DOLPHIN
Self-powered IoT by EnOcean

TCM 515Z – 2.4 GHZ IEEE 802.15.4 Transceiver

19 July 2016

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,
US 6,747,573, US 7,019,241

TCM 515Z – 2.4 GHZ IEEE 802.15.4 Transceiver

REVISION HISTORY

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

Version	Author	Reviewer	Date	Major Changes
1.0	MKA	MK, MF	01.03.2016	Initial Release
1.1	MKA		01.05.2016	Added protocol description, changed location of TURBO Pin
1.2	MKA		19.07.2016	Added reflow profile

Published by EnOcean GmbH, Kolpingring 18a, 82041 Oberhaching, Germany
www.enocean.com, info@enocean.com, phone +49 (89) 6734 6890

Important!
This information 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

TCM 515Z enables the realization of line-powered actuators, controllers and gateways communicating based on the 2.4 GHz IEEE 802.15.4 radio standard. It provides a transparent radio link between EnOcean 2.4 GHz devices and an external host connected via the standardized ESP3 interface (EnOcean Serial Protocol V3).

TCM 515Z receives and transmits radio telegrams based on a 50 Ohm or whip antenna connected to the host PCB. It forwards received 2.4 GHz IEEE 802.15.4 radio telegrams to an external host processor or host PC via the ESP3 interface.

IEEE 802.15.4 messages received from an external host via the ESP3 interface will be transmitted by TCM 515Z as 2.4 GHz radio telegrams.

TCM 515Z is implemented as 31 pin reflow-solderable module with optimized form factor for size constrained applications.

Figure 1 below shows TCM 515Z.

Figure 1 – TCM 515Z outline

1.2 Technical data

Antenna	External 50 Ohm or whip antenna (connected at host board)
Supported Radio Frequency Range	Radio channel 11 … 26 according to IEEE 802.15.4 standard
Default Radio Channel	IEEE 802.15.4 radio channel 11
Receiver Sensitivity (typ, at 25°C)	–95 dBm
Transmit Power (typ, at 25°C)	+2 dBm
Power Supply	3.3 V +- 10%
Serial Host Interface	UART according to ESP3 Standard with Turbo Mode Option
Current Consumption (typ, at 25°C)	Transmit: 20mA, Receive: 15 mA
Radio Regulation	R&TTE (Europe)

1.3 Physical dimensions

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

1.4 Environmental conditions

Operating Temperature	-25°C … 85°C
Storage Temperature	-25°C … 85°C
Humidity	0% to 95% r.h. (non-condensing)

1.5 Packaging information

Packaging Unit	250 units
Packaging Method	Tape and reel

1.6 Ordering information

Type	Ordering Code	Frequency
TCM 515Z	S3073-K515	2.4 GHz (IEE 802.15.4)

2 FUNCTIONAL INFORMATION

2.1 TCM 515Z Device Interface

TCM 515Z implements a 31 pin reflow-solderable interface. Solder mask data is available on request from EnOcean. The pin assignment (as seen from the top of the device) is shown in Figure 2 below.

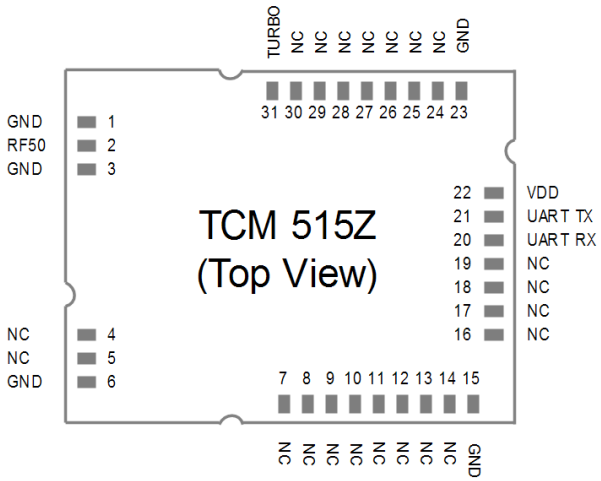

Figure 2 – TCM 515Z device interface

Table 1 below summarizes the signal assignment.

PIN	NAME	PIN	NAME	PIN	NAME
1	GND	12	NC	23	GND
2	ANTENNA (50 Ohms)	13	NC	24	NC
3	GND	14	NC	25	NC
4	NC	15	GND	26	NC
5	NC	16	NC	27	NC
6	GND	17	NC	28	NC
7	NC	18	NC	29	NC
8	NC	19	NC	30	NC
9	NC	20	UART_RX (Input)	31	TURBO
10	NC	21	UART_TX (Output)		
11	NC	22	VDD		

Table 1 - TCM 5151Z device interface pin assignment

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

2.1.1 Signal Description

TCM 515Z is supplied by the VDD and GND Pins. The required supply voltage is 3.3V with a tolerance of no more than +-10%.

TCM 515Z receives and transmits data based on a 50Ω whip antenna connected to its ANTENNA input (Pin 2).

TCM 515Z communicates with the external host using the standard ESP3 serial (UART) interface based on the signals UART_TX (Pin 21, direction from TCM 515Z to external host) and UART_RX (Pin 20, direction from external host to TCM 51Z).

The default interface speed of the ESP3 interface is 57600 bit per second (the exact speed is 57347 Bit per second, a deviation of -0.04%).

It is possible to select a faster communication speed of 460800 bit per second (exact speed is 457143 bit per second, a deviation of -0.79%) during operation using the CO_SET_BAUDRATE command as shown in Table 11.

Only interface speeds of 57.600 bit per second and 460.800 bit per second are supported by TCM 515Z.

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 TURBO input (Pin 31) 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.

2.2 High-level operation principle

In receive mode, TCM 515Z forwards the content of received IEEE 802.15.4 radio telegrams (which pass frame check sum validation) unmodified to the external host via the ESP3 interface.

The forwarded frame starts with the *Length* field of the IEEE 802.15.4 PHY Header, continues with the MAC Header and ends with the last Byte of the MAC Payload. The frame check sum (MAC Trailer) will not be forwarded to the host.

In transmit mode, TCM 515Z receives from the external host the precomputed message payload starting with the *Length* field of the IEEE 802.15.4 PHY Header, continuing with the MAC Header and ending with the last Byte of the MAC Payload.

TCM 515Z then calculates the frame check sum (MAC Trailer) and appends it to the message. The full frame (including the Preamble and Start of Frame fields) will then be transmitted as IEEE 802.15.4 radio telegram (TX mode).

2.3 Supported Radio Channels

TCM 515Z support all radio channels of the IEEE 802.15.4 standard in the 2.4 GHz band. The radio channel used by TCM 515Z can be set by an external host using the ESP3 SET_CHANNEL command as described in Appendix C.2.3.

The channel notation used by TCM 515Z follows IEEE 802.15.4 standard, i.e. channel 11 is the first channel (lowest frequency) and channel 26 is the last channel (highest frequency).

Table 2 below shows the correspondence between channel ID and channel frequency.

Channel ID	Lower Frequency	Centre Frequency	Upper Frequency
11	2404	2405	2406
12	2409	2410	2411
13	2414	2415	2416
14	2419	2420	2421
15	2424	2425	2426
16	2429	2430	2431
17	2434	2435	2436
18	2439	2440	2441
19	2444	2445	2446
20	2449	2450	2451
21	2454	2455	2456
22	2459	2460	2461
23	2464	2465	2466
24	2469	2470	2471
25	2474	2475	2476
26	2479	2480	2481

Table 2 - Supported radio channels

2.4 ESP3 Data Format

TCM 515Z communicate with external hosts using EnOcean Serial Protocol version 3 (ESP3) with EnOcean 2.4 GHz IEEE 802.15.4 extensions.

Please refer to Appendix C for an overview of the ESP3 interface format. Please consult also the detailed ESP3 specification at https://www.enocean.com/esp.

3 Device Integration

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

3.1 Recommended PCB Footprint

Figure 3 below shows the recommended PCB footprint for TCM 515Z.

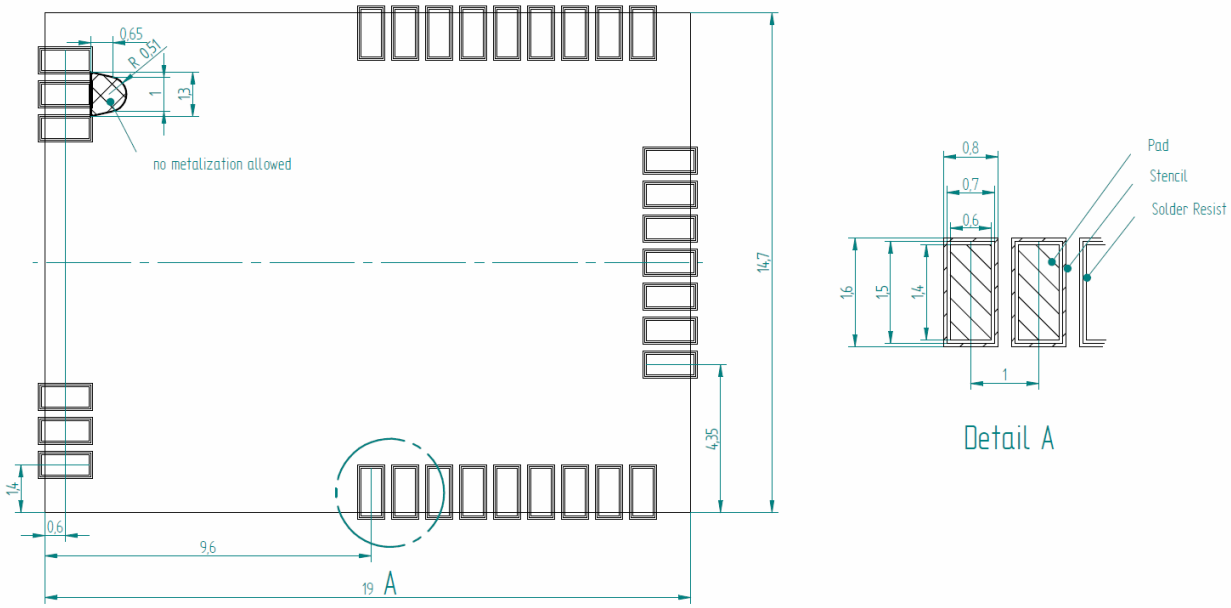

Figure 3 – Recommended PCB footprint

3.2 Antenna options

TCM 515Z has been certified for use in Europe. TCM 515Z modules used in Europe do not need additional radio approval if the external antenna fulfils the following requirements:

Frequency band	2.4 GHz ISM	Antenna must be suited for this band
Antenna type	Passive	Mandatory for radio approval
Impedance	~50 Ohm	Mandatory for radio approval
Maximum gain	≤ 0 dBd	Mandatory for radio approval

3.3 Soldering information

TCM 515Z has to be soldered according to IPC/JEDEC J-STD-020C standard as outline in Figure 4 below.

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.

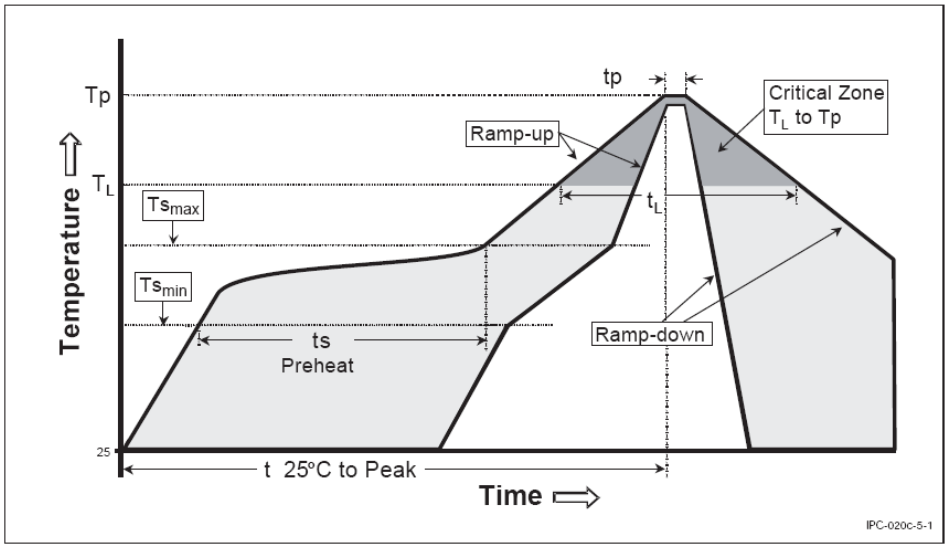

Figure 4 – Recommended temperature profile

3.4 Device handling instructions

TCM 515Z shall be handled according to Moisture Sensitivity Level MSL 3. TCM 515Z 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 168 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 515Z modules have to be soldered within 6 months after delivery!

In general we recommend a no clean flux process. If washing is needed, then TCM 515Z radio modules have a shield cover with small openings at the top of the edges.

It is very important to mount the modules in a top down position during the drying process as this will allow getting the aggregated washing fluid removed properly from within the shield cover area.

To prevent damage, modules have to be checked for any remaining fluid after the drying.

3.5 Tape & Reel specification

TCM 515Z is delivered in Tape & Reel packaging with 250 units per reel. Figure 5 below illustrates the dimensions.

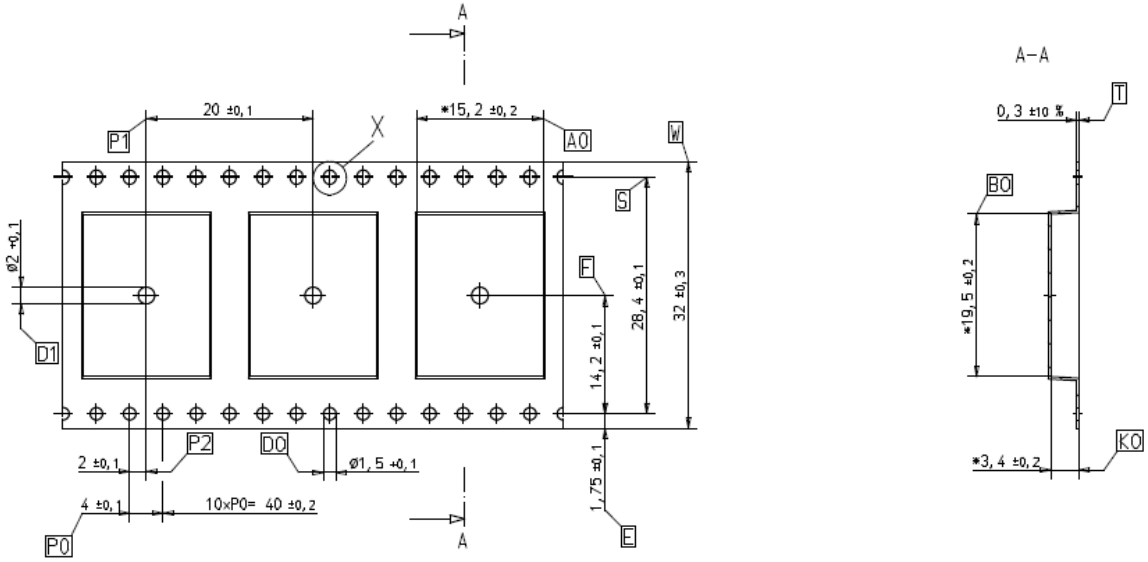

Figure 5 – Tape & Reel dimensions of TCM 515Z

Figure 6 below shows the positioning of TCM 515Z in the Tape & Reel packaging.

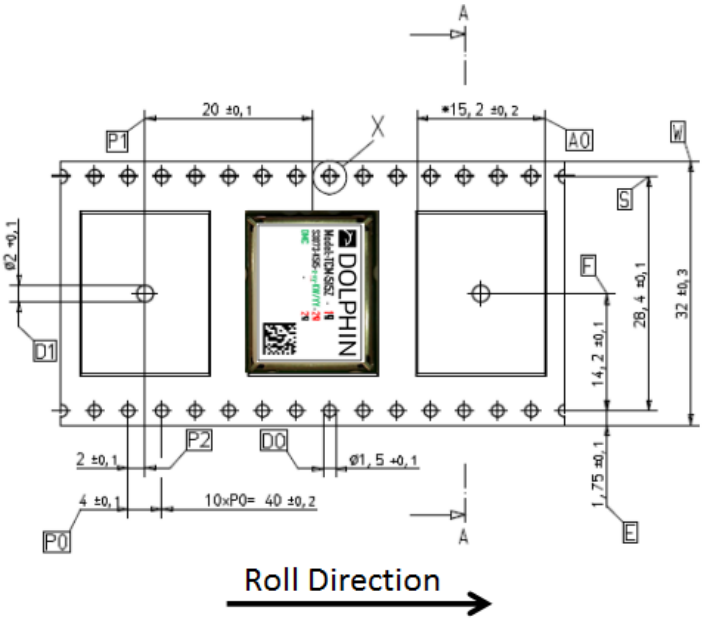

Figure 6 – Position of TCM 515Z in the reel

4 APPLICATION INFORMATION

4.1 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 15 m range in corridors, up to 50 m in halls

- Plasterboard walls / dry wood
  Typically 15 m range, through max. 2 walls

- Ferro concrete walls / ceilings
  Maximum 1 wall or ceiling, depending on thickness and material

- Fire-safety walls, elevator shafts, staircases and similar areas should be considered as shielded

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, audio and video equipment that also emit high-frequency signals should be at least 0.5 m.

5 REGULATORY INFORMATION

TCM 515Z has been certified according to CE regulation.

Changes or modifications not expressly approved by EnOcean could void the user's authority to operate the equipment.

Appendix A IEEE 802.15.4 Frame Structure

A.1 IEEE 802.15.4 High Level Frame Structure

TCM 515Z transmits and receives radio telegrams in the 2.4 GHz band according to IEEE 802.15.4 frame structure. The external host is responsible for the proper decoding of received telegrams and proper encoding of telegrams to be transmitted.

The following information about the IEEE 802.15.4 standard and its implementation in PTM 215ZE and PTM 515Z is given for reference only. Please refer to the applicable documents for detailed information.

Note that the data format is little endian. This means that for multi-byte structures (such as 2 byte, 4 byte or 8 byte fields) the least significant byte (LSB) is transmitted first.

The IEEE 802.15.4 frame structure consists of the following four main parts:

- PHY Header
  The PHY header indicates to the receiver the start of a transmission and provides information about the length of the transmission.
  It contains the following fields:
  - Preamble
    Pre-defined sequence (4 byte, value 0x00000000) used to adjust the receiver to the transmission of the sender
  - Start of frame
    Pre-defined symbol (1 byte, value 0xA7) identifying the start of the actual data frame
  - Length of Frame
    1 byte indicating the combined length of all following fields

- MAC Header
  The MAC header provides detailed information about the frame.
  It contains the following fields:
  - Frame control field
    2 bytes to identify frame type, protocol version, addressing and security mode
  - Sequence number
    1 byte sequential number to identify the order of transmitted frames
  - Address
    PAN ID and address of source (if present) and destination of the telegram
    EnOcean PTM 535Z and PTM 215ZE do not use source address and source PAN ID (the EnOcean ID is part of the payload).

- MAC Payload
  The MAC Payload field contains telegram control, device ID, telegram data and telegram security (if present) fields.
  The MAC Payload field structure depends on telegram type (data or commissioning) and security mode (secure or standard transmission).

- MAC Trailer
  The MAC Trailer contains the Frame Check Sum (FCS) field used to verify the integrity of the telegram data.

Figure 7 below summarizes the IEEE 802.15.4 frame structure.

Figure 7: IEEE 802.15.4 frame structure

The content of these fields is described in more detail below.

A.2 PHY Header

The IEEE 802.15.4 PHY header consists of the following fields:

- Preamble
- Start of Frame
- Length of Frame fields

The content of the Preamble and Start of Frame fields is fixed for all telegram types supported by EnOcean devices as follows:

- Preamble = 0x00000000
- Start of Frame = 0xA7

A.2.1 Length of Frame values used by PTM 215ZE and PTM 535Z

Below are reference values for the *Length of Frame* field for different type of telegrams used by PTM 215ZE and PTM 535Z:

- Secure commissioning telegram (Default for PTM 215ZE and PTM 535Z)
  Length of Frame = 42 bytes (0x2A)
- Secure data telegram (Default for PTM 215ZE and PTM 535Z)
  Length of Frame = 24 bytes (0x18)
- Standard commissioning telegram (Optional feature for PTM 535Z only)
  Length of Frame = 17 bytes (0x11)
- PTM switch: Standard data telegram (Optional feature for PTM 535Z only)
  Length of Frame = 15 bytes (0x0F)

A.3 MAC Header

The IEEE 802.15.4 MAC Header contains the following fields:

- Frame Control Field (2 byte)
  The Frame Control Field is set to 0x0801 in PTM 215ZE and PTM 535Z telegrams in order to identify them as data telegrams with short addresses based on version IEEE 802.15.4-2003

- Sequence Number (1 byte)
  The Sequence Number is an incremental number used to identify the order of telegrams

- Address Field (4 byte in EnOcean implementation)
  EnOcean devices use short Destination Address (16 Bit) together with the Destination PAN ID (16 Bit). Both are set to 0xFFFF to identify the telegrams as broadcast. Source address and Source PAN ID are not used by PTM 215ZE and PTM 535Z.

A.4 MAC Payload

The IEEE 802.15.4 MAC Payload depends on the telegram type. Appendix B describes the MAC Payload structure used by EnOcean PTM 215ZE and PTM 535Z products.

A.5 MAC Trailer

The MAC Trailer only contains the Frame Check Sum (FCS) field.

Its length is 2 byte and it is calculated as Cyclic Redundancy Check (CRC16) over the entire MAC payload including the Length field of the PHY Header using the following polynomial: $x^{16} + x^{12} + x^5 + 1$

TCM 515Z will automatically calculate and append the frame check sum to radio telegrams it is transmitting.

For received radio telegrams, TCM 515Z will calculate the frame check sum and verify data integrity based on that. If the checksum does not match, the received radio telegram will be discarded. Otherwise the received radio telegram will be forwarded to the external host via the ESP3 interface.

Appendix B MAC Payload Structure

The MAC Payload depends on the telegram type. This appendix gives examples of MAC payload structures used by EnOcean PTM 215ZE and PTM 535Z devices.

The following telegram types are used by these devices:

- Data telegram
- Commissioning telegram

The following security modes are supported by these devices:

- Secure communication (AES128 security processing)
  Default mode on PTM 215ZE and PTM 535Z
- Standard communication (without AES128 security processing)
  Optional mode for PTM 535Z, not available for PTM 215ZE

Standard communication (without AES128 security processing) is supported as an optional feature for PTM 535Z in case shorter payloads are desired for certain applications without requirements for strong security. This mode is not available for PTM 215ZE.

B.1 Secure data telegram format used by PTM 215ZE and PTM 535Z

Figure 8 below shows the MAC Payload structure of a secure data telegram used by PTM 215ZE or PTM 535Z.

Telegram Control	Source ID	Sequence Counter	Command	Telegram Signature
2 Byte	4 Byte	4 Byte	1 Byte	4 Byte

Figure 8: MAC Payload structure for secure data telegrams

The following fields are used:

- Telegram Control (2 bytes)
  The default security mode of PTM 215ZE and PTM 535Z uses a 4 byte payload signature based on a device-unique key and a 4 byte Sequence Counter.
  The *Telegram Control* field is set to 0x308C for this mode.

  PTM 535Z supports an alternative security mode using both payload encryption and 4 byte payload signature based on a device-unique key and a 4 byte Rolling Code Counter.
  The *Telegram Control* field is set to 0x388C for that mode.

- Source ID (4 bytes)
  The *Source ID* field contains a 4 byte ID uniquely identifying each PTM 215ZE or PTM 535Z device

- Sequence Counter (4 bytes)
  The *Sequence Counter* field contains an always incrementing counter.
  Security processing is based on the combination of the Command and Sequence Counter in order to prevent replay attacks (sending the same telegram again)

- Command (1 byte)
  The *Command* field is a one byte field which identifies the state of the different inputs of PTM 215ZE or PTM 535Z. For the encoding please see the applicable data manual.

- Telegram Signature (4 byte)
  The *Telegram Signature* field is used to validate the telegram authenticity. The telegram signature is calculated based on the telegram payload using AES128 (CBC mode).
  EnOcean can provide upon request additional information on how to implement telegram validation for PTM 215ZE or PTM 535Z data telegrams.

B.2 Secure commissioning telegram format used by PTM 215ZE and PTM 535Z

Figure 9 below shows the MAC payload structure of a secure commissioning telegram used by PTM 215ZE and PTM 535Z.

Telegram Control	Source ID	Commissioning Command	Device Type	Device Options	Device-unique Security Key	Security Key Validation	Sequence Counter
1 Byte	4 Byte	1 Byte	1 Byte	2 Byte	16 Byte	4 Byte	4 Byte

Figure 9: MAC Payload structure for secure commissioning telegrams

The following fields are used for secure commissioning telegrams:

- Telegram Control (1 byte)
  The *Telegram Control* field is set to 0x0C to identify a standard telegram (secure communication will be established based on the commissioning telegram)

- Source ID (4 bytes)
  The *Source ID* field contains a 4 byte ID uniquely identifying each PTM 215ZE or PTM 535ZE device

- Commissioning Command (1 byte)
  The *Command* field is set to 0xE0 by PTM 215ZE and PTM 535Z

- Device Type (1 byte)
  The *Device Type* field is set to 0x02 by PTM 215ZE and PTM 535Z

- Device Options (2 bytes)
  The *Device Options* field is set to 0xF281 by PTM 215ZE and PTM 535Z when operating in AES128 secure mode with authentication.
  The *Device Options* field is set to 0xF381 by PTM 535Z when operating in AES128 secure mode with authentication and additional payload encryption (optional feature).

- Device-unique Security Key (16 bytes)
  PTM 215ZE and PTM 535Z implement a random, device-specific security key which is generated as part of the production flow. During commissioning, this key is transmitted in encrypted format. Contact EnOcean for details.

- Security Key Validation (4 bytes)
  In order to ensure correct reception, an additional 4 byte validation value is provided. Contact EnOcean for details.

- Sequence Counter (4 bytes)
  The *Sequence Counter* is an always incrementing counter which is used as part of the security processing to avoid replay attacks (sending the same telegram again).
  Receiving devices shall only accept data telegrams with sequence counter values higher than that of the last received telegram; therefore the current value needs to be communicated during commissioning.

B.3 Standard data telegram format used by PTM 535Z

Figure 10 below shows the MAC Payload structure of a standard data telegram used by PTM 535Z.

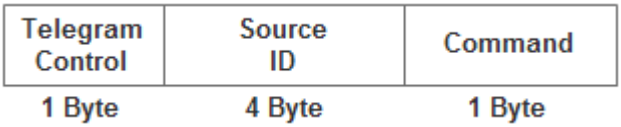

Figure 10: MAC Payload structure for standard data telegrams

The following fields are used for Standard Data Telegrams:

- Telegram Control (1 byte)
  The *Telegram Control* field is set to 0x0C by PTM 535Z to identify a standard data telegram
- Source ID (4 bytes)
  The *Source ID* field contains a 4 byte ID uniquely identifying each PTM 535Z device
- Command (1 byte)
  The *Command* field is a one byte field which identifies the state of the PTM 215ZE button contacts or PTM 535Z input signals. For the encoding please refer to the applicable datasheet.

B.4 Standard commissioning telegram format used by PTM 535Z

Figure 11 below shows the MAC payload structure of a standard commissioning telegram used by PTM 535Z.

Telegram Control	Source ID	Commissioning Command	Device Type	Device Options
1 Byte	4 Byte	1 Byte	1 Byte	1 Byte

Figure 11: MAC Payload structure for standard commissioning telegrams

The following fields are used for standard commissioning telegrams:

- Telegram Control (1 byte)
  The *Telegram Control* field is set to 0x0C to identify a standard telegram (secure communication will be established based on the commissioning telegram)

- Source ID (4 bytes)
  The *Source ID* field contains a 4 byte ID uniquely identifying each PTM 535Z device

- Commissioning Command (1 byte)
  The *Commissioning Command* field is set to 0xE0 by PTM 535Z

- Device Type (1 byte)
  The *Device Type* field is set to 0x02 by PTM 535Z

- Device Options (1 byte)
  The *Device Options* field is set to 0x01 by PTM 535Z

Appendix C ESP3 Interface Format

C.1 Packet Type 0x10: IEEE 802.15.4 Raw Packet

In receive mode, TCM 515Z forwards the content of received IEEE 802.15.4 radio telegrams (which pass frame check sum validation) unmodified to the external host via the ESP3 interface.

The forwarded frame starts with the *Length* field of the IEEE 802.15.4 PHY Header, continues with the MAC Header and ends with the last Byte of the MAC Payload. The frame check sum (MAC Trailer) will not be forwarded to the host.

In transmit mode, TCM 515Z receives from the external host the precomputed message payload starting with the *Length* field of the IEEE 802.15.4 PHY Header, continuing with the MAC Header and ending with the last Byte of the MAC Payload.

TCM 515Z then calculates the frame check sum (MAC Trailer) based on the received payload and appends it to the message. The full frame (including the Preamble and Start of Frame fields) will then be transmitted as IEEE 802.15.4 radio telegram (TX mode).

C.1.1 ESP3 packet structure for IEEE 802.15.4 Raw Packets

The MAC frame is embedded as 802.15.4 payload into the ESP3 packet as shown in Figure 12 below.

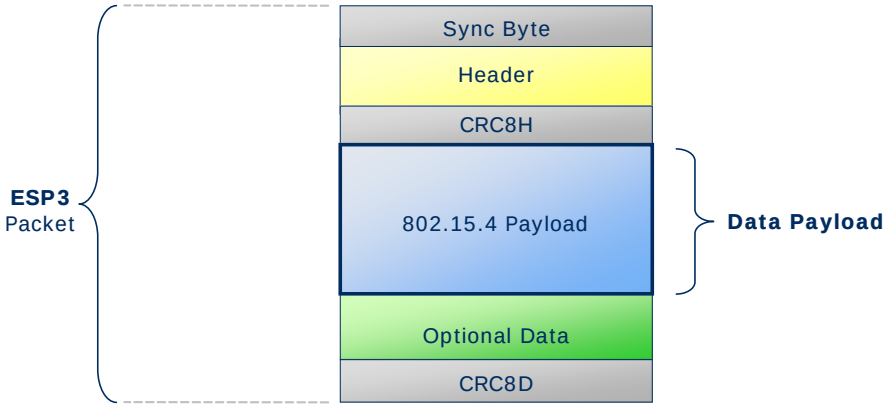

Figure 12: ESP3 packet structure for IEEE 802.15.4 Raw Packets

The detailed structure of the IEEE 802.15.4 Raw Packets is shown in Table 3 below.
IEEE 802.15.4 Raw Packets are identified by Packet Type 0x10.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0xnnnn	Variable length *x* of raw packet payload
	3	1	Optional Length	0x01	1 field fixed
	4	1	Packet Type	0x10	Packet Type 0x10: 802.15.4 Raw Packet
-	5	1	CRC8H	0xnn	
Data	6	x	Raw data	... ...	802.15.4 Raw Packet payload
Optional Data	6+x	1	RSSI	0xnn	Send case: FF Receive case: best RSSI value of all received sub telegrams (value decimal without minus)
-	7+x	1	CRC8D	0xnn	CRC8 Data byte; Calculated checksum for whole byte groups: DATA and OPTIONAL_DATA

Table 3 – Packet structure for IEEE 802.15.4 Raw Packets

C.1.2 RESPONSE for IEEE 802.15.4 Raw Packets

When receiving a telegram, no RESPONSE has to be sent from the external host to the gateway to acknowledge reception of the telegram via ESP3 interface.

When transmitting a telegram, the gateway will send a RESPOND message to the external host via ESP3 interface to indicate the acceptance of the telegram for transmission. The following return codes are applicable for such a RESPONSE message:

- 00 RET_OK
- 02 RET_NOT_SUPPORTED
- 03 RET_WRONG_PARAM

The structure of the gateway RESPONSE message to the request for transmission of an IEEE 802.15.4 Raw Packet is shown in Table 4 below. TCM 515Z will transmit a dedicated message to a connected host if transmission of an accepted telegram subsequently fails.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0004	1 byte
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x02	Packet Type 0x02: RESPONSE
-	5	1	CRC8H	0xnn	
Data	6	1	Return Code	0xnn	00 / 02 / 03
-	7	1	CRC8D	0xnn	

Table 4 - RESPONSE frame structure to IEEE 802.15.4 Raw Packet transmission

C.1.3 Failure Indication for IEEE 802.15.4 Raw Packet transmission

TCM 515Z will accept and immediately acknowledge via ESP3 correctly formatted telegrams for radio transmission as described above.

Should transmission subsequently fail due to channel non-availability then this will be subsequently indicated to the host using an ESP3 Event (Packet Type 0x04) with Event Code 07: CO_TRANSMIT_FAILED.

The structure of ESP3 Event messages is shown in Figure 13 below.

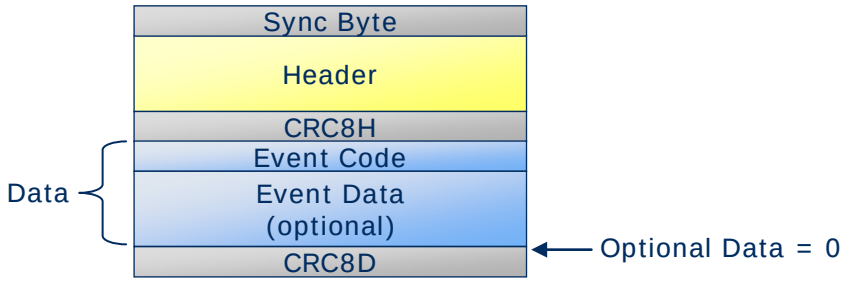

Figure 13: ESP3 packet structure for Events

The structure of the CO_TRANSMIT_FAILED Event is shown in Table 5 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	0x04	EVENT = 4
-	5	1	CRC8H	0xnn	
Data	6	1	Event Code	0x07	CO_TRANSMIT_FAILED = 7
	7	1	Event Cause	0xnn	**00** = CSMA failed, channel was never free **01** = No Acknowledge received, telegram was transmitted, but no ack received. **02...255** = reserved
-	8	1	CRC8D	0xnn	

Table 5 – Structure of Event Code 07: CO_TRANSMIT_FAILED

C.2 Packet Type 0x11: IEEE 802.15.4 COMMAND

The packet type IEEE 802.15.4 COMMAND is used to set and read parameters of TCM 515Z.

C.2.1 Packet structure for IEEE 802.15.4 COMMAND

The packet structure for IEEE 802.15.4 COMMAND is shown in Figure 14 below.

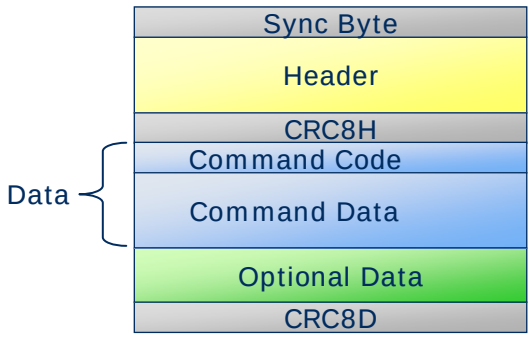

Figure 14 - Packet structure for IEEE 802.15.4 COMMAND

The structure of supported commands and expected responses are described in detail in the following chapters.

C.2.2 List of supported commands

Table 6 below lists the currently supported commands.

Code	Command Name	Description
01	SET_CHANNEL	Sets the radio channel used by the gateway
02	GET_CHANNEL	Reads the radio channel used by the gateway

Table 6 - List of supported commands

C.2.3 SET_CHANNEL Command

The SET_CHANNEL command sets the radio channel used by TCM 515Z. Please refer to chapter 2.3 for details about the supported radio channels.

The command structure of the SET_CHANNEL command is shown in Table 7 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	0x11	Packet Type 0x11: IEEE 802.15.4 COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x01	COMMAND 0x01: SET_CHANNEL
	7	1	Channel	11-26	IEEE 802.15.4 radio channel
-	8	1	CRC8D	0xnn	

Table 7 - Command Structure for the SET_CHANNEL command

C.2.4 RESPONSE for SET_CHANNEL Command

The expected RESPONSE code for a SET_CHANNEL command is:

- 00: RET_OK

The frame structure for a RESPONSE to the SET_CHANNEL command is shown in Table 8 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	0x02	Packet Type 0x02: RESPONSE
-	5	1	CRC8H	0xnn	
Data	6	1	Return Code	0xnn	00
-	7	1	CRC8D	0xnn	

Table 8 - RESPONSE Frame Structure for SET_CHANNEL command

C.2.5 GET_CHANNEL Command

The GET_CHANNEL command requests information about the radio channel currently used by TCM 515Z. The command structure of the GET_CHANNEL command is shown in Table 9 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	0x11	Packet Type 0x11: IEEE 802.15.4 COMMAND
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x02	COMMAND 0x02: GET_CHANNEL
-	7	1	CRC8D	0xnn	

Table 9 - Command structure of the GET_CHANNEL command

C.2.6 RESPONSE for GET_CHANNEL Command

The expected RESPONSE code for a GET_CHANNEL command issued to TCM 515Z is:

- 00: RET_OK

The currently used radio channel is then encoded in the subsequent byte. The frame structure for a RESPONSE to the GET_CHANNEL command is shown in Table 10 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	0x02	COMMAND 0x02: GET_CHANNEL
-	5	1	CRC8H	0xnn	
Data	6	1	Return Code	0	OK
	7	1	Channel	11..26	Used Channel
-	8	1	CRC8D	0xnn	

Table 10 - RESPONSE frame structure for GET_CHANNEL command

C.3 Packet Type Common Command

C.3.1 Command Code 0x24: CO_SET_BAUDRATE

The command CO_SET_BAUDRATE modifies the baud rate of the ESP3 interface. The standard baud rate defined by the ESP3 interface is 57600 Baud. TCM 515Z supports faster baud rates as listed in Table 11 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	COMMON_COMMAND = 0x05
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x24	CO_SET_BAUDRATE = 0x24
	7	1	BAUDRATE	0xnn	0x00 = 57600 BAUD 0x01 = 115200 BAUD 0x02 = 230400 BAUD 0x03 = 460800 BAUD
-	8	1	CRC8D	0xnn	

Table 11 - Command structure of the CO_SET_BAUDRATE command

C.3.2 RESPONSE for CO_SET_BAUDRATE Command

Possible RESPONSE codes to a CO_SET_CHANNEL command are:

- 00: RET_OK
- 02: RET_NOT_SUPPORTED

The frame structure for a RESPONSE to the CO_SET_CHANNEL command is shown in Table 12 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. byte	0x55	
Header	1	2	Data Length	0x0001	Data = 1 byte
	3	1	Optional Length	0x00	Optional Data = 0 byte
	4	1	Packet Type	0x02	RESPONSE = 2
-	5	1	CRC8H	0xnn	
Data	6	1	Return Code	0x00	RET_OK
-	7	1	CRC8D	0xnn	

Table 12 - RESPONSE frame structure for CO_SET_BAUDRATE command

C.3.3 Command Code 0x25: CO_GET_FREQUENCY_INFO

The command CO_GET_FREQUENCY_INFO reports the radio frequency and the communication protocol used by the device. The structure of the command is listed in Table 13 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	COMMON_COMMAND = 5
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x25	CO_GET_FREQUENCY_INFO = 37
-	7	1	CRC8D	0xnn	

Table 13 - Command structure of the CO_GET_FREQUENCY_INFO command

C.3.4 RESPONSE for CO_GET_FREQUENCY_INFO Command

Possible RESPONSE codes to a CO_GET_FREQUENCY_INFO command are:

- 00: RET_OK
- 02: RET_NOT_SUPPORTED

The frame structure for a RESPONSE to the CO_SET_CHANNEL command on devices that support this command is shown in Table 14 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	RESPONSE = 2
-	5	1	CRC8H	0xnn	
Data	6	1	Return Code	0x00	RET_OK = 0
	7	1	Frequency	0xnn	0x00 315Mhz 0x01 868.3Mhz 0x02 902.875Mhz 0x03 925 Mhz 0x04 928 Mhz 0x20 2.4 Ghz
	8	1	Protocol	0xnn	0x00 ERP1 0x01 ERP2 0x10 802.15.4 0x20 Bluetooth 0x30 Long Range
-	9	1	CRC8D	0xnn	

Table 14 - RESPONSE frame structure for CO_GET_FREQUENCY_INFO command

C.3.5 Command Code 37: CO_GET_STEPCODE

The command CO_GET_STEPCODE reports the device revision. The Stepcode is expressed as combination as major revision (DA, DB, DC, …) and minor revision (01, 02, 03, …).
The structure of the command is listed in Table 15 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	COMMON_COMMAND = 5
-	5	1	CRC8H	0xnn	
Data	6	1	COMMAND Code	0x27	CO_GET_STEPCODE = 39
-	7	1	CRC8D	0xnn	

Table 15 - Command structure of the CO_GET_STEPCODE command

C.3.6 RESPONSE for CO_GET_STEPCODE Command

Possible RESPONSE codes to a CO_GET_STEPCODE command are:

- 00: RET_OK
- 02: RET_NOT_SUPPORTED

The frame structure for a RESPONSE to the CO_GET_STEPCODE command on devices that support this command is shown in Table 16 below.

Group	Offset	Size	Field	Value hex	Description
-	0	1	Sync. Byte	0x55	
Header	1	2	Data Length	0x00023	3 bytes
	3	1	Optional Length	0x00	0 byte
	4	1	Packet Type	0x02	RESPONSE = 2
-	5	1	CRC8H	0xnn	
Data	6	1	Return Code	0x00	RET_OK = 0
	7	1	Major Revision	0xnn	e.g. 0xDA, 0xDB …
	8	1	Minor Revision	0xnn	e.g. 0x01, 0x02 …
-	9	1	CRC8D	0xnn	

Table 16 - RESPONSE frame structure for CO_GET_STEPCODE command