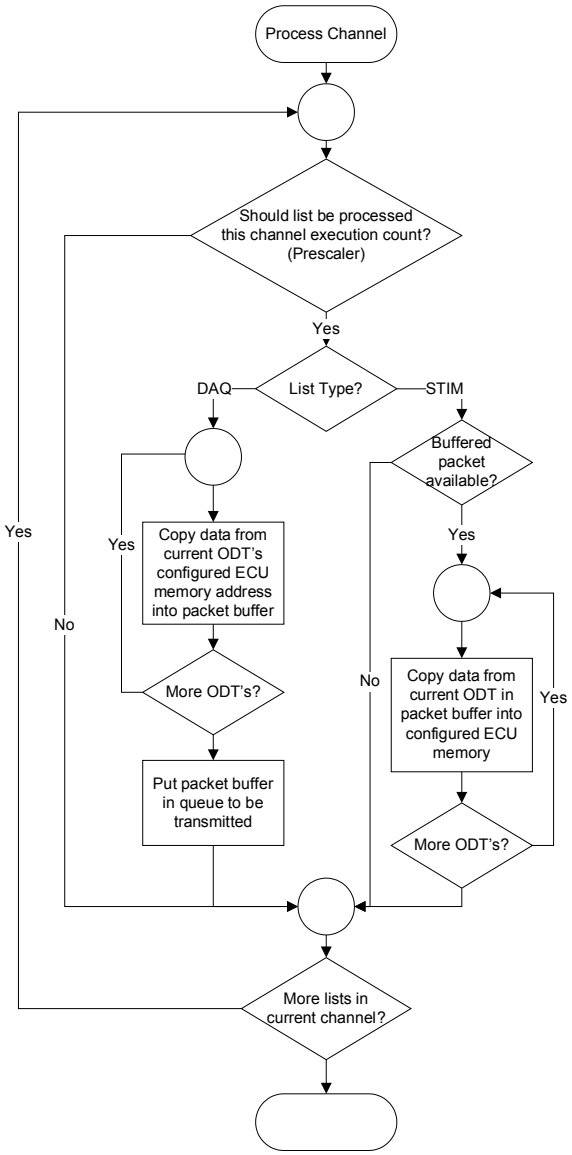


**Figure 13: Flow chart over the processing steps done for an XCP Event Channel each time it is activated**

## 4.5 Bypassing

Bypassing is a feature of XCP that allows replacing some part of an ECU's control logic with code that resides on the XCP master. For example: one could replace part of a calculation in the ECU with code that executes in Matlab/Simulink on the master to test out new controller methods without the need to re-program the ECU. It combines the use of DAQ lists with STIM lists to achieve this.

Use of this feature of XCP requires additional instrumentation of the ECU's code in order to function. When bypassing is activated on some part of the ECU's program, the ECU will send a DAQ packet as it enters the bypassed code, with the parameters required to calculate a response to the master. Then the slave enters a waiting state. When the master receives the DAQ list for the bypassed code, it replies with a STIM packet containing the result of the calculation. At this point the ECU resumes operation with the received STIM data as the result of the bypassed code.

## 4.6 Flashing / Firmware upload

The flashing feature of XCP allows modification of persistent memory for replacement of firmware or calibration parameters.

Firmware replacement allows the master to do a complete replacement of the code that runs in the ECU. After the firmware has been uploaded, the ECU is restarted and is then running with the new firmware in place. This avoids the need for a boot loader, and allows an XCP master full control of the ECU program without resorting to other tools for replacing ECU firmware.

XCP also supports a more feature-based flashing to allow only calibration parameters to be made permanent in the slave.

## 4.7 Security – Seed & Key

Each feature-set of XCP can be protected with a Seed and Key architecture. This allows protection from tampering with control units. The protection functions according to a seed and key methodology to avoid the ability to sniff the password over the transport protocol. The slave provides the master with a seed, which is used to compute a password for the feature.

The actual logic used to calculate the SEED and the KEY is device-dependent and is provided by the ECU integrator.

To allow different XCP master vendors to communicate with a XCP slave protected by a vendor specific seed and key logic, it is normal for the master to dynamically load a shared library (for example a Windows dll) which contains the code necessary to calculate the key from the seed.

This avoids the requirement that the XCP master vendor needs to know the logic used to unlock a specific ECU.

# 5 Development Environment

## 5.1 Arctic Core

The AUTOSAR platform implementation that was used in the project is Arctic Core. It is developed and maintained by ArcCore, a Swedish software company. The platform aims to comply with AUTOSAR release 3.1. Some modules are not complete, e.g. parts of the memory interface.

## 5.2 Arctic Studio

Arctic Studio is a rebranded Eclipse release with a few modifications tailored towards AUTOSAR compliant software developing. In addition to the regular source code editing capabilities Arctic Studio (the professional edition) offers a number of other eclipse based tools that are used for AUTOSAR specific development:

- Extract Builder – The extract builder is used when connecting the different software components and creating an ECU extract. When connecting the different software components the user can either choose to do so manually or to let the tool do it automatically. The connections are created by pairing two ports on different components to each other. If the providing port and the requesting port have the same name they can be connected automatically. Because the tool is a part of the Eclipse environment it can automatically find the various software components in the project, regardless of which file they are located in. This is a particularly useful feature when working in a large project with many developers.

- SWC Builder – The Software Component tool is used to create and edit AUTOSAR components. By limiting the user's choices the tool will aid in developing components that are sound and make sense. In addition to drag and drop capabilities it also offers validation, i.e. ensuring that the configuration is valid. The SWC Builder is also compatible with the AUTOSAR XML format (ARXML).

- BSW Builder – The Basic Software Builder is a central tool for using the Arctic Core AUTOSAR platform. In the ECU Configuration Overview the user can choose which BSW modules are needed for the project and then using the custom editor, adapt them according to the intended application. After the appropriate modules have been selected and configured, the tool generates new configuration files that are used when creating the AUTOSAR platform. As with SWC Builder, the BSW Builder makes use of the validation rules which helps the user in keeping the configuration valid.

- RTE Builder – As previously stated, parts of the Run Time Environment (RTE) must be generated because of the fact that some software components are unknown at the time of the first build. This tool is used to generate the source code for the parts of the RTE that cannot be written beforehand.

## 5.3 MinGW

Arctic Core and Arctic Studio use the MinGW environment to cross-compile binaries for embedded devices on Windows. This allows for a toolset that is equal between multiple different operating systems used for development of AUTOSAR modules.

MinGW stands for "Minimalist GNU[4] for Windows". It is a library/environment for developing Windows applications using a toolset similar to that of Linux/Unix/Bsd. It provides the normal GCC/LD binutils with its support for a multitude of different platforms. It differs somewhat from Cygwin, in that it does not try to provide full POSIX[5] compliance on Windows and as such is fully native to Windows. In comparison Cygwin requires emulation of many POSIX features not natively supported on Windows and is as such slower.

## 5.4 Vector CANape

As has been previously stated, XCP is a master-slave designed system. In order to test the slave being developed a master device has to be available. Vector CANape had previously been used at QRtech and was therefore the natural choice for the project. The tool offers a wide range of protocols to use for collecting data including XCP which was of course crucial.

CANape can create a DAQ-list configuration automatically. The user only needs to define the variables or parameters that are to be measured; this is done in the following way:

1. The first step is to add the addresses and properties of the variable to the database (see Figure 14).
2. After the database has been updated with the new value the variable can be included in the measurement list.

[4] The name “GNU” is a recursive acronym for “GNU's Not Unix!”
[5] Portable Operating System Interface for Unix

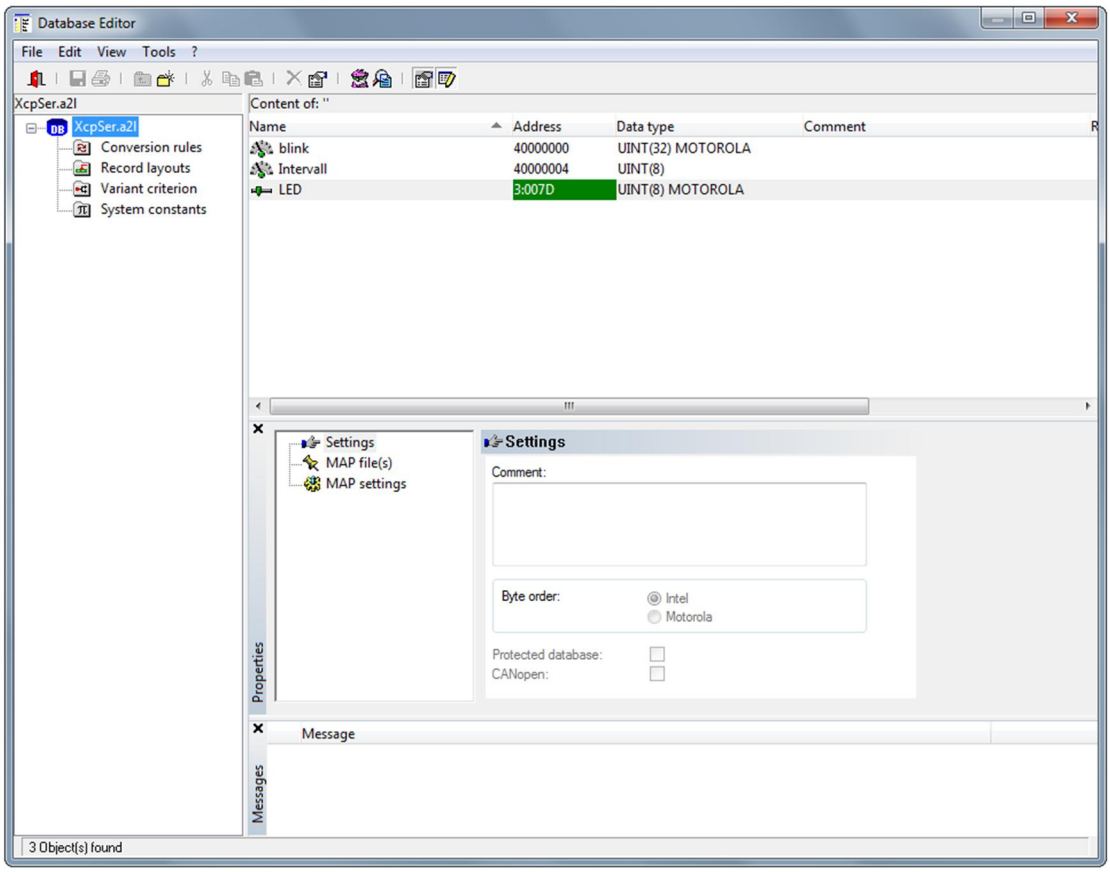


Figure 14: CANape Database Editor

3. Once in the measurement list, a number of different methods for data retrieval are available. The two most interesting for the project are the cyclic mode and the event channel mode, which in essence are the same thing. At 'connect' CANape receives a list with all available event channels. In event channel mode the user defines which event channel the variable is to be connected to. The variable will be sent at the same interval as the event channel rate.

4. When the 'Start Measurement' button is clicked CANape will combine the prescaler and event channel so that the DAQ-lists transmission rate is as close to the desired interval as possible.

5. Once the configuration is complete and the DAQ-list(s) have been started CANape will display the measurement in a diagram as seen in Figure 15.

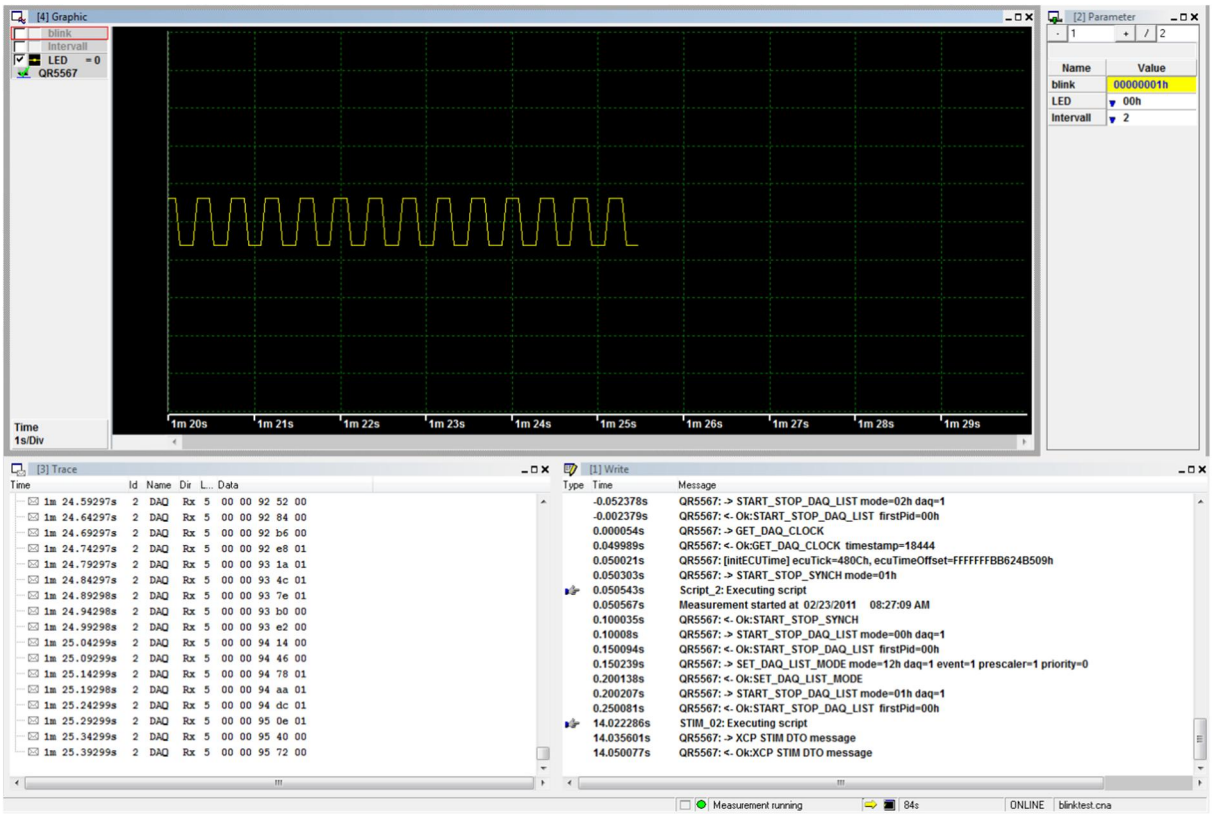


**Figure 15: CANape during measurement**

The version of Vector CANape (6.1 with SP 3) that was available during the project did not offer a direct way to use DAQ-lists in STIM mode. This proved hampering at first as this was virtually the only tool used for testing and verification. Without a way to check the implementation, ensuring correctness was very difficult. The solution was to use the script-editor in CANape to write our own sequence of commands and thereby having full control over everything that was sent to the slave device. This proved useful also for verifying correctness of the implemented protocol's error handling.

Another problem with the version of CANape used is that it doesn't care if the DAQ-list is predefined or not. Even though the tool acknowledges that there are predefined list and even knows how many there are it still tries to write to DAQ-list zero (the predefined lists are always have the lowest numbers).

Another oddity is that CANape defaults to not expecting the counter of TCP slave packets to be incremented by normal response packets which the specification says it should be. At least they in this case allow you to follow spec by an advanced setting.

## 5.5 QR5567

The target hardware for the XCP implementation is the QR5567 platform (also known as the G3-board or as ODEEP – Open Dependable Electrical and Electronics Platform). It is a rapid prototyping platform designed by QRTECH for developing systems and application within the automotive domain. The physical layout can be seen in Figure 16.

The following features are available:

- 128MHz 32-bit FreeScale MPC5567™ microcontroller
- Four CAN 2.0B interfaces with TJA1050 transceivers
- Two LIN 2.0 interfaces
- Two FlexRay interfaces with TJA1080 transceivers
- 10/100mbit Ethernet interface
- Four 3.0A High Side Driver Outputs (HDO)
- Four 2.8A Low Side Driver Outputs (LDO)
- Eight analog or digital inputs
- Micro SD-Card Interface
- 5V External Output
- Two H-Bridge Drivers
- One Universal Serial Bus (USB) interface
- Compact Layout (160 * 100 mm)

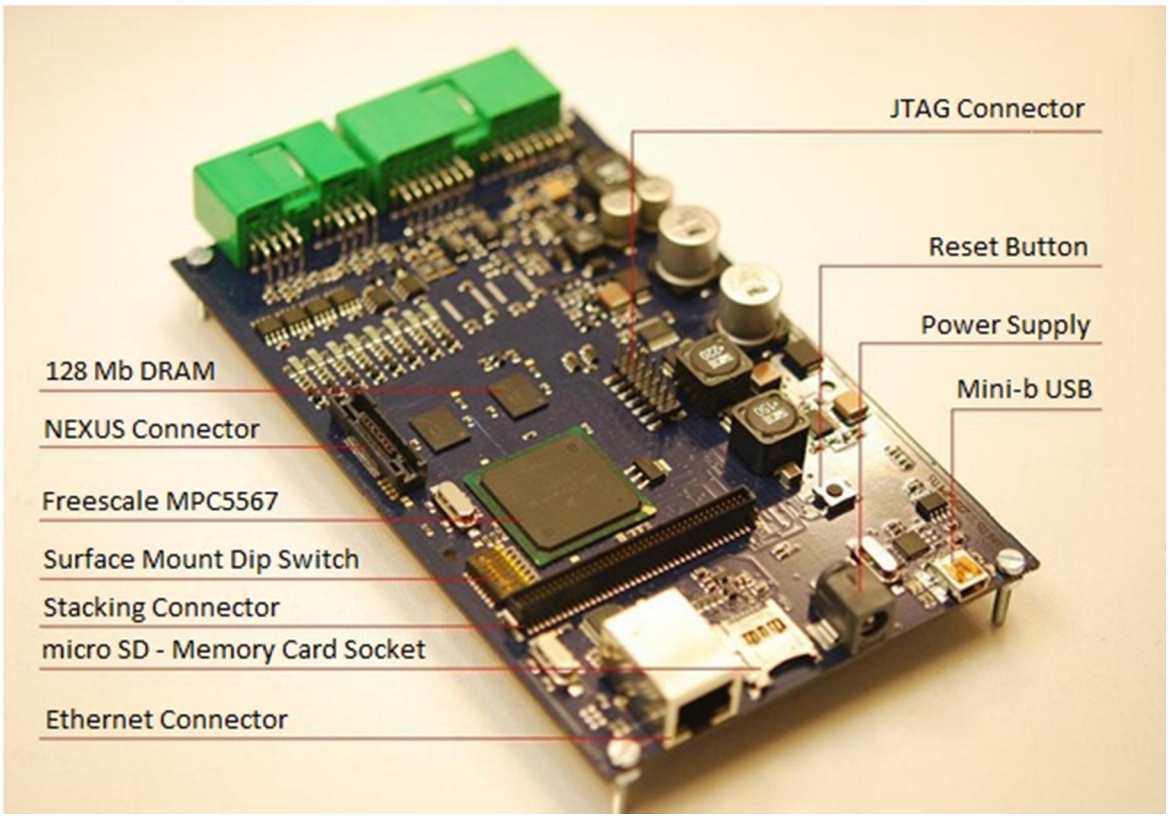


**Figure 16: The QR5567 rapid prototyping platform.**

QR5567 is also one of the reference boards for Arctic Core, which means that a significant amount of testing has taken place in regards of running Arctic Core on QR5567. This should (in theory) result in a higher level of dependability for the project.

In order to transfer programs from the development platform (usually a PC or similar) to the board itself, a programming device is needed. A simple solution to this problem is to use a programmer that connects to the board via the JTAG connector and downloads the specified files directly to the flash memory area on the board. The one used for the project was a USB Multilink Interface from P&E Microcomputer Systems. In addition to the basic flashing feature it also has the capability to verify the memory. To have the ability to debug a PEEDI (Powerful Embedded Ethernet Debug Interface) from Ronetix was used. By using Telnet and TFTP (Trivial File Transfer Protocol) it is possible to program the device and also use debug.

## 5.6 Vector CANcaseXL

In order to run CANape in so called online mode, an external device containing the certification key is needed. In addition to this key, the CANcaseXL also contains two physical CAN channels with D-SUB connector ports and a power synchronization port.

In order to make use of the CANcaseXL's CAN channels a special cable had to be manufactured that could connect the D-sub9 connectors with the connectors on the QR5567. This was done in the laboratory at QRtech.

There were some issues with the CANcaseXL, the most severe was the fact that when connected it seemed to cause Blue-Screen events at random. Although never confirmed that it was the cause, the CANcaseXL was always connected to the computer if it had an occurrence of Blue-Screen, typically one or two per day, regardless of whether it was being used or not.

# 6 Development Process

The initial step in the development process was to create the configuration structures (and some of the runtime structures) as defined by the AUTOSAR XCP specification (6). Figure 17 shows an example on how the specification defines the runtime/configuration parameters for XCP.

Configuration and runtime structures in AUTOSAR lend themselves very well to the normal C struct feature. This made defining the basic structures a straightforward process. On completion it gave a base to build on, with many of the required runtime data structures in place. It also avoided the situation of having to conform to the AUTOSAR XCP runtime structures at a later stage in the project.

## 6.1 Basic Protocol Infrastructure

The next logical step in the development was to get some sort of infrastructure in place for handling protocol parsing and packet handling. In order to comply with both AUTOSAR and the XCP specifications, several considerations had to be made.

- Requirements on how the XCP module should communicate with other parts of the AUTOSAR layered infrastructure. (7)
- AUTOSAR defines how the code should be structured into files and how they should be named.

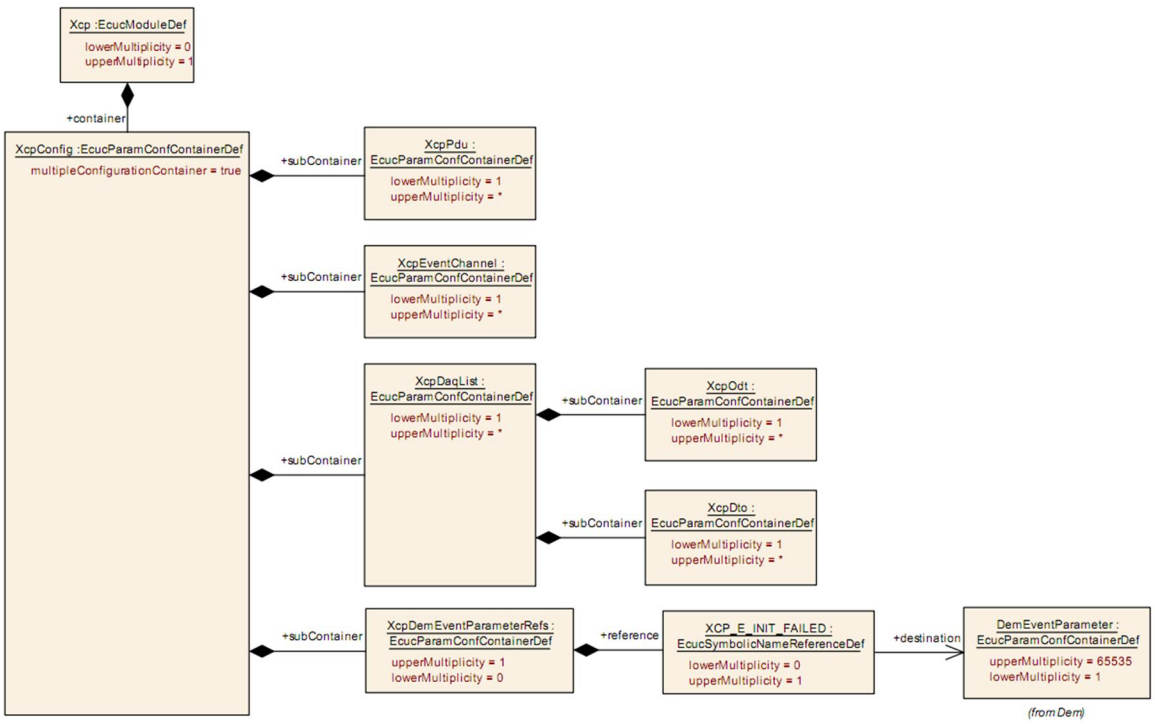


**Figure 17: Example view from AUTOSAR Xcp specification on configuration and runtime structures**

- AUTOSAR defines to a large extent how the configuration of the module should look
- Memory requirements should be known at compile time.
- XCP has timing requirements on data collection (DAQ) and data stimulation (STIM) (4)

## 6.2 Development of testing tools

In order to develop and simultaneously test the implementation without the constant need to flash the code onto the hardware, it was decided to create a standalone Windows XCP slave (XcpServer[6]) using the same codebase library as would run on the actual hardware. Arctic Core itself was not designed to be compiled on a non-embedded system, which ruled out using it as a host for the XCP module.

It was however important that the interface to the core XCP code remained as close as possible to that which would be required to run on the actual platform to reduce problems and bugs that might be introduced due to differences in behaviour. This implied emulating the interfaces that the XCP module would be using when communicating.

Since it had been previously determined that Arctic Core only had support for CAN communication, this would be the initial choice of communication model. As it turns out, Vectors CANape toolkit installs a virtual CAN bus, which can be used to communicate with CANape as if the real CANcaseXL CAN bus is used, the API of which was available as a download from the authors of CANape.

The first instance of the XCP slave was using the above mentioned Virtual CAN bus and was working as a starting point. However, due to some annoying behaviour of this bus, where a single error could throw the whole virtual bus into an error state requiring a 'disconnect' of all CAN devices before it would normalize, testing was tedious.

Given that XCP is also defined to run on TCP/IP for which CANape also has support, the development platform was rewritten to function as a standard TCP/IP server, and the interface against the core XCP module was changed to that which would have been used for TCP/IP communication with the module inside Arctic Core had it supported this type of communication.

This change simplified XcpServer, since it was now using standard Posix[7] socket API instead of a proprietary API for the virtual CAN bus, it was able to run the XCP slave on one physical computer and CANape on another as well as prepare the module for TCP/IP support when Arctic Core adds support for TCP/IP as a communication model.

[6] XCP slave based in windows for used in the development of XCP protocol
[7] Portable Operating System Interface for Unix

# 7 Result

The XCP module is developed in C, taking advantage of C99 features such as designated initializers/inttypes.h and varadic macros. It is geared towards integration into an AUTOSAR compatible system. However it has few actual requirements on the surrounding system, allowing the module to be used in a non AUTOSAR context with only small adaptations.

## 7.1 AUTOSAR Integration of the XCP module

The AUTOSAR XCP specification has defined entry points into the XCP module for the different transport protocols. For the two of interest in this case (CAN and Ethernet) the following entry points are defined where <module> is either “Eth” or “Can”

- <module>_Transmit():
  Implemented by the CanIf/SoAdIf AUTOSAR subsystems. This function is used to signal transmission of data over the given transport protocol. It allows for two different modes. A buffering model or a copy free model.
  - With the buffering model, the transport subsystem copies the given data into internal buffers and transmits at a later stage, at which point it calls a confirmation function (Xcp_<module>TxConfirmation()) to signal the finished transmission of data.
  - In the copy free model, only the size of the data requested to be transmitted is given in the call to Transmit. When the transport layer subsystem is ready to transmit it asks for a pointer to the actual data from the requesting subsystem (Xcp_<module>TriggerTransmit())
- Xcp_<module>RxIndication():
  Implemented in the XCP module. This function is called by the CAN/Ethernet subsystems in AUTOSAR when a data packet on a XCP assigned PDU is received. It contains the packet and the packet length.
- Xcp_<module>TxConfirmation():
  Implemented in the XCP module. Called by AUTOSAR CAN/Ethernet… subsystems to confirm that a data packet has been transmitted by the transport layer.
- Xcp_<module>TriggerTransmit():
  Implemented in the XCP module. Called by AUTOSAR CAN/Ethernet… subsystems when the transport layer subsystem is about to send a data packet previously requested by a <module>_Transmit() call by XCP. This allows a memory copy free transmit of data.

Only the buffered approach to transmission was implemented, partly due to its simplicity but mainly due to lack of support in the Arctic Core AUTOSAR implementation for the copy free method.

The specification also states that the XCP module should implement a main function that should be called on a fixed cyclic speed. It is said that “These functions are directly called by Basic Software Scheduler.” (3) But there is no mention on how this is expected to be realized in the RTE or Basic

Scheduler. Thus currently the following functions need to be explicitly called by the integrator of the AUTOSAR system.

- Xcp_MainFunction():
  Implemented in the XCP module and expected to be called by the Basic Software Scheduler. Since this is currently not realized in the Arctic Core AUTOSAR implementation. The Integrator is required to call this on a fixed cyclic speed to process received and sent XCP messages.
- Xcp_MainFunction_Channel(channel)
  Implemented in the XCP module and is the entry point for triggering the specified XCP event channel. This should be called by the AUTOSAR integrator at the rate configured for that event channel and preferably at points in the software where the internal state is consistent.

## 7.2 Code Organization

The AUTOSAR XCP specification also imposes restrictions on the namespace of global variables as well as how the file/name and structure of your module should be defined. All global variables in an AUTOSAR module must be named according to the standard "<module>(_)<name>" to avoid namespace clashes between modules in the AUTOSAR layered architecture. The underscore has apparently been deemed optional since it is often omitted in the specifications. Filename should follow the same pattern of naming.

The AUTOSAR XCP specification defines the following files explicitly (see Figure 18 for the correlations between the files):

- Xcp.c – Main code for the XCP subsystem.
- Xcp_Cfg.c/h – Compile time configuration parameters for the XCP module.
- XcpOnEth.c – All code concerning XCP being transported over Ethernet.
- XcpOnEth_Cbk.h – Extern function declarations for callbacks that other AUTOSAR components will call on reception of data over Ethernet.
- XcpOnCan.c – All code concerning XCP being transported over CAN.
- XcpOnCan_Cbk.h – Extern function declarations for callbacks that other AUTOSAR components will call on reception of data over CAN.
- Xcp_ConfigTypes.h – Should contain all structures required in Xcp_Cfg.h/c to configure the XCP subsystem.

A few additional files were deemed logical to separate distinct parts of the XCP implementation:

- Xcp_Memory.c/h – Containing a memory abstraction interface to handle reading and writing to memory and ports through the use of an address extension.
- Xcp_ByteStream.c/h – Containing helper functions and defines for reading and writing to an arbitrary bytestream, as well as functions for handling the receive and transmit fifos.

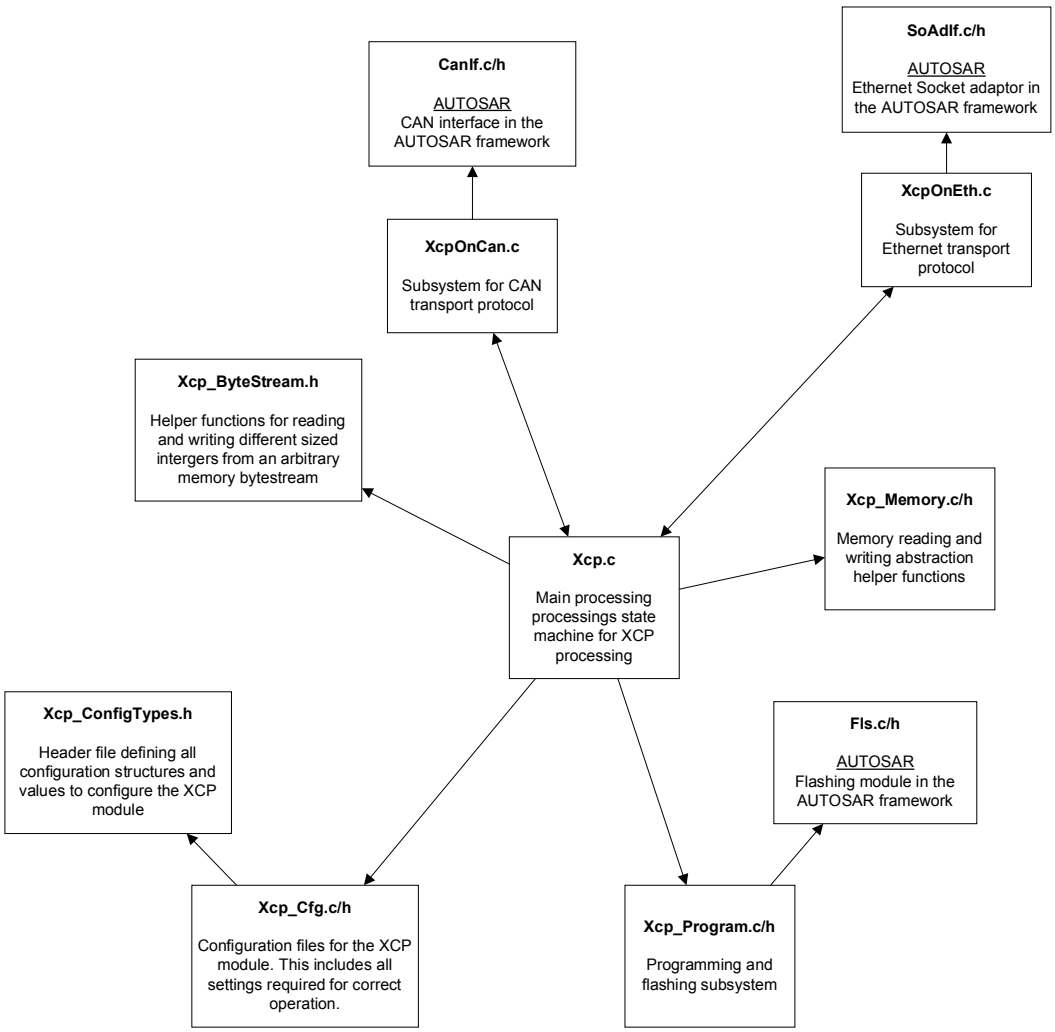


**Figure 18: Organization of code modules**

## 7.3 Memory Abstraction

The XCP specification defines that any address used to reference an object/variable through the XCP protocol should be combined with an address extension to fully identify the object. It is quite vague in defining how the address extension should be used, but one example mentioned is to be able to address multiple CPU's address spaces even if they do not share physical memory.

To address this, a lightweight memory access abstraction was added to the module through which all memory reading and writing is performed. This has the additional benefit that any internal or external data of the ECU can be mapped into a flat address space and read and written as normal memory. The use of the memory abstraction layer allowed the implementation of reading and writing directly to AUTOSAR DIO[8] Ports and Channels without any intermediary code written by the user of the XCP module.

## 7.4 Demo Application

During the development process a demonstrator application on the QR5567 was created. A standard RC-Servo[9] was attached to a PWM port of the QR5567 as well as to an analog port reading the electrical current draw of the servo. This allowed monitoring of the current draw over XCP utilizing DAQ lists, whilst controlling the servo using the online calibration feature of XCP.

The XCP demonstrator shows, in an understandable and simple way, the areas of application of XCP itself. It could easily be extended to support optional features such as writing to non-volatile memory for a more complete demonstration device when implemented in the core XCP module.

The usefulness of XCP was also made clear, and an actual need for calibration occurred, when the initial RC-Servo used had to be replaced. The new servo required different pulse widths in order to use its full range.

[8] DIO: Digital Input Output
[9] RC-Servo: Normal servo using in remote-controlled cars/planes/boats

# 8 Discussion

## 8.1 Implementation

The behavior of the protocol is defined by the specification, there for no consideration regarding functionality had to be made. The implementation had to conform. This can be an advantage; no time needs to be spent on deciding how the implementation should work. The drawback is of course that as a developer a lot of freedom is lost. As an example a sizeable amount of rework was done when the dynamic allocation of DAQ-lists was added, due to the way in which AUTOSAR's XCP specification defined runtime structures. Initially, the specification was followed to the letter, which at the time seemed like the logical choice. This however caused the implementation of dynamic DAQ lists to become much more complicated than need be. It was eventually decided to modify the runtime structures in a way more suited to dynamic memory allocation.

The refactoring of the configuration structures could have been avoided if the specification had been clear that runtime structures where mainly a guide instead of a requirement which it was eventually understood to be. If known in advance, less code would have been written to rely on a suboptimal structure.

Making use of the functionality of the QR5567 proved slightly more labor intensive than was assumed at first. The Arctic Core configuration template that maps the AUTOSAR ports to physical pins only had support for the LED; the rest had to be added by hand. It should however be emphasized that Arctic Core isn't a QR5567 specific implementation and that no claim ever has been made that states the availability of a complete configuration. Even so, the lack of a useable configuration did require a lot of work that in essence was outside the scope of the project.

The Arctic Core AUTOSAR implementation had a nasty habit of crashing when too much debug information was enabled and tasks where set to run often. It crashed in a mysterious way during scheduling of tasks with no reference to what caused it. Since this was the default configuration, XCP had to be limited to run processing at a very slow pace. 4 messages per second were about as fast as it could run before triggering scheduling errors. Due to the lack of working debugging tools at the start of the project, the reason was unknown during a large part of the initial phase of development. This in turn caused the focus to shift to the development of virtual environment for a slave device running on windows, rather than running on the targeted ECU.

## 8.2 The AUTOSAR initiative

At a glance, AUTOSAR seems to be offering a lot of pros without any cons. This is of course not entirely the case. First of all one must keep in mind that the AUTOSAR initiative is based on the desire to make *development* of new E/E functionality less costly. Less effort has been put into making software *maintenance* simpler. The assumption is that AUTOSAR will reduce the need for maintenance and debugging because the platform itself will take care of most of the connections and other sources of error. While this might be true, the fact that it is not obvious where the code is executed does make it harder to find the source of the error. Whether this will be less time- and money consuming than in the past remains to be seen, but at a glance it is uncertain. Introducing a completely new architecture also means that knowledge of the old has little value.

Another drawback that is not mentioned in the AUTOSAR documentation is the increased complexity for repairs and aftermarket services. Today, if there is a problem with an E/E component at the brakes for example, the service technician can replace the appropriate ECU-box easily because all the functionality is located in the same place. In an AUTOSAR compliant system there is no easy way to know which box to replace or even if it is enough to replace just one. This means that auto mechanics will have to master the art of computer software, becoming computer technicians as well.

A big incitement for creating large vehicle corporations has in the past been that a lot of the systems and solutions can be reused in different car models all of which have essentially the same base model. As an example the VW group owns many brands all producing similar standard cars; VW, SEAT, Skoda and AUDI have a very similar range in small and medium sized segments. Instead of developing a completely new model for each make a common platform is developed and the final touch and finish is varied depending on which brand it is being produced as. As was stated in previous chapters, the share of E/E in terms of new added value might be as much as 90% and that the industry realizes that sharing the cost for the basic infrastructure would be a good idea. One argument is that if the lion's share of new development is in E/E and a lot of this will be done in a more public fashion, the gain of having large corporations to reduce development costs might be a thing of the past.

## 8.3 Future Work

**Programming**

The ability to write to non-volatile memory was left out of the implementation. AUTOSAR and Arctic Core have defined means of doing this, but currently reprogramming is left out of the XCP in AUTOSAR specification. This does not necessarily hinder adding support for this in the Arctic Core framework or for a specific device. It also seems likely that a future updated AUTOSAR XCP specification might include XCP as a means for reprogramming devices.

**Protocols**

The big advantage with XCP over CCP is the possibility to run the same protocol over different transport layers. As the project stands today the only available transport is CAN and to some extent Ethernet. A logical continuation would be to implement the remaining transport layers. This depends on how the development of Arctic Core progresses, if it is to be an AUTOSAR module it must use interfaces that are yet to be included in Arctic Core.

**Master**

For some of QRtech's customers the tools used in this project are considered to be too expensive. They are very advanced with a lot of functionality which might not be used on a regular basis, at least not in smaller application areas. A long term extension of the XCP project for QRtech could be to create an XCP master application. The shape and form of such an implementation is of course open to debate; but one option would be to base it on another tool that many customers already have e.g. Matlab. This would allow for simple installation and reduced development time as a lot of the framework would already be in place. It must however be emphasized that such a task, that of writing an XCP master, is considerably larger than the original project i.e. the protocol implementation.

# 9 References


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# Appendix A – Thesis proposal

QRTECH
INNOVATIVE ENGINEERING

## Exjobb - AUTOSAR Measurement And Calibration

*QRTECH är ett framgångsrikt produktutvecklingsbolag specialiserat på utveckling och industrialisering av produkter som innehåller elektronik, kraftelektronik och mjukvara. Med lång erfarenhet från fordonsindustrin och egen forskning som bas expanderar vi nu kraftigt inom industri-, medicin- och energitillämpningar.*
*Lösningarna innehåller teknik inom ett brett spektra där styrelektronik, elmotorstyrning, batteristyrning, grafiska displayer och många typer av trådlös och trådbunden kommunikation är exempel.*

Målet med exjobbet är att i C-kod implementera och verifiera valda delar av Universal Measurement and Calibration Protocol (XCP). XCP används bl.a. för att kalibrera miljöpåverkande parametrar i motorstyrsystem i fordon.
Koden skall köras på Arccores AUTOSAR plattform (Artic Core) som stöder ett inbyggt system utvecklat av QRTECH med bl.a. en PowerPC-processor, CAN och Ethernet.
Verktygsuppsättningen är baserad på Eclipse och GNU.

Arbetet består av:

- Studier av AUTOSAR, Arccores implementation samt XCP
- Urval av XCP-tjänster
- Implementation av valda XCP-tjänster över CAN och Ethernet (TCP/IP)
- Verifiering av implementationen
- Dokumentation av arbetet

Exjobbet är på mastersnivå och skall bedrivas av 2 personer med start så snart som möjligt.
Arbetet bedrivs i huvudsak i QRTECHs lokaler i Kallebäck.
Vi kan eventuellt matcha enskilda sökanden med varandra.

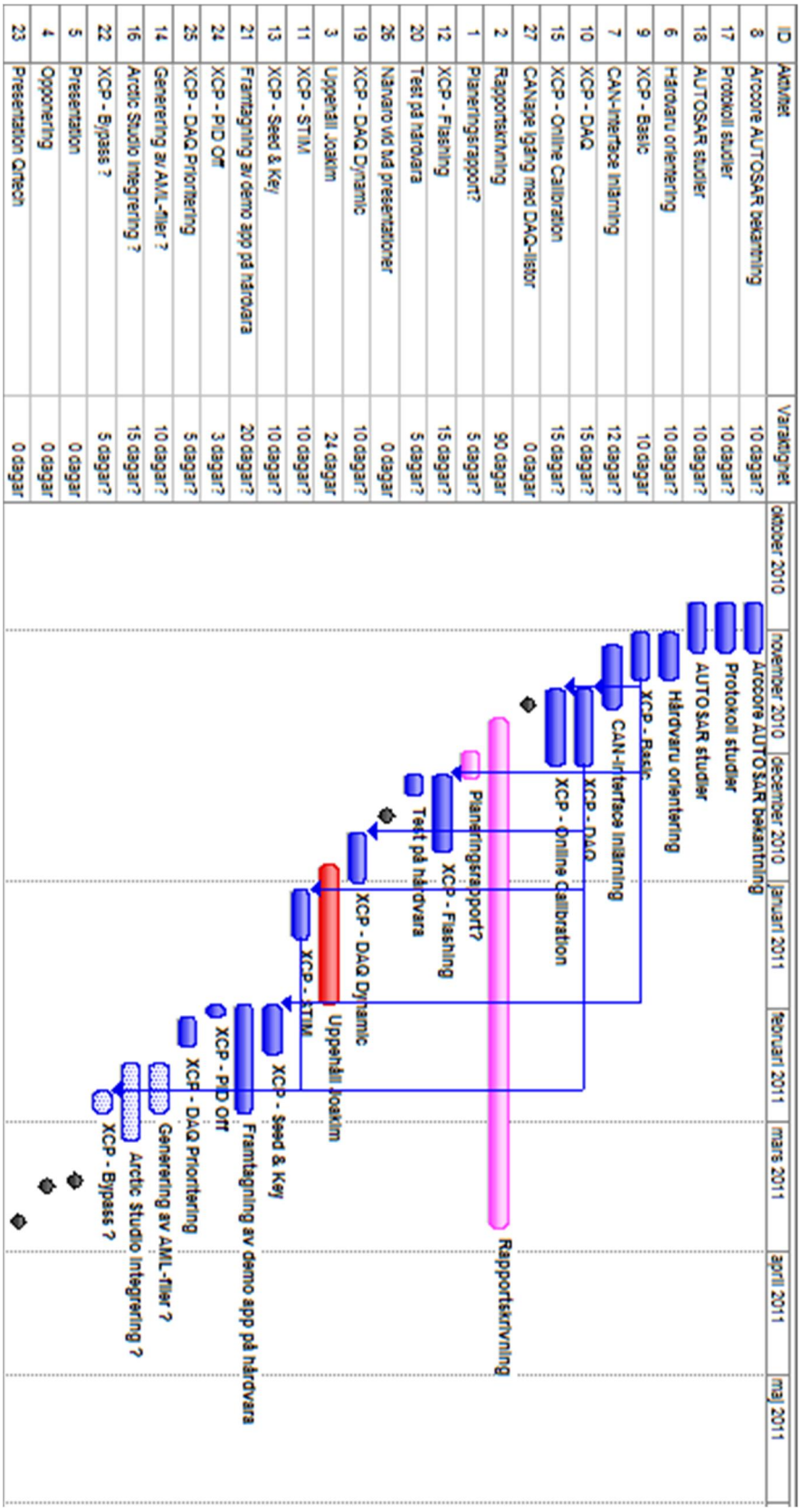
Skicka med CV och betyg vid ansökan.
För mer information samt ansökan, kontakta:

Joacim Bergman
E-mail: joacim.bergman@qrtech.se
Phone: 0708-246034

**Arctic Core** is the world's most advanced open source platform for embedded systems. It is a module-based platform complying with the **AUTOSAR** standard, embraced by all major manufacturers in the automotive industry.
För mer information, se www.arccore.com

**Universal Measurement and Calibration Protocol** (XCP) originates from the "Association for Standardization of Automation and Measuring Systems" (ASAM) and was standardized in 2003.
För mer information, se www.autosar.org/download/R4.0/AUTOSAR_SRS_XCP.pdf

# Appendix B – Time plan



# Appendix C – Readme for XCP AUTOSAR module

```
***************** XCP - Calibration and Measurement Protocol ******************

XCP is a Calibration and Measurement protocol for use in embedded systems.
It's a generalization of the previously existing CCP (CAN Calibration Protocol)
This implementation is designed for integration in an AUTOSAR project. It
follows AUTOSAR 4.0 XCP specification but support integration into an
AUTOSAR 3.0 system.

The requirements on the AUTOSAR infrastructure is limited, thus creating
"emulation" functions to use the XCP module standalone is not a major
hurdle for integration.

Module support both static an dynamically configured DAQ lists, with
dynamic DAQ lists the easier of the two to configure. It also support
predefined DAQ lists when in dynamic mode in preparation for RESUME
more support.

There is support for reading and writing directly in memory on the device
as well as a abstraction layer for memory to allow reading/writing
directly to ports or user defined data.

Module support multi threaded execution of data receive callbacks
and main functions as long as a global mutex or interrupt disabling
routine exists. It's only locked for very short periods of time
during addition or removal of packets from queues. (the code should
suite itself well for being replaced with a lockless alternative
with atomic operations instead).

Support Seed and Key protection for the different features of
XCP.

 LIMITATIONS
-------------

* Lack of page switching support for Online Calibration means it can
be a bit error prone if large or multiple variables need to be modified
while ECU is executing, since there is a risk it will sample the values
while XCP is writing parts of them.

* Currently in dynamic DAQ list configuration we malloc/free the number
of DAQ's. This should probably be made into some internal pool of
memory that can be configured at compile time. The requirements
of how dynamic DAQ lists are allocated and released makes this internal
HEAP reasonably simple to implement.

* No support for RESUME mode, ECU Programming and PID off.

* Interleaved mode is only partially tested since it
is not allowed over the CAN protocol.

* Only simple checksum support is implemented

 INTEGRATION
-------------

To integrate XCP in a AUTOSAR project add the XCP code files to your project as
a subdirectory. Make sure the subdirectory is in your C include path, as well
as that all the .c files are compiled and linked to your project. There is
no complete makefile included in the project.

The application must call Xcp_MainFunction() at fast
regular intervals to process incoming packets and send queued
packets out onto the actual transport protocol. [This will be
automatically taken care of when Arctic Core get XCP support
built in]

Arctic Core:
    Add the Xcp.mk file as an include directive to your projects makefile
    this should make use of Arctic Core build system to build XCP as a part
```

```
    of your project. [Currently this will default to CAN interface]

Standalone:
    Somewhat more complicated since it requires creation of a few headers
    to emulate AUTOSAR functionality, as well as hooking XCP up to a
    communication bus (Ethernet or CAN)

    XCP communicate with the actual protocol layer through two defined
    entry points Xcp_<protocol>RxIndication and <protocol>_Transmit, where
    <protocol> is either SoAdIf or CanIf depending on what underlying
    protocol is in use. For example for TCP/UDP the application needs to
    read first byte to get packet length and then pass this complete
    packet to XCP.

    For timestamp support the system also need to provide:
        StatusType GetCounterValue( CounterType, TickRefType );

    You also need to provide implementation for a global mutex locking:
        void XcpStandaloneLock();
        void XcpStandaloneUnlock();


 CONFIGURATION
---------------

All configuration of the module is done through the Xcp_Cfg.h and Xcp_Cfg.c file.
These files could be automatically generated from AUTOSAR xml files or manually
configured.


Xcp_Cfg.h defines:
    XCP_PDU_ID_TX:
        The PDU id the Xcp submodule will use when transmitting data using
        CanIf or SoAd.

    XCP_PDU_ID_RX:
        The PDU id the XCP sub module will expect data on when it's callbacks
        are called from CanIf or SoAd.

    XCP_CAN_ID_RX:
        If GET_SLAVE_ID feature is wanted over CAN, XCP must know what CAN id it
        is receiving data on.

    XCP_PDU_ID_BROADCAST:
        If GET_SLAVE_ID feature is wanted over CAN, XCP must know what PDU id it
        will receive broadcasts on

    XCP_E_INIT_FAILED:
        Error code for a failed initialization. Should have been defined
        by DEM.

    XCP_COUNTER_ID:
        Counter id for the master clock XCP will use when sending DAQ lists
        this will be used as an argument to AUTOSAR GetCounterValue.

    XCP_TIMESTAMP_SIZE:
        Number of bytes used for transmitting timestamps (0;1;2;4). If clock
        has higher number of bytes, XCP will wrap timestamps as the max
        byte size is reached. Set to 0 to disable timestamp support

    XCP_IDENTIFICATION:
        Defines how ODT's are identified when DAQ lists are sent. Possible
        values are:
            XCP_IDENTIFICATION_ABSOLUTE:
                All ODT's in the slave have a unique number.
            XCP_IDENTIFICATION_RELATIVE_BYTE:
            XCP_IDENTIFICATION_RELATIVE_WORD:
            XCP_IDENTIFICATION_RELATIVE_WORD_ALIGNED:
                ODT's identification is relative to DAQ list id.
                Where the DAQ list is either byte or word sized.
                And possibly aligned to 16 byte borders.

        Since CAN has a limit of 8 bytes per packets, this will
        modify the limit on how much each ODT can contain.
```

```
    XCP_MAX_RXTX_QUEUE:
        Number of data packets the protocol can queue up for processing.
        This should include send buffer as well as STIM packet buffers.
        This should at the minimum be set to
            1 receive packet + 1 send packet + number of DTO objects that
            can be configured in STIM mode + allowed interleaved queue size.

    XCP_FEATURE_DAQSTIM_DYNAMIC: (STD_ON; STD_OFF)   [Default: STD_OFF]
        Enables dynamic configuration of DAQ lists instead of
        statically defining the number of lists as well as their
        number of odts/entries at compile time.

    XCP_FEATURE_BLOCKMODE: (STD_ON; STD_OFF)   [Default: STD_OFF]
        Enables XCP blockmode transfers which speed up Online Calibration
        transfers.

    XCP_FEATURE_PGM: (STD_ON; STD_OFF)   [Default: STD_OFF]
        Enables the programming/flashing feature of XCP
        (NOT IMPLEMENTED)

    XCP_FEATURE_CALPAG: (STD_ON; STD_OFF)   [Default: STD_OFF]
        Enabled page switching for Online Calibration
        (NOT IMPLEMENTED)

    XCP_FEATURE_DAQ: (STD_ON; STD_OFF)   [Default: STD_OFF]
        Enabled use of DAQ lists. Requires setup of event channels
        and the calling of event channels from code:
            Xcp_MainFunction_Channel()

    XCP_FEATURE_STIM (STD_ON; STD_OFF)  [Default: STD_OFF]
        Enabled use of STIM lists. Requires setup of event channels
        and the calling of event channels from code:
            Xcp_MainFunction_Channel()

    XCP_FEATURE_DIO (STD_ON; STD_OFF)   [Default: STD_OFF]
        Enabled direct read/write support using Online Calibration
        to AUTOSAR DIO ports using memory extensions:
                0x2: DIO port
                0x3: DIO channel
        All ports are considered to be of sizeof(Dio_PortLevelType)
        bytes long. So port 5 is at memory address 5 * sizeof(Dio_PortLevelType)
        Channels are of BYTE length.

    XCP_FEATURE_GET_SLAVE_ID (STD_ON; STD_OFF)   [Default: STD_OFF]
        Enable GET_SLAVE_ID support over the CAN protocol.
        Needs the following additional config:
            XCP_PDU_ID_BROADCAST
            XCP_CAN_ID_RX

    XCP_FEATURE_PROTECTION:
        Enables seed and key protection for certain features.
        Needs configured callback functions in XcpConfig for
        the seed calculation and key verification.

    XCP_MAX_DTO: [Default: CAN=8, IP=255]
    XCP_MAX_CTO: [Default: CAN=8, IP=255]
        Define the maximum size of a data/control packet. This will also
        directly affect memory consumptions for XCP since the code will
        always allocate XCP_MAX_DTO * XCP_MAX_RXTX_QUEUE bytes for
        data buffers.


Xcp_Cfg.c:
    Should define a complete Xcp_ConfigType structure that then
    will be passed to Xcp_Init().

    Example config with two event channels and dynamic DAQ lists
    follows below. The application should call Xcp_Mainfunction_Channel(0)
    once every 50 ms and Xcp_Mainfunction_Channel(1) once every second.


    ***************
```

```
        #define COUNTOF(a) (sizeof(a)/sizeof(*(a)))

        static Xcp_DaqListType* g_channels_daqlist[2][253];

        static Xcp_EventChannelType g_channels[2] = {
            {   .XcpEventChannelNumber              = 0
              , .XcpEventChannelMaxDaqList          = COUNTOF(g_channels_daqlist[0])
              , .XcpEventChannelTriggeredDaqListRef = g_channels_daqlist[0]
              , .XcpEventChannelName                = "Default 50MS"
              , .XcpEventChannelRate                = 50
              , .XcpEventChannelUnit                = XCP_TIMESTAMP_UNIT_1MS
              , .XcpEventChannelProperties          = 1 << 2 /* DAQ  */
                                                    | 0 << 3 /* STIM */
            },
            {   .XcpEventChannelNumber              = 1
              , .XcpEventChannelMaxDaqList          = COUNTOF(g_channels_daqlist[1])
              , .XcpEventChannelTriggeredDaqListRef = g_channels_daqlist[1]
              , .XcpEventChannelName                = "Default 1S"
              , .XcpEventChannelRate                = 1
              , .XcpEventChannelUnit                = XCP_TIMESTAMP_UNIT_1S
              , .XcpEventChannelProperties          = 1 << 2 /* DAQ  */
                                                    | 1 << 3 /* STIM */
            }
        };

        Xcp_ConfigType g_DefaultConfig = {
            .XcpEventChannel  = g_channels
          , .XcpSegment       = g_segments
          , .XcpInfo          = { .XcpMC2File = "XcpSer" }
          , .XcpMaxEventChannel = COUNTOF(g_channels)
          , .XcpMaxSegment      = COUNTOF(g_segments)

        };

    ****************

Seed & Key:
    To support Seed & Key you need to provide two functions to the config structure
    (XcpSeedFn and XcpUnlockFn) the seed function (XcpSeedFn) should populate the
    supplied buffer with a seed which will be transmitted to the master for it
    to calculate a key from.

    After the master have replied with the key, XcpUnlockFn will be called with the
    seed and key to verify access. If successfull the protected resource will be unlock
    during this session.

    Example for seed and key functions which just accept an identical reply of the seed:
    *****************
        static uint8 GetSeed(Xcp_ProtectType res, uint8* seed)
        {
            strcpy((char*)seed, "HELLO");
            return strlen((const char*)seed);
        }

        static Std_ReturnType Unlock(Xcp_ProtectType res, const uint8* seed, uint8 seed_len,
                                     const uint8* key, uint8 key_len)
        {
            if(seed_len != key_len)
                return E_NOT_OK;
            if(memcmp(seed, key, seed_len))
                return E_NOT_OK;
            return E_OK;
        }
    *****************



 CANAPE
--------

    Advanced settings:
        DAQ_COUNTER_HANDLING: Include command response
            Oddly CANAPE defaults to not expecting CTR value of tcp slave packets
            to be incremented by RES packets and the like which the specification
```

```
    says they should be. At least they allow you to follow spec.
DAQ_PRESCALER_SUPPORTED: Yes
    Implementation support prescaler
```