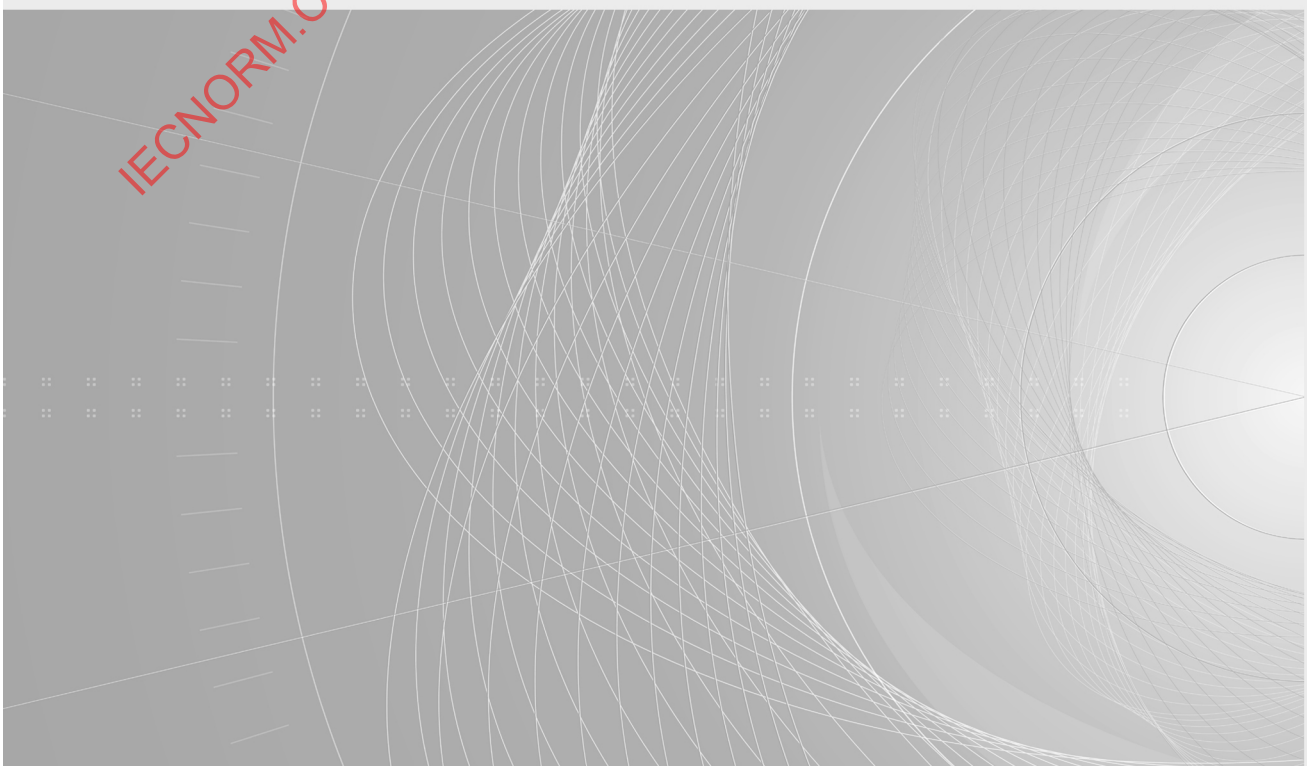
IEC TS 60747-19-2

Edition 1.0 2021-05

TECHNICAL SPECIFICATION

Semiconductor devices –
Part 19-2: Smart sensors – Indication of specifications of sensors and power supplies to drive smart sensors for low power operation



IEC TS 60747-19-2:2021-05(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC online collection - oc.iec.ch
Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 18 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC TS 60747-19-2

Edition 1.0 2021-05

TECHNICAL SPECIFICATION

Semiconductor devices –
Part 19-2: Smart sensors – Indication of specifications of sensors and power supplies to drive smart sensors for low power operation

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 31.080.99

ISBN 978-2-8322-9803-9

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

SEMICONDUCTOR DEVICES –

Part 19-2: Smart sensors – Indication of specifications of sensors and power supplies to drive smart sensors for low power operation

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

IEC TS 60747-19-2 has been prepared by subcommittee 47E: Discrete semiconductor devices, of IEC technical committee 47: Semiconductor devices. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

DTS	Report on voting
47E/693/DTS	47E/742/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 60747 series, published under the general title *Semiconductor devices*, can be found on the IEC website.

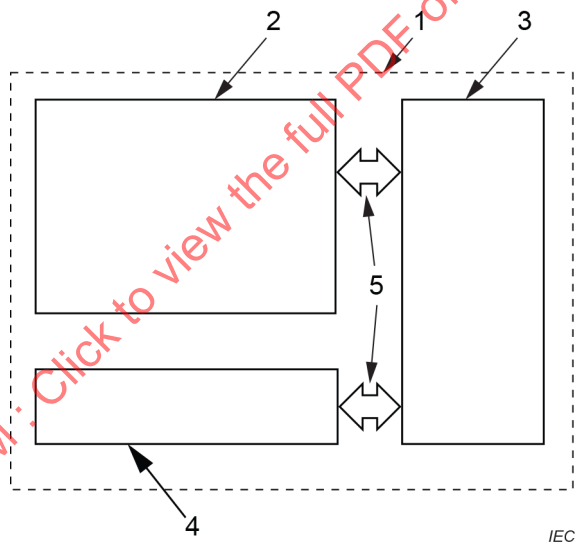
The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

The development of smart sensors which integrate analogue-to-digital conversion and digital processing of the captured sensor signal(s) is in progress. A smart sensing unit, which comprises a smart sensor; a terminal module, to control the smart sensor and perform wireless communication; and a power supply for the smart sensor and the terminal module, can send the output data of the smart sensor wirelessly to the outside. Here, the power supply may be a plug-in power supply, a battery, an energy harvester, or their combination. A smart sensing network where a large number of smart sensing units are located in manufacturing factories, offices, and stores has been examined. With this network, environmental monitoring, sensing operational situations of manufacturing equipment and sensing other various events contribute to the realization of the following outcomes by analysing the collected sensing data. Namely, energy saving, improvement in factory productivity such as operation rate, shortening of production lead time, preventive equipment maintenance, and product quality improvement can be achieved.

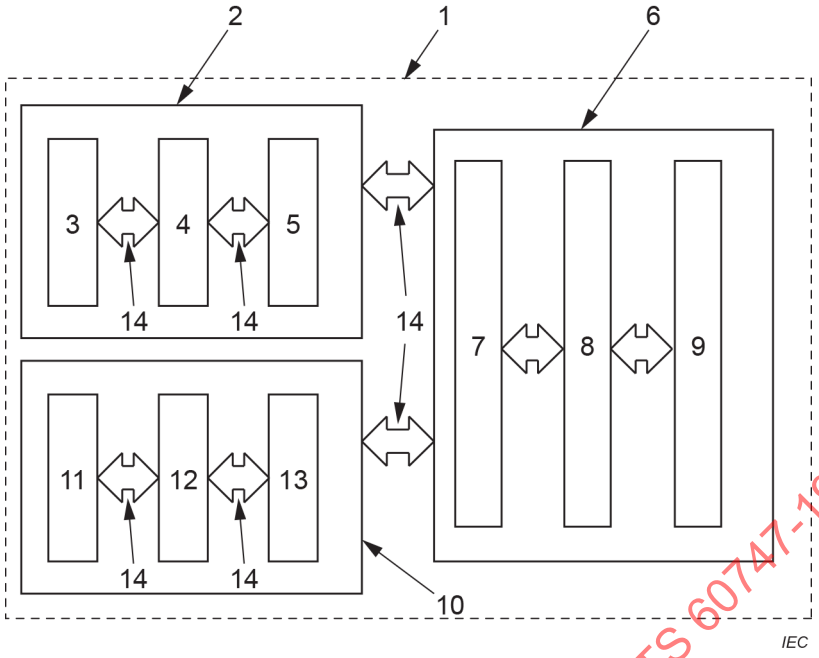
However, as to the three components of the smart sensing unit, namely, smart sensor, terminal module, and power supply, standardization regarding control schemes to connect the components mutually and regarding indication of specifications of the components has not been sufficiently established yet. This issue leads to the present situation, where the development of each component in the smart sensing unit has not proceeded efficiently. (Figure 1 shows the block diagram of the components in the smart sensing unit and Figure 2 shows an example of the detailed block diagram of the smart sensing unit.)



Key:

1 smart sensing unit
2 smart sensor
3 terminal module
4 power supply
5 electrical connections

Figure 1 – Block diagram of components in a smart sensing unit



Key:

1	smart sensing unit	8	data processing circuit
2	smart sensor	9	wireless communication circuit
3	sensor element	10	autonomous power supply module
4	analogue-to-digital converting circuit	11	power generation element
5	digital processing circuit	12	power storage element
6	terminal module	13	power management circuit
7	smart sensor control unit	14	electrical connections

Figure 2 – Example of detailed block diagram of a smart sensing unit

The IEC 60747-19 series aims to address this issue. The IEC 60747-19 series comprises two parts and its structure is currently conceived as follows:

Part 19-1 – Control scheme of smart sensors

Part 19-2 – Indication of specifications of sensors and power supplies to drive smart sensors for low power operation

Part 19-1 specifies a control scheme of the smart sensor from the terminal module in the smart sensing unit. Generally, the manufacturers of sensors have incorporated into the sensors various parameters and conditions for sensing operations to fulfil various requests and needs of the users. Therefore, it has been quite difficult for the users to understand how to set the parameters and conditions adequately and master the use of sensors. This issue has been a considerable obstacle in designing the smart sensing unit and smart sensing system. The main objective of IEC 60747 Part 19-1 is to solve this obstacle for future expansion of the smart sensors and smart sensing network systems.

This document aims to provide a guideline to indicate information that is required when the smart sensing unit is newly designed. When the smart sensing unit is newly designed especially using an autonomous power supply, the designers have to appropriately arrange selection of the components of the unit and their usage conditions to satisfy that power capability of the power supply successfully exceeds total power budget to be consumed in the unit as a whole. First, information about the detailed power consumption characteristics of the smart sensors is indispensable for this achievement. Namely, information about time-variation power consumption characteristics which is not necessarily described in the datasheet of sensors is essential when intermittent sensing operations are often adopted and a careful lower power design including time-variation characteristics to allow adoption of an autonomous power supply is needed in IoT (Internet of Things) applications. Therefore, this document discusses an indication of smart sensors' time-variation power consumption characteristics. Second, information about total power capability of the power supply to drive the unit and the smart sensor(s) is essential. This power supply as a module comprises (a) primary battery(ies), and(or) (a) secondary battery (ies), and (or) (an) energy harvester(s), or their combinations. To accomplish proper configuration, the information of specifications of power supply is needed. Thus this document also discusses indication of specification of power supply. With the establishments of the appropriate indication, the three components of the smart sensing unit can be easily selected and combined from the point-of-view of a low-power design, when the smart sensing unit is newly designed and the overall design of the smart sensing unit itself can be facilitated. If the telecommunication between smart sensor unit and autonomous power supply unit is done well, the both units work optimally.

Regading smart sensors, many kinds of operation modes are equipped with the availability of various functions by digital processing. When developing these smart sensors, a careful and precise power consumption design including time-variation characteristics and depending on each operation mode become essential. Therefore, the guideline specified in this document is essential for developing low-power smart sensors and their related devices.

Because the corresponding market has been evolving, and the requirements of the specifications of the components can be slightly changed during this process, guidelines are reported in this document as a Technical Specification (TS) to design the smart sensing unit and its components.

SEMICONDUCTOR DEVICES –

Part 19-2: Smart sensors – Indication of specifications of sensors and power supplies to drive smart sensors for low power operation

1 Scope

This part of IEC 60747 provides a guideline of indication of specifications of a low-power sensor being a device or a module allowing autonomous power supply operation, which contributes to the low-power design of a smart sensing unit. Here, the smart sensing unit comprises a smart sensor, a terminal module, and a power supply, which can send output data of the smart sensor to the outside. This part also provides a guideline of indication of specifications of the power supply to drive the smart sensor(s) in the smart sensing unit. Based on these, the three components of the smart sensing unit can be easily selected and combined from the point-of-view of newly designed, low-power, smart sensing units.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
autonomous power supply
standalone power supply with batteries and (or) energy harvesters obtaining energy from the so-called ambient energy sources, such as light, vibration, thermal, or biological sources

4 Indication of specifications of low-power smart sensors

4.1 Datasheet description of current consumption – time characteristics

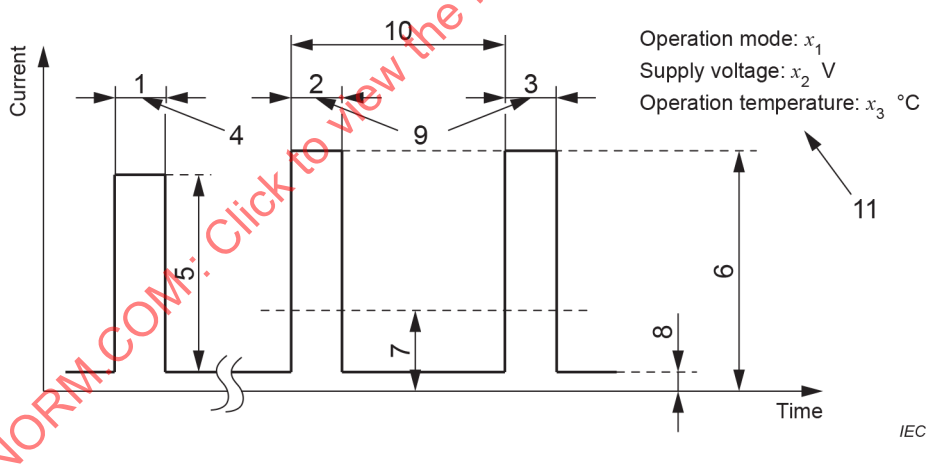
In order to realize a low-power smart sensor allowing an autonomous power supply operation that is the target of this document, clarifying power consumption characteristics of the smart sensor to its users is significant. Therefore, its current consumption-time characteristics and information regarding its operation conditions should be described in the datasheet of the smart sensor.

An example of this description in the datasheet is shown in Figure 3. Namely, current consumption-time characteristics during the starting and continuous periodic (intermittent) sensing operations should be described. In Figure 3, the following seven values should be described: current consumption period during the starting operation (t_{st}), peak current consumption value during the starting operation (I_{stpeak}), peak current consumption value during the sensing operation (I_{oppeak}), average current consumption value during the sensing operation (I_{opave}), standby current consumption value ($I_{standby}$), current consumption period during the sensing operation (t_{op}), and the sensing operation cycle time (t_{cyc}).

Furthermore, the current consumption-time characteristics should be quantified at least for the following two conditions: (1) a typical condition where the applied supply voltage is the typical voltage and the operating temperature is the room temperature, and (2) the worst condition where the applied supply voltage is the maximum voltage within the supply voltage range and the operating temperature is the highest within the operating temperature range. Herein, the "worst" condition refers to the condition where the power consumption is the highest within the sensor's recommended supply voltage range and operating temperature range. The operating temperature may be substituted for the ambient temperature.

In Figure 3, where the characteristics are shown for each condition, the values of the supply voltages and operation temperatures for each condition should be described. If the characteristics vary among the operation parameters including the operation modes, each characteristic should described for each parameter. Herein, descriptions using tables or values may be used and listed if the required information to be described is fully satisfied. Table 1 is a datasheet description example for the consumed current.

A practical example of a datasheet description of specifications of the smart sensor is shown in Annex A.



Key:

1 starting operation
2 [n]th sensing operation
3 [n + 1]th sensing operation
4 current consumption period during starting operation (t_{st})
5 peak current consumption value during starting operation (I_{stpeak})
6 peak current consumption value during sensing operation (I_{oppeak})
7 average current consumption value during sensing operation (I_{opave})
8 standby current consumption value ($I_{standby}$)
9 current consumption period during sensing operation (t_{op})
10 sensing operation cycle time (t_{cyc})
11 caption of operation mode and operation conditions

Figure 3 – Example of datasheet description of current consumption–time characteristics (timing chart) with continuous periodic operations of the low-power smart sensor

Table 1 – Example of datasheet description of current consumption–time characteristics table with continuous periodic operations of the low-power smart sensor

Operation mode	Operation condition	Item						
		I_{stpeak} A	t_{st} s	I_{oppeak} A	I_{opave} A	$I_{standby}$ A	t_{op} A	t_{cyc} s
Operation mode 1	Typical condition	x_1	x_2	x_3	x_4	x_5	x_6	x_7
	Worst condition	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}
Operation mode 2	Typical condition	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}
	Worst condition	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}
Operation mode 3	Typical condition	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}
	Worst condition	x_{36}	x_{37}	x_{38}	x_{39}	x_{40}	x_{41}	x_{42}
Typical condition: T_a = x_{43} °C, *Vdd* = x_{44} V Worst condition (where power consumption is the highest): T_a = x_{45} °C, *Vdd* = x_{46} V (T_a: ambient temperature, *Vdd*: power supply voltage of smart sensor) I_{stpeak}: peak current consumption value during starting operation t_{st}: current consumption period during starting operation I_{oppeak}: peak current consumption value during sensing operation I_{opave}: average current consumption value during sensing operation $I_{standby}$: standby current consumption value t_{op}: current consumption period during sensing operation t_{cyc}: sensing operation cycle time								
NOTE x_1 to x_{46}: optional								

4.2 Datasheet description of information regarding under voltage lock out circuit

If a voltage lower than the supply voltage range (as specified in the smart sensor datasheet) is applied to the smart sensor, increased current consumption is evidenced unexpectedly in some cases because some internal circuits in the smart sensor do not work properly. This event may lead to an undesirable trouble of wastage of the stored charge in the smart sensing unit that the smart sensor includes. To avoid this problem, adopting an under voltage lock out (UVLO) circuit is essential. It should be specified in the datasheet whether the UVLO circuit is embedded in the low-power smart sensor, or whether the circuit shall be prepared externally.

5 Indication of specifications of power supplies to drive smart sensors

To appropriately design a low-power smart sensing unit that allows an autonomous power supply operation, information on specifications of the power supply which is one of the components in the smart sensing unit shall also be available in addition to information on the specifications of the smart sensor(s) in the smart sensing unit (discussed in the last chapter). Herein, in regard to the power supply used to drive the smart sensor(s), recommended guidelines to indicate its specifications in the datasheet are specified. Hardware configuration examples of a power supply to drive smart sensor(s) in a smart sensing unit are shown in Annex B.

Autonomous power supply types used to drive smart sensors include the primary battery(ies), or secondary battery(ies), or an environmental power generation device(s) with or without a storage device(s), or their combinations. These power supplies are increasingly utilized owing to lack of power lines. Herein, indicative specification guidelines of DC output power supplies, including the autonomous power supplies used to drive the smart sensor(s) in the smart sensing unit are provided. Items recommended for use in these indicative guidelines are listed below. Supplementary explanations of various signals among the storage device, the battery and the power generation device are described in Annex C.

1) Supply power capability (from storage batteries and (or) storage devices) and its measurement condition. For example,
   a) Supply power capability from primary battery:

      200 mAh (intermittent operation of 1 mA and 1 μA, duty ratio = 10 %),

      300 mAh (constant load current of 100 μA)

   b) Supply power capability from storage capacitor: 100 mAh (constant load current of 100 μA)
2) Output voltage and its variation. For example,3,3 V ± 0,3 V
3) Maximum supply current

   In the case of a discontinuous supply, a supply period condition is indicated. For example, 10 mA (maximum 3 ms), 3 mA (continuous)
4) Leakage current (leakage current, including self-discharge). For example, 1 μA
5) Operation temperature range. For example, 40 °C to 85 °C
6) Temperature dependence of each characteristic in the operation temperature range

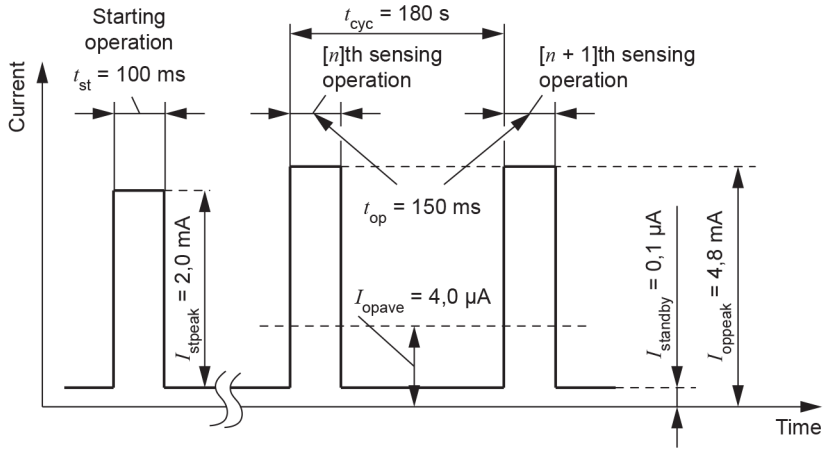
   If each characteristic is temperature-dependent, the characteristics of at least three typical temperatures are indicated in the low-, middle- and high-ranges, when the operational temperature range is divided into low-, middle- and high-range levels.
7) Other power supply characteristics, such as ripple characteristics, output impedance characteristics, lifetime characteristics, limited numbers of charge and discharge cycles, and so on, are indicated accordingly.
8) Information about applied standards is indicated in the case they exist.
9) Power generation characteristics of power generation elements are reported in an appropriate manner (with the utilization of standards regarding each power generation device).
10) Information about the implementation (or not) of a power-good signal line, and the signal specifications in the case this signal line is implemented (either an analogue or a digital signal may be used).
11) Information about the implementation (or not) of a signal line to output information on the remaining quantity of the storage device, and the signal specifications in the case this signal line is implemented (either an analogue or a digital signal may be used).
12) Information about the implementation (or not) of a signal line to output information on the remaining quantity of the battery, and the signal specifications in the case this signal line is implemented (either an analogue or a digital signal may be used).
13) Information about the implementation (or not) of a signal line to output information on the output power of the power generation device, and the signal specifications in the case this signal line is implemented (either an analogue or a digital signal may be used).

A practical example of the datasheet description of the specifications of the power supply used to drive smart sensor(s) is shown in Annex D.

Annex A
(informative)

Practical example of datasheet description of specifications of smart sensors

A practical example of a datasheet description of specifications of the smart sensor is shown in this Annex. Figure A.1 shows the example in the case of a smart accelerometer.



Current consumption – time characteristics (timing chart) with continuous periodic operations
(Operation mode: Operation mode 1, supply voltage: 3,3 V, operation temperature: 27 °C)

Current consumption – time characteristics with continuous periodic operations
in the case with different operation modes and condtions

Operation mode	Operation condition	Item						
		I_{stpeak} mA	t_{st} ms	I_{oppeak} mA	I_{opave} µA	$I_{standby}$ µA	t_{op} ms	t_{cyc} s
Operation mode 1 (XYZ composition vector output with three axes detection, T_{cyc} = 180 s)	Typical condition	2,0	100	4,8	4,0	0,1	150	180
	Worst condition	3,0	100	7,2	6,0	0,2	150	180
Operation mode 2 (Only one axis detection, X-axis value, T_{cyc} = 180 s)	Typical condition	2,0	100	2,4	2,0	0,1	150	180
	Worst condition	3,0	100	3,6	3,0	0,2	150	180
Operation mode 3 (XYZ composition vector output with three axes detection, T_{cyc} = 300 s)	Typical condition	2,0	100	4,8	2,4	0,1	150	300
	Worst condition	3,0	100	7,2	3,6	0,2	150	300
Typical condition: T_a = 27 °C, Vdd = 3,3 V Worst condtion (where power consumption is the highest): T_a = 85 °C, Vdd = 3,6 V (T_a: ambient temperature, Vdd: power supply voltage of smart sensor)								

t_{st}: current consumption period during starting operation
I_{stpeak}: peak current consumption value during starting operation
I_{oppeak}: peak current consumption value during sensing operation
I_{opave}: average current consumption value during sensing operation
$I_{standby}$: standby current consumption value
t_{op}: current consumption period during sensing operation
t_{cyc}: sensing operation cycle time

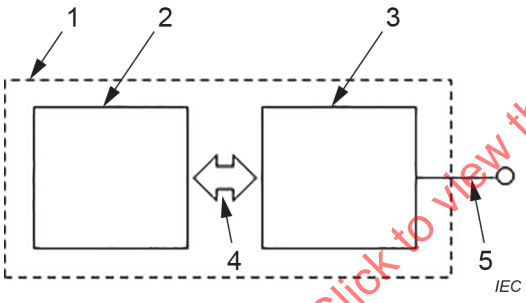
IEC

Figure A.1 – Practical example of datasheet description of specifications of smart accelerometer

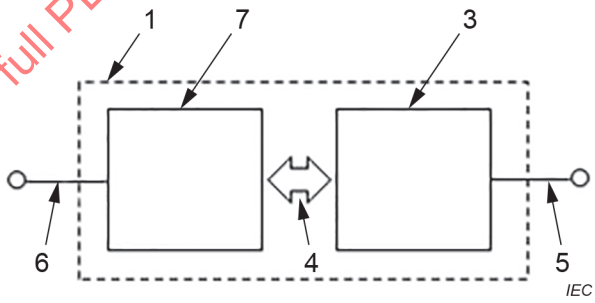
Annex B
(informative)

Hardware configuration examples of a power supply to drive smart sensor(s) in a smart sensing unit

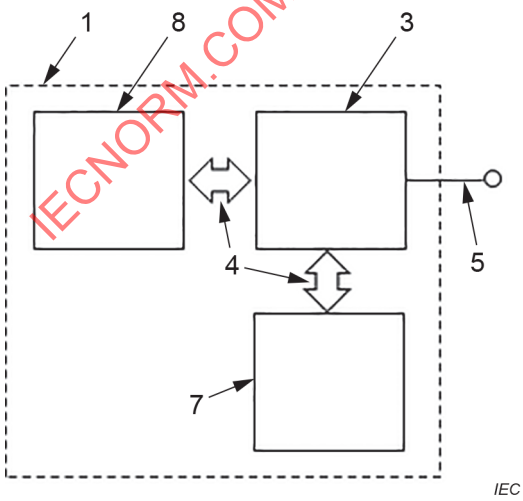
Hardware configuration examples of a power supply to drive smart sensor(s) in a smart sensing unit are shown in this Annex. Figure B.1 provides relevant examples. All examples are autonomous power supplies and consist of power management circuits. Figure B.1 a) and Figure B.1 b) provide the examples in the case where a primary battery is used as a power supply and in the case where a secondary battery is used as a power supply. Figure B.1 c) provides the example in the case where a combination of a power generation device and a secondary battery are used as a power supply. The power generated by the power generation device charges the secondary battery. Figure B.1 d) provides the example in the case where a combination of a power generation device and a storage capacitor are used as a power supply. The power generated by the power generation device charges the storage capacitor. Figure B.1 e) provides the example in the case where a combination of a primary battery, a power generation device and a storage capacitor are used as a power supply. The power generated by the power generation device charges the storage capacitor. If the stored charge in the storage capacitor from the accumulation of the generated power from the power generation device is not enough compared to the power consumption of the load, the charge in the primary battery is then consumed switching by the power management circuits.



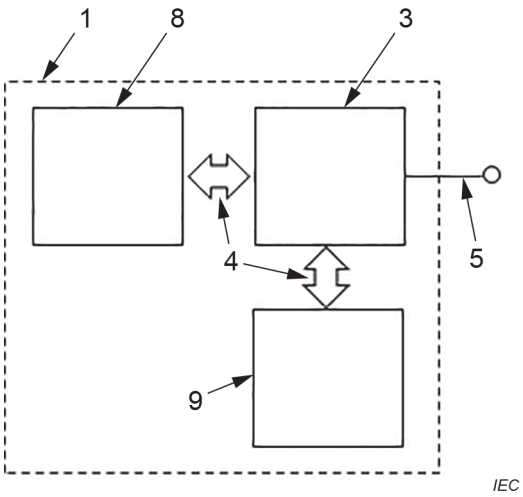
a) Example 1



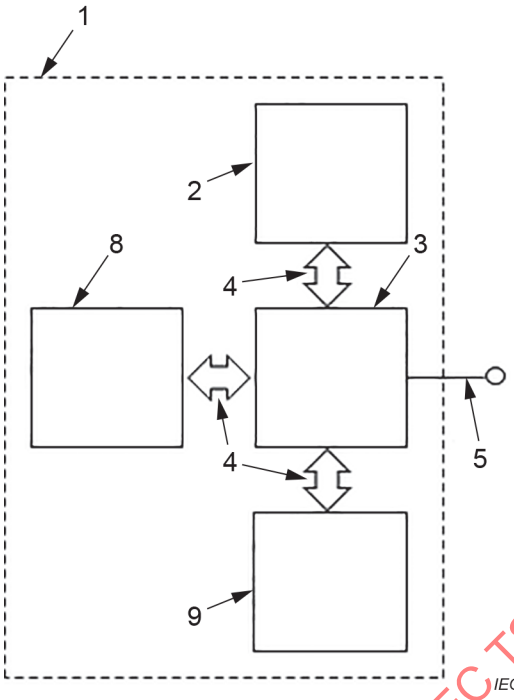
b) Example 2



c) Example 3



d) Example 4



e) Example 5

Key:

1 power supply
2 primary battery
3 power management circuits
4 electrical connections
5 power supply output line
6 battery charging input line
7 secondary battery
8 power generation device
9 storage capacitor

Figure B.1 – Hardware configuration examples of a power supply to drive smart sensor(s) in a smart sensing unit

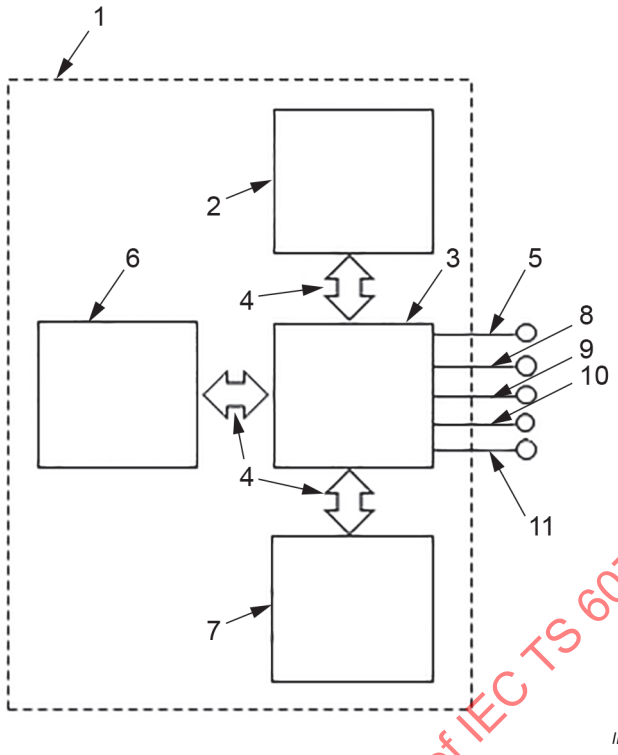
Annex C
(informative)

Supplementary explanations of various signals among the storage device, the battery and the power generation device

In the case of autonomous power supplies, the charge of the primary and (or) the secondary battery(ies), and the stored charge in the storage device(s) and(or) the secondary battery(ies) that resulted from the accumulation of the generated power by the power generation devices is limited and may fall below the power consumption of the load. In such a case, the output voltage of the power supply cannot keep up with the targeted voltage and generally decreases. If the decreased voltage is too low to operate the load properly, irregular(non-preferred) operation of the load can occur. To prevent such issues, specific power supply functionalities are essential to alert the undesirable output voltage decreases. The power-good signal plays this role. The signal level indicates whether the output voltage is higher than the predetermined threshold voltage or not. Herein, it has to be noted that the voltages are often different owing to existence of hysteresis as to the threshold voltage (in such a case, the respective threshold voltages corresponding to the cases at which the output voltage rises and falls are indicated).

Furthermore, in addition to the power-good signal, signals used to output information on the remaining quantities of the storage device and the battery, and signals to output information on the output power of the power generation device, are also convenient. Based on this information on the available power, an autonomous power supply operation can be achieved more easily by realizing an efficient power consumption planning in the operation of the load.

Figure C.1 depicts a hardware configuration example. In this example, the power supply comprises a combination of the primary battery, power generation device, and storage capacitor. The power generated by the power generation device charges the storage capacitor. The example implements a power-good signal line which indicates whether the output voltage of the power supply (that is, the combination of the primary battery, the power generation device and the storage capacitor) is higher than the predetermined voltage or not. The example also implements signal lines to output information on the remaining quantities of the storage capacitor and the primary battery, and a signal line to output information on the output power of the power generation device.



Key:

1 power supply
2 primary battery
3 power management circuits
4 electrical connections
5 power supply output line
6 power generation device
7 storage capacitor
8 power-good signal line
9 signal line to output information on the remaining quantity of the storage capacitor
10 signal line to output information on the remaining quantity of the primary battery
11 signal line to output information on the output power of the power generation device

Figure C.1 – Practical examples of hardware configurations of several signal lines among the storage, the battery and the power generation device