System Specification

EnOcean Alliance Certification Specification, part 4
Energy Harvesting
V 1.0, preliminary

Approved for release: June 12th 2018

San Ramon, CA, USA, Apr 09, 2018

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-powered devices

This document specifies part (4) *Energy Harvesting of self-supplied devices* which is a mandatory part for energy harvesting devices of the *EnOcean Certification Program*. It aims to standardize definition and test of key parameters of energy harvesting systems.

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 *Energy Harvesting Certification Specification* is now in the status PRELIMINARY for a "proof-of-concept" period. During a period of nine months it is expected to observe and test first applications of the *Energy Harvesting Certification Specification* at member companies of the EnOcean Alliance. The main aim is to discover hidden issues/bugs of the concept of *Energy Harvesting Certification* and receive feedback on its applicability during product implementation process. This specification would then be modified by the team according to this feedback. At that time we would welcome additional change requests which might affect existing implementations.

After this period the *Energy Harvesting Certification Specification* will be submitted to the TWG and BoD for final approval (i.e. planned March 2019). After final approval the restriction PRELIMINARY will be removed.

From then on changes have to be proposed to the TWG for decision. The EnOcean Certification Task Group will then act upon request by the TWG.

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REVISION HISTORY

Ver.	Editor	Change	Date
0.1	AP	Draft Document created, based on template of the EnOcean Alliance, text complete	Aug 10, 2017
0.2	MKA	Rework based on review with AP	Oct 18, 2017
0.3	MKA	Addressed review comments from EnOcean GmbH	Oct 19, 2017
0.4	AP	Minor changes and update the dates etc.	Apr 09, 2018
1.0	AP	Minor changes after TWG review Disclaimer added Dates actualized, correction of typos	May 14, 2018 June 29, 2018

The EnOcean Alliance “Energy Harvesting Certification Specification” is available free of charge to companies, individuals and institutions for all non-commercial purposes (including educational research, technical evaluation and development of non-commercial tools or documentation.)

This specification includes intellectual property („IPR“) of the EnOcean Alliance and joint intellectual properties („joint IPR“) with contributing member companies. No part of this specification may be used in development of a product or service for sale without being a participant or promoter member of the EnOcean Alliance and/or joint owner of the appropriate joint IPR.

These errata may not have been subjected to an Intellectual Property review, and as such, may contain undeclared Necessary Claims.

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1. Introduction and Motivation

1.1. General

System planers, system-integrators and users demand reliable devices and procedures which facilitate the implementation of versatile solutions with an increasing offer of use cases of EnOcean technology. The EnOcean Alliance Certification Program – linked with a corresponding marking on devices – is THE tool for the EnOcean Alliance to secure interoperability of EnOcean-based devices.

It covers all elements of the communication adequately defined. The primary objective of the EnOcean Alliance Certification Program is a self-declaration of the device manufacturer, similar to the European CE-declaration. As a part of the program an extension for a supplementary verification by an independent and accredited test laboratory is foreseen straight from the beginning.

At the same time the Certification Program is a guideline for the product development process, supporting the development based product quality and thus the desired product interoperability.

The "EnOcean Alliance Energy Harvesting Certification Specification" – this document – amends part 1 to 3 of the Certification Program by providing clear, standardized definitions and validation procedures for key parameters related to energy harvesting applications in general and self-powered devices in particular.

In combination with an adequate product labelling - in particular within a continuously growing market of suppliers and products - planers, system integrators, and users can identify reliably EnOcean-based devices interoperating with each other.

1.2. Approach

The document is structured in the following sequence:

- Definition of key terms and parameters
- Definition of energy-harvesting scenarios
- Definition of test procedures

The energy harvesting certification will be based on the specific use case addressed by the product that will be certified. It is therefore neither intended nor feasible to define specific limits or use cases. Rather, the focus is on:

- Standardizing and harmonizing the language applied to describe energy harvesting devices
- Definition of clear and simple test scenarios which deliver relevant guidance on the application-specific energy harvesting performance of the device
- Transparency on devices offered by members of the EnOcean Alliance

This specification will start with the minimum subset of application and tests and might be extended according to future needs.

1.3. Objective

A properly designed and implemented energy concept is a pre-requisite for a stable operation of a self-powered, energy-harvesting device over its lifetime. As such, it is in the interest of the EnOcean Alliance and its members to objectively define and validate the performance of such devices.

The *Energy Harvesting Certification* supports this goal as it will provide transparent and standardized information while at the same time taking into account the wide range of innovative products available today and in the future.

1.4. Definitions

This chapter aims to establish clear and unambiguous definitions for key terms specifically related to energy harvesting devices.

Ambient energy
Energy that is available in the environment, e.g. kinetic energy, light, thermal energy and can be used by the device for its operation.

Autonomy
Period of time for which a self-powered device might operate in absence of available ambient energy based on previously harvested energy when its energy storage is fully charged. Commonly also called dark-time for the specific case of solar-powered devices.

Back-up battery
Power source that is used if the actual energy availability is below the required energy availability, e.g. if a solar sensor is used in a darkend room

Energy accumulation
Process by which small amounts of energy are collected in a suitable storage element (typically a capacitor) until the required amount for one operation cycle is reached. The storage element is sometimes also called Short Term Storage.

Energy for balance
Amount of energy required for the device to maintain the same energy level of its internal energy storage (if present) while executing its standard use case

Energy for full charge
Amount of energy required to fully charge its internal energy storage (if present) while the device is executing its standard use case

Energy for start-up
Amount of energy required for the device to execute its standard use case for the first time after its internal energy storage (if present) was fully discharged

Energy harvesting
Collection and - if required - conversion and accumulation of available ambient energy for the purpose of supplying a self-powered device

Energy storage
Storage of harvested energy in a suitable storage element (typically a supercapacitor or a secondary battery) to ensure operation for a limited period of time (Autonomy) without available ambient energy. The storage element is sometimes also called Long Term Storage.

Minimum discharge level

Lowest energy level to which the energy storage can be discharged during operation of the device without causing damage

Self-powered device

Device where all energy required for the execution of its use case is provided by energy harvesting.

Standard use case

Reference usage and operation model of the device specified by the manufacturer. This model should be representative for the most common use of the device.

Test acceleration

Testing using modified use case or ambient energy scenarios in order to yield shorter test times

1.5. *References*

[1] EnOcean Certification Specification, part 1, Air Interface, EnOcean Alliance (1a/1b)
http://portal.enocean-alliance.org/DesktopModules/Inventures_Document/FileDownload.aspx?ContentID=21634

[2] EnOcean Certification Specification, part 2, Radio Performance, EnOcean Alliance
http://portal.enocean-alliance.org/DesktopModules/Inventures_Document/FileDownload.aspx?ContentID=21600

[3] EnOcean Certification Specification, part 3, Communication Profiles, EnOcean Alliance
http://portal.enocean-alliance.org/DesktopModules/Inventures_Document/FileDownload.aspx?ContentID=21608

[4] EnOcean Certification Handbook, EnOcean Alliance

2. Description of energy harvesting systems

This chapter will describe key characteristics of energy-harvesting systems and categorize them as necessary for the purpose of certification.

2.1. Self-powered devices

Self-powered devices are defined by their ability to operate (execute the defined use case) solely based on ambient energy, i.e. energy that is naturally present in the environment for which the device was designed.

The process of converting ambient energy into energy that is usable for powering the device is called energy harvesting. Self-powered devices are therefore sometimes also called energy-harvesting devices.

Two important criteria that have to be met to qualify as self-powered (energy-harvesting) device:

1. The device must be able to execute its defined use case without the need for an additional power source (e.g. battery) based on ambient energy, i.e. the energy present in the environment for which it is specified.

2. The energy source must be present independent of the energy-harvesting devices, i.e. no dedicated energy source has to be installed into the environment in order to supply an energy-harvesting device.

Both criteria have to be met in order to qualify as self-powered energy-harvesting device.

If a device is not functional without back-up battery when its required ambient energy is available then it cannot be considered to be an energy-harvesting (self-powered) device.

Back-up batteries might be used for the case that the available ambient energy is less than required ambient energy, e.g. if a solar-powered sensor is used in a darkend room.

Likewise, a device that is powered by means of a dedicated power source that would not be normally present (e.g. a wireless charger) cannot be considered to be an energy-harvesting (self-powered) device either.

2.2. Ambient energy

Ambient energy is typically characterized by amount of available energy which can be converted via energy-harvesting. Ambient energy is often specified by indirectly, i.e. the actual amount of usable power is not given.

Example of such ambient energy specification:

- Solar harvesting: Illumination of 200 lux
  Note that this is an indirect specification – the actual available energy depends on the spectral distribution of the light source

- Thermal harvesting: Temperature gradient of 10 Kelvin
  Note that this is an indirect specification – the actual energy depends on the mass and the thermal constant

- Kinetic harvesting
  One lateral movement with 10 N force and 2 mm travel

Type and amount of ambient energy is not defined or constrained by this specification.

It is the responsibility of the manufacturer to properly define the ambient energy and to ensure that this definition meets the intended use case and is plausible. Appendix B gives typical values for the case of solar harvesting.

In most cases, the harvested energy is accumulated into a suitable device (typically a capacitor) until the required amount of energy for one operation cycle has been collected.

2.3. Energy accumulation

Self-powered devices might include an energy storage element to be able to accumulate small amounts of energy into a larger amount which is sufficient to supply the device during its operation.

For instance, solar-powered sensors might accumulate the energy delivered by the solar cell into a capacitor of sufficient size to supply the device during one measurement and transmission cycle.

Energy accumulation is a device design topic and therefore not in scope of this specification. This specification is concerned with the required amount of energy (e.g. 200 lux for 60 seconds or 10 N for 1mm of travel) but not with the question how this energy is collected.

2.4. Energy storage

Self-powered devices might include an energy storage element (in addition to the accumulation mechanism described above).

Those devices are characterized by their ability to operate in absence of ambient energy. Common examples include the operation of solar powered sensors during the night or of thermal powered heating valves outside of the heating period.

Note that specific harvesting mechanisms do not necessarily imply the need for energy storage. Solar-powered sensors for instance can be intentionally built to be operational only if ambient light is available. Likewise, a thermal sensor might be designed to be active only in case of overheating. In both cases energy storage is not required.

This certification defines testing procedures to measure the energy storage capability of a self-powered device – if applicable – since the aspect of operation without ambient energy is a common requirement.

2.5. Standard use case

Self-powered devices are characterized by their ability to function based on energy harvesting. The exact meaning of “function” in the sentence above is defined by a standard use case which represents a model for the device operation. This use case has to be defined by the manufacturer and is subsequently used to test the energy harvesting functionality.

For instance, consider the case of a self-powered window sensor. The manufacturer might define a standard use case where the window is opened four times per hour and every time a specified event telegram is sent. In addition, once per hour a telegram will be sent even if the window was not opened (heartbeat telegram).

Note that individual devices can support a multitude of use cases – if the same sensor was mounted onto the entrance door of a shop then the use case could be totally different since the door might be opened every 5 seconds.

The specified standard use case might be constrained by available energy, i.e. it might apply only if energy is available. Taking the example of a kinetic switch without energy storage, the use case (e.g. transmission of 3 subtelegrams) applies only if energy is available (push or release of the switch).

2.6. Test acceleration

Self-powered devices might have ambient energy or use standard use case scenarios that would lead to very long test times. This case can be illustrated by considering a self-powered heating valve.

One possible scenario for a self-powered heating valve could be as follows:

- Ambient energy
  Thermal gradient of 10 K which is available during a period of 3.5 month per year (heating period) for 12 hours per day

- Standard use case
  Heating valve measures temperature and transmits status as 4BS telegram with +5 dBm output power every 14 minutes
  Heating valve fully opens or closes 10 times a day during a period of 4 months per year
  Heating valve fully opens or closes 1 time per week during a period of 8 months per year

- Autonomy
  8 months (from the end of the last heating period until the start of the next heating period)

From above, it can be seen that testing based on the actual ambient energy and the actual use case would lead to very long test times (one year in this case) which might not be practical.

Test acceleration seeks to shorten the test time by using different ambient energy and use case scenarios which yield a shorter test time while at the same time providing a test result from which the behavior under the specified conditions can be derived.

Taking the case described above, test acceleration could seek to shorten the autonomy test time by increasing the energy demand during the autonomy period as follows:

- Heating valve fully opens or closes 1 time per day
- Heating valve measures temperature and transmits status as 4BS telegram with +5 dBm output power every 2 minutes

This approach would increase the energy demand for the most energy-consuming activities (measurement, transmission, heating valve actuation) by factor 7. The overall energy consumption might however not be increasing exactly by this factor due to possible additional energy consuming mechanisms in the system (e.g. leakage) that were not affected by this parameter change.

For the same case described above, test acceleration could also seek to shorten the test time for charging of the energy store by increasing the energy demand supply during the heating period as follows:

- Ambient energy
  Thermal gradient of 70 K which is available during a period of 0.25 month per year (heating period) for 24 hours per day

Here it might be expected that this approach should yield the same amount of harvested energy compared to the original ambient energy scenario. This would however not be true since the decreased harvesting period means that less energy is consumed for the device operation (measurement, transmission, valve actuation). It also has to be considered that the efficiency of thermal harvesting system is typically lower for smaller temperature gradients.

Care therefore has to be taken in the development of accelerated testing strategies since the relations between different parameters are often not linear.

If test acceleration is used then the acceleration strategy that was used has to be described as part of the test documentation.

3. Certification of self-powered devices

3.1. General considerations

All self-powered devices are characterized by their ability to execute their defined use case if the required amount of ambient energy is present. Certification of self-powered devices therefore always tests this basic ability.

Additional – and more complex – testing is required if the device contains energy storage to enable operation in absence of usable ambient energy. Different testing procedures are therefore defined for self-powered devices without energy storage and for self-powered devices with energy storage.

3.2. Testing for self-powered devices without energy storage

Self-powered devices without energy storage operate only if the ambient energy which they harvest is present.

The most obvious examples are kinetic switches which operate only when they are actuated. As discussed previously, also solar-harvesting or thermal-harvesting devices might not always contain an energy storage mechanism and therefore only operate if their energy source is present.

Self-powered devices without energy storage can be tested in a simple and straight-forward way by providing the required amount of ambient energy and checking if the defined standard use case is executed.

3.2.1. Input data

For each self-powered device without energy storage, the manufacturer shall provide the following data:

(1) Required type and amount of ambient energy

(2) Standard use case executed by the device during test

The items above shall be included in the device documentation (datasheet / user manual).

3.2.2. Test execution

Testing is suggested to be executed as follows:

(1) The defined amount and type of ambient energy is provided

(2) The execution of the standard use case is validated

It is up to the manufacturer to define and execute specific aspects of this testing as long as the required parameters are properly verified.

3.2.3. Test documentation

Test documentation shall contain be provided containing at a minimum the following items:

(1) Required type and amount of ambient energy

(2) Standard use case executed by the device during test

(3) Test approach (description of how the test was executed, description of test acceleration strategies if applicable)

(4) Test results (pass / no pass)

3.2.4. Example

The subsequent chapter gives a simple example of a test procedure for a self-powered kinetic switch without energy storage. This example is intended as guidance only.

3.2.4.1. Input data

The following data might be provided for a kinetic switch by the manufacturer:

(1) Standard use case
- Transmission of 3 RPS subtelegrams with 4 dBm output power

(2) Required type and amount of ambient energy
- Type: Kinetic energy
- Amount: 10 N x 2 mm

It shall be checked that the parameters above are documented in the device documentation (datasheet, user manual).

3.2.4.2. Test execution

Testing for the kinetic switch without energy storage could be performed as follows:

1. Insert the switch into a force-travel measurement system

2. Execute 2 mm of travel

3. Validate that the force does not exceed 10 N

4. Check that the use case is correctly executed (based on the received telegrams)

3.3. Testing for self-powered devices with energy storage

Self-powered devices with energy storage can operate also in absence of the ambient energy which they harvest.

The most obvious examples are solar-powered or thermal-powered sensor devices which operate also if their power source (light, temperature gradient) is temporarily not available (e.g. during the night).

Testing of such devices is more complex compared to devices without energy storage due to the additional parameters to be considered.

3.3.1. Input data

For self-powered device with energy storage to be certified, the manufacturer shall provide the following data:

(1) Standard use case

(2) Required type and amount of ambient energy for start-up (Energy for start-up)

(3) Required type and amount of ambient energy to fully charge the device (Energy for full charge)

(4) Required type and amount of ambient energy to execute its use case (Energy for balance)

(5) Autonomy

It shall be checked that the parameters above are documented in the device documentation (datasheet, user manual).

3.3.2. Execution

Testing is suggested to be executed as follows:

1. The energy storage of the device is fully discharged.
   For devices where full discharge is technically not possible (e.g. if the energy storage element would become damaged), the energy storage shall be discharged to its lowest possible level (as specified by the manufacturer).

2. The defined amount and type of ambient energy for start-up (Energy for start-up) is provided to the device

3. Execution of the standard use case is verified (verification that the device has started up correctly)

4. The difference between energy for full charge and energy for start-up is provided to the device while it is executing its standard use case

5. Ambient energy is cut off, the device keeps executing its standard use case and autonomy is measured as the time between the first and the last execution of the standard use case

6. After the device stopped execution, ambient energy shall again be provided to it until it restarts operation. Energy for balance shall then be applied to verify that the device maintains operation over a sufficiently long period of time

It is up to the manufacturer to define and execute specific aspects of this testing as long as the required parameters are properly verified.

3.3.3. Documentation

Test documentation for the test of self-powered devices with energy storage shall contain the following items:

(1) Standard use case

(2) Type of ambient energy

(3) Amount of energy for start-up

(4) Amount of energy for full charge

(5) Amount of energy for balance

(6) Autonomy

(7) Test approach (description of how the test was executed, description of test acceleration strategies if applicable)

(8) Minimum energy levels that were used for the energy storage element (if the energy storage element could not be fully discharged)

(9) Test results (pass / no pass)

3.3.4. Example

This chapter gives a simple example of a test procedure for a self-powered window sensor with energy storage and is intended as guidance only.

3.3.4.1. Input data

The following performance data might be provided for the self-powered window sensor with energy storage by the manufacturer:

(1) Standard use case
- Four events per hour which are transmitted using three subtelegrams of type 4BS with +5dBm output power.
- Additionally one heartbeat telegram per hour transmitted using three subtelegrams of type 4BS with +5dBm output power.

(2) Required type and amount of ambient energy for start-up (Energy for start-up)
- 2 minutes of illumination with 1000 lux

(3) Required type and amount of ambient energy to fully charge the device (Energy for full charge)
- 6 hours of illumination with 1000 lux

(4) Required type and amount of ambient energy to execute its use case (Energy for balance)
- 6 hours of illumination with 200 lux

(5) Autonomy
- 4 days

The parameters above should be documented in the device documentation (datasheet, user manual).

Additionally, the manufacturer might provide the following information:

(6) Minimum discharge level for the energy storage element
- 1.8V

3.3.4.2. Test execution

Testing could be performed for this device as follows:

1. Discharge the energy storage of the device to the minimum possible voltage of 1.8V

2. Expose the device to 1000 lux of illumination for 2 minutes, then cover the solar cell

3. Trigger an event (by changing the state of the window sensor) and check that the device reports this event using three subtelegrams of type 4BS with +5dBm output power.

4. Remove the cover from the solar cell and expose the device to 1000 lux of illumination for 6 hours while triggering state changes of the window sensor every 15 minutes. Verify that the state changes are reported and heartbeat telegrams are sent every hour.

5. Note the time, cover the solar cell and continue to trigger state changes of the window sensor every 15 minutes. Verify that the state changes are reported and heartbeat telegrams are sent every hour. Continue until the device stops execution (no telegram received when upon state change of the window sensor). Note the time and calculate autonomy as interval from the time the solar cell was covered until the device stopped execution

6. Apply 1000 lux until device starts execution again (as evidenced by received telegrams).

7. Repeat a sequence of applying 200 lux for 6 hours and covering the solar cell for 18 hours for a sufficiently long period (e.g. 10 days). During that time, trigger state changes of the window sensor every 15 minutes. Verify that the state changes are reported and heartbeat telegrams are sent every hour.

Document each test step and list the results. Document also the fact that the minimum discharge level of 1.8V was used for testing.

Annex A: Typical values, tables

A1 Typical values of illumination at typical environments

This list of illumination values is supposed to support the assessment of typical environments. The given numbers are reference values only. Please use an illuminometer (lux meter) to verify a particular case.

Illumination Area	Type Destination / Workspace	Typical Brightness
Home	Usually	100 – 500 lx
Schools	Corridor	100 – 300 lx
	Classroom in general	300 – 750 lx
	Reading room, laboratory	500 – 1,500 lx
Offices	PC room, working at PC	200 – 500 lx
	Meeting room	300 – 700 lx
	Canteen	150 – 300 lx
	Corridors	50 – 100 lx
	Reception	300 – 700 lx
	Restroom	100 – 300 lx
Factories	Production hall	500 – 1,500 lx
	Development, office	300 – 750 lx
	Design CAD	500 – 1,500 lx
	Laboratory, inspection work	750 – 1,500 lx
	Packaging of products	150 – 500 lx
	Storage	100 – 300 lx
Hospitals	Visitor room	300 – 500 lx
	First aid, surgery	500 – 1,500 lx
	Bedroom	100 – 300 lx
	Pharmacies	500 – 1,000 lx
	Wash rooms	150 – 300 lx
Hotels	Reception	200 – 500 lx
	Entrance area	100 – 300 lx
	Restaurant	150 – 300 lx
	Restroom	100 – 300 lx
	Bars	50 – 150 lx
	Corridors	50 – 100 lx
	Staircases	50 – 150 lx
Stores	Sale room	300 – 1,000 lx
	Show room	500 – 1,500 lx
	Packaging area	500 – 1,500 lx
	Lounge	300 – 500 lx
	Conference room	300 – 700 lx
Trade show	Booth	300 – 500 lx
Sports arena	Indoor area	200 – 500 lx