USER MANUAL

TCM 515 – ENOCEAN TRANSCEIVER GATEWAY MODULE

TCM 515 / TCM 515U

EnOcean Transceiver Gateway Module

Observe precautions! Electrostatic sensitive devices!

Patent protected:
WO98/36395, DE 100 25 561, DE 101 50 128,
WO 2004/051591, DE 103 01 678 A1, DE 10309334,
WO 04/109236, WO 05/096482, WO 02/095707,
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TCM 515 – ENOCEAN TRANSCEIVER GATEWAY MODULE

REVISION HISTORY

The following major modifications and improvements have been made to this document:

Version	Author	Reviewer	Date	Major Changes
1.0	MKA	MK, CB	12.05.2017	First public release
1.1	MKA	MKA	22.05.2017	Added detailed antenna information
1.2	MKA	MH, MK	22.06.2017	Added receiver class due to RED requirement
1.3	OS	MKA	08.08.2017	Added FCC grant and regulatory information for FCC and ISED; Added maximum input power
1.4	MKA	MKA	31.08.2017	Added Tape & Reel specification
1.5	MKA	MKA	19.09.2017	Added detailed description of filtering functionality
1.6	MKA	MKA	25.10.2017	Added maximum number of filters
1.7	MKA	MKA	10.01.2018	Extensive update for production version. Added detailed description of telegram processing, security operations and noise filtering.
1.8	MKA	MKA	30.01.2018	Added product revision history Added maximum input power and RSSI accuracy. Added current during start-up.
1.9	MKA	MKA	30.04.2018	Added DA-7 to product history
1.10	MKA	MKA	31.07.2018	Added DB-8 to product history, extended description of ESP3 interface, telegram filtering and BaseID functionality
1.11	MKA	MKA	08.01.2019	Added application info for SAW circuit
1.12	MKA	MKA	05.02.2019	Added note regarding test points and regarding RLC storage.
1.13	MKA	MKA	08.08.2019	Update with new features in product version DB-09
1.14	MKA	MKA	28.01.2020	Corrected list of supported secure RORG
1.15	MKA	MKA	18.03.2020	Added information about ESP3 command for transmission
1.16	MKA	MKA	31.07.2020	Added new features in product version DC, Added introduction to EnOcean radio in Appendix A and EnOcean security in Appendix B
1.17	MKA	MKA	08.12.2020	Added PCB parameters for whip antenna Added description of product label
1.18	MKA	MKA	22.06.2021	New release for TCM 515 (868.3 MHz) product revision DD-18

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Disclaimer

This user manual describes the type of component and shall not be considered as assured characteristics. No responsibility is assumed for possible omissions or inaccuracies. Circuitry and specifications are subject to change without notice. For the latest product specifications, refer to the EnOcean website: http://www.enocean.com.

As far as patents or other rights of third parties are concerned, liability is only assumed for modules, not for the described applications, processes and circuits.

EnOcean does not assume responsibility for use of modules described and limits its liability to the replacement of modules determined to be defective due to workmanship. Devices or systems containing RF components must meet the essential requirements of the local legal authorities.

The modules must not be used in any relation with equipment that supports, directly or indirectly, human health or life or with applications that can result in danger for people, animals or real value.

Components of the modules are considered and should be disposed of as hazardous waste. Local government regulations are to be observed.

Packing: Please use the recycling operators known to you.

TABLE OF CONTENT

1 General description

1.1 Basic functionality

TCM515 and TCM 515U are additions to the existing TCM 300 / 310 / 320 transceiver module family with the following functionality:

- TCM 515
  Transceiver Gateway for 868.3 MHz ASK (EnOcean Radio Protocol version 1); main market for this variant is Europe. This User Manual describes the functionality of TCM 515 with product revision DD-18. For a product revision history of TCM 515 please refer to Chapter 16; for documentation of previous revisions, please contact EnOcean.

- TCM 515U
  902.875 MHz FSK (EnOcean Radio Protocol version 2), main market for this variant is US and Canada. This User Manual describes the functionality of TCM 515U with product revision DC-06. For a product revision history of TCM 515U please refer to Chapter 16; for documentation of previous revisions, please contact EnOcean.

TCM 515 and TCM 515U will be commonly referred to as "TCM 515" throughout the remainder of this document. In addition to the description of TCM 515 and TCM 515U, this document also provides an introduction to EnOcean radio networks in Appendix A and an introduction to EnOcean security architecture in Appendix B.

TCM 515 is optimized for application requiring smallest possible size and integrated security handling such as line-powered actuators or controllers. TCM 515 products are limited to OEM installation ONLY.

TCM 515 provides a radio link between EnOcean radio devices and an external host connected via UART interface using the standardized EnOcean Serial Protocol V3 (ESP3) communication protocol.

TCM 515 receives and transmits radio telegrams based on a 50 Ohm or whip antenna connected to the host PCB. It forwards received radio telegrams to an external host processor or host PC via the ESP3 interface. Messages received from an external host via the ESP3 interface will be transmitted by TCM 515 as EnOcean radio telegrams according to the chosen frequency.

TCM 515 is implemented as 31 pin reflow-solderable module with optimized form factor for size constrained applications. It is not pin compatible with existing TCM 310 products. Figure 1 below shows TCM 515.

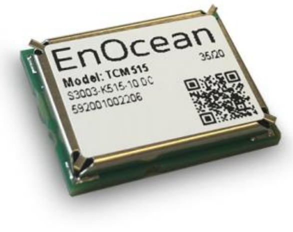


Figure 1 – TCM 515

1.2 Technical data

Antenna		50 Ohm whip antenna (connected at host board)
Supported Radio Frequencies	TCM 515:	868.300 MHz ASK
	TCM 515U:	902.875 MHz FSK
Data Rate		125 kbps
Receiver Sensitivity (1)	TCM 515:	-93 dBm
	TCM 515U:	-98 dBm
Maximum Input Power (1)		-17 dBm
Receiver Blocking Performance		Class 2 according to EN 300 220-1
Radiated RF Immunity		10 V / m according to EN 301 489-3
Transmit Power	TCM 515:	+10 dBm
	TCM 515U:	+1 dBm
Supply Voltage (min / max / typ)		2.0 V / 3.6 V / 3.3 V
Supply Current RX State		25 mA
Supply Current TX State (2)		25 mA
Supply Current Idle State (3)		5 mA
Supply Current Sleep Mode	TCM 515:	< 5 uA
	TCM 515U:	< 50 uA
Power-up to Ready State Timing		50 ms
Ready State to RX State Delay (4)		200 ms (default setting, adjustable via ESP3)
Supply Current between Power-up and RX		12 mA
TX to RX switching time (5)		< 1 ms
Serial Interface To Host		UART according to ESP3 Standard (TURBO option)

General Note: All figures are typical values at 25°C unless otherwise specified.

Note 1: Sensitivity and Maximum Input Power figures are based on 0.1% telegram error rate for the combination of 3 received sub-telegrams

Note 2: ASK modulation encodes the bit status (0 or 1) using different radio power levels where 0 is encoded with a high-power level and 1 with a low power level. The TX current therefore depends on the ration between bits with the value 0 and bits with the value 1 in the bit stream. The figure given here is for a PN9 sequence.

Note 3: Idle Mode is used when TCM 515 operates in transmit-only mode while no telegram is transmitted.

Note 4: During start-up, TCM 515 waits for a configurable additional delay before transitioning to RX state to allow for power supply stabilization and start-up of the external host.
The default value for this delay is 200 ms; this is adjustable via ESP3

Note 5: TX to RX switch over time is measured from the transmission of the last bit (end of frame) of a radio frame until the receiver is ready to receive the first bit (preamble) of a radio frame

1.3 Physical dimensions

Module Dimensions	19.0 mm x 14.7 mm x 3.0 mm (all +- 0.3 mm)
Module Weight	1 g

1.4 Environmental conditions

Operating Temperature	-40°C ... +85°C
Storage Temperature	-40°C ... +85°C
Humidity	0% to 95% r.h. (non-condensing)

1.5 Packaging information

Packaging Unit / Method	250 units / Tape and reel

1.6 Ordering information

Type	Ordering Code
TCM 515 (DD-18)	S3003-K515:DD
TCM 515 (DC-06)	S3053-K515:DC

2 Functional information

2.1 High-level functionality

TCM 515 is a fully integrated radio transceiver family which enables communication with other devices implementing the EnOcean Radio Protocol (ERP) as specified in [2].

TCM 515 is used to exchange (send and / or receive) radio telegrams with external sensors, switches or actuators.

TCM 515 is connected to an external host which for instance could be a microprocessor, a controller or a gateway via the EnOcean Serial Protocol v3 (ESP3) interface. ESP3 commands are listed within this document for information purposes only; for details about ESP3 commands refer to the ESP3 specification [1].

Figure 2 below shows the integration of TCM 515 into a typical system environment.

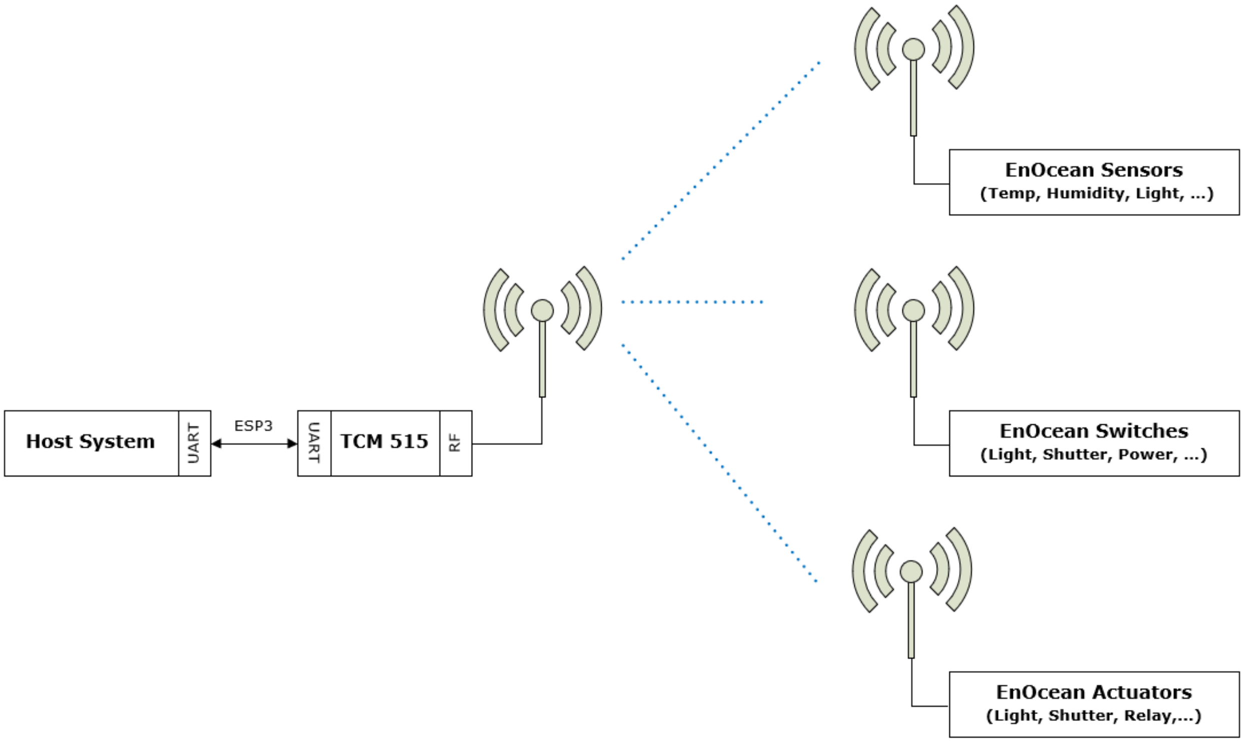

Host System
UART
ESP3
UART
TCM 515
RF
EnOcean Sensors
(Temp, Humidity, Light, ...)
EnOcean Switches
(Light, Shutter, Power, ...)
EnOcean Actuators
(Light, Shutter, Relay,...)

Figure 2 – TCM 515 system environment

2.2 Functional states

TCM 515 implements the following functional states:

- Power-up and system initialization (with user-configurable delay)
  This state is described in chapter 3
- RX state (telegram reception with security processing, filtering, repeating as required)
  This state is described in chapter 4
- TX state (telegram transmission with security processing as required)
  This state is described in chapter 5
- Sleep state (low power state to conserve energy)
  This state is described in chapter 8

The transition between these functional states is shown in Figure 3 below.

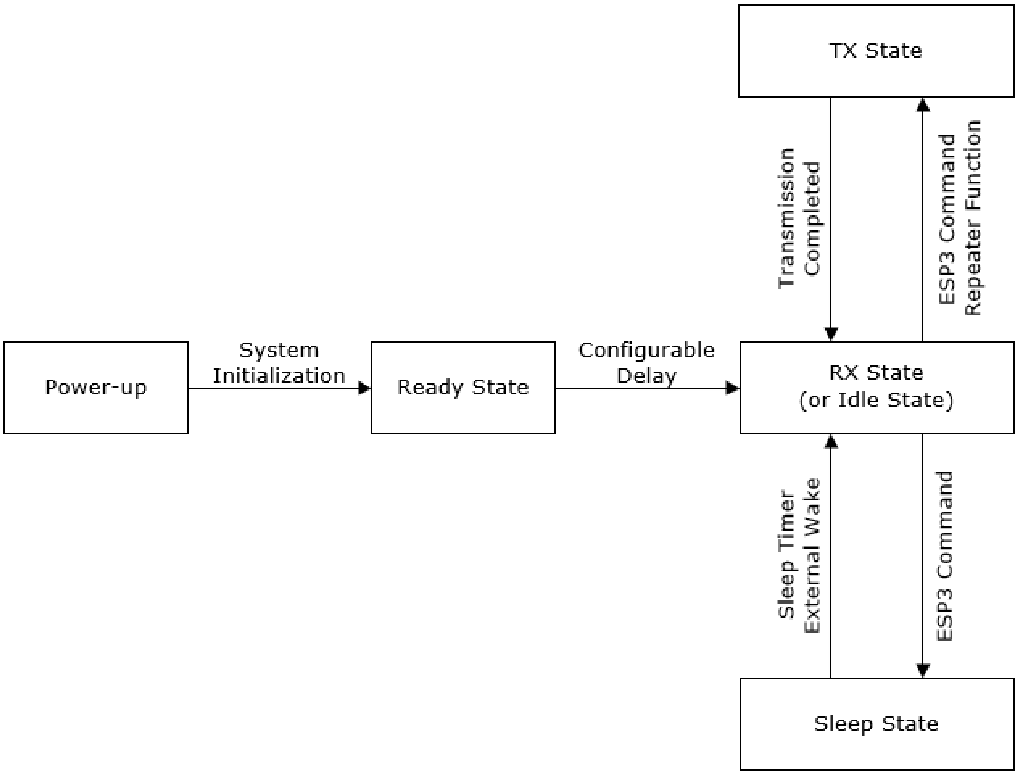


Figure 3 – TCM 515 functional states

Note that it is possible to configure TCM 515 to operate as transmit-only device which disables receive functionality. If TCM 515 is configured to operate as transmit-only device, then RX state is replaced by Idle state where TCM 515 will wait for ESP3 commands. Transmit-only functionality is described in chapter 5.7.

2.3 Device interface

TCM 515 implements a 31 pin reflow-solderable interface. Solder mask data is available on request from EnOcean.

2.3.1 Pin-out

The pin assignment (as seen from the top of the TCM 515 device) is shown in Figure 4 below. Solder mask and mechanical data is available from EnOcean.

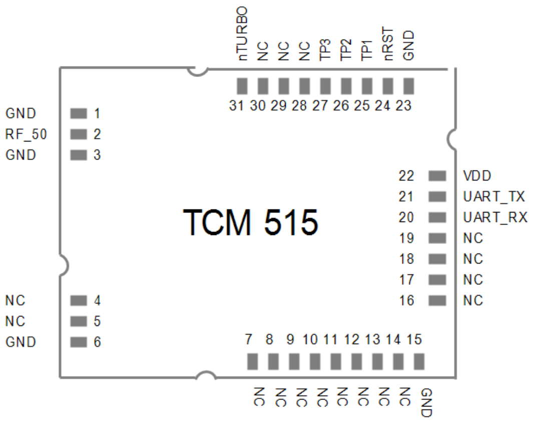


Figure 4 – TCM 515 device interface

Table 1 below summarizes the signal assignment.

PIN	NAME	PIN	NAME	PIN	NAME
1	GND	12	NC	23	GND
2	RF_50 (50Ω antenna)	13	NC	24	nRESET (Reset input, active low)
3	GND	14	NC	25	TP1 (Test Interface)
4	NC	15	GND	26	TP2 (Test Interface)
5	NC	16	NC	27	TP3 (Test Interface)
6	GND	17	NC	28	NC
7	NC	18	NC	29	NC
8	NC	19	NC	30	NC
9	NC	20	UART_RX (Input to TCM 515)	31	nTURBO (UART speed, active low)
10	NC	21	UART_TX (Output from TCM 515)		
11	NC	22	VDD		

Table 1 - TCM 515 pin assignment

Signals marked with “NC” are reserved for production test and future device variants and must not be connected in the design.

2.4 Power supply

TCM 515 is supplied by the VDD and GND Pins and supports a supply voltage range between 2.0 V and 3.6 V. For best radio performance it is very important to minimize noise on the supply voltage lines. Please see chapter 11.5 and 11.6.

⚠ The TCM 515 supply voltage must not drop below the minimum permitted supply voltage of 2.0 V during operation; otherwise correct operation cannot be guaranteed. Power supply design must account for load transients (e.g. at start-up or wake-up from Sleep state) and possible voltage drops to provide the required supply voltage.

2.5 Antenna

TCM 515 receives and transmits data based on a 50Ω whip antenna connected to its RF_50 input (Pin 2). Please see chapter 12.

2.6 UART interface

TCM 515 communicates with the external host using the standard ESP3 serial (UART) interface based on the signals UART_TX (Pin 21, direction from TCM 515 to external host) and UART_RX (Pin 20, direction from external host to TCM 515).

⚠ It is strongly recommended that the PCB design provides the ability to connect to the UART signals – e.g. by means of providing suitable test point pads on the PCB - for the purpose of analysis and debug.

The default interface speed of the ESP3 interface is 57600 bit per second and data is transmitted using 8 data bits, 1 STOP bit and no parity (8N1).

It is possible to select faster communication speeds during operation using the ESP3 CO_SET_BAUDRATE command (see chapter 9.1). The following interface speeds are supported by TCM 515:

- 57600 bit per second
- 460800 bit per second

Additionally, it is possible to change the default ESP3 interface speed at power up from 57.600 bit per second to 460.800 bit per second by connecting the nTURBO input (Pin 31, active low) to Ground.

Subsequent modification of the interface speed during operation using the CO_SET_BAUDRATE command is always possible irrespective of the state of the TURBO input pin.

⚠ Care should be taken not to select a UART interface speed which cannot be supported by the connected host processor as this would prevent subsequent communication.

2.7 Reset

TCM 515 can be reset by pulling the nRESET pin (Pin 24, active low) to Ground. Please see Chapter 11.8 for reset circuit recommendations.

It is strongly recommended that the PCB design provides the ability to connect to the nRESET signal – e.g. by means of providing a suitable test point pad on the PCB - for the purpose of analysis and debug.

2.8 Test interface (TP1, TP2, TP3)

TCM 515 provides a test interface (TP1, TP2 and TP3). The intended use of this interface is for analysis and debugging of customer products by EnOcean.

It is strongly recommended that customer PCB design provides the ability to connect external devices to the TP1, TP2 and TP3 signals – e.g. by means of providing suitable test point pads on the PCB - for the purpose of analysis and debug.

2.9 Product label

Each TCM 515 contains a product label as shown in Figure 5 below.

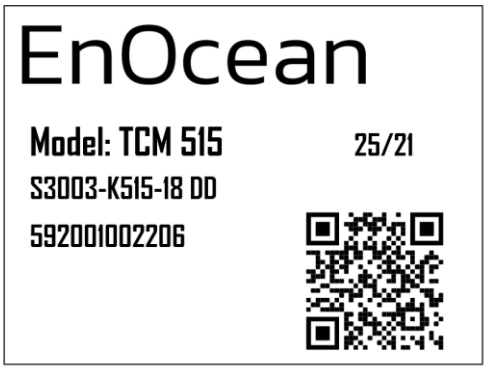


Figure 5 – TCM 515 product label

The label shown above identifies the following parameters in writing:

- Product name (TCM 515)
- Order number (S3003-K515)
- Product revision (DD-18)
- Manufacturing date (week 25, 2021)
- Manufacturer traceability code (592001002206)

2.9.1 QR code

The TCM 515 product label contains an automatically readable QR code in the lower right corner which encodes certain product parameters according to the ANSI/MH10.8.2-2013 standard as listed in Table 2 below.

Data Identifier	Data Length (excluding identifier)	Data Content
30S	8 characters (hexadecimal)	EnOcean Radio ID (EURID)
30P	10 characters (alphanumeric)	Ordering Code
2P	4 characters (alphanumeric)	Step Code and Revision
S	14 characters (decimal)	Serial Number (starts with 01)

Table 2 – TCM 515 product QR code structure

3 Power-up, initialization and system operation

After power-up, TCM 515 executes the following steps:

- Initialization of the system
  TCM 515 initializes all system components and peripherals.
  After that, TCM 515 transitions to Ready state

- Wait for pre-configured delay
  This delay allows the power supply to stabilize and the external host to initialize the system. The default value of this delay is 200 ms; this is configurable This delay can be configured as persistent parameter (maintained after power down) using the ESP3 command CO_WR_STARTUP_DELAY.

After that, TCM 515 is in ready for operation depending on the selected TCM 515 operation mode (transmit and receive mode or transmit-only mode).

3.1 Typical operation sequence for transmit and receive mode

The default configuration of TCM 515 is transmit and receive mode. In this mode, TCM 515 is continuously scan for EnOcean radio telegrams in RX state unless it receives a request from the host to transmit a telegram.

If TCM 515 receives a valid EnOcean radio telegram, then it will process this as described in chapter 4 and forward it to the host via ESP3.

If TCM 515 receives a request from the host to transmit a telegram, then it will transition to TX state and transmit the telegram as described in chapter 5. After that, it will automatically transition back to RX state and continue to scan for EnOcean radio telegrams.

Figure 6 below shows a typical operation sequence for transmit and receive mode with manual sleep entry and exit.

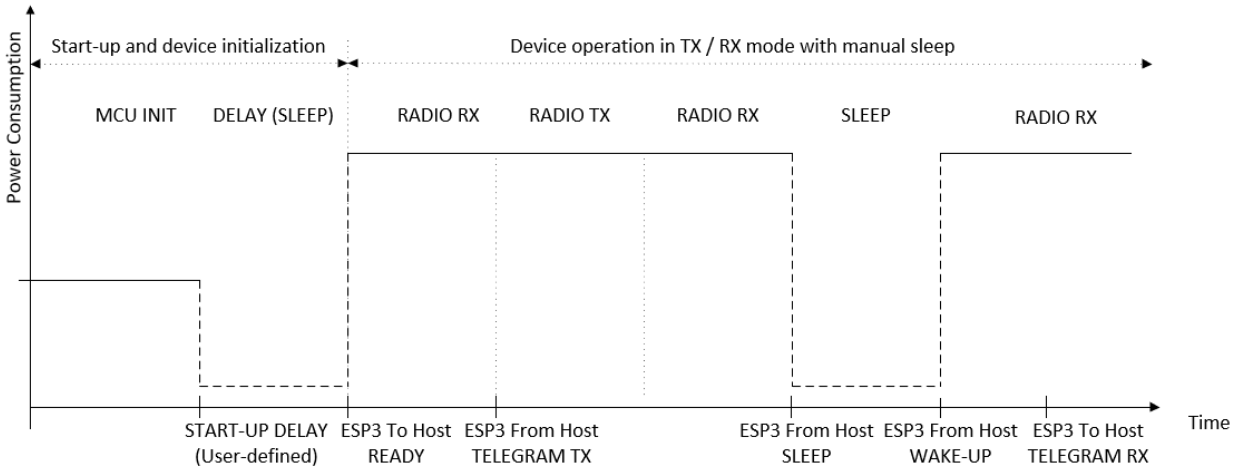


Figure 6 – Operation sequence for transmit and receive mode with manual sleep

3.2 Typical operation sequence for transmit-only mode

In transmit-only mode, TCM 515 will wait in Idle state until an ESP3 command from the host requesting the transmission of a telegram has been received. It will then transmit the telegram as described in chapter 5 and inform the host once the transmission of a telegram has been completed.

After completion of the telegram transmission, TCM 515 will either transition back to Idle state waiting for the next command from the host (default configuration) or automatically enter Sleep state waiting for a wake-up via ESP3 command (Auto Sleep configuration).

Figure 7 below shows a typical operation sequence for transmit-only mode with automatic sleep entry (Auto Sleep). See chapter 5.7 for a detailed description of transmit-only mode.

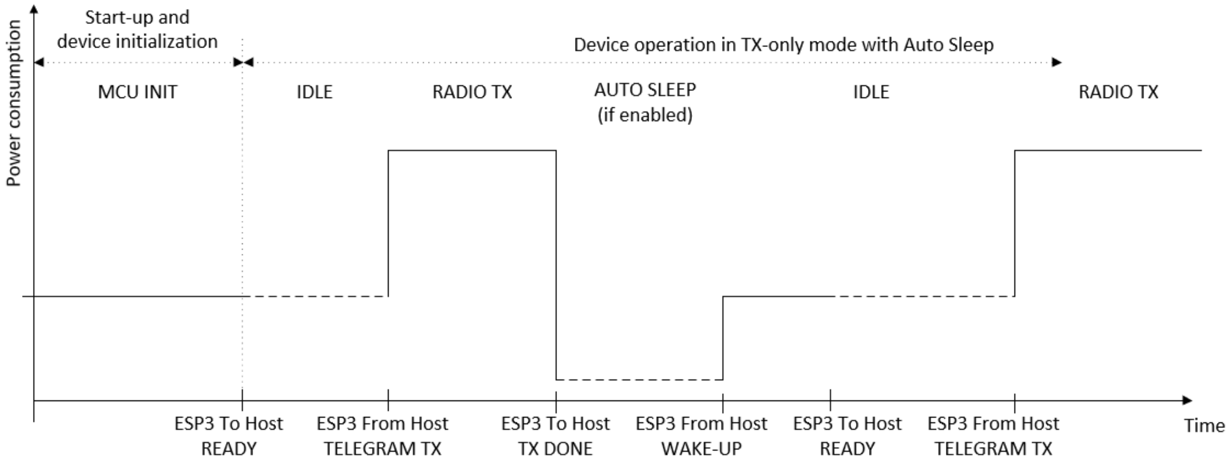


Figure 7 – Operation sequence for transmit-only mode with Auto Sleep

4 Telegram reception

After start-up, TCM 515 will enter receive state unless TX-only mode is active as discussed in chapter 5.7.

4.1 Telegram reception flow

While in receive state, TCM 515 will wait for valid EnOcean radio telegrams and then performs the following functions:

- RX telegram processing
  Received data bitstream is processed (detection and removal of preamble, start of frame, end of frame and redundant bits, CRC check, subtelegram merge) and formatted as EnOcean radio telegrams

- Repeater handling
  Received telegrams are checked if they should be repeated based on the repeater mode configured at TCM 515 (Level1 Repeater, Level2 Repeater, Selective Repeater) and the repeater information reported as part of the radio telegram. If the received telegram should be repeated, then it will be inserted into the transmission queue. See chapter 5.7 for details on the repeater functionality.

- Telegram filtering
  Received telegrams can be classified according to user-defined characteristics so that only telegrams matching these characteristics will be processed and forwarded to the external host via the ESP3 interface. See chapter 4.2 for details.

- Security processing
  Telegrams from senders using high security mode can be automatically decrypted and authenticated according to their security parameters stored in the inbound secure link table. See chapter 7 for details.

- ESP3 formatting and telegram forwarding
  Processed telegrams will be formatted as ESP3 packet (RADIO_ERP1 by default) and forwarded to the external host via the ESP3 interface. See chapter 9 for details regarding the ESP3 interface.

Figure 8 below shows the processing flow for received telegrams.

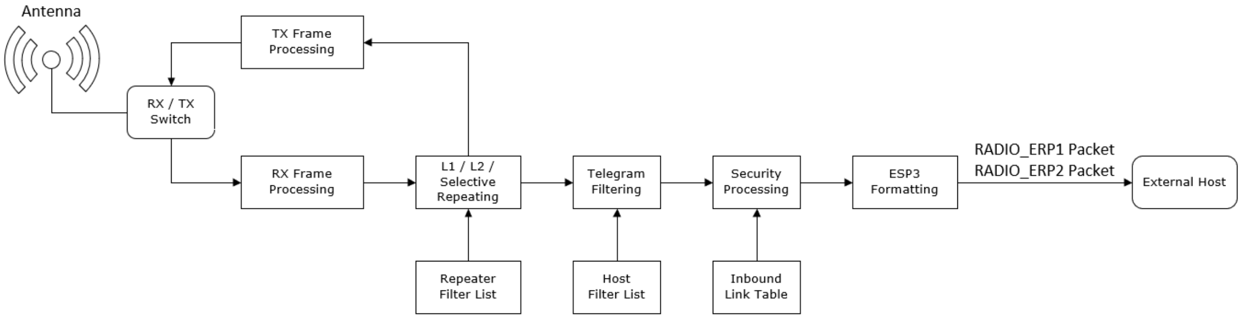


Figure 8 – Telegram Reception Flow

4.2 Telegram filtering

By default, TCM 515 will forward all valid telegrams received by it (including such that are addressed to a different receiver) to the host via its ESP3 interface.

Additionally, TCM 515 will repeat all received telegrams if repeating is enabled.

Filtering allows the host to configure via the ESP3 interface conditions based on which telegrams are forwarded to the host or repeated. Telegram filtering is based on the following parameters:

- Filter type
  The filter type defines based on what property TCM 515 should evaluate in received telegrams, e.g. if it should check the source address, the destination address, the telegram type or the signal strength

- Filter value
  The filter value defines the reference value against which TCM 515 will compare the property of the received telegram

- Filter condition
  The filter condition defines the desired relation between the defined filter value and the corresponding property of the received telegram.
  For the case of source address, destination address and RORG, the filter condition can be *Equal* (e.g. the source address of received telegram is the same as the defined filter value) or *Not Equal* (e.g. the RORG of the received telegram is not the same as the defined filter value).
  For the case of signal strength, the filter condition can be *Lower Than Or Equal* (the received signal strength is lower than the defined value or equal to it) or *Higher Than* (the received signal strength is higher than the defined value).

- Filter action
  The filter action defines what TCM 515 should do if the filter condition is true, e.g. if it should forward the telegram to the host or if it should forward the telegram to the host and repeat the telegram

- Filter combination
  The filter combination defines what happens if more than one filter condition is defined for a specific set filter action, e.g. if the filters controlling telegram forwarding to the host should be combined in a logic OR fashion or a logic AND fashion.

The following chapters describe these parameters in more detail.

4.2.1 Filter type

TCM 515 supports the following filter types:

- Source EURID Filter
  The source EURID (EnOcean Universal Radio ID = EURID of the sender of the telegram) is evaluated.
  This filter type can for instance be used in actuators which only accept input from certain devices (e.g. switches) identified by their EURID

- Destination EURID Filter
  The destination EURID (EnOcean Universal Radio ID = EURID of the intended receiver of the telegram) is evaluated.
  This filter type can for instance be used by a receiver to not repeat radio telegrams that are directly addressed to it (and therefore do not need to be received by other devices).

- Telegram Type (RORG) Filter
  The telegram type of the received telegram is evaluated.
  This filter type can be used for instance be used in actuators which should react only to switch telegrams (RPS Telegram Type).

- Received signal strength (RSSI) Filter
  The received signal strength (RSSI) of the received telegram is evaluated.
  This filter type can for instance be used during learn-in if an actuator should only accept teach-in telegrams from devices close to the receiver.
  Alternatively, this filter type could also be used in repeaters so that only telegrams with weak signal strength (low RSSI value) would be repeated in order to limit radio congestion.

4.2.2 Filter value

The filter value field contains the value against which the corresponding property of the received telegram is compared. The filter value field is 4 byte long and – depending on the configured filter type - contains the following:

- 32 bit Source EURID (radio address of the sender)

- 32 bit Destination EURID (radio address of the intended receiver)

- 8 bit RORG
  The RORG value has to be allocated in the least significant byte and the remaining 3 byte of the value field should be set to 0x000000

- 8 bit RSSI
  The RSSI value has to be allocated in the least significant byte and the remaining 3 byte of the value field should be set to 0x000000. The absolute value of the desired RSSI shall be entered, i.e. an RSSI threshold of -80 dBm is desired then the value 80 shall be entered

4.2.3 Filter condition

TCM 515 supports the following filter conditions for Source ID, Destination ID and RORG:

- Is Equal
  The value in the received telegram is the same as the defined filter value

- Is Not Equal
  The value in the received telegram is different from the defined filter value

TCM 515 supports the following filter conditions for signal strength (RSSI):

- Is Less Than Or Equal (used instead of the Is Equal condition for RSSI)
  If the defined signal strength (RSSI) value is -50 dBm then received telegrams with signal strength – 50 dBm, -51 dBm, …, -98 dBm will all match this condition. Note that TCM 515 cannot receive signals with a signal strength below the specified RX sensitivity.

- Is Greater Than (used instead of the Is Not Equal condition for RSSI)
  If the defined signal strength (RSSI) value is -50 dBm then received telegrams with signal strength -49 dBm, -48 dBm, … -17 dBm will all match this condition. Note that TCM 515 cannot receive signals with a signal strength above the specified maximum input power.

4.2.4 Filter action

TCM 515 supports two types of filter actions:

- Forward the received telegram to the host via ESP3 function
  This filter is ignored for the repeater function

- Forward the received telegram to the host via ESP3 interface and
  Repeat (retransmit) the received telegram if selective repeating is enabled

Note that the filter action for telegram repeating is only considered if the repeater functionality is configured for Selective Repeating as described in chapter 6.1.

4.2.5 Filter combination

For each of the two actions (telegram forwarding to the host, telegram repeating) it is possible to define one or several filters.

The combination between the defined filters for the same filter action can either be a logical AND (all filter conditions must be true in order to execute the filter action) or a logical OR (one of the filter conditions must be true in order to execute the filter action). For the case of selective repeating, filters with condition / action codes 0x00 and 0x40 will be ignored when evaluating the defined filters.

TCM 515 support the definition of up to 30 individual filters in total. Attempting to define more than 30 filters will result in the response 01: RET_ERROR (memory space full).

4.2.6 Filter definition

Telegram filters are defined using the CO_WR_FILTER_ADD command as shown in Table 3 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0007	7 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x0B	0x0B: CO_WR_FILTER_ADD
	7	1	Filter type	0x00…0x03	Telegram property that will be evaluated 0x00: Source EURID 0x01: Telegram type (RORG) 0x02: Received signal strength (RSSI, in dBm) 0x03: Destination EURID
	8	4	Filter value	0xnnnnnnnn	Value to compare against - Source EURID (4 byte) - RORG (1 byte) - Signal strength (1 byte, interpreted as negative of this value, e.g. 85 means -85 dBm) - Destination EURID (4 byte)
	12	1	Filter condition and action	0x00 0x80 0x40 0xC0	0x00: Forward to host if condition is false Ignore this filter for selective repeating 0x80: Forward to host if condition is true Ignore this filter for selective repeating 0x40: Forward to host if condition is false Repeat telegram if condition is false 0xC0: Forward to host if condition is true Repeat telegram if condition is true
-	13	1	CRC8D	0xnn	

Table 3 – Syntax for CO_WR_FILTER_ADD

Note that if the filter value is only 8 bit long (for RORG or RSSI filters) then the remaining bits of the filter value field should bet set to 0x000000.

4.2.7 Filter enabling

Once all filters have been defined, the CO_WR_FILTER_ENABLE command shown in Table 4 below has to be used to select the logical relation between the defined filters (logical AND versus logical OR) and to enable the filtering mechanism for telegram forwarding via ESP3.

Note that the combination between the defined filters can be set independently for the host filters determining if a received telegram will be forwarded to the host via the ESP3 interface and the repeater filters determining if a received telegram will be repeated.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0003	3 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x0E	0x0E: CO_WR_FILTER_ENABLE = 14
	7	1	Forward Filter ON/OFF	0x00 0x01	0x00: Forwarding filter disabled 0x01: Forwarding filter enabled
	8	1	Filter Operator	0x00 0x01 0x08 0x09	0x00: OR connection between all filters 0x01: AND connection between all filters 0x08: OR connection between host filters AND connection between repeater filters 0x09: AND connection between host filters OR connection between repeater filters
-	9	1	CRC8D	0xnn	

Table 4 – Syntax for CO_WR_FILTER_ENABLE command

The use of the defined filters for the repeater is enabled separately by means of the CO_WR_REPEATER command shown in Table 23 in chapter 446.1. There, REP_ENABLE has to be set to 0x02 to enable selective repeating based on the defined filters.

Note that if a filter is set to be ignored for the cases of repeating (filter condition / action 0x00 or 0x80), then this filter will not be evaluated and the result of the evaluation of the other filters (not set to be ignored) will not be influenced by it.

4.2.8 Filter reading

It is possible to read the currently defined filters using the CO_RD_FILTER command shown in Table 5 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0001	1 byte
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x0F	0x0F: CO_RD_FILTER
-	7	1	CRC8D	0xnn	

Table 5 – Syntax for CO_RD_FILTER

TCM 515 will reply to the CO_RD_FILTER command with a response containing all defined filters as shown in below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0xnnnn	1 + 5*f bytes (f = number of filters)
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x02	0x02: RESPONSE
-	5	1	CRC8H	0xnn	
Data	6	1	Return Code	0x00	0x00: RET_OK
	7+5*f	1	Filter type	0xnn	Telegram property that will be evaluated 0x00: Source EURID 0x01: Telegram type (RORG) 0x02: Received signal strength (RSSI, in dBm) 0x03: Destination EURID
	8+5*f	4	Filter value	0xnnnnnnnn	Value to compare against - Source EURID (4 byte) - RORG (1 byte) - Signal strength (1 byte, interpreted as negative of this value, e.g. 85 means -85 dBm) - Destination EURID (4 byte)
-	12+5*f	1	CRC8D	0xnn	

Table 6 – Syntax of the response to CO_RD_FILTER_ENABLE command

4.2.9 Filter deletion

Filters can be deleted individually using the CO_WR_FILTER_DEL command as shown in Table 7 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0007	7 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x0C	0x0C: CO_WR_FILTER_DEL
	7	1	Filter type	0x00…0x03	Telegram property that will be evaluated 0x00: Source EURID 0x01: Telegram type (RORG) 0x02: Received signal strength (RSSI, in dBm) 0x03: Destination EURID
	8	4	Filter value	0xnnnnnnnn	Value to compare against - Source EURID (4 byte) - RORG (1 byte) - Signal strength (1 byte, interpreted as negative of this value, e.g. 85 means -85 dBm) - Destination EURID (4 byte)
	12	1	Filter action and condition	0x00 0x80 0x40 0xC0	0x00: Forward to host if condition is false Ignore this filter for selective repeating 0x80: Forward to host if condition is true Ignore this filter for selective repeating 0x40: Forward to host if condition is false Repeat telegram if condition is false 0xC0: Forward to host if condition is true Repeat telegram if condition is true
-	13	1	CRC8D	0xnn	

Table 7 – Syntax for CO_WR_FILTER_DEL command

It is possible to delete all configured filters using the CO_WR_FILTER_DEL_ALL command as shown in Table 8 below. It is strongly recommended to use this command to clear the filter table from existing entries before starting the filter table configuration.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0001	1 byte
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x0D	0x0D: CO_WR_FILTER_DEL_ALL
-	13	1	CRC8D	0xnn	

Table 8 – Syntax for CO_WR_FILTER_DEL_ALL command

4.2.10 Filter examples

4.2.10.1 Forwarding (ESP3 to host) filter examples

The examples below show common filter conditions for the telegram forwarding of received telegrams to the external host via the ESP3 interface.

```
// Do not forward telegrams sent from the specified ID
// All telegrams will be forwarded except those from the specified ID
Filter_type    = 0x00 (Sender EURID matches specified value)
Filter_value   = 0x12345678 (device source ID)
Filter_action  = 0x00 (Forward to host via ESP3 if condition is false)

// Forward telegrams sent from the specified ID
// Only telegrams from the specified ID will be forwarded
Filter_type    = 0x00 (Sender EURID matches specified value)
Filter_value   = 0x12345678 (device source ID)
Filter_action  = 0x80 (Forward to host via ESP3 if condition is true)

// Do not forward telegrams having the specified R-ORG
// All telegrams will be forwarded except those having the specified R-ORG
Filter_type    = 0x01 (R-ORG matches specified value)
Filter_value   = 0x000000A5 (4BS)
Filter_ action = 0x00 (Forward to host via ESP3 if condition is true)

// Forward telegrams with the specified R-ORG
// Only telegrams with the specified R-ORG will be forwarded
Filter_type    = 0x01 (R-ORG matches specified value)
Filter_value   = 0x00000A5 (4BS)
Filter_ action = 0x80 (Forward to host via ESP3 if condition is true)

// Do not forward telegrams with a signal strength below -70dBm (ignore weak telegrams)
// Only telegrams with a signal strength greater than -70dBm will be forwarded
Filter_type    = 0x02 (RSSI is less than or equal the specified value)
Filter_value   = 0x00000046 (decimal: 70)
Filter_ action = 0x00 (Forward to host via ESP3 if condition is false)
```

4.2.10.2 Repeater filter examples

The examples below show possible filter conditions for the telegram repeating of received telegrams (selective repeating). Note that repeating always works in conjunction with forwarding of a telegram to the host, i.e. you can not specify an individual filter to repeat a telegram but not forward it to the host.

```
// Repeat telegrams sent from the specified EURID (requires REP_ENABLE = 0x02)
// Telegrams sent from other senders (with different EURID) will not be repeated
Filter_type    = 0x00 (Sender EURID matches specified value)
Filter_value   = 0x12345678 (sender EURID)
Filter_action  = 0xC0 (Forward to host via ESP3 and repeat telegram if condition is true)
```

```
// Repeat telegrams with an RORG other than 0xA5 (requires REP_ENABLE = 0x02)
// Telegrams with R-ORG 0xA5 will not be repeated
Filter_type    = 0x01 (R-ORG matches specified value)
Filter_value   = 0x000000A5 (4BS)
Filter_action  = 0x40 (Forward to host via ESP3 and repeat telegram if condition is false)
```

```
// Repeat telegrams with a signal strength <= -70dBm (requires REP_ENABLE = 0x02)
// Telegrams with a signal strength above -70dBm will not be repeated
Filter_type    = 0x02 (RSSI is less than or equal the specified value)
Filter_value   = 0x00000046 (decimal: 70)
Filter_action  = 0xC0 (Forward to host via ESP3 and repeat telegram if condition is true)
```

4.3 RADIO_ERP1 packet for received telegrams

The telegram payload of received telegrams is forwarded to the external host using the RADIO_ERP1 packet with the structure shown in Table 9 below.

The Data field of the RADIO_ERP1 packet contains the ERP1 telegram (excluding the Hash field used for data verification) as shown in Table 9 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. Byte	0x55	
Header	1	2	Data Length	0xnnnn	Variable length of radio telegram
	3	1	Optional Length	0x07	7 fields fixed
	4	1	Packet Type	0x01	RADIO_ERP1 = 1
-	5	1	CRC8H	0xnn	
Data	6	x	... ...	... ...	Radio telegram without checksum/CRC x = variable length / size
Optional Data	6+x	1	SubTelNum	0xnn	Number of received subtelegrams If “wait for maturity time” is disabled, then this field will be set to 0 (not applicable)
	7+x	4	Destination ID	0xnnnnnnnn	Broadcast: Broadcast ID (FF FF FF FF) ADT: Destination EURID
	11+x	1	dBm	0xnn	Highest (best) RSSI value of all received subtelegrams. Value is expressed as positive decimal number (60 means – 60 dBm)
	12+x		Security Level	0x0n	0x00: Telegram not processed by TCM 515 0x01: Obsolete (old security concept) 0x02: Telegram decrypted by TCM 515 0x03: Telegram authenticated by TCM 515 0x04: Telegram decrypted + authenticated
-	13+x	1	CRC8D	0xnn	CRC8 Data byte; calculated checksum for DATA and OPTIONAL_DATA fields

Table 9 – Syntax of the RADIO_ERP1 packet for received messages

TCM 515 will respond to the RADIO_ERP1 packet immediately with the RESPONSE message 00: RET_OK if it can transmit the message (correct format used in the command). TCM 515 will additionally send an event with code 0x08: CO_TX_DONE to the host as soon as the transmission of the telegram has been completed.

⚠ Note that the transmission of the three subtelegrams will last for up to 40 ms after receiving the RET_OK message. Do not shut-down TCM 515 before this period has elapsed or the CO_TX_DONE event has been received.

4.4 RADIO_ERP2 packet for received telegrams (TCM 515U only)

TCM 515U uses EnOcean Radio Protocol 2 (ERP2) for radio communication as described in [3]. To ensure compatibility between TCM 515 (using ERP1) and TCM 515U (using ERP2) from serial interface (ESP3) perspective, TCM 515U by default uses RADIO_ERP1 packets for forwarding received telegrams to the external host via the ESP3 interface.

It is possible to change from this default setting to using RADIO_ERP2 packets using the CO_WR_MODE command as shown in Table 10 below. Note that this command is only supported for TCM 515U; trying to use this command with TCM 515 will result in a response 0x02: RET_NOT_SUPPORTED.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. Byte	0x55	
Header	1	2	Data Length	0x0002	2 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	COMMON_COMMAND = 5
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x1C	CO_WR_MODE = 28
	6	1	Mode	0xnn	0x00: Use Radio_ERP1 packets (default) 0x01: Use Radio_ERP2 packets
-	7	1	CRC8D	0xnn	

Table 10 – Syntax of CO_WR_MODE (TCM 515U only)

If the use of RADIO_ERP2 packets is selected, then received telegrams will be forwarded to the external host using the Radio_ERP2 packet format shown in Table 11 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. Byte	0x55	
Header	1	2	Data Length	0xnnnn	Variable length of radio telegram
	3	1	Optional Length	0x02	2 fields fixed
	4	1	Packet Type	0x0A	RADIO_ERP2 = 10
-	5	1	CRC8H	0xnn	
Data	6	x	Raw data	… …	ERP2 telegram without the first Length byte
Optional Data	6+x	1	SubTelNum	0xnn	Number of received subtelegrams If "wait for maturity time" is disabled, then this field will be set to 0 (not applicable)
	7+x	1	dBm	0xnn	Highest (best) RSSI value of all received subtelegrams. Value is expressed as positive decimal number (60 means – 60 dBm)
	8+x	1	Security Level	0x0n	0x00: Telegram not processed by TCM 515 0x01: Obsolete (old security concept) 0x02: Telegram decrypted by TCM 515 0x03: Telegram authenticated by TCM 515 0x04: Telegram decrypted + authenticated
-	8+x	1	CRC8D	0xnn	CRC8 checksum

Table 11 – ESP3 structure for RADIO_ERP2 packet used for reception

4.5 Wait for RX maturity time

As discussed in appendix A.3.3, the RX maturity time defines the longest possible interval between the reception of the first subtelegram and the reception of the last subtelegram belonging to the same telegram.

TCM 515 can be configured to wait for the RX maturity time (100 ms) after reception of a subtelegram in order to determine the number of received subtelegrams. TCM 515 will in that case report the actual number of received subtelegrams to the external host.

Alternatively, TCM 515 can be configured to immediately forward a received subtelegram to the host and discard subsequent identical subtelegrams. This provides the lowest latency and is the default operation mode for TCM 515.

The selection between these two options is done using the CO_WR_WAIT_MATURITY command as shown in Table 12 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0002	2 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x10	0x10: CO_WR_WAIT_MATURITY
	7	1	Wait End Maturity	0xnn	0x00: Received telegrams are forwarded to the external host immediately 0x01: Received telegrams are forwarded to the external host after the maturity time elapsed
-	8	1	CRC8D	0xnn	

Table 12 – CO_WR_MATURITY

4.6 Transparent mode

In certain applications all higher-level protocol handling (encryption, decryption, authentication, telegram chaining) is executed by the external host and TCM 515 is used as simple transmitter / receiver only.

TCM 515 can be configured to operate in transparent mode to disable all higher-level protocol handling in TCM 515. If this mode is active, then repeating, filtering and subtelegram merge functionality will still be provided by TCM 515 while security processing and the processing of chained telegrams will be disabled.

Transparent mode can be enabled using the CO_WR_TRANSPARENT_MODE command as shown in Table 13 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0004	2 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x3E	0x3E: CO_WR_TRANSPARENT_MODE
	7	1	Transparent Mode	0xnn	0x00: Disable Transparent Mode 0x01: Enable Transparent Mode
-	8	1	CRC8D	0xnn	

Table 13 – Syntax for CO_WR_ TRANSPARENT_MODE command

4.7 RSSI test mode

TCM 515 can report the signal strength of received radio telegrams using SIGNAL telegram type 0x0A. This allows evaluation of the radio conditions without the need to physically connect to the ESP3 interface and is intended to support product qualification.

⚠ RSSI test mode functionality is only intended for product development and qualification. It should not be used in production devices since it significantly increases the radio traffic. Do not permanently enable this mode.

Reporting of the received signal strength is enabled using an ESP3 command as shown in Table 14 below. It is strongly recommended to specify a timeout when using this command to ensure that the retransmission of all received telegrams will not be permanently active.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0004	4 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x3A	0x3A: CO_WR_RSSITESTMODE
	7	1	Enable	0x00 0x01	0x00: RSSI Test Mode Disabled 0x01: RSSI Test Mode Enabled
	8	2	Timeout (s)	0xnnnnn	0x0000: No timeout (Stop using this command) 0x0001 … 0xFFFF: Timeout (in seconds)
-	12	1	CRC8D	0xnn	

Table 14 – Syntax for CO_WR_RSSITESTMODE command

For each received telegram, TCM 515 will first evaluate if a received telegram matches the filter criteria (if filter criteria have been configured). If this is the case and RSSI Test Mode is enabled, then TCM 515 will report the signal strength and the repeater level for each received telegram using a SIGNAL telegram with MID (type) 0x0A.

The payload format for a SIGNAL telegram with MID=0x0A is shown in Table 15 below.

Offset	Size	Content	Description
0	8	Message index	Enumeration: 0x0A: RX-channel quality
8	32	ID	32 bit EURID of the sender of the telegram for which the quality is reported
40	8	Lowest RSSI	0x00: Lowest RSSI was +127 dBm … 0x7F: Lowest RSSI was 0 dBm … 0xFE: Lowest RSSI was -127 dBm 0xFF: Lowest RSSI is unknown
48	8	Highest RSSI	0x00: Highest RSSI was +127 dBm … 0x7F: Highest RSSI was 0 dBm … 0xFE: Highest RSSI was -127 dBm 0xFF: Highest RSSI is unknown
56	4	Subtelegram count	0b0000: Subtelegram count unknown 0b0001: 1 sub telegram received … 0b1111: 15 or more sub telegrams received
60	4	Maximum repeater level	0b0000: No repeated telegrams received 0b0001: One-time repeated telegrams received 0b0010: Two-time repeated telegrams received 0b0011 … 0b1110: Reserved 0b1111: Maximum repeater level unknown

Table 15 – Syntax for SIGNAL 0x0A

5 Telegram transmission

TCM 515 will enter transmit state if it receives radio telegrams for transmission from the external host via the ESP3 interface or if repeating is enabled and a telegram is received that has to be repeated based on the defined conditions.

5.1 Transmission flow

TCM 515 performs the following functions to transmit radio telegrams:

- Telegram input
TCM 515 receives the radio telegram data from the external host via the ESP3 interface as described in chapter 9 or from the receiver in case repeating is enabled and a telegram is received that has to be repeated as described in chapter 5.7

- Security handling
Telegrams to receivers supporting high security mode can be automatically encrypted and authenticated according to the parameters specified by their outbound secure link table entry as described in chapter 7

- Telegram transmission
Processed telegrams will be transmitted as a set of redundant subtelegrams as described in Appendix A.3

Figure 9 below shows the process for the transmission of EnOcean radio telegrams.

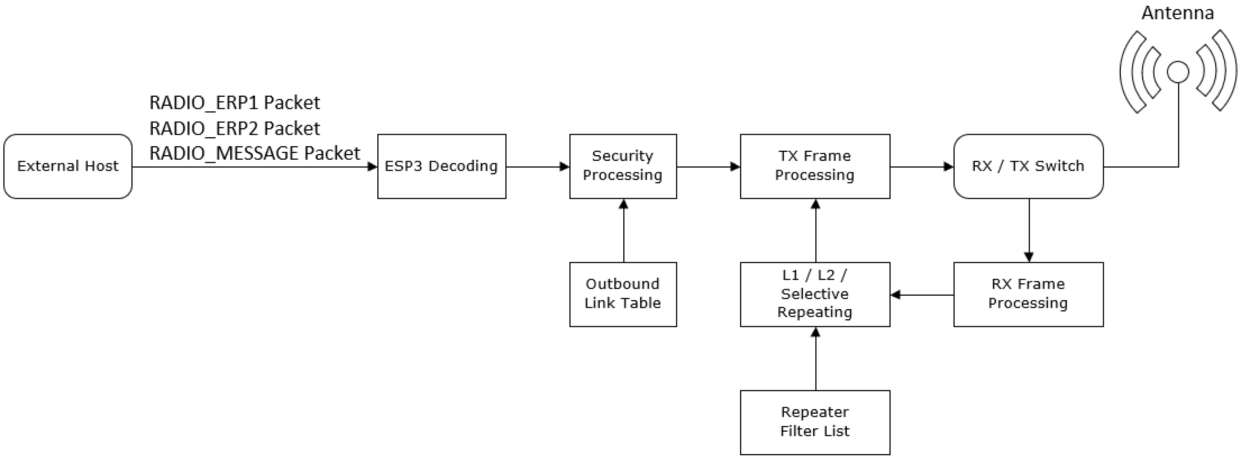


Figure 9 – Telegram Transmission Flow

Telegram transmission can be initiated via ESP3 either using the RADIO_ERP1 packet, the RADIO_ERP2 packet or the RADIO_MESSAGE packet as described in subsequent chapters.

5.2 RADIO_ERP1 packet for telegram transmission

Telegram transmission can be initiated by the external host by sending the ESP3 packet RADIO_ERP1 to TCM 515 using the structure shown in Table 16 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0xnnnn	Length *x* of radio telegram (variable)
	3	1	Optional Length	0x07	Length of Optional Data (always 7 bytes)
	4	1	Packet Type	0x01	0x01: RADIO_ERP1
-	5	1	CRC8H	0xnn	CRC8 checksum for Header
Data	6	x	… …	… …	Radio telegram content (variable length *x*) Maximum length for broadcast: 14 byte Maximum length for addressed: 9 byte
Optional Data	6+x	1	SubTelNum	0x03	Number of subtelegrams to send (3)
	7+x	4	Destination ID	0xnnnnnnnn	Broadcast: FF FF FF FF Addressed (ADT): Destination EURID
	11+x	1	dBm	0xFF	Send case: FF (not used)
	12+x		Security Level	0x00	Will be ignored (Security level is defined by the corresponding link table entry)
-	13+x	1	CRC8D	0xnn	CRC8 checksum for Data and Optional Data

Table 16 – ESP3 structure for RADIO_ERP1 packet used for transmission

TCM 515 will respond to the RADIO_ERP1 command immediately with the RESPONSE message 00: RET_OK if TCM 515 can transmit the message (correct format used in the command and duty cycle limit not active).

⚠ Note that the maximum payload length for RADIO_ERP1 is 14 byte for the case of a broadcast and 9 byte for the case of an addressed transmission (ADT). Attempting to send longer messages will result in the RESPONSE 0x03 (RET_WRONG_PARAM). Use RADIO_MESSAGE for the transmission of larger radio telegrams or create chained messages in the host.

If duty cycle lock is active (permissible duty cycle has been exceeded) and no transmission is possible then TCM 515 will respond with the RESPONSE message 05: RET_LOCK_SET. See chapter 5.6 for a description of the duty cycle limit functionality.

TCM 515 will send an event with code 0x08: CO_TX_DONE to the host as soon as the requested telegram transmission has been completed.

⚠ Note that the transmission of the three subtelegrams will last for up to 40 ms after receiving the RET_OK message as described in appendix A.3.2.
Do not shut-down TCM 515 before this period has elapsed or the CO_TX_DONE event has been received.

5.3 RADIO_ERP2 packet for telegram transmission (TCM 515U only)

TCM 515U uses EnOcean Radio Protocol 2 (ERP2) for radio communication as described in [3]. In order to maximize ESP3 compatibility between the different variants, TCM 515U accepts both RADIO_ERP1 and RADIO_ERP2 packets for transmission.

To ensure compatibility between TCM 515 (using ERP1) and TCM 515U (using ERP2) from serial interface (ESP3) perspective, TCM 515U by default also uses RADIO_ERP1 packets for communicating with the external host.

The structure of the RADIO_ERP2 packet is shown in Table 17 below. It is only supported for TCM 515U (902 MHz ERP2). Trying to use the RADIO_ERP2 packet with TCM 515 (868 MHz ERP1) will result in response 02: RET_NOT_SUPPORTED.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. Byte	0x55	
Header	1	2	Data Length	0xnnnn	Variable length of radio telegram
	3	1	Optional Length	0x02	2 fields fixed
	4	1	Packet Type	0x0A	RADIO_ERP2 = 10
-	5	1	CRC8H	0xnn	
Data	6	x	Raw data	… …	ERP2 radio protocol telegram without the first Length byte. The ERP2 CRC8 byte can be set to any value.
Optional Data	6+x	1	SubTelNum	0xnn	Number of sub telegrams Set to 0x03 (3 subtelegrams)
	7+x	1	dBm	0xnn	Set to 0xFF
	8+x	1	Security Level	0x0n	Will be ignored (Security is selected by link table entries)
-	8+x	1	CRC8D	0xnn	CRC8 Data byte; calculated checksum for DATA and OPTIONAL_DATA

Table 17 – ESP3 structure for RADIO_ERP2 packet used for transmission

Unlike for the RADIO_ERP1 packet, the maximum payload length of a RADIO_ERP2 packet is not restricted to 14 byte for the case of broadcast or 9 byte for the case of addressed transmission. The maximum payload length is limited only by the maximum ESP3 frame length supported by TCM 515 which is 255 byte.

TCM 515U will respond to the RADIO_ERP2 packet immediately with the RESPONSE message 00: RET_OK if it can transmit the message (correct format used in the command). TCM 515 will additionally send an event with code 0x08: CO_TX_DONE to the host as soon as the transmission of the telegram has been completed.

⚠ Note that the transmission of the three subtelegrams will last for up to 40 ms after receiving the RET_OK message as described in appendix A.3.2.
Do not shut-down TCM 515 before this period has elapsed or the CO_TX_DONE event has been received.

5.4 RADIO_MESSAGE packet for telegram transmission

TCM 515 supports RADIO_MESSAGE packets which allow the transmission of telegrams with more than 14 byte (broadcast) / 9 byte (addressed) of payload. Using RADIO_MESSAGE therefore allows using the same command for telegram transmission on all TCM 515 products irrespective of the payload length and the radio protocol that is used.

The structure of the RADIO_MESSAGE packet is shown in Table 18 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. Byte	0x55	
Header	1	2	Data Length	0xnnnn	Variable length of message
	3	1	Optional Length	0x09	Optional Data = 9 bytes
	4	1	Packet Type	0x09	RADIO_MESSAGE = 9
-	5	1	CRC8H	0xnn	
Data	6	1	Message RORG	0xnn	RORG
Data	7	x	Message Data	…	Message Data Content
Optional Data	7+x	4	Destination ID	0xnnnnnnnn	Destination ID Broadcast ID: FF FF FF FF
	11+x	4	Source ID	0xnnnnnnnn	Set to 0x00000000 for transmission
	15+x	1	dBm	0xnn	Set to 0xFF for transmission
	16+x	1	Security Level	0x0n	Ignored for transmission (Security is selected by link table entries)
-	13+x	1	CRC8D	0xnn	CRC8 Data byte; calculated checksum for DATA and OPTIONAL_DATA

Table 18 – ESP3 structure for RADIO_MESSAGE packet used for transmission

Unlike for the RADIO_ERP1 packet, the maximum payload length of a RADIO_MESSAGE packet is not restricted to 14 byte for the case of broadcast or 9 byte for the case of addressed transmission. The maximum payload length is limited only by the maximum ESP3 frame length supported by TCM 515 which is 255 byte.

TCM 515 will respond to the RADIO_MESSAGE packet immediately with the RESPONSE message 00: RET_OK if it can transmit the message (correct format used in the command).

If duty cycle lock is active (permissible duty cycle has been exceeded) and no transmission is possible then TCM 515 will respond with the RESPONSE message 05: RET_LOCK_SET. See chapter 5.6 for a description of the duty cycle limit functionality.

TCM 515 will send an event with code 0x08: CO_TX_DONE to the host as soon as the requested telegram transmission has been completed.

Note that the transmission of the three subtelegrams will last for up to 40 ms after receiving the RET_OK message as described in appendix A.3.2.
Do not shut-down TCM 515 before this period has elapsed or the CO_TX_DONE event has been received.

5.5 Using Base ID for transmission

As described in Appendix A.4.4, the use of Base ID allows TCM 515 modules to transmit messages using an ID different from its own EURID. Base ID is a legacy feature supported by TCM 515 for backwards compatibility and should not be used in new designs.

⚠ The use of Base ID is not supported for secure transmission, remote management (Reman) or Smart Acknowledgement (SmartAck).

The Base ID Range (128 addresses) of a device can be allocated anywhere in between `0xFF80:0000` and `0xFFFF:FFFE` (which represents a total range of approximately 8 million addresses). The location of the Base ID Range is defined by the start (lowest) address of the range which will always be aligned on a 7 bit (128) boundary, i.e. the last byte of the start address can be either `0x00` or `0x80`.

This start address is pre-configured randomly for each TCM 515 module during production but can be modified using the ESP3 command CO_WR_IDBASE shown in Table 19 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0005	5 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x07	0x07: CO_WR_IDBASE
	7	4	Base ID	0xFFnnnnnn	Range between 0xFF800000 and 0xFFFFFF80
-	11	1	CRC8D	0xnn	

Table 19 – CO_WR_IDBASE

Alignment is automatically enforced within TCM 515, i.e. if a non-aligned address is provided in the ESP3 command then TCM 515 will use the next lower aligned address as start address of the Base ID range.

⚠ Note that BASE ID cannot be guaranteed to be unique; especially in larger installations there is a significant likelihood that two devices might use the same BASE ID. Use of BASE ID is therefore not recommended for new designs.

5.6 Duty cycle limit (TCM 515 / 868.300 MHz variant only)

European radio regulation mandates that the duty cycle limits of radio transmitters have to be enforced by technical means. TCM 515 (868.3 MHz ERP1) therefore implements a hardware duty cycle monitor which enforces the regulatory duty cycle limit of 1% per hour.

The functionality of this monitor is as follows:

- Each 1 hour (3600 seconds) period is sub-divided into 10 time slots of 360 seconds each and during each time slot, the used transmission time is accumulated.
- The total used transmission time during the last hour is calculated as the sum of the transmission time of the last 10 time slots
- The total available transmission time within a one 1 hour period is 36 seconds (1% of 3600 s) and the remaining available transmission time is calculated as difference between 36 seconds and the total used transmission time during the last 10 time slots. This difference is the available transmission time in the current time slot.
- If the available transmission time reaches zero (no more transmission time available) then TCM 515 will not transmit any additional messages during this time interval. TCM 515 will respond with RET_LOCK_SET to the host if this requests transmission of additional telegrams in this case.
- After the current time slot elapses, the used transmission time of this time slot is added as first entry to the list, the last entry (the oldest time slot) is deleted from the list and the available transmission time for the next time slot is calculated.

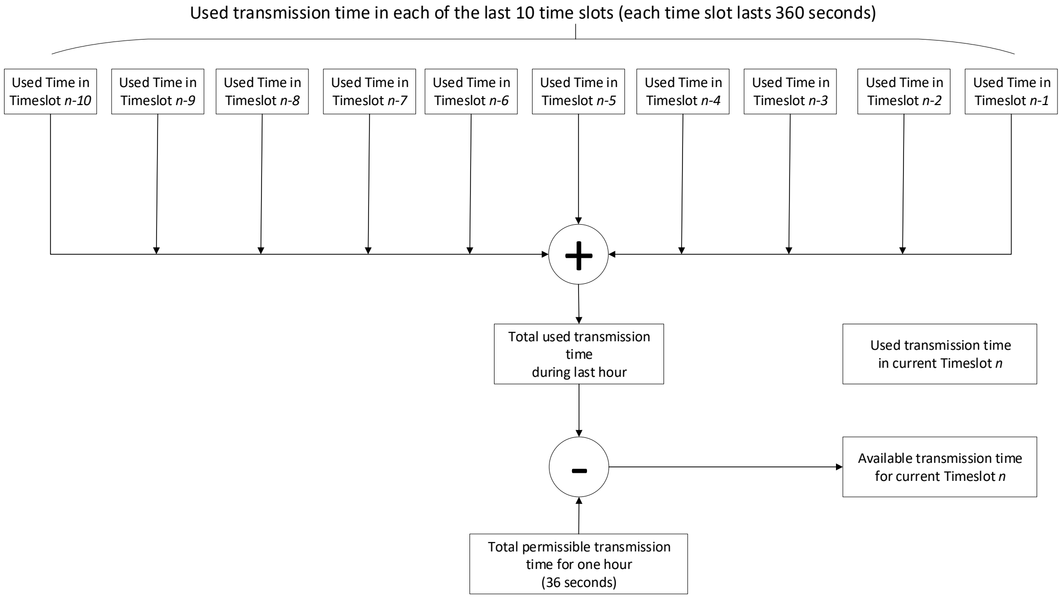

Used transmission time in each of the last 10 time slots (each time slot lasts 360 seconds)
Used Time in Timeslot n-10
Used Time in Timeslot n-9
Used Time in Timeslot n-8
Used Time in Timeslot n-7
Used Time in Timeslot n-6
Used Time in Timeslot n-5
Used Time in Timeslot n-4
Used Time in Timeslot n-3
Used Time in Timeslot n-2
Used Time in Timeslot n-1
+
Total used transmission time during last hour
Used transmission time in current Timeslot n
-
Available transmission time for current Timeslot n
Total permissible transmission time for one hour (36 seconds)

Figure 10 – Duty cycle monitor implementation

5.6.1 Determining available transmission time

The host can query the duty cycle status (available transmission time) using the ESP3 command CO_RD_DUTYCYCLE_LIMIT as shown in Table 20 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0001	1 byte
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x23	0x23: CO_RD_DUTYCYCLE_LIMIT
-	-	1	CRC8D	0xnn	

Table 20 – CO_RD_DUTYCYCLE_LIMIT

The response from TCM 515 will specify both the already used percentage of available transmission time within the current time slot (0% … 100%) and the remaining time (in seconds) until the start of the next time slot as shown in Table 21.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0008	8 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x02	0x02: RESPONSE
-	5	1	CRC8H	0xnn	
Data	6	1	Return Code	0x00	0x00: RET_OK
	7	1	Available duty cycle	0..0x64	Total load of the available 1% duty cycle (expressed from 0 ...100%)
	8	1	Slots	0xnn	Total number of duty cycle slots
	9	2	Slot period	0xnnnn	Period of one slot (in seconds)
	11	2	Actual slot left	0xnnnn	Time left in actual slot (in seconds)
	13	1	Load after actual	0..0x64	Load available when period ends (expressed from 0 ...100%)
-	14	1	CRC8D	0xnn	

Table 21 – Response to CO_RD_DUTYCYCLE_LIMIT

5.7 Transmit-only mode

As described in chapter 2.2, TCM 515 is in receive state whenever it is not transmitting a telegram or has not been put into Sleep state. In some applications such as simple button or sensor transmitters, TCM 515 is used only for transmission. In these cases, the additional power consumption in receive state or the added complexity of putting TCM 515 into Sleep state after each telegram transmission might not be desired.

Reception functionality can be disabled using the ESP3 command CO_WR_TX_ONLY_MODE so that TCM 515 operates as transmit-only device. Table 22 below shows the syntax of the CO_WR_TX_ONLY_MODE command.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0002	2 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x40	0x40: CO_WR_TX_ONLY_MODE
	7	1	Enable	0x00 0x01 0x02	0x00: RX / TX Mode (default setting) 0x01: TX-only Mode, Auto Sleep disabled 0x02: TX-only Mode, Auto Sleep enabled
-	8	1	CRC8D	0xnn	

Table 22 – Syntax for CO_WR_TX_ONLY_MODE command

If TX-only mode is active and Auto Sleep is disabled, then TCM 515 will transition into Idle state after completion of a transmission where it will be waiting for reception of the next ESP3 command requesting the transmission of a telegram. Once such command is received, TCM 515 will transmit the telegram, report the successful completion of a telegram transmission using the CO_TX_DONE event and then transition back to Idle state waiting for the next ESP3 command.

If TX-only mode is active and Auto Sleep is enabled, then TCM 515 will transition into indefinite Sleep state after completion of a transmission. In this configuration, TCM 515 will enter Sleep state in the same way as if it had received a CO_WR_SLEEP command with parameter 0x0000. TCM 515 will remain in Sleep state until it is woken up again via an ESP3 command.

Please refer to chapter 8 for a detailed description of Sleep state.

6 Telegram repeating

TCM 515 can act as repeater for all or selected radio telegrams. The repeating functionality is configured via ESP3 interface. Note that repeating functionality is not available if TCM 515 is configured to operate in transmit-only mode as described in chapter 5.7.

If TCM 515 is configured to act as repeater and it receives a radio telegram that it is configured to repeat, then TCM 515 will automatically transition from receive to transmit state to re-transmit (repeat) this telegram. After successful transmission, it will automatically transition back to receive mode.

TCM 515 provides the option to activate a one or two-level repeater for received EnOcean radio telegrams.

- One-level repeater: If a received telegram is a valid and original (not yet repeated), the telegram is repeated after a random delay.
- Two-level repeater: If a received telegram is valid and original or repeated once, the telegram is repeated after a random delay.

Repeated telegrams are marked as "repeated" by an increased repeater counter. Configuration of the repeater functionality is done via serial interface commands.

⚠ When using repeaters, care must be taken to ensure that regulatory transmitter duty cycle limits (if applicable) are not exceeded.

⚠ Two-level repeating function should only be activated after careful study of the radio conditions! Otherwise the system function can be compromised by collisions of telegrams.

For detailed recommendations regarding the usage of repeaters please refer to our application note EnOcean Wireless Systems - Installation Notes (PDF), 09/2010.

TCM 515 also provides selective repeating, i.e. the option to only repeat certain telegrams with match pre-defined filter criteria. The filter criteria that can be applied for repeating are the same as the ones for telegram reception, see chapter 4.2

6.1 Configuration of telegram repeating

The telegram repeating functionality of TCM 515 is configured using the ESP3 command CO_WR_REPEATER as shown in Table 23 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0003	3 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x09	0x09: CO_WR_REPEATER
	7	1	REP_ENABLE	0x00…0x02	0x00: No repeating 0x01: Repeating of all telegrams 0x02: Selective repeating
	8	1	REP_LEVEL	0x00…0x02	0x00: No repeating 0x01: One-level repeating 0x02: Two-level repeating
-	9	1	CRC8D	0xnn	

Table 23 – CO_WR_REPEATER

The repeater configuration (no repeating, one-level repeating, two-level repeating, selective repeating) is stored persistently in non-volatile memory and will therefore not be affected by a power cycle.

This mechanism enables the option of configuring USB stick repeaters on a PC via the ESP3 interface and then transferring them to a USB power supply for subsequent operation.

7 Security processing

TCM 515 implements the security handling functions as specified in the EnOcean security specification: https://www.enocean-alliance.org/sec/.
TCM 515 and TCM 515U can process secure messages from the following EnOcean products (note that the sender has to use the same radio frequency as the TCM 515 receiver):

- PTM 210 (from revision DC)
- PTM 215 / PTM 215U
- PTM 535 / PTM 535U
- STM 320 / STM 329 / STM 320U / EMCS / EMCSU (or similar with same profile)
- STM 330 / STM 331 / STM 332U / STM 333U (or similar with same profile)
- STM 350 / STM 350U / ETHS / ETHSU
- STM 550 / STM 550U / EMSIA / EMSIU
- EMDCA / EMDCU
- TCM 515 / TCM 515U

7.1 TCM 515 security architecture

TCM 515 supports all three security mechanisms outlined previously and can manage secure bi-directional connections to up to 32 remote devices using its secure link table.

For each such connection, TCM 515 maintains separate security keys and rolling codes for the communication to the remote device (outbound, transmission using KEY1 and RLC1) and for communication from the remote device (inbound, reception using KEY2 and RLC2) as discussed in chapter B.4.1.

Figure 11 below illustrates the two different directions of secure communication from the perspective of TCM 515.

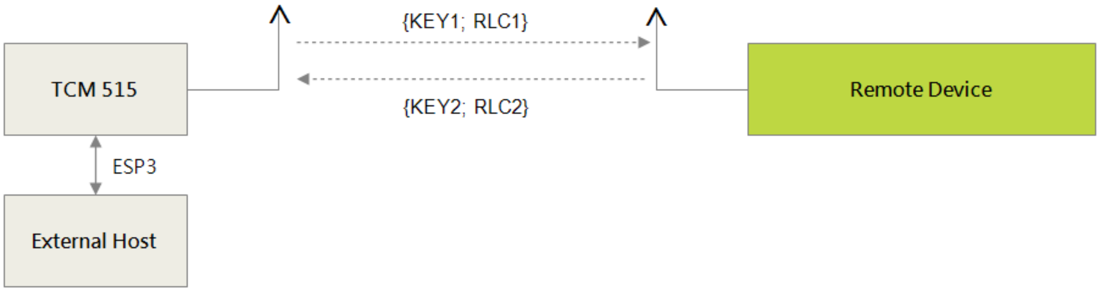


Figure 11 – Secure communication flow

7.2 Telegram processing flow

TCM 515 can automatically decrypt and authenticate messages originating from taught-in remote devices transmitting messages according to the EnOcean Network Security specification.

Security processing requires the receiver to know the security key and the latest rolling code counter. Therefore, this is only possible for devices that have previously been teached-in as discussed in chapter 7.7.

If a high security radio telegram is received from a device that has not been teched-in then TCM 515 will report forward the high security telegram without processing to the host for further analysis.

Figure 12 below illustrates the high-level processing flow for received EnOcean high security radio telegrams.

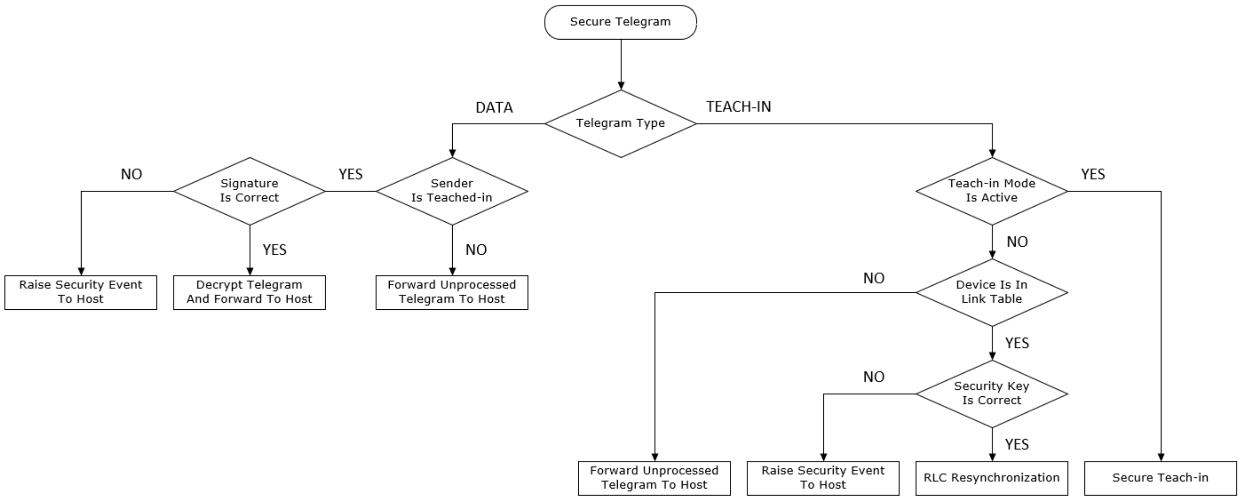


Figure 12 – TCM 515 high security telegram processing flow

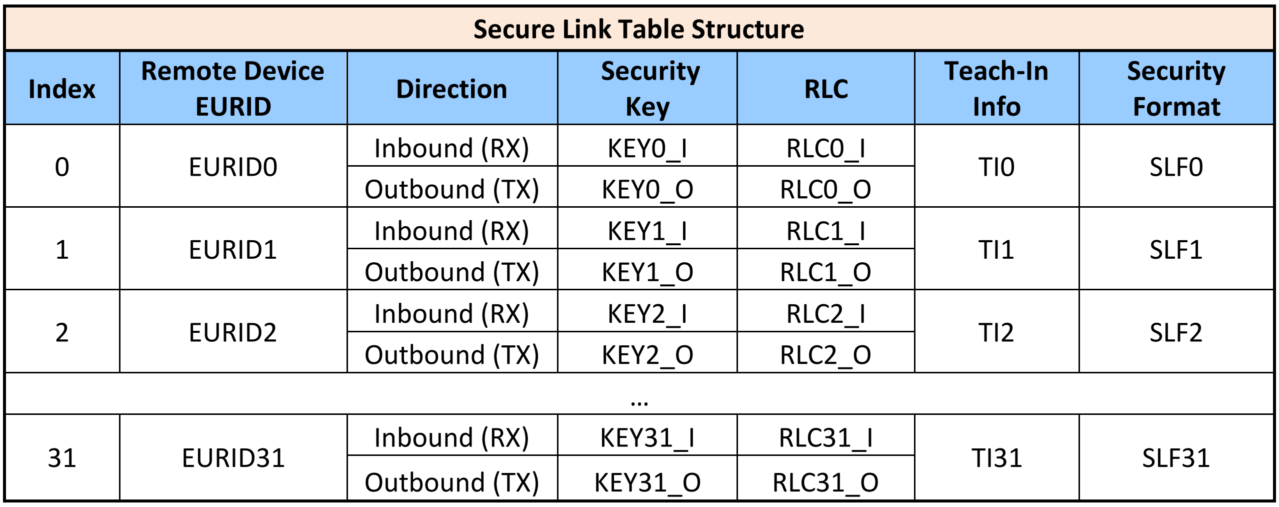
7.3 Secure link table

TCM 515 stores all required information for secure communication with a remote device in the secure link table. The secure link table can store up to 32 entries in order to manage secure connection to up to 32 remote devices.

For communication with more than 32 devices it is recommended to execute the security processing in the external host system.

⚠ Note that TCM 515 requires approximately 100 ms to process a secure link table update request (addition, removal or modification of a link table entry) which has been received via ESP3. Host SW has to provide a sufficient interval between ESP3 update request and any ESP3 command using the updated link table entry.

Figure 13 below shows the structure of the secure link table.



Secure Link Table Structure						
Index	Remote Device EURID	Direction	Security Key	RLC	Teach-In Info	Security Format
0	EURID0	Inbound (RX)	KEY0_I	RLC0_I	TI0	SLF0
		Outbound (TX)	KEY0_O	RLC0_O		
1	EURID1	Inbound (RX)	KEY1_I	RLC1_I	TI1	SLF1
		Outbound (TX)	KEY1_O	RLC1_O		
2	EURID2	Inbound (RX)	KEY2_I	RLC2_I	TI2	SLF2
		Outbound (TX)	KEY2_O	RLC2_O		
…						
31	EURID31	Inbound (RX)	KEY31_I	RLC31_I	TI31	SLF31
		Outbound (TX)	KEY31_O	RLC31_O		

Figure 13 – Secure link table structure

7.3.1 Secure link table parameters

Each entry in the secure link table contains the following parameters:

- Index
  The index indicates the location of the entry in the secure link table. The table will be filled starting with Index = 0 and is full once Index = 31

- Remote Device EURID
  This field contains the EURID (radio address) of the remote device with which TCM 515 can communicate based on the parameters for this entry

- Security Key
  This field contains the security key used by TCM 515 to transmit telegrams to the remote device (KEY_O) and the security key used by the remote device to transmit telegrams to TCM 515 (KEY_I)

- RLC
  This field contains the RLC used by TCM 515 to transmit telegrams to the remote device (RLC_O) and the RLC used by the remote device to transmit telegrams to TCM 515 (RLC_I)

- Teach-in Info
  This field contains information about the type of the remote device (specifically if this is a rocker switch or not and if A or B side of the rocker switch were used for teach-in)

- Security Level (SLF)
  This field contains the security level (SLF) which specifies the encryption, authentication and RLC parameters used for the communication with the remote device as described below. For bi-directional communication, the same SLF must be used for inbound (telegrams received by TCM 515 from the remote device) and outbound (telegrams transmitted by TCM 515 to the remote device) communication.

The security processing in TCM 515 supports both secure messages that specify the original telegram type (RORG) and those who don’t. Table 24 below summarizes the different RORG supported by TCM 515 security processing.

RORG	Description
0x30	Secure message that does not identify the type (RORG) of the encrypted telegram
0x31	Secure message that does identify the type (RORG) of the encrypted telegram
0x32	Message that results from the decryption of a secure message with RORG = 0x30 (secure message that does not identify the type (RORG) of the encrypted telegram)
0x33	Secure Chained Messages (SEC_CDM)
0x35	Secure Teach-in telegram (SEC_TI)

Table 24 – RORG supported by the security implementation in TCM 515

7.4 Telegram encryption and decryption

TCM 515 used the AES-128 algorithm together with a 16 byte security key and an RLC to encrypt and decrypt radio telegrams as described in chapter B.2.

TCM 515 supports both VAES and AES-CBC modes of the AES-128 algorithm. The mode which is used can be selected using the ENCRYPTION_ALGO field in the SLF described in chapter B.5.1.2.

Refer to the EnOcean Alliance Security Specification for details about the VAES and AES-CBC modes.

7.5 Telegram authentication

TCM 515 can authenticate the content of received telegrams based on the telegram signature (CMAC), the security key and a rolling code as described in chapter B.3.

Additionally, TCM 515 can calculate the signature and add it to transmitted telegrams according to the same mechanism.

TCM 515 supports signature lengths of 3 byte and 4 byte. The signature length that is transmitted as part of the telegram is defined by the CMAC_SIZE field in the SLF described in chapter B.5.1.2.

CMAC_SIZE encodes the following options:

- CMAC_SIZE = 0b00: No CMAC is included in the secure telegram
- CMAC_SIZE = 0b01: CMAC is a 3 byte long signature
- CMAC_SIZE = 0b10: CMAC is a 4 byte long signature

Refer to the EnOcean Alliance Security Specification for details about the CMAC modes.

7.6 RLC support

TCM 515 supports the use of RLC generated by a monotonously incrementing sequence counter as described in chapter B.4.

TCM 515 supports RLC sizes of 16 bit, 24 bit and 32 bit according to the setting of the RLC_MODE field in the SLF as described in chapter B.5.1.2.

Note that the 32 bit sequence counter size has been added by EnOcean Alliance in version 2.5 of the EnOcean Alliance Security Specification.

7.6.1 Explicit and implicit rolling code support

TCM 515 supports both explicit RLC mode and implicit RLC mode as described in chapter B.4.2.

The maximum number of RLC values that will be tested in implicit RLC mode (the RLC Window size) is 128 in TCM 515. The RLC window size can be temporarily changed (increased) in order to attempt resynchronization using ESP3 Command Code 33: CO_WR_TEMPORARY_RLC_WINDOW. This increased RLC window is only applied to the first telegram received for each address in the inbound link table after the reception of this command. Refer to the ESP3 documentation for reference.

If the RLC window has been exhausted without successfully decrypting and authenticating the telegram, then the telegram will be discarded. In order to re-synchronize the sequence counter between transmitter and receiver, the transmitter must send a teach-in telegram. The receiver – upon receiving a valid teach-in telegram from a previously taught-in transmitter – will adjust its own sequence counter to the one specified in the teach-in telegram.

Successful resynchronization of the RLC by means of a secure teach-in telegram will be indicated to the host by a CO_EVENT_SECUREDEVICES event with event type 0x0A (successful RLC resynchronization).

7.6.2 RLC roll-over

For the case of 16 bit or 24 bit RLC sizes, it is possible that the number of transmitted telegrams during the product lifetime exceeds the amount of possible RLC values. In this case, the sequence counter that generates the RLC will be reset to zero after reaching the maximum value (65535 for 16 bit RLC, 16.777.216 for 24 bit RLC) and start counting up again. This means that previously used RLC values will be used again and is called *RLC roll-over*. The case of RLC roll-over can be addressed in two ways:

1. Roll-over is not allowed and the only restriction for consecutive RLC values is that the most recently received one is higher than previously received ones.
   This mode is always used for the 32 bit explicit RLC modes and is the default setting for the 24 bit explicit RLC mode.

2. Roll-over is allowed but two consecutively received RLC values have to be no more than a certain value - called *RLC Window* - apart. The value of RLC Window is 128 in EnOcean devices.
   This mode is used for the 16 bit RLC modes and the 24 bit implicit RLC mode. It is an option for the 24 bit explicit RLC mode configurable via ESP3 command as described below.

It is possible to select which strategy is applied for the case of 24 bit explicit RLC mode with the first option (no roll-over allowed) being the default setting. It is possible to select the second option (roll-over allowed if within RLC window) using the ESP3 command CO_WR_RLC_LEGACY_MODE as shown in Table 25 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0002	2 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x37	0x37: CO_WR_RLC_LEGACY_MODE
Data	7	1	Legacy Mode	0x00 0x01	0x00: Default setting No roll-over allowed in 24 bit explicit RLC mode (SLF = 0b101), no restriction on distance between consecutive RLC 0x01: Legacy mode Roll-over allowed in 24 bit explicit RLC mode (SLF = 0b101), consecutive RLC must be within RLC WINDOW
-	8	1	CRC8D	0xnn	

Table 25 – CO_WR_RLC_LEGACY_MODE

7.6.3 RLC backup

The constant part of the secure link table entries (device addresses, security keys, security level format, teach-in info) is stored in non-volatile memory in order to preserve the content in case of a temporary power loss.

In contrast to that, the RLC values – which change for each transmitted or received telegram – are stored in internal volatile memory to optimize encryption and decryption performance since the storage to non-volatile memory requires a significant amount of time.

To account for the option of a power loss, it is necessary to periodically backup the RLC from volatile to non-volatile memory. The RLC value of a link table entry is by default backed up to non-volatile memory once for every 64 telegrams that have been sent (outbound RLC – RLC_O) or received (inbound RLC – RLC_I) for that entry.

Should TCM 515 encounter a power loss then the RLC value for each entry in the outbound link table will be incremented by 64 to account for the possibility that the last backup of the RLC might have occurred 63 telegrams ago (if power loss occurred directly before the next RLC backup).

If TCM 515 is continuously power-cycled such that it is only active during a brief period for the transmission of one or several telegrams, then the transmitted RLC will "jump" by up to 64 every time the device is powered up and transmits a telegram.

It is possible to change the rate at which the RLC is backed up to non-volatile memory from its default setting of 64 to a user-defined setting using the command CO_WR_RLC_SAVE_PERIOD as shown in Table 26.

⚠ Note that lowering the backup interval will increase the time spent for backing up the RLC values and thereby reduce the device performance. This function should therefore only be used if necessary.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0002	2 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x36	0x36: CO_WR_RLC_SAVE_PERIOD
Data	7	1	Save Period	0xnn	0x00: All RLC in the secure link table will be saved immediately 0x01..0xFF: RLC are saved every n times
-	8	1	CRC8D	0xnn	

Table 26 –CO_WR_RLC_SAVE_PERIOD

Using a Save Period of 0 in this command will result in TCM 515 backing up all RLC values in its link table to non-volatile memory leaving the RLC backup interval otherwise unchanged. This is intended for cases of expected power down where volatile data should be stored before power loss.

7.7 Teach-in of secure devices

When establishing secure communication, the sender and the receiver have to agree on the parameters to be used and exchange the security credentials (security key, current RLC value). This process is called *Secure Teach-in* or teach-in in short.

7.7.1 Security parameters

The following security parameters are used to define secure communication between a sender and a receiver:

- Security key
- RLC size and current value
- Signature (CMAC) size
- Security algorithm

Those parameters are described in the subsequent chapters and have to be setup by means of a secure teach-in procedure as described in chapter 7.7.2.

7.7.1.1 Security key

The security key is a random 128 bit (16 byte) value that is known only to the sender and the receiver(s). It is used to encrypt, decrypt and authenticate telegrams.

For the case of transmission, TCM 515 defines the security key that will be used to secure communication. It has to be generated by the external host using a suitable random number generation algorithm.

For the case of reception, the external sender defines the security key that will be used to secure communication.

7.7.1.2 RLC

The RLC is a monotonously incrementing counter used to modify the content of secure telegrams as described in chapter B.4. The RLC is generated by the sender and monitored by the receiver.

The receiver will store the most recently received RLC value and only accept telegrams with higher RLC values to avoid retransmission of previously transmitted messages.

7.7.2 Secure teach-in procedure

Secure teach-in can be performed in two different ways:

- Using a secure teach-in telegram if TCM 515 is in teach-in mode (see chapter 7.7.3) TCM 515 can automatically derive the required parameters for telegram encryption, decryption and authentication from such secure teach-in telegram.
  Conversely, TCM 515 can also be instructed via its ESP3 interface to transmit such secure teach-in telegram to a remote device.

- Using an ESP3 command (see Chapter 9)
  The required parameters for telegram encryption, decryption and authentication can also be configured TCM 515 can be configured via an ESP3 command

In both cases, the configured parameters have to be the same for both the sender and the receiver.

Until secure communication has been established, TCM 515 will forward received telegrams to the external host and transmit telegrams from the external host without security processing. If secure communication between a remote device and TCM 515 has been established, then TCM 515 will handle all security-related functionality such as encryption, decryption, authentication and RLC management. This greatly facilitates the implementation of secure communication in resource-constrained applications such as simple actuators.

7.7.3 Teach-in of secure devices with secure teach-in telegram

Teach-in is the process by which a remote device communicates to TCM 515 all parameters required to establish secure communication using a special radio telegram as described in Appendix B.5.1.

7.7.3.1 Transmission of a secure teach-in telegram

If the parameters for secure communication with a remote device have been setup in the outbound link table, then a secure teach-in telegram can be transmitted to that device using the CO_WR_SENDTEACHIN command as shown in Table 27 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0005	5 bytes
	3	1	Optional Length	0x00...0x01	1 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x20	0x20: CO_WR_SECUREDEVICE_SENDTEACHIN
	8	4	ID	0xnnnnnnnn	Device ID
Optional Data	8	1	TeachInInfo	0xnn	Teach-In Info
-	-	1	CRC8D	0xnn	

Table 27 – CO_WR_SECUREDEVICE_SENDTEACHIN

7.7.3.2 Reception of a secure teach-in telegram (Teach-in mode)

TCM 515 can be configured to automatically accept secure teach-in telegrams and store their parameters in the secure link table by enabling the so-called *Teach-in Mode*. Teach-in mode can be enabled for a specific time (the default setting is 60 seconds) using the CO_WR_LEARNMODE command shown in Table 28 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0006	6 bytes
	3	1	Optional Length	0x01	1 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x17	0x17: CO_WR_LEARNMODE
	7	1	Enable	0x0n	0x00: Stop Teach-in Mode 0x01: Start Teach-in mode
	8	4	Timeout	0xnnnnnnnn	Time-Out for Teach-in Mode in ms. When time is set to 0x00000000 then the default period of 60’000 ms is used
Optional Data	12	1	Channel	0xnn	0x00 ... 0xFD: Channel number (absolute) 0xFE Previous channel (relative) 0xFF Next channel (relative)
-	-	1	CRC8D	0xnn	

Table 28 – CO_WR_LEARNMODE

If a valid teach-in telegram is received while teach-in mode is active, then an entry with the corresponding parameters is added to the inbound secure link table.

TCM 515 will indicate successful teach-in with a CO_EVENT_SECUREDEVICES event message as described in chapter 7.8. Additionally, TCM 515 will indicate that the teach-in mode has ended by sending the Event CO_LRN_MODE_DISABLED shown in Table 29 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0001	1 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x04	0x04: EVENT
-	5	1	CRC8H	0xnn	
Data	6	1	Event Code	0x09	0x09: CO_LRN_MODE_DISABLED
-	7	1	CRC8D	0xnn	

Table 29 – CO_LRN_MODE_DISABLED

The maximum number of remote devices that can be teached-in is 32. Attempting to teach in additional devices will result in a CO_EVENT_SECUREDEVICES with error code 00 (Teach in failed, because no more space available).

If TCM 515 is not in teach-in mode and it receives a valid (same key, same SLF, same Teach-in Info) secure teach-in telegram then it will adjust its inbound RLC to the RLC specified within this secure teach-in telegram as described in chapter 7.7.3.3.

7.7.3.3 Handling of secure teach-in telegrams if teach-in mode is not active

If TCM 515 is not in teach-in mode, then secure teach-in telegrams from unknown senders are ignored.

If TCM 515 receives a secure teach-in telegram from a known (previously teched-in) sender containing the correct security key, then the sequence counter information in the TCM 515 secure link table is updated to the value specified in the telegram. This approach is used in case sequence counters of receiver and sender become desynchronized.

TCM 515 will indicate a successful sequence counter resynchronization using this mechanism by sending a CO_EVENT_SECUREDEVICES event message as described in chapter 7.8.

7.7.4 Teach-in of secure devices using ESP3

The security parameters required for secure communication with a remote device can also be setup by the external host via the ESP3 interface using the CO_WR_SECUREDEVICE_ADD command.

This approach is always used for the case of outbound communication (from TCM 515 to the remote device). This approach might also be used (instead of relying on secure teach-in telegrams) for inbound communication (from the remote device to TCM 515) if the relevant parameters are known to the local host. This could for instance be the case if the security information of the remote device has been read by the host from a QR code on the remote device.

The information provided will either be added to the inbound (reception) or to the outbound (transmission) link table depending on the value of the Direction field. For the case of addition to the outbound link table, setting the ID field to the own EURID (or 0x00000000) will cause the provided information to be used for secure broadcast transmissions. Otherwise, it will be used for secure addressed transmissions to the specified ID.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0019	25 bytes
	3	1	Optional Length	0x02	2 bytes
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x19	0x19: CO_WR_SECUREDEVICE_ADD
	7	1	SLF	0xnn	Security Level Format
	8	4	ID	0xnnnnnnnn	Device ID
	12	16	Private key	0xnnnnnnnn 0xnnnnnnnn 0xnnnnnnnn 0xnnnnnnnn	16 bytes private key of the device
	28	3	Rolling code	0xnnnnnn	If a 16 bit rolling code is defined in SLF, the MSB is undefined
Optional Data	31	1	Direction	0xnn	Add device security information to: 0x00: Inbound table (default) ID = Source EURID 0x01: Outbound table ID = Destination EURID Used for secure addressed telegrams ID = Own EURID or 0x00000000 Used for secure broadcast telegrams 0x02 ... 0xFF: Not used
	32	1	PTM Sender	0xnn	0x00: Not a PTM sender 0x01: PTM sender 0x02 … 0xFF: Not Used
	33	1	Teach-Info	0x0n	Secure device Teach-In info
-	-	1	CRC8D	0xnn	

Table 30 – CO_WR_SECUREDEVICE_ADD

Note that the CO_WR_SECUREDEVICE_ADD allows only adding devices using 2 byte or 3 byte rolling code size.

Due to the recent addition of the option for using 4 byte rolling code size into the EnOcean Alliance Security Specification, the new command CO_WR_SECUREDEVICEV2_ADD has been defined.

This command is supported starting with product revision DB-09 and uses the structure shown in Table 31 below.

Exactly as for the CO_WR_SECUREDEVICE_ADD command, the information provided will either be added to the inbound (reception) or to the outbound (transmission) link table depending on the value of the Direction field.

For the case of addition to the outbound link table, setting the ID field to the own EURID (or 0x00000000) will cause the provided information to be used for secure broadcast transmissions. Otherwise it will be used for secure addressed transmissions to the specified ID.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0018	27 bytes
	3	1	Optional Length	0x01	1 bytes
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x38	0x38: CO_WR_SECUREDEVICE2_ADD
	7	1	SLF	0xnn	Security Level Format
	8	4	ID	0xnnnnnnnn	Device ID
	12	16	Private key	0xnnnnnnnn 0xnnnnnnnn 0xnnnnnnnn 0xnnnnnnnn	16 bytes private key of the device
	28	4	Rolling code	0xnnnnnnnn	If a 24/16 bit rolling code is defined in SLF, then the MSBs are undefined
	32	1	Teach-Info	0xnn	Full SEC_TEACH_INFO, like defined in the security SPEC
Optional Data	31	1	Direction	0xnn	Add device security information to: 0x00: Inbound table (default) ID = Source EURID 0x01: Outbound table ID = Destination EURID Used for secure addressed telegrams ID = Own EURID or 0x00000000 Used for secure broadcast telegrams 0x02 ... 0xFF: Not used
-	48	1	CRC8D	0xnn	

Table 31 – CO_WR_SECUREDEVICE2_ADD

7.8 Reporting of security-related events

TCM 515 can report to the host the following security-related events by means of a CO_EVENT_SECUREDEVICES event using the structure shown below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0006	6 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x04	0x04: EVENT
-	5	1	CRC8H	0xnn	
Data	6	1	Event Code	0x05	0x05: CO_EVENT_SECUREDEVICES
	7	1	Event Type	0xnn	0x00: Teach in failed because no more space is available in the secure link table 0x02: Resynchronization attempt with wrong private key 0x03: Configured count of telegrams with wrong CMAC received 0x04: Teach-in failed due to incorrect teach-in telegram content or format 0x07: CMAC or RLC not correct 0x08: Standard telegram received from device in secure link table 0x09: Teach-In successful 0x0A: Received valid RLC sync via Teach-In Others: Reserved or not supported
	8	4	Device ID	0xnnnnnnnn	Device ID
-	12	1	CRC8D	0xnn	

Table 32 – Secure event reporting

The following reporting codes are supported by TCM 515:

- 0x00: Teach in failed, no more space is available in the secure link table
- 0x02: Resynchronization attempt with wrong private key
  Secure teach in telegram received with non-matching security key from device already in the link table
- 0x03: Configured count of telegrams with wrong CMAC received
  128 messages with wrong CMAC have been received from the same sender
- 0x04: Teach-In failed due to unexpected structure and content
- 0x07: CMAC or RLC not correct, the received CMAC did not match the expected CMAC after exhausting all RLC within the RLC window
- 0x08: Standard telegram received from device in secure link table
- 0x09: Teach-in successful
- 0x0A: Successful RLC resync via secure teach-in telegram

8 Low power sleep mode

TCM 515 can be set into a low power sleep mode for a defined period of time by means of the CO_WR_SLEEP command shown in Table 33 below. After expiry of the requested sleep period, TCM 515 will automatically wake-up and transition back to receive mode.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0005	5 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x01	0x01: CO_WR_SLEEP
	7	4	Deep sleep period	0x00nnnnnn	0x00000000: Wake by UART Supported from revision DB-09 0x00000001 … 0x00FFFFFF: Duration of sleep in 10 ms units (maximum value ~ 46h). After waking up, the module generates an internal hardware reset
-	11	1	CRC8D	0xnn	

Table 33 – CO_WR_SLEEP

It is possible to put TCM 515 into low power sleep mode indefinitely by using 0x00000000 as sleep period. TCM 515 will in this case remain in low power sleep mode until it is woken up by the external host via activity on the ESP3 interface.

Any activity on the ESP3 interface will wake-up TCM 515 in this case but the command used for wake-up will not be processed. Any ESP3 command can be used for the purpose of wake-up; it is suggested however to use a command without possible side effects such as CO_RD_VERSION.

9 ESP3 interface

TCM 515 provides an external interface according to the EnOcean Serial Protocol, version 3 (ESP3).

This interface is used both to exchange telegrams and command / status messages with an external host system (e.g. microcontroller or PC) and EnOcean gateway transceiver modules.

The information in the subsequent chapters as well as any previous references to specific ESP3 commands are provided for information purposes only. For detailed information, please refer to the ESP3 specification [1].

9.1 ESP3 physical interface

The physical interface used by ESP3 for communication between host system and an EnOcean Gateway Controller is a 3-wire full duplex UART / RS-232 connection (RX, TX, GND).

The standard UART baud rate is 57600 baud per second. TCM 515 supports a higher baud rate of 460800 baud per second which can be selected using the command CO_SET_BAUDRATE as shown in Table 34 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0002	2 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x24	0x24: CO_SET_BAUDRATE
	7	1	BAUDRATE	0xnn	0x00: 57600 baud 0x01: Not supported 0x02: Not supported 0x03: 460800 baud
-	-	1	CRC8D	0xnn	

Table 34 – CO_SET_BAUDRATE

Before changing the baud rate, please make sure that the connected host supports the selected setting; otherwise communication will be lost and the device has to be reset to restore the previous baud rate.

9.2 ESP3 packet structure

ESP3 is a point-to-point (one to one) protocol based on a packet data structure.
Figure 14 below illustrates the ESP3 packet structure.

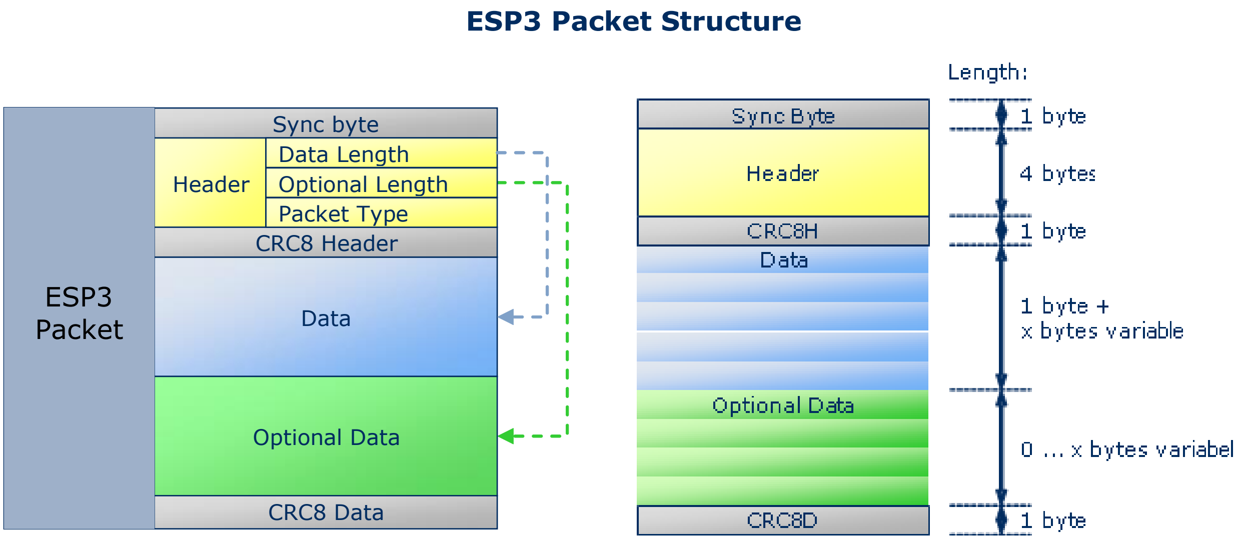


Figure 14 – ESP3 Packet Structure

Each ESP3 packet contains the following fields:

- Header
- Data
- Optional Data.

In addition to those fields, the Sync byte (`0x55`) identifies the start of the packet while separate CRC8 for Header and Data (incl. Optional Data) are used to verify data integrity.

The Header consists of the following fields:

- Data Length (number of bytes of the group Data)
- Optional Length (number of bytes of the group Optional Data)
- Packet Type (RADIO, RESPONSE, EVENT, COMMAND ...)

The Data field encodes the ESP3 command together with the required parameter data. For some commands, the Optional Data field is used to provide additional parameter data.

The maximum length of an ESP3 packet in TCM 515 is 255 byte.

9.3 Supported ESP3 commands

The following ESP3 commands are supported by TCM 515:

- Type 1: ERP1 Radio Telegram
- Type 2: Responses
  - RET_OK
  - RET_ERROR
  - RET_NOT_SUPPORTED
  - RET_WRONG_PARAM
  - RET_OPERATION_DENIED
  - RET_LOCK_SET
  - RET_BUFFER_TO_SMALL
  - RET_NO_FREE_BUFFER
- Type 4: Events
  - SA_CONFIRM_LEARN to confirm/discard SmartAck learn in/out
  - CO_READY to indicate wake up from deep sleep initiated by CO_WR_SLEEP
  - CO_EVENT_SECUREDEVICES to inform about security processing issues
  - CO_DUTYCYCLE_LIMIT to inform about a current limitation due to duty cycle
  - CO_TX_DONE to inform that the transmission of a telegram has completed
  - CO_LRN_MODE_DISABLED to inform that the learn mode has timed-out
- Type 5: Common commands
  - CO_WR_RESET to reset the device
  - CO_RD_VERSION to read SW/HW versions, chip ID etc.
  - CO_GET_FREQUENCY_INFO to read the operating frequency of the device
  - CO_WR_STARTUP_DELAY
  - CO_WR_SLEEP to put the device into low power sleep mode
  - CO_WR_IDBASE to set the Base ID range
  - CO_RD_IDBASE to read the Base ID range
  - CO_WR_REPEATER to set repeater functionality
  - CO_RD_REPEATER to read repeater functionality
  - CO_WR_FILTER_ADD to add filter to filter list or to selective repeating
  - CO_WR_FILTER_DEL and CO_WR_FILTER_DEL_ALL to delete filters
  - CO_RD_FILTER to read the configured filters
  - CO_WR_FILTER_ENABLE to enable/disable the configured filters
  - CO_WR_LEARNMODE to set teach-in mode
  - CO_RD_LEARNMODE to read teach-in mode status
  - CO_WR_WAIT_MATURITY to wait until the end of the maturity time
  - CO_RD_DUTYCYCLE_LIMIT to read the duty cycle (for 868 MHz EU version)
  - CO_SET_BAUDRATE to set the baud rate of the ESP3 interface
  - CO_WR_SECUREDEVICE_ADD to add a device to a link table
  - CO_WR_SECUREDEVICE_DEL to delete a device from a link table
  - CO_RD_SECUREDEVICE_COUNT to read the number of devices in a link table
  - CO_RD_SECUREDEVICE_BY_INDEX to read a link table entry using its index
  - CO_RD_SECUREDEVICE_BY_ID to read a link table entry using its EURID
  - CO_WR_SECUREDEVICE_SENDTEACHIN to send a secure teach-in telegram
  - CO_WR_RLC_SAVE_PERIOD to set the interval for the backup of RLC values
  - CO_WR_RLC_LEGACY_MODE to set the legacy RLC mode (window-based)

  - CO_WR_SECUREDEVICEV2_ADD to add a device to a link table
  - CO_RD_SECUREDEVICEV2_BY_INDEX to read a link table entry using its index
  - CO_WR_RSSITEST_MODE to enable RSSI test mode
  - CO_RD_RSSITEST_MODE to read the status of RSSI test mode
  - CO_WR_SECUREDEVICE_MAINTENANCEKEY to set the Reman security key
  - CO_RD_SECUREDEVICE_MAINTENANCEKEY to read the Reman security key
  - CO_WR_TRANSPARENT_MODE to enable transparent mode
  - CO_RD_TRANSPARENT_MODE to check if transparent mode is active
  - CO_WR_TX_ONLY_MODE to enable TX-only mode
  - CO_RD_TX_ONLY_MODE to check if TX-only mode is active

- Type 6 Smart Acknowledge commands (postmaster / mailbox functions)
  TCM 515 contains 19 Smart Acknowledge mailboxes which can be configured using the following commands:
  - SA_WR_LEARNMODE to set/reset Smart Acknowledge learn mode
  - SA_RD_LEARNMODE to get learn mode
  - SA_WR_LEARNCONFIRM to add or delete a mailbox of a client
  - SA_DEL_MAILBOX to delete a mailbox of a client
  - SA_WR_RESET to send a reset command to a client
  - SA_RD_LEARNEDCLIENTS to get learned mailboxes/clients
  - SA_WR_POSTMASTER to activate/deactivate post master functionality

- Type 7 Remote Management
  - Messages with up to 255 byte of payload

- Type 9 Radio Message (ERP1 or ERP2)
  - Messages with up to 255 byte of payload. TCM 515 will automatically chain (segment) / de-chain (reassemble) messages as needed based on the maximum payload size of EnOcean radio telegrams

9.4 Persistent versus not persistent configuration settings

TCM 515 will store certain configuration settings in persistent memory, i.e. those settings will be maintained even after a power cycle. The CO_WR_RESET command can be used to reset the persistent settings.

There are three classes of persistent settings:

1. Repeater and filter configuration
   The repeater and filter configuration defined via the following commands will be maintained after power failure:
   - CO_WR_REPEATER
   - CO_WR_FILTER_ADD
   - CO_WR_FILTER_DEL
   - CO_WR_FILTER_DEL_ALL
   - CO_WR_FILTER_ENABLE

2. List of secure devices as defined by the following commands:
   - CO_WR_SECUREDEVICE_ADD or CO_WR_SECUREDEVICEV2_ADD
   - CO_WR_SECUREDEVICE_DEL

3. System parameters as defined by the following commands:
   - CO_WR_STARTUP_DELAY
   - CO_WR_IDBASE
   - CO_WR_RLC_SAVE_PERIOD
   - CO_WR_TX_ONLY_MODE

All other settings need to be reinitialized at power up or after a reset.

10 Remote management

TCM 515 provides a transparent radio channel also for remote management messages with a message length of up to 255 bytes. This enables an external micro controller connected to TCM 515 to handle remote management request from external devices or to control other devices via remote management.

For more information on remote management please refer to the EnOcean End Equipment Profiles (EEP) specification [5] and the Remote Management specification [7].

11 Device integration

TCM 515 is designed for integration onto a host PCB. Detailed Gerber data of the device footprint is available from EnOcean.

11.1 Recommended PCB Footprint

Figure 15 below shows the recommended PCB footprint for TCM 515.

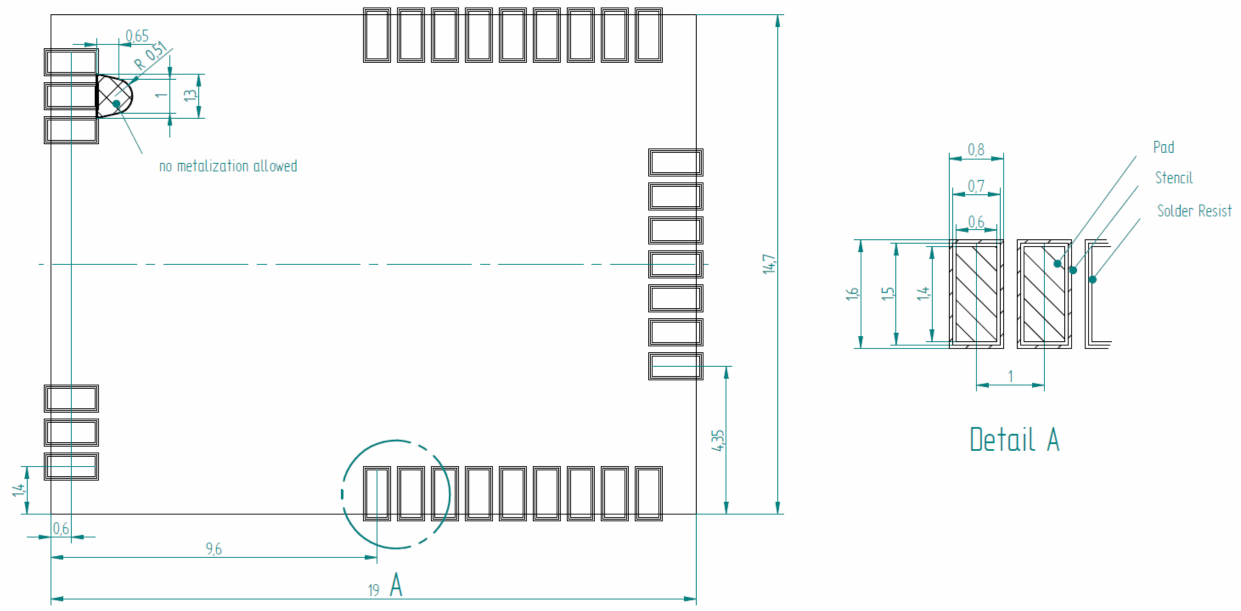


Figure 15 – Recommended PCB footprint

11.2 Device outline

Figure 16 below shows the device outline of TCM 515. In addition, EnOcean can provide upon request a 3D model of TCM 515.

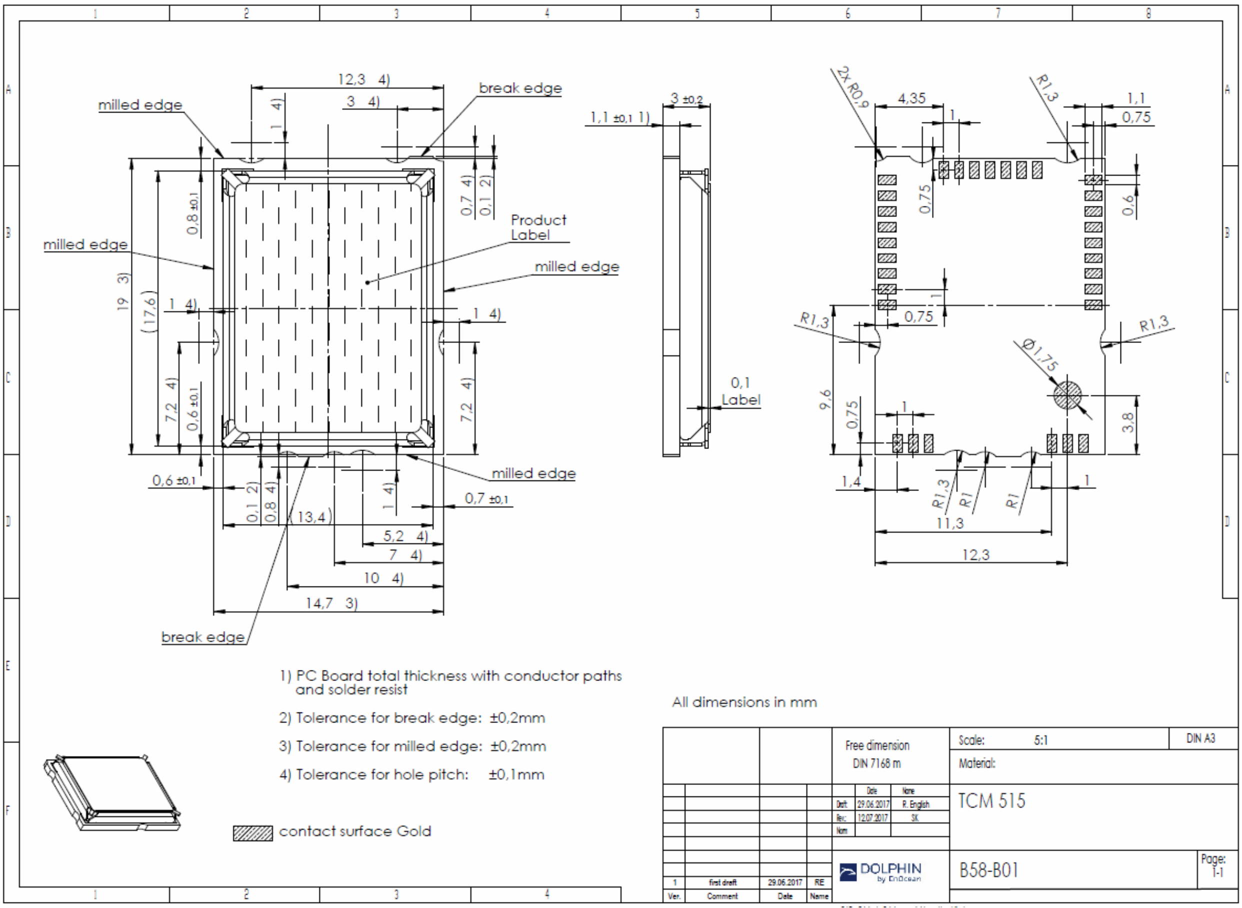


Figure 16 – Device outline

11.3 Soldering information

TCM 515 shall be soldered according to IPC/JEDEC J-STD-020C standard.

Profile Feature	Pb-Free Assembly
Average Ramp-Up Rate (Ts_{max} to Tp)	3° C/second max.
Preheat – Temperature Min (Ts_{min}) – Temperature Max (Ts_{max}) – Time (ts_{min} to ts_{max})	 150 °C 200 °C 60-180 seconds
Time maintained above: – Temperature (T_L) – Time (t_L)	 217 °C 60-150 seconds
Peak/Classification Temperature (Tp)	260 °C
Time within 5 °C of actual Peak Temperature (tp)	20-40 seconds
Ramp-Down Rate	6 °C/second max.
Time 25 °C to Peak Temperature	8 minutes max.

Note 1: All temperatures refer to topside of the package, measured on the package body surface.

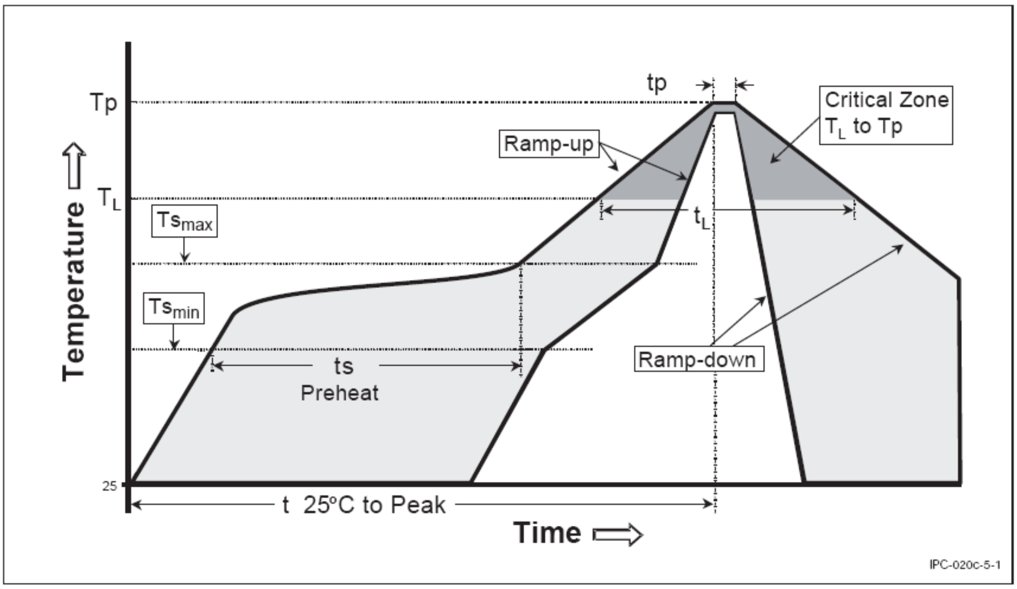


Figure 17 – Recommended soldering profile

TCM 515 shall be handled according to Moisture Sensitivity Level MSL4 which means a floor time of 72 h. TCM 515 may be soldered only once, since one time is already consumed at production of the module itself.

Once the dry pack bag is opened, the desired quantity of units should be removed and the bag resealed within two hours. If the bag is left open longer than 30 minutes the desiccant should be replaced with dry desiccant. If devices have exceeded the specified floor life time of 72 h, they may be baked according IPC/JEDEC J-STD-033B at max. 90°C for less than 60 h.

Devices packaged in moisture-proof packaging should be stored in ambient conditions not exceeding temperatures of 40 °C or humidity levels of 90% r.H.

TCM 515 modules shall be soldered within 6 months after delivery!

11.4 Packaging information

TCM 515 is delivered in Tape & Reel packaging with 250 units per reel. Figure 18 below illustrates the dimensions.

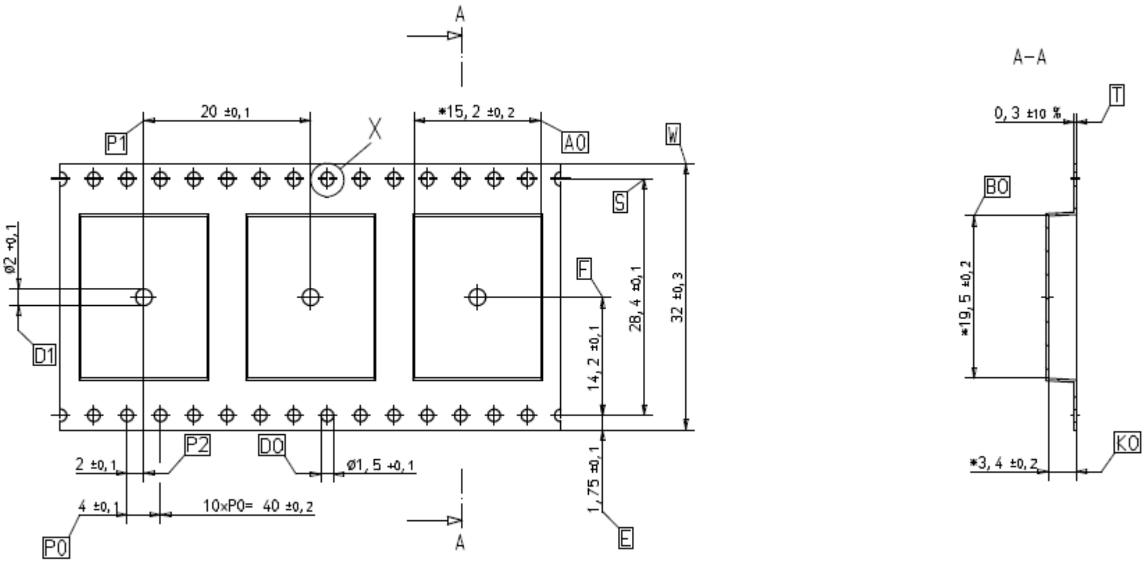


Figure 18 – Tape & Reel dimensions of TCM 515

Figure 19 below shows the positioning of TCM 515 in the Tape & Reel packaging.

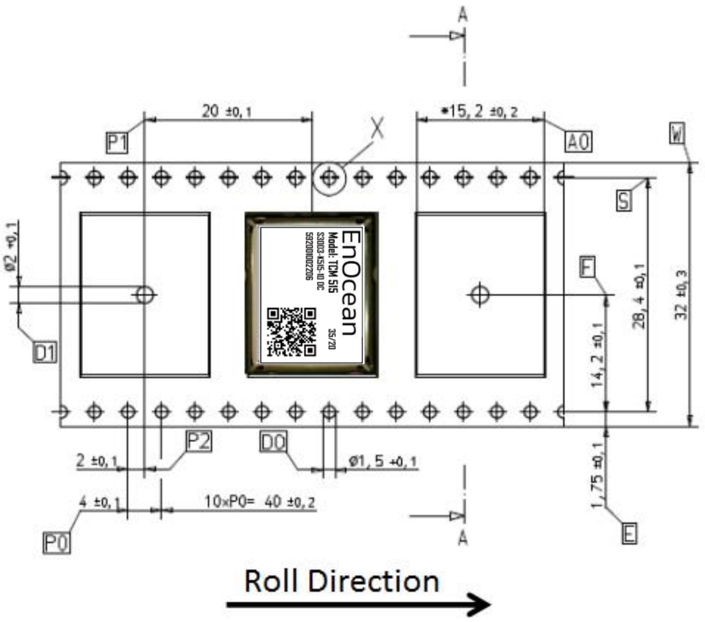


Figure 19 – Position of TCM 515 in the reel

11.5 Layout recommendations

⚠ The length of lines connected to I/O signals should not exceed 5 cm.

⚠ It is recommended to have a complete GND layer (for instance the mid-layer of your application PCB) at least in the area below the module and the directly connected components.

⚠ Due to non-isolated test points, there are live signals accessible on the bottom side of the module. We suggest avoiding any copper structure in the area directly underneath the module (top-layer layout of your application PCB). If this is not possible in your design, please provide coating on top of your PCB to prevent short circuits to the module. All bare metal surfaces including vias must be covered (for instance by using an adequate layout of solder resist).

⚠ Distortive signals (such as input or output signals, signals from other radio transmitters or signals from switched power supplies) should not be routed underneath the module. If such signals are present in your design, we suggest separating them from the TCM 515 module as much as possible and to provide a ground plane between the TCM 515 module and such signal lines.

11.6 Power supply requirements

Suitable power supply design, layout and shielding is essential to optimize the radio performance of TCM 515. It is recommended to place a 22 µF ceramic capacitor between VDD and GND close to the module (material: X5R, X7R, min 6.3 V to avoid derating effects).

In addition, an HF SMD EMI Suppression Ferrite Bead such as the Würth WE-CBF HF SMD EMI Suppression Ferrite Bead (Würth order number 742863160) shall be inserted in the power supply line.

For best performance it is recommended to keep the ripple on the power supply rail below 10 mVpp.

Radiated emissions from power supplies (especially DCDC designs) towards the TCM 515 RF input must be minimized as they can significantly impact RF performance. Place such power supplies as much as possible away from the radio path between antenna and TCM 515 or consider using designs with low RF emissions.

TCM 515 integrates approximately 10 uF of capacitance for filtering the internal supply voltage bus. The power supply architecture needs to be designed to supply sufficient current to charge this capacitance during power up.

11.7 Low noise design considerations

For best performance, the HW design of TCM 515 systems must minimize radiated or conducted noise that interferes with the correct reception of RF signals. Strong emphasis should be placed onto good RF and power supply design to eliminate or minimize the level of noise introduced into the RF path.

In addition, special consideration should be used to minimize periodic noise sources (such as radiated noise from DCDC inductors or from high data rate input or output signals) in TCM 515 based systems. TCM 515 (868.300 MHz ASK) transmits and receives signals using amplitude shift keying where the amplitude of a carrier frequency (868.300 MHz) is changed according to the encoded bit value (0 = high amplitude or 1 = low amplitude).

Periodic noise signals where the period between high and low signal states is close to the symbol duration of 8 us can be erroneously interpreted as the preamble of an ASK telegram (10101010 sequence) and therefore prevent correct reception of other ASK telegrams that are received at the same time.

Suitable RF design techniques such as a good separation between signal lines and the RF path, a ground plane in the PCB layout as well as decoupling and filtering on the power supply should be used to minimize the radio performance degradation due to noise.

11.8 Suggested Reset circuit

TCM 515 can be reset by pulling the nRESET pin (active low) to Ground. TCM 515 integrated a weak (50kΩ) pull-up resistor that will maintain the internal nRESET input active high (not active).

In order to avoid spurious reset events, it is recommended to filter the input signals by means of a small capacitor which is placed as close as possible to the TCM 515 nRESET pin as shown in Figure 20 below.

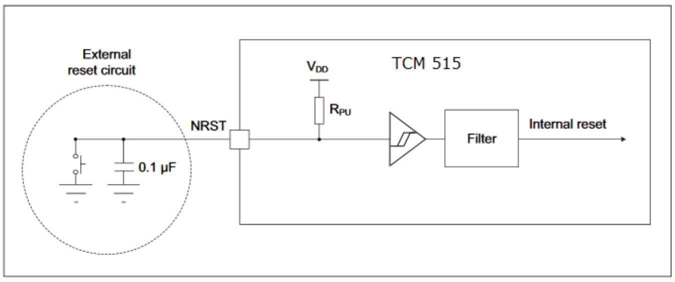


Figure 20 – Recommended reset circuit

The reset pulse should have a duration of at least 1 ms to guarantee reliable reset operation.

11.9 Test interface

TCM 515 provides 3 test points (TP1, TP2, TP3) which together with the RESET, UART_TX and UART_RX signals can be used for product test and debug.

⚠ It is strongly recommended to make the pins TP1, TP2, TP3, nRESET, UART_TX and UART_RX together with VDD and GND accessible to external devices - e.g. by means of providing suitable test point pads on the PCB – for the purpose of debug and analysis.

11.10 Identifying the TCM 515 product revision

Several new functions – such as support for the latest security modes - have been introduced as product updates to TCM 515 and will only be supported by certain product revisions.

The connected host can determine the TCM 515 product revision using the CO_GET_STEP-CODE command as shown in Table 35 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0001	1 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x05	0x05: COMMON_COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x27	0x27: CO_GET_STEPCODE
-	7	1	CRC8D	0xnn	

Table 35 – CO_GET_STEPCODE

TCM 515 will respond to this command with a response as shown in Table 36 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0003	3 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x02	0x02: RESPONSE
-	5	1	CRC8H	0xnn	
Data	6	1	Return Code	0x00	0x00: RET_OK
	7	1	Step code	0xnn	e.g. 0xDA ,0xCA …
	8	1	Status code	0xnn	e.g. 0x01, 0x02 …
-	9	1	CRC8D	0xnn	

Table 36 – Response to CO_GET_STEPCODE

12 Antenna options

This chapter outlines options for antenna that can be used with TCM 515. Note that this chapter is for guidance purposes only, please consult with an authorized certification body for specific information.

12.1 Antenna options for 868 MHz (European Union)

In order to be compliant with the Radio Equipment Directive (RED) of the European Union, an antenna needs to fulfil at least following requirements to be usable with TCM 515:

Frequency band	868.300 MHz ISM	Antenna must be suited for this band
Antenna type	Passive	Mandatory for radio approval
Impedance	~50 Ohm	Mandatory for radio approval
Maximum	≤ 0 dBd	Mandatory for radio approval

In addition, it is important to fulfill the following requirements in order to achieve compatibility with other EnOcean products and to ensure EMI robustness:

VSWR	≤ 3:1	Important for compatibility with EnOcean protocol
Return Loss	> 6 dB	Important for compatibility with EnOcean protocol
Bandwidth	≤ 20 MHz	Important if 10 V/m EMI robustness required for device

See chapter 14.1 for additional important remarks regarding RED certification.

12.1.1 Whip antenna

TCM 515 modules have been certified for use with a whip antenna under EU (RED) regulations. Figure 21 below shows key whip antenna parameters.

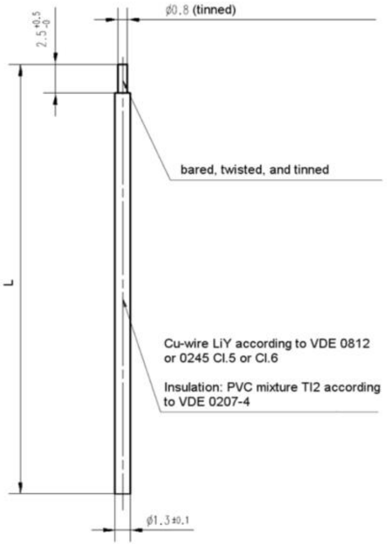

ø0.8 (tinned)
2.5 +0.5 -0
L
bared, twisted, and tinned
Cu-wire LiY according to VDE 0812
or 0245 Cl.5 or Cl.6
Insulation: PVC mixture TI2 according
to VDE 0207-4
ø1.3±0.1

Figure 21 – Whip antenna parameters

The whip antenna be implemented with the following parameters in order to be compliant to the regulations mentioned above:

- Antenna length (L): 86 mm wire, connect to RF_50
- Minimum size of GND plane: 38 mm x 18 mm
- Minimum distance between antenna and ground plane (d): 10 mm

The whip antenna should ideally be mounted vertically as shown on the left side of Figure 22. If this is not possible then the whip antenna should be placed such that a minimum distance *d* between GND plane and antenna is provided.

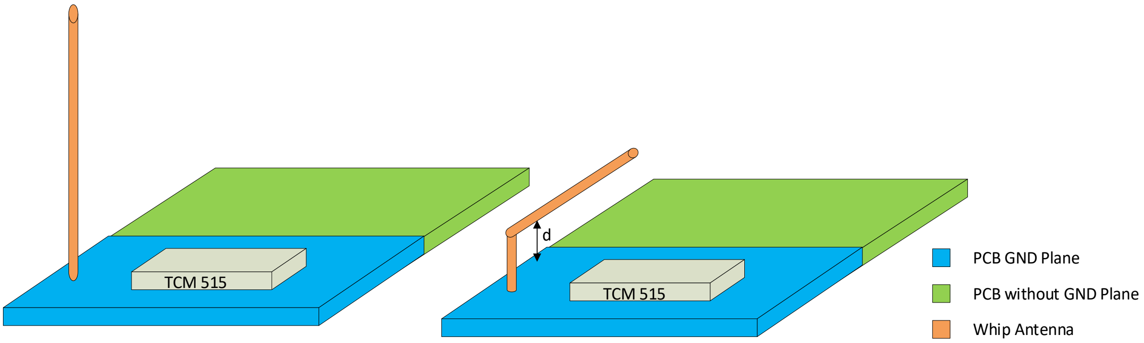


Figure 22 – Whip antenna positioning

13 Application information

13.1 Transmission range

The main factors that influence the system transmission range are:

- Type and location of the antennas of receiver and transmitter
- Type of terrain and degree of obstruction of the link path
- Sources of interference affecting the receiver
- "Dead spots" caused by signal reflections from nearby conductive objects.

Since the expected transmission range strongly depends on this system conditions, range tests should always be performed to determine the reliably achievable range under the given conditions. The following figures should be treated as a rough guide only:

- Line-of-sight connections
  Typically 30 m range in corridors, up to 100 m in halls
- Plasterboard walls / dry wood
  Typically 30 m range, through max. 5 walls
- Ferro concrete walls / ceilings
  Typically 10 m range, through max. 1 ceiling
- Fire-safety walls, elevator shafts, staircases and supply areas
  Such areas should be considered as screening.

The angle at which the transmitted signal hits the wall is very important. The effective wall thickness – and with it the signal attenuation – varies according to this angle. Signals should be transmitted as directly as possible through the wall. Wall niches should be avoided. Other factors restricting transmission range include:

- Switch mounting on metal surfaces (up to 30% loss of transmission range)
- Hollow lightweight walls filled with insulating wool on metal foil
- False ceilings with panels of metal or carbon fibre
- Lead glass or glass with metal coating, steel furniture

The distance between the receiver and other transmitting devices such as computers, WiFi routers, audio and video equipment that also emit high-frequency signals should be at least 0.5 m.

13.2 RSSI reporting

TCM 515 will report the signal strength (RSSI) for received telegrams as part of the ERP1 or ERP2 radio packet. This information can be treated as an indicator for the quality of the radio link keeping in mind that this is affected by several factors such as temporary fading or obstructions.

The RSSI reporting of TCM 515 (868.300 MHz ASK radio) works within a range from -95 dBm up to -40 dBm with a typical accuracy of +- 2dBm.

⚠ Due to limitations of the RSSI detection functionality for ASK radio signals, the RSSI level reported by TCM 515 might under certain conditions be that of the low power state - and therefore significantly too low - as the signal strength of the low power state can sometimes be strong enough to trigger the RSSI detection mechanism.

14 Regulatory information

TCM 515 has been tested according to standards for RED (European Union) certification, FCC (US) and ISED (Canada) regulations.

14.1 RED (European Union)

The Radio Equipment Directive (2014/53/EU, typically referred to as RED) replaces the old R&TTE directive from 1999 as regulatory framework for radio products in the European Union. All products sold to final customers after 12th of June, 2017 have to be compliant to RED.

At the time of writing, the text of the RED legislation was available from this link:
http://eur-lex.europa.eu/eli/dir/2014/53/oj

Radio modules such as TCM 515 are components which are delivered to OEM manufacturers for their use in final or combined products.

It is the responsibility of the OEM manufacturer to demonstrate compliance to all applicable EU directives and standards. The attestation of conformity for TCM 515 serves as input to the declaration of conformity for the full product.

At the time of writing, guidance on the implementation of EU product rules – the so called "Blue Guide" – was available from this link:
http://ec.europa.eu/DocsRoom/documents/18027/

Specifically within the new RED framework, all OEM manufacturers have for instance to fulfill the following additional requirements:

- Provide product branding (on the product) clearly identifying company name or brand and product name as well as type, charge or serial number for market surveillance
- Include (with the product) documentation containing full postal address of the manufacturer as well as radio frequency band and max. transmitting power
- Include (with the product) user manual, safety information and a declaration of conformity for the final product in local language
- Provide product development and test documentation upon request

Please contact an accredited test house for detailed guidance.

The maximum transmitting power of TCM 515 using a whip antenna is +10.8 dBm.

15 References

Please use below references for an in-depth description of features supported by TCM 515.

[1] EnOcean Serial Protocol 3

[2] EnOcean Radio Protocol 1 (ERP1)

[3] EnOcean Radio Protocol 2 (ERP2)

[4] Security of EnOcean Radio Networks

[5] EnOcean Equipment Profiles

[6] Signal Telegram

[7] Remote Management

16 Product history

Table 37 below outlines the product history of TCM 515 and indicates key changes made between different revisions.

Revision	Release	Key features / changes
TCM 515 CC-03	Mar 2017	- First product prototypes for lead customer evaluation
TCM 515 DA-04	Jul 2017	- First release of TCM 515 with TCM 310 equivalent functionality - Introduction of option for repeated Reman telegrams - Introduction of CO_GET_STEPCODE feature
TCM 515 DA-05 TCM 515U DA-01	Nov 2017	- First release of TCM 515U - Introduction of end to end security support (encryption, decryption and authentication) - Bug fix for duty cycle supervisor
TCM 515 DA-06 TCM 515U DA-02	Jan 2018	- Implementation of customer enhancement requests for security processing (identification of processed telegrams via ESP3, rejection of standard telegrams from devices in secure link table, support for secure telegram broadcast, option to determine number of remaining link table entries) - Introduction of adjustable noise filter functionality
TCM 515 DA-07 TCM 515U DA-03	Mar 2018	- Bug fix: Incorrect radio ID handling might lead to use of wrong source ID when responding to SYS_EX messages
TCM 515 DB-08 TCM 515U DB-04	Aug 2018	- Persistent repeater and filter settings (no reinitialization needed after power cycle)
TCM 515 DB-09 TCM 515U DB-05	Aug 2019	- Support for new security features defined in EnOcean Alliance Security spec v2.5 - Start-up time optimization - Adjustable RLC storage interval - Option for HW wake-up from Sleep via ESP3 activity
TCM 515 DC-10 TCM 515U DC-06	Aug 2020	- Added support for SEC_CDM - Added TX-only mode - Added Transparent Mode - Increased maximum allowed input power in RX mode from -23 dBm to -17 dBm - Added event to indicate end of teach-in mode - Added event to indicate successful secure teach-in - Added event to indicate completion of telegram transmission - Added event code to CO_READY to indicate successful wake-up from Sleep - Added RSSI test mode
TCM 515 DD-18	Jun 2021	- Addition of an integrated SAW filter - Addition of an integrated amplifier - Automatic control of the noise threshold - CO_TX_DONE event restricted to host-initiated transmissions - CO_WR_RESET resets persistent parameters - Reduction of sleep current (from 50 uA to 5 uA)

Table 37 – TCM 515 product history

A. Introduction to EnOcean radio protocol

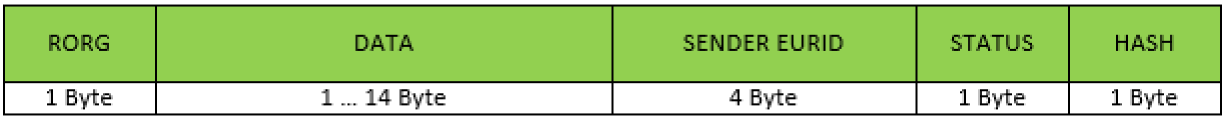
This chapter gives a high-level introduction to key aspects of the EnOcean radio protocol to help the understanding of TCM 515 features. Refer to the EnOcean Radio Protocol 1 (ERP1) specification [2] and the EnOcean Radio Protocol 2 (ERP2) specification [3].

Devices within the EnOcean ecosystem communicate using the EnOcean Radio Protocol (ERP). Two versions of this radio protocol are in use today – ERP version 1 (ERP1 in short) is used for 868.3 MHz radio systems in Europe while ERP version 2 (ERP2 in short) is used for 902.875 MHz radio systems in the US / Canada and 928.35 MHz radio systems in Japan.

Note that EnOcean radio transceivers such as TCM 310 or TCM 515 will by default convert received ERP1 and ERP2 telegrams into the same RADIO_ERP1 packet type so that the difference between ERP1 and ERP2 is transparent to the connected host.

A.1 ERP1 telegram format

The ERP1 telegram format is shown in Figure 23 below for the case of a broadcast telegram.



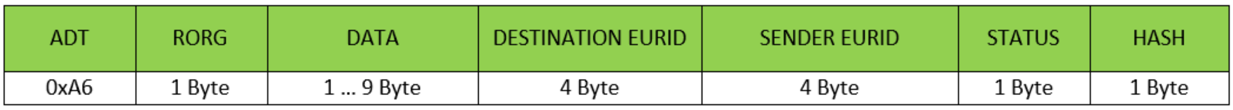
RORG	DATA	SENDER EURID	STATUS	HASH
1 Byte	1 … 14 Byte	4 Byte	1 Byte	1 Byte

Figure 23 – ERP1 telegram format for broadcast telegrams

An ERP1 telegram contains the following fields:

- RORG specifies the EEP or SIGNAL type used by this telegram
- DATA contains the telegram payload
- SENDER EURID specifies the address of the sender
- STATUS specifies transmission properties such as the repeater hop count
- HASH is used to verify the integrity of the telegram

It is possible to specify the intended receiver (the destination) of a telegram by prefixing the telegram content with the R-ORG 0xA6 (ADT = Addressed Data Telegram) to indicate that a destination address is present and including the DESTINATION EURID before the SENDER EURID as shown in Figure 24 below.

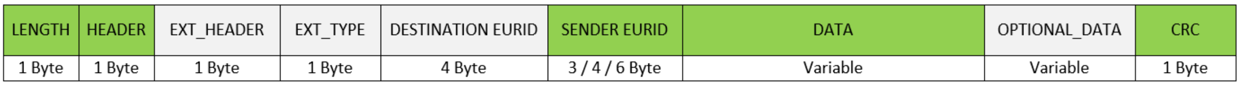


ADT	RORG	DATA	DESTINATION EURID	SENDER EURID	STATUS	HASH
0xA6	1 Byte	1 … 9 Byte	4 Byte	4 Byte	1 Byte	1 Byte

Figure 24 – ERP1 telegram format for addressed telegrams

A.2 ERP2 telegram format

The ERP2 radio telegram format is shown in Figure 25 below.



LENGTH	HEADER	EXT_HEADER	EXT_TYPE	DESTINATION EURID	SENDER EURID	DATA	OPTIONAL_DATA	CRC
1 Byte	1 Byte	1 Byte	1 Byte	4 Byte	3 / 4 / 6 Byte	Variable	Variable	1 Byte

Figure 25 – ERP2 Telegram Format

The ERP2 telegram contains the following fields:

- LENGTH specifies the total length of the ERP2 radio telegram
- HEADER specifies the EURID types and sizes, the RORG that is used (based on a selection of the most common EEP) and specifies if EXT_HEADER is present
- EXT_HEADER specifies the repeater count and the length of OPTIONAL_DATA. It is an optional field that might be omitted by energy-constrained devices
- EXT_TYPE specifies less common RORG which are not available within the HEADER field
- SENDER EURID specifies the device address of the sender
- DESTINATION EURID can be used to specify the device address of the intended recipient of a data telegram (optional)
- DATA contains the telegram data
- OPTIONAL_DATA can be used to transmit additional data that should be treated separately from the main telegram data (optional)
- CRC is used to verify the integrity of the telegram

A.3 Subtelegrams

EnOcean radio systems use the concept of redundant subtelegrams in order to increase the communication reliability. In addition to using redundant transmissions, first and second level repeaters can be used to increase communication distance and reliability as described in chapter 6.

Within this scheme, telegrams are transmitted redundantly with random (but small) delays between them. The total number of redundant subtelegrams can be either two or three.
Certain telegram types (e.g. those used in very limited energy scenarios such as SMART_ACK) do not support redundant transmission, i.e. they are transmitted only once.

If a telegram is transmitted redundantly as set of two or three subtelegrams then the first subtelegram is sent immediately upon receiving and processing the ESP3 command for telegram transmission.

The timing offset between this first subtelegram and the remaining (second or third) subtelegrams is random within pre-defined time intervals.

A.3.1 Subtelegram timing

EnOcean Radio Protocol 1 (ERP1) and EnOcean Radio Protocol 2 (ERP2) uses a repeater-level dependent time slot mechanism for the subtelegram timing during transmission.

The sender of a radio telegram will transmit the first telegram immediately upon receiving the request for transmission. After that, the time offset (interval) between the first subtelegram and the second subtelegram is a random value between 1 ms and 9 ms. Likewise, the time offset (interval) between the first subtelegram and the third subtelegram is a random value between 20 ms and 39 ms.

For the first-level repeater (which received the telegram from the sender), the time offset (interval) between the reception of the telegram and the transmission of the first subtelegram is a random value between 10 ms and 19 ms. Likewise, the time offset (interval) between the reception of the telegram and the second subtelegram is a random value between 20 ms and 29 ms.

For the second-level repeater (which received the telegram from the first-level repeater), the time offset (interval) between the reception of the telegram and the transmission of the first subtelegram is a random value between 0 ms and 9 ms. Likewise, the time offset (interval) between the reception of the telegram and the second subtelegram is a random value between 20 ms and 29 ms.

Both first and second level repeaters do not transmit a third subtelegram. The standard subtelegram timing is summarized in Table 38 below. It is used both by TCM 515 and TCM 515U.

Repeater Level	Time Offset [ms] First Subtelegram	Time Offset [ms] Second Subtelegram	Time Offset [ms] Third Subtelegram
0 (Original Telegram)	0	1 … 9	20 … 39
1 (Repeated for the first time)	10 … 19	20 … 29	No 3rd Subtelegram
2 (Repeated for the second time)	0 … 9	20 … 29	No 3rd Subtelegram

Table 38 – Standard subtelegram timing

Certain countries have regulatory limitations for the total duration of a radio transmission in certain frequency bands including those used by EnOcean products. For these cases, a compressed subtelegram timing has been defined. This would for instance be used in Japan which requires that all transmissions related to one event have to be finished after 50 ms.

Table 39 below summarizes the compressed subtelegram timing.

Repeater Level	Time Offset [ms] First Subtelegram	Time Offset [ms] Second Subtelegram	Time Offset [ms] Third Subtelegram
0 (Original Telegram)	0 … 1	4 … 12	14 … 22
1 (Repeated for the first time)	0 … 1	4 … 12	14 … 22
2 (Repeated for the second time)	0 … 1	4 … 12	14 … 22

Table 39 – Compressed subtelegram timing

A.3.2 TX maturity time

The maximum time between the request for transmission and the end of transmission of all subtelegrams is called the TX Maturity Time.

In radio systems using standard subtelegram timing, the TX maturity time is 40 ms because the transmission of the last telegram will start no later than 39 ms after the transmission request. In radio systems using compressed subtelegram timing, the TX maturity time is 25 ms.

After the TX maturity time has elapsed, the host can be sure that all subtelegrams corresponding to the telegram have been transmitted. In practical applications this means for instance that an external controller can power down the transmitter after the TX maturity time has elapsed.

A.3.3 RX maturity time

The maximum time allowed for reception of a radio telegram is called the RX Maturity Time. Identical subtelegrams from the same sender are considered to belong to the same telegram if they are received within the RX maturity time.

In EnOcean radio systems, the RX maturity time is 100 ms.

A.4 Addressing

Each radio transmission within an EnOcean radio network will contain information about the originator (sender) of the transmitted radio telegram.

In addition, the intended receiver of a transmitted telegram can optionally be specified as well. Telegrams where the intended receiver is designated are called Addressed Data Telegram or ADT in short. Telegrams where the intended receiver is not designated are called Broadcast Telegrams.

Different types of addresses can be used to designate sender and receiver of an EnOcean radio telegram.

A.4.1 Address types

EnOcean radio systems support three different types of addresses:

- EnOcean Unique Radio ID (EURID)
- Base ID
- Broadcast ID

Each of these three address types corresponds to a specific address or address range as shown Figure 26 below.

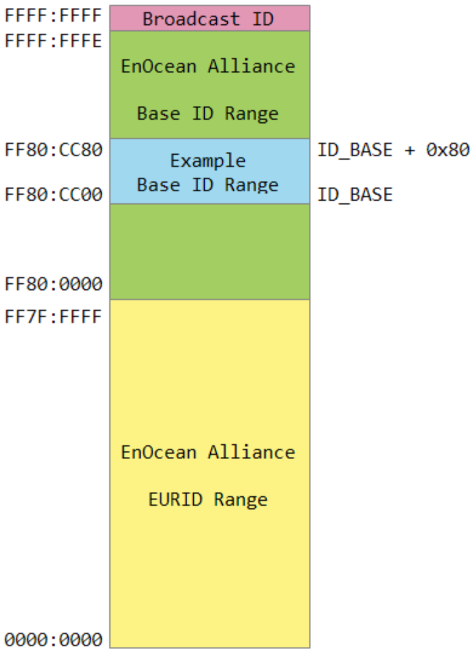


Figure 26 – Address map of EnOcean radio systems

A.4.2 EURID (Radio ID)

Each device communicating within an EnOcean radio network contains its own EnOcean Unique Radio ID (EURID) which is assigned by EnOcean Alliance. The EURID uniquely identifies each EnOcean device; no two EnOcean devices can have the same EURID.

When transmitting a radio telegram, the sender might either use the EURID or a selected Base ID (as described below) to identify itself as the originator of the telegram.

In addition, the sender might use the EURID of the intended receiver to designate this as the intended recipient of the telegram. If no receiver is designated, then the radio telegram will be transmitted as a broadcast. In this case, the receivers of such broadcast telegram decide if they accept this telegram.

A.4.3 Broadcast ID

The Broadcast ID can be used as destination address instead of the EURID of the intended receiver if a telegram should be received by more than one receiver or if the EURID of the intended receiver is unknown.

Telegrams where the destination address is the Broadcast ID are called "Broadcast Telegrams" and are commonly used by sensors and switches. The Broadcast ID is `0xFFFF:FFFF`. Note that the broadcast ID is not transmitted as part of the radio telegram.

Receivers of broadcast telegrams can decide based on the EURID of the sender (originator) of the telegram if this telegram is relevant for them or not.

A.4.4 Base ID

Normally, EnOcean devices will use their own EURID in order to identify themselves as the originator of transmitted telegrams. For very specific use cases, they can instead choose to use an address (ID) from within a defined range of 128 addresses. These 128 addresses are called the Base ID Range of the device.

The Base ID Range (128 addresses) of a device can be allocated anywhere in between `0xFF80:0000` and `0xFFFF:FFFE` (which represents a total range of approximately 8 million addresses). The location of the Base ID Range is defined by the start (lowest) address of the range which will always be aligned on a 7 bit (128) boundary, i.e. the last byte of the start address can be either `0x00` or `0x80`.

Note that Base ID - unlike EURID - are not guaranteed to be globally unique. Many devices with the same Base ID might exist within the EnOcean ecosystem. Having several devices using the same Base ID within a system might lead to undefined system behaviour.

Note also that the use of Base ID is not defined within the scope of secure communication, remote management or smart acknowledge. TCM 515 applications shall not use the Base ID functionality for these applications. TCM 515 supports the Base ID feature only for the purpose of backwards compatibility; it is not recommended for new designs.

A.5 Data payload

EnOcean radio systems encode the data using so called EEP (EnOcean Equipment Profile). Each transmitter might choose one (or sometimes several) EEP for data transmission depending on the type of transmitted data.

A.5.1 EnOcean Equipment Profiles (EEP) structure

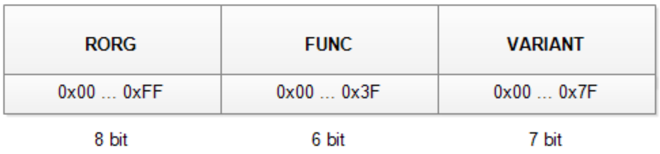
EnOcean Equipment Profiles (EEP) are identified using three fields:

- RORG
  RORG identifies the high-level telegram type, e.g. rocker switch telegram, four-byte sensor telegram, variable length telegram etc.

- FUNC
  FUNC identifies the function group to which this telegram belongs, e.g. the function group of temperature sensors within the four-byte sensor telegram type

- VARIANT (or TYPE)
  VARIANT (sometimes also called TYPE) identifies the exact sensor variant within the function group, e.g. a 0 °C – 40 °C temperature sensor that is defined within the function group of temperature sensors

Figure 27 below shows the structure of the EEP identifier.



RORG	FUNC	VARIANT
0x00 ... 0xFF	0x00 ... 0x3F	0x00 ... 0x7F
8 bit	6 bit	7 bit

Figure 27 – EEP identifier structure

The complete EEP identifier is typically only transmitted during the initial teach-in (paring) between devices. After that, only the RORG which identifies the high-level telegram is transmitted. Transmission of the RORG allows distinguishing between different telegram types (e.g. data and signal telegrams) originating from the same sender.

A.5.2 Common RORG

Within EnOcean radio telegrams, the RORG field identifies the telegram type as described in the previous chapter. Table 40 below lists common RORG used for communication in EnOcean systems.

RORG	Description	Typical Use
0x30	Encrypted telegram without RORG of the original telegram	Encrypted switch or magnet contact telegrams
0x31	Secure message that does identify the type (RORG) of the encrypted telegram	Encrypted sensor telegrams
0x32	Decrypted telegram without RORG	Decrypted telegrams from switches or magnet contacts
0x33	Secure chained messages (SEC_CDM)	Encrypted sensor telegrams requiring chaining due to length
0x35	Secure teach-in telegram (SEC_TI)	Setup of a secure communication channel
0xA5	4 Byte Sensor Telegram (4BS)	Common (simple) sensor telegrams expressed with 4 byte payload
0xA6	Addressed data telegram (ADT)	Telegrams that specify the intended receiver
0xC5	Remote management telegram (SYS_EX)	Configuration of functional parameters in the receiver
0xD0	Signal telegram (SIGNAL)	Reporting of system parameters
0xD1	Manufacturer-specific content (MSC)	Manufacturer-defined telegrams
0xD2	Variable length telegram (VLD)	Variable length telegrams requiring more than 4 byte of payload
0xD5	1 Byte sensor telegram (1BS)	Simple sensors with 1 byte payload such as magnet contact sensors
0xF6	Rocker and pushbutton switches (RPS)	Rocker switches or push buttons

Table 40 – Common RORG used in EnOcean radio systems

For full details about EnOcean Equipment Profiles (EEP) please refer to the EnOcean Equipment Profiles specification [5].

A.5.3 Data payload size

The maximum telegram data payload size used by EnOcean radio telegrams is 14 byte of data payload for the case of standard broadcast telegrams. For the case of standard addressed telegrams, the maximum length of the data payload is 9 byte.

If the radio telegram contains security information such as the RLC value or the authentication signature, then the maximum data payload of one EnOcean radio telegram is reduced further according to the size of the security information.

If the telegram data payload exceeds the maximum available data payload then it has to be transmitted as a chain of radio telegrams which together transfer the message payload.

The type of chaining that is used depends on the type of telegram that is transmitted. Standard telegrams are transmitted as Chained Data Messages (CDM) while secure telegrams are transmitted as Secure Chained Data Messages (SEC_CDM).

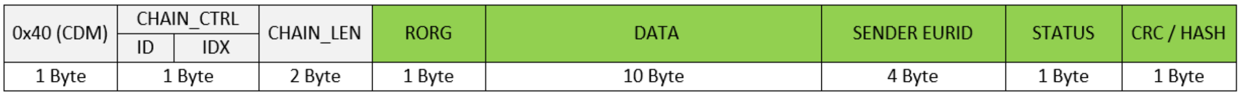
A.6 Telegram chaining

Telegram chaining is a feature that allows transmission of a payload that is larger than the maximum supported DATA payload.

For the transmission of a telegram with a data payload larger than 14 byte, the payload is distributed (segmented) across several telegrams using the telegram structure shown below. Upon reception, the payload of the received telegrams is combined (reassembled) into the original telegram and forwarded to the host via the ESP3 interface once the last telegram in the chain has been received.

A.6.1 Telegram chaining for broadcast telegrams

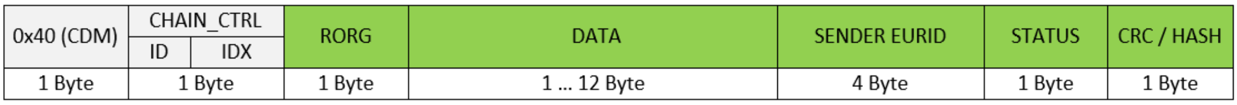
Chained broadcast telegrams can be identified by the R-ORG 0x40 (CDM). The first telegram in a chain (with IDX = 0b000000) uses the CHAIN_LEN field to specify the total length of the DATA payload that is transported by this chain. Figure 28 below shows the structure of the first telegram in a chain of broadcast telegrams.



0x40 (CDM)	CHAIN_CTRL		CHAIN_LEN	RORG	DATA	SENDER EURID	STATUS	CRC / HASH
	ID	IDX						
1 Byte	1 Byte		2 Byte	1 Byte	10 Byte	4 Byte	1 Byte	1 Byte

Figure 28 – Structure of the first telegram in a chain of broadcast telegrams

Subsequent telegrams in the chain (with IDX > 0b000000) omit the CHAIN_LEN field as shown in Figure 29 below.



0x40 (CDM)	CHAIN_CTRL		RORG	DATA	SENDER EURID	STATUS	CRC / HASH
	ID	IDX					
1 Byte	1 Byte		1 Byte	1 … 12 Byte	4 Byte	1 Byte	1 Byte

Figure 29 – Structure of subsequent telegrams in a chain of broadcast telegrams

Up to 4 telegram chains from the same sender can be in progress at any time. The individual chains are identified by the 2 bit wide ID field. Telegrams having the same ID field setting are considered to be part of the same chain.

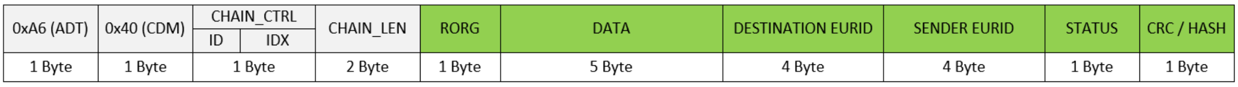
The order of the telegrams within each chain are identified by the 6 bit IDX field with the first telegram using IDX = 0b000000, the second telegram IDX = 0b000001 and so on. The maximum length of a telegram chain is therefore 64 telegrams.

The theoretical maximum DATA length within a chain of telegrams is 766 byte (63 * 12 byte + 1 * 10 byte). Note that in TCM 515 the maximum length is limited by the maximum size of an ESP3 command accepted by TCM 515 which is 255 byte.

A.6.2 Telegram chaining for addressed telegrams (ADT)

Chained addressed telegrams extend the format of chained broadcast telegrams by adding the RORG 0xA6 (Addressed Data Telegram) at the begin of the message and EURID of the intended receiver of the message before the EURID of the sender.

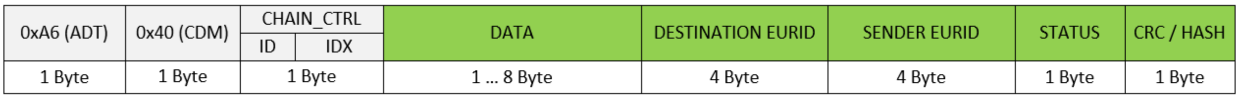
Figure 30 below shows the structure for the first telegram in a chain of addressed telegrams.



0xA6 (ADT)	0x40 (CDM)	CHAIN_CTRL		CHAIN_LEN	RORG	DATA	DESTINATION EURID	SENDER EURID	STATUS	CRC / HASH
		ID	IDX							
1 Byte	1 Byte	1 Byte		2 Byte	1 Byte	5 Byte	4 Byte	4 Byte	1 Byte	1 Byte

Figure 30 – Structure of the first telegram in a chain of addressed telegrams

Subsequent telegrams in a chain of addressed telegrams omit both the CHAIN_LEN and the RORG field as shown in Figure 31 below.



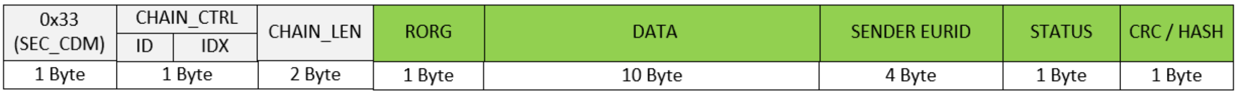
0xA6 (ADT)	0x40 (CDM)	CHAIN_CTRL		DATA	DESTINATION EURID	SENDER EURID	STATUS	CRC / HASH
		ID	IDX					
1 Byte	1 Byte	1 Byte		1 … 8 Byte	4 Byte	4 Byte	1 Byte	1 Byte

Figure 31 – Structure of subsequent telegrams in a chain of addressed telegrams

A.6.3 Telegram chaining for secure telegram (SEC_CDM)

Chained secure telegrams – identified by RORG 0x33 (SEC_CDM) - extend the format of chained broadcast telegrams by defining three different telegram structures – one for the first telegram in a chain, one for the last telegram in a chain and one for all telegrams in between the first and the last.

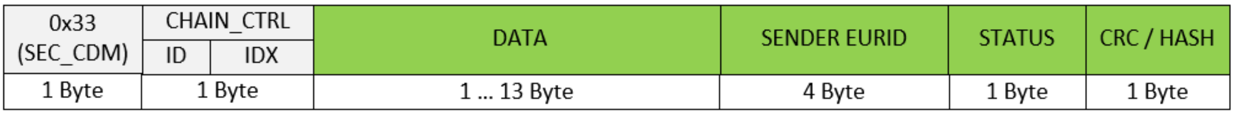
Figure 32 shows the structure for the first telegram in a chain of secure telegrams.



0x33 (SEC_CDM)	CHAIN_CTRL		CHAIN_LEN	RORG	DATA	SENDER EURID	STATUS	CRC / HASH
	ID	IDX						
1 Byte	1 Byte		2 Byte	1 Byte	10 Byte	4 Byte	1 Byte	1 Byte

Figure 32 – Structure of the first telegram in a chain of secure telegrams

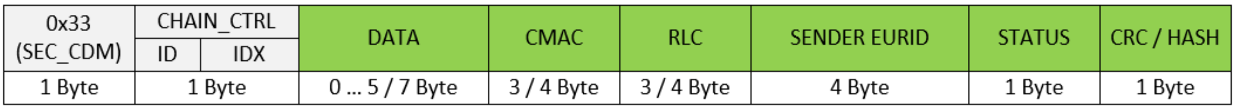
Intermediary telegrams in a chain of secure telegrams omit both the CHAIN_LEN and the RORG field as shown in Figure 33 below.



0x33 (SEC_CDM)	CHAIN_CTRL		DATA	SENDER EURID	STATUS	CRC / HASH
	ID	IDX				
1 Byte	1 Byte		1 … 13 Byte	4 Byte	1 Byte	1 Byte

Figure 33 – Structure of intermediary telegrams in a chain of secure telegrams

The last telegram of the chain contains the rolling code (RLC) value and the message signature (CMAC) as shown in Figure 34 below. Note that the last telegram in a chain of secure telegrams might have no data payload (if the data exactly fits into the previous telegram in the chain).



0x33 (SEC_CDM)	CHAIN_CTRL		DATA	CMAC	RLC	SENDER EURID	STATUS	CRC / HASH
	ID	IDX						
1 Byte	1 Byte		0 … 5 / 7 Byte	3 / 4 Byte	3 / 4 Byte	4 Byte	1 Byte	1 Byte

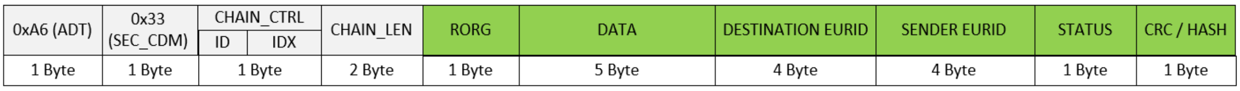
Figure 34 – Structure of the last telegram in a chain of secure telegrams

A.6.4 Telegram chaining for addressed secure telegram (ADT SEC_CDM)

Chained secure telegrams may also be transmitted as addressed telegram (ADT) to identify the intended receiver of this telegram chain.

Chained addressed secure telegrams extend the format of chained secure telegrams by adding the RORG 0xA6 (Addressed Data Telegram) at the begin of the message and EURID of the intended receiver of the message before the EURID of the sender.

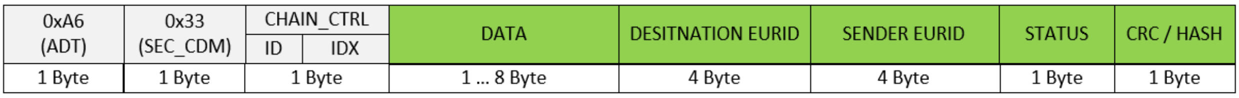
Figure 35 below shows the structure for the first telegram in a chain of secure telegrams.



0xA6 (ADT)	0x33 (SEC_CDM)	CHAIN_CTRL		CHAIN_LEN	RORG	DATA	DESTINATION EURID	SENDER EURID	STATUS	CRC / HASH
		ID	IDX							
1 Byte	1 Byte	1 Byte		2 Byte	1 Byte	5 Byte	4 Byte	4 Byte	1 Byte	1 Byte

Figure 35 – First telegram in a chain of addressed secure telegrams

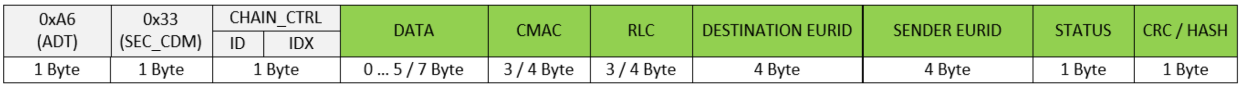
Intermediary telegrams in a chain of secure telegrams omit both the CHAIN_LEN and the RORG field as shown in Figure 36 below.



0xA6 (ADT)	0x33 (SEC_CDM)	CHAIN_CTRL		DATA	DESITNATION EURID	SENDER EURID	STATUS	CRC / HASH
		ID	IDX					
1 Byte	1 Byte	1 Byte		1 … 8 Byte	4 Byte	4 Byte	1 Byte	1 Byte

Figure 36 – Intermediary telegrams in a chain of addressed secure telegrams

The last telegram of the chain contains the rolling code (RLC) value and the message signature (CMAC) as shown in Figure 37 below.



0xA6 (ADT)	0x33 (SEC_CDM)	CHAIN_CTRL		DATA	CMAC	RLC	DESTINATION EURID	SENDER EURID	STATUS	CRC / HASH
		ID	IDX							
1 Byte	1 Byte	1 Byte		0 … 5 / 7 Byte	3 / 4 Byte	3 / 4 Byte	4 Byte	4 Byte	1 Byte	1 Byte

Figure 37 – Last telegram in a chain of addressed secure telegrams

Note that the encapsulation as addressed (ADT) telegram is applied after the SEC_CDM telegram has been formed. The last SEC_CDM telegram might therefore be split into two addressed SEC_CDM telegrams due to the addition of the RORG and DESTINATION EURID addressing fields resulting in a telegram size larger than the maximum size of EnOcean radio telegrams.

B. Introduction to EnOcean security protocol

This chapter gives a high-level introduction to key aspects of the security protocol used in EnOcean radio networks to help the understanding of TCM 515 features.

Refer to the EnOcean Alliance Security Specification for a detailed up to date description of all features.

B.1 Goals of secure radio communication

Secure radio communication aims to address two main issues:

- Unauthorized interception (reception and correct interpretation) of transmitted data
  In doing so, a third (unauthorized) party is able to understand the content of a received content.

- Unauthorized transmission of radio telegrams
  In doing so, a third (unauthorized) party is able to transmit a radio telegram that is treated by a receiver as valid request.

Somewhat loosely speaking, the goal of security is to prevent an unauthorized person (often referred to as an *Attacker*) both from learning about the current state of a system and from actively changing it.

These goals can be achieved via techniques such as telegram encryption, telegram authorization and dynamic modification. All three techniques will be reviewed in the subsequent chapters for reference.

B.2 Telegram encryption

The goal of telegram encryption is to prevent unauthorized receivers from correctly interpreting the content of a telegram.

In order to do so, the original (plain text) data is *encrypted* with a *security key* thus transforming it into encrypted, unreadable data. Only when the correct key is known it is possible to transform – *decrypt* - the encrypted data into readable data again. Figure 38 below shows the concept.

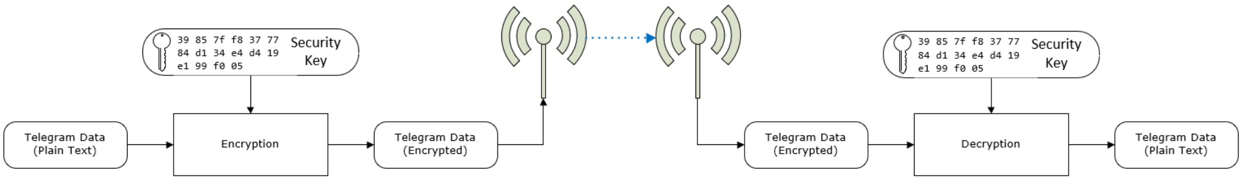


Figure 38 – Telegram encryption

If the same security key is used for encryption at the sender and decryption at the receiver then this is called a *symmetric key* algorithm. AES (AES128 / AES256) and DES / 3DES algorithms are typical examples of this category. TCM 515 uses this approach.

If different security keys are used for encryption at the sender and decryption at the receiver then this is called an *asymmetric key* algorithm or a *public key* algorithm. Public / private key algorithms such as PGP, GPG or TLS fall into this category. TCM 515 does not support asymmetric key algorithms.

B.3 Telegram authentication

The goal of telegram authentication is to prevent unauthorized senders to transmit apparently valid commands causing the receiver to perform unauthorized actions. Telegram authentication is typically used in conjunction with telegram encryption.

Telegram authentication works by creating a *signature* (often called *Cipher-based Message Authentication Code* or *CMAC* in short) based on the content of the telegram and the security key.

Essentially, the telegram data is transformed via a defined algorithm using the security key into a unique, fixed size signature (where typical signature lengths include 24 bit, 32 bit, 512 bit and 1024 bit) which identifies this specific message.

For an optimal signature algorithm, the likelihood of two different telegrams creating the same telegram signature should be inversely proportional to the signature size, so for instance for 24 bit signatures the likelihood should be one in 16 million and for 32 bit signatures it should be one in 4 billion.

Conceptually the correspondence between telegram content and telegram signature is like the one between a person and a fingerprint:

- Each person has a unique fingerprint. Based on a given person one can determine her or his fingerprint
- Based on a given fingerprint one can check if it originated from a given person
- Based on the fingerprint one cannot determine any other properties of the person

For telegram authentication purposes, the telegram signature (CMAC) is usually appended to the telegram content so that the telegram content and the telegram signature are transmitted together.

When the receiver receives such a telegram, it will itself calculate the telegram signature (CMAC) based on the security key and the telegram content. The receiver then compares the signature that it calculated with the signature it received as part of the telegram.

If both signatures are the same, then the receiver can establish two important facts:

1. The telegram originates from a sender knowing the security key
2. The content of the telegram has not been modified after the sender added the signature to it

Figure 39 below illustrates the concept of telegram authorization via a telegram signature.

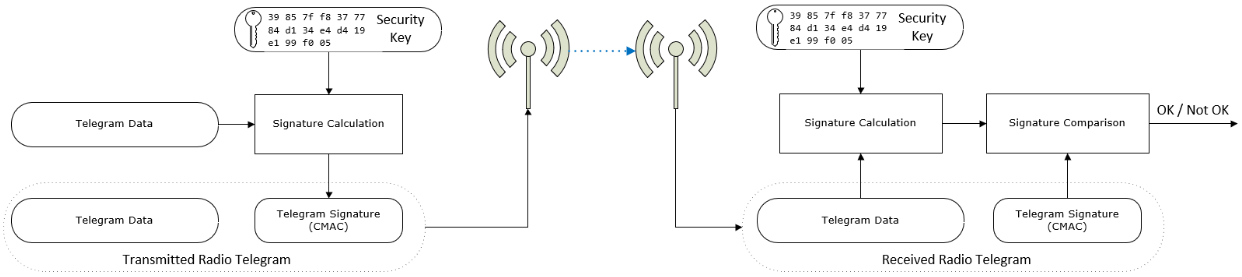


Figure 39 – Telegram authentication via telegram signature

B.4 Replay protection

One fundamental problem with both telegram encryption and telegram authorization is that using the same input data (plain text) with the same security key will always result in the same encrypted data and the same signature. This enables attacks based on monitoring previous system behaviour. If an attacker has observed that a certain data telegram results in a certain light being turned on, then he could use this information to identify - or even actively send - similar telegrams in the future. This type of attack is often called *Replay Attack* since it works by reusing (replaying) previously transmitted (valid) data telegrams.

In order to prevent this type of attack, either the telegram data or the security material (e.g. the security key or the initialization vector / nonce) must change to ensure that identical input data does not create identical encrypted radio telegrams.

The change of telegram data or security material is done based on a sequence of values that are guaranteed to be unique so that the same value will not be used twice. This sequence of changing values is often referred to as *Rolling Code* or *RLC* in short.

In order to prevent replay of an already received message, the receiver will keep track of the latest received RLC value and will only accept telegrams with an RLC value that comes later (after the last received RLC value) in the sequence.

Both sender and receiver have to know the mechanism how to generate the next RLC (the next value in the sequence) based on the current RLC (the current value of the sequence). The easiest - and most common - approach for that is to use the value of a monotonously incrementing counter that is incremented for each telegram.

Such counter is often referred to as *Sequence Counter*; the current value of the sequence counter is the RLC. Figure 40 below shows the concept of adding an RLC to the telegram data.

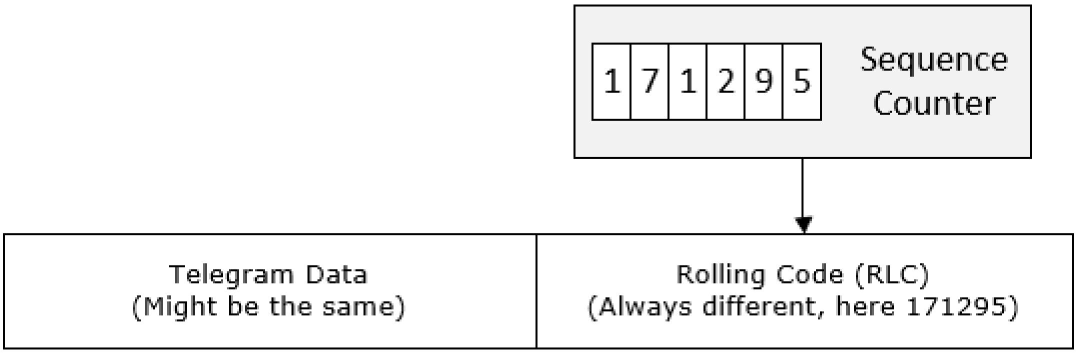


Figure 40 – Addition of an RLC to the telegram data

TCM 515 uses an approach where the RLC is used to change the security material (specifically, the initialization vector – often called *Nonce* - used by the security algorithms together with the security key) to ensure that the encrypted telegram payload and the telegram signature change even when the content of the telegram itself stays the same.

Figure 41 below illustrates this approach.

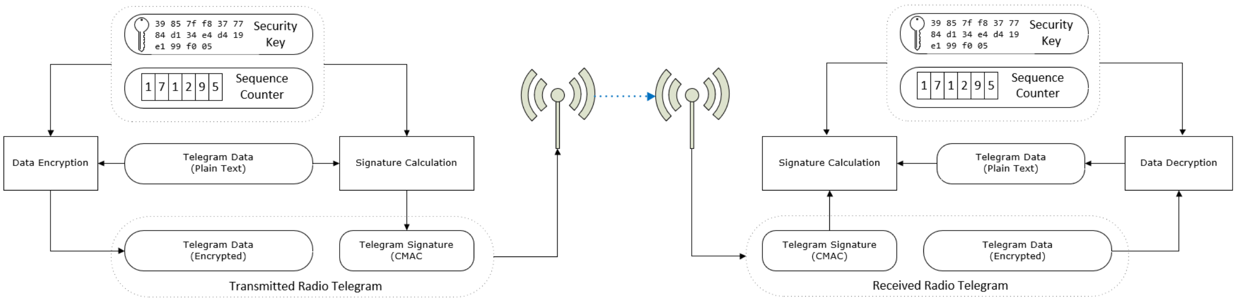


Figure 41 – Encryption and authentication in TCM 515

B.4.1 RLC and security key in bi-directional communication

If the communication between two devices (*Device1* and *Device2*) is bi-directional, i.e. each device can either transmit or receive telegrams, then two independent RLC (*RLC1* and *RLC2*) have to be used (since the number of telegrams one direction might be different from the number of telegrams in the other direction) and two different security Keys (Key1 and Key2) might be used (using the same key in both directions would also be possible).

The first pair (RLC1, Key1) will be used for the telegram transmission from Device1 to Device2 while the second pair (RLC2, Key2) will be used for the telegram transmission from Device2 to Device1.

Device1 will store RLC1 and Key1 together with the address of Device2 in its so-called *outbound secure link table* since they are used for transmission of telegrams to the remote device. RLC2 and Key2 together with the address of Device2 will be stored in its so-called *inbound secure link table* since they are used for reception of telegrams from the remote device.

Conversely, Device2 will store RLC1 and Key1 together with the address of Device1 in its inbound secure link table and RLC2 and Key2 together with the address of Device1 in its outbound secure link table. Figure 42 below illustrates that.

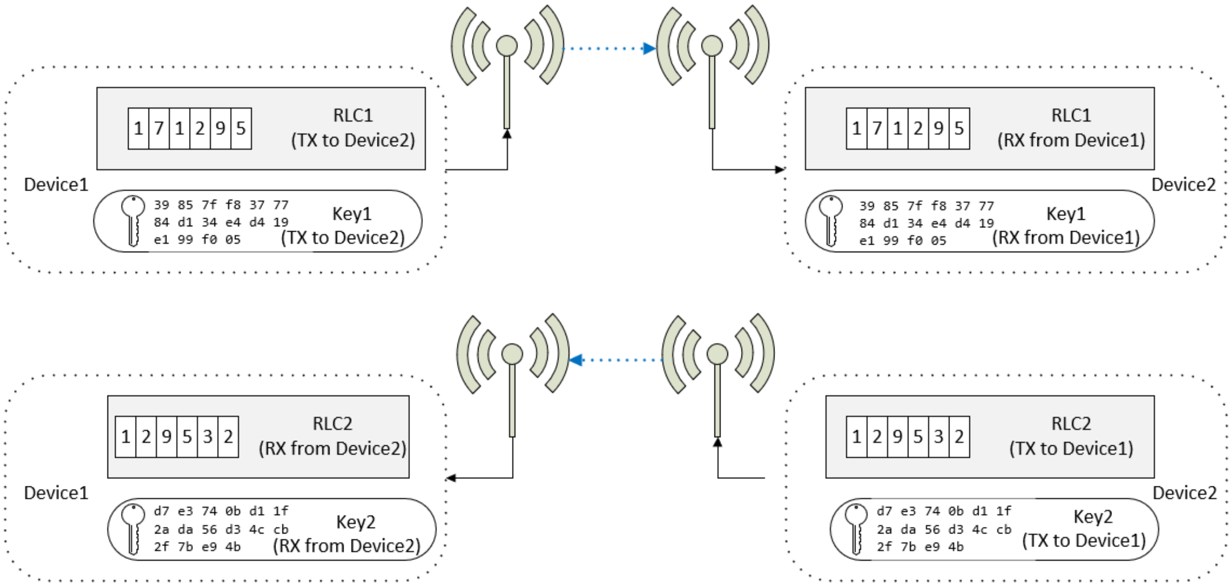


Figure 42 – Security key and RLC usage in bi-directional communication

B.4.2 RLC synchronization between sender and receiver

For encryption and authentication using RLC, it is important that the RLC on the transmitter side and the RLC on the receiver side remain synchronized, i.e. that they always have the same value.

This can be ensured either by transmitting the RLC as part of the telegram (this is called *explicit RLC mode*) or by tracking the expected RLC when it is not transmitted as part of the telegram (this is called *implicit RLC mode*).

Explicit RLC mode is the recommended procedure since it ensures that the receiver always knows the current RLC used by the sender; it requires however to increase the size of the telegram in order to transmit this RLC.

Implicit RLC mode might be used in energy-constrained systems where there might not be enough energy to additionally transmit the current RLC as part of the telegram.

For implicit RLC mode, the initial value of the RLC at the sender and at the receiver will be aligned during the establishment of the secure communication so that the receiver knows the current RLC used by the sender. For systems using TCM 515, this can be done either via a dedicated secure teach-in telegram as described in chapter 7.7.3 or via the ESP3 interface as described in Chapter 9.

After that, both sender and receiver will adjust (increment for the case of using a sequence counter to generate the RLC) the RLC for each telegram that is transmitted to this specific receiver (RLC adjustment in the sender) or received from this specific sender (RLC adjustment in the receiver).

In order to guard against the case of telegrams being lost (not received by the receiver), the receiver will check if the RLC it assumes is used in the received telegram will result in a matching message signature (CMAC) when executing telegram authentication using this RLC together with the security key.

If this is the case, then the receiver will decrypt the telegram content using this RLC together with the security key. If this is not the case, then the receiver can retry using the next RLC in the sequence and so on. Typically, a maximum number of future RLC values to be tried will be defined. This parameter is often referred to as the *Rolling Code Window Size*.

If message decryption based on a future RLC is successful then the RLC used by the receiver will be updated to this value, thereby re-synchronizing the transmitter and receiver RLC. If no matching RLC is found within the rolling code window, then the message cannot be decrypted and authenticated and might be forwarded to the host for further analysis.

B.5 Secure telegram types

Secure communication is based on two telegram types:

- Secure teach-in telegrams are used to establish a secure communication channel by providing the receiver with the required information to decrypt and authenticate received secure data telegrams
- Secure data telegrams are used to securely transmit data

The format of these two telegram types is described in the subsequent chapters.

B.5.1 Secure teach-in telegram

Teach-in is the process by which a sender communicates to a receiver the parameters required to decrypt and authenticate received secure telegrams. These parameters can be communicated from the sender to the receiver by transmitting a secure teach-in telegram with the structure shown in Figure 43 below.

RORG (0x35: SEC_TI)	TEACH-IN INFO	SECURITY FORMAT (SLF)	CURRENT RLC VALUE	SECURITY KEY
1 byte	1 byte	1 byte	2 / 3 / 4 byte	16 byte

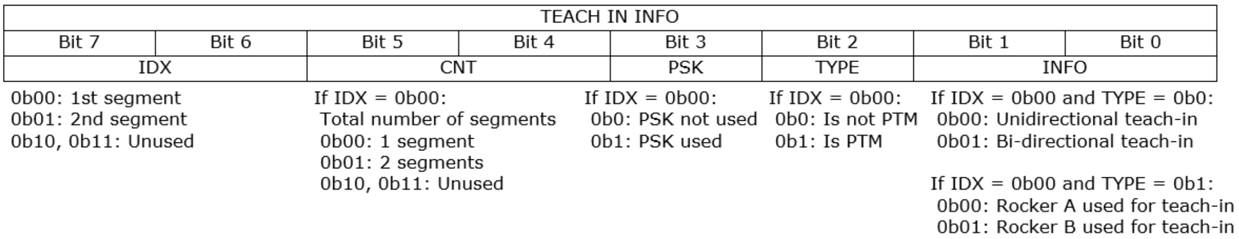
Figure 43 – Secure teach-in telegram structure

The secure teach-in telegram contains the following parameters:

- RORG 0x35 (SEC_TI)
  Secure teach-in telegrams are identified by the RORG 0x35 (SEC_TI)
- Teach-in Info
  This field contains information about the secure teach-in telegram allowing the receiver to properly it. The structure of the Teach-in Info field is shown below.
- SLF
  The SLF specifies the type of encryption and authentication used by for the communication with the remote device as described in chapter B.5.1.2.
- RLC
  This field contains the current value of the RLC used by the sender.
- Key
  The 128 bit security key is used by the sender to encrypt and authenticate the transmitted telegram and by the receiver to decrypt and authenticate the received telegram

B.5.1.1 Teach-in Info

Figure 44 below shows the structure of the Teach-in Info field.



TEACH IN INFO							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
IDX		CNT		PSK	TYPE	INFO	
0b00: 1st segment 0b01: 2nd segment 0b10, 0b11: Unused		If IDX = 0b00: Total number of segments 0b00: 1 segment 0b01: 2 segments 0b10, 0b11: Unused		If IDX = 0b00: 0b0: PSK not used 0b1: PSK used	If IDX = 0b00: 0b0: Is not PTM 0b1: Is PTM	If IDX = 0b00 and TYPE = 0b0: 0b00: Unidirectional teach-in 0b01: Bi-directional teach-in If IDX = 0b00 and TYPE = 0b1: 0b00: Rocker A used for teach-in 0b01: Rocker B used for teach-in	

Figure 44 – Teach-in Info structure

B.5.1.2 Security level format (SLF)

The security level format (SLF) defines the security parameters used for communication between two devices. If the communication is bi-directional (send and receive) then the same SLF setting has to be used in both directions.

Figure 45 below shows the supported security parameter options of the SLF field.

7	6	5	4	3	2	1	0
RLC_MODE			**CMAC_SIZE**		**ENCRYPTION_ALGO**		
0b000: No RLC algorithm			0b00: No MAC		0b000: No data encryption		
0b001: RFU			0b01: 3 byte CMAC		0b001: Deprecated		
0b010: 16 bit RLC (not transmitted)			0b10: 4 byte CMAC		0b010: Deprecated		
0b011: 16 bit RLC (16 bit transmitted)			0b11: RFU		0b011: VAES using AES128		
0b100: 24 bit RLC (not transmitted)					0b100: AES-CBC using AES128		
0b101: 24 bit RLC (24 bit transmitted)					Others: RFU		
0b110: 32 bit RLC (24 bit transmitted)							
0b111: 32 bit RLC (32 bit transmitted)							

Figure 45 – SLF structure