

EnOcean Certification Specification, part 1a Air Interface (ASK)

V 1.4, RELEASED

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San Ramon, CA, USA, Dec 17, 2013

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 (1a) *Air Interface (ASK)*¹ which is a mandatory part of the *EnOcean Certification Program*. Goal of this part is to assess the radio interoperability of the device under test (DUT) with other devices (existing or future) in the EnOcean ecosystem which is based on the ISO / IEC 14543-3-10 standard [1].

This document defines the minimum set of test cases that have to be executed in order to assess radio interoperability. The test procedures have been defined to minimize effort (test time, equipment and resources) as much as possible while still producing meaningful and reproducible results. It is expected that customer testing during device qualification will exceed this minimum set.

¹ The certification of Air Interface (FSK) according to ISO / IEC 14543-3-11 is specified in part 1b.

Normative requirements, resulting from national or regional regulations for short range radio devices, are reflected in this document only as far as they are referenced in the EnOcean Air Interface Specifications [1]. In general such national or regional regulations 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.

Following approval this specification is now in the status RELEASED.

Changes to this document have to be proposed to the TWG for decision. The EnOcean Certification Task Group will then act up on request by the TWG.

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1. Scope of this document

This document defines a minimum set of test cases for device under test (DUT) to confirm their correct implementations of the ISO 14543-3-10 standard [1] and to ensure interoperability within the EnOcean ecosystem of devices.

The focus of this part of the certification is on correct radio telegram reception and transmission and – as far as applicable – also on the correct communication flow and timing.

This document defines necessary test cases and the testing procedures required to achieve meaningful and reproducible testing results.

Normative requirements that result from national or regional regulations for short range radio devices are reflected in this document only as far as they are referenced in the EnOcean Air Interface Specifications. In general such national or regional regulations are out of scope of this system specification.

Within this document “EnOcean” is used as synonym for “compliant to ISO / IEC 14543-3-10”.

2. References

2.1. Normative references

- [1] EnOcean Air Interface Specification, EHW Protocol IEC/ISO 14543-3-10, March 2012
- [2] EN300220-1, latest release

2.2. Informative references

- [3] EnOcean Certification Handbook, EnOcean Alliance
<https://www.enocean-alliance.org/cb/>
- [4] EnOcean Certification Specification, part 2, Radio Performance, EnOcean Alliance
<https://www.enocean-alliance.org/rpc/>
- [5] EnOcean Certification Specification, part 1, Air Interface (FSK), EnOcean Alliance (1b)
<https://www.enocean-alliance.org/aicfsk/>
- [6] 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. Please refer there for further details.

In addition, the following definitions shall apply:

None, so far.

3.2. Abbreviations

BER – Bit Error Rate, the likelihood at which one bit within a radio telegram is not received correctly at a certain input signal strength

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.

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

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

LBT – Listen before talk, a mechanism by which a radio transmitter checks if the radio channel is available, i.e. no other transmission is on-going, before starting its own transmission.

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.

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.

4. Test conditions

Testing shall be made under clearly defined external conditions which are defined by the combination of power supply, ambient temperature and ambient humidity as described below.

4.1. Power supply

The DUT shall be supplied by an external power supply (e.g. laboratory power supply) capable of providing the required supply voltage (nominal, minimum and maximum supply voltage as specified by the manufacturer) with the required operating current.

4.2. Temperature

The DUT shall be tested at standard, minimum and maximum temperature as defined by the manufacturer. If no standard temperature is defined by the manufacturer (i.e. if the manufacturer only specifies a temperature range), then normal room temperature (between +17°C to +27°C) shall constitute standard temperature.

4.3. 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")

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 $\pm 5\%$ 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) 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 $<1\text{dB}$
- Timing $<100\text{ns}$

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

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) and support the following test cases:

- 1) Transmit a test signal using RF parameters as defined by ISO 14543-3-10 (physical layer).
- 2) Modulate a test signal as defined by ISO 14543-3-10 (physical layer)
- 3) Encode a frame with data content as defined by ISO 14543-3-10 (physical layer)

- 4) Generate subtelegrams with data and timing as defined by ISO 14543-3-10 (data link layer)
- 5) Generate a telegram with data and timing as defined by ISO 14543-3-10 (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 14543-3-10) 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 $<1\text{dB}$
- Timing $<100\text{ns}$

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

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 facilitated greatly 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 recommended strongly 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 (see chapter 5.1. above). If the DUT contains its own internal power source then its HW has to be modified in order 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 to obtain reproducible results. DUT without suitable RF connection (e.g. modules with integrated antenna) cannot be certified as it is not possible to determine reliably 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 the defined radio telegrams. If their standard firmware does not allow to do so (e.g. for devices using RPS or VLD telegrams) then a custom test SW shall be used to transmit 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

7.1. Transmitter parameters

In case the DUT is able to operate at different output power levels the DUT manufacturer shall state all possible power levels with the output power related to each power level.

7.1.1. Frequency Error

7.1.1.1. Definition

Frequency error is the difference between the unmodulated carrier frequency of the DUT and the TX center frequency of 868.300 MHz as defined in [1].

7.1.1.2. Measurement conditions

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.

7.1.1.3. Measurement procedure

The DUT shall transmit an unmodulated continuous carrier for at least 10ms and the frequency error shall be calculated as the maximum frequency difference between the transmitted carrier of the DUT during the time of transmission and the TX center frequency.

7.1.1.4. Limits

The frequency error shall not exceed a maximum of ± 82.634 kHz for any test condition.

7.1.2. Output power and output power stability

7.1.2.1. Definition

Output power is the power of the high state amplitude of a modulated carrier transmitted by the DUT. Output power stability is the difference between two consecutive high state amplitudes within a single frame.

7.1.2.2. Measurement conditions

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

7.1.2.4. Measurement procedure

The DUT shall transmit a total number of 10 frames which are encoded from the 4BS subtelegram type 1 as defined in Annex A (A 1.1.) of this document. The signal analyzer shall receive and demodulate the received frames. The demodulation bandwidth of the signal analyzer shall be set to 500 kHz to be similar to that of an actual receiver.

The static high levels shall be measured for each 0b000 and 0b0000 modulation pattern of all frames transmitted, ignoring overshoot and undershoot effects.

The output power stability shall be calculated per each frame as the maximum positive and the maximum negative difference between any two consecutive static high levels of such frame.

7.1.2.5. Limits

Under all test conditions the output power shall not exceed +13.0 dBm and it shall be within the range of ± 3.0 dB relative to the output power stated by the DUT manufacturer.

Under all test conditions the output power stability shall not exceed a positive maximum of +2.0 dB and a negative maximum of -1.0 dB. This shall apply to both, the highest and the lowest output power stated by the DUT manufacturer.

7.1.3. Modulation

7.1.3.1. Definition

Modulation is the way the bits of each frame are converted to an analogue RF signal using the Amplitude Shift Keying (ASK) modulation scheme. This ASK modulation scheme is defined by several parameters that are all relevant for a reliable radio communication between devices, especially in conditions of very weak or very high signal environments.

7.1.3.2. Measurement conditions

Measurements shall be made under Standard and Extreme conditions as defined in chapter 4.4.

7.1.3.3. Measurement procedure

The DUT shall transmit a total number of 10 frames using the 4BS subtelegram type 1 defined in Annex A (A 1.1.) of this document.

The signal analyzer shall receive and demodulate the frames applying a demodulation bandwidth and a sampling rate sufficient for a time resolution of 100 ns to the timing parameters listed below.

The bit rate shall be calculated from the demodulated data of the frames by measuring the time between the mesial amplitude crossing of the 0b01 bit pattern between PRE and SOF and the mesial amplitude crossing of the 0b10 bit pattern in the EOF (in total 135 bits). For all frames transmitted by the DUT the bit rate shall not exceed the limits defined below.

The bit duration shall be measured from the demodulated data of the frames for 0b1 bits as well as for 0b0 bits. Bit duration for 0b1 bits is measured as the time between the two subsequent mesial amplitude crossings in any 0b010 pattern of the frame transmitted by the DUT, while bit duration for the 0b0 bit is defined as the time between the two subsequent mesial amplitude crossings in any 0b101 pattern. For all frames transmitted by the DUT the bit duration measured shall not exceed the limits defined below.

The modulation lead time shall be measured from when the ramping up transmitter signal gets higher than -75.0 dBm until the start of preamble modulation, excluding the leading 0b1 of the preamble. For all frames, no value shall exceed the limits defined below.

The modulation overtravel time shall be measured from the end of frame modulation, excluding the trailing 0b11 of EOF, until the ramping down transmitter signal gets lower than -75.0 dBm. For all frames, no value shall exceed the limits defined below.

The signal analyzer shall receive and demodulate the frames applying a bandwidth filter of 500 kHz (-3.0 dB) to represent actual receiver input bandwidth in order to analyze bit shape parameters listed below.

The static low levels shall be measured for each 0b111 and 0b1111 modulation pattern of all frames transmitted, ignoring overshoot and undershoot effects.

The high state to low state ratio (modulation depth) shall be calculated determined based on the measured static high and static low levels. For all frames, no value shall exceed the limits defined below.

The overshoot and undershoot ratios shall be measured for each 0b0011 and 0b1100 modulation pattern of a frame as the maximum overshoot and undershoot ratios separated for high state and low state level. For all frames, no value shall exceed the limits defined below.

7.1.3.4. Limits

Under all test conditions a 0b0 bit shall be transmitted by the high power state and a 0b1 bit shall be transmitted by the low power state of the modulation scheme. Further, limits shall apply as following:

Bit rate:	124 500 bps ... 125 500 bps ²
Bit duration:	bit rate nominal value \pm 0.5 μ s
High state to low state ratio:	20.0 dB ... 40.0 dB
Positive overshoot to high state:	0 dB ... 1.0 dB
Positive undershoot to high state:	0 dB ... 0.5 dB
Negative overshoot to low state:	0 dB ... 4.0 dB

² Technology continues to evolve and the restriction and test boundaries need to be tightened to reflect the state of the art. Therefore the EnOcean Alliance compiles with the ISO standard and to ensure high quality products we go beyond and set the testing boundaries above the requested levels.

Negative undershoot to low state:	0 dB ... 2.0 dB
Modulation lead time:	0 μ s ... 56.0 μ s
Modulation overtravel time:	0 μ s ... 40.0 μ s

7.1.4. Duty Cycle

The TX duty cycle defines the percentage of a specific time frame that a DUT uses for transmitting purposes. Measurements shall be done in accordance with national regulations that are relevant for the markets where the DUT is being sold. No specific testing is required as part of this certification.

7.1.5. Frame structure encoding

7.1.5.1. Definition

The frame structure encoding defines the conversion from any subtelegram into a frame sent by a transmitter. This coding adds the required INV and SYNC bits into the payload data of a subtelegram as well as PRE plus SOF bits at the beginning of a frame and EOF bits at its end.

7.1.5.2. Measurement conditions

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

7.1.5.3. Measurement procedure

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 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 content and length, STATUS and TXID fields and a HASH calculated according to [1] shall be tested. 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 able to handle random subtelegram data transparently may be used.

Remark:

If HASH is generated and MSB of STATUS is consistently controlled by the DUT, testing of data integrity may be combined with testing of the frame structure encoding. Refer to chapter 8.2.1. (Transmitter hash functionality) for further information.

7.1.5.4. Limits

The DUT shall encode all subtelegrams without error.

7.2. Receiver parameters

7.2.1. Test scenarios

Receiver testing is performed using defined test scenarios where each scenario is a combination of key signal parameters. This provides reproducible conditions to determine key parameters such as sensitivity and large signal tolerance. The defined scenarios also serve to test interoperability with non-ideal transmitters.

7.2.1.1. Modulation test scenarios

The following modulation test scenarios are used for receiver test:

Modulation scheme MS0 (reference / “ideal” scenario):

Bit rate:	125 000 bps
Bit duration low state:	bit rate nominal value
Bit duration high state:	bit rate nominal value
High state to low state ratio:	30.0 dB
Positive overshoot to high state:	< 0.1 dB
Positive undershoot to high state:	< 0.1 dB
Negative overshoot to low state:	< 0.1 dB
Negative undershoot to low state:	< 0.1 dB
Modulation lead time:	56.0 μ s
Modulation overtravel time:	40.0 μ s

Modulation scheme MS1 (minimum data rate):

Bit rate:	125 000 bps – 0.1% ³
Bit duration low state:	bit rate nominal value – 1.0 μ s
Bit duration high state:	bit rate nominal value + 1.0 μ s
High state to low state ratio:	30.0 dB
Positive overshoot to high state:	< 0.1 dB
Positive undershoot to high state:	< 0.1 dB
Negative overshoot to low state:	< 0.1 dB
Negative undershoot to low state:	< 0.1 dB
Modulation lead time:	56.0 μ s
Modulation overtravel time:	40.0 μ s

³ The first definition of boundaries was defined to reflect technological restrictions in transmitters, mostly related to oscillators. Since the eco system is using modern oscillators in all products for over 10 years, the boundaries are adjusted to reflect current state of the art TX and RX technological capabilities.

Modulation scheme MS2 (maximum data rate):

Bit rate:	125 000 bps + 0.1% ⁴
Bit duration low state:	bit rate nominal value + 1.0 μ s
Bit duration high state:	bit rate nominal value –1.0 μ s
High state to low state ratio:	30.0 dB
Positive overshoot to high state:	< 0.1 dB
Positive undershoot to high state:	< 0.1 dB
Negative overshoot to low state:	< 0.1 dB
Negative undershoot to low state:	< 0.1 dB
Modulation lead time:	56.0 μ s
Modulation overtravel time:	40.0 μ s

Modulation scheme MS3 (minimum modulation depth):

Bit rate:	125 000 bps
Bit duration low state:	8.0 μ s
Bit duration high state:	8.0 μ s
High state to low state ratio:	20.0 dB
Positive overshoot to high state:	1.0 dB
Positive undershoot to high state:	0.5 dB
Negative overshoot to low state:	4.0 dB
Negative undershoot to low state:	2.0 dB
Modulation lead time:	< 1.0 μ s
Modulation overtravel time:	< 1.0 μ s

Modulation scheme MS4 (maximum modulation depth):

Bit rate:	125 000 bps
Bit duration low state:	8.0 μ s
Bit duration high state:	8.0 μ s
High state to low state ratio:	40.0 dB
Positive overshoot to high state:	< 0.1 dB
Positive undershoot to high state:	< 0.1 dB
Negative overshoot to low state:	< 0.1 dB
Negative undershoot to low state:	< 0.1 dB
Modulation lead time:	< 1.0 μ s
Modulation overtravel time:	< 1.0 μ s

⁴ The first definition of boundaries was defined to reflect technological restrictions in transmitters, mostly related to oscillators. Since the eco system is using modern oscillators in all products for over 10 years, the boundaries are adjusted to reflect current state of the art TX and RX technological capabilities.

7.2.1.2. Center frequency test scenarios

The following modulation test scenarios are used for receiver test:

$$F_{\text{minimum}} = 868\,300.000 \text{ MHz} - 82\,634 \text{ kHz}$$

$$f_{\text{standard}} = 868\,300.000 \text{ MHz}$$

$$f_{\text{maximum}} = 868\,300.000 \text{ MHz} + 82\,634 \text{ kHz}$$

7.2.2. Center frequency test

Center frequency is the frequency at which the receiver shows the best demodulation capabilities. No specific measurement for center frequency is required; it is sufficient to demonstrate that the receiver achieves the required performance for the test cases defined below.

7.2.3. Sensitivity and Maximum Power Level

7.2.3.1. Definition

Sensitivity is the minimum RF input power level at which (or below) the bit error rate exceeds a defined value due to noise. Maximum input power level is the RF level at which a DUT is able to receive and decode a strong RF signal at a defined bit error rate.

7.2.3.2. Measurement conditions

Measurements shall be made under Standard and Extreme conditions as defined in chapter 4.4.

7.2.3.3. Measurement procedure

The ISO 14543-3-10 standard [1] defines that a bit error rate of 0.1% shall be used to determine the sensitivity. An RF input power level of -95 dBm shall be sufficient to reach this bit error rate according to the standard. No operating conditions are specified in conjunction with that requirement.

The definition based on the bit error rate in [1] was chosen to establish a metric that is independent of the subtelegram or frame structure. However, from a certification perspective this approach is not optimal. Experience with current solutions has shown that many demodulation errors occur on subtelegram or frame level (not bit stream level) and are caused by issues such as incorrect preamble detection or incorrect demodulation settings (static high level / low level). To be able to detect such issues, certification testing will be made on subtelegram level.

In order to do so, an equivalent subtelegram (or packet) error rate PER is derived from the specified bit error rate (BER) of 0.1% together with the known number of bits (NoB) of the reference subtelegram defined in Annex A which is 138 bit (complete telegram including SOF and EOF, but without preamble). The subtelegram error rate PER which is equivalent to a bit error rate of 0,1% for a subtelegram size of 138 bit is therefore:

$$PER = 1 - (1 - BER)^{NoB} = 1 - (0.999)^{138} = 12.9\%$$

Performance of the DUT is in general affected by the supported operating conditions (especially the supported temperature range). DUT supporting a wide temperature range typically will have less performance compared to DUT supporting only operation at room temperature due to parameter variation (e.g. in crystal frequency).

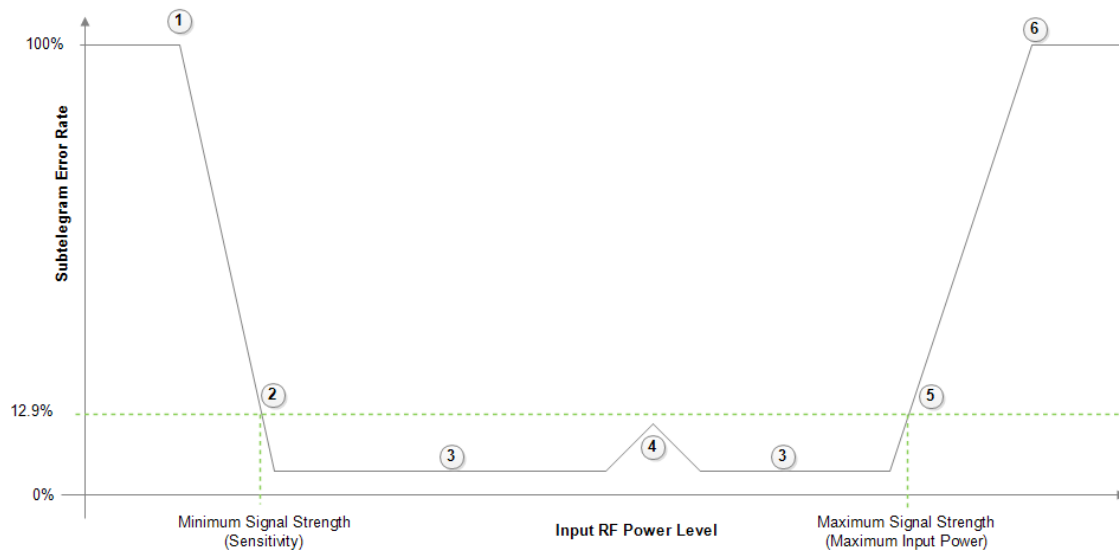
Measurement has to consider this aspect while at the same time ensuring a minimum performance for all DUT irrespective of their supported operating conditions.

The following compensation factor between 0 dB and 3 dB can therefore be used for DUT during sensitivity and maximum power level testing:

<i>Supported Operation Temperature Range ($T_{max} - T_{min}$)</i>	<i>Compensation Factor</i>
<40 °C	0 dB
40 °C ... 79 °C	1 dB
80 °C ... 119 °C	2 dB
>120 °C	3 dB

Please, note: the customer documentation of the DUT (Datasheet / User Manual) shall use the actual sensitivity (without compensation factor) to avoid ambiguities.

Measurements shall be executed across the range of supported input power levels ranging from the defined sensitivity (minimum input power) up to the maximum input power. As a result, a graph will be obtained showing the correspondence between input signal strength (RF power level at the input to the DUT) and the resulting subtelegram (packet) error rate similar to the one shown below.



From such a graph, we can determine the characteristics of the receiver, most notably the sensitivity (minimum signal strength at which the subtelegram error rate does not exceed 12.9% - marked as “2” in the diagram) and the maximum input power (maximum signal strength at which the subtelegram error rate does not exceed 12.9%, marked as “5” in this diagram).

The graph shown above shall be obtained as follows:

- 1) The 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.
- 2) The subtelegram error rate is calculated based on at least 250 subtelegrams of 4BS reference telegram type 1 as defined in Annex A (A 1.1.) using the standard modulation scheme MS0 as defined above at the center frequency of 868 300 MHz with the power level corresponding to the data point. For each subtelegram, the correct frame (including the required preamble, start of frame, end of frame and inverse bits) is generated by the signal generator and presented to the RF input of the DUT. The time difference between two frames shall be at least 150 ms.
- 3) The DUT decodes the frame and feeds back the decoded subtelegram content to the test system where it is compared with the expected content (4BS reference telegram type 1, A 1.1.). Received subtelegrams with at least one bit error are counted as subtelegram error. The subtelegram error rate for each data point is then calculated as ratio between the number of subtelegram errors and the number of subtelegrams that were generated by the signal generator.
- 4) Between an input RF power level of -95 dBm and -85 dBm the data point resolution shall be 1 dBm or better. Between an input RF power level of -85 dBm and -30 dBm the data point resolution shall be 5 dBm or better. Between an input RF power level of -30 dBm and -10 dBm the data point resolution shall be 1 dBm or better.

Based on this graph, the sensitivity shall be obtained as the data point with the smallest signal strength for which the subtelegram error rate does not exceed 12.9%. Likewise, the maximum

input power shall be obtained as the data point with the largest signal strength for which the subtelegram error rate does not exceed 12.9%. The subtelegram error rate for all points in between the smallest and the largest signal strength shall not exceed 12.9%.

7.2.3.4. Limits

The sensitivity (minimum signal strength) shall be at -95 dBm or less under all conditions listed above after subtracting the compensation factor as defined above.

The maximum input power level (maximum signal strength) shall be -23 dBm or more under all conditions listed above after adding the compensation factor as defined above.

7.2.4. Blocking

Blocking is the ability to reject unwanted signals in frequencies adjacent to the operating frequency. Within the EU legislative framework, blocking is now tested as part of EN 300 220 radio testing. The DUT shall achieve at least class 2 blocking performance.

Compliance with this requirement has to be demonstrated as part of radio approval testing within the European Union and is therefore not separately tested as part of EnOcean Alliance certification.

7.2.5. Demodulation robustness

7.2.5.1. Definition

Demodulation robustness is the ability to correctly decode RF input signals with parameters deviating from the ideal values. Considering the variety of devices within the EnOcean Alliance ecosystem, demodulation robustness is a key capability and therefore has to be extensively tested.

7.2.5.2. Measurement conditions

The measurement shall be made under normal and extreme test conditions as defined in chapter 4.4.

7.2.5.3. Measurement procedure

Testing shall be executed for each combination of the three center frequency test scenarios defined in chapter 7.2.1.2. (Center frequency test scenarios) with each of the five modulation test scenarios listed in chapter 7.2.1.1.

For each such combination of modulation scheme and test frequency, the signal generator shall transmit a minimum number of 100 subsequent frames, not more than one frame each 150 ms, which are encoded from the 4BS subtelegram type 1 defined in Annex A (A 1.1.) of this document.

Subsequent frames shall be transmitted at alternating input levels to the DUT of -40.0 dBm and -80.0 dBm. The DUT shall receive the frames, decode the subtelegrams and loop-back the subtelegram data to the test setup where this data is compared to the data sent by the signal generator.

Per each modulation scheme and test frequency, a subtelegram error rate shall be calculated as the number of subtelegrams the DUT decoded incorrectly versus the total number of subtelegrams transmitted by the signal generator.

7.2.5.4. Limits

Under all test conditions, the subtelegram error rate shall not exceed a value of 12.9 %.

Remark:

The ISO 14543-3-10 standard [1] does not specify modulation-specific performance limits. The suitability of using the same performance (error rate) boundaries needs to be confirmed during certification testing.

7.2.6. Frame structure decoding

7.2.6.1. Definition

The frame structure decoding defines the conversion from any frame received by a receiver to the subtelegram encoded into such frame. This decoding removes the PRE and SOF bits at the beginning of a frame and the EOF bits at its end. In addition, it checks and removes the INV and SYNC bits within the payload of a frame.

7.2.6.2. Measurement

The measurement shall be made under normal test conditions.

The test setup shall generate subtelegram data, frame encode this data and transmit one frame per subtelegram data. The signal generator shall be set to an output level that results in -50.0 dBm signal strength at the input or antenna of the DUT.

The DUT shall receive such frames, perform frame structure decoding and loop-back the decoded subtelegram data to the test setup where this data is compared to the subtelegram data generated.

As an alternative to the signal generator, a reference EnOcean transmitter that is able to handle random subtelegram data transparently may be used. In this case the random subtelegram data generated by the test setup is fed into the certified EnOcean transmitter.

Subtelegram data shall mean:

- All feasible combination of subtelegram data a DUT is able to receive. This includes one dedicated RORG, a wide variety of supported values of DATA, random TXID bytes and a

STATUS byte containing meaningful values derived from RORG, plus a HASH calculated according to [1]. RORG and DATA values have to be declared by the DUT manufacturer.

- Random subtelegram data if the DUT is a universal device supporting multiple RORGs or repeating functionality. Random data is characterized by an equally distributed usage of all possible subtelegram lengths, ranging from 8 bytes through 21 bytes, where RORG, all DATA and TXID bytes are filled with random data, STATUS contains meaningful values derived from RORG and the HASH is calculated according to [1].

To achieve a meaningful test result, at least a number of 1 000 frames shall be generated by the test setup and decoded by the DUT.

Remark:

If HASH is verified by the DUT and the result is communicated to the test setup, testing of data integrity may be combined with testing of the frame structure decoding. See chapter 8.2.2. (Receiver hash functionality) for further information.

In addition to testing correct decoding of correct frames, it shall also be tested that frames with incorrect structure will be discarded by the DUT. To do so, a suitable subset of at least 100 telegrams shall be selected from above and frame structure errors (especially incorrect SYNC or INV bits) shall be introduced. These incorrect frames shall be presented to the DUT and its behavior shall be checked.

7.2.6.3. Limits

The DUT shall frame structure decode all correct frames without error. The DUT shall discard all incorrect frames.

7.3. Transceiver

7.3.1. TX-RX switch-over time

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 as it limits the minimum answering time of two devices communicating to each other.

Testing of this parameter is not within the scope of this specification since it is not defined within the ISO 14543-3-10 standard [1].

8. Data Link Layer

8.1. Subtelegram timing

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

8.1.1. Transmitter maturity time

8.1.1.1. 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.

8.1.1.2. Measurement conditions

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

8.1.1.3. Measurement procedure

The DUT shall transmit a total number of 100 messages, at a maximum one message each 150 ms, which are encoded from the 4BS subtelegram defined in Annex A (A 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 10 µs 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 0b01 bit pattern of the PRE (thus, excluding the leading 0b1) belonging to the first frame transmitted by the DUT to the start of the 0b01 bit pattern of the PRE (thus, excluding the leading 0b1) 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.

8.1.1.4. Limits

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

2 nd subtelegram:	1.0 ms ... 9.0 ms
3 rd subtelegram:	20.0 ms ... 39.0 ms

For energy harvesting devices, a tolerance of up to $\pm 10\%$ relative to these time limits shall be allowed. For non-energy harvesting devices a tolerance of up to $\pm 100\ \mu\text{s}$ shall be allowed.

8.1.2. Receiver maturity time

8.1.2.1. 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.

8.1.2.2. Measurement conditions

The measurement shall be made under normal test conditions.

8.1.2.3. 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 below.

Message type	Test description	Timing of first bit sent	Subtelegram acc. to ANNEX A	STATUS
M01	Same sub telegrams <u>inside</u> the receiver maturity time with same repeater level have to result in one radio telegram.	1, 10, 30, 60, 80, 98 ms	4 BS type 1 (A 1.1.)	0x00
M02	Same sub telegrams <u>inside</u> 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 type 1 (A 1.1.) 4 BS type 1 (A 1.1.)	0x00 0x01
M03	Same sub telegrams <u>outside</u> the receiver maturity time have to result in different radio telegrams.	1, 10, 30, 101, 110, 130 ms	4 BS type 1 (A 1.1.)	0x00
M04	Different sub telegrams <u>inside</u> the receiver maturity time have to result in different radio telegrams.	1, 10, 30 ms 70, 80, 98 ms	4 BS type 1 (A 1.1.) 4 BS type 2 (A 1.2.)	0x00 0x00

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.

8.1.2.4. Limits

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

Message type	Test description	Received telegram(s)
M01	Same subtelegrams <u>inside</u> 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 <u>inside</u> 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 <u>outside</u> the receiver maturity time have to result in different radio telegrams.	2 telegrams (combination of 3 subtelegrams each)
M04	Different subtelegrams <u>inside</u> the receiver maturity time have to result in different radio telegrams.	2 telegrams (combination of 3 subtelegrams each)

8.1.3. Repeater subtelegram timing

This test applies only to a DUT 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 9.2.

8.1.3.1. Definition

To minimize the probability of on-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.

8.1.3.2. Measurement conditions

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

8.1.3.3. 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 type 1 defined in Annex A (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 0b01 bit pattern of the PRE (thus, excluding the leading 0b1) belonging to the frame transmitted by the signal generator to the start of the 0b01 bit pattern of the PRE (thus, excluding the leading 0b1) belonging to the 1st, 2nd and 3rd frame transmitted by the repeating DUT.

8.1.3.4. 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:

Level 1 repeated EnOcean message

1 st repeated subtelegram:	10.0 ms ... 19.0 ms
2 nd repeated subtelegram:	20.0 ms ... 29.0 ms
3 rd repeated subtelegram:	20.0 ms ... 29.0 ms

Level 2 repeated EnOcean message

1 st repeated subtelegram:	1.0 ms ... 9.0 ms
2 nd repeated subtelegram:	20.0 ms ... 29.0 ms
3 rd repeated subtelegram:	20.0 ms ... 29.0 ms

8.2. Certification of data integrity

Data integrity of EnOcean frames is verified using three different hash algorithms: 4 bit and 8 bit summation and 8 bit cyclic redundancy check. The first algorithm is applied only in switch telegrams, the two other algorithms may be used for any other EnOcean communication.

This chapter defines testing of the 8 bit summation hash function and the 8 bit cyclic redundancy check hash function. Testing of the 4 bit summation hash function is defined in chapter 9.1. (Certification of switch telegram functionality) of this document.

8.2.1. Transmitter hash functionality

8.2.1.1. Definition

A transmitting EnOcean devices decides upon which hash functionality to use and communicates this information by setting bit 7 (MSB) of the STATUS byte accordingly:

- 0b0 8 bit summation hash algorithm
- 0b1 8 bit cyclic redundancy check hash algorithm

The hash functionality supported by a DUT has to be declared by the manufacturer.

8.2.1.2. Measurement conditions

The measurement shall be made under normal test conditions.

8.2.1.3. Measurement procedure

Testing of data integrity shall be done with the same test setup and the very similar test definitions that are used for testing frame structure encoding of a transmitter, refer to chapter 7.1.5. (Frame structure encoding) for details.

The only difference is, for data integrity testing calculation of the HASH byte and setting of the appropriate MSB value in the STATUS byte is to be executed by the DUT. Consequently, only the remaining part of the subtelegram data is generated by the test setup.

To achieve a meaningful test result, the DUT shall calculate the HASH byte for at least 1 000 different subtelegrams.

8.2.1.4. Limits

The DUT shall calculate all HASH bytes correctly and in accordance with the MSB of the STATUS byte.

8.2.2. Receiver hash functionality

8.2.2.1. Definition

Receivers must support both 8 bit hash algorithms in accordance with the MSB of the STATUS byte received as part of an EnOcean subtelegram.

If the HASH byte received in a subtelegram does not match the subtelegram content then the subtelegram shall be discarded by the receiver.

8.2.2.2. Measurement conditions

The measurement shall be made under normal test conditions.

8.2.2.3. Measurement procedure

Testing of data integrity shall be done with the same test setup and the very similar test definitions that are used for testing frame structure decoding of a receiver, see chapter 7.1.5. (Frame structure encoding) for details.

The difference is, for data integrity testing checking of the HASH byte in accordance with the MSB value in the STATUS byte is to be executed by the DUT. In case the HASH is classified correct the subtelegram shall be looped-back to the test setup, otherwise not at all or with a proper notification of incorrectness.

In addition to subtelegrams containing correct HASH values, subtelegrams containing incorrect HASH bytes have to be generated by the test setup. Such subtelegrams shall be classified by the

DUT as incorrect and the subtelegrams shall be looped back to the test setup not at all, or only with a proper notification of incorrectness.

To achieve a meaningful test result, the DUT shall classify at least a number of 1 000 subtelegrams containing correct HASH values as well as an additional minimum number of 1 000 subtelegrams containing incorrect HASH values.

8.2.2.4. Limits

The DUT shall classify all correct HASH values as correct and all incorrect HASH values as incorrect. The DUT shall discard subtelegrams with incorrect HASH values.

8.3. 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 the 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.

9. Network Layer

9.1. Certification of switch telegram functionality

The DUT manufacturer shall declare whether or not the DUT supports switch telegram functionality. Further, the manufacturer shall detail whether transmission or reception of switch telegrams is supported.

9.1.1. Transmitter supporting switch telegrams

9.1.1.1. Definition

A DUT shall be able to encode correct EnOcean frames from switch subtelegrams that contain a 4 bit RORG, one DATA byte, a four byte TXID and a 4 bit summation HASH.

9.1.1.2. Measurement conditions

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

9.1.1.3. Measurement procedure

The DUT shall encode and transmit the switch subtelegram type 1 and type 2 defined in ANNEX A (A 1.1., A 1.2.). The signal analyzer shall demodulate and decode the frames transmitted by the DUT and shall analyze the correctness of the DUT's frame structure encoding.

In addition, all feasible combination of switch subtelegram data a DUT is able to transmit shall be tested. This includes RORG 0x5 and / or 0x6 in combination with all supported values of the DATA byte – entirely to be defined by the DUT manufacturer – plus random TXID and the 4 bit summation HASH calculated according to [1]. The signal analyzer shall demodulate and decode the frames transmitted by the DUT and shall check the DUT's switch subtelegram data for correctness.

9.1.1.4. Limits

The DUT shall encode and transmit all switch subtelegrams without error.

9.1.2. Receiver supporting switch telegrams

9.1.2.1. Definition

A DUT shall be able to receive, demodulate and decode EnOcean switch frames and shall be able to convert such frames into RPS subtelegrams containing the RORG 0xF6, the original DATA byte and TXID, one STATUS byte and an 8 bit summation HASH.

9.1.2.2. Measurement conditions

The measurement shall be made under normal test conditions.

9.1.2.3. Measurement procedure

The test setup shall transmit a minimum number of 100 frames, not more than one frame each 150 ms, which are encoded from the switch subtelegrams type 1 and type 2 defined in ANNEX A (A 2.1., A 2.3.) of this document (randomly mixed, equally distributed in number). The signal generator or a reference transmitter with suitable firmware shall be set to an output level that results in a signal strength of -50.0 dBm at the input or antenna of the DUT. The DUT shall decode all switch subtelegrams, convert them into RPS subtelegrams and loop-back those to the test setup where the RPS subtelegram data is checked for correctness.

9.1.2.4. Limits

The DUT shall decode and convert all switch subtelegrams without error.

9.2. Certification of repeater functionality

The DUT manufacturer shall declare whether or not the DUT supports repeater functionality. Further, the manufacturer shall detail whether level 1 and / or level 2 repeating is supported.

For detailed information about testing of the repeater subtelegram timing, see chapter 8.1.3. (Repeater subtelegram timing).

9.2.1. Definition

A repeater is an EnOcean transceiver that receives EnOcean messages, stores them and re-transmits them within a defined period of time.

The repeater is triggered by the reception of the first EnOcean frame belonging to an EnOcean message. According to the repeater level bits of the STATUS byte and the destination address in case of an addressed transmission, the repeater re-transmits this original frame as a full EnOcean message or does not process it at all. In case of re-transmission the repeater modifies the received frame by changing the repeater level bits of the STATUS byte and by re-calculation of the HASH byte.

9.2.2. Measurement conditions

The measurement shall be made under normal test conditions.

9.2.3. Measurement procedure

The DUT shall be set either to repeater level 1 or repeater level 2 and the test described shall be repeated for each setting. The test setup shall transmit a minimum number of 400 EnOcean messages, not more than one message each 150 ms, encoded from the subtelegram and STATUS combinations defined in the table below (equally distributed in number between M01 and M40).

Message type	Subtelegram acc. to ANNEX A	STATUS Subtel. 1	STATUS Subtel. 2	STATUS Subtel. 3	DESTID
M01	4 BS type 1	0x00	0x00	0x00	None
M02	4 BS type 1	0x80	0x80	0x81	None
M03	4 BS type 1	0x00	0x01	0x00	None
M04	4 BS type 1	0x80	0x81	0x81	None
M05	4 BS type 1	0x01	0x00	0x00	None
M06	4 BS type 1	0x81	0x80	0x81	None
M07	4 BS type 1	0x01	0x01	0x00	None
M08	4 BS type 1	0x81	0x81	0x81	None
M09	4 BS type 1	0x02	0x00	0x00	None
M10	4 BS type 1	0x03	0x00	0x00	None
M11	4 BS type 1	0x04	0x00	0x00	None
M12	4 BS type 1	0x05	0x00	0x00	None
M13	4 BS type 1	0x06	0x00	0x00	None
M14	4 BS type 1	0x07	0x00	0x00	None
M15	4 BS type 1	0x08	0x00	0x00	None
M16	4 BS type 1	0x09	0x00	0x00	None
M17	4 BS type 1	0x0A	0x00	0x00	None
M18	4 BS type 1	0x0B	0x00	0x00	None
M19	4 BS type 1	0x0C	0x00	0x00	None
M20	4 BS type 1	0x0D	0x00	0x00	None
M21	4 BS type 1	0x0E	0x00	0x00	None
M22	4 BS type 1	0x0F	0x0F	0x0F	None
M23	4 BS addressed	0x00	0x00	0x00	0x00000001
M24	4 BS addressed	0x81	0x81	0x81	0x00000001
M25	4 BS addressed	0x82	0x82	0x82	0x00000001
M26	4 BS addressed	0x0F	0x0F	0x0F	0x00000001
M27	4 BS addressed	0x80	0x80	0x80	DUT EURID
M28	4 BS addressed	0x01	0x01	0x01	DUT EURID
M29	4 BS addressed	0x02	0x02	0x02	DUT EURID
M30	4 BS addressed	0x8F	0x8F	0x8F	DUT EURID
M31	Switch type 1	n.a.	n.a.	n.a.	None
M32	Switch type 2	n.a.	n.a.	n.a.	None
M33	RPS type 1	0x20	0x20	0x20	None
M34	RPS type 1	0x21	0x21	0x21	None
M35	RPS type 1	0x22	0x22	0x22	None
M36	RPS type 1	0x2F	0x2F	0x2F	None
M37	RPS type 2	0x30	0x30	0x30	None

M38	RPS type 2	0x31	0x31	0x31	None
M39	RPS type 2	0x32	0x32	0x32	None
M40	RPS type 2	0x3F	0x3F	0x3F	None

TABLE 1: Message types and STATUS bytes per subtelegram generated by the test setup.

The signal generator or a reference transmitter with suitable firmware shall be set to an output level that results in a signal strength of -85.0 dBm at the input or antenna of the DUT. The DUT shall repeat each message received as valid level 1 or level 2 repeated EnOcean message, or shall discard the message if required. The signal analyzer shall receive, demodulate and decode each repeated messages and shall validate the correctness of all repeated subtelegram data.

9.2.4. Limits of level 1 repeater functionality

A DUT supporting level 1 repeater functionality shall repeat the EnOcean message types listed in TABLE 2 below and shall set the STATUS and HASH bytes per subtelegram accordingly.

Message type	Subtelegram acc. to ANNEX A	STATUS Subtel. 1	STATUS Subtel. 1	STATUS Subtel. 1	DESTID
M01	4 BS type 1	0x01	0x01	0x01	None
M02	4 BS type 1	0x81	0x81	0x81	None
M03	4 BS type 1	0x01	0x01	0x01	None
M04	4 BS type 1	0x81	0x81	0x81	None
M05	Not repeated				
M06	Not repeated				
M07	Not repeated				
M08	Not repeated				
M09	Not repeated				
M10	Not repeated				
M11	Not repeated				
M12	Not repeated				
M13	Not repeated				
M14	Not repeated				
M15	Not repeated				
M16	Not repeated				
M17	Not repeated				
M18	Not repeated				
M19	Not repeated				
M20	Not repeated				
M21	Not repeated				
M22	Not repeated				

M23	4 BS addressed	0x1	0x1	0x1	0x00000001
M24	Not repeated				
M25	Not repeated				
M26	Not repeated				
M27 ⁵	Not repeated				
M28 ²	Not repeated				
M29 ²	Not repeated				
M30 ²	Not repeated				
M31	RPS type 1	0x21	0x21	0x21	None
M32	RPS type 2	0x31	0x31	0x31	None
M33	RPS type 1	0x21	0x21	0x21	None
M34	Not repeated				
M35	Not repeated				
M36	Not repeated				
M37	RPS type 2	0x31	0x31	0x31	None
M38	Not repeated				
M39	Not repeated				
M40	Not repeated				

TABLE 2: Message types and STATUS bytes per subtelegram repeated by a level 1 repeater.

9.2.5. Limits of level 2 repeater functionality

A DUT supporting the functionality of a level 2 repeater shall repeat the EnOcean message types listed in TABLE 2 below and shall set the STATUS and HASH bytes per subtelegram accordingly.

Message type	Subtelegram acc. to ANNEX A	STATUS Subtel. 1	STATUS Subtel. 2	STATUS Subtel. 3	DESTID
M01	4 BS type 1	0x01	0x01	0x01	None
M02	4 BS type 1	0x81	0x81	0x81	None
M03	4 BS type 1	0x01	0x01	0x01	None
M04	4 BS type 1	0x81	0x81	0x81	None
M05	4 BS type 1	0x02	0x02	0x02	None
M06	4 BS type 1	0x82	0x82	0x82	None
M07	4 BS type 1	0x02	0x02	0x02	None
M08	4 BS type 1	0x82	0x82	0x82	None

⁵ The ISO 14543-3-10 standard [1] does not specify how an EnOcean message addressed to a repeater shall be handled by this repeater. The recommendation is, that such a message will not be repeated, but devices which repeat them will also pass the test.

M09	Not repeated				
M10	Not repeated				
M11	Not repeated				
M12	Not repeated				
M13	Not repeated				
M14	Not repeated				
M15	Not repeated				
M16	Not repeated				
M17	Not repeated				
M18	Not repeated				
M19	Not repeated				
M20	Not repeated				
M21	Not repeated				
M22	Not repeated				
M23	4 BS addressed	0x01	0x01	0x01	0x00000001
M24	4 BS addressed	0x82	0x82	0x82	0x00000001
M25	Not repeated				
M26	Not repeated				
M27 ⁶	Not repeated				
M28 ³	Not repeated				
M29 ³	Not repeated				
M30 ³	Not repeated				
M31	RPS type 1	0x21	0x21	0x21	None
M32	RPS type 2	0x31	0x31	0x31	None
M33	RPS type 1	0x21	0x21	0x21	None
M34	RPS type 1	0x22	0x22	0x22	None
M35	Not repeated				
M36	Not repeated				
M37	RPS type 2	0x31	0x31	0x31	None
M38	RPS type 2	0x32	0x32	0x32	None
M39	Not repeated				
M40	Not repeated				

TABLE 3: Message types and STATUS bytes per subtelegram repeated by a level 2 repeater.

⁶ The ISO 14543-3-10 standard [1] does not specify how an EnOcean message addressed to a repeater shall be handled by this repeater. The recommendation is, that such a message will not be repeated, but devices which repeat them will also pass the test.

9.3. Certification of addressing functionality

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

9.3.1. Transmitter supporting addressing functionality

9.3.1.1. Definition

A transmitter supporting addressing functionality encapsulates an EnOcean subtelegram to be addressed into an EnOcean subtelegram that uses a specific RORG and adds the destination address of the target receiver.

9.3.1.2. Measurement conditions

The measurement shall be made under normal test conditions.

9.3.1.3. Measurement procedure

The test setup shall generate a minimum number of 100 4BS subtelegrams of type 3 as defined in Annex A (A 1.3.), 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.

9.3.1.4. Limits

The DUT shall encode all addressed subtelegrams using RORG 0xA6 and shall place the destination addresses correctly between DATA and TXID of the original subtelegram to be addressed.

9.3.2. Receiver supporting addressing functionality

9.3.2.1. Definition

A receiver supporting addressing functionality receives encapsulated 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.

9.3.2.2. Measurement

The measurement shall be made under normal test conditions.

The signal generator or a reference transmitter with suitable firmware shall transmit a minimum number of 100 addressed subtelegrams (4BS subtelegram type 3, A 1.3.).

For 10% of the addressed subtelegrams, the address 0x1F2F3F4F shall be replaced with the EURID of the DUT. For the remaining 90 %, the address 0x1F2F3F4F shall be replaced with a random destination addresses.

The signal generator or a reference transmitter with suitable firmware shall be set to an output level that results in -50.0 dBm signal strength at the input or antenna of the DUT.

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 stripped down to the encapsulated subtelegram data and those shall be looped-back to the test setup where this data is compared to the original 4BS subtelegram data sent by the signal generator.

9.3.2.3. Limits

The DUT shall discard all addressed subtelegrams with destination addresses different from its own EURID and shall strip down correctly all subtelegrams addressed to such EURID.

9.4. Certification of Secure Low Power switch telegram functionality

The DUT manufacturer shall declare whether or not the DUT supports secure low power switch telegram functionality. Further, the manufacturer shall detail whether transmission or reception of switch telegrams is supported.

9.4.1. Transmitter supporting switch telegrams

For a transmitter it is only allowed to support secure low power switch telegrams when the DUT is at least enabled to be fully powered by Energy Harvesting. It is then allowed that the final product is battery powered.

9.4.1.1. Definition

A DUT shall be able to encode correct EnOcean frames from secure low power switch subtelegrams that contain a one byte RORG, 4 bits of DATA, a three byte CMAC, a three byte TXID and a 4 bit summation HASH.

9.4.1.2. Measurement conditions

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

9.4.1.3. Measurement procedure

The DUT shall encode and transmit the secure switch subtelegram type 1 and type 2 defined in ANNEX A (1. A 3.1. 1. A 3.3. 1. A 3.1.) The signal analyzer shall demodulate and decode the frames transmitted by the DUT and shall analyze the correctness of the DUT's frame structure encoding.

In addition, all feasible combination of secure low power switch subtelegram data a DUT is able to transmit shall be tested. This includes a combination with all supported values of the DATA byte – entirely to be defined by the DUT manufacturer – plus random TXID and the 4 bit summation HASH calculated according to [1]. The public key and the RLC shall be random. The

signal analyzer shall demodulate and decode the frames transmitted by the DUT and shall check the DUT's secure low power switch subtelegram data for correctness.

9.4.1.4. Limits

The DUT shall encode and transmit all low power switch subtelegrams without error.

9.4.2. Receiver supporting secure low power switch telegrams

9.4.2.1. Definition

A DUT shall be able to receive, demodulate and decode EnOcean secure low power switch frames and shall be able to convert such frames into secure subtelegrams containing the RORG 0x30, the original DATA byte and CMAC, extend the three bytes TXID by the MSB 0xFE, one STATUS byte and an 8 bit summation HASH.

9.4.2.2. Measurement conditions

The measurement shall be made under normal test conditions.

9.4.2.3. Measurement procedure

The test setup shall transmit a minimum number of 100 frames, not more than one frame each 150 ms, which are encoded from the secure low power switch subtelegrams type 1 and type 2 defined in ANNEX A (1. A 3.1. 1. A 3.3. of this document (randomly mixed, equally distributed in number). The signal generator or a reference transmitter with suitable firmware shall be set to an output level that results in a signal strength of -50.0 dBm at the input or antenna of the DUT. The DUT shall decode all secure low power switch subtelegrams, convert them into secure subtelegrams and loop-back those to the test setup where the secure subtelegram data is checked for correctness.

9.4.2.4. Limits

The DUT shall decode and convert all secure low power switch subtelegrams without error.

10. 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 Subtelegrams used for Testing

A 1. 4BS subtelegram

A 1.1. 4BS subtelegram type 1

The 4BS subtelegram type 1 shall be defined as following:

RORG: 0x A5
DATA: 0x FF FF D2 D2
TXID: 0x 49 1C 1C 00
STATUS: 0x 00
HASH: 0x C8

Subtelegram data results as following: 0x A5 FF FF D2 D2 49 1C 1C 00 00 C8

Encoding this subtelegram data into an EnOcean frame results in the following bit stream, with a total length of 146 bits:

```
10101010 10011010 00100101 11101110 11011110 11101101 11011001 10011101
10011001 01010101 01010001 11100001 00011110 00010001 00010001 00010001
00011101 01010010 11
```

The meaning of the color-coding is as following:

PRE SOF / SYNC / EOF INV

A 1.2. 4BS subtelegram type 2

The 4BS subtelegram type 2 differs from the 4BS subtelegram type 1 (A 1.1.) only by one single bit in the least significant nibble of the DATA bytes:

RORG: 0x A5
DATA: 0x FF FF D2 D0
TXID: 0x 49 1C 1C 00
STATUS: 0x 00
HASH: 0x C6

Subtelegram data results as following: 0x A5 FF FF D2 D0 49 1C 1C 00 00 C6

Encoding this subtelegram data into an EnOcean frame results in the following bit stream, with a total length of 146 bits:

```
10101010 10011010 00100101 11101110 11011110 11101101 11011001 10011101
10011001 01010101 01010001 11100001 00011110 00010001 00010001 00010001
00011101 00101010 11
```

The meaning of the color-coding is as following:

PRE **SOF / SYNC / EOF** **INV**

A 1.3. 4BS subtelegram type 3 (addressed)

The 4BS subtelegram type 1 defined above is encapsulated for addressing purposes:

RORG_ADT: 0x A6
RORG: 0x A5
DATA: 0x FF FF D2 D2
DESTID: 0x F1 F2 F3 F4 (Different DESTID might be used depending on the test case)
TXID: 0x 49 1C 1C 00
STATUS: 0x 00
HASH: 0x 44

Subtelegram data results as following: 0x A6 A5 FF FF D2 D2 F1 F2 F3 F4 49 1C 1C 00 00 44

Encoding this subtelegram data into an EnOcean frame results in the following bit stream, with a total length of 146 bits:

```
10101010 10011010 00101001 10100010 01011110 11101101 11101110 11011101
10011001 11011001 10011110 10010101 11101001 10011110 10011101 11101010
00010101 01010101 00011110 00010001 11100001 00010001 00010001 00010001
01010010 001011
```

The meaning of the color-coding is as following:

PRE **SOF / SYNC / EOF** **INV**

A 1.4. 4BS subtelegram type 4

The 4BS subtelegram type 4 can be used alternatively to type 1 and 2, and shall be defined as following:

RORG: 0x A5
DATA: 0x 00 00 00 00
TXID: 0x 49 49 49 A5
STATUS: 0x 00
HASH: 0x 48

Subtelegram data results as following: 0x A5 00 00 00 00 49 49 49 A5 00 48

Encoding this subtelegram data into an EnOcean frame results in the following bit stream, with a total length of 146 bits:

```
10101010 10011010 00101001 00010001 00010001 00010001 00010001 00010001
00010001 01010101 01010101 01010101 01010101 01010101 00010101 00010001
00010101 01010011
```

The meaning of the color-coding is as following:

PRE **SOF / SYNC / EOF** **INV**

A 2. Switch and related RPS subtelegram

A 2.1. Switch subtelegram type 1

The switch subtelegram type 1 represents a rocker pushbutton switch at release time. The data is send at the release when simultaneously zero or more than two buttons are activated:

RORG: 0x 5
DATA: 0x 00
TXID: 0x 49 4C 4C 00
HASH: 0x 2

Subtelegram data results as following: 0x 50 04 94 C4 C0 02

Encoding this subtelegram data into an EnOcean frame results in the following bit stream, with a total length of 86 bits:

10101010 10010101 10010001 00010010 00010011 10100001 11010010 00011101
00010001 00010001 101011

The meaning of the color-coding is as following:

PRE **SOF / SYNC / EOF** **INV**

A 2.2. RPS subtelegram type 1

The RPS subtelegram type 1 results from the conversion of the SWITCH subtelegram type 1 (A 2.1.) into a subtelegram containing the 8 bit RORG 0x F6, a STATUS byte and an 8 bit HASH:

RORG: 0x F6
DATA: 0x 00
TXID: 0x 49 4C 4C 00
STATUS: 0x 20
HASH: 0x F7

Subtelegram data results as following: 0x F6 00 49 4C 4C 00 20 F7

A 2.3. Switch subtelegram type 2

The switch subtelegram type 2 represents a rocker pushbutton switch at which either one or two buttons are pressed:

RORG: 0x 6
DATA: 0x 30
TXID: 0x 49 4C 4C 00
HASH: 0x 6

Subtelegram data results as following: 0x 63 04 94 C4 C0 06

Encoding this subtelegram data into an EnOcean frame results in the following bit stream, with a total length of 86 bits:

10101010 10010110 00011101 00010010 00011001 10100001 11010010 00011101
00010001 00010010 101011

The meaning of the color-coding is as following:

PRE SOF / SYNC / EOF INV

A 2.4. RPS subtelegram type 2

The RPS subtelegram type 2 results from the conversion of the SWITCH subtelegram type 2 (A2.3.) into a subtelegram containing the 8 bit RORG 0x F6, a STATUS byte and an 8 bit HASH:

RORG: 0x F6
DATA: 0x 30
TXID: 0x 49 4C 4C 00
STATUS: 0x 30
HASH: 0x 37

Subtelegram data results as following: 0x F6 30 49 4C 4C 00 30 37

A 3. Secure Low Power Switch and related Secure subtelegram

A 3.1. Secure Low Power Switch subtelegram type 1

The secure low power switch subtelegram type 1 represents a rocker pushbutton switch at which none buttons are pressed and the energy bow is pressed:

SLF: 0x4B
Public key: E0 C7 D6 12 8C 93 B6 91 83 A8 BC CB 00 A8 70 14
Rolling code: 0x B0 6C
CMAC: 0x 9C 84 10
RORG: 0x 7F
DATA: 0x 9 (encoded)
TXID: 0x FF FE B8
HASH: 0x 3

Encoded subtelegram data results as following: 0x 7F 99 C8 41 0F FF EB 83

Encoding this subtelegram data into an EnOcean frame results in the following bit stream, with a total length of 110 bits:

10101010 10010110 11101101 10011101 10101110 10101000 01010100 01000101 010001
01101101 11101110 11011101 11100101 11101001 00011110 111011

The meaning of the color-coding is as following:

PRE SOF / SYNC / EOF INV

A 3.2. Secure subtelegram type 1

The secure subtelegram type 1 results from the conversion of the Secure Low Power Switch subtelegram type 1 (A 3.1.) into a subtelegram containing the 8 bit RORG 0x 30, 8 bit DATA, 24 bit CMAC, 32 bit TXID, a STATUS byte and an 8 bit HASH:

RORG: 0x 30
DATA: 0x 09 (encoded)
CMAC: 0x 9C 84 10
TXID: 0x FE FF FE B8
STATUS: 0x 00
HASH: 0x 1C

Encoded subtelegram data results as following: 0x 30 09 9C 84 10 FE FF FE B8 00 1C

After decrypting it becomes a Decrypted Security Message:

RORG: 0x 32
DATA: 0x 08
TXID: 0x FE FF FE B8
STATUS: 0x 00
HASH: 0x ED

Decoded subtelegram data results as following: 0x 32 08 FE FF FE B8 00 ED

A 3.3. Secure Low Power Switch subtelegram type 2

The secure subtelegram type 2 represents a rocker pushbutton switch at which the energy bow was released:

SLF: 0x4B
Public key: 0x E0 C7 D6 12 8C 93 B6 91 83 A8 BC CB 00 A8 70 14
Rolling code: 0x B0 6D
CMAC: 0x DD 9E 48
RORG: 0x 7F
DATA: 0x F

TXID: 0x FF FE B8

HASH: 0x 5

Encoded Subtelegram data results as following: 0x 7F FD D9 E4 8F FF EB 85

Encoding this subtelegram data into an EnOcean frame results in the following bit stream, with a total length of 110 bits:

10101010 10010110 11101101 11101110 01011101 11010101 11100010 00011001
01101101 11101110 11011100 10100110 01001011

The meaning of the color-coding is as following:

PRE SOF / SYNC / EOF INV

A 3.4. Secure subtelegram type 2

The secure subtelegram type 2 results from the conversion of the Secure Low Power Switch subtelegram type 2 (A 3.3.) into a subtelegram containing the 8 bit RORG 0x 30, 8 bit DATA, 24 bit CMAC, 32 bit TXID, a STATUS byte and an 8 bit HASH:

RORG: 0x 30

DATA: 0x 0F (encoded)

CMAC: 0x DD 9E 48

TXID: 0x FE FF FE B8

STATUS: 0x 00

HASH: 0x B5

Encoded subtelegram data results as following: 0x 30 0F DD 9E 48 FE FF FE B8 00 B5

After decrypting it becomes a Decrypted Security Message:

RORG: 0x 32

DATA: 0x 0F (decoded)

TXID: 0x FE FF FE B8

STATUS: 0x 00

HASH: 0x F4

Decoded subtelegram data results as following: 0x 32 0F FE FF FE B8 00 F4

A 4. End of Frame (EOF) usage

Even though in [1] EOF is defined as 0b1011, for the purpose of the EnOcean Air Interface Certification a DUT shall be allowed to end a frame transmission using an alternative 0b10 or 0b101111 bit sequence.

This is due to limitations that may arise from hardware that only is capable of transmitting bit streams that are multiples of 8 bits as well as from energy constraints of self-powered energy harvesting devices.