System Specification

EnOcean Certification Specification, part 1b
Air Interface (FSK)

V 1.2, RELEASE

Approved for release: Feb 10, 2019

San Ramon, CA, USA, Oct 19, 2017

EXECUTIVE SUMMARY

A proper review of every device shipped is an important step to secure a correct functioning of every single device, especially to ensure a working interoperability.

The EnOcean Alliance developed and agreed upon a specification which describes the certification steps to be passed by every device before being introduced into the market(s). These steps are:

(1) Air Interface
(2) Radio Performance
(3) Communication Profiles
(4) Energy Harvesting of Self supplied devices

This document specifies part (1b) *Air Interface (FSK)* for devices operating based on the ISO 14543-3-11 standard (EnOcean Radio Protocol 2, ERP2) and as such complements the existing specification for devices operating based on the ISO 14543-3-10 standard (EnOcean Radio Protocol 1, ERP1, ASK modulation).

Demonstrating compliance of the device under test (DUT) with one of these two specifications – depending on the technology applied - is a mandatory part of the *EnOcean Certification Program*. This document defines the minimum set of test cases required to demonstrate the compliance with the standard ISO 14543-3-11 [1] . It is expected that proper product testing will exceed these minimum requirements.

This document aims to clearly specify the purpose and the requirements of each test case together with a defined test setup and clear acceptance criteria to achieve relevant and reproducible testing results.

Normative requirements, resulting from national or regional regulations for short range radio devices, are out of scope of this system specification.

This document is owned by the Technical Working Group (TWG) of the EnOcean Alliance. It is maintained and will be progressed within the authority of the chairman of the TWG.

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REVISION HISTORY

Ver.	Editor	Change	Date
0.1	MKA	Document created	Sep. 09, 2017
0.2	NM	Chapter 8.4 and Annex A created; editorial modifications.	Sep. 18, 2017
0.3	NM	Incorporated review by EnOcean GmbH	Sep. 25, 2017
1.0	NM	Created release version	Oct. 18, 2017
1.1	AP	Disclaimer added; References and links updated; Applying ISO 31-0 for correct displaying of numbers;	Jan. 19, 2019
1.2	AP	Changed sub telegram timing limits for 928 MHz	Jul. 07, 2023

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1. Scope of this document

This document specifies part (1b) *Air Interface (FSK)* for devices operating based on the ISO 14543-3-11 standard (EnOcean Radio Protocol 2, ERP2, FSK) and as such complements the existing specification for devices operating based on the based on the ISO 14543-3-10 standard (EnOcean Radio Protocol 1, ERP1, ASK).

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Normative requirements, resulting from national or regional regulations for short range radio devices, are out of scope of this system specification.

Within this document “EnOcean” is used as synonym for “compliant to ISO / IEC 14543-3-11”.

As EnOcean operates worldwide in the unlicensed ISM band different center frequencies / carrier frequencies have to be applied according to national / international regulation. Currently ISO 14543-3-11 is defined for three center frequencies: 868.300 MHz (China), 902.875 MHz (NorAm), and 928.350 MHz (Japan). Different parameters (e.g. frequency deviation) and timings are to be respected per center frequency.

2. References

2.1. Normative references

[1] EnOcean Air Interface Specification for ERP2, FMWSP Protocol
ISO/IEC DIS 14543-3-11

[2] EN300220-1, latest release

[3] ARIB STD-T108

2.2. Informative references

[4] EnOcean Certification Handbook, EnOcean Alliance
https: //www.enocean-alliance.org/cb/

[5] EnOcean Certification Specification, part 2, Radio Performance, EnOcean Alliance
https://www.enocean-alliance.org/rpc/

[6] EEP-Specification, latest version 2.6.8

[7] EnOcean Certification Specification, part 3, Communication Profiles, EnOcean Alliance
https://www.enocean-alliance.org/cpc/

3. Definitions and abbreviations

3.1. Definitions

Where ever possible this document uses the definitions that are defined by the normative documents it is related to. The listing below is only intended as quick reference.

Mark – The transmission of a logical '1'

Space – The transmission of a logical '0'

3.2. Abbreviations

4BS – 4 byte sensor telegram (telegram with 4 byte payload that is used by many sensors)

ASK – Amplitude Shift Keying

DUT – Device Under Test

DESTID – Destination Identifier, the identification number used in EnOcean transmissions to identify the destination of an addressed transmission; DESTID always needs to be the EURID of an EnOcean device.

EOF – End Of Frame bit pattern, a fixed bit combination that marks the end of an EnOcean frame.

ERP1 – EnOcean Radio Protocol version 1, standardized as ISO 14543-3-10

ERP2 – EnOcean Radio Protocol version 2, standardized as ISO 14543-3-11

EURID – EnOcean Unique Radio Identifier, a unique and non-changeable identification number assigned every EnOcean transmitter during its production process.

FSK – Frequency Shift Keying

INV – Inverse bit, a bit that is inserted into the EnOcean frame to avoid too static ASK waveforms during transmission.

NRZ – No Return to Zero (meaning that there is no neutral / inactive state between the transmission of individual symbols)

PRE – Preamble bit pattern, a fixed bit combination that allows first synchronization of a receiver to an EnOcean frame transmission.

RF – Radio Frequency, a dedicated part of the radio spectrum that is used for wireless communication in line with the provisions of this document.

RPS – Repeated Switch telegram, a telegram used by simple switches

R-ORG – Radio ORGanisation, organization number for EnOcean radio telegram types [6].

SOF – Start Of Frame bit pattern, a fixed bit combination that marks the start of an EnOcean frame.

SYNC – Synchronization bit pattern, a fixed bit combination that allows re-synchronization of a receiver during the reception of an EnOcean frame.

TXID – Transmitter Identifier, the identification number used in EnOcean transmissions to identify the source of such transmission; may either be the EURID or an EnOcean Identifier that belongs to the multi user ID space, defined by the EnOcean Alliance.

VSWR – Voltage Standing Wave Ratio, a parameter that defines the impedance matching of an RF port to a specified RF load.

VLD – Variable Length Data – telegram type that is used by more complex sensors

4. Test conditions

Test conditions shall mean the combination of technical and environmental parameters that are representative for the conditions under which the DUT might operate. Within the scope of this certification, the following parameters are considered:

(1) Supply voltage provided to the DUT
(2) Ambient temperature
(3) Ambient humidity

Normal test conditions shall mean the combination of the typical values given by the manufacturer for above parameters.

Extreme test conditions shall mean the combination of minimum and maximum values for supply voltage and ambient temperature as described below.

Extreme conditions of humidity (very dry or very humid) are not tested since almost all devices within the EnOcean ecosystem are specified for indoor use without condensation. Devices specified differently (e.g. water-proof or for outdoor use) have to be tested accordingly by the manufacturer.

4.1. Test power source

The typical power source of a DUT shall be replaced by an external power supply capable of simulating power source conditions representative for the operation of the DUT.

Normal test conditions shall mean that the DUT is supplied from the external power source with its nominal supply voltage as stated by the DUT manufacturer.

Extreme test conditions shall mean that the DUT is supplied from the external power source with either the minimum or the maximum supply voltage as stated by the DUT manufacturer.

4.2. Test temperature

Normal test conditions shall mean that the DUT is operated at the typical temperature as stated by the DUT manufacturer. If this is not defined otherwise by the DUT manufacturer, then testing at normal test conditions shall be made at a suitable temperature between +17°C and +27°C.

Extreme test conditions shall mean that the DUT is operated either at the minimum or the maximum temperature as stated by the DUT manufacturer.

4.3. Test humidity

Testing shall occur at a relative humidity in the range of 20% to 75%. Condensation on the DUT shall be avoided for all tests.

4.4. Test scenarios

To test the DUT across the full range of test parameters (temperature and supply voltage), five test scenarios are defined:

1) The combination of standard temperature with standard supply voltage (“Standard”)
2) The combination of minimum temperature with minimum supply voltage (“Extreme 1”)
3) The combination of minimum temperature with maximum supply voltage (“Extreme 2”)
4) The combination of maximum temperature and minimum supply voltage (“Extreme 3”)
5) The combination of maximum temperature and maximum supply voltage (“Extreme 4”)

If only a specific supply voltage level or a specific temperature is supported, then the test scenarios shall be reduced accordingly.

5. Test equipment

All test equipment used to perform measurements according to this specification document shall be properly selected and calibrated. Measurement accuracy as stated in this document shall include aging of the test equipment over the period of a calibration cycle.

5.1. Power supply

The external power supply shall generate the required minimum through maximum supply voltage at an impedance low enough to ensure negligible influence on the measurements. It shall be electrically connected to and decoupled from the DUT in such way as not to affect any measurement results.

The output voltage of the power supply shall have a sufficient accuracy of ±5% or better relative to the set output voltage.

5.2. Signal analyzer

The signal analyzer is required to assess the parameters of radio telegrams transmitted by the DUT. The signal analyzer shall be capable to operate at the radio frequency used by the DUT (i.e. 868.300 MHz, 902.875 MHz or 928.35 MHz) and support the following test cases:

1) Measure all RF and modulation parameters of the DUT transmission (physical layer)
2) Demodulate the DUT transmission and validate its frame coding (physical layer)
3) Extract the subtelegram and validate its data structure and timing (data link layer)
4) Analyze data structure and timing on telegram level (network layer)

Measurement accuracy of the signal analyzer shall be at least as follows:

- RF frequency $<10^{-6}$
- RF level <1dB
- Timing <100ns

Some testing (e.g. for protocol accuracy) may be executed or assisted by a reference receiver (e.g. TCM 310U or TCM 410J).

5.3. Signal generator

The signal generator is required to generate radio telegrams to test the receiver functionality of the DUT. The signal generator shall be capable to operate at the radio frequency used by the DUT (i.e. 868.300 MHz, 902.875 MHz or 928.35 MHz) and support the following test cases:

1) Transmit a test signal using RF parameters as defined by ISO 14543-3-11 (physical layer).
2) Modulate a test signal as defined by ISO 14543-3-11 (physical layer)
3) Encode a frame with data content as defined by ISO 14543-3-11 (physical layer)
4) Generate subtelegrams with data and timing as defined by ISO 14543-3-11 (data link layer)

5) Generate a telegram with data and timing as defined by ISO 14543-3-11 (network layer)

For all test cases defined above, the signal generator shall be capable both to generate telegrams with correct parameters and data (as defined by ISO 14543-3-11) and with deviating parameters and data (to verify resilience and error handling).

The accuracy of the generated signals shall be at least as follows:

- RF frequency $<10^{-6}$
- RF level <1dB
- Timing <100ns

Some testing (e.g. for protocol accuracy) may be executed or assisted by a reference transmitter (e.g. TCM 310U or TCM 410J).

5.4. Climate chamber

Test of the DUT across the full range of its supported operating temperature as defined in chapter 4.4. shall be executed using a climate chamber. The difference between requested temperature and actual temperature within the climate chamber shall be less than 5 Kelvin.

5.5. Automated Test System

Testing is greatly facilitated by having an automatic test system capable of the following:

- Triggering a telegram transmission
- Evaluating received telegrams for correct content
- Controlling the output power level of the signal generator (or alternatively the attenuation of a signal attenuator)

It is strongly recommended to use such automatic test system.

6. Test setup

6.1. Power supply

All measurements shall be made with the DUT being supplied by an external power supply (refer to chapter 5.1 above). If the DUT contains its own internal power source then its HW has to be modified to use an external power supply.

6.2. Antenna connection

The test equipment (signal generator or signal analyzer) shall be connected to the DUT with a standard 50 Ω coaxial cable in order to obtain reproducible results. DUT without suitable RF connection (e.g. modules with integrated antenna) cannot be certified as it is not possible to reliably determine key parameters such as transmit power and receive sensitivity.

If the DUT is equipped with a suitable 50 Ω RF connector then all measurements shall be performed using this port.

If no direct connection to the antenna port of the DUT is possible then the HW design of the DUT shall be modified for the purpose of certification to include a suitable antenna connection or use an antenna coupler. Differences between the modified DUT and the original DUT shall be described as part of the certification documentation and be as small as possible so that the behavior of the modified DUT is representative for that of the original DUT.

6.3. Radio telegram transmission and reception

All testing is done using clearly defined radio telegrams, see Annex A. This ensures that radio parameter measurements are well-defined and reproducible yielding results that are comparable between different platforms.

DUT providing transmit functionality shall be capable to transmit these defined radio telegrams. If their standard firmware does not allow to do so (e.g. for devices using RPS or VLD telegrams) then the DUT shall be modified (e.g. via a custom test SW) to be capable of transmitting these telegrams.

DUT providing receive functionality shall be capable to receive the defined radio telegrams and forward them to an external host (e.g. via a serial interface) for validation of its content. If the DUT does not normally provide this function then it shall be modified as necessary for that purpose.

Differences between the modified DUT and the original DUT shall be described as part of the certification documentation and be as small as possible so that the behavior of the modified DUT is representative for that of the original DUT.

7. Physical Layer Testing

7.1. Definition of transmitter parameters

Radio transmissions according to the ISO14543-3-11 standard encode the bit values by means of frequency shift keying (FSK) without return to zero (NRZ). FSK means that the value of individual bits (which can have a value of 0b0 or 0b1) is encoded by transmitting a lower or a higher frequency for the duration of this individual bit. NRZ means that there is no neutral state between the transmission of two consecutive bits.

The ISO14543-3-11 standard defines that 0b0 is encoded using a lower frequency f_{Space} and is called a "Space". Likewise, 0b1 is encoded using a higher frequency f_{Mark} and is called a "Mark".

The median value between the upper frequency f_{MARK} and the lower frequency f_{SPACE} is called the center frequency f_{CENTER}. The center frequency can be calculated according to the following formula:

$$f_{CENTER} = \frac{f_{MARK} + f_{SPACE}}{2} \qquad \text{(Equation 1)}$$

The difference between the center frequency and the upper or lower frequencies is called the frequency deviation f_{DEV}. It can be calculated according to the following formula:

$$f_{DEV} = \frac{f_{MARK} - f_{SPACE}}{2} \qquad \text{(Equation 2)}$$

The frequency error f_{ERROR} is the value by which f_{CENTER} deviates from the intended operating frequency (868.300 MHz, 902.875 MHz or 928.35 MHz).

The data rate specifies the amount of bits that are transmitted within one second. The inverse value – the period of time required for the transmission of one bit – is called the bit duration t_{BIT}.

The deviation of actual bit duration versus specified bit duration is called the data rate error. It can be calculated according to the following formula:

$$Data\ Rate\ Error = 1 - \frac{Actual\ Bit\ Duration}{Specified\ Bit\ Duration} \qquad \text{(Equation 3)}$$

The time from switching-on of the output amplifier – leading to on-band transmissions – until the transmission of the first bit is called the PA Ramp On Time t_{RAMP_ON}. Likewise, the time from end of the transmission of the last bit until the switch off of the output amplifier is called the PA Ramp Off Time t_{RAMP_OFF}.

The power with which the output amplifier transmits the radio signal is called the radio transmission power P_{RF}.

7.2. Measurement of transmitter parameters

7.2.1. Measurement procedure for transmitter parameters

All transmitter parameters shall be measured by transmitting clearly defined radio telegrams to obtain representative and reproducible results. The power with which the output amplifier transmits the radio signal is called the transmission power.

Measurements shall be made under Standard and Extreme conditions as defined in chapter 4.4. If the DUT supports more than one RF power level then measurements for both the highest and lowest output power stated by the DUT manufacturer.

The DUT shall transmit a total number of 10 frames which are encoded from the 4BS subtelegram as defined in Annex A (A 1.1.) of this document.

The signal analyzer shall receive and demodulate the received frames so that the parameters defined in the following chapters can be analyzed. The demodulation bandwidth of the signal analyzer shall be set to 500 kHz to be similar to that of an actual receiver.

Within each transmitted frame, the following parameters shall be extracted for each transmitted bit (where the previous and the subsequent bit have a different value) or each sequence of identical transmitted bits (where several bits have the same value such as 0b00 or 0b111):

(1) Radio transmission frequency (f_{MARK} or f_{SPACE} - depending on the bit value)
(2) Bit duration t_{BIT} (adjusted to individual bits for sequences of bits with the same value)

7.2.2. Center frequency calculation

To determine the center frequency, an average value f_{MARK_AVG} of all measured f_{MARK} shall be calculated. Likewise, an average value f_{SPACE_AVG} of all measured f_{SPACE} shall be calculated. The center frequency is then calculated according to $\boldsymbol{f_{DEV}}=\frac{\boldsymbol{f_{MARK}-f_{SPACE}}}{\boldsymbol{2}}$

(Equation **2** using these average values.

7.2.3. Data rate calculation

To determine the data rate, an average value t_{BIT_AVG} of all *n* measured bit durations t_{BIT} shall be calculated as follows:

$$t_{BIT\_AVG} = \frac{1}{n}\sum_{k=1}^{n} t_{BIT}(k) \qquad \text{(Equation 4)}$$

The data rate can then be obtained as inverse of this average bit duration:

$$Data\ Rate = \frac{1}{t_{BIT\_AVG}} \qquad \text{(Equation 5)}$$

7.2.4. Data rate error calculation

To determine the data rate error, both the maximum bit duration t_{BIT_MAX} and the minimum bit duration t_{BIT_MIN} of all measured bit durations shall be determined.

The positive and negative data rate error shall then be calculated based on t_{BIT_MIN} and t_{BIT_MAX} together with the specified bit duration t_{Bit} using $Data\ Rate\ Error = 1 - \frac{Actual\ Bit\ Duration}{Specified\ Bit\ Duration}$ (Equation 3.

7.2.5. Frequency deviation calculation

To determine the frequency, the maximum transmitted frequencies f_{SPACE_MAX} and f_{MARK_MAX} as well as the minimum transmitted frequencies f_{SPACE_MIN} and f_{MARK_MIN} of all measured radio transmission frequencies shall be determined.

For each of these four transmission frequencies, the frequency deviation f_{DEV} versus the center frequency f_{CENTER} shall then be calculated as absolute values.

7.2.6. Output power calculation

The average output power P_{AVG} shall be calculated based on all bits within the telegrams.

7.2.7. PA Ramp On and Ramp OFF Time

For each transmitted telegram, the PA Ramp On Time t_{RAMP_ON} shall be measured as the interval from the moment the DUT emits in-band signals until the transmission of the first bit of the preamble.

Likewise, for each transmitted telegram, the PA Ramp Off Time t_{RAMP_OFF} shall be measured as the interval from the moment the transmission of the last bit of the data telegram occurred until the DUT no longer emits in-band signals.

In the context of this measurement, in-band emission is defined as the transmission of a radio signal with an output power of more than -60 dBm within the frequency band defined by f_{CENTER} ± 250 kHz.

7.2.8. Acceptance criteria for transmitter parameters

Table 1 below specifies the acceptance criteria for transmitter parameters as defined by the standard ISO 14543-3-11 [1]. The DUT has to meet all acceptance criteria to pass certification.

Parameter	Minimum	Nominal	Maximum
Data Rate	124 992 bps	125 000 bps	125 008 bps
Modulation		FSK (NRZ)	
Center Frequency f_{CENTER}	902.857 MHz	902.875 MHz	902.893 MHz
	928.332 MHz	928.350 MHz	928.368 MHz
Frequency Deviation f_{DEV}	55.0 kHz	62.5 kHz	70.0 kHz
Encoding: Logic 0		$f_{CENTER} - f_{DEV}$	
Encoding: Logic 1		$f_{CENTER} + f_{DEV}$	
Transmission Power P_{AVG}	0 dBm	Defined by the manufacturer	Defined by local radio regulation
PA Ramp On Time t_{RAMP_ON}	0 us		40 us
PA Ramp Off Time t_{RAMP_OFF}	0 us		40 us

Table 1 - Acceptance criteria for transmitter parameters according ISO 14543-3-11 [1]

7.3. Measurement of receiver parameters

7.3.1. Measurement procedure for receiver parameters

The performance of a receiver is characterized by the ability to reliably demodulate (decode) received radio telegrams correctly over a wide range of input power levels.

The range of input power levels where the receiver is demodulating correctly is determined in two steps:

(1) Define a specific packet error rate PER_{REF} which shall not be exceeded when receiving a specific telegram

(2) Measure for which continuous range of input power levels the DUT is able to demodulate the received signals with an error rate not exceeding the one defined above

The boundaries of the range of supported input power levels are then defined by the minimum input power level P_{MIN} (called receiver sensitivity) and the maximum power level P_{MAX} (called the maximum input power).

The error rate for different input power levels shall be defined by means of a so-called bathtub curve which plots packet error rate versus input power level. Figure 1 below shows an example of such bathtub curve.

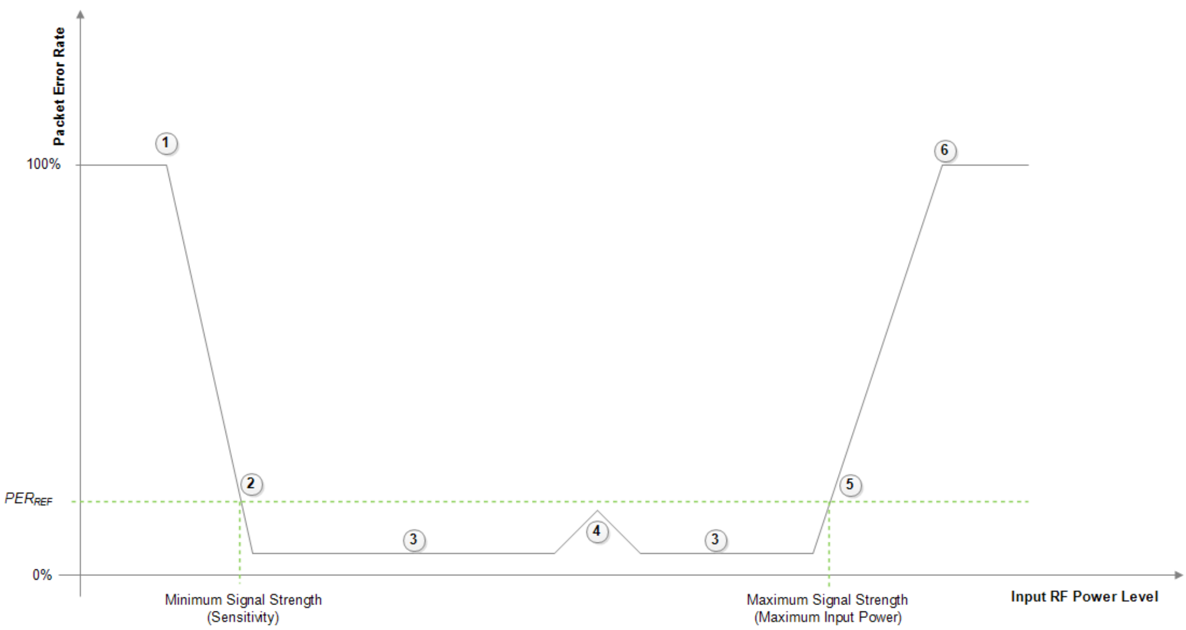

Figure 1 – Bathtub Curve (example)

From such a graph, we can determine the two key characteristics of the receiver:

(1) Sensitivity (P_{MIN})
P_{MIN} is the minimum signal strength at which the subtelegram error rate does not exceed PER_{REF} and is marked as "2" in the diagram.

(2) Maximum input power (P_{MAX})
P_{MAX} is the maximum signal strength at which the subtelegram error rate does not exceed PER_{REF}, marked as "5" in this diagram.

The packet error rate for all input power levels between P_{MIN} and P_{MAX} shall not exceed PER_{REF}.

For the purpose of certification testing, this graph shall be obtained from a series of data points where each data point represents the subtelegram error rate for a given input signal strength.

The radio telegrams used for testing shall be generated by a suitable signal generator as specified in chapter 5.3. . (Signal generator) using the nominal settings provided in Table 1. These radio telegrams shall be presented to the DUT by means of a 50Ω connection with suitable shielding against external disturbances.

For each data point, the subtelegram error rate corresponding to the input power level shall be determined based on the reception of at least 1 000 packets of 4BS reference telegram as defined in Annex A (A 1.1.). The time difference between two consecutive packets shall be at least 150 ms.

The DUT shall decode each received packet and forward the decoded bits to the test system which shall compare it with the expected content (4BS reference telegram, A 1.1.). Received packets with at least one bit error are counted as packet error.

The packet error rate for each data point is then calculated as ratio between the number of packet errors and the total number of packets that were presented to the DUT.

The data points shall be chosen as follows:

(1) Between an input RF power level of -95 dBm and -85 dBm the data point resolution (difference between two consecutive power levels) shall be 1 dBm or less.
(2) Between an input RF power level of -85 dBm and -30 dBm the data point resolution (difference between two consecutive power levels) shall be 5 dBm or less.
(3) Between an input RF power level of -30 dBm and -10 dBm the data point resolution (difference between two consecutive power levels) shall be 1 dBm or less.

Measurements shall be made under Standard and Extreme conditions as defined in chapter 4.4. If the DUT supports more than one RF power level then measurements for both the highest and lowest output power stated by the DUT manufacturer.

7.3.2. Acceptance criteria for receiver parameters

Table 2 below specifies the acceptance criteria for transmitter parameters as defined by the standard ISO14543-3-11 [1]. The DUT has to meet all acceptance criteria to pass certification.

Parameter	Minimum	Nominal	Maximum
Reference packet		Annex A 1.1.	
Reference packet error rate PER_{REF}			0.1%
Sensitivity P_{MIN}			-95 dBm
Maximum Input Power P_{MAX}	-20 dBm		

Table 2 – Acceptance criteria for transmitter parameters according ISO 14543-3-11 [1]

7.3.3. Blocking

Blocking is the ability to reject unwanted signals in frequencies adjacent to the operating frequency. Compliance with this requirement has to be demonstrated as part of radio approval testing (where required) and is therefore not separately tested as part of EnOcean Alliance certification.

7.4. Measurement of transceiver parameters

Transceivers are devices capable both of transmission and reception. The TX-RX switch-over time is the time required by a transceiver to switch from transmitting state to receiving state. This time shall be defined and documented (in Datasheet / User Manual) by the manufacturer.

The TX-RX switch-over time shall not exceed 2 ms as higher values would limit the minimum answering time of two devices communicating to each other.

Validation of this requirement is suggested to be done using a reference transceiver that waits for a well-defined request message from the DUT and responds with another – different – well-defined response message. The start of the transmission of the response message by the reference transceiver shall start no later than 2 ms after the reception of the request message. It shall then be verified that the response message from the reference transceiver is received correctly by the DUT.

8. Data Link Layer Testing

Data Link Layer testing verifies that radio telegrams are formatted correctly (by adding certain bit fields) during transmission and verified correctly (by comparing the content of certain bit fields with the expected value) during reception.

8.1. Frame structure for ISO14543-3-11 telegrams

The ISO14543-3-11 standard defines the frame structure shown in Figure 2 for radio telegrams.

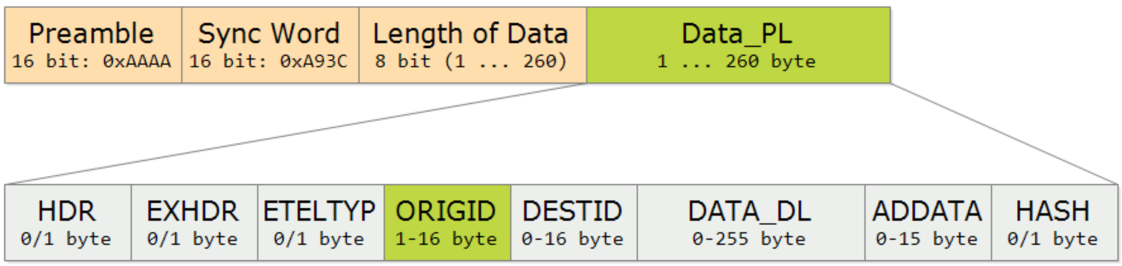

Figure 2 – Frame Structure as defined by ISO14543-3-11 [1]

Note that for the DATA_PL content, only the ORIGID has to be always present. The presence and size of all other data fields depends on the content of the HDR (HEADER) field.

Note also that the content of all data fields except the HASH field can be configured by the HDR field.

The value of the HASH field – if present – is calculated by a cyclic redundancy check (CRC) with the given polynomial G(x):

$$G(x) = x^8 + x^2 + x^1 + x^0 \qquad \text{(Equation 6)}$$

An example for an implementation of G(x) is provided in Annex B.

The data structure of the HDR (HEADER) contains the parameters address control, extended header available, and the type of telegram. The type of telegram follows the R-ORG structure as defined by the valid release of the EEP-specification [6]. The definition of HDR is reflected in Table 3.

Bit position	Parameter	Value	Context
5 … 7	Address Control	000	Originator–ID 24 bit, NO Destination-ID
		001	Originator–ID 32 bit, NO Destination-ID
		010	Originator–ID 32 bit, Destination-ID 32 bit
		011	Originator–ID 48 bit, NO Destination-ID
		100	reserved
		101	reserved
		110	reserved
		111	reserved
4	Ext. header available	0	No extended header
		1	Extended header available
0 … 3	Type of telegram	0000	RPS (0x F6)
	(R-ORG)	0001	1BS (0x D5)
		0010	4BS (0x A5)
		0011	Smart acknowledge signal telegram (0x D0)
		0100	Variable length data telegram (0x D2)
		0101	Universal teach-in, EEP-based (0x D4)
		0110	Manufacturer specific communication (0xD1)
		0111	Secure telegram (0x 30)
		1000	Secure telegram with encapsulation (0x 31)
		1001	Secure teach-in telegram for switch (0x 35)
		1010	Generic Profiles, selective data (0x B3)
		1011	reserved
		1100	reserved
		1101	reserved
		1110	reserved
		1111	Extended telegram type available (ETELTYP)

Table 3 –Definition of data fields for HDR (HEADER)

8.2. Frame structure testing for transmitters

The test setup shall generate subtelegram data and feed this data through a suitable interface into the DUT. The DUT shall perform the frame structure encoding and transmit one frame for each subtelegram to be tested.

The subtelegram data presented to the DUT transmitter shall be chosen such that it provides a representative set of data which the DUT could be transmitting. All R-ORG supported by the DUT together with a sufficiently wide variety of DATA_DL, HDR, EXHDR, ORIGID, DESTID, DATA_DL and ADDATA content shall be presented to the DUT. The content of the HASH field shall be calculated by the DUT. To achieve a meaningful test result, at least a set of 1 000 subtelegrams shall be used for testing.

The signal analyzer shall demodulate and decode the frame transmitted by the DUT and shall analyze the correctness of the DUT's frame structure encoding. As an alternative to the signal analyzer, a reference EnOcean receiver that is able to handle random subtelegram data transparently may be used.

8.2.1. Acceptance criteria for transmitters

The DUT shall correctly encode and transmit all frames.

8.3. Frame structure testing for receivers

The frame structure testing for receivers verifies the correct extraction of the data payload (DATA_PL) from received frames by removing the PREAMBLE and SYNC bits. Additionally, it verifies that incorrect frames (e.g. such where the calculated HASH does not match the received HASH) are discarded by the DUT.

To do so, the test setup shall generate a set of representative radio telegrams with a power level between -80dBm and -50dBm and provide these radio telegrams to the DUT radio input by means of a 50Ω connection.

The telegram data presented to the DUT shall be chosen such that it provides a representative set of data which the DUT could be transmitting. All RORG supported by the DUT together with a sufficiently wide variety of DATA_DL, HDR, EXHDR, ORIGID, DESTID, DATA_DL, ADDATA and HASH content shall be presented to the DUT.

The content of the HASH field shall be calculated by the test setup. To achieve a meaningful test result, at least a set of 1 000 subtelegrams shall be used for testing. To test correct validation of the HASH field, at least 250 subtelegrams shall have incorrect values for the HASH field.

The DUT shall perform the frame structure decoding and forward the DATA_PL to the test setup for validation.

8.3.1. Acceptance criteria for receivers

The DUT shall decode properly all correct frames without error. The DUT shall discard all incorrect frames. The reported signal strength should differ by no more than +-3 dB from the actual signal strength.

8.4. Subtelegram Timing

EnOcean messages consist of up to three consecutive subtelegrams containing identical subtelegram data. To minimize potential on-the-air collisions of subtelegrams sent by EnOcean devices, the transmission time of the 2nd and 3rd subtelegram is randomized.

8.4.1. Transmitter maturity time

8.4.1.1. Definition

Transmitter maturity time is the time frame, relative to the first subtelegram transmitted by a DUT, within which the 2nd and 3rd subtelegram of a message has to be transmitted, irrespective of any listen before talk (LBT) functionality that may be implemented in the DUT.

8.4.1.2. Measurement conditions

The measurement shall be made under normal test conditions and using the highest output power stated by the DUT manufacturer.

8.4.1.3. Measurement procedure

The DUT shall transmit a total number of 100 messages, at a minimum one message each 150 ms, which are encoded from the 4BS subtelegram defined in Annex A 1.1. of this document. The signal analyzer shall receive, demodulate and decode all frames of these messages applying a demodulation bandwidth and a sampling rate sufficient for a time resolution of 1µs when analyzing the analogue modulation waveform.

For each message the transmit time of the 2nd and 3rd subtelegram shall be measured relative to the 1st subtelegram of the same message. Such relative transmit time shall be defined from the start of the 0b 10 bit pattern of the PRE belonging to the first frame transmitted by the DUT to the start of the 0b 10 bit pattern of the PRE belonging to the 2nd and 3rd frame transmitted.

In addition to the measurement of the relative transmit time the signal analyzer shall, per each subtelegram, validate the correctness of the subtelegram data.

8.4.1.4. Limits

Under all test conditions decoded subtelegram data shall be correct and the relative transmit time shall be within the limits as following:

For devices transmitting at center frequency 868.300 MHz or 902.875 MHz:

2nd subtelegram: 1.0 ms … 8.0 ms
3rd subtelegram: 20.0 ms … 38.0 ms

For devices transmitting at center frequency 928.350 MHz:

2nd subtelegram: 4.0 ms … 12.0 ms
3rd subtelegram: 14.0 ms … 22.0 ms

For energy harvesting devices, a tolerance of up to ±10% relative to these time limits shall be allowed.

The subtelegrams should be distributed equally (randomly) within the given limits. Thus, each module produced transmits according to a different scheduling which is a crucial pre-requisit to reduce the probability for collisions of the signals transmitted by the products of one manufacturer.

8.4.2. Receiver maturity time

8.4.2.1. Definition

The receiver maturity time is defined to be the period while receiving equal sub telegrams from same transmitter, independent of the repeater level, are assigned to the same radio telegram.

The receiver maturity time for each radio telegram will be started when the first sub telegram of a radio telegram will be received and ends after 100 ms.

8.4.2.2. Measurement conditions

The measurement shall be made under normal test conditions.

8.4.2.3. Measurement procedure

The test setup (either a signal generator or a reference transmitter with suitable firmware) shall transmit a number of 6 frames with type and timing as defined in the table (Table 4) below.

Message type	Test description	Timing of first bit sent	Subtelegram acc. to ANNEX A	STATUS
M01	**Same** sub telegrams inside the receiver maturity time with **same** repeater level have to result in **one** radio telegram.	1, 10, 30, 60, 80, 98 ms	4 BS (A 1.1.)	0x00
M02	**Same** sub telegrams inside the receiver maturity time with **different** repeater levels have to result in **one** radio telegram.	1, 30, 60 ms 10, 80, 98 ms	4 BS (A 1.1.) 4 BS (A 1.1.)	0x00 0x01
M03	**Same** sub telegrams outside the receiver maturity time have to result in **different** radio telegrams.	1, 10, 30, 101, 110, 130 ms	4 BS (A 1.1.)	0x00
M04	**Different** sub telegrams inside the receiver maturity time have to result in **different** radio telegrams.	1, 10, 30 ms 70, 80, 98 ms	4 BS (A 1.1.) 4 BS (A 1.1.)	0x00 0x00

Table 4 –Message types defined for receiver testing

The signal generator or a reference transmitter with suitable firmware shall be set to an output level that results in signal strength of approximately 50.0 dBm at the input or antenna of the DUT. The DUT shall decode all subtelegrams, combine them to radio telegrams, and loop-back those to the test setup where the received telegrams are checked for correctness.

8.4.2.4. Limits

The DUT shall decode the subtelegrams and combine them into telegrams without error according the following table (Table 5):

Message type	Test description	Received telegram(s)
M01	**Same** subtelegrams inside the receiver maturity time with **same** repeater level have to result in **one** radio telegram.	1 telegram (combination of 6 sub telegrams)
M02	**Same** subtelegrams inside the receiver maturity time with **different** repeater levels have to result in **one** radio telegram.	1 telegram (combination of 6 sub telegrams)
M03	**Same** subtelegrams outside the receiver maturity time have to result in **different** radio telegrams.	2 telegrams (combination of 3 subtelegrams each)
M04	**Different** subtelegrams inside the receiver maturity time have to result in **different** radio telegrams.	2 telegrams (combination of 3 subtelegrams each)

Table 5 – Received telegrams per message type as defined by table 4

8.4.3. Repeater subtelegram timing

This test applies only to a DUT that has been declared by the manufacturer to support repeating functionality. Further, the manufacturer shall detail whether level 1 and / or level 2 repeating is supported.

For detailed information about testing of the repeater functionality, refer to chapter 8.5. (Repeating).

8.4.3.1. Definition

To minimize the probability of on-the-air collisions between the subtelegrams of the original EnOcean message and the subtelegrams of the repeated EnOcean message, the subtelegrams of the repeated EnOcean message shall be transmitted using defined repeater subtelegram timing.

The receiver part of a repeater shall apply the receiver maturity time and the transmitter part shall execute the transmitter maturity time.

8.4.3.2. Measurement conditions

The measurement shall be made under normal test conditions and using the highest output power stated by the DUT manufacturer.

8.4.3.3. Measurement procedure

The test setup shall transmit a minimum number of 100 frames, not more than one message each 150 ms, which are encoded from the 4BS subtelegram defined in Annex A 1.1. of this document. In case the DUT supports level 2 repeating, 50% of the frames shall have the repeater level bits set to 0x0 while all other frames shall have the repeater level bits set to 0x1. The signal generator or a reference transmitter with suitable firmware shall be set to an output level that results in a signal strength of approximately 50.0 dBm at the input or antenna of the DUT. The DUT shall, in accordance to the repeater level bits of the STATUS byte, repeat the subtelegram received as valid level 1 or level 2 repeated EnOcean message.

For each repeated message the transmit time of the 1st, 2nd and 3rd subtelegram shall be measured relative to the frame transmitted by the signal generator or the reference transmitter with suitable firmware. Such relative transmit time shall be defined from the start of the 0b 10 bit pattern of the PRE belonging to the frame transmitted by the signal generator to the start of the 0b 10 bit pattern of the PRE belonging to the 1st, 2nd and 3rd frame transmitted by the repeating DUT.

8.4.3.4. Limits

For all tests the repeated EnOcean message shall consist of three repeated subtelegrams and the relative transmit time shall be within the limits as following:

For devices transmitting at center frequency 868.300 MHz or 902.875 MHz:

- Level 1 repeated EnOcean message

  1st repeated subtelegram 10.0 ms … 14.0 ms

  2nd repeated subtelegram 14.0ms … 18.0 ms

  NO 3rd repeated subtelegram !

- Level 2 repeated EnOcean message

  1st repeated subtelegram 30.0 ms … 34.0 ms

  2nd repeated subtelegram 34.0ms … 38.0 ms

  NO 3rd repeated subtelegram !

The subtelegrams should be distributed equally (randomly) within the given limits. Thus, each module produced transmits according to a different scheduling which is a crucial pre-requisit to reduce the probability for collisions of the signals transmitted by the products of one manufacturer.

Note: Energy-harvesting devices might not be able to generate a random distribution.

For devices transmitting at center frequency 928.350 MHz:

- Level 1 repeated EnOcean message

  1st repeated subtelegram 2.0 ms … 3.0 ms

  2nd repeated subtelegram 7.0ms … 14.0 ms

  3rd repeated subtelegram 17.0 ms … 25.0ms

- Level 2 repeated EnOcean message

  NOT DEFINED !

REMARK: according to ARIB STD-T108 [3] multiple transmission up to 50ms can be transmitted at once. A pause of 50ms has to follow after such a transmission. This impacts a repeater as follows: if the 1st subtelegram is received by the repeater as it just started to pause transmission the transmission of the 1st repeated subtelegram will be delayed by a maximum of 50ms.

8.5. Repeating

The ISO14543-3-11 standard specifies that only telegrams where the repeater count is set to a value less than 0b1111 shall be repeated.

Additionally, each product can – and in fact should – restrict the amount of repetitions for each individual telegram to a maximum number. This maximum number (typically set to 2) has to be specified by the manufacturer.

Repeater testing shall demonstrate by means of suitable test telegrams that telegrams where the repeater count is set to 0b1111 will NOT be repeated. Likewise, it shall be demonstrated that the maximum number of repetitions (as defined by the manufacturer) will not be exceeded by the product.

The test strategy for this requirement can be defined by the manufacturer.

8.6. Listen before talk – LBT

According to [1] LBT is an optional feature of a transceiver. However, the EnOcean certification requires LBT to be implemented in any line powered EnOcean transceiver.

Irrespective of the kind of LBT implementation, the transmitter maturity time has to be respected by the transmitting part of an LBT enabled transceiver.

The manufacturer of a line powered device shall describe in detail the implementation of the LBT functionality in a DUT, and shall especially mention the handling of channel occupation by non-EnOcean frequency users as well the provisions to comply to the transmit maturity time regulations.

Testing of LBT functionality may only be required, if the manufacturer's documentation is technically not sufficient to proof LBT functionality of the DUT. In this case a DUT specific test case shall be generated.

8.7. Addressed Data Telegrams (ADT)

The DUT manufacturer shall declare whether or not the DUT supports addressing functionality.

8.7.1. Transmitter supporting addressing functionality

A transmitter supporting addressing functionality modifies the HDR field and adds the destination address of the receiver to be addressed to an EnOcean subtelegram.

The test setup shall generate a minimum number of 100 4BS subtelegrams with destination ID (DESTID) as defined in Annex A, not more than one subtelegram each 150 ms, using random destination addresses (instead of 0x1F2F3F4F used in the example telegram) and feed each set of data into the DUT. The DUT shall encapsulate and transmit all original subtelegrams into addressed subtelegrams. The signal analyzer shall receive and decode such addressed subtelegrams and check the correctness of the encapsulation as well as of the original subtelegram data.

8.7.2. Receiver supporting addressing functionality

A receiver supporting addressing functionality receives addressed EnOcean subtelegrams only if the destination address is identical with the EURID of such receiver, and it discards all addressed subtelegrams carrying other destination addresses.

The signal generator or a reference transmitter with suitable firmware shall transmit a minimum number of 100 addressed subtelegrams (4BS subtelegram with destination ID (DESTID)).

For 10% of the addressed subtelegrams, the destination address shall be identical to the EURID of the DUT. For the remaining 90%, the destination address shall be a random destination addresses (i.e., not identical to the EURID of the receiver).

The DUT shall receive and decode the addressed subtelegrams carrying its own EURID and shall discard all others. All subtelegrams addressed to the EURID of the DUT shall be compared to the original addressed 4BS subtelegram data sent by the signal generator.

8.7.3. Acceptance criteria

For the case of transmission, all transmitted telegrams shall be formatted correctly by the DUT.

For the case of reception, the DUT shall discard all addressed subtelegrams with destination addresses different from its own EURID and shall extract and forward correctly all subtelegrams addressed to its own EURID.

9. Test result and test documentation

The results of all individual tests defined by this specification shall be documented per DUT following these minimum requirements:

- Location and date of the certification tests.
- Ambient conditions of the testing location (temperature, relative humidity).
- DUT unique identification and technical description.
- Test cases applied and test cases not applicable.
- Overall result per each test case, either PASS or FAIL.
- Overall result per certification test, either PASS or FAIL.
- List of test equipment used to execute the test cases of the certification test, including calibration due date per each device.
- Person responsible for the execution of the certification test, including contact data.

In addition to the mandatory documentation defined above, it is strongly recommended to include the following details in the test documentation:

- Per each test case, all test conditions that are declared by the DUT manufacturer and thus deviate from the standard test conditions defined in this specification.
- Per each test case, all individual measurement result as well as the range to PASS.

ANNEX A: Definition of Reference-Subtelegrams applied for Testing

A 1. 4BS broadcast telegram

The 4BS test telegram shall be defined as following:

A 1.1. 4BS subtelegram, reference

PREAMBLE (16 bit):	0x AA AA
SYNCWORD (16 bit):	0x A9 3C
LENGTH of data (8 bit):	0x 0A
DATA_PL (max. 260 Bytes)	
HDR (HEADER, 1 Byte):	0x 22
EXHDR (max. 1 Byte):	None
ETELTYP (max. 1 Byte):	None
ORIGID (max. 16 Bytes):	0x 00 80 45 D8
DESTID (max. 16 Bytes):	None
DATA_DL(max. 255 Bytes):	0x 55 55 55 55
ADDATA (max. 15 Bytes):	None
HASH (max.1 Bytes):	0x 4D

The HDR is defined as:

Address control	001	Originator-ID 32 bit, no Destination-ID
Ext.header availability	0	No extended header
Type of telegram	0010	4BS telegram

Resulting bit stream:

SYNCWORD + LENGTH + HDR:
10101001 00111100 00001010 00100010
ORIGID + DATA_DL + HASH:
00000000 10000000 01000101 11011000 01010101 01010101 01010101 01010101 01001101

For certification purposes the ID maybe modified. In this case: keep in mind to adapt the CRC.

A 2. 4BS subtelegram, adressed, reference

A 4BS subtelegram (as defined under A 1.) is modified for addressing purposes.

A reference is NOT defined.

The HDR ist o be adapted and a DESTID has to be provided. An encapsulation is not required. Testing company may define and publish its own test telegram.

ANNEX B: Reference implementation of HASH (CRC-8)

The polynomial $G(x) = x^8 + x^2 + x^1 + x^0$ is used to generate the CRC8 table, required for the CRC8 calculation. Following C code illustrates how the CRC8 value is calculated:

Implementation:

```
uint8 u8CRC8Table[256] = {
  0x00, 0x07, 0x0e, 0x09, 0x1c, 0x1b, 0x12, 0x15,
  0x38, 0x3f, 0x36, 0x31, 0x24, 0x23, 0x2a, 0x2d,
  0x70, 0x77, 0x7e, 0x79, 0x6c, 0x6b, 0x62, 0x65,
  0x48, 0x4f, 0x46, 0x41, 0x54, 0x53, 0x5a, 0x5d,
  0xe0, 0xe7, 0xee, 0xe9, 0xfc, 0xfb, 0xf2, 0xf5,
  0xd8, 0xdf, 0xd6, 0xd1, 0xc4, 0xc3, 0xca, 0xcd,
  0x90, 0x97, 0x9e, 0x99, 0x8c, 0x8b, 0x82, 0x85,
  0xa8, 0xaf, 0xa6, 0xa1, 0xb4, 0xb3, 0xba, 0xbd,
  0xc7, 0xc0, 0xc9, 0xce, 0xdb, 0xdc, 0xd5, 0xd2,
  0xff, 0xf8, 0xf1, 0xf6, 0xe3, 0xe4, 0xed, 0xea,
  0xb7, 0xb0, 0xb9, 0xbe, 0xab, 0xac, 0xa5, 0xa2,
  0x8f, 0x88, 0x81, 0x86, 0x93, 0x94, 0x9d, 0x9a,
  0x27, 0x20, 0x29, 0x2e, 0x3b, 0x3c, 0x35, 0x32,
  0x1f, 0x18, 0x11, 0x16, 0x03, 0x04, 0x0d, 0x0a,
  0x57, 0x50, 0x59, 0x5e, 0x4b, 0x4c, 0x45, 0x42,
  0x6f, 0x68, 0x61, 0x66, 0x73, 0x74, 0x7d, 0x7a,
  0x89, 0x8e, 0x87, 0x80, 0x95, 0x92, 0x9b, 0x9c,
  0xb1, 0xb6, 0xbf, 0xb8, 0xad, 0xaa, 0xa3, 0xa4,
  0xf9, 0xfe, 0xf7, 0xf0, 0xe5, 0xe2, 0xeb, 0xec,
  0xc1, 0xc6, 0xcf, 0xc8, 0xdd, 0xda, 0xd3, 0xd4,
  0x69, 0x6e, 0x67, 0x60, 0x75, 0x72, 0x7b, 0x7c,
  0x51, 0x56, 0x5f, 0x58, 0x4d, 0x4a, 0x43, 0x44,
  0x19, 0x1e, 0x17, 0x10, 0x05, 0x02, 0x0b, 0x0c,
  0x21, 0x26, 0x2f, 0x28, 0x3d, 0x3a, 0x33, 0x34,
  0x4e, 0x49, 0x40, 0x47, 0x52, 0x55, 0x5c, 0x5b,
  0x76, 0x71, 0x78, 0x7f, 0x6A, 0x6d, 0x64, 0x63,
  0x3e, 0x39, 0x30, 0x37, 0x22, 0x25, 0x2c, 0x2b,
  0x06, 0x01, 0x08, 0x0f, 0x1a, 0x1d, 0x14, 0x13,
  0xae, 0xa9, 0xa0, 0xa7, 0xb2, 0xb5, 0xbc, 0xbb,
  0x96, 0x91, 0x98, 0x9f, 0x8a, 0x8D, 0x84, 0x83,
  0xde, 0xd9, 0xd0, 0xd7, 0xc2, 0xc5, 0xcc, 0xcb,
  0xe6, 0xe1, 0xe8, 0xef, 0xfa, 0xfd, 0xf4, 0xf3
  };

#define proccrc8(u8CRC, u8Data) (u8CRC8Table[u8CRC ^ u8Data])
```

Example:

```
u8CRC = 0;
for (i = 0 ; i < u16DataSize ; i++)
  u8CRC = proccrc8(u8CRC, u8Data[i]);
printf("CRC8 = %02X\n", u8CRC);
```