

ICOtronic Documentation

MyTooliT

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1 Documentation

This repository collects various documentation for the ICOTronic system.

2 Download

You can access this repository and its submodules using the following command:

```
git clone --recursive git@github.com:MyToolIT/Documentation.git
```

3 Build

You can use bookdown to generate

- HTML,
- EPUB, and
- PDF

versions of this documentation. To do that please use the following make commands:

```
# Generate HTML documentation
make html

# Generate PDF
make pdf

# Generate EPUB document
make epub
```

4 Akronyms

- **AEM**: Advanced Energy Monitoring
- **BP**: Byte Position
- **CAN**: Controller Area Network
- **CAN-FD**: CAN Flexible Data Rate
- **CSMA/CD**: Carrier Sense Multiple Access/Collision Detection
- **CSMA/CR**: Carrier Sense Multiple Access/Collision Resolution
- **DLC**: Data Length Code
- **ECU**: Electronic Control Units
- **ESD**: Electro Statical Discharge

- **GD1:** Graceful Degradation Level 1
- **GD2:** Graceful Degradation Level 2
- **MSB:** Most Significant Byte
- **SHA:** Sensory Holder Assembly
- **STH:** Sensory Tool Holder
- **STU:** Stationary Transceiver Unit

5 Terms

- **Event (Message):** Even messages transport information about signals and events/states
- **Header:** Supplemental data placed at the beginning of a block
- **Jitter:** Difference between best-case time and worst-case time
- **Node:** Self-contained unit that interacts with other nodes via the MyTooliT communication protocol
- **Payload:** Transmitted user data
- **Trailer:** Terminating part of a message; May support check functionality

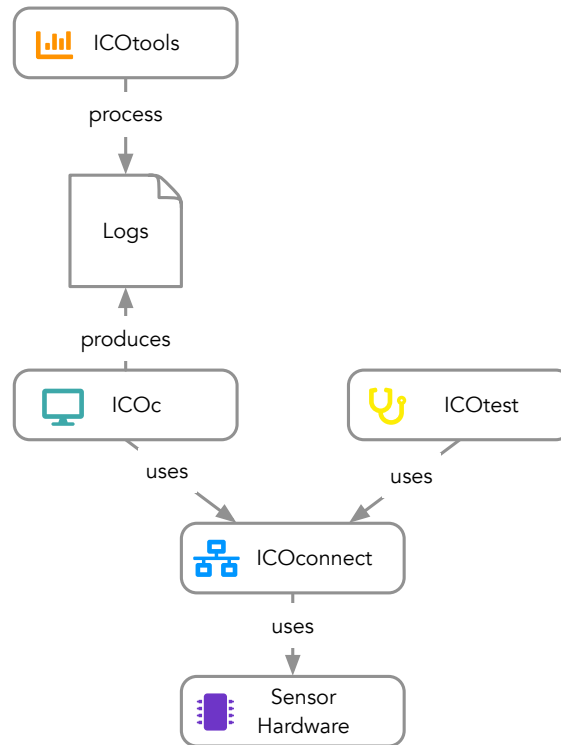
6 Overview ICOTronic System

The text below describes how the (lower levels) of the ICOTronic system *should work*. Currently the system works similarly, but

- the communication interface (ICOconnect),
- the tests (ICOTest), and
- the user interface (ICOc)

are all part of a single monolithic code base.

- **ICOconnect**
 - Python package for CAN access to sensor hardware
 - Based on MyTooliT Communication protocol
 - Ideally available online (via PyPi) (requires opening up the code)
- **ICOc**
 - Uses ICOconnect to communicate with sensor hardware
 - User interface for sensor hardware
 - Configures STH/STU attributes (e.g. name, sampling frequency)
 - Records data (e.g. acceleration values) as log files
- **ICOTest**
 - Uses ICOconnect to communicate with sensor hardware
 - Test environment for sensor hardware (STH, STU)
 - Tests if the hardware works correctly
- **ICOtools**
 - Scripts that use data stored by ICOc to analyze captured data



7 EEPROM

7.1 Terms

- Little Endian: Store the least significant byte (LSB) at the first (smallest) memory address and the most significant byte (MSB) at the last (highest) memory address

7.2 Layout

- Every page consists of 256 bytes
- The address of a page is the page number multiplied by 256

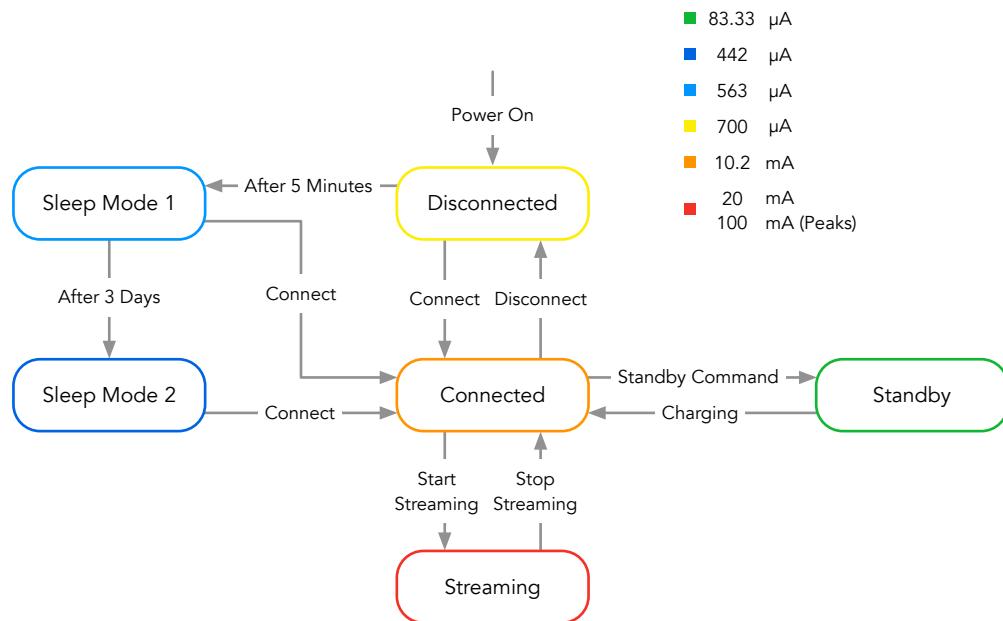
7.2.1 Pages:

Page Number	Name	Description
0	System Configuration	Store system specific data e.g. Bluetooth name and advertisement time
4	Product Data	Store product data e.g. serial number
5	Statistics	Store statistic data e.g. power on/off cycles
8	Calibration	Store configuration data like slope (k) and offset (d) values to derive SI value from ADC value

7.2.1.1 Page System Configuration

Byte	Length	Name	Comment	Format	Unit
0	1	Init	• 0xac: Initialized • 0xca: Locked • Other Value: Uninitialized)	-	-
1	8	Radio Name	Bluetooth advertisement name	ASCII	-
9	4	Sleep Time 1	Little Endian	Unsigned	ms
13	2	Advertisement Time 1	Little Endian	Unsigned	ms
15	4	Sleep Time 2	Little Endian	Unsigned	ms
19	2	Advertisement Time 2	Little Endian	Unsigned	ms

7.2.1.1.1 Sleep & Advertisement Times



- Sleep Time 1: Time to switch from the Disconnected state to Sleep Mode 1 (low power usage)
- Sleep Time 2: Time switch from the Sleep Mode 1 state to Sleep Mode 2 (very low power usage)
- Advertisement Time 1: Advertisement time in Sleep Mode 1
- Advertisement Time 2: Advertisement time in Sleep Mode 2

7.2.1.1.2 Page Product Data

Byte	Length	Name	Comment	Format
0	8	Global Trade Identification Number (GTIN)	Little Endian	Unsigned
8	5	Hardware Revision: Reserved		—
13	1	Hardware Revision: Major		Unsigned
14	1	Hardware Revision: Minor		Unsigned
15	1	Hardware Revision: Patch		Unsigned
16	5	Firmware Version: Reserved		—
21	1	Firmware Version: Major		Unsigned
22	1	Firmware Version: Minor		Unsigned
23	1	Firmware Version: Patch		Unsigned

Byte	Length	Name	Comment	Format
24	8	Release Name		UTF-8
32	32	Serial Number		UTF-8
64	128	Product Name		UTF-8
192	64	OEM Free Use		-

7.2.1.2.1 Version Numbers

- Version numbers will look like this **Major.Minor.Patch** (e.g. 1.2.3)
- Major specifies the first digit of the version number (usually only increased for “breaking” changes)
- Minor specifies the second digit of the version number (usually only increased for “minor” changes)
- Patch specifies the third digit of the version number (usually increased for “bug fixes”)

7.2.1.2.2 Release Name This text specifies the code name of the STH/STU software release

7.2.1.2.3 Serial Number

- Place for manufacture serial number (derived from ISBN)
- Possible Layout:
 - Product Group
 - Subgroup
 - Manufacture ID
 - Product Number
 - Check Digit
- Currently unused

7.2.1.2.4 Product Name

- This text might be used to extend the serial Number
- Possible Use: URL that point to additional information
- Currently unused

7.2.1.2.5 OEM Free Use

- Manufacture specific information
- Format is free to choose

7.2.1.3 Page Statistics

Byte	Length	Name	Comment	Format	Unit
0	4	Power On Cycles	Little Endian	Unsigned	-
4	4	Power Off Cycles	Little Endian	Unsigned	-
8	4	Operating Time	Little Endian	Unsigned	s
12	4	Under Voltage Counter	Little Endian	Unsigned	-
16	4	Watchdog Reset Counter	Little Endian	Unsigned	-
20	4	Production Date: Year		ASCII	-
24	2	Production Date: Month		ASCII	-
26	2	Production Date: Day		ASCII	-
28	4	Batch Number	Consecutive number for manufactured devices	ASCII	-

7.2.1.3.1 Power On Cycles Please note, that a reset also counts as power on cycle

7.2.1.3.2 Under Voltage Counter Counts of under voltages that cause turn off state (brownout)

7.2.1.4 Page Calibration

Byte	Length	Name	Comment	Format
0	4	Acceleration X: Slope	Little Endian	Float
4	4	Acceleration X: Offset	Little Endian	Float
8	4	Acceleration Y: Slope	Little Endian	Float
12	4	Acceleration Y: Offset	Little Endian	Float
16	4	Acceleration Z: Slope	Little Endian	Float
20	4	Acceleration Z: Offset	Little Endian	Float
24	4	Voltage Battery: Slope	Little Endian	Float
28	4	Voltage Battery: Offset	Little Endian	Float
32	4	Voltage 2: Slope	Little Endian	Float
36	4	Voltage 2: Offset	Little Endian	Float
40	4	Voltage 3: Slope	Little Endian	Float
44	4	Voltage 3: Offset	Little Endian	Float
48	4	Internal Temperature: Slope	Little Endian	Float
52	4	Internal Temperature: Offset	Little Endian	Float
56	4	Temperature 2: Slope	Little Endian	Float
60	4	Temperature 2: Offset	Little Endian	Float
64	4	Temperature 3: Slope	Little Endian	Float
68	4	Temperature 3: Offset	Little Endian	Float

7.2.1.4.1 Slope & Offset The values slope (k) and offset (d) specify the values in the equation for the linear function:

$$y = f(x) = k \cdot x + d$$

8 EEPROM-STH

This file contains the default values of the STH EEPROM. For a more detailed description of the values, please take a look at the description of the EEPROM layout.

8.1 Used Pages

Page Number	Page Name
0x0	System Configuration
0x4	Product Data
0x5	Statistics
0x8	Calibration

8.1.1 Page System Configuration

Name	Address	Length	Read Only	Value	Comment	Unit	Format
EEPROM Status	0	1	True	0xac	Value for initialized EEPROM	-	
STH Name	1	8	False	Base64 encoded Bluetooth MAC address or firmware name	e.g. CGvXAd6B (08:6b:d7:01:de:81), 8 Tanja	-	UTF-
Sleep Time 1	9	4	False	300000	5 minutes	ms	Unsigned
Advertisen Time 1	13	2	False	2000	2 seconds	ms	Unsigned
Sleep Time 2	15	4	False	259200000	3 days	ms	Unsigned
Advertisen Time 2	19	2	False	4000	4 seconds	ms	Unsigned

8.1.1.1 Initialization All of the values of the system configuration are set to default values on reset of the STH, if the EEPROM status (byte) is **not** set to **Initialized** (0xac) or **Locked** (0xca). The default values are described above. The name is set to the firmware version name (**Tanja**) and does not use the Base64 encoded Bluetooth MAC address.

8.1.2 Page Product Data

Name	Address	Length	Read Only	Value	Format
GTIN	0	8	True	0	Unsigned
Hardware Revision: Major	13	1	False	-	Unsigned
Hardware Revision: Minor	14	1	False	-	Unsigned
Hardware Revision: Patch	15	1	False	-	Unsigned
Firmware Version: Major	21	1	False	-	Unsigned
Firmware Version: Minor	22	1	False	-	Unsigned
Firmware Version: Patch	23	1	False	-	Unsigned
Release Name	24	8	False	Tanja	UTF-8
Serial Number	32	32	True	0	UTF-8
Product Name	64	128	True	0	UTF-8
OEM Free Use	192	64	True	0	-

8.1.2.1 Version Numbers

- **Hardware Revision:** This number depends on the hardware revision (printed on the PCB). The value itself can be changed in the main configuration file of ICOC
- **Firmware Version:** This number depends on the current STH software version
- **Release Name:** This text can be changed in the configuration of ICOC
- **Serial Number:** This text can be changed in the configuration of ICOC
- **Product Name:** This text can be changed in the configuration of ICOC
- **OEM Free Use:** This value can be changed in the configuration of ICOC.

8.1.3 Page Statistics

Name	Address	Length	Read Only	Value	Unit	Format
Power On Cycles	0	4	True	0	-	Unsigned
Power Off Cycles	4	4	True	0	-	Unsigned
Operating Time	8	4	True	0	s	Unsigned
Under Voltage Counter	12	4	True	0	-	Unsigned
Watchdog Reset Counter	16	4	True	0	-	Unsigned
Production Date: Year	20	4	False	-	-	ASCII
Production Date: Month	24	2	False	-	-	ASCII
Production Date: Day	26	2	False	-	-	ASCII
Batch Number	28	4	True	-	-	Unsigned

- **Production Date:** This date depends on the production date of the STH (printed on the PCB). It can be changed in the configuration of ICOC.
- **Batch Number:** This value can be changed in the configuration of ICOC.

8.1.4 Page Calibration

Name	Address	Length	Read Only	Value	Format
Acceleration X: Slope	0	4	False	-	Float
Acceleration X: Offset	4	4	False	-	Float

8.1.4.1 Acceleration

- **Acceleration X: Slope:** A Acceleration increase for a single step according to the following formula:

$$\frac{a_{max}}{ADC_{max}}$$

Here

- a_{max} is the maximum acceleration difference (e.g. 200 for a ± 100 g sensor)
- ADC_{max} is the maximum value of the ADC (e.g. 65533 ($= 2^1$) for a 16-bit analog-digital converter)

- **Acceleration X: Offset:** The negative offset of the acceleration value according to the following formula

$$-\frac{a_{max}}{2}$$

Here a_{max} is the maximum acceleration difference (e.g. 100 for a ± 50 g sensor)

9 EEPROM-STU

This file contains the default values for the STU EEPROM. For a more detailed description of the values, please take a look at the description of the EEPROM layout.

9.1 Used Pages

Page Number	Page Name
0x0	System Configuration
0x4	Product Data
0x5	Statistics

9.1.1 Page System Configuration

Name	Address	Length	Read Only	Value	Comment	Unit	For
EEPROM Status	0	1	True	0xac	Value for initialized EEPROM	-	
STH Name	1	8	False	Firmware version name	e.g. Valerie	-	UT

9.1.1.1 Initialization All of the values of the system configuration are set to the default values above on reset of the STU, if the EEPROM status (byte) is **not** set to **Initialized** (0xac) or **Locked** (0xca). The values for the sleep times and advertisement times are set (to the same values the STH uses) on initialization too. However, since the STU is not battery-powered these timing values are probably not relevant.

9.1.2 Page Product Data

Name	Address	Length	Read Only	Value	Format
GTIN	0	8	True	0	Unsigned
Hardware Revision: Major	13	1	True	-	Unsigned
Hardware Revision: Minor	14	1	True	-	Unsigned
Hardware Revision: Patch	15	1	True	-	Unsigned
Firmware Version: Major	21	1	True	-	Unsigned
Firmware Version: Minor	22	1	True	-	Unsigned
Firmware Version: Patch	23	1	True	-	Unsigned
Release Name	24	8	True	Valerie	UTF-8
Serial Number	32	32	True	0	UTF-8
Product Name	64	128	True	0	UTF-8
OEM Free Use	192	64	True	0	-

9.1.2.1 Version Numbers

- **Hardware Revision:** This number depends on the hardware revision (printed on the PCB). The value itself can be changed in the main configuration file of ICOC
- **Firmware Version:** This number depends on the current STU software version
- **Release Name:** This text can be changed in the configuration of ICOC
- **Serial Number:** This text can be changed in the configuration of ICOC
- **Product Name:** This text can be changed in the configuration of ICOC
- **OEM Free Use:** This value can be changed in the configuration of ICOC.

9.1.3 Page Statistics

Name	Address	Length	Read Only	Value	Unit	Format
Power On Cycles	0	4	True	0	-	Unsigned
Power Off Cycles	4	4	True	0	-	Unsigned

Name	Address	Length	Read Only	Value	Unit	Format
Operating Time	8	4	True	0	s	Unsigned
Under Voltage Counter	12	4	True	0	-	Unsigned
Watchdog Reset Counter	16	4	True	0	-	Unsigned
Production Date: Year	20	4	True	-	-	ASCII
Production Date: Month	24	2	True	-	-	ASCII
Production Date: Day	26	2	True	-	-	ASCII
Batch Number	28	4	True	-	-	Unsigned

- **Production Date:** This date depends on the production date of the STU. It can be changed in the configuration of ICOC.
- **Batch Number:** This value can be changed in the configuration of ICOC.

10 MyTooliT Communication Protocol

This document defines the MyTooliT network protocol. The MyTooliT network protocol exchanges information over data link layers like Bluetooth or Controller Area Network (CAN).

CAN (2.0) logically splits a message into

- a payload, and
- an identifier.

The identifier contains

- a sender field to define the node of origin of each message,
- a receiver field to define a message receiver, and
- the command number to
 - specify actions,
 - answers to actions,
 - or specify errors.

Each command, defined by its number, will be acknowledged via the same command number. A

- request bit defines request (acknowledgement) commands, and
- an error bit defines errors.

Please note that errors must not requested.

The MyTooliT communication protocol may also exchange information via Bluetooth. For that purpose CAN messages will be stored into the payload of a data link layer like Bluetooth. The identifier field is handled via a 4 byte header and the payload by an additional payload that follows each message header. Note that a message may have a larger payload than 8 bytes (up to 64 Bytes per message as defined by the CAN-FD specification) but the length is limited to 8 bytes, if CAN 2.0 is used in the transport chain.

The MyTooliT protocol can also use other data link layer formats like CAN-FD. For example, you can use the protocol for IP application because it is an end-to-end based network protocol.

10.1 Introduction

CAN was introduced by BOSCH in the 1980s in the automotive industry to exchange short real time messages between Electronic Control Units (ECU). Each ECU may act as a master i.e. send frames and thus each ECU may control the system

- by inserting error frames,
- acknowledging frames,
- sending information or
- processing information.

A standard base format (11 bit identifier) and an extended format (29 bit identifier) exist. The MyTooliT communication protocol is based on the extended format. The following figure describes the extended format:

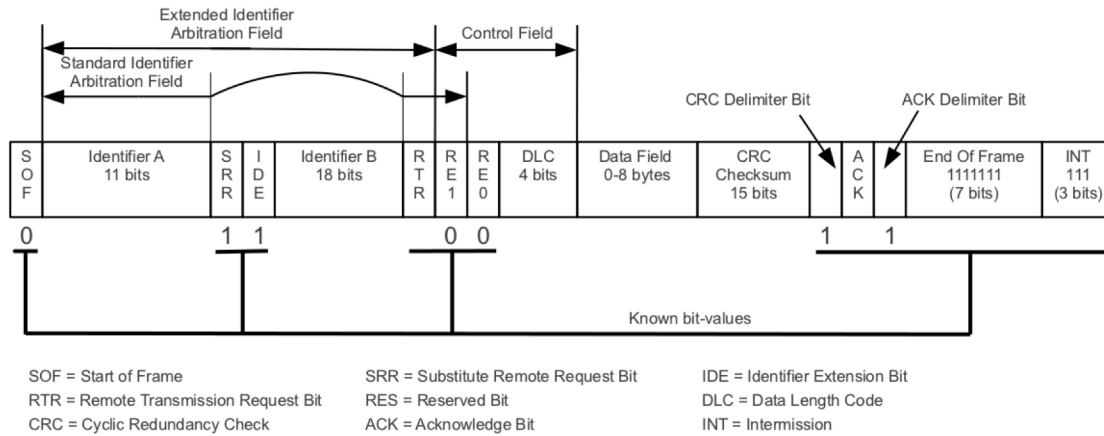


Figure 1: CAN Frame

For more information, please take a look at the Wikipedia article about CAN or other available literature (e.g. Experimental Framework for Controller Area Network based on a Multi-Processor-System-on-a- Chip).

A main feature of CAN are prioritized messages i.e. if two or more senders try to send messages simultaneously, the message with the highest priority (lowest identifier) will be sent instantly and the remaining ones afterwards (CSMA/CR).

This design requires that each message identifier must be unique (each sender has a set of messages) and subscribers must queue messages according to their priority.

The priority-based concept of messages is a key feature of the MyTooliT network protocol. The protocol uses CAN 2.0, Bluetooth and other data link layer protocols to transport messages between end nodes. Thus, MyTooliT transport messages between end nodes over diverse data link protocols. The flow control is managed by the prioritization of messages, the end-to-end-communication and by limiting the overall traffic to 40%/60% of the total bandwidth.

10.1.1 Reserved Bits

Reserved Bits must be transmitted as 0. This is required for compatibility.

10.2 Protocol Specification

Each CAN 2.0 frame consists of

- an identifier,
- a payload,
- a data length code (DLC), and
- physical transport bits.

The following figure shows the essential parts of an extended CAN 2.0 frame:

Identifier	DLC	Payload
29 Bits	4 Bits	0 – 8 Bytes

The

- identifier describes the message,
- the data length code stores the length of the payload (CAN 2.0: 0 – 8 Byte, CAN-FD 0 – 64 bytes), and
- the payload stores message data.

10.2.1 Identifier

	V	Command	R1	Sender	R2	Receiver
Bit	0	1 – 16	17	18 – 22	23	24 – 28

The following table describes the identifier field.

Field	Purpose
V	Version number • Must be 0 or the frame will be discarded
Command	Command to be executed or acknowledged
R1/R2	Reserved
Sender	Number of the original sender (frames may hop) • 0 Not allowed
Receiver	Number of the target receiver (frames may hop) • 0 broadcasts at field bus (local network) with ACK • 0x1F broadcasts at field bus(local network) without ACK

10.2.2 Command

	Command Number	A	E
Bit	0 – 13	14	15

The command number contains the command block and the block command:

Block	Block Command
0 – 5	6 – 13

The following table describes the whole command field.

Field	Purpose
Command	fill command blocks (6 Bit) • A command block supports up to 256 (8 Bit) block commands •
Number	Values: 1 – 16383 (14 bit), 0 is not valid • Commands are described here
A	Acknowledge field • 1 for a request • 0 for an acknowledgement Note that a single command may trigger multiple acknowledgements (streaming).
E	Error Bit • Indicates an error • 1 if it is an error • 0 if it is not an error • An error code is supported via the payload • The error format is 8 bytes long. The first byte describes the error number and the following 7 bytes are used for an error description. Furthermore, there are general errors (1 – 255) that are followed by 0 and specific errors that are followed by variable bits.

10.2.3 Abstracted CAN Messages

As mentioned in the introduction the MyTooliT protocol derives the priorities message concept from CAN 2.0. Therefore, the CAN header (identifier and DLC) are abstracted by a 4 byte header as described in the table below.

Note: The DLC0 bit is at position 0 and the command resides in the 2 bytes at the highest addresses.

Bit	Name	Description
0 – 3	Data Length Code (DLC)	Length of message as described by the CAN-FD standard
4 – 8	Receiver	End subscriber to be addressed as described in the Section “Identifier”
9	Reserved	Reserved
10 – 14	Sender	End subscriber that sends message as described in the Section “Identifier”
15	Reserved	Reserved
16 – 31	Command	Command as described in Section “Command Field”

The transport of messages over a data link layer (except CAN 2.0) are fulfilled by putting messages consisting of header and payload in a row up to the length of the data link layer payload. Each node manage the prioritization of messages in each send queue by a prioritized message queue.

10.2.4 Addressing

A network consists of two or more subscribers and each subscriber use a unique number (1 – 30; 0 = Broadcast with ACK; 31 = Broadcast without ACK) called address. The address targets a specific subscriber (or all subscribers). Note that the send number is important for the acknowledgement.

This addressing scheme yields an end-to-end management of the communication state i.e. the internal states of elements inside the end-to-end subscribers do not influence the logical communication state. Thus, only a single channel must be supported for a MyTooliT information exchange i.e. an incoming message that does not address the subscriber is discarded or forwarded. This means the MyTooliT commands can be used over other communication protocols like Bluetooth. Note that the simultaneous transport via CAN 2.0 may not be possible due to the replication of the sender and receiver (and the command) at the data link layer.

In the MyTooliT protocol the subscribers manage the error handling e.g. re-request something after a timeout. If that is not the case, then other counter measurements must be fulfilled.

The following figure shows the overall idea of network addressing.

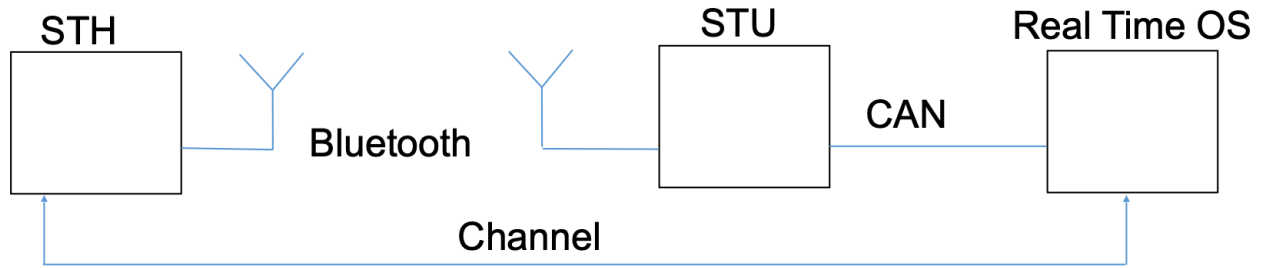


Figure 2: End To End Communication

10.2.5 DLC

The MyTooliT protocol uses the DLC as described the CAN-FD standard. The DLC must transfer over other protocols in the same format. Thus the DLC is limited by the data link layer i.e. requesting a command via CAN 2.0 and Bluetooth yields a limit of 8 bytes.

10.2.6 Payload

The payload transports user data and/or sub-payloads.

10.2.7 Startup an Backup Strategy

This is currently not implemented. CAN transmits at 1 MBit gross (gross bitrate: bitrate including physical protocol overhead) and Bluetooth transmits the payload at 1Mbit net (net bitrate: bitrate excluding physical protocol overhead). Note, that Bluetooth is a CSMA/CD protocol that will cause jitter without taking any other actions. Collisions also reduce the total bandwidth.

10.2.8 Transmission Speed

The transmission speed depends of the supported data link layer formats.

10.2.9 Bluetooth

The actual Bluetooth transmissions speed is 1 MBit gross. However, a message transmission might be delayed due to CSMA/CD. CSMA/CD prevents transmission, if an ongoing transport is in process in the corresponding transport frequency interval. Each collision delays the transport time exponentially. Note that simultaneously sending or any radio interference may destroy any radio frame and the actual Bluetooth configuration avoids re-requests at the protocol stack level (application must do this).

Bluetooth supports a net bandwidth of about 700 kBit if each frame is 255 bytes long. However, Bluetooth applications supports a maximum net bandwidth of about 420 kbit/s.

10.2.10 CAN 2.0

The transmission speed should be aligned to a maximum of 40% of the total bandwidth. However, in any case there must not be any higher utilization than 60% of the overall bandwidth. In the case of fair message distribution with many nodes and many sporadic messages, the limit should be a utilization of 40%. In cases with many permanent messages the limit may be set to 60%.

The 40% utilization for CAN2.0 with bit stuffing is calculated as follows:

$$U = \frac{m \cdot 79 + \sum_{m=0}^m (8 \cdot p_m + \lfloor p_m \cdot \frac{8}{5} \rfloor)}{B}$$

Here

- B is the gross bandwidth per second (e.g. 1Mbit/s),
- m is the overall number of send messages per second,
- p_m the payload length in bytes for each message and
- U is the overall utilization.

The 60% utilization without bit stuffing is calculated as follows:

$$U = \frac{m \cdot 67 + \sum_{m=0}^m (8 \cdot p_m)}{B}$$

The 40% utilization for CAN-FD with bit stuffing is calculated as follows:

$$U = \frac{m \cdot 79}{B_{ID}} + \frac{\sum_{m=0}^m (8 \cdot p_m + \lfloor p_m \cdot \frac{8}{5} \rfloor)}{B_p}$$

Here

- B_{ID} is the gross identifier bandwidth per second (e.g. 1Mbit/s), and
- B_p is the gross payload bandwidth per second (e.g. 8 Mbit/s).

The 60% utilization for CAN-FD without bit stuffing is calculated as follows:

$$U = \frac{m \cdot 67}{B_{ID}} + \frac{\sum_{m=0}^m (8 \cdot p_m)}{B_p}$$

Thus the bandwidth consumption for a streaming message (64 bytes payload each ms) calculates as follows at 1Mbit/8Mbit:

$$U_{Stuff} = \frac{1000 \cdot 79}{1000000} + \frac{1000 \cdot (512 + 102)}{8000000} = 0.079 + 0.07675 = 0.15575(15.6\%)$$

and

$$U = \frac{1000 \cdot 67}{1000000} + \frac{1000 \cdot 512}{8000000} = 0.067 + 0.064 = 0.131(13.1\%)$$

Alarm messages – they will be periodically repeated until muted or alarm off event occurs e.g. temperature drops under a certain limit after reaching certain alarm limit – and streaming messages are periodic messages.

Sporadic messages trigger on demand e.g. setting a program status word requires a request and an acknowledgement. The acknowledgement and the request are sporadic messages.

Sporadic messages should have a reserved bandwidth of at least 10% (in an alarm shower case, the alarm messages will be prioritized). An overload case must be handled at the application level e.g. turn off all streaming messages and go to a graceful degradation state or a fail-save state. Note that time triggered communication eliminates such cases because each message transmission is pre-scheduled.

11 Commands

11.1 Blocks

Block	Short Description	Extended Description
0x00	System	System commands are used to modify/request the state of each unit (e.g. reset) or an the overall system state (e.g. transmission speed)
0x04	Streaming	Streaming commands are used to transmit data streams, but may be also used for single requests. The super frame is also located in this block.
0x08	Statistical Data and Quantity	This command group is used to store statistical data that can be used for histograms such as operating time and the number of power on/off cycles
0x28	Configuration	This command block is used to set configuration data (e.g. you can set the sampling rate of acceleration data here).
0x3D	EEPROM	Used for writing and reading EEPROM data directly
0x3E	ProductData and RFID	Used to store product data like a serial number. Furthermore, this block provides access to RFID information that is supported via connected tools.
0x3F	Test	Test Config Page

11.2 Block System

Number	Block Command	Access	Permanently Stored
0x00	Verboten	–	–
0x01	Reset	Event	–
0x02	Get/Set State	Read/Write	–
0x05	Get Node Status	Read/Write	–
0x06	Get Error Status	Read/Write	–
0x0B	Bluetooth	Read	–

11.2.1 Command Verboten

This command is mainly used for initialization purposes

11.2.2 Command Reset

Reset the specified receiver. This command has no payload.

11.2.3 Command Get/Set State

- Not fully implemented
- Startup state determines operating state
- Standby state works

11.2.3.1 Values

- Get/Set State:

Value	Meaning
0	Get State
1	Set State

- Location:

Value	Meaning
0	No Change
1	Bootloader
2	Application
3	Reserved

- State:

Value	Meaning
0	Failure (No acknowledgement will be sent; Only power on resets this state)
1	Error (No active communication)
2	Turn Off/Standby
3	Graceful degradation level 2
4	Graceful degradation level 1
5	Operating
6	Startup
7	No change

- Error Reason:

Value	Meaning
1	Set state not available
2	Wrong subscriber (e.g. accessing application as bootloader)

11.2.3.2 Payload

Byte 1				
Bit 7	Bit 6	Bit 5 – 4	Bit 3	Bit 2 – 0
Get/Set State	Reserved	Location	Reserved	State

11.2.3.3 Acknowledgment Payload

Byte 1
0x08

11.2.3.4 Error Payload

Byte 2
Error Reason

11.2.4 Command Get Node Status

- Note that the state may not be set instantly.
- The node status word is defined differently for STH and STU
- STH node status word:

```
typedef union
{
    struct
    {
        uint32_t bError :1; /**< Error or healthy */
        uint32_t u3NetworkState :3; /**< Which state has node in the network */
        uint32_t Reserved :28; /**< Reserved */
    };
    uint32_t u32Word;
    uint8_t au8Bytes[4U];
} NodeStatusWord_t;
```

- STU node status word:

```
struct
{
    uint32_t bError :1; /**< Indicates an overall Error */
    uint32_t u3NetworkState :3; /**< Which state has node in the network */
    uint32_t bEnabledRadio :1; /**< Radio port enabled(1) or disabled(0) */
    uint32_t bEnabledCan :1; /**< CAN port enabled(1) or disabled(0) */
    uint32_t bRadioActive :1; /**< Radio Active(Connected to Bluetooth) or not */
    uint32_t Reserved :25; /**< Reserved */
};
uint32_t u32Word;
uint8_t au8Bytes[4U];
} NodeStatusWord_t;
```

- Error Bit:

Value	Meaning
0	No Error
1	Error

- Network State:

Value	Meaning
0	Failure
1	Error
2	Standby
3	Graceful Degradation 2

Value	Meaning
4	Graceful Degradation 1
5	Operating
6	Startup
7	No Change

- Radio Port:

Value	Meaning
0	Radio Port Disabled
1	Radio Port Enabled

- CAN Port:

Value	Meaning
0	CAN Port Disabled
1	CAN Port Enabled

- Radio Activity:

Value	Meaning
0	Disconnected from Bluetooth
1	Connected to Bluetooth

11.2.4.1 Payload

- Setting the value 0 for the node status word mask means that we request the status word
- Currently the only supported payload should be 8 null (0x00) bytes

11.2.4.1.1 STH

Byte 1		
Bit 7 – 4	Bit 3 – 1	Bit 0
Reserved	Network State	Error Bit

11.2.4.1.2 STU

Byte 1					
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3 – 1	Bit 0
Reserved	Radio Activity	CAN Port Enabled	Radio Port Enabled	Network State	Error Bit

11.2.4.1.3 STH & STU

Byte 2
Reserved

Byte 3
Reserved

Byte 4
Reserved

Byte 5
Status Word Mask

Byte 6
Status Word Mask

Byte 7
Status Word Mask

Byte 8
Status Word Mask

11.2.4.2 Acknowledgement Payload

- Same structure as payload

11.2.4.3 Error Payload

- The (possibly incorrect) length of the status word (5 instead of 4 bytes) was taken from the original documentation.

Byte 1
Mask Used Not Allowed

Byte 4
Status Word

Byte 5
Status Word

Byte 6
Status Word

Byte 7
Status Word

Byte 8
Status Word

11.2.5 Command Get Error Status

- STH definition:

```
typedef union
{
    struct
    {
        uint32_t bTxBluetoothFail :1; /**< Tx Fail Counter for Bluetooth (non single set) */
        uint32_t bAdcOverRun :1; /**< Determines ADC over run (not able to shuffle data in time) */
        uint32_t Reserved :30;
    };
    uint32_t u32Word;
    uint8_t au8Bytes[4U];
} ErrorStatusWord_t;
```

- STU definition:

```
typedef union
{
    struct
    {
        uint32_t bTxCanFail :1; /**< Tx Fail Counter for CAN (non single set) */
        uint32_t Reserved :31; /**< DAC was not fed */
    };
    uint32_t u32Word;
    uint8_t au8Bytes[4U];
} ErrorStatusWord_t;
```

- Transmission Failure (Bluetooth for STH, CAN for STU):

Value	Meaning
0	No Transmission Failure
1	Transmission Failure

- ADC Overrun:

Value	Meaning
0	No ADC Overrun Error
1	ADC Overrun Error

11.2.5.1 Payload

- Setting the value 0 for the status word mask means that we request the error status word
- Currently the only supported payload should be 8 null (0x00) bytes

11.2.5.1.1 STH

Byte 1		
Bit 7 – 2	Bit 1	Bit 0
Reserved	ADC Overrun	Bluetooth Transmission Failure

11.2.5.1.2 STU

Byte 1	
Bit 7 – 2	Bit 0
Reserved	CAN Transmission Failure

11.2.5.1.3 STH & STU

Byte 2
Reserved

Byte 3
Reserved

Byte 4
Reserved

Byte 5
Status Word Mask

Byte 6
Status Word Mask
Byte 7
Status Word Mask
Byte 8
Status Word Mask

11.2.5.2 Acknowledgement Payload

- Same structure as payload

11.2.5.3 Error Payload

- Same structure as error payload for node status command

11.2.6 Command Bluetooth

- Bluetooth Subcommand

Value	Meaning
0	Reserved
1	Connect
2	Get number of available devices
3	Write device name #1 and set device name #2 to NULL
4	Write device name #2 and push it to STH (read will be equivalent in the future)
5	Read first part (6 bytes) of device name
6	Read second part (2 bytes) of device name
7	Connect to device (with device number)
8	Check if connected
9	Disconnect
10	Get send counter
11	Received RX frames
12	Absolute RSSI indicator (number must be interpreted as negative)
13	Read energy mode reduced
14	Write energy mode reduced
15	Read energy mode lowest
16	Write energy mode lowest
17	Bluetooth MAC address
18	Connect to device (with Bluetooth MAC address)

- **Device Number:** Sequential positive number assigned by STU to available STH nodes; For a single STH this number will be 0.
- **Bluetooth Value**

Bluetooth Subcommand	Value
0	–
1	–
2	–
3	ASCII string
4	ASCII string (NULL)
5	–
6	–
7	–
8	–
9	–
10	–
11	–
12	–
13	–
14	Byte 3 – 6: Time form normal to reduced energy mode in ms Byte 7 – 8: Advertisement time for reduced energy mode in ms Big endian
15	–
16	Byte 3 – 6: Time form reduced to lowest energy mode in ms Byte 7 – 8: Advertisement time for lowest energy mode in ms Little endian 0 = read
17	Byte 3: Value 255 (self addressing)

- Bluetooth Return Value

Bluetooth Subcommand	Value
0	NULL
1	NULL
2	ASCII string containing the number of available devices
3	ASCII string containing the first 6 characters of the Bluetooth advertisement name
4	ASCII string containing the last 2 characters of the Bluetooth advertisement name
5	ASCII string
6	ASCII string of connected device or NULL if not connected
7	NULL (Byte 3 is true if in search mode, at least single device was found, no legacy mode and scanning mode active; false otherwise)
8	NULL if not connected Not NULL otherwise
9	NULL
10	6 Byte unsigned int
11	6 Byte unsigned int
12	Byte 3: uint8_t deviceType Byte 4: int8_t Byte 5 – 8: NULL
13	Byte 3 – 6: Time form normal to reduced energy mode in ms Byte 7 – 8: Advertisement time for reduced energy mode in ms Big Endian
14	Byte 3 – 6: Time form normal to reduced energy mode in ms Byte 7 – 8: Advertisement time for reduced energy mode in ms Big Endian
15	Byte 3 – 6: Time form reduced to lowest energy mode in ms Byte 7 – 8: Advertisement time for lowest energy mode in ms Little Endian
16	Byte 3 – 6: Time form reduced to lowest energy mode in ms Byte 7 – 8: Advertisement time for lowest energy mode in ms Little Endian
17	Byte 3 – 6: Bluetooth MAC address in little endian format

11.2.6.1 Payload

Byte 1
Bluetooth Subcommand
Byte 2
Device Number
Byte 3 – 8
Bluetooth Value

Note: Use 0 bytes if Device Number or Bluetooth Value are not applicable (e.g. when you use the **Connect** command)

11.2.6.2 Acknowledgement Payload

Byte 1
Same as Payload
Byte 2
Same as Payload
Byte 3 – 8
Bluetooth Return Value

11.3 Block Streaming

Number	Block Command	Access	Permanently Stored
0x01	Acceleration	Event	–
0x20	Voltage	Event	–

11.3.1 Values

- The **Data Sets** bits used in the sections below can have the following values:

Value	Data Amount
0	Stop (stream)
1	1 data set
2	3 data sets
3	6 data sets

Value	Data Amount
4	10 data sets
5	15 data sets
6	20 data sets
7	30 data sets

The streaming data itself can have the following structure:

- value 1
- value 2
- value 3
- value 1 / value 2 / value 3
- value 1 / value 2
- value 1 / value 3
- value 2 / value 3

The chronological order starts with the oldest set (BP) and continues with newer values (BP + t), where t is the time point.

- **Request:**

Value	Meaning
0	Stream
1	Single Request

- **Bytes:**

Value	Meaning
0	2 Bytes for each data point
1	3 Byte for data point

- **Active**

Value	Meaning
0	Data for specified data point will not be measured/sent
1	Data for specified data point will be measured/sent

11.3.2 Command Acceleration

- Requesting while streaming is possible
- Only single stream allowed
- Requesting stream in different format stops last stream
- Tuple format (depending on active axis, see payload):
 - x/y/z
 - x/y
 - x/z
 - y/z

11.3.2.1 Payload

Byte 1					
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2 – 0
Request	Bytes	X-Axis Active	Y-Axis Active	Z-Axis Active	Data Sets

11.3.2.2 Acknowledgment Payload

Byte 1
Same as Payload

Byte 2
Sequence Counter

11.3.2.2.1 2 Byte Format

Byte 3
MSB (BP)

Byte 4
LSB (BP + 1)

11.3.2.2.2 3 Byte Format

Byte 3
MSB (BP)

Byte 4
(BP + 1)

Byte 5
LSB (BP + 2)

11.3.3 Command Voltage

11.3.3.1 Notes

- Highest voltage sampling rate determines bit stream rate
- Requesting while streaming is possible

11.3.3.2 Payload

Byte 1					
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2 – 0
Request	Bytes	Voltage 1 Active	Voltage 2 Active	Voltage 3 Active	Data Sets

11.3.3.3 Acknowledgment Payload The command uses the same format as the “Acknowledgment Payload” of the Acceleration command.

11.4 Block Statistical Data and Quantity

Number	Block Command	Access	Permanently Stored
0x00	Power On Cycles, Power Off Cycles	Read	x
0x01	Operating time	Read	x
0x02	Under Voltage Counter	Read	x
0x03	Watchdog Reset Counter	Read	x
0x04	Production Date	Read	x

11.4.1 Command Power On Cycles, Power Off Cycles

11.4.1.1 Notes

- Power off means power away e.g. Accumulator out of energy
- Power On includes resets

11.4.1.2 ACK Payload

Byte 1 (MSB) - Byte 4 (LSB)
Power On Cycles

Byte 5 (MSB) - Byte 8 (LSB)
Power Off Cycles

11.4.2 Command Operating time

11.4.2.1 Notes

- Seconds since first power are stored each half an hour
- The STH also stored seconds since reset in disconnect case.

11.4.2.2 ACK Payload

Byte 1 (MSB) - Byte 4 (LSB)
Seconds since reset

Byte 5 (MSB) - Byte 8 (LSB)
Seconds since first power on

11.4.3 Command Under Voltage Counter

11.4.3.1 ACK Payload

Byte 1 (MSB) - Byte 4 (LSB)
Under voltage counter since first power on

11.4.4 Command Watchdog Reset Counter

11.4.4.1 ACK Payload

Byte 1 (MSB) - Byte 4 (LSB)
Watchdog Resets since first power on

11.4.5 Command Production Date

11.4.5.1 ACK Payload

Byte 1 (MSB) - Byte 4 (LSB)
ASCII String of the Production Date in the format: yyyyymmdd where y=year, m=month, d=day

11.5 Block Configuration

Number	Block Command	Access	Permanently Stored
0x00	Get/Set Acceleration Configuration	Read/Write	x
0x60	Get/Set Calibration Factor k	Read/Write	x
0x61	Get/Set Calibration Factor d	Read/Write	x
0x62	Calibration Measurement	Read/Write	x
0xC0	HMI Configuration	Read/Write	x

11.5.1 Command Get/Set Acceleration Configuration

11.5.1.1 Notes

11.5.1.1.1 Sampling Rate

$$\frac{f_CLOCK}{(Prescaler + 1) \cdot (AcquisitionTime + 12 + 1) \cdot OverSamplingRate}$$

$$f_{clock} = 38400000Hz$$

11.5.1.1.2 Prescaler

- Byte2

11.5.1.1.3 Acquisition Time

- Sample and Hold Time i.e. Time to charge capacitor that is cut off and measured at digital quantisation
- $2^{(Byte3-1)}$ iff $Byte3 > AdcAcquisitionTime4$
- $(Byte3+2)$ iff $Byte3 \leq AdcAcquisitionTime4$

11.5.1.1.4 Over Sampling Rate

- 2^{Byte4} ; No Over Sampling if $Byte4=0$

11.5.1.1.5 ADC Reference Voltage

- 1V25
- 1V65
- 1V8
- 2V1
- 2V2
- 2V5
- 2V7
- 3V3(VDD)
- 5V
- 6V6

11.5.1.1.6 Setting at Reset

- $2/Acu8(4)/OverSampling64(6)/VDD$

11.5.1.2 Values

- Get/Set State:

Value	Meaning
0	Get State
1	Set State

11.5.1.3 Payload

Byte 1
Bit 7 Bit 6 – 0
Get/Set State Reserved
Byte 2
ADC Prescaler
Byte 3
Acquisition time (See Note)
Byte 4
Power of over sampling rate e.g. 10->1024 OverSampling Rate, 0=no Over Sampling
Byte 5
Reference: Voltage*20 e.g. 3.3V->66
Byte 6 - Byte 8
Reserved

11.5.1.4 Acknowledgment Payload

- Same structure as payload

11.5.2 Command Get/Set Calibration Factor k

11.5.2.1 Values

- Calibration Element:

Value	Meaning
0	Acceleration
1	Temperature
32	Voltage

- Number or axis:

Value	Meaning
0	Reserved
1	x-Axis / First measure point
2	y-Axis / Second measure point

Value	Meaning
3	z-Axis / Third measure point

- Get/Set Value:

Value	Meaning
0	Get Value
1	Set Value

11.5.2.2 Payload

Byte 1
Calibration Element

Byte 2
Number or axis

Byte 3	
Bit 7	Bit 6 – 0
Get/Set Value	Reserved

Byte 4
Reserved

Byte 5 (MSB) - Byte 8 (LSB)
k (Slope) according to IEEE 754 single precision (float) Calibration= $kx+d$ (Also calculation to SI value or any other value)

11.5.2.3 Acknowledgment Payload

Byte 1
Calibration Element

Byte 2
Number or axis

Byte 3
Reserved

Byte 4
Reserved

Byte 5 (MSB) - Byte 8 (LSB)
k (Slope) according to IEEE 754 single precision (float)Calibration= $kx+d$ (Also calculation to SI value or any other value)

11.5.3 Command Get/Set Calibration Factor d

Payload and Acknowledgment Payload have the same Structure as Get/Set Calibration Factor k but with d (Offset) instead of k (Slope) from $kx+d$.

11.5.4 Command Calibration Measurement

11.5.4.1 Values

- Calibration Get/Set:

Value	Meaning
0	Get (Ignores the remaining bits of this byte)
1	Set

- Calibration Method:

Value	Meaning
0	Reserved
1	Inject
2	Eject
3	Measure

- Calibration Measurement Element:

Value	Meaning
0	Acceleration
1	Temperature (for VREF=1250 temperature gets calculated to m°C)
32	Voltage
96	VSS(Ground)
97	VDD (Supply)
98	Regulated Internal Power
99	Operation Amplifier Output

- Dimension:

Value	Meaning
0	Reserved
1	1. Dimension(x)
2	2. Dimension(y)
3	3. Dimension(z)

11.5.4.2 Payload

Byte 1			
Bit 7	Bit 6 - Bit 5	Bit 4	Bit 3 - Bit 0
Calibration Get/Set	Calibration Method	Reset	Reserved

Byte 2
Calibration Measurement Element

Byte 3
Dimension

Byte 4
Reserved

Byte 5 - Byte 8
Reserved

11.5.4.3 Acknowledgment Payload

Byte 1 - Byte 4
Same as Payload

Byte 5 - Byte 8
Result

11.5.5 Command HMI Configuration

11.5.5.1 Values

- Get/Set Sampling Rate:

Value	Meaning
0	Get Sampling Rate
1	Set Sampling Rate

- LED:

Value	Meaning
0	Reserved
1	LED

- ON/OFF:

Value	Meaning
0	Reserved
1	On (Reset value)
2	Off

11.5.5.2 Payload

Byte 1	
Bit 7	Bit 6 - Bit 0
Get/Set Sampling Rate	LED

Byte 2
Number (0-255)

Byte 3
ON/OFF

Byte 4
Reserved

Byte 5 - Byte 8
Reserved

11.5.5.3 Acknowledgment Payload

- Same structure as payload

11.6 Block EEPROM

Number	Block Command	Access	Permanently Stored
0x00	EEPROM Read	Read	x
0x01	EEPROM Write	Write	x

11.6.1 Command EEPROM Read

11.6.1.1 Notes

- Used to read data from EEPROM directly

11.6.1.2 Payload

Byte 1	Byte 2	Byte 3	Byte 4 - Byte 8
Page	Offset	Length	Reserved

11.6.1.3 Acknowledgment Payload

Byte 1	Byte 2	Byte 3	Byte 4	Byte 5 - Byte 8
Page	Offset	Length	Reserved	Data

11.6.2 Command EEPROM Write

11.6.2.1 Notes

- Used to write data to EEPROM directly
- You are not allowed to change all values, if the EEPROM is locked (byte 0 is set to value 0xca)

11.6.2.2 Payload

Byte 1	Byte 2	Byte 3	Byte 4	Byte 5 - Byte 8
Page	Offset	Length	Reserved	Data

11.6.2.3 Acknowledgment Payload

- Same structure as payload

11.7 Block ProductData and RFID

Number	Block Command	Access	Permanently Stored
0x00	Global Trade Identification Number (GTIN)	Read	x
0x01	Hardware Revision	Read	x

Number	Block Command	Access	Permanently Stored
0x02	Firmware Version	Read	x
0x03	Release Name	Read	x
0x04 - 0x07	Serial Number 1-4	Read	x
0x08 - 0x17	Name 1-16	Read	x
0x18 - 0x1F	OEM Free Use 0-7	Read	x
0x80	Tool RFID product information	Read	-

11.7.1 Command Global Trade Identification Number (GTIN)

11.7.1.1 Acknowledgment Payload

- 8 Byte GTIN
- Format: uint64_t (unsigned int)
- MSB: Byte 0
- LSB: Byte 7

11.7.2 Command Hardware Revision

11.7.2.1 Acknowledgment Payload

- 8 Bytes totally
 - 5 Bytes Reserved
 - 1 Byte Major Revision
 - 1 Byte Minor Revision
 - 1 Byte Build Revision

11.7.3 Command Firmware Version

11.7.3.1 Acknowledgment Payload

- 8 Bytes totally
 - 5 Bytes Reserved
 - 1 Byte Major Revision
 - 1 Byte Minor Revision
 - 1 Byte Build Revision

11.7.4 Command Release Name

11.7.4.1 Acknowledgment Payload

- 8 Byte ASCII Code
- NULL terminated or 8 Byte long

11.7.5 Command Serial Number

11.7.5.1 Notes

Command	Purpose
0x04	Serial Number 1
0x05	Serial Number 2
0x06	Serial Number 3
0x07	Serial Number 4

11.7.5.2 Acknowledgment Payload

- UTF-8 String (8 Byte)

11.7.6 Command Name

11.7.6.1 Notes

- Multiple Strings in different languages possible

Command	Purpose
0x08	Name 1
0x09	Name 2
0x0A	Name 3
0x0B	Name 4
0x0C	Name 5
0x0D	Name 6
0x0E	Name 7
0x0F	Name 8
0x10	Name 9
0x11	Name 10
0x12	Name 11
0x13	Name 12
0x14	Name 13
0x15	Name 14
0x16	Name 15
0x17	Name 16

11.7.6.2 Acknowledgment Payload

- UTF-8 String (8 Byte)

11.7.7 Command OEM Free Use

11.7.7.1 Notes

Command	Purpose
0x18	OEM Free Use 0
0x19	OEM Free Use 1
0x1A	OEM Free Use 2
0x1B	OEM Free Use 3
0x1C	OEM Free Use 4

Command	Purpose
0x1D	OEM Free Use 5
0x1E	OEM Free Use 6
0x1F	OEM Free Use 7

11.7.7.2 Acknowledgment Payload

- 8 Byte

11.7.8 Command Tool RFID product information

11.7.8.1 Acknowledgment Payload

- to be determined

11.8 Block Test

Number	Block Command	Access	Permanently Stored
0x00	Reserved	-	-
0x01	Test signal	-	-

11.8.1 Command Test signal

11.8.1.1 Payload

11.8.1.1.1 Byte 1:

Value	Meaning
0	Reserved
1	Line
2	Ramp

11.8.1.1.2 Byte 2: Module (Module specific)

11.8.1.1.3 Byte 3-8: Module specific

11.8.1.2 Acknowledgment Payload

11.8.1.2.1 Byte 1:

Value	Meaning
0	Reserved
1	Line
2	Ramp

11.8.1.2.2 Byte 2-3: Module (Module specific)

11.8.1.2.3 Byte 4-8: Module specific

11.9 Errors

Value	Description	Example
0	Specific Error	
1	Not available	
2	General Error	
3	Write not allowed	Setting of memory area in word not allowed
4	Unsupported format	64 Byte Data via CAN2.0 is not possible
5	Wrong key/magic number	
6	No SuperFrame inside SuperFrame	
7	EEPROM defect	