

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

PTM 215ZE 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

25 November 2019



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

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

REVISION HISTORY

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

Version	Author	Reviewer	Date	Major Changes
1.0	MKA	MHö / MF	01.03.2016	Initial Release
1.1	MKA	MKA	02.05.2016	More detailed protocol description
1.2	MKA	MKA	12.05.2016	Added DMC structure, clarified commissioning
1.3	MKA	MKA	26.01.2017	Added description of authentication process
1.4	MKA	MKA	24.07.2017	Changed EU certification (R&TTE -> RED) Added step by step example for authentication
1.5	MK	MKA	12.10.2017	Added warning: no magnet or ferromagnetic near PTM 215ZE
1.6	MKA	MKA	26.06.2019	Update for DA-03 (new product label)
1.7	MKA	MKA	25.11.2019	Added clarification on push / release behavior in button mapping table

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

© EnOcean GmbH, All Rights Reserved

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.

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

TABLE OF CONTENT

- 1 General Description 5
- 1.1 Key Functionality 5
- 1.2 Technical Data 6
- 1.3 Physical Dimensions 6
- 1.4 Environmental Conditions 6
- 1.5 Packaging Information 6
- 1.6 Ordering Information 6
- 2 Functional Information 7
- 2.1 Device Overview 7
- 2.2 Functional Principle 7
- 2.3 Block Diagram 8
- 2.4 User Interface 9
- 3 Radio Transmission 10
- 3.1 Radio Channel Parameters 10
- 3.2 Telegram Structure 11
 - 3.2.1 PHY Header 12
 - 3.2.2 MAC Header 13
 - 3.2.3 MAC Trailer 13
- 3.3 Payload Structure 14
 - 3.3.1 Button Contact Encoding 15
- 4 Telegram Authentication 16
- 4.1 Authentication Implementation 17
- 5 Commissioning 18
- 5.1 Commissioning Mode Entry 18
- 5.2 Commissioning Telegram Transmission 19
- 5.3 Commissioning Telegram Format 20
 - 5.3.1 Commissioning Telegram Example 21
- 5.4 Radio channel adjustment 22
 - 5.4.1 Radio channel adjustment examples 22
- 5.5 Determining the correct radio channel 23
- 5.6 Storing the new radio channel and return to data mode 23
- 6 Device Integration 24
- 6.1 Mechanical Interface Characteristics 24
- 6.2 Mechanical Interface Drawings 24
- 6.3 Device Label 30
 - 6.3.1 Legacy Product Label 30
 - 6.3.1.1 Data Matrix Code (DMC) format 31
 - 6.3.2 Standard Product Label 32
 - 6.3.2.1 QR Code format 32

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

- 7 Application Information 33
- 7.1 Transmission range 33
- 8 Regulatory Information 34
- 8.1 RED for the European Market 34
- 8.2 FCC (United States) Certificate 35
 - 8.2.1 FCC (United States) Regulatory Statement 35
 - 8.2.2 ISED (former Industry Canada) Regulatory Statement 36
- A Understanding PTM 215ZE telegram structure 37
 - A.1 Installation instructions for TI CC2531 packet sniffer 37
 - A.1.1 CC2531EMK setup 37
 - A.2 Configuration 38
 - A.3 Data capture 40
 - A.4 Interpretation of the telegram data 41
 - A.4.1 MAC Payload 41
 - A.4.2 Device ID 41
 - A.4.3 Sequence Counter 41
 - A.4.4 Command payload 42
 - A.4.5 Telegram Signature 42
- B Authentication of PTM 215ZE data telegrams 43
 - B.1 Algorithm input parameters 43
 - B.1.1 Constant input parameters 43
 - B.1.2 Variable input parameters 44
 - B.1.3 Obtaining the private key 45
 - B.1.3.1 Obtaining the private key via the product DMC code 45
 - B.1.3.2 Obtaining the private key via a commissioning telegram 45
 - B.2 Internal parameters 46
 - B.3 Constant internal parameters 46
 - B.4 Variable internal parameters 47
 - B.4.1 Forming the Nonce 47
 - B.4.2 Calculating the flags 47
 - B.5 Algorithm execution sequence 48

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

1 General Description

1.1 Key Functionality

PTM 215ZE enables the realization of energy harvesting wireless switches for systems communicating based on the 2.4 GHz IEEE 802.15.4 radio standard including those supporting the ZigBee Green Power standard.

PTM 215ZE is mechanically compatible with the established PTM 21x form factor enabling quick integration into a wide range of designs. Key applications are wall-mounted or portable switches either with up to two rockers or up to four push buttons.

PTM 215ZE pushbutton transmitters are self-powered (no batteries) and fully maintenance-free. They can therefore be used in all environments including locations that are difficult to reach or within hermetically sealed housings. The required energy is generated by an electro-dynamic energy transducer actuated by an energy bow located on the left and right of the module. This energy bow which can be pushed from outside the module by an appropriate pushbutton or switch rocker.

When the energy bow is pushed down or released, electrical energy is created and a 2.4GHz radio telegram according to the ZigBee Green Power standard is transmitted. This radio telegram transmits the operating status of all four contact nipples at the moment when the energy bow was pushed down or released. PTM 215ZE telegrams are protected with an AES-128 signature based on a device-unique private key.

Figure 1 below shows PTM 215ZE.



Figure 1 – PTM 215ZE Product Outline

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

1.2 Technical Data

Antenna	Integrated antenna
Max. radio transmit power (measured)	7dBm / 5mW
Radio Standard	ZigBee Green Power (IEEE 802.15.4)
Supported Radio Channels	2.4 GHz Channel 11 ... 26 (Default: Channel 11)
Radio Channel Selection	User-selectable (Commissioning)
Device Identification	Individual 32 Bit Device ID (factory programmed)
Telegram Authentication	AES128 (CBC Mode) with Sequence Code
Power Supply	Integrated Kinetic Energy Harvester
Button Inputs	Up to four buttons or two rockers

1.3 Physical Dimensions

Module Dimensions	40.0 x 40.0 x 11.2 mm
Module Weight	20 g

1.4 Environmental Conditions

Operating Temperature	-25°C ... 65°C
Storage Temperature	-25°C ... 65°C
Humidity	0% to 95% r.h. (non-condensing)

1.5 Packaging Information

Packaging Unit	100 units
Packaging Method	Tray / Box (10 units per tray, 10 trays per box)

1.6 Ordering Information

Type	Ordering Code	Frequency
PTM 215ZE	S3271-A215	2.4 GHz (IEEE 802.15.4)

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

2 Functional Information

2.1 Device Overview

The pushbutton transmitter module PTM 215ZE from EnOcean enables the implementation of wireless switches and remote controls without batteries. Power is provided by a built-in electro-dynamic power generator.

The outer appearance of PTM 215ZE is shown in Figure 2 below.

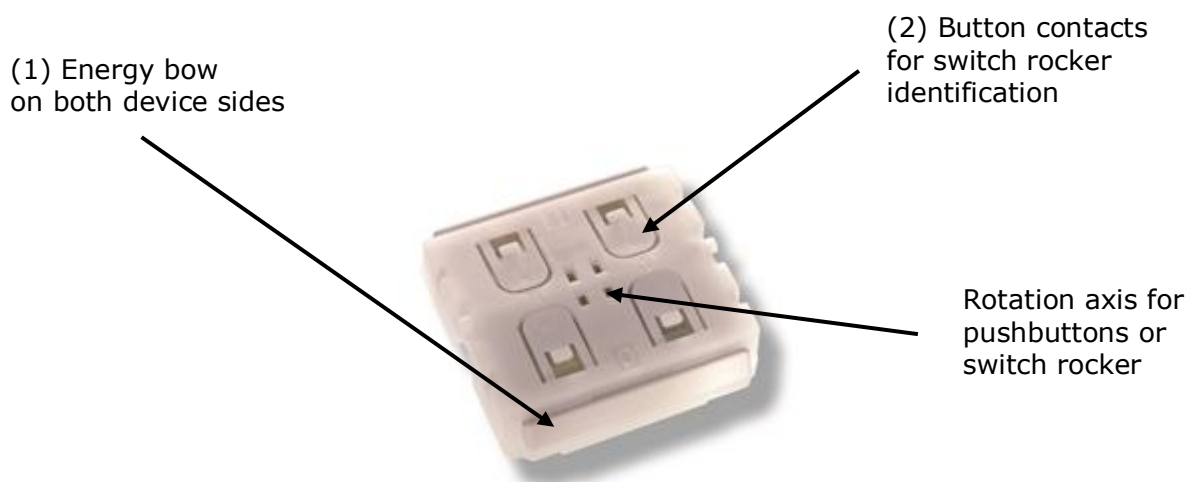


Figure 2 – Electro-dynamic powered pushbutton transmitter module PTM 215ZE

2.2 Functional Principle

PTM 215ZE devices contain an electro-dynamic energy transducer which is actuated by an energy bow (1). This bow is pushed by an appropriate push button, switch rocker or a similar construction mounted onto the device. An internal spring will release the energy bow as soon as it is not pushed down anymore.

When the energy bow is pushed down, electrical energy is created and a ZigBee Green Power radio telegram is transmitted which identifies the status (pressed or not pressed) of the four button contacts (2). Releasing the energy bow similarly generates energy which is used to transmit a different radio telegram.

It is therefore possible to distinguish between radio telegrams sent when the energy bar was pushed and radio telegrams sent when the energy bar was released.

By identifying these different telegram types and measuring the time between pushing and releasing of the energy bar, it is possible to distinguish between “Long” and “Short” button contact presses. This enables simple implementation of applications such as dimming control or blinds control including slat action.

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

2.3 Block Diagram

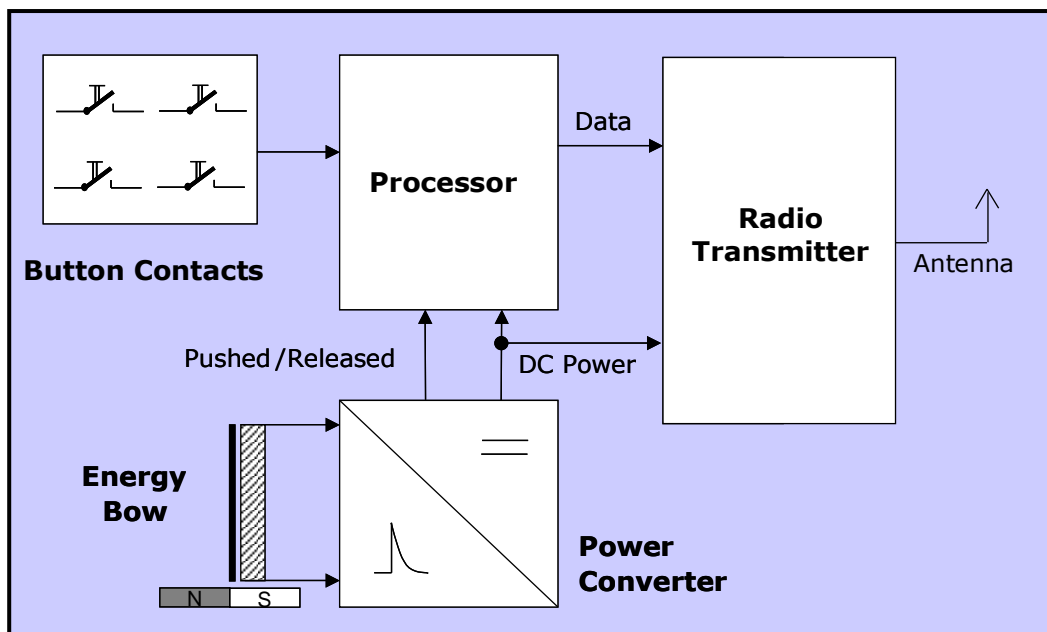


Figure 3 – Block diagram of PTM 215ZE

Energy Bow / Power Generator

Converts the motion of the energy bow into electrical energy

Power Converter

Converts the energy of the power generator into a stable DC supply voltage for the device electronics

Processor

Determines the status of the button contacts and the energy bow, encodes this status into a data word, generates the proper radio telegram structure and sends it to the radio transmitter

Radio transmitter

Transmits the data in the form of a series of short ZigBee Green Power radio telegrams using the integrated antenna

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

2.4 User Interface

PTM 215ZE devices provide four button contacts. They are grouped into two channels (Channel A and Channel B) each containing two button contacts (State O and State I).

The state of all four button contacts (pressed or not pressed) is transmitted together with a unique device identification (32 Bit ZigBee Green Power Device ID) whenever the energy bow is pushed or released.

Figure 4 below shows the arrangement of the four button contacts and their designation.

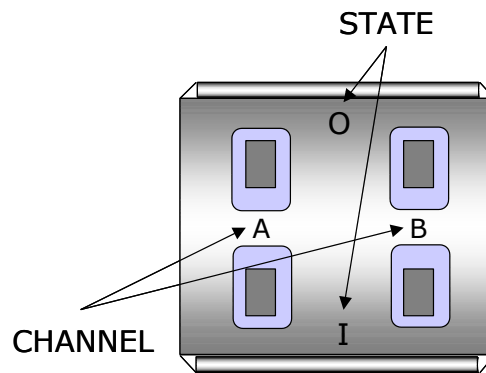


Figure 4 – Button contact designation

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

3 Radio Transmission

PTM 215ZE transmits data telegrams according to IEEE 802.15.4 physical radio interface using ZigBee Green Power data and commissioning telegrams.

3.1 Radio Channel Parameters

PTM 215ZE supports all sixteen IEEE 802.15.4 / ZigBee Green Power radio channels in the 2.4 GHz band (channels 11 ... 26 according to IEEE 802.15.4 notation) which can be selected as described above.

Table 1 below shows the correspondence between channel number and channel frequency (in MHz).

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 1 - IEEE 802.15.4 Radio Channels and Frequencies (in MHz)

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

3.2 Telegram Structure

PTM 215ZE transmits radio telegrams in the 2.4 GHz band according to the IEEE 802.15.4 frame structure using a ZigBee Green Power compliant payload.

Note that the byte order used by these standards 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 frame structure used by PTM 215ZE 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 (always `0x0801`) which 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
PTM 215ZE does not use source address and source PAN ID

■ MAC Payload

The MAC payload is based on the ZigBee Green Power standard. It contains telegram control, device ID, telegram data and telegram security fields.

■ MAC Trailer

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

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

Figure 5 below summarizes the IEEE 802.15.4 frame structure.

802.15.4 PHY Header			802.15.4 MAC Header			802.15.4 Payload (ZigBee Green Power Protocol)			802.15.4 MAC Trailer
Preamble	Start of Frame	Length of Frame	Frame Control	Sequence Number	DstAddress PAN Addr	ZGP Header	ZGP Payload	ZGP Trailer	Frame Check Sum (FCS)
4 Byte 0x00:00:00:00	1 Byte 0xA7	1 Byte	2 Byte 0x01:08	1 Byte	4 Byte 0xFFFF 0xFFFF	10 Byte	28 Byte (COM) 1 Byte (DATA)	4 Byte	2 Byte

Figure 5 – IEEE 802.15.4 Frame Structure

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

3.2.1 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 PTM 215ZE as follows:

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

The content of the *Length of Frame* field differs depending on the telegram type as follows:

- Commissioning telegram
Length= 42 bytes (0x2A)
- Data telegram
Length = 24 bytes (0x18)

3.2.2 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 all PTM 215ZE 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 PTM 215ZE implementation)**
The *Address Field* is set to $0xFFFFFFFF$ to identify PTM 215ZE telegrams as broadcast telegrams using short Destination Address (16 Bit) together with the Destination PAN ID (16 Bit). Source address and Source PAN ID are not present in PTM 215ZE MAC Header.

3.2.3 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 of Frame* field of the PHY Header using the following polynomial: $x^{16} + x^{12} + x^5 + 1$

3.3 Payload Structure

The MAC Payload is encoded to be compatible with the zigbee Green Power protocol. Figure 6 below shows the MAC Payload structure for data telegrams.

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

Figure 6 – MAC Payload structure for data telegrams

The following fields are used for the MAC Payload of data telegrams:

- **Telegram Control (2 byte)**
The *Telegram Control* field is set to 0x308C to identify a secure telegram with device-unique key
- **Source ID (4 byte)**
The *Source ID* field contains a 4 byte ID uniquely identifying each PTM 215ZE device
- **Sequence Counter (4 byte)**
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 PTM 215ZE contacts. For the encoding please refer to Table 2 below.
- **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). For details, see chapter 4

In addition to data telegrams, PTM 215ZE can also transmit commissioning telegrams as described in chapter 5.3

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

3.3.1 Button Contact Encoding

Table 2 below shows the supported single and dual button contact actions of PTM 215ZE together with the encoding used for the transmission.

In this table, the meaning of “0” and “1” is the following for press and release events:

- “0”
Button is not pressed upon push
Button was not pressed before release
- “1”
Button is pressed upon push
Button was pressed before release

A0	A1	B0	B1	Energy Bar	Command
0	0	0	0	Press	0x10
0	0	0	0	Release	0x11
0	0	0	1	Press	0x12
0	0	0	1	Release	0x13
0	0	1	0	Press	0x14
0	0	1	0	Release	0x15
0	1	0	0	Press	0x18
0	1	0	0	Release	0x19
1	0	0	0	Press	0x22
1	0	0	0	Release	0x23
0	0	1	1	Press	0x16
0	0	1	1	Release	0x17
0	1	0	1	Press	0x1A
0	1	0	1	Release	0x1B
0	1	1	0	Press	0x1C
0	1	1	0	Release	0x1D
1	0	0	1	Press	0x1E
1	0	0	1	Release	0x1F
1	0	1	0	Press	0x62
1	0	1	0	Release	0x63
1	1	0	0	Press	0x64
1	1	0	0	Release	0x65

Table 2 - PTM 215ZE button contact status encoding

4 Telegram Authentication

PTM 215ZE implements telegram authentication for data telegrams to ensure that only telegrams from senders using a previously exchanged security key will be accepted. Authentication relies on a 32 bit telegram signature which is calculated as shown in Figure 7 below and exchanged as part of the radio telegram.

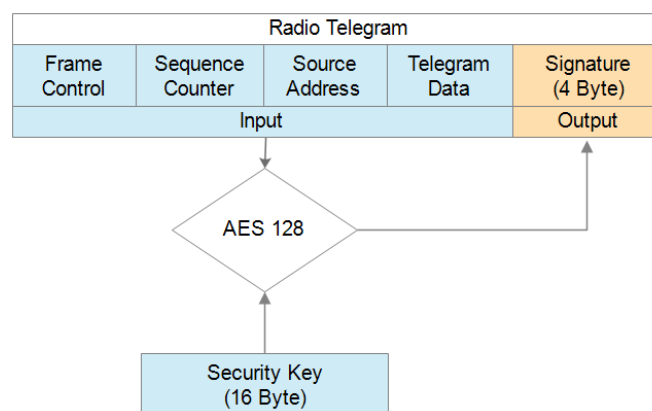


Figure 7 – Telegram authentication flow

Sequence counter, source address and the remaining telegram data together form the input data for the signature algorithm. This algorithm uses AES128 encryption based on the device-unique random security key to generate a 32 bit signature which will be transmitted as part of the radio telegram.

The signature is therefore dependent both on the current value of the sequence counter, the device source address and the telegram payload. Changing any of these three parameters will therefore result in a different signature.

The receiver performs the same signature calculation based on sequence counter, source address and the remaining telegram data of the received telegram using the security key it received from PTM 215ZE during commissioning.

The receiver then compares the signature reported as part of the telegram with the signature it has calculated. If these two signatures match then the following statements are true:

- Sender (PTM 215ZE) and receiver use the same security key
- The message content (address, sequence counter, data) has not been modified

In order to avoid message replay (capture and retransmission of a valid message), it is required that the receiver tracks the value of the sequence counter used by PTM 215ZE and only accepts messages with higher sequence counter values (i.e. not accepts equal or lower sequence counter values for subsequent telegrams).

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

4.1 Authentication Implementation

PTM 215ZE implements telegram authentication according to the ZigBee Green Power specification. It uses AES128 in CCM (Counter with CBC-MAC) mode as described in IETF RFC3610. At the time of writing, the RFC3610 standard could be found here: <https://www.ietf.org/rfc/rfc3610.txt>

The 13 Byte CCM Nonce (number used once – unique) initialization value is constructed as concatenation of 4 byte Device ID, 4 byte Device ID again, 4 byte Sequence Counter and 1 status byte of value 0x05.

Note that both Device ID and Sequence Counter use little endian format (least significant byte first).

Figure 8 below shows the structure of the AES128 Nonce.

AES128 Nonce (13 Byte)													
Device ID				Device ID				Sequence Counter				STATUS	
Byte 0	Byte 1	Byte 2	Byte 3	Byte 0	Byte 1	Byte 2	Byte 3	Byte 0	Byte 1	Byte 2	Byte 3	0x05	

Figure 8 – AES128 Nonce structure

The AES128 Nonce and the 128 bit device-unique security key are then used to calculate a 32 bit signature of the authenticated telegram payload shown in Figure 9 below.

Authenticated Data (11 Byte)											
Frame Control		Source ID				Sequence Counter				Command	
0x8C	0x30	Byte 0	Byte 1	Byte 2	Byte 3	Byte 0	Byte 1	Byte 2	Byte 3	Byte 0	

Figure 9 – Authenticated payload

The calculated 32 bit signature is then appended to the data telegram payload as shown in chapter 3.3.

The security key required for the telegram authentication can be obtained in two ways:

- **Product DMC code**
Each PTM 215ZE device contains a product label with a DMC code that identifies the Source ID and the Private Security Key used by this device, see below.
- **Commissioning telegram**
The security key is transmitted as part of the commissioning telegram, see chapter 5.3

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

5 Commissioning

Commissioning is used to commission (teach-in, learn in) PTM 215ZE into a specific receiver or network. To do so, PTM 215ZE provides two key functions:

- Transmission of a commissioning telegram in order to learn-in PTM 215ZE into a network
- Radio channel selection in order to set the radio channel of PTM 215ZE to that used by the network

These functions are described subsequently in more detail.

5.1 Commissioning Mode Entry

Commissioning mode is entered using a special button contact sequence. This is illustrated in Figure 10 below.

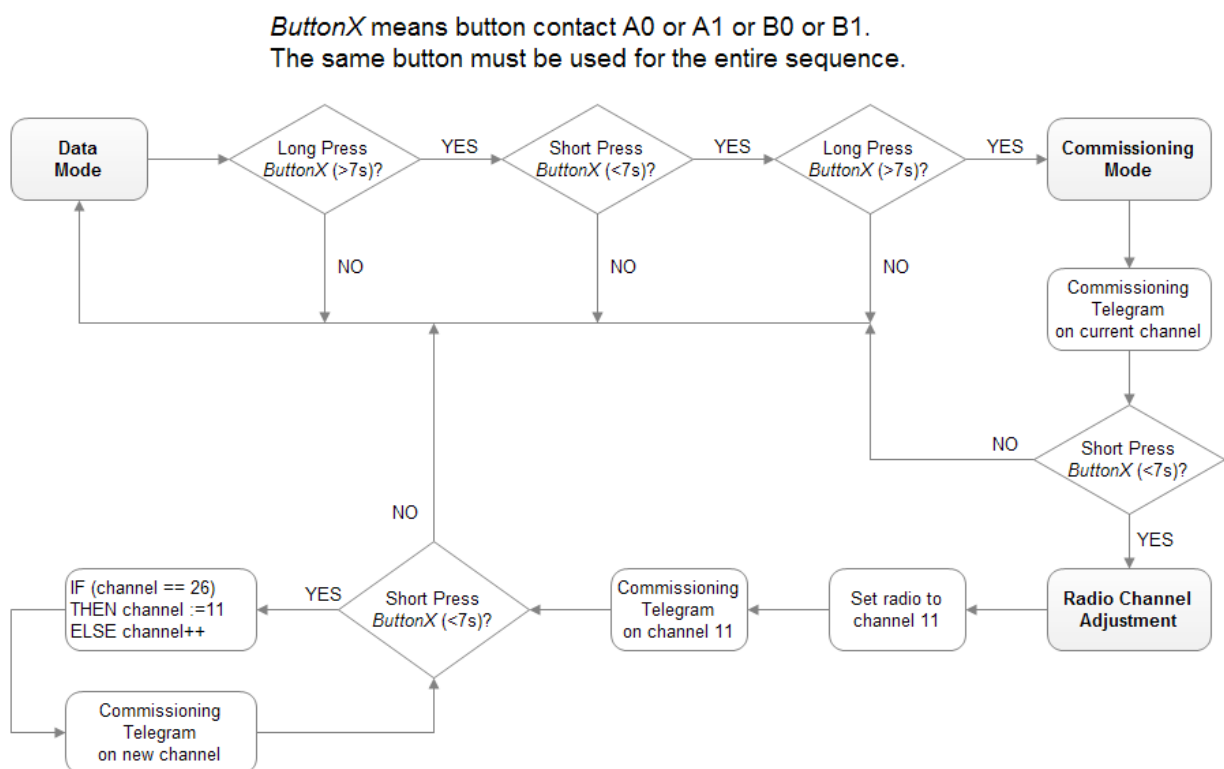


Figure 10 – Button sequence for commissioning mode

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

To enter commissioning mode, start by selecting one button contact of PTM 215ZE. Any contact of PTM 215ZE (A0, A1, B0, B1) can be used. This contact is referred to as *ButtonX* in Figure 10 above.

Next, execute the following long-short-long sequence:

1. Press and hold the selected button contact together with the energy bar for more than 7 seconds before releasing it
2. Press the selected button contact together with the energy bar quickly (hold for less than 2 seconds)
3. Press and hold the selected button contact together with the energy bar again for more than 7 seconds before releasing it

Upon detection of this sequence, PTM 215ZE will enter commissioning mode and transmit a commissioning telegram on the current radio channel.

Sometimes the user might be unsure if PTM 215ZE is operating in normal mode or in commissioning mode and if part of the entry sequence into commissioning mode has already been executed.

PTM 215ZE can always be set into a defined state (normal mode) by shortly (< 7s) pressing two different buttons one after another. After that, PTM 215ZE will operate in data mode and the full sequence for commissioning mode entry (long-sort-long) has to be executed to enter commissioning mode.

5.2 Commissioning Telegram Transmission

PTM 215ZE will transmit a commissioning telegram on the current radio channel immediately upon entering commissioning mode. This allows teach-in into additional devices without changing the currently used radio channel.

The default radio channel used by PTM 215ZE is channel 11 (see chapter 3). It can be subsequently adjusted as described in the following chapter.

Whenever a new radio channel is selected, PTM 215ZE will transmit a commissioning telegram on the new radio channel. This enables the receiver to provide feedback to the user to indicate when PTM 215ZE has reached the correct radio channel (i.e. when the receiver receives a commissioning telegram from PTM 215ZE on the radio channel the receiver is using). See chapter 5.5 for a discussion of feedback mechanisms.

The format of PTM 215ZE radio telegrams including commissioning telegrams is described below.

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

5.3 Commissioning Telegram Format

Figure 11 below shows the MAC payload structure for commissioning telegrams.

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 11 – MAC Payload structure for commissioning telegrams

The following fields are used for 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 device
- **Command (1 byte)**
The *Command* field is set to $0xE0$ to identify this command as commissioning command
- **Device Type (1 byte)**
The *Device Type* field is set to $0x02$ to identify PTM 215ZE as ON / OFF switch
- **Device Options (2 byte)**
The *Device Options* field is set to $0xF281$ to identify the device as PTM 215ZE communicating securely using the AES128 (CBC mode) algorithm and a 4 byte sequence counter to generate a 4 byte signature
- **Encrypted Device-unique Security Key (16 bytes)**
Each PTM 215ZE contains a random, device-specific security key which is generated as part of the production flow. During commissioning, this key is transmitted in encrypted form as specified by the zigbee Green Power specification.
- **Security Key Validation (4 bytes)**
In order to ensure correct reception, an additional 4 byte validation value is provided.
- **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.

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

5.3.1 Commissioning Telegram Example

Below is an example of the MAC payload of a commissioning telegram from a PTM 215ZE device:

```
0C FB 02 50 01 E0 02 81 F2 88 42 0A 19 66 16 6C 7A A2 15 B2 B7 72 18 BD A3 0F 32 8C
32 27 00 00 00
```

The three most relevant fields for commissioning are marked red in the example above:

- Source ID
Note that this is transmitted in little endian format, i.e. the actual Source ID is `0x015002FB`
- Encrypted security key
This the encrypted version of the actual security key; the encryption is implemented according to the zigbee Green Power specification
- Sequence Counter
Note that this is transmitted in little endian format, i.e. the actual Sequence Counter is `0x00000027`

For a description how to decode the encrypted security key please refer to the zigbee Green Power specification.

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

5.4 Radio Channel Adjustment

The radio channel used by PTM 215ZE can be changed whenever PTM 215ZE is in commissioning mode. Refer to chapter 3 for a summary of the supported radio channels.

In order to change the radio channel, press the selected button contact shortly (< 7s) once after entry into commissioning mode. This will reset the radio channel used by PTM 215ZE to channel 11 and enable subsequent channel adjustment.

If PTM 215ZE was already operating on channel 11 (default condition) then the radio channel will remain unchanged. This ensures that PTM 215ZE will always use channel 11 as starting point for the radio channel adjustment.

The radio channel can now be incremented by continuing to press the selected button contact shortly (< 7s). For each such button press, the radio channel is incremented. If channel 26 has been reached, then channel 11 will be used next.

5.4.1 Adjustment examples

Example 1: PTM 215ZE operating on channel 11 (out of the box condition)

In this case, PTM 215ZE would send a commissioning telegram on channel 11 immediately after detecting the long-short-long sequence.

After that, it would for each additional short button press send commissioning telegrams on incrementing radio channels starting with channel 11.

This means that the channel sequence would be:

11 (current channel) - 11 - 12 - 13 ... 25 - 26 - 11 - 12 and so on

Example 2: PTM 215ZE operating on channel 15

In this case, PTM 215ZE would send a commissioning telegram on channel 15 immediately after detecting the long-short-long sequence.

After that, it would for each additional button press send commissioning telegrams on incrementing radio channels starting with channel 11.

This means that the channel sequence would be:

15 (current channel) - 11 - 12 - 13 ... 25 - 26 - 11 - 12 and so on

5.5 Determining The Correct Radio Channel

The user requires system feedback to determine if the correct radio channel has been reached.

Several methods are possible for that, including:

- Feedback from the device into which PTM 215ZE is learned in
E.g. blinking a status light, toggling a connected load, moving a motor etc.
- Feedback from a dedicated user interface
This could for instance instruct the user on the required key sequence and confirm correct execution

It is the responsibility of the system designer to define a suitable feedback mechanism.

5.6 Radio Channel Storage And Return To Data Mode

If PTM 215ZE has been successfully set to the desired radio channel, then this radio channel has to be stored and operation should return to data mode.

This is achieved by pressing any button contact other than the one used for entry into commissioning mode (and channel change). So if button contact A0 was used to enter commissioning mode then pressing button contact A1, B0 or B1 will cause storing of the current radio channel and return to data mode.

Failure to store the selected radio channel and to return to normal mode could cause accidental reconfiguration of PTM 215ZE.

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

6 Device Integration

PTM 215ZE is designed for integration into button or rocker-based switches with manual activation (press and release by user input). It implements the established PTM 2xx mechanical form factor and can therefore be used with a wide variety of existing designs.

6.1 Mechanical Interface Characteristics

Energy bow travel / operating force	1.8 mm / typ. 10 N At room temperature Only one of the two energy bows may be actuated at the same time!
Restoring force at energy bow	typ. 0.7 N Minimum restoring force of 0.5 N is required for correct operation
Number of operations at 25°C	typ. 100.000 actuations tested according to VDE 0632 / EN 60669
Cover material	Hostaform (POM)
Energy bow material	PBT (50% GV)

6.2 Mechanical Interface Drawings

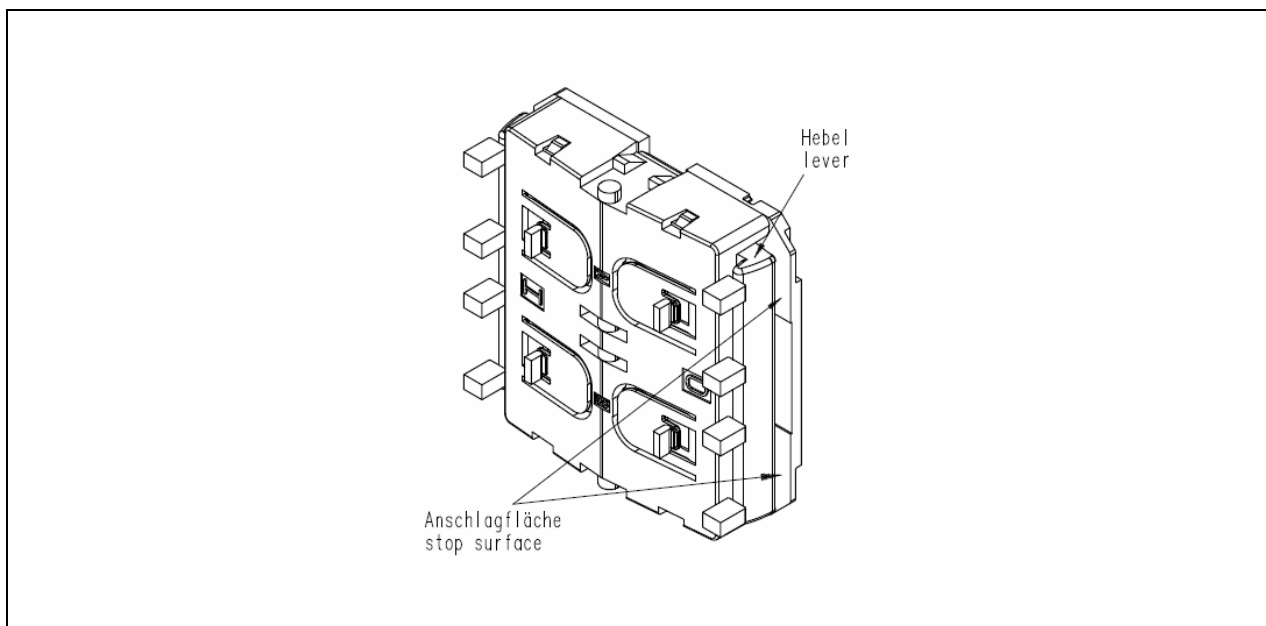
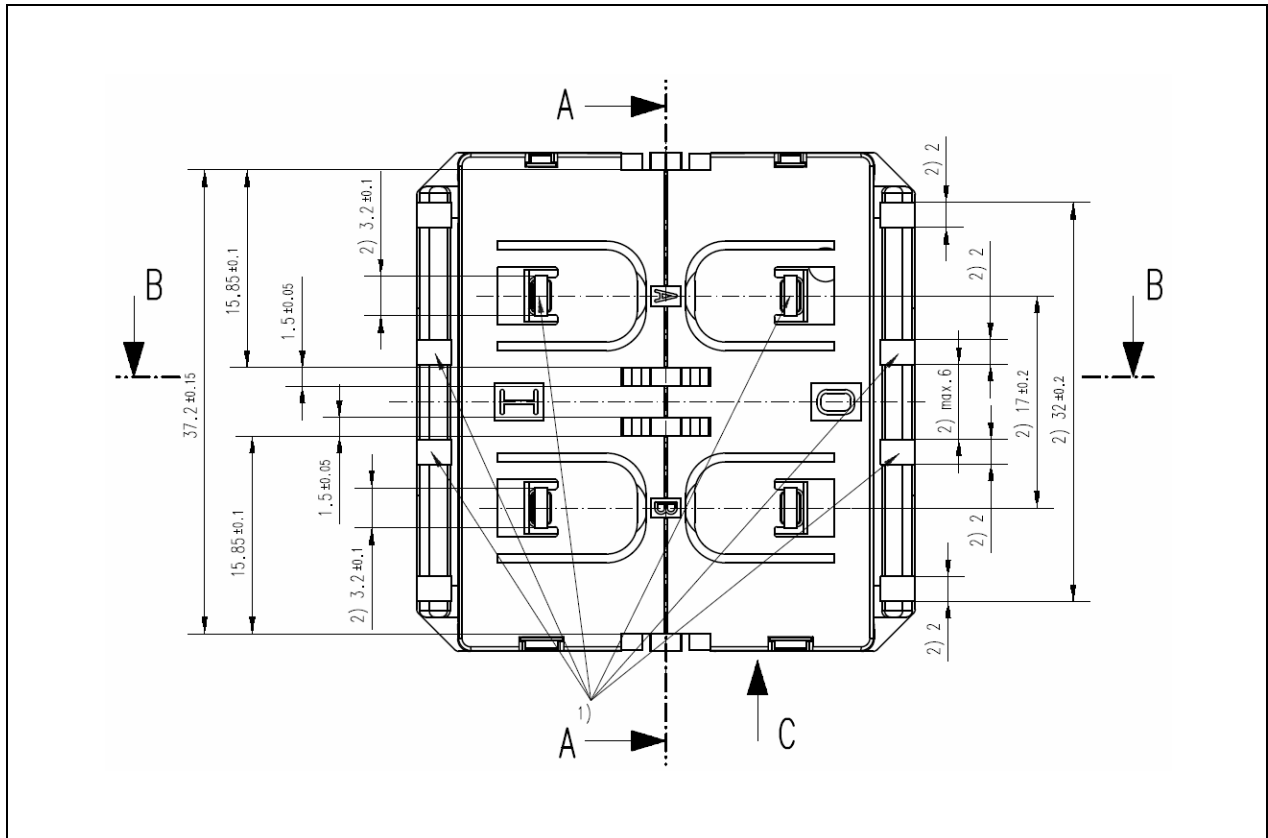


Figure 12 – PTM 215ZE, tilted view (including rocker catwalks)

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module



1) these catwalks are not needed when using one single rocker only 2) dimensions of rocker part

Figure 13 – PTM 215ZE, top view (note cut A, B and C marking)

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

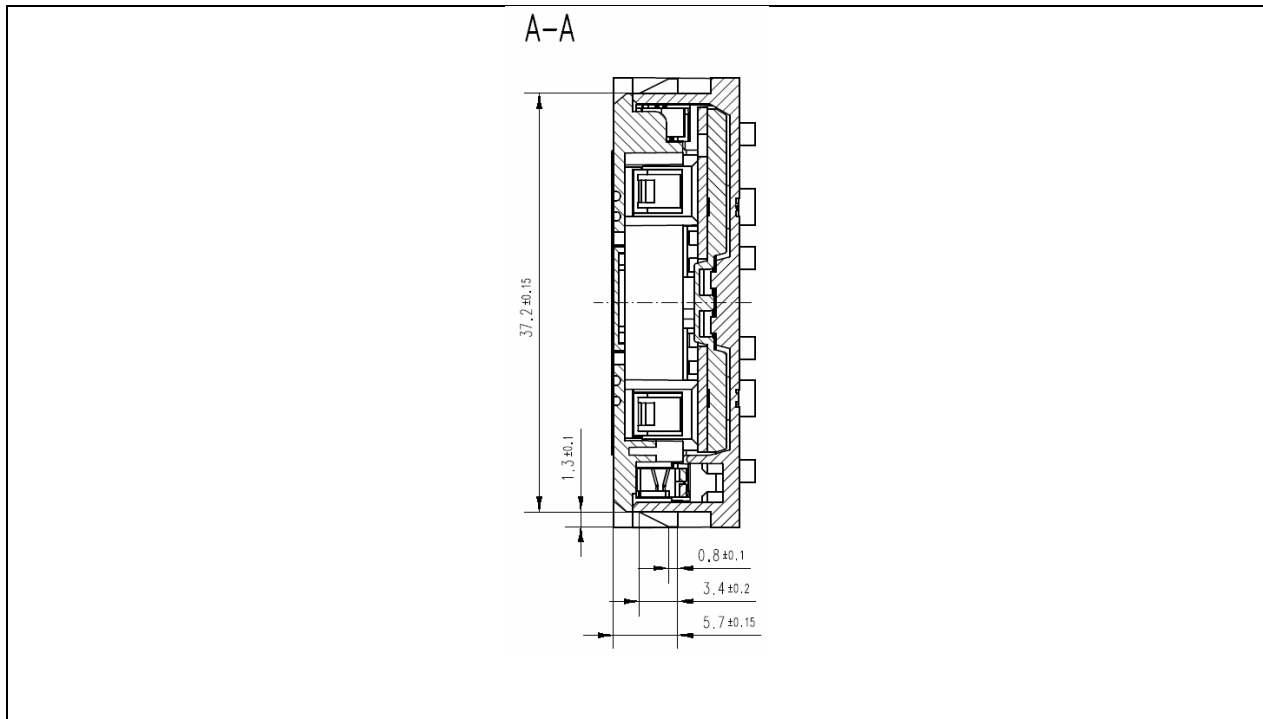
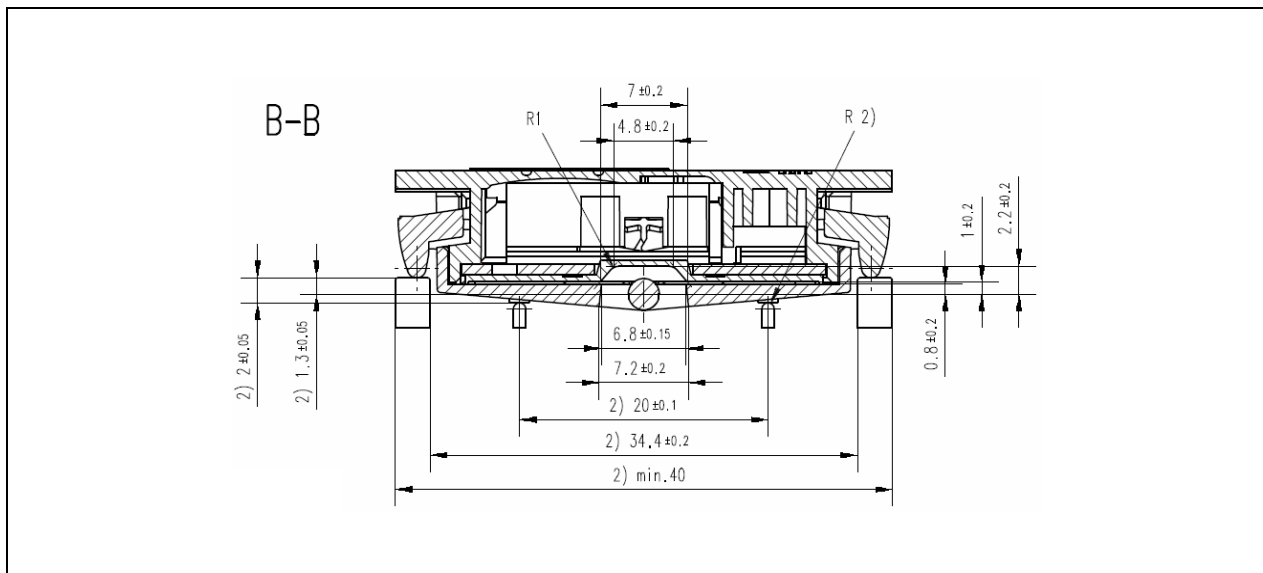


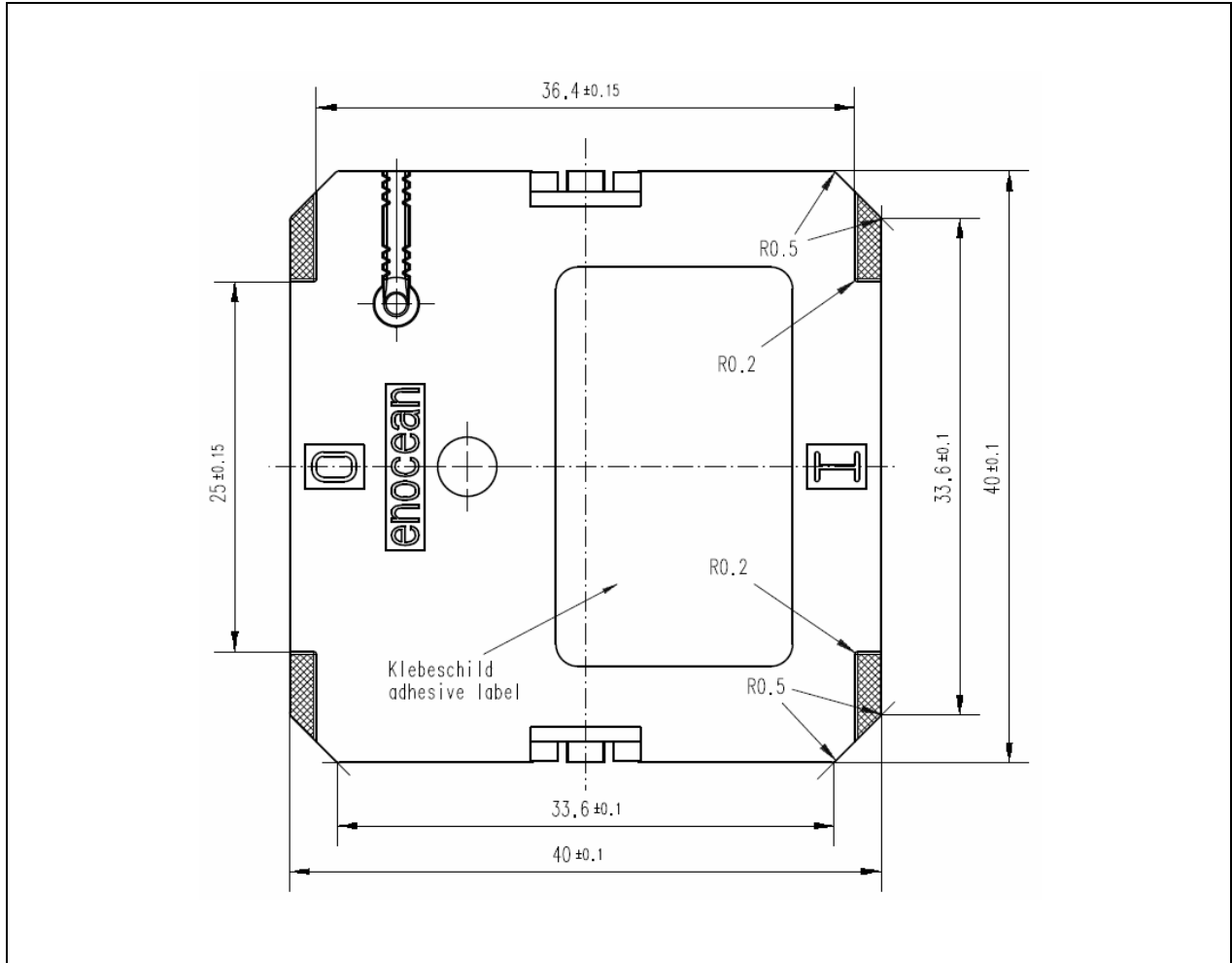
Figure 14 – PTM 215ZE, cut A



2) dimensions of rocker part

Figure 15 – PTM 215ZE, cut B and C

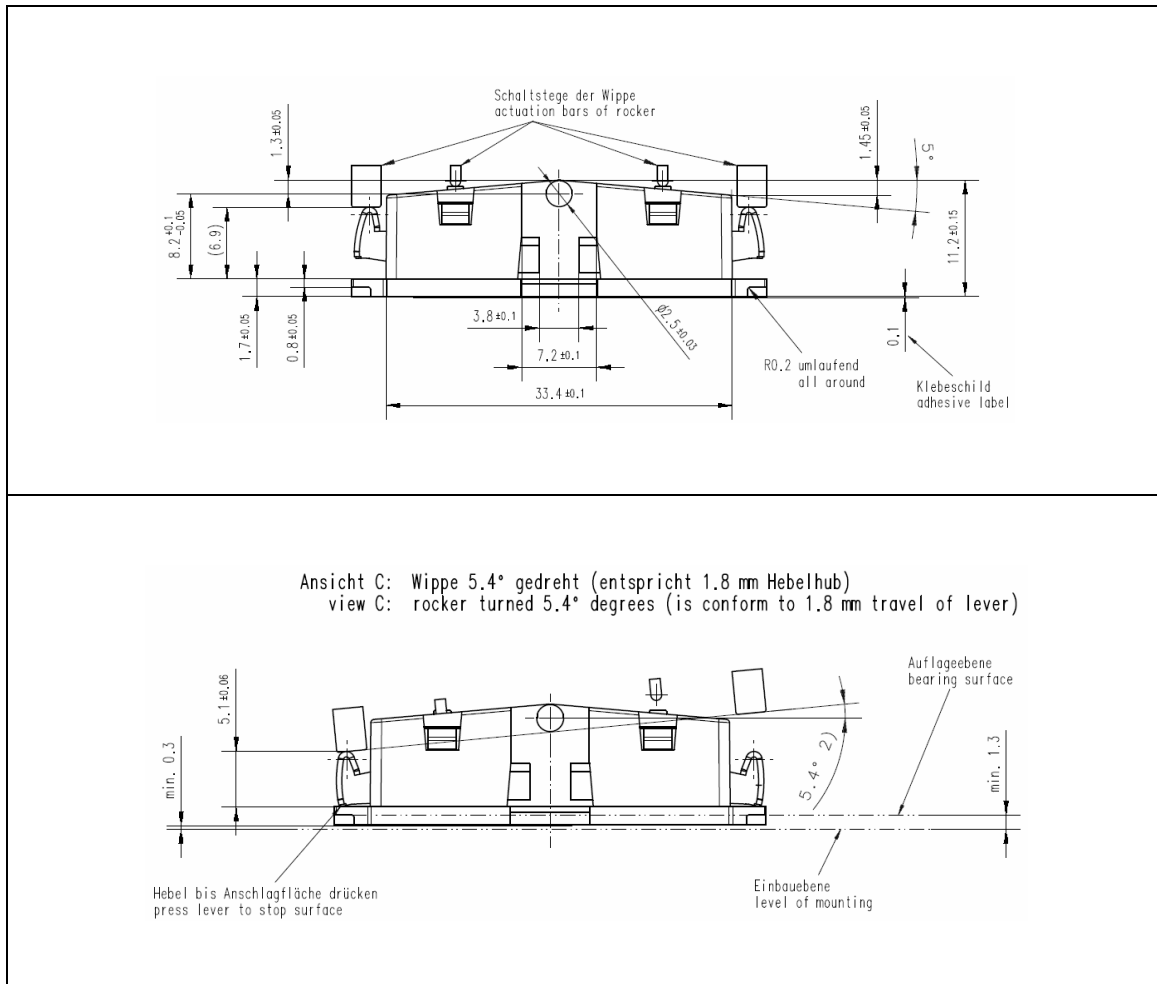
PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module



Hatched areas: support planes

Figure 16 – PTM 215ZE rear view

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module



2) dimensions of rocker part

Figure 17 – PTM 215ZE, side view



If the rocker is not mounted on the rotation axis of PTM 215ZE several tolerances have to be considered! The measure from support plane to top of the energy bow is 7.70 mm +/- 0.3 mm!



The movement of the energy bow must not be limited by mounted rockers!



Catwalks of the switch rocker must not exert continuous forces on the button contacts!

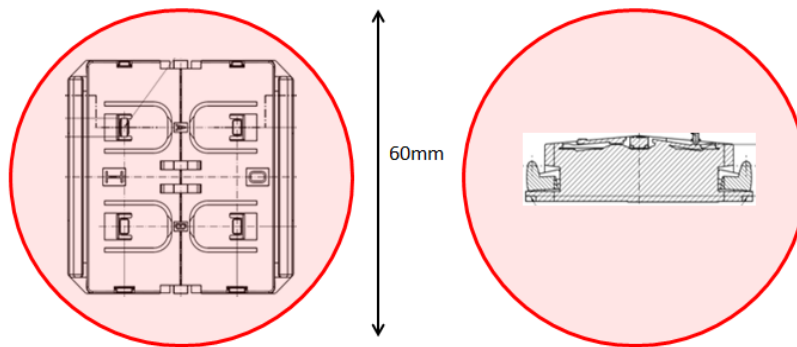
PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module



It is required to use non-conductive material (no metal or plastic with metal or graphite elements) for the rockers, the frame and the base plate to ensure best transmission range.



PTM 215ZE is powered by the electromagnetic generator ECO 200. For proper function there has to be a keep out zone of 60mm for magnets or ferromagnetic materials around the center of PTM 215ZE.



PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

6.3 Device Label

Each PTM 215ZE module contains a product label identifying key parameters such as manufacturing date, device ID and an optically readable code that can be used to automatically scan device parameters.

Previous versions (DA-02) used a legacy device label described in chapter 6.3.1 while recent versions use the EnOcean standard product label as described in chapter 6.3.2

6.3.1 Legacy Product Label

The legacy device label structure used up to product revision DA-02 is shown for reference in Figure 18 below.

This label version contains an optically readable Data Matrix Code (DMC, marked with a green frame) on the lower right-hand side of the device label which can be used to automatically scan device parameters.

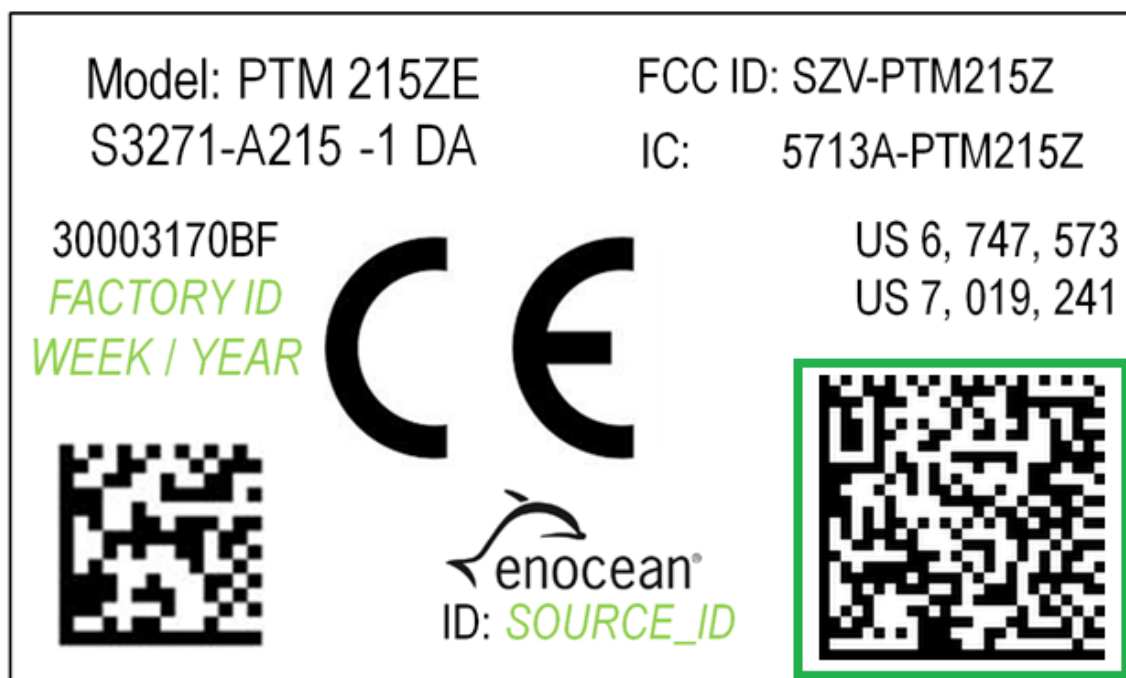


Figure 18 – PTM 215ZE Device Label (Up to revision DA-02)

The DMC uses the ECC200 standard and can be read by a suitable commissioning tool (e.g. smartphone) which is already part of the network into which PTM 215ZE will be commissioned.

The commissioning tool can then send these parameters to the intended receiver of PTM 215ZE radio telegrams.

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

6.3.1.1 Data Matrix Code (DMC) format

The commissioning DMC provided by PTM 215ZE uses the following format:

```
<PRODUCT_NAME>ID<SOURCE_ID>00B<DEVICE_KEY>
```

This identifies the following parameters:

- Product name (always "PTM215ZE")
- 4 byte Source ID (unique for each device)
- 16 byte device-unique random security key (different for each device)

Figure 19 below shows an example of a PTM 215ZE DMC code.



Figure 19 – Example of a PTM 215ZE DMC code

This specific DMC encodes the following string:

```
PTM215ZEID015002FB00BD8F7048D01F7AAEEC0A757B862F96301
```

For better readability, the same reading is shown below coloured red, green and blue to identify the different parts:

```
PTM215ZEID015002FB00BD8F7048D01F7AAEEC0A757B862F96301
```

This particular DMC reading would identify the following parameters:

- Product name = PTM215ZE
- Source ID = 015002FB
- Device-unique random security key = D8F7048D01F7AAEEC0A757B862F96301

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

6.3.2 Standard Product Label

Recent revisions of PTM 215ZE (starting with DA-02) use the new EnOcean standard product label as shown in Figure 20 below.

The key difference to the previous format is the use of one unified (and larger) QR code instead of two separate small Data Matric Code which improves readability.

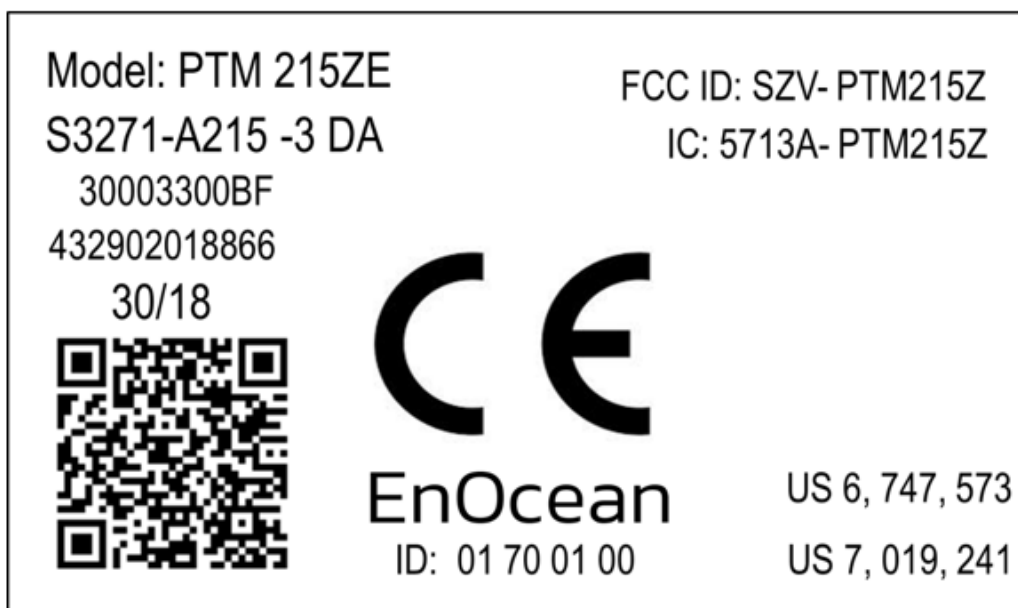


Figure 20 – PTM 215ZE device label (From revision DA-03 onwards)

6.3.2.1 QR Code Format

The QR code used in the new product label encodes the product parameter according to the ANSI/MH10.8.2-2013 industry standard. The QR code shown in Figure 20 above encodes the following string:

30S01700100+Z0123456789ABCDEF0123456789ABCDEF+30PS3271-A215+2PDA03+S01432902018866

Table 3 below describes the ANSI/MH10.8.2 data identifiers used by the PTM 215B device label and shows the interpretation of the data therein.

Identifier	Length of data (excluding identifier)	Value
30S	8 characters	Source Address (hex)
Z	32 characters	Security Key (hex)
30P	10 characters	Ordering Code (S3271-A215)
2P	4 characters	Step Code - Revision (DA-03)
S	14 characters	Serial Number

Table 3 – QR code format

7 Application Information

7.1 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.

8 Regulatory Information

PTM 215ZE has been certified according to FCC (US), ISED (Canada) and RED (Europe) regulations. Changes or modifications not expressly approved by EnOcean could void the user's authority to operate the equipment.

8.1 RED for the European Market

The Radio Equipment Directive (2014/53/EU, typically referred to as RED) replaces 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>

Dolphin radio modules are components which are delivered to OEM manufacturers for their use/integration in final or combined products. It is the responsibility of the OEM manufacturer to demonstrate compliance to all applicable EU directives and standards. The EnOcean attestation of conformity can be used 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.

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

8.2 FCC (United States) Certificate

TCB	<p>GRANT OF EQUIPMENT AUTHORIZATION</p> <p>Certification Issued Under the Authority of the Federal Communications Commission</p> <p>By:</p> <p>EMCCert Dr, Rasek GmbH Stoermhofer Berg 15 91364 Unterleinleiter, Germany</p>	TCB			
<p>EnOcean GmbH Kolpingring 18a Oberhaching, 82041 Germany</p> <p>Attention: Armin Anders , Director Product Marketing</p>	<p>Date of Grant: 05/12/2016 Application Dated: 05/12/2016</p>				
<p>NOT TRANSFERABLE</p> <p>EQUIPMENT AUTHORIZATION is hereby issued to the named GRANTEE, and is VALID ONLY for the equipment identified hereon for use under the Commission's Rules and Regulations listed below.</p>					
<p>FCC IDENTIFIER: SZV-PTM215Z</p> <p>Name of Grantee: EnOcean GmbH</p> <p>Equipment Class: Part 15 Low Power Communication Device Transmitter</p> <p>Notes: 2405 MHz - 2480 MHz transmitter</p>					
<u>Grant Notes</u>	<u>FCC Rule Parts</u>	<u>Frequency Range (MHZ)</u>	<u>Output Watts</u>	<u>Frequency Tolerance</u>	<u>Emission Designator</u>
	15C	2405.0 – 2480.0			



8.2.1 FCC (United States) Regulatory Statement

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

- (1) this device may not cause harmful interference, and
- (2) this device must accept any interference received, including interference that may cause undesired operation.

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

5.3 ISED (former Industry Canada) Certificate



FCB under the Canada-EC MRA
 TCB under the USA-EC MRA
 RSCAB under the Japan-EC MRA
 Notified Body PTTE Directive 99/5/EC
 Notified Body EMC Directive 2014/30/EU
 No. CA001666G

<p style="text-align: center;">TECHNICAL ACCEPTANCE CERTIFICATE CANADA</p> <p>CERTIFICATION No. ▶ 5713A-PTM215Z No. DE CERTIFICATION ISSUED TO ▶ EnOcean GmbH DELIVRE A</p> <p>Street Address ▶ Kolpingring 18 a Numéro et rue Province or State ▶ Germany Province ou Etat</p> <p>TYPE OF EQUIPMENT ▶ Low Power Device (2400-2483.5 MHz) GÈNRE DE MATÉRIEL</p> <p>ANTENNA ▶ Integrated ANTENNE Incorporé</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>FREQUENCY RANGE BANDE DE FRÉQUENCES</th> <th>EMISSION TYPE GÈNRE D'ÉMISSION</th> <th>RF POWER PUISSANCE H.F.</th> <th>SPECIFICATION / ISSUE / DATE SPÉCIFICATION / ÉDITION / DATE</th> </tr> </thead> <tbody> <tr> <td>2405 - 2480 Mhz</td> <td>2M4SG1D0N</td> <td>71.3 dBµV/m</td> <td>RSS-210 / 8 / December 2010</td> </tr> </tbody> </table> <p>TEST LABORATORY ▶ EMCCons DR. RAŠEK GmbH & Co. KG LABORATOIRE D'ESSAY</p> <p>Street Address ▶ Stoernhofer Berg 15 Numéro et rue Province or State ▶ Germany Province ou Etat</p> <p>Name ▶ Reinhard Sauersschell Nom E-mail ▶ r.sauersschell@emcc.de</p> <p>Certification of equipment means only that the equipment has met the requirements of the above-noted specification. Licence applications, where applicable to use certified equipment, are acted on accordingly by the Industry Canada Issuing office and will depend on the existing radio environment, service and location of operation. This certificate is issued on condition that the holder complies and will continue to comply with the requirements and procedures issued by Industry Canada. The equipment for which this certificate is issued shall not be manufactured, imported, distributed, leased, offered for sale or sold unless the equipment complies with the applicable technical specifications and procedures issued by Industry Canada.</p> <p>I hereby attest that the subject equipment was tested and found in compliance with the above-noted specification.</p> <p>DATE 12 May 2016</p>	FREQUENCY RANGE BANDE DE FRÉQUENCES	EMISSION TYPE GÈNRE D'ÉMISSION	RF POWER PUISSANCE H.F.	SPECIFICATION / ISSUE / DATE SPÉCIFICATION / ÉDITION / DATE	2405 - 2480 Mhz	2M4SG1D0N	71.3 dBµV/m	RSS-210 / 8 / December 2010	<p style="text-align: center;">CERTIFICAT D'ACCEPTABILITÉ TECHNIQUE CANADA</p> <p>City ▶ Oberhaching Ville Postal Code ▶ 82041 Code postal</p> <p>PMN ▶ PTM 215ZE HVIN ▶ PTM 215ZE</p> <p>ANTENNA GAIN GAIN D'ANTENNE ▶</p> <p>CN 3464C OATS 3464C-1</p> <p>City ▶ Unterleinleiter Ville Postal Code ▶ 91364 Code Postal</p> <p>Tel 0049 9194 7263-301 Fax 0049 9194 7263-309</p> <p>La certification du matériel signifie seulement que le matériel a satisfait aux exigences de la norme indiquée ci-dessus. Les demandes de licences nécessaires pour l'utilisation du matériel certifié sont traitées en conséquence par le bureau de délivrance d'industrie Canada et dépendent des conditions radio ambiantes, du service et de l'emplacement d'exploitation. Le présent certificat est délivré à la condition que le titulaire satisfasse et continue de satisfaire aux exigences et aux procédures d'industrie Canada. Le matériel à l'égard duquel le présent certificat est délivré ne doit pas être fabriqué, importé, distribué, loué, mis en vente ou vendu à moins d'être conforme aux procédures et aux spécifications techniques applicables publiées par industrie Canada.</p> <p>J'atteste par la présente que le matériel a fait l'objet d'essai et jugé conforme à la spécification ci-dessus.</p> <p style="text-align: center;"> Certification Officer</p>
FREQUENCY RANGE BANDE DE FRÉQUENCES	EMISSION TYPE GÈNRE D'ÉMISSION	RF POWER PUISSANCE H.F.	SPECIFICATION / ISSUE / DATE SPÉCIFICATION / ÉDITION / DATE						
2405 - 2480 Mhz	2M4SG1D0N	71.3 dBµV/m	RSS-210 / 8 / December 2010						

EMCCert DR. RAŠEK GmbH • Stoernhofer Berg 15, 91364 Unterleinleiter, Germany
 Tel.: +49 9194 72279-01 • Fax: +49 9194 72279-06 • E-mail: emc.cert@emcc.de • Web: www.emcc.de

8.2.2 ISED (former Industry Canada) Regulatory Statement

This device complies with Industry Canada licence-exempt RSS standard(s). Operation is subject to the following two conditions:

- (1) this device may not cause interference, and
- (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence.

L'exploitation est autorisée aux deux conditions suivantes :

- (1) l'appareil ne doit pas produire de brouillage, et
- (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement."

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

A Understanding PTM 215ZE Telegram Structure

This appendix describes – purely for reference purposes – how to analyse the PTM 215ZE radio telegram structure using the TI CC2531EMK packet sniffer (USB dongle) on a Windows 7 based system.

A.1 Installation Instructions For TI CC2531 Packet Sniffer

The following description assumes the use of the TI CC2531EMK described here:

<http://www.ti.com/tool/cc2531emk>

CC2531EMK can be used in conjunction with the “TI SmartRF Protocol Packet Sniffer” to capture and visualize IEEE 802.15.4 data telegrams.

To use TI SmartRF Protocol Packet Sniffer, please download the SW package from the TI website. At the time of writing, the SW could be obtained using this link:

<http://www.ti.com/tool/packet-sniffer>

Please download and install this SW before proceeding with the instructions given in the next chapter.

A.1.1 CC2531EMK Setup

After setting up the TI SmartRF Protocol Packet Sniffer please insert the CC2531EMK USB dongle into a USB port of the PC and make sure that the green LED of the dongle is active.

Please make sure that the required device driver for the CC2531EMK has been correctly installed. To do so, please check the Device Manager where you should see an entry named “CC2531 USB Dongle” under the group label “CEBAL Controlled Devices”.

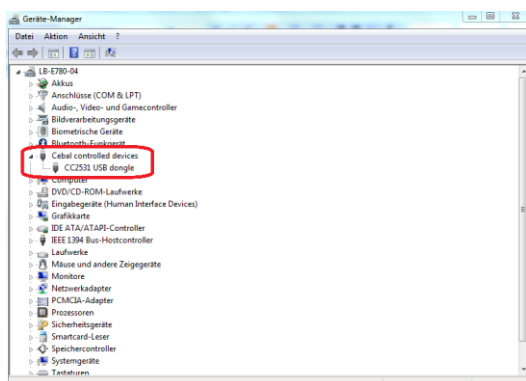


Figure 21 – Correctly installed CC2531EMK

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

A.2 Configuration

After the installation of the CC2531EMK driver, please start the TI SmartRF Packet Sniffer program. The protocol selection dialog program window which appears after the start of is shown in Figure 22 below.

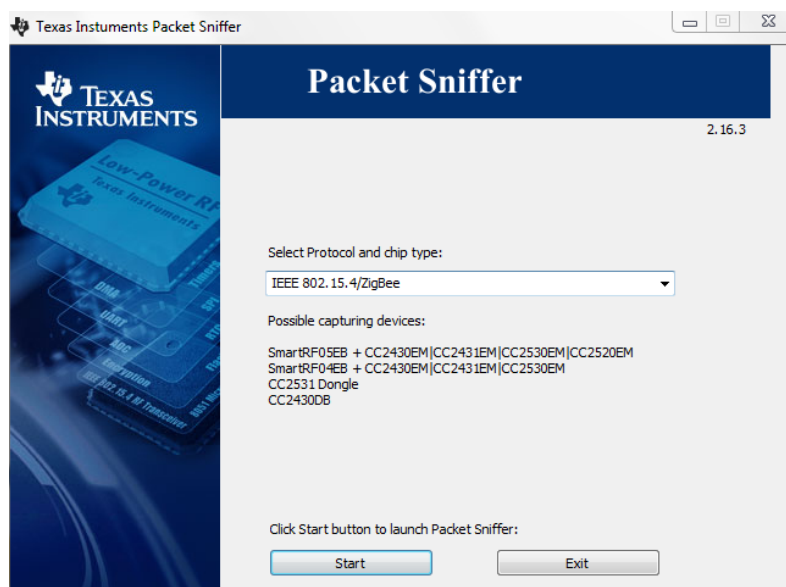


Figure 22 – Protocol selection dialog of TI SmartRF Packet Sniffer

In this dialog, please select “IEEE 802.15.4/ZigBee” as shown above and press the “Start” button. Once the main window comes up, please make sure that “CC2531” is shown in the “Capturing device” tab and in the “RF device:” footer line as shown in Figure 23 below.

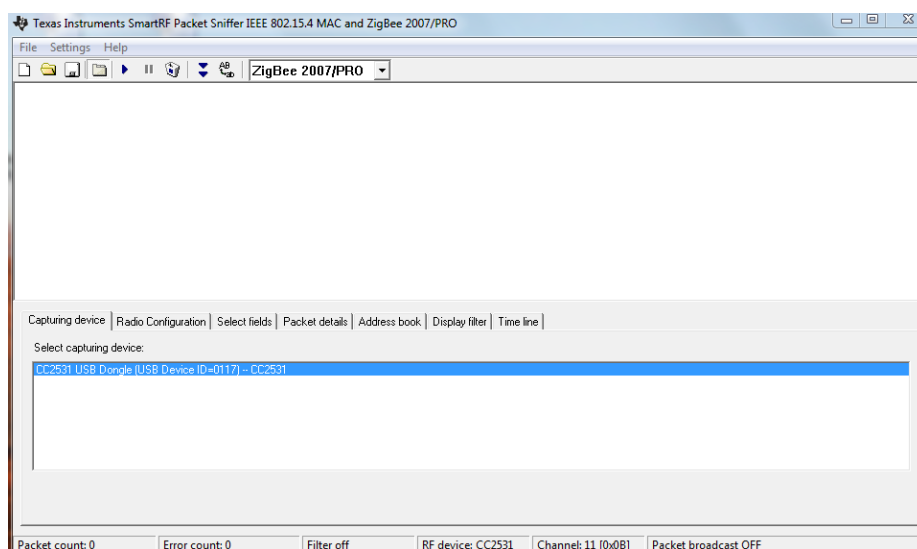


Figure 23 – Main window TI SmartRF Packet Sniffer

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

Out of the box, PTM 215ZE is configured for using IEEE 802.15.4 radio channel 11. Make sure that this radio channel (0x0B) is selected in the “Radio Configuration” tab and shown in the “Channel:” footer line.

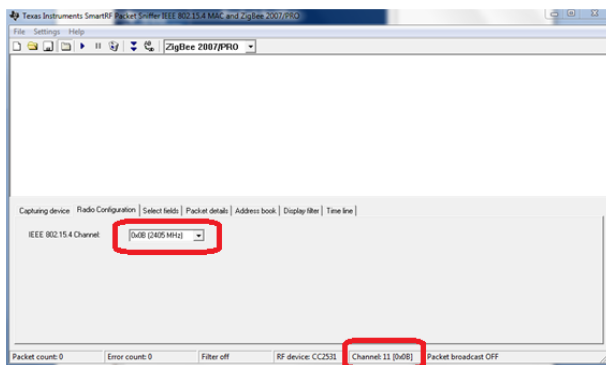


Figure 24 – Radio channel selection

The data fields that will be displayed can be selected in the “Select fields” tab. Make sure that all “MAC Header”, “Data” and “Footer” fields are selected and that the “LQI/RSSI” drop-down list is set to “RSSI”.

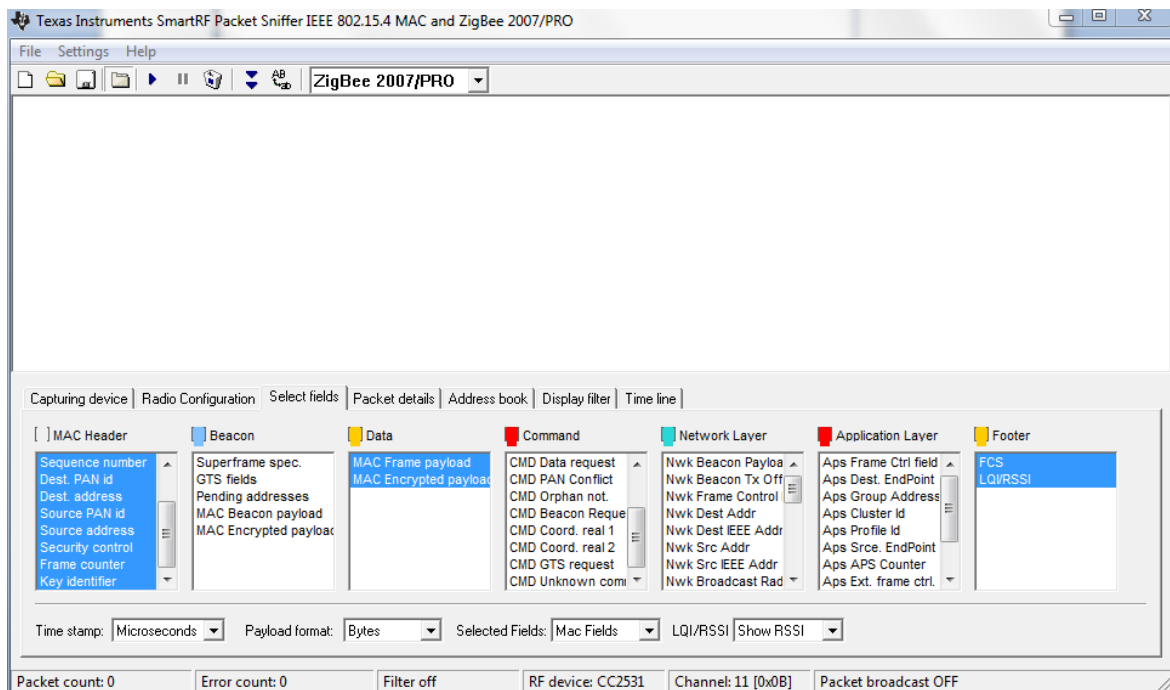


Figure 25 – Payload selection

The TI SmartRF Packet Sniffer is now ready.

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

A.3 Data capture

Press the triangular button (▶) to start the radio capture and press the auto-scroll button (⏮) to automatically select the most recent data telegram. Then press a button of PTM 215ZE. You should now see the captured radio telegrams (PTM 215ZE sends several redundant radio telegrams per user action).

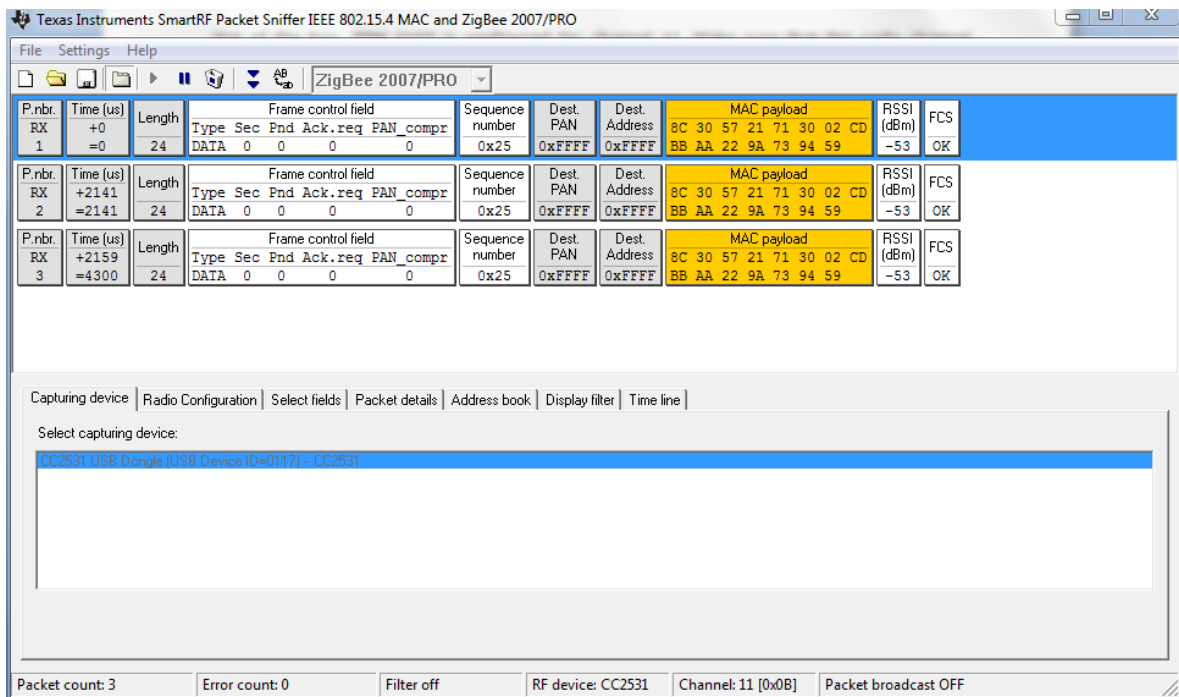


Figure 26 – Captured telegram data

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

A.4 Interpretation of the telegram data

The following parameters within captured radio telegrams are typically of interest:

1. MAC Payload
This will contain the ID of the sender, various control and security data fields as well as the actual command data (1 byte)
The structure of this field is outlined subsequently in more detail.
2. RSSI
This will show the received signal strength
3. FCS
This will show the frame integrity (OK / not OK) and should normally show "OK".

A.4.1 MAC Payload

Below is an example of a captured MAC payload:

MAC payload							
8C	30	FB	02	50	01	25	00
00	00	23	AA	99	E8	76	

The hexadecimal representation of this specific payload is:

8C 30 FB 02 50 01 25 00 00 00 23 AA 99 E8 76

The location and interpretation of key parameters is described in the following chapters.

A.4.2 Device ID

The device ID is used to uniquely identify each device in the network. It is 4 byte long and is allocated to byte 2...5 of the MAC payload as highlighted below:

8C 30 **FB 02 50 01** 25 00 00 00 23 AA 99 E8 76

Note that the byte order is little endian, therefore the ID of this specific device is 0x015002FB.

A.4.3 Sequence Counter

The sequence counter is used to uniquely identify each telegram in order to avoid telegram replay. It is 4 byte long and is allocated to byte 6...9 of the MAC payload as highlighted below:

8C 30 FB 02 50 01 **25 00 00 00** 23 AA 99 E8 76

Note that the byte order is little endian, therefore the current sequence counter value of this specific device is 0x00000025.

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

A.4.4 Command Payload

The command payload identifies the action performed on the switch (i.e. which buttons have been pressed). The command is allocated to byte 10 of the MAC payload as highlighted below:

```
8C 30 FB 02 50 01 25 00 00 00 23 AA 99 E8 76
```

In this case it is 0x23 meaning that button A0 has been released. Refer to chapter 3.3.1 for the description of commands supported by PTM 215ZE.

A.4.5 Telegram Signature

The PTM 215ZE radio telegram is authenticated via a 32 Bit signature. This signature is calculated based on the private key (unique for each device), the data payload and a 32 Bit sequence counter (which is incremented for each data telegram).

This approach prevents unauthorized senders from sending commands. Note that the content of the telegram itself is not encrypted, i.e. the switch command is sent as plain text.

The telegram signature is transmitted using the last 4 byte of the telegram:

```
8C 30 FB 02 50 01 25 00 00 00 23 AA 99 E8 76
```

Note that the signature changes with each transmission even if the remainder of the MAC payload remains the same.

This is due to the inclusion of the rolling code into the MIC calculation which prevents message replay attacks (capture and reuse of a previous message).

B Authentication of PTM 215ZE data telegrams

PTM 215ZE provides the option to authenticate its data telegrams as described in chapter 4. The authentication mechanism used by PTM 215ZE is standardized as RFC3610 and specified within the zigbee Green Power specification. The full RFC3610 specification could be found here at the time of writing and should be used as primary source of information: <https://www.ietf.org/rfc/rfc3610.txt>

The following description aims to summarize the security processing steps for users not deeply familiar with cryptography in general or RFC3610 and zigbee Green Power in particular.

B.1 Algorithm input parameters

The purpose of the security processing in PTM 215ZE is to calculate a unique signature that can be used to verify authenticity (telegram has not been modified) and originality (telegram comes from the assumed sender) of a telegram. To do so, two types of algorithm parameters are required:

- Constant algorithm input parameters
These parameters identify high level algorithm and telegram properties and are the same for any PTM 215ZE telegram
- Variable algorithm input parameters
These parameters identify telegram-specific parameters and therefore depend on the specifics of the transmitted telegram

B.1.1 Constant input parameters

The RFC3610 implementation in PTM 215ZE requires two constant input parameters:

- Length field size
This is the size (in byte) of the field used to encode the length of the input data (which is the payload to be authenticated). The size of PTM 215ZE payload to be authenticated is 11 byte; therefore one byte would be easily sufficient to encode the payload size. The minimum value permitted by the standard is however 2 bytes which is therefore chosen.
- Signature size
This is the desired size of the generated signature which is 4 byte for PTM 215ZE

Table 4 below summarizes these constant algorithm parameters.

Parameter	Comment / Description	Example
Length Field Size	Size (in bytes) of the field used to encode the input length	2 (always, minimum permissible size)
Signature Size	Desired size (in byte) of the signature generated by the algorithm	4 (always)

Table 4 – Constant algorithm input parameters

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

B.1.2 Variable input parameters

The RFC3610 implementation in PTM 215ZE requires four variable input parameters:

- **Source address**
The 4 byte source address used to identify the sender of an authenticated message. The source address is required in little endian (least significant byte first) format.
- **Input data (Payload to be authenticated)**
The authenticated payload contains source address, sequence counter, switch status and optional data (if present). See chapter 4.1 for a description of the authenticated payload.
- **Input length (Size of the payload to be authenticated)**
The length of the payload to be authenticated is always 11 byte as described in chapter 4.1.
- **Sequence counter**
Each PTM 215ZE contains a sequence counter which is initialized to zero during production and increased for each telegram that is sent. The sequence counter is transmitted as part of the input data. The receiver of PTM 215ZE telegrams keeps track of this counter and will accept only telegrams with counter values higher than the highest previously used value. This eliminates the possibility of reusing previously transmitted telegrams. Note that the individual (identical) advertising telegrams used to encode the same data telegram use the same sequence counter value.
- **Private key**
Each PTM 215ZE is programmed with a random 16 byte security key during manufacturing.

Table 5 below summarizes these parameters.

Parameter	Comment / Description	Example
Source Address	Unique source address of the PTM 215ZE module (little endian)	FB025001 (little endian representation of 015002FB)
Input Data	Telegram data to be authenticated	8C30FB0250012500000023
Length of Input Data	Length of input data in bytes, encoded using 2 bytes	0x000B (11 bytes)
Sequence Counter	Incrementing counter to avoid replay Part of the input data	25000000 (little endian representation of the counter value 0000025)
Private Key	128 bit random key that is known both to sender and receiver	D8F7048D01F7AAEEC0A757B862F96301

Table 5 – Variable input parameters

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

B.1.3 Obtaining the private key

All required parameters except the private key can be directly extracted from the received message that shall be authenticated.

The private key – the common secret shared between sender and receiver – has to be obtained via specific mechanisms. There are two different ways to obtain the security key of a PTM 215ZE module:

- Obtaining the private key via the product DMC code
- Obtaining the private key via a dedicated commissioning telegram

Each option is described now in detail.

B.1.3.1 Obtaining the private key via the product DMC code

Each PTM 215ZE module contains a DMC code on its product label which identifies source address and private key of the module, The DMC code of the device used for this tutorial is shown in Figure 27 below.



Figure 27 – Example DMC code

This DMC code can be read using a suitable DMC code reader (e.g. QRbot smartphones). The content of this example DMC code is:

PTM215ZEID015002FB00BD8F7048D01F7AAEEC0A757B862F96301

The structure of the DMC code is described in chapter 6.3.1.1. The location of the security key in above DMC string is marked red for reference. This means that the private key of this device is:

D8F7048D01F7AAEEC0A757B862F96301

B.1.3.2 Obtaining the private key via a commissioning telegram

PTM 215ZE modules can send dedicated commissioning telegrams that identify their private key. Transmission of such commissioning telegrams can be triggered by means of a specific button sequence as described in chapter 5. The format of the commissioning telegram is described in chapter 5.3

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

B.2 Internal parameters

The RFC3610 implementation in PTM 215ZE derives a set of internal parameters for further processing from the provided input parameters.

Again, there are two types of internal parameters:

- Constant internal parameters
These parameters are based on the high level algorithm and telegram properties and are the same for any PTM 215ZE telegram
- Variable input parameters
These parameters are based on the telegram-specific parameters and therefore depend on the specifics of the transmitted telegram

B.3 Constant internal parameters

The RFC3610 implementation in PTM 215ZE derives two internal parameters – M' and L' – based on the input data and uses them to construct A0_Flag and B_0_Flag which are required for subsequent processing.

The value of these internal parameters - listed in Table 6 below - is the same for all PTM 215ZE data telegrams.

Parameter	Comment / Description	Example
M'	Binary encoded output length $M' = (\text{Output length} / 2) - 1$	0b001 (always)
L'	Binary encoded length field size $L' = \text{length field size} - 1$	0b001 (always)
A0_Flag	L'	0x01 (always)
B0_Flag	$(0b01 \ll 6) + (M' \ll 3) + L'$	0x49 (always)

Table 6 – Constant internal parameters

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

B.4 Variable internal parameters

The RFC3610 implementation in PTM 215ZE derives four internal parameters – Nonce, A0, B0 and B1 – based on the telegram specific input data and the constant internal parameters.

B.4.1 Forming the Nonce

The Nonce is a 13 byte initialization vector which is formed based on the concatenation of the following items:

- Source address
- Source address (again)
- Sequence counter
- 0x05

Note that source address and sequence counter have to be in little endian format, see chapter 4.1.

In this example, the source address is 015002FB and the sequence counter is 00000025. The Nonce therefore is FB025001FB0250012500000005

B.4.2 Calculating the flags

The calculation uses 3 flags together with the security key:

- A0_Flag is formed as concatenation of A0_Flag, Nonce and 0x0000. In this example, A0_Flag would be 01FB025001FB02500125000000050000
- B0_Flag is formed as concatenation of B0_Flag, Nonce and 0x0000. In this example, B0_Flag would be 49FB025001FB02500125000000050000
- B1_Flag is formed as concatenation of two byte data length (always 0x000B) followed by the 11 byte of input data to be authenticated (8C30FB0250012500000023 in this example) followed by 0x000000. In this example, B1_Flag would be 000B8C30FB0250012500000023000000

Table 7 below summarizes the internal parameters.

Parameter	Comment / Description	Example
Nonce	13 byte initialization vector based on concatenation of source address, sequence counter and padding, see 4.1	FB025001FB0250012500000005
A0	A0_Flag followed by Nonce followed by 2 byte 0x00	01FB025001FB02500125000000050000
B0	B0_Flag followed by Nonce followed by 2 byte 0x00 (no message to encode)	49FB025001FB02500125000000050000
B1	Input Length followed by Input Data followed by 5 / 4 / 3 / 1 byte of 0x00 padding (for optional data size = 0 / 1 / 2 / 4 byte)	000B8C30FB0250012500000023000000
Private Key	16 byte device-unique random key	D8F7048D01F7AAEEC0A757B862F96301

Table 7 – Variable internal parameters

B.5 Algorithm execution sequence

The algorithm uses the internal parameters A_0 , B_0 , B_1 together with the Private Key to generate the authentication vector T_0 using three AES-128 and two XOR operations. The algorithm execution sequence is shown in Figure 28 below.

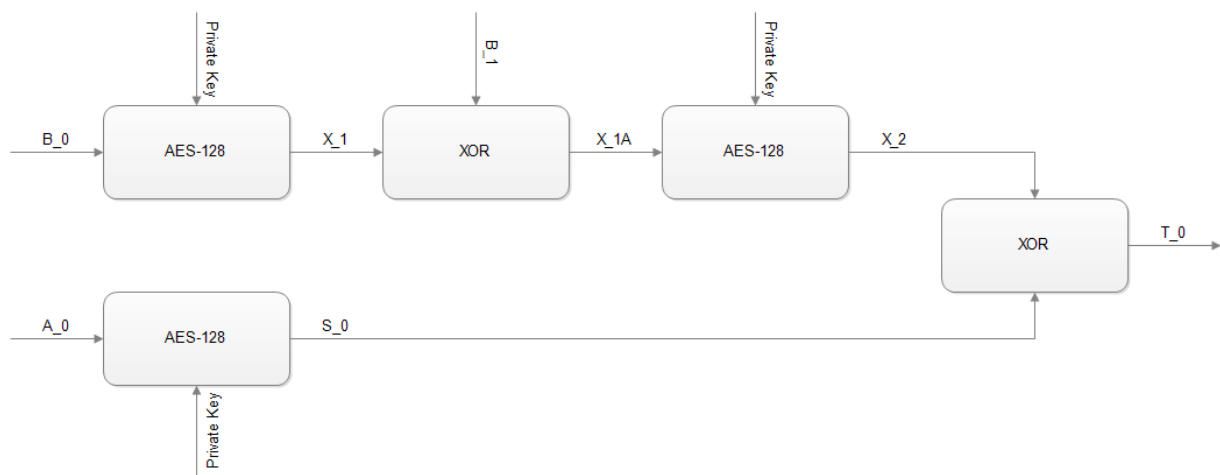


Figure 28 – Authentication algorithm sequence

The first four bytes of T_0 are then used to authenticate PTM 215ZE telegrams by comparing them with the transmitted telegram signature (sender signature) which is transmitted as part of the data telegram.

The data telegram received in this example was 8C30FB0250012500000023AA99E876. The sender signature is specified by the last four bytes and therefore would be AA99E876 in this example.

We now calculate the receiver signature based on the received telegram payload and the private key according to the flow shown in Figure 28 above.

At the time of writing, a suitable online AES calculator could be found here:
<http://testprotect.com/appendix/AEScalc>

Likewise, a suitable XOR calculator could be found here:
<http://xor.pw/>

PTM 215ZE – 2.4 GHz IEEE 802.15.4 Pushbutton Transmitter Module

```
X_1 = AES128(B0, Key)
X_1 = AES128(49fb025001fb0250012500000050000, d8f7048d01f7aaeec0a757b862f96301)
X_1 = 58bca6770cd92f723387693dcce53456

X_1A = XOR(X_1, B_1)
X_1A = XOR(58bca6770cd92f723387693dcce53456, 000b8c30fb0250012500000023000000)
X_1A = 58b72a47f7db7f731687693defe53456

X_2 = AES128(X1A, Key)
X_2 = AES128(58b72a47f7db7f731687693defe53456, d8f7048d01f7aaeec0a757b862f96301)
X_2 = a0631db5e8d9d267a61fc4f48551d608

S_0 = AES128(A0, Key)
S_0 = AES128(01fb025001fb0250012500000050000, d8f7048d01f7aaeec0a757b862f96301)
S_0 = 0afaf5c3ee1cedf0a3fdee22718102b0

T_0 = XOR(X_2, S_0)
T_0 = XOR(a0631db5e8d9d267a61fc4f48551d608, 0afaf5c3ee1cedf0a3fdee22718102b0)
T_0 = aa99e87606c53f9705e22ad6f4d0d4b8
```

The calculated receiver signature is formed by the first four bytes of T_0 , i.e. it is AA99E876. The receiver signature therefore matches the sender signature that was transmitted as part of the payload. This proves that the telegram originates from a sender that possesses the same private key and the telegram content has not been modified.