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Piezoelectric sensors –
Part 1: Generic specifications

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INTERNATIONAL
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PIEZOELECTRIC SENSORS –

Part 1: Generic specifications

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.

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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.

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC 63041-1:2017. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IEC 63041-1 has been prepared by IEC technical committee 49: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection. It is an International Standard.

This second edition cancels and replaces the first edition published in 2017. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) the new terms "piezoelectric sensor system" and "wireless SAW sensor system" and their definitions have been added;
b) new types of sensor modules and sensor system have been added;
c) some symbols of sensor elements are added in Clause 4;
d) a new Figure B.3 has been added in Annex B;
e) Annex C has been added.

The text of this International Standard is based on the following documents:

Draft	Report on voting
49/1357/CDV	49/1364/RVC

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 International Standard 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 63041 series, published under the general title *Piezoelectric sensors*, 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.

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PIEZOELECTRIC SENSORS –

Part 1: Generic specifications

1 Scope

This part of IEC 63041 applies to piezoelectric sensors of resonator, delay-line and non-acoustic types, which are used in physical and engineering sciences, chemistry and biochemistry, medical and environmental sciences, etc.

The purpose of this document is to specify the terms and definitions for piezoelectric sensors, and to make sure from a technological perspective that users understand the state-of-art piezoelectric sensors and how to use them correctly.

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.

IEC 60027 (all parts), *Letter symbols to be used in electrical technology*

IEC 60050-561~~:2014~~, *International Electrotechnical Vocabulary – Part 561: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection*

IEC 60122-2-1, *Quartz crystal units for frequency control and selection – Part 2: Guide to the use of quartz crystal units for frequency control and selection – Section One: Quartz ~~crystal units~~ crystals for microprocessor clock supply*

IEC 60444-9, *Measurement of quartz crystal unit parameters – Part 9: Measurement of spurious resonances of piezoelectric crystal units*

IEC 60617, *Graphical symbols for diagrams,* available at https://std.iec.ch/iec60617

IEC 63041-3:2020, *Piezoelectric sensors – Part 3: Physical sensors*

ISO 2859-1:1999, *Sampling procedures for inspection by attributes – Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

ISO 80000-1~~:2009~~, *Quantities and units – Part 1: General*

3 Terms and definitions

~~3.1 General~~

For the purposes of this document, the terms and definitions given in IEC 60027, IEC 60050-561, IEC 60617, ISO 80000-1 and the following apply.

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

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

~~Units, letter symbols and terminology shall, wherever possible, be taken from the following standards: IEC 60027, IEC 60050-561, IEC 60617, and ISO 80000-1.~~

NOTE Piezoelectric sensors covered herein are those used for the detection and measurement of physical quantities, chemical substances or biological molecules.

3.1 Piezoelectric sensors

3.1.1
piezoelectric sensor element
electronic component which is able to detect physical quantities as a change in its frequency, phase, delay, electrical charge, resistance, Q-value, bandwidth, etc.

Note 1 to entry: For chemical and biochemical sensor applications, the piezoelectric sensor element includes a sensitive or receptive layer (target recognition material).

3.1.2
resonator type sensor element
piezoelectric sensor component using acoustic resonances

3.1.3
delay-line type sensor element
piezoelectric sensor component using a delay-line of surface acoustic wave (SAW) ~~delay-line of~~ transversal filter type

3.1.4
non-acoustic type sensor element
piezoelectric sensor component using the electrical charge induced by a quasi-static force, torque or the like

Note 1 to entry: Here, the term "non-acoustic", represents "quasi-static piezoelectric". Accordingly, the (piezoelectric) non-acoustic type sensor element means a sensor element using the quasi-static piezoelectric effect.

3.1.5
piezoelectric sensor cell
sensor element equipped with necessary mechanical accessories and attachments to correctly detect the parameters to be measured

3.1.6
piezoelectric sensor module
sensor element or cell equipped with electronic accessories for interfacing to external data acquisitions

3.1.7
piezoelectric sensor system
organized system including detection, amplification of detected value, communication with other equipment and analysis of detected value

Note 1 to entry: Here, these functions cooperate mutually.

3.1.8
piezoelectric sensor
generic term that includes a sensor element, cell, module and system

3.1.9
QCM
quartz crystal microbalance
one of the families of chemical and biochemical sensors using crystal resonators

Note 1 to entry: A thickness ~~share~~ shear mode (TSM) sensor is identical with a QCM.

3.2 Types of chemical sensors

3.2.1
piezoelectric chemical sensor element
piezoelectric sensor component including a sensitive layer (target recognition material), which is necessary for the practical measurement of simple non-biological molecules in quantity, and which works and detects chemical substances mainly in the gas phase

Note 1 to entry: A gas sensor element is one of the chemical sensor elements.

3.2.2
piezoelectric biochemical sensor element
piezoelectric sensor component including a receptive layer (target recognition material), which is necessary for the practical measurement of complex biological molecules in quantity, and which works mainly in aqueous media and detects biomolecules therein

3.3 Types of physical sensors

3.3.1
piezoelectric force sensor element
piezoelectric sensor component whose resonance frequency, delay or electrical charge/voltage is used for force measurement

3.3.2
piezoelectric pressure sensor element
piezoelectric sensor component whose resonance frequency, delay or electrical charge/voltage is used for pressure measurement

3.3.3
piezoelectric torque sensor element
piezoelectric sensor component whose resonance frequency, delay or electrical charge/voltage is used for torque measurement

3.3.4
piezoelectric viscosity sensor element
piezoelectric sensor component whose resonance frequency, delay or insertion loss/gain is used for viscosity measurement

3.3.5
piezoelectric temperature sensor element
piezoelectric sensor component whose resonance frequency or delay is used for temperature measurement

3.3.6
piezoelectric film-thickness sensor element
piezoelectric sensor component whose resonance frequency is used for film-thickness measurement

3.4 Types of sensor modules

3.4.1
wireless SAW sensor module
piezoelectric sensor element or cell equipped with an antenna for wirelessly connecting with interrogation unit

Note 1 to entry: Here, the resonator and delay line type elements of the SAW are used for the piezoelectric sensor element or cell.

3.4.2
dual mode sensor module
dual mode sensor element or cell equipped with circuit units for temperature compensation and electronic accessories for interfacing to external data acquisitions

Note 1 to entry: Dual mode sensor is a piezoelectric sensor which is able to detect physical quantities from a change in resonance frequencies of two independent modes on a single piezoelectric plate (see IEC 63041-3:2020, 3.1.5).

3.5 Types of sensor systems

3.5.1
wireless SAW sensor system
generic term that includes wireless SAW sensors and reader unit for sending and receiving RF signals

SEE: Annex C.

3.5.2
dual mode sensor system
generic term that includes dual mode quartz crystal sensor modules, electric device, PC, memory, wired or wireless devices, software, etc.

4 Symbols of sensor elements

4.1 General

Figures 1 to 6 show the conceptual diagrams and defined symbols for sensor elements of bulk acoustic wave (BAW) resonator, SAW resonator and SAW delay-line types. The symbols are essentially the same as those given in IEC 60122-1, IEC 61019-1 and IEC 60862-1.

Figure 7 and Figure 8 show the conceptual diagram and defined symbol for sensor elements of non-acoustic type.

Figures 9 to 12 show the conceptual diagram and defined symbol for sensor elements of wireless SAW resonator and SAW delay-line types. This is shown in Annex C.

NOTE ~~1~~ The diagonal line in Figure 2, Figure 4, Figure 6, Figure 8, Figure 10 and Figure 12 shows an emblem expressing changes in objects to be measured.

~~NOTE 2~~ For letter symbols (see 4.7) showing the types of sensors, these symbols ~~are put~~ should be defined in the circle at the upper right corner of Figure 2, Figure 4, Figure 6, Figure 8, Figure 10 and Figure 12, and for each sensor application.

4.2 Symbol for sensor elements of BAW resonator type

Figure 1 shows the conceptual diagrams for sensor elements of BAW resonator type from which a mounting portion is omitted. Figure 2 shows the symbol for sensor elements of BAW resonator type.

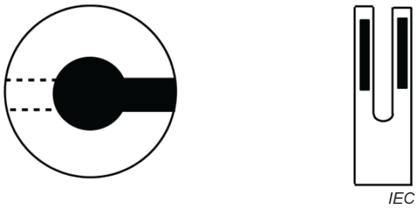

Figure 1 – Conceptual diagrams for sensor elements of BAW resonator type

NOTE Figure 1 shows examples of disk type and tuning fork type sensor elements.

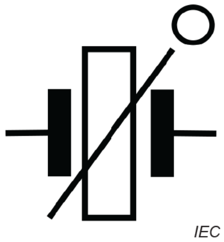

Figure 2 – Symbol for sensor elements of BAW resonator type

4.3 Symbol for sensor elements of SAW resonator type

Figure 3 and Figure 4 show, respectively, the conceptual diagram and symbol for sensor elements of SAW resonator type.

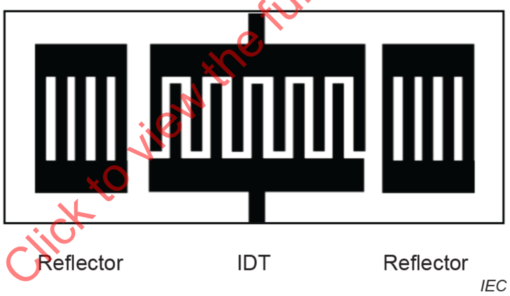

Figure 3 – Conceptual diagram of sensor elements of SAW resonator type

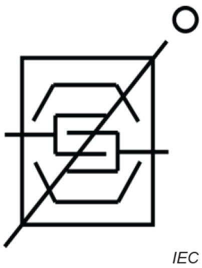

Figure 4 – Symbol for sensor elements of SAW resonator type

4.4 Symbol for sensor elements of SAW delay-line type

Figure 5 and Figure 6 show, respectively, the conceptual diagram and symbol for sensor elements of SAW delay-line type.

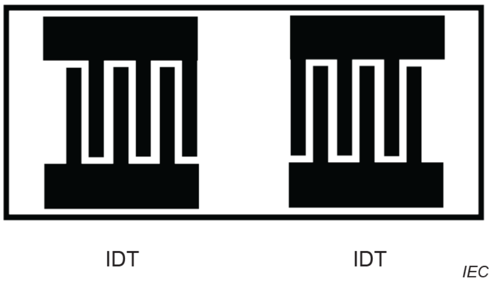

Figure 5 – Conceptual diagram for sensor elements of SAW delay-line type

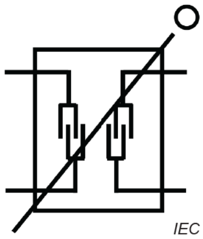

Figure 6 – Symbol for sensor elements of SAW delay-line type

4.5 Symbol for sensor elements of non-acoustic type

Figure 7 shows the conceptual diagrams for sensor elements of non-acoustic type from which a mounting portion is omitted. Figure 8 shows the symbol for sensor elements of non-acoustic type.

Figure 7 – Conceptual diagrams for sensor elements of non-acoustic type

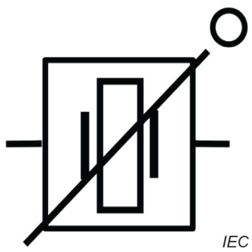

Figure 8 – Symbol for sensor elements of non-acoustic type

4.6 Symbol for wireless SAW sensor element

Figures 9 to 12 show, respectively, the conceptual diagram and symbol for sensor elements of wireless SAW resonator and delay-line type.

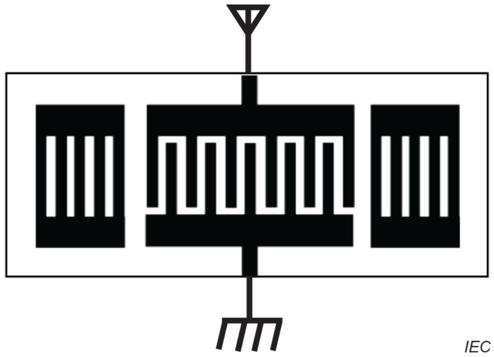

Figure 9 – Conceptual diagram for basic sensor elements of wireless SAW resonator type

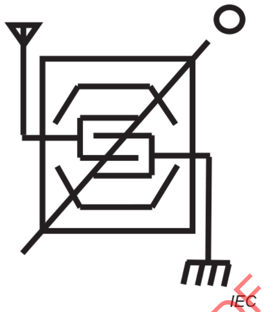

Figure 10 – Symbol for basic sensor elements of wireless SAW resonator type

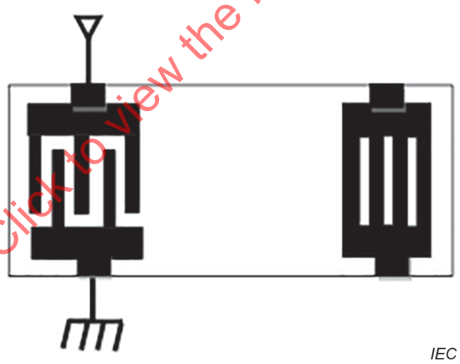

Figure 11 – Conceptual diagram for basic sensor elements of wireless SAW reflective delay-line type

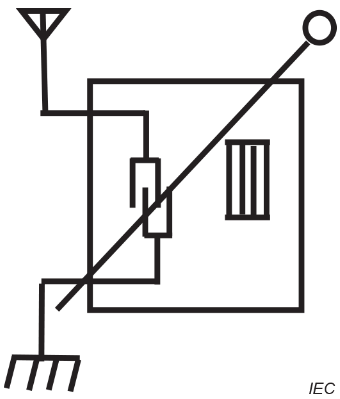

Figure 12 – Symbol for basic sensor elements of wireless SAW reflective delay-line type

NOTE Patch antenna is a type of low-profile wireless antenna that can be mounted on a flat surface and is connected to the SAW element and cells.

4.7 Symbols

The symbols put in the circle at the upper right corner in Figure 2, Figure 4, Figure 6, Figure 8, Figure 10 and Figure 12 are defined below (see the ISO 80000 series):

a) film-thickness: d;

b) force: F;

c) mass: m;

d) density: ρ;

e) pressure: P;

f) temperature: T;

g) torque: τ;

h) viscosity: υ.

In chemical, biochemical and gas sensor applications, antigen-antibody or chemical reaction occurs between the sensitive or receptive layer and target substances, which is detected as a change in mass density, viscosity or shear modulus of the sensitive or receptive layer. Accordingly, the following specific symbols are defined for biochemical, chemical and gas sensor elements:

i) biochemical: Bi;

j) chemical: Ch;

k) gas: Ga.

5 Specifications

5.1 Sensor elements

5.1.1 General

In consideration of the target sensitivity, dynamic range or the like, the specifications of sensor elements and cells shall be determined. They should be defined clearly in the contract to be concluded between the manufacturer and customers.

Subclauses 5.1.2 and 5.1.3 present key points to be described in the specifications. These elements should be specified numerically unless confidential technological information is concerned.

5.1.2 Sensor elements of resonator and delay-line types

Sensor elements of resonator and delay-line types include the following:

a) range of measurand;

b) sensitivity of output signal with respect to measurand;

c) nominal frequency;

d) frequency tolerance;

e) parameters of equivalent circuit;

f) operating temperature range;

g) unwanted response;

h) level of drive or input power;

i) insertion loss/gain;

j) delay time (for sensor elements of SAW delay-line type);
k) phase response;
l) piezoelectric material, cut angle, or the like;
m) electrode material, dimension, shape, structure or the like;
n) mounting material, dimension, shape, structure or the like;
o) dimensions of enclosure, or name, model number or the like corresponding thereto;
p) category of environmental test;
q) others.

5.1.3 Sensor elements of non-acoustic type

Sensor elements of non-acoustic type include the following:

a) operating temperature range;
b) piezoelectric material, cut angle, dimension, shape, structure or the like;
c) electrode material, dimension, shape, structure or the like;
d) mounting material, dimension, shape, structure or the like;
e) dimensions of enclosure, or name, model number or the like corresponding thereto;
f) category of environmental test;
g) others.

5.2 Frequency ranges

The frequency range applied herein should be 10 kHz to 10 GHz.

When one of the higher-order overtones is used or the frequency deviates from the specified range, the manufacturer and customer shall consult, and the results shall clearly be defined in the contract.

NOTE The frequency ranges for sensor elements of non-acoustic type are not defined.

5.3 Level of drive or input power

For sensor elements and cells, the level of drive or input power shall be limited so that an influence of "heat generation" or a "non-linear effect" does not deteriorate their performance.

NOTE The level of drive or input power for non-acoustic type sensor elements is not defined.

5.4 Unwanted response

Unwanted responses shall be measured based on IEC 60444-9. This rule shall be applied only to sensor elements of BAW resonator type.

According to IEC 60122-2-1, the ratio of the motional resistance R_N for the unwanted response to R_1 for the main response (N = R_N/R_1) shall be two and a half times or more.

NOTE Conceptually, the sensitivity increases with an increase in the electrode area, which reduces the ratio of R_N/R_1. Under this situation, unwanted responses affect the main response, and sensor elements of BAW resonator type occasionally oscillate, caused by the unwanted response.

5.5 Analysis of measurements

Electronic circuits and measuring instruments are generally used in sensor systems. The output signals such as frequency, phase, insertion loss/gain, electrical charge / voltage, etc., and their response functions and graphs are obtained as system data.

The rule on how to apply this system data to data analyses shall clearly be defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

NOTE The response function based on the linear response theory is effective in the analysis of acoustic wave sensor elements and cells of resonator and delay-line types. For example, it is possible for the frequency response to predict the resonant response levels of the acoustic wave sensor.

5.6 Enclosure

Holder specifications shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

5.7 Performance confirmation

The basic performance of sensor elements and cells such as the minimum and maximum detection limits, dynamic range, sensitivity, etc. should be specified.

5.8 Long-term and short-term stabilities

At the time of the measurement, attention should be paid to long-term stability as well as to short-term stability affected by a background noise such as an electronic and/or foreign noise.

The specifications for long-term and short-term stabilities shall clearly be defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

NOTE The long-term and short-term stabilities for sensor elements of non-acoustic type are not defined.

5.9 Transmission power

Transmit power and communication distance are related to the electric field strength of wireless SAW sensor systems. This should be dealt with in accordance with the country specific radio laws and regulations.

6 Measurement and detection methods

Required measurement and detection methods are shown in Annex A to ~~Annex B~~ Annex C.

7 Delivery conditions

7.1 Marking

The content to be marked should be selected at least out of the following items. Moreover, the marking shall be made at the place from which sensor elements and cells can easily be viewed to the greatest extent possible. If such a place is unavailable, the marking shall be made on a packing plane.

a) type designation as defined in the detailed specifications;

b) year and week (four digits) of manufacture, or serial number;

c) factory identification code;

d) name of manufacturer or trademark;

e) country of production;

f) mark of conformity (unless a certificate of conformity is used).

7.2 Wrapping

In the wrapping of sensor elements and cells, sealing is desirable. Moreover, vacuum wrapping must also be taken into consideration. This rule shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

7.3 Packaging

The packaging specifications shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

8 Quality and reliability

8.1 Reuse

Reuse of sensor elements and cells shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

8.2 Validity of release

Inspection before shipment and re-inspection when the products are stored for a predetermined period of time and then shipped, shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

8.3 Test procedures

Test procedures to be used shall be selected from this document. If any required test is not found, then it shall be defined in detailed individual specifications.

8.4 Screening requirements

Where screening by the customer is required for sensor elements and cells, this shall be defined in the detailed individual specifications.

8.5 Unchecked parameters

Only those parameters of sensor elements and cells which have been described in detailed specifications and which were subjected to testing can be assumed to be within the specified limits. It should not be assumed that any parameter not specified will remain unchanged from one sensor element and cell to another. Should it be necessary for further unchecked parameters to be ~~controlled~~ verified, then new, more extensive and detailed specifications should be prepared. The additional test method(s) shall be fully described with appropriate limits, AQLs and inspection levels specified (see ISO 2859-1).

9 Test and measurement procedures

9.1 General

9.1.1 ~~Classification of tests~~ Test classification

The tests are classified into tests for shipping products, and mechanical and environmental tests for confirming the reliability of products.

9.1.2 Shipping test

The test is conducted to confirm whether sensor elements and cells maintain the state satisfying the contract between the manufacturer and customer when unsealed sensor elements are shipped. The following shall be clearly defined in the contract between the manufacturer and customer, or individual specifications.

a) When the specifications can presumably be sufficiently ensured, no inspection or sampling inspection shall be allowed.
b) When inspections are required, all sensor elements and cells shall be inspected.

9.1.3 Mechanical and environmental test

9.1.3.1 General

Tests should be conducted to confirm whether or not sensor elements and cells have predetermined performances. Regarding test samples, those sealed into enclosures shall be used. When no sealing is required, however, such samples may also be used.

9.1.3.2 Test samples

With regard to all test samples, the sensor elements and cells which maintain the state meeting the contract between the manufacturer and customer shall be used. Selection of the test sample shall be clearly defined in the contract between the manufacturer and customer, or in individual specifications.

9.1.3.3 Test items

Test items such as vibration, shock, thermal shock, heat resistance, bump, salt fog, ageing, bending of enclosure and the like are strongly dependent upon the requirement specifications of sensor elements and cells. Therefore, the test items shall be discussed between the manufacturer and customer, and shall be settled by the contract.

9.2 Test and measurement conditions

9.2.1 Standard conditions for testing

Unless otherwise specified, all of electrical tests shall be conducted under the following conditions;

– temperature 15 °C to 35 °C;
– relative humidity 45 % to 75 %;
– atmosphere 86 kPa to 106 kPa (860 mbar to 1 060 mbar).

If any doubt ~~arises~~ may arise, the following conditions shall be applied;

– temperature 25 °C ± 2 °C;
– relative humidity 48 % to 52 %;

Before starting the measurement, the test samples shall be stored at the measurement (inspection) temperature for a period of time enough to reach the thermal equilibrium state. The ambient temperature during the measurement shall be recorded in the test report.

9.2.2 Equilibrium state

Unless otherwise specified, all of the electrical tests shall be conducted under an equilibrium state. In the case where the test state causes significant time dependence on the measurement of characteristics, a means for compensating such dependence shall be specified.

9.2.3 Power supply

When the oscillation method (see Clause A.3) is employed, a direct current power supply to be used for testing samples should have no ripples which influence the measurement accuracies required. An alternate current power supply shall have no transient response characteristics. When the ripples and transient response characteristics influence the measurement, such an influence shall clearly be described in individual standards.

9.2.4 Alternative test system

Measurement shall be conducted according to specified methods as much as possible. If there is no doubt, another method by which equivalent results are expected may be applied.

NOTE "Equivalent" means that the measured values obtained by the alternative test method are correlated to the specified method.

9.2.5 Visual inspection

9.2.5.1 General

Unless otherwise specified, external visual examination shall be performed under normal factory lighting and visual conditions.

9.2.5.2 Visual test A

The test samples shall visually be examined to ensure that the condition, workmanship and finish are satisfactory. The marking shall be legible.

9.2.5.3 Visual test B

The test samples should visually be examined under the lighting condition of ten times the normal condition. There shall be no cracks in the glass (base, cover, etc.) or damages to the terminations. Minute flaking around the feather edge of a meniscus shall not be considered a crack.

9.2.5.4 Visual test C

The test samples shall visually be examined. There shall be no corrosion or other deterioration likely to impair satisfactory operation. The marking shall be legible.

9.3 Test conditions for shipment

9.3.1 Temperature dependence of frequency, phase, insertion loss/gain, motional resistance, and electric charge / voltage

The performance of the test samples shall be measured under stepwise changing temperature over the specified range.

The shipment test shall be conducted either at ordinary temperature or according to the specification settled in the contract to be concluded between the manufacturer and customer.

9.3.2 Unwanted response

The measurement of unwanted response shall be applied to sensor elements and cells of quartz crystal BAW resonator type (see 5.4).

9.3.3 Shunt capacitance

Based on the contract of the manufacture and customer, when testing the shunt capacitance C_0 should be ~~measured~~ tested at a frequency far below the fundamental resonance frequency at which sensor elements are not badly affected by acoustic responses.

NOTE The shunt capacitance for sensor elements of non-acoustic type is not defined.

9.3.4 Insulation resistance

The insulation resistance measurement using DC voltage and its conditions shall be discussed between the manufacturer and customer, and shall be settled by the contract.

The insulation resistance shall be larger than the value specified in the relevant detailed specification.

Annex A
(normative)

Measurement methods

A.1 General

Annex A applies to measurement methods and systems for quality management of piezoelectric sensor elements and cells.

A.2 Measurement methods using reflection and transmission characteristics

Figure A.1, Figure A.2 and Figure A.3 show the measurement methods using the reflection and transmission characteristics, respectively, for sensor elements and cells of BAW and SAW resonator types, and SAW delay-line type. The methods are basically defined in IEC 60444-1, IEC 60444-5, IEC 61019-1.

NOTE The part surrounded by the broken line in Figures A.1 to A.3 represents the test fixture.

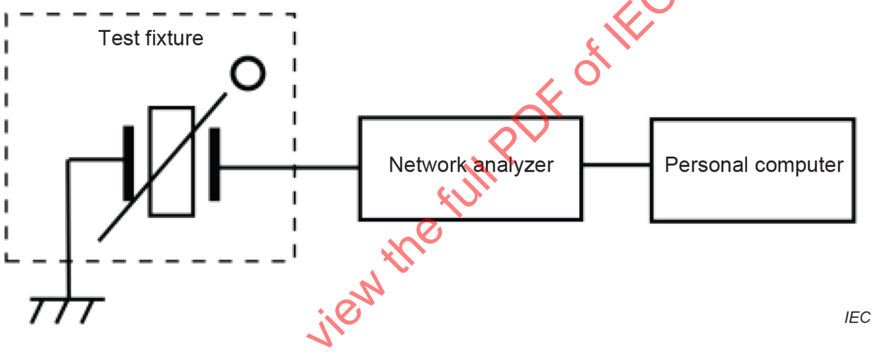

Figure A.1 – Measurement method using reflection characteristics of BAW resonator type sensor elements and cells

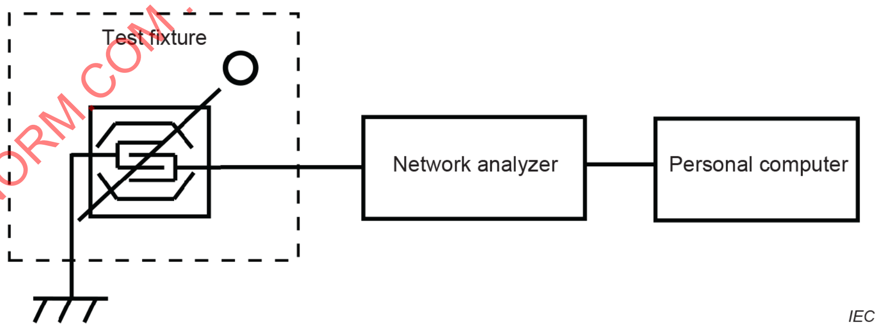

Figure A.2 – Measurement method using reflection characteristics of SAW resonator type sensor elements and cells

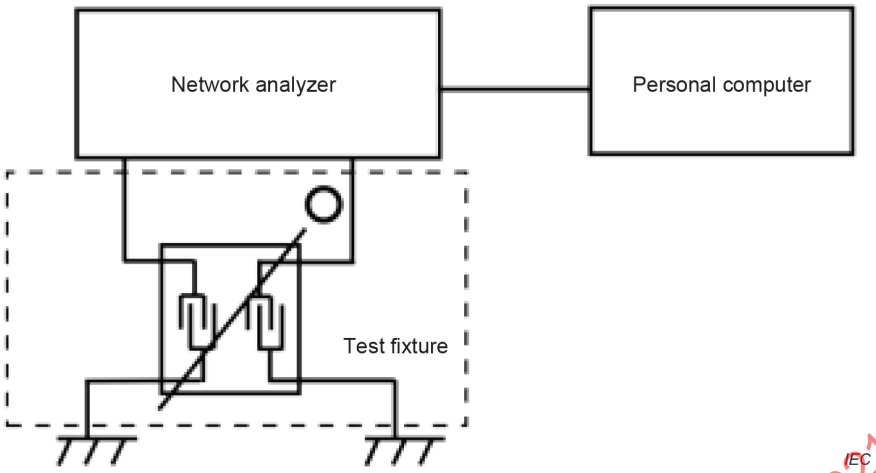

Figure A.3 – Measurement method using transmission characteristics of SAW delay-line type sensor elements and cells

A.3 Measurement methods using oscillation circuits

For a simplified measurement of frequency, the block diagrams of the oscillation method are shown in Figure A.4, Figure A.5 and Figure A.6.

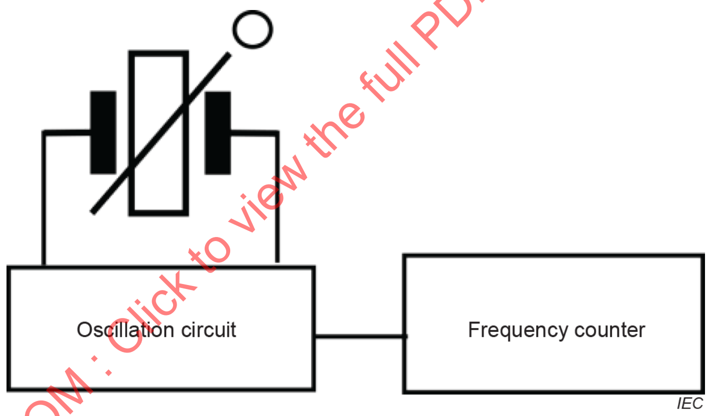

Figure A.4 – Measurement method using oscillation circuit consisting of BAW resonator type sensor elements and cells

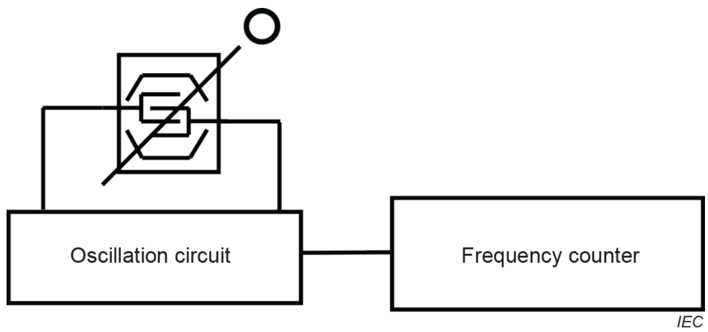

Figure A.5 – Measurement method using oscillation circuit consisting of SAW resonator type sensor elements and cells

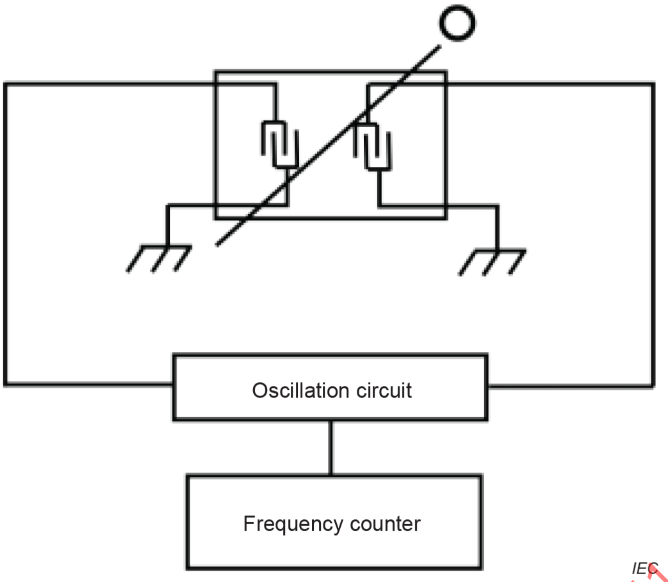

Figure A.6 – Measurement method using oscillation circuit consisting of SAW delay-line type sensor elements and cells

A.4 Measurement method of non-acoustic type sensor elements and cells

The block diagram for a simplified measurement of electric charge/voltage is shown in Figure A.7.

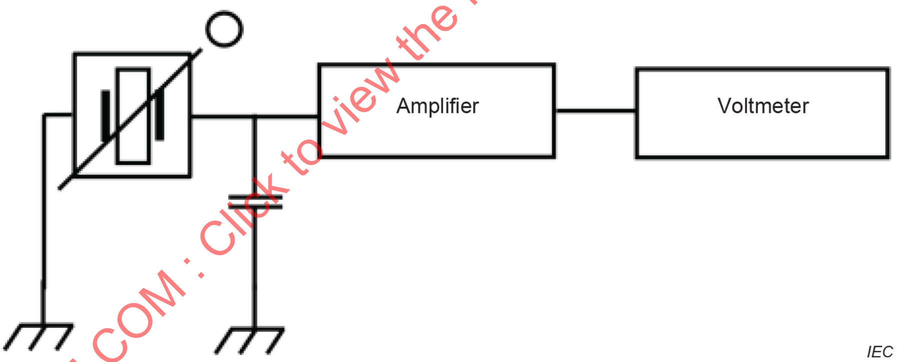

Figure A.7 – Measurement method using amplifier consisting of non-acoustic type sensor elements and cells

A.5 Other measurement methods

Other measurement methods shall clearly be defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

Annex B
(normative)

Detection methods

B.1 General

Annex B describes some basic methods of utilizing piezoelectric sensor elements and cells of resonator and delay-line types. The output of the sensor elements and cells is obtained as a change in their frequency, phase, delay, insertion loss/gain, etc. in response to detected physical quantities or chemical and biochemical reactions. Accordingly, the detection is conventionally carried out by the following methods.

B.2 Detection methods

B.2.1 Frequency difference measurement

The method measures a frequency difference between the two signals generated by the oscillation circuits employing the detecting and reference sensor elements and cells as shown in Figure B.1.

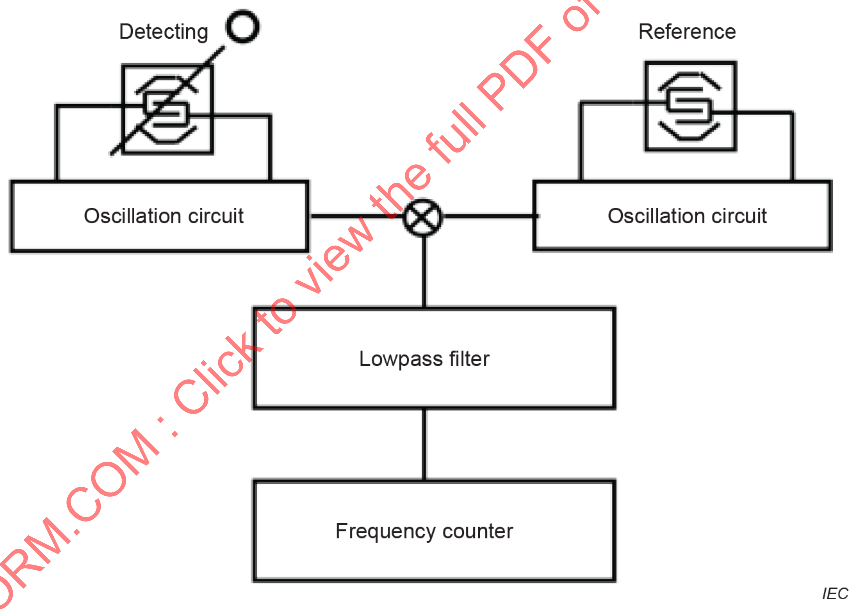

Figure B.1 – Measurement of frequency difference using two oscillation circuits

A frequency synthesizer may be used as a source of the reference frequency as shown in Figure B.2.

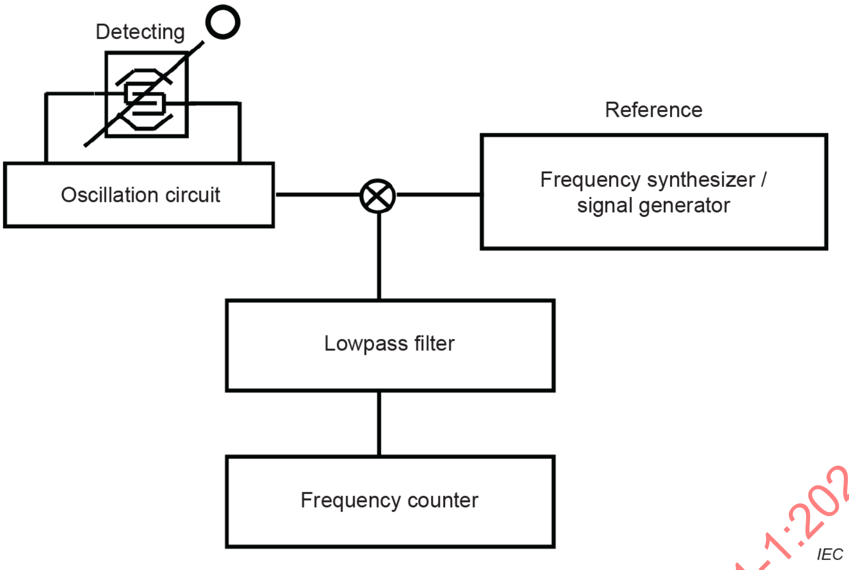

Figure B.2 – Measurement of frequency difference using an oscillation circuit and frequency synthesizer

Piezoelectric resonators have several vibration modes with different characteristics that can be used to connect two oscillator circuits to one piezoelectric sensor element, as shown in Figure B.3. In this figure, two oscillation frequencies with different characteristics can be obtained, and the difference of two oscillation frequencies is the output frequency of the piezoelectric dual mode sensor module.

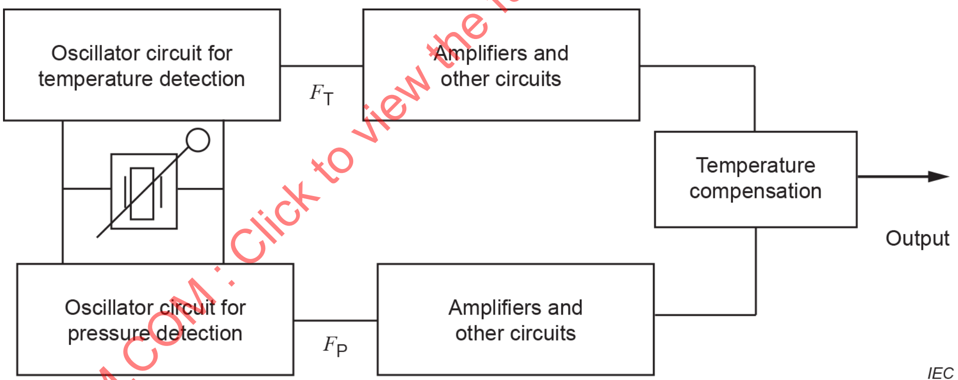

Figure B.3 – Conceptual diagram of piezoelectric dual mode sensor module

NOTE Quartz crystal sensor elements and cells have many vibration modes, and the main vibration mode is used for the main measurement target. Figure B.3 shows an example of a pressure measurement system. The frequency change of the temperature sensor part is used to compensate the unexpected error of the measurement frequency due to the temperature change of the sensor element.

B.2.2 Insertion loss/gain measurement

If an automatic gain control circuit is added, then the measurement of a change in insertion loss/gain is made possible for the oscillation signal of the detecting sensor elements and cells (see Figure B.4).

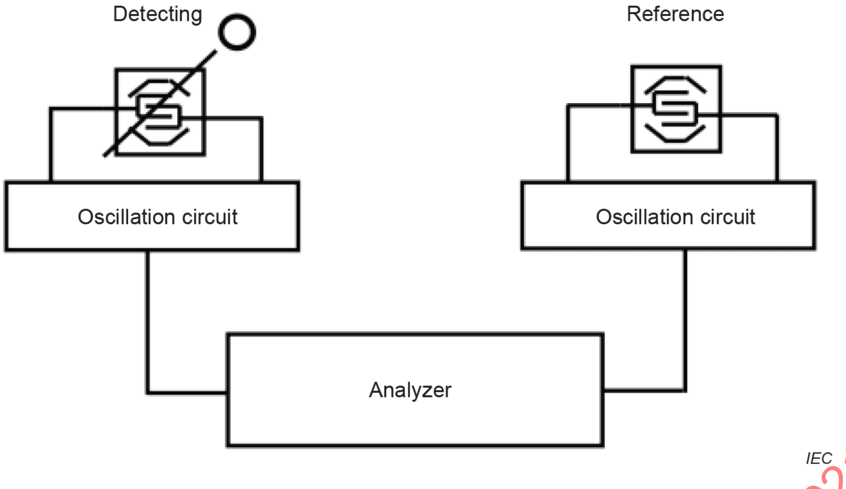

Figure B.4 – Measurement of insertion loss/gain difference using two oscillation circuits

B.2.3 Phase difference measurement

For delay-line type sensor elements and cells, a phase difference between the input and output signals is measured, as shown in Figure B.5.

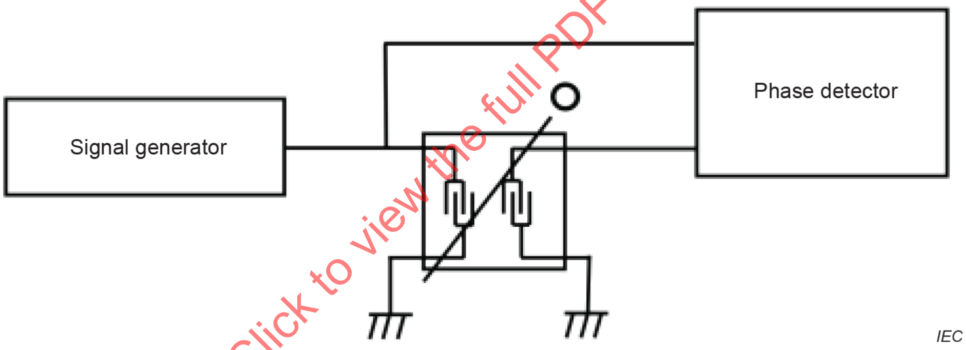

Figure B.5 – Measurement of phase difference using signal generator and phase detector

B.2.4 Other detection methods

The measurement methods shown in Figures A.1 to A.7 may be also used as detection methods.

Annex C
(normative)

Wireless SAW sensor

C.1 General

Annex C describes some basic methods of utilizing piezoelectric sensor elements and cells of resonator and delay-line types.

C.2 Detection methods

C.2.1 General

The output of the sensor elements and cells are obtained as a change in their frequency, phase, delay, amplitude, etc. in response to detected physical quantities.

C.2.2 Conceptual diagrams of wireless SAW resonator type sensor system

Figure C.1 shows the wireless SAW resonator type sensor system that mainly measures the frequency. The physical properties determined from change in frequency are temperature, pressure, strain, etc.

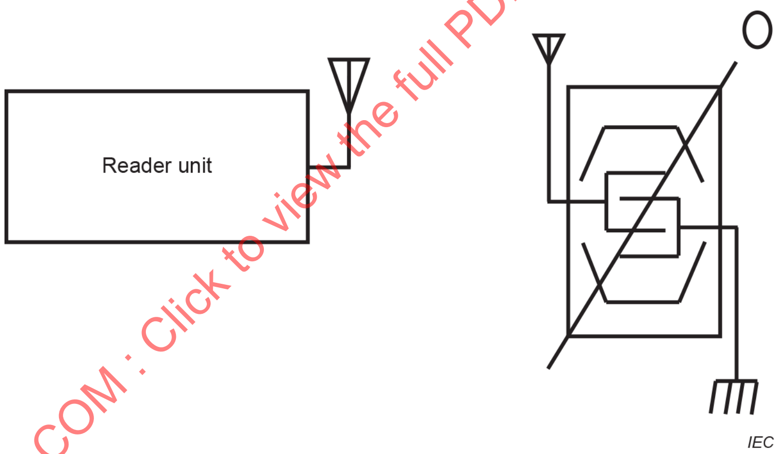

Figure C.1 – Fundamental measurement system of wireless SAW resonator type sensor

C.2.3 Conceptual diagrams of wireless SAW reflective delay-line type sensor system

Figure C.2 shows the wireless SAW reflective delay-line type that measures phase, delay, amplitude, etc. See 4.2 and Figure 4 of IEC 63041-3:2020.

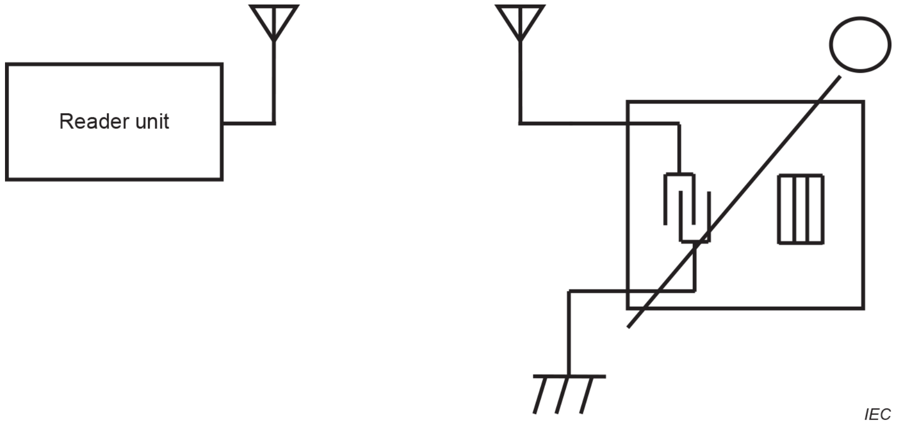

Figure C.2 – Fundamental measurement system of wireless SAW reflective delay-line type sensor

C.2.4 Key points of detection mechanism

When a signal is transmitted from the reader unit to the wireless SAW sensor element or cell, the antenna connected to this sensor element or cell receives this signal, and the surface acoustic wave is generated in this sensor element or cell.

For example, in the case of Figure C.2, the surface acoustic wave of the sensor element or cell is reflected by the reflector electrode, this reflected wave is converted into a signal by the IDT, and returns to the reader unit via the antenna. This reflected wave changes when the measurement value of the sensor element or cell changes. As a result, the signal returned to the reader unit changes.

C.2.5 Technical documents

The following items a) to d) shall clearly be defined in the specifications to be concluded between the manufacturer and customers:

a) selection of measurement system (resonator type or delay-line type).

b) parameters to be detected such as frequency, phase, delay and amplitude.

c) distance between reader antenna and SAW sensor antenna.

d) other.

Bibliography

IEC 60068 (all parts), *Environmental testing*

IEC 60122-1, *Quartz crystal units of assessed quality – Part 1: Generic specification*

IEC 60642, *Piezoelectric ceramic resonators and resonator units for frequency control and selection – Chapter I: Standard values and conditions – Chapter II: Measuring and test conditions*

IEC 60444-1, *Measurement of quartz crystal unit parameters by zero phase technique in a pi network – Part 1: Basic method for the measurement of resonance frequency and resonance resistance of quartz crystal units by zero phase technique in a pi-network*

IEC 60444-5, *Measurement of quartz crystal unit parameters – Part 5: Methods for the determination of equivalent electrical parameters using automatic network analyzer techniques and error correction*

IEC 60679 (all parts), *Piezoelectric, dielectric and electrostatic oscillators of assessed quality*

IEC 60689, *Measurements and test methods for tuning fork quartz crystal units in the range from 10 kHz to 200 kHz and standard values*

IEC 60758:2016, *Synthetic quartz crystal – Specifications and guidelines for use*

IEC 60862-1, *Surface acoustic wave (SAW) filters of assessed quality – Part 1: Generic specification*

IEC 61019-1, *Surface acoustic wave (SAW) resonators – Part 1: Generic specification*

IEC 61240:2016, *Piezoelectric devices – Preparation of outline drawings of surface-mounted devices (SMD) for frequency control and selection – General rules*

IEC 61760 (all parts), *Surface mounting technology*

IEC 61837 (all parts), *Surface mounted piezoelectric devices for frequency control and selection – Standard outlines and terminal lead connections*

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IEC 63041-2, *Piezoelectric sensors – Part 2: Chemical and biochemical sensors*

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IEC 63041-1

Edition 2.0 2021-09

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Piezoelectric sensors –
Part 1: Generic specifications

Capteurs piézoélectriques –
Partie 1: Spécifications génériques

IEC 63041-1:2021-09(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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PIEZOELECTRIC SENSORS –

Part 1: Generic specifications

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.
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IEC 63041-1 has been prepared by IEC technical committee 49: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection. It is an International Standard.

This second edition cancels and replaces the first edition published in 2017. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) the new terms "piezoelectric sensor system" and "wireless SAW sensor system" and their definitions have been added;
b) new types of sensor modules and sensor system have been added;
c) some symbols of sensor elements are added in Clause 4;
d) a new Figure B.3 has been added in Annex B;
e) Annex C has been added.

The text of this International Standard is based on the following documents:

Draft	Report on voting
49/1357/CDV	49/1364/RVC

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 International Standard 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 63041 series, published under the general title *Piezoelectric sensors*, 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.

PIEZOELECTRIC SENSORS –

Part 1: Generic specifications

1 Scope

This part of IEC 63041 applies to piezoelectric sensors of resonator, delay-line and non-acoustic types, which are used in physical and engineering sciences, chemistry and biochemistry, medical and environmental sciences, etc.

The purpose of this document is to specify the terms and definitions for piezoelectric sensors, and to make sure from a technological perspective that users understand the state-of-art piezoelectric sensors and how to use them correctly.

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.

IEC 60027 (all parts), *Letter symbols to be used in electrical technology*

IEC 60050-561, *International Electrotechnical Vocabulary – Part 561: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection*

IEC 60122-2-1, *Quartz crystal units for frequency control and selection – Part 2: Guide to the use of quartz crystal units for frequency control and selection – Section One: Quartz crystals for microprocessor clock supply*

IEC 60444-9, *Measurement of quartz crystal unit parameters – Part 9: Measurement of spurious resonances of piezoelectric crystal units*

IEC 60617, *Graphical symbols for diagrams,* available at https://std.iec.ch/iec60617

IEC 63041-3:2020, *Piezoelectric sensors – Part 3: Physical sensors*

ISO 2859-1:1999, *Sampling procedures for inspection by attributes – Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

ISO 80000-1, *Quantities and units – Part 1: General*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60027, IEC 60050-561, IEC 60617, ISO 80000-1 and the following apply.

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

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

NOTE Piezoelectric sensors covered herein are those used for the detection and measurement of physical quantities, chemical substances or biological molecules.

3.1 Piezoelectric sensors

3.1.1
piezoelectric sensor element
electronic component which is able to detect physical quantities as a change in its frequency, phase, delay, electrical charge, resistance, Q-value, bandwidth, etc.

Note 1 to entry: For chemical and biochemical sensor applications, the piezoelectric sensor element includes a sensitive or receptive layer (target recognition material).

3.1.2
resonator type sensor element
piezoelectric sensor component using acoustic resonances

3.1.3
delay-line type sensor element
piezoelectric sensor component using a delay-line of surface acoustic wave (SAW) transversal filter type

3.1.4
non-acoustic type sensor element
piezoelectric sensor component using the electrical charge induced by a quasi-static force, torque or the like

Note 1 to entry: Here, the term, "non-acoustic", represents "quasi-static piezoelectric". Accordingly, the (piezoelectric) non-acoustic type sensor element means a sensor element using the quasi-static piezoelectric effect.

3.1.5
piezoelectric sensor cell
sensor element equipped with necessary mechanical accessories and attachments to correctly detect the parameters to be measured

3.1.6
piezoelectric sensor module
sensor element or cell equipped with electronic accessories for interfacing to external data acquisitions

3.1.7
piezoelectric sensor system
organized system including detection, amplification of detected value, communication with other equipment and analysis of detected value

Note 1 to entry: Here, these functions cooperate mutually.

3.1.8
piezoelectric sensor
generic term that includes a sensor element, cell, module and system

3.1.9
QCM
quartz crystal microbalance
one of the families of chemical and biochemical sensors using crystal resonators

Note 1 to entry: A thickness shear mode (TSM) sensor is identical with a QCM.

3.2 Types of chemical sensors

3.2.1
piezoelectric chemical sensor element
piezoelectric sensor component including a sensitive layer (target recognition material), which is necessary for the practical measurement of simple non-biological molecules in quantity, and which works and detects chemical substances mainly in the gas phase

Note 1 to entry: A gas sensor element is one of the chemical sensor elements.

3.2.2
piezoelectric biochemical sensor element
piezoelectric sensor component including a receptive layer (target recognition material), which is necessary for the practical measurement of complex biological molecules in quantity, and which works mainly in aqueous media and detects biomolecules therein

3.3 Types of physical sensors

3.3.1
piezoelectric force sensor element
piezoelectric sensor component whose resonance frequency, delay or electrical charge/voltage is used for force measurement

3.3.2
piezoelectric pressure sensor element
piezoelectric sensor component whose resonance frequency, delay or electrical charge/voltage is used for pressure measurement

3.3.3
piezoelectric torque sensor element
piezoelectric sensor component whose resonance frequency, delay or electrical charge/voltage is used for torque measurement

3.3.4
piezoelectric viscosity sensor element
piezoelectric sensor component whose resonance frequency, delay or insertion loss/gain is used for viscosity measurement

3.3.5
piezoelectric temperature sensor element
piezoelectric sensor component whose resonance frequency or delay is used for temperature measurement

3.3.6
piezoelectric film-thickness sensor element
piezoelectric sensor component whose resonance frequency is used for film-thickness measurement

3.4 Types of sensor modules

3.4.1
wireless SAW sensor module
piezoelectric sensor element or cell equipped with an antenna for wirelessly connecting with interrogation unit

Note 1 to entry: Here, the resonator and delay line type elements of the SAW are used for the piezoelectric sensor element or cell.

3.4.2
dual mode sensor module
dual mode sensor element or cell equipped with circuit units for temperature compensation and electronic accessories for interfacing to external data acquisitions

Note 1 to entry: Dual mode sensor is a piezoelectric sensor which is able to detect physical quantities from a change in resonance frequencies of two independent modes on a single piezoelectric plate (see IEC 63041-3:2020, 3.1.5).

3.5 Types of sensor systems

3.5.1
wireless SAW sensor system
generic term that includes wireless SAW sensors and reader unit for sending and receiving RF signals

SEE: Annex C.

3.5.2
dual mode sensor system
generic term that includes dual mode quartz crystal sensor modules, electric device, PC, memory, wired or wireless devices, software, etc.

4 Symbols of sensor elements

4.1 General

Figures 1 to 6 show the conceptual diagrams and defined symbols for sensor elements of bulk acoustic wave (BAW) resonator, SAW resonator and SAW delay-line types. The symbols are essentially the same as those given in IEC 60122-1, IEC 61019-1 and IEC 60862-1.

Figure 7 and Figure 8 show the conceptual diagram and defined symbol for sensor elements of non-acoustic type.

Figures 9 to 12 show the conceptual diagram and defined symbol for sensor elements of wireless SAW resonator and SAW delay-line types. This is shown in Annex C.

NOTE The diagonal line in Figure 2, Figure 4, Figure 6, Figure 8, Figure 10 and Figure 12 shows an emblem expressing changes in objects to be measured.

For letter symbols (see 4.7) showing the types of sensors, these symbols should be defined in the circle at the upper right corner of Figure 2, Figure 4, Figure 6, Figure 8, Figure 10 and Figure 12, and for each sensor application.

4.2 Symbol for sensor elements of BAW resonator type

Figure 1 shows the conceptual diagrams for sensor elements of BAW resonator type from which a mounting portion is omitted. Figure 2 shows the symbol for sensor elements of BAW resonator type.

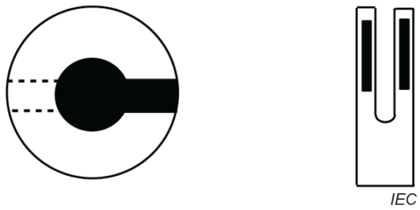

Figure 1 – Conceptual diagrams for sensor elements of BAW resonator type

NOTE Figure 1 shows examples of disk type and tuning fork type sensor elements.

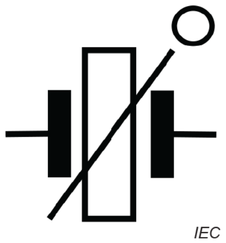

Figure 2 – Symbol for sensor elements of BAW resonator type

4.3 Symbol for sensor elements of SAW resonator type

Figure 3 and Figure 4 show, respectively, the conceptual diagram and symbol for sensor elements of SAW resonator type.

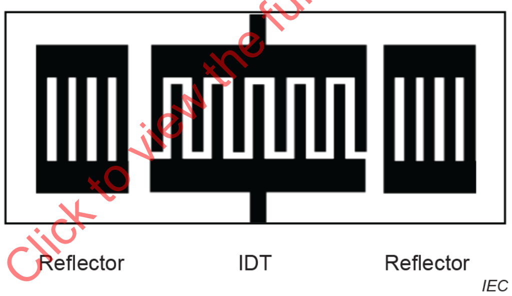

Figure 3 – Conceptual diagram of sensor elements of SAW resonator type

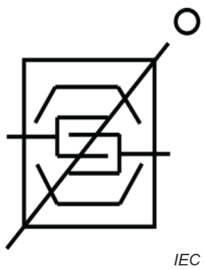

Figure 4 – Symbol for sensor elements of SAW resonator type

4.4 Symbol for sensor elements of SAW delay-line type

Figure 5 and Figure 6 show, respectively, the conceptual diagram and symbol for sensor elements of SAW delay-line type.

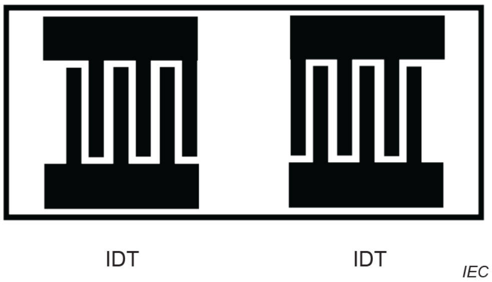

Figure 5 – Conceptual diagram for sensor elements of SAW delay-line type

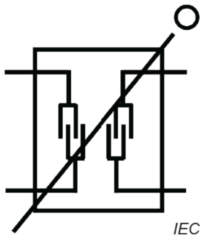

Figure 6 – Symbol for sensor elements of SAW delay-line type

4.5 Symbol for sensor elements of non-acoustic type

Figure 7 shows the conceptual diagrams for sensor elements of non-acoustic type from which a mounting portion is omitted. Figure 8 shows the symbol for sensor elements of non-acoustic type.

Figure 7 – Conceptual diagrams for sensor elements of non-acoustic type

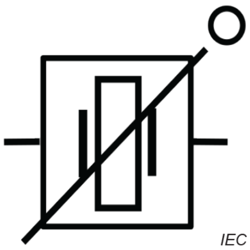

Figure 8 – Symbol for sensor elements of non-acoustic type

4.6 Symbol for wireless SAW sensor element

Figures 9 to 12 show, respectively, the conceptual diagram and symbol for sensor elements of wireless SAW resonator and delay-line type.

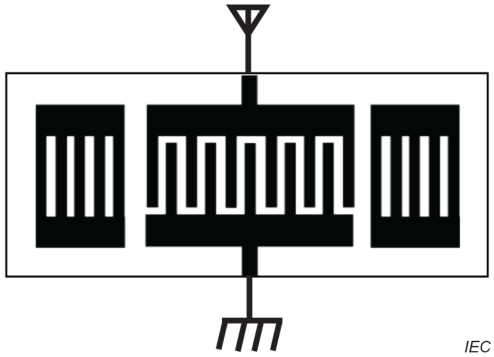

Figure 9 – Conceptual diagram for basic sensor elements of wireless SAW resonator type

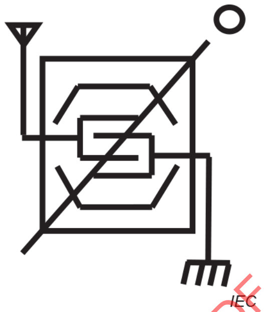

Figure 10 – Symbol for basic sensor elements of wireless SAW resonator type

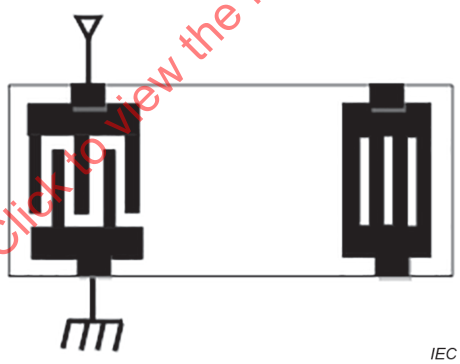

Figure 11 – Conceptual diagram for basic sensor elements of wireless SAW reflective delay-line type

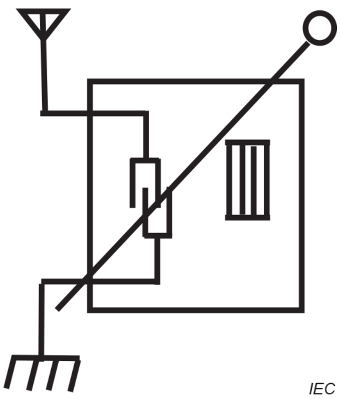

Figure 12 – Symbol for basic sensor elements of wireless SAW reflective delay-line type

NOTE Patch antenna is a type of low-profile wireless antenna that can be mounted on a flat surface and is connected to the SAW element and cells.

4.7 Symbols

The symbols put in the circle at the upper right corner in Figure 2, Figure 4, Figure 6, Figure 8, Figure 10 and Figure 12 are defined below (see the ISO 80000 series):

a) film-thickness: d;

b) force: F;

c) mass: m;

d) density: ρ;

e) pressure: P;

f) temperature: T;

g) torque: τ;

h) viscosity: υ.

In chemical, biochemical and gas sensor applications, antigen-antibody or chemical reaction occurs between the sensitive or receptive layer and target substances, which is detected as a change in mass density, viscosity or shear modulus of the sensitive or receptive layer. Accordingly, the following specific symbols are defined for biochemical, chemical and gas sensor elements:

i) biochemical: Bi;

j) chemical: Ch;

k) gas: Ga.

5 Specifications

5.1 Sensor elements

5.1.1 General

In consideration of the target sensitivity, dynamic range or the like, the specifications of sensor elements and cells shall be determined. They should be defined clearly in the contract to be concluded between the manufacturer and customers.

Subclauses 5.1.2 and 5.1.3 present key points to be described in the specifications. These elements should be specified numerically unless confidential technological information is concerned.

5.1.2 Sensor elements of resonator and delay-line types

Sensor elements of resonator and delay-line types include the following:

a) range of measurand;

b) sensitivity of output signal with respect to measurand;

c) nominal frequency;

d) frequency tolerance;

e) parameters of equivalent circuit;

f) operating temperature range;

g) unwanted response;

h) level of drive or input power;

i) insertion loss/gain;

j) delay time (for sensor elements of SAW delay-line type);
k) phase response;
l) piezoelectric material, cut angle, or the like;
m) electrode material, dimension, shape, structure or the like;
n) mounting material, dimension, shape, structure or the like;
o) dimensions of enclosure, or name, model number or the like corresponding thereto;
p) category of environmental test;
q) others.

5.1.3 Sensor elements of non-acoustic type

Sensor elements of non-acoustic type include the following:

a) operating temperature range;
b) piezoelectric material, cut angle, dimension, shape, structure or the like;
c) electrode material, dimension, shape, structure or the like;
d) mounting material, dimension, shape, structure or the like;
e) dimensions of enclosure, or name, model number or the like corresponding thereto;
f) category of environmental test;
g) others.

5.2 Frequency ranges

The frequency range applied herein should be 10 kHz to 10 GHz.

When one of the higher-order overtones is used or the frequency deviates from the specified range, the manufacturer and customer shall consult, and the results shall clearly be defined in the contract.

NOTE The frequency ranges for sensor elements of non-acoustic type are not defined.

5.3 Level of drive or input power

For sensor elements and cells, the level of drive or input power shall be limited so that an influence of "heat generation" or a "non-linear effect" does not deteriorate their performance.

NOTE The level of drive or input power for non-acoustic type sensor elements is not defined.

5.4 Unwanted response

Unwanted responses shall be measured based on IEC 60444-9. This rule shall be applied only to sensor elements of BAW resonator type.

According to IEC 60122-2-1, the ratio of the motional resistance R_N for the unwanted response to R_1 for the main response (N = R_N/R_1) shall be two and a half times or more.

NOTE Conceptually, the sensitivity increases with an increase in the electrode area, which reduces the ratio of R_N/R_1. Under this situation, unwanted responses affect the main response, and sensor elements of BAW resonator type occasionally oscillate, caused by the unwanted response.

5.5 Analysis of measurements

Electronic circuits and measuring instruments are generally used in sensor systems. The output signals such as frequency, phase, insertion loss/gain, electrical charge / voltage, etc., and their response functions and graphs are obtained as system data.

The rule on how to apply this system data to data analyses shall clearly be defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

NOTE The response function based on the linear response theory is effective in the analysis of acoustic wave sensor elements and cells of resonator and delay-line types. For example, it is possible for the frequency response to predict the resonant response levels of the acoustic wave sensor.

5.6 Enclosure

Holder specifications shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

5.7 Performance confirmation

The basic performance of sensor elements and cells such as the minimum and maximum detection limits, dynamic range, sensitivity, etc. should be specified.

5.8 Long-term and short-term stabilities

At the time of the measurement, attention should be paid to long-term stability as well as to short-term stability affected by a background noise such as an electronic and/or foreign noise.

The specifications for long-term and short-term stabilities shall clearly be defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

NOTE The long-term and short-term stabilities for sensor elements of non-acoustic type are not defined.

5.9 Transmission power

Transmit power and communication distance are related to the electric field strength of wireless SAW sensor systems. This should be dealt with in accordance with the country specific radio laws and regulations.

6 Measurement and detection methods

Required measurement and detection methods are shown in Annex A to Annex C.

7 Delivery conditions

7.1 Marking

The content to be marked should be selected at least out of the following items. Moreover, the marking shall be made at the place from which sensor elements and cells can easily be viewed to the greatest extent possible. If such a place is unavailable, the marking shall be made on a packing plane.

a) type designation as defined in the detailed specifications;
b) year and week (four digits) of manufacture, or serial number;
c) factory identification code;
d) name of manufacturer or trademark;
e) country of production;
f) mark of conformity (unless a certificate of conformity is used).

7.2 Wrapping

In the wrapping of sensor elements and cells, sealing is desirable. Moreover, vacuum wrapping must also be taken into consideration. This rule shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

7.3 Packaging

The packaging specifications shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

8 Quality and reliability

8.1 Reuse

Reuse of sensor elements and cells shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

8.2 Validity of release

Inspection before shipment and re-inspection when the products are stored for a predetermined period of time and then shipped, shall be clearly defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

8.3 Test procedures

Test procedures to be used shall be selected from this document. If any required test is not found, then it shall be defined in detailed individual specifications.

8.4 Screening requirements

Where screening by the customer is required for sensor elements and cells, this shall be defined in the detailed individual specifications.

8.5 Unchecked parameters

Only those parameters of sensor elements and cells which have been described in detailed specifications and which were subjected to testing can be assumed to be within the specified limits. It should not be assumed that any parameter not specified will remain unchanged from one sensor element and cell to another. Should it be necessary for further unchecked parameters to be verified, then new, more extensive and detailed specifications should be prepared. The additional test method(s) shall be fully described with appropriate limits, AQLs and inspection levels specified (see ISO 2859-1).

9 Test and measurement procedures

9.1 General

9.1.1 Test classification

The tests are classified into tests for shipping products, and mechanical and environmental tests for confirming the reliability of products.

9.1.2 Shipping test

The test is conducted to confirm whether sensor elements and cells maintain the state satisfying the contract between the manufacturer and customer when unsealed sensor elements are shipped. The following shall be clearly defined in the contract between the manufacturer and customer, or individual specifications.

a) When the specifications can presumably be sufficiently ensured, no inspection or sampling inspection shall be allowed.

b) When inspections are required, all sensor elements and cells shall be inspected.

9.1.3 Mechanical and environmental test

9.1.3.1 General

Tests should be conducted to confirm whether or not sensor elements and cells have predetermined performances. Regarding test samples, those sealed into enclosures shall be used. When no sealing is required, however, such samples may also be used.

9.1.3.2 Test samples

With regard to all test samples, the sensor elements and cells which maintain the state meeting the contract between the manufacturer and customer shall be used. Selection of the test sample shall be clearly defined in the contract between the manufacturer and customer, or in individual specifications.

9.1.3.3 Test items

Test items such as vibration, shock, thermal shock, heat resistance, bump, salt fog, ageing, bending of enclosure and the like are strongly dependent upon the requirement specifications of sensor elements and cells. Therefore, the test items shall be discussed between the manufacturer and customer, and shall be settled by the contract.

9.2 Test and measurement conditions

9.2.1 Standard conditions for testing

Unless otherwise specified, all of electrical tests shall be conducted under the following conditions;

– temperature 15 °C to 35 °C;
– relative humidity 45 % to 75 %;
– atmosphere 86 kPa to 106 kPa (860 mbar to 1 060 mbar).

If any doubt may arise, the following conditions shall be applied;

– temperature 25 °C ± 2 °C;
– relative humidity 48 % to 52 %;

Before starting the measurement, the test samples shall be stored at the measurement (inspection) temperature for a period of time enough to reach the thermal equilibrium state. The ambient temperature during the measurement shall be recorded in the test report.

9.2.2 Equilibrium state

Unless otherwise specified, all of the electrical tests shall be conducted under an equilibrium state. In the case where the test state causes significant time dependence on the measurement of characteristics, a means for compensating such dependence shall be specified.

9.2.3 Power supply

When the oscillation method (see Clause A.3) is employed, a direct current power supply to be used for testing samples should have no ripples which influence the measurement accuracies required. An alternate current power supply shall have no transient response characteristics. When the ripples and transient response characteristics influence the measurement, such an influence shall clearly be described in individual standards.

9.2.4 Alternative test system

Measurement shall be conducted according to specified methods as much as possible. If there is no doubt, another method by which equivalent results are expected may be applied.

NOTE "Equivalent" means that the measured values obtained by the alternative test method are correlated to the specified method.

9.2.5 Visual inspection

9.2.5.1 General

Unless otherwise specified, external visual examination shall be performed under normal factory lighting and visual conditions.

9.2.5.2 Visual test A

The test samples shall visually be examined to ensure that the condition, workmanship and finish are satisfactory. The marking shall be legible.

9.2.5.3 Visual test B

The test samples should visually be examined under the lighting condition of ten times the normal condition. There shall be no cracks in the glass (base, cover, etc.) or damages to the terminations. Minute flaking around the feather edge of a meniscus shall not be considered a crack.

9.2.5.4 Visual test C

The test samples shall visually be examined. There shall be no corrosion or other deterioration likely to impair satisfactory operation. The marking shall be legible.

9.3 Test conditions for shipment

9.3.1 Temperature dependence of frequency, phase, insertion loss/gain, motional resistance, and electric charge / voltage

The performance of the test samples shall be measured under stepwise changing temperature over the specified range.

The shipment test shall be conducted either at ordinary temperature or according to the specification settled in the contract to be concluded between the manufacturer and customer.

9.3.2 Unwanted response

The measurement of unwanted response shall be applied to sensor elements and cells of quartz crystal BAW resonator type (see 5.4).

9.3.3 Shunt capacitance

Based on the contract of the manufacture and customer, when testing the shunt capacitance C_0 should be tested at a frequency far below the fundamental resonance frequency at which sensor elements are not badly affected by acoustic responses.

NOTE The shunt capacitance for sensor elements of non-acoustic type is not defined.

9.3.4 Insulation resistance

The insulation resistance measurement using DC voltage and its conditions shall be discussed between the manufacturer and customer, and shall be settled by the contract.

The insulation resistance shall be larger than the value specified in the relevant detailed specification.

Annex A
(normative)

Measurement methods

A.1 General

Annex A applies to measurement methods and systems for quality management of piezoelectric sensor elements and cells.

A.2 Measurement methods using reflection and transmission characteristics

Figure A.1, Figure A.2 and Figure A.3 show the measurement methods using the reflection and transmission characteristics, respectively, for sensor elements and cells of BAW and SAW resonator types, and SAW delay-line type. The methods are basically defined in IEC 60444-1, IEC 60444-5, IEC 61019-1.

NOTE The part surrounded by the broken line in Figures A.1 to A.3 represents the test fixture.

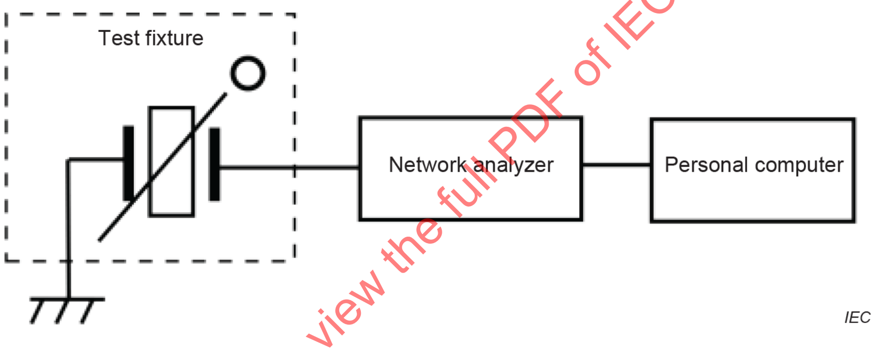

Figure A.1 – Measurement method using reflection characteristics of BAW resonator type sensor elements and cells

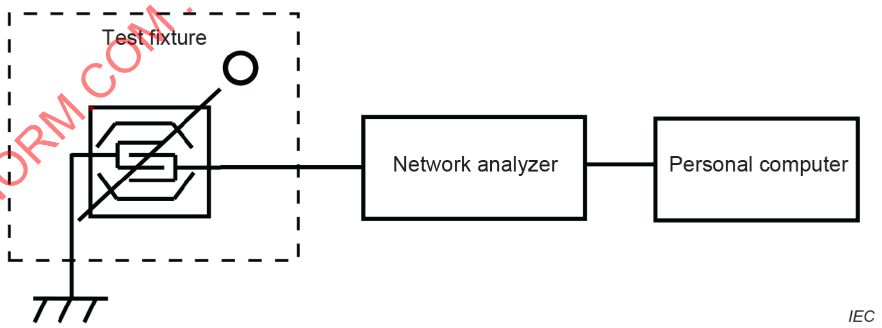

Figure A.2 – Measurement method using reflection characteristics of SAW resonator type sensor elements and cells

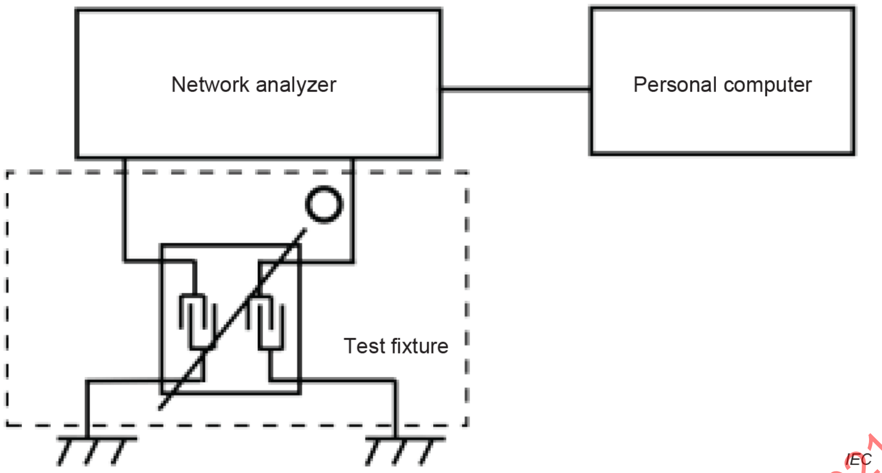

Figure A.3 – Measurement method using transmission characteristics of SAW delay-line type sensor elements and cells

A.3 Measurement methods using oscillation circuits

For a simplified measurement of frequency, the block diagrams of the oscillation method are shown in Figure A.4, Figure A.5 and Figure A.6.

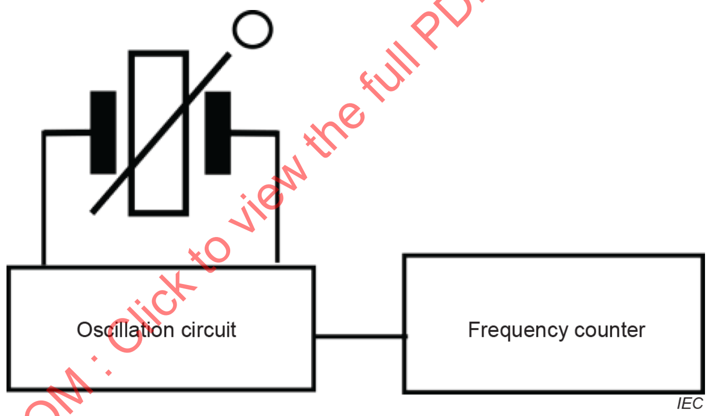

Figure A.4 – Measurement method using oscillation circuit consisting of BAW resonator type sensor elements and cells

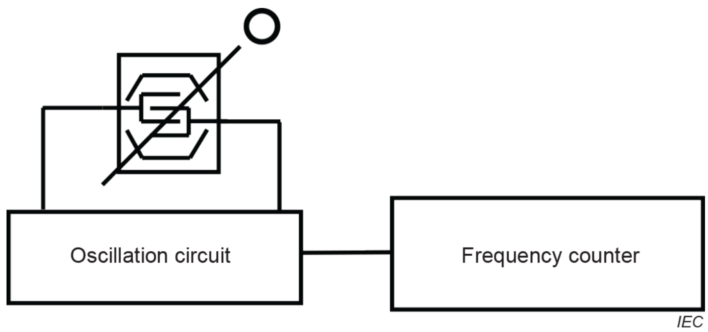

Figure A.5 – Measurement method using oscillation circuit consisting of SAW resonator type sensor elements and cells

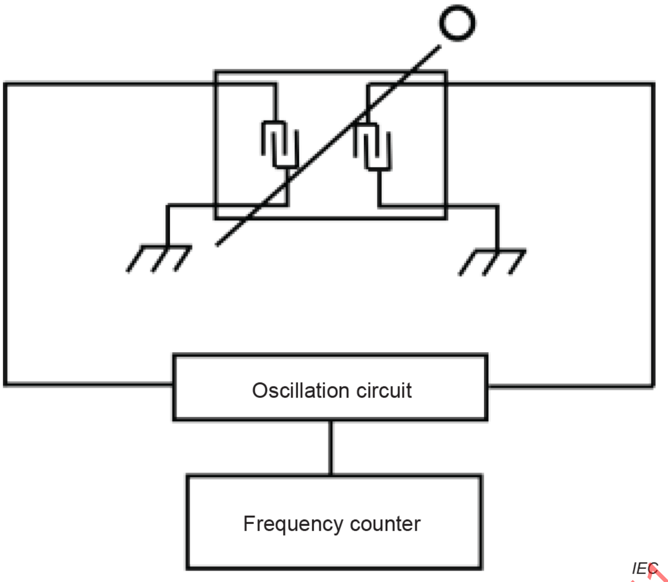

Figure A.6 – Measurement method using oscillation circuit consisting of SAW delay-line type sensor elements and cells

A.4 Measurement method of non-acoustic type sensor elements and cells

The block diagram for a simplified measurement of electric charge/voltage is shown in Figure A.7.

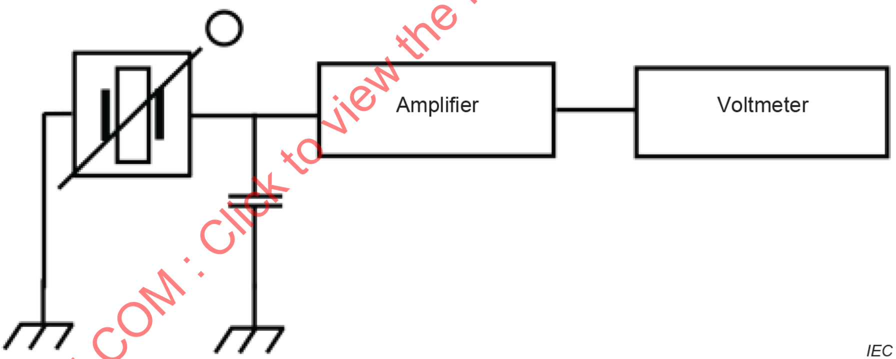

Figure A.7 – Measurement method using amplifier consisting of non-acoustic type sensor elements and cells

A.5 Other measurement methods

Other measurement methods shall clearly be defined in the contract to be concluded between the manufacturer and customer, or in individual specifications.

Annex B
(normative)

Detection methods

B.1 General

Annex B describes some basic methods of utilizing piezoelectric sensor elements and cells of resonator and delay-line types. The output of the sensor elements and cells is obtained as a change in their frequency, phase, delay, insertion loss/gain, etc. in response to detected physical quantities or chemical and biochemical reactions. Accordingly, the detection is conventionally carried out by the following methods.

B.2 Detection methods

B.2.1 Frequency difference measurement

The method measures a frequency difference between the two signals generated by the oscillation circuits employing the detecting and reference sensor elements and cells as shown in Figure B.1.

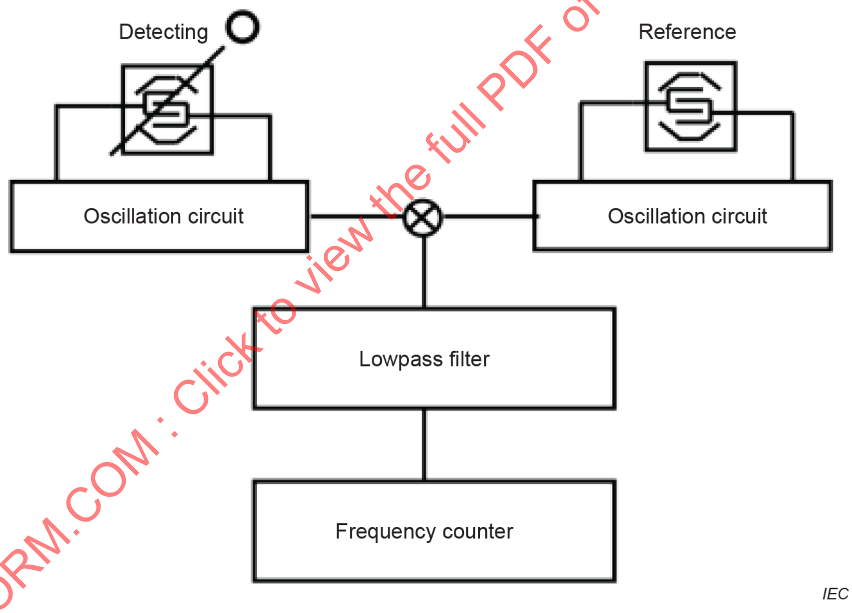

Figure B.1 – Measurement of frequency difference using two oscillation circuits

A frequency synthesizer may be used as a source of the reference frequency as shown in Figure B.2.

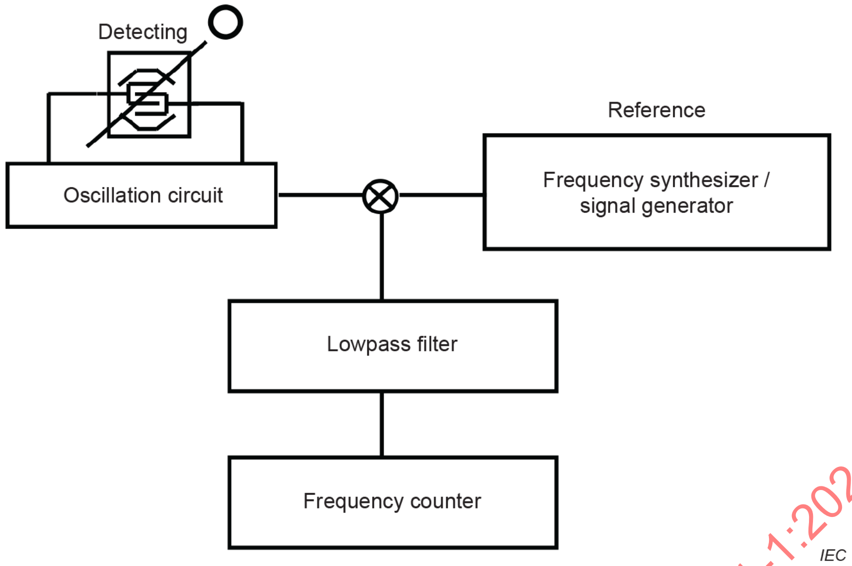

Figure B.2 – Measurement of frequency difference using an oscillation circuit and frequency synthesizer

Piezoelectric resonators have several vibration modes with different characteristics that can be used to connect two oscillator circuits to one piezoelectric sensor element, as shown in Figure B.3. In this figure, two oscillation frequencies with different characteristics can be obtained, and the difference of two oscillation frequencies is the output frequency of the piezoelectric dual mode sensor module.

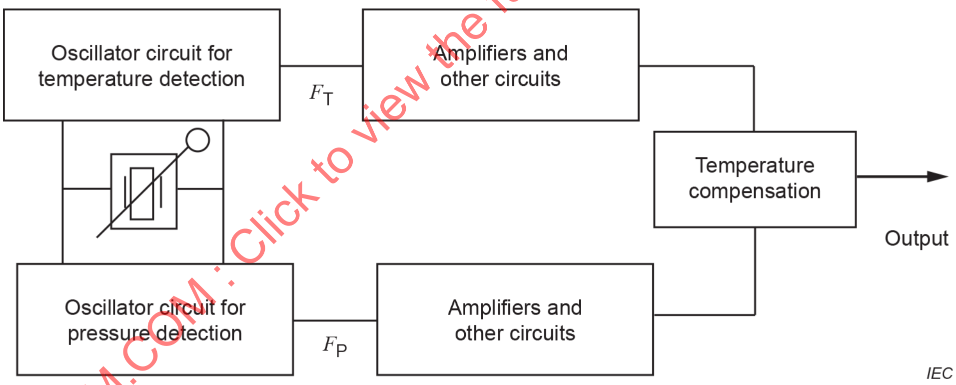

Figure B.3 – Conceptual diagram of piezoelectric dual mode sensor module

NOTE Quartz crystal sensor elements and cells have many vibration modes, and the main vibration mode is used for the main measurement target. Figure B.3 shows an example of a pressure measurement system. The frequency change of the temperature sensor part is used to compensate the unexpected error of the measurement frequency due to the temperature change of the sensor element.

B.2.2 Insertion loss/gain measurement

If an automatic gain control circuit is added, then the measurement of a change in insertion loss/gain is made possible for the oscillation signal of the detecting sensor elements and cells (see Figure B.4).

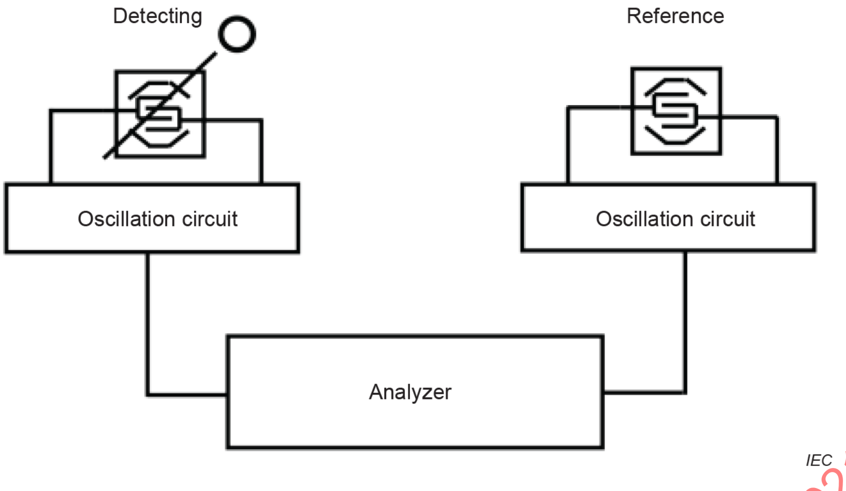

Figure B.4 – Measurement of insertion loss/gain difference using two oscillation circuits

B.2.3 Phase difference measurement

For delay-line type sensor elements and cells, a phase difference between the input and output signals is measured, as shown in Figure B.5.

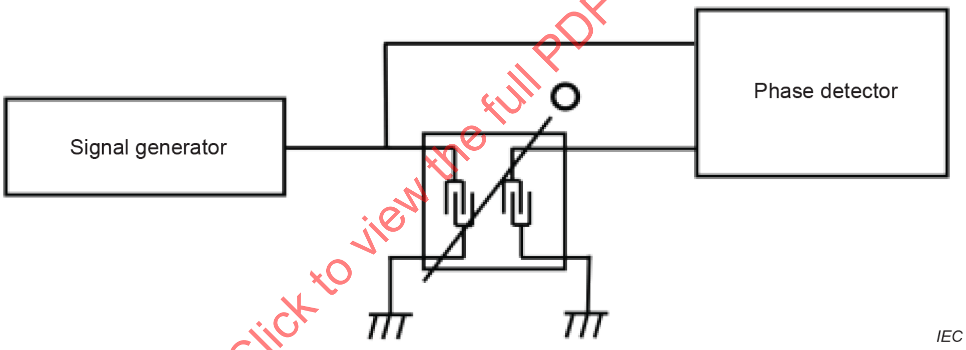

Figure B.5 – Measurement of phase difference using signal generator and phase detector

B.2.4 Other detection methods

The measurement methods shown in Figures A.1 to A.7 may be also used as detection methods.

Annex C
(normative)

Wireless SAW sensor

C.1 General

Annex C describes some basic methods of utilizing piezoelectric sensor elements and cells of resonator and delay-line types.

C.2 Detection methods

C.2.1 General

The output of the sensor elements and cells are obtained as a change in their frequency, phase, delay, amplitude, etc. in response to detected physical quantities.

C.2.2 Conceptual diagrams of wireless SAW resonator type sensor system

Figure C.1 shows the wireless SAW resonator type sensor system that mainly measures the frequency. The physical properties determined from change in frequency are temperature, pressure, strain, etc.

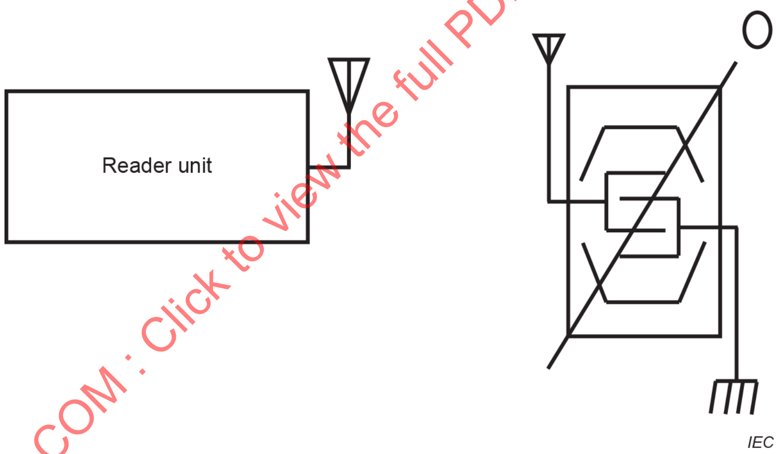

Figure C.1 – Fundamental measurement system of wireless SAW resonator type sensor

C.2.3 Conceptual diagrams of wireless SAW reflective delay-line type sensor system

Figure C.2 shows the wireless SAW reflective delay-line type that measures phase, delay, amplitude, etc. See 4.2 and Figure 4 of IEC 63041-3:2020.

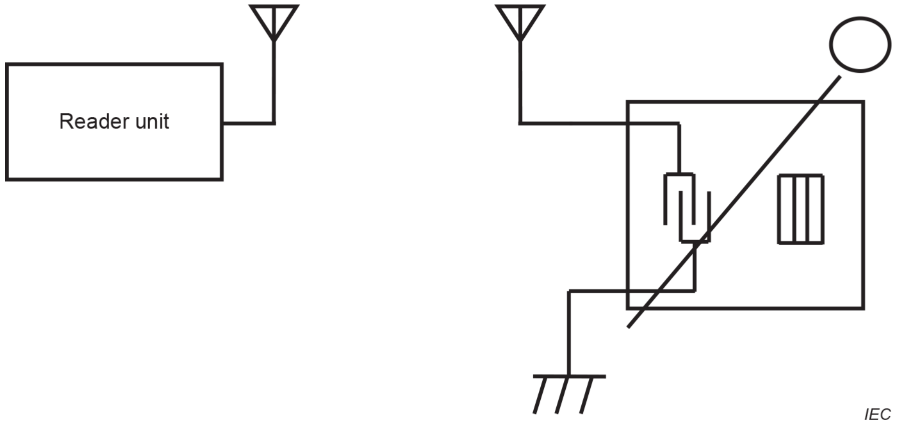

Figure C.2 – Fundamental measurement system of wireless SAW reflective delay-line type sensor

C.2.4 Key points of detection mechanism

When a signal is transmitted from the reader unit to the wireless SAW sensor element or cell, the antenna connected to this sensor element or cell receives this signal, and the surface acoustic wave is generated in this sensor element or cell.

For example, in the case of Figure C.2, the surface acoustic wave of the sensor element or cell is reflected by the reflector electrode, this reflected wave is converted into a signal by the IDT, and returns to the reader unit via the antenna. This reflected wave changes when the measurement value of the sensor element or cell changes. As a result, the signal returned to the reader unit changes.

C.2.5 Technical documents

The following items a) to d) shall clearly be defined in the specifications to be concluded between the manufacturer and customers:

a) selection of measurement system (resonator type or delay-line type).

b) parameters to be detected such as frequency, phase, delay and amplitude.

c) distance between reader antenna and SAW sensor antenna.

d) other.

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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CAPTEURS PIÉZOÉLECTRIQUES –

Partie 1: Spécifications génériques

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L'IEC 63041-1 a été établie par le comité d'études 49 de l'IEC: Dispositifs piézoélectriques, diélectriques et électrostatiques et matériaux associés pour la détection, le choix et la commande de la fréquence. Il s'agit d'une Norme internationale.

Cette deuxième édition annule et remplace la première édition parue en 2017. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) ajout de nouveaux termes et définitions (système de capteur piézoélectrique et système de capteur à OAS sans fil);
b) ajout de nouveaux types de modules et de systèmes de capteurs;
c) ajout de certains symboles des éléments de capteurs à l'Article 4;

d) ajout d'une nouvelle Figure B.3 à l'Annexe B;

e) ajout de l'Annexe C.

Le texte de cette Norme internationale est issu des documents suivants:

Projet	Rapport de vote
49/1357/CDV	49/1364/RVC

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2, il a été développé selon les Directives ISO/IEC, Partie 1 et les Directives ISO/IEC, Supplément IEC, disponibles sous www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous www.iec.ch/standardsdev/publications.

Une liste de toutes les parties de la série IEC 63041, publiées sous le titre général *Capteurs piézoélectriques*, peut être consultée sur le site web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous webstore.iec.ch dans les données relatives au document recherché. À cette date, le document sera

- reconduit,
- supprimé,
- remplacé par une édition révisée, ou
- amendé.

CAPTEURS PIÉZOÉLECTRIQUES –

Partie 1: Spécifications génériques

1 Domaine d'application

La présente partie de l'IEC 63041 s'applique aux capteurs piézoélectriques de type résonateur, de type à ligne à retard et de type non acoustique, utilisés en sciences physiques, en sciences de l'ingénierie, en chimie et en biochimie, en sciences médicales et environnementales, etc.

Le présent document a pour objet de spécifier les termes et définitions relatifs aux capteurs piézoélectriques et de vérifier, d'un point de vue technologique, que les utilisateurs ont une bonne approche des capteurs piézoélectriques de pointe et qu'ils savent les utiliser correctement.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60027 (toutes les parties), *Symboles littéraux à utiliser en électrotechnique*

IEC 60050-561, *Vocabulaire Électrotechnique International – Partie 561: Dispositifs piézoélectriques, diélectriques et électrostatiques et matériaux associés pour la détection, le choix et la commande de la fréquence*

IEC 60122-2-1, *Quartz pour le contrôle et la sélection de la fréquence – Deuxième partie: Guide pour l'emploi des résonateurs à quartz pour le contrôle et la sélection de la fréquence – Section un: Résonateurs à quartz comme base de temps dans les microprocesseurs*

IEC 60444-9, *Mesure des paramètres des résonateurs à quartz – Partie 9: Mesure des résonances parasites des résonateurs piézoélectriques*

IEC 60617, *Symboles graphiques pour schémas, disponible sur* https://std.iec.ch/iec60617

IEC 63041-3:2020, *Capteurs piézoélectriques – Partie 3: Capteurs physiques*

ISO 2859-1:1999, *Règles d'échantillonnage pour les contrôles par attributs – Partie 1: Procédures d'échantillonnage pour les contrôles lot par lot, indexés d'après le niveau de qualité acceptable (NQA)*

ISO 80000-1*, Grandeurs et unités – Partie 1: Généralités*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions de l'IEC 60027, de l'IEC 60050-561, de l'IEC 60617 et de l'ISO 80000-1, ainsi que les suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse https://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse https://www.iso.org/obp

NOTE Les capteurs piézoélectriques présentés ici sont ceux utilisés pour détecter et mesurer des grandeurs physiques, des substances chimiques ou des molécules biologiques.

3.1 Capteurs piézoélectriques

3.1.1
élément de capteur piézoélectrique
composant électronique capable de détecter des grandeurs physiques dont la fréquence, la phase, le retard, la charge électrique, la résistance, la valeur de Q, la bande passante, etc., varient

Note 1 à l'article: Pour les applications de capteur chimique ou biochimique, l'élément de capteur piézoélectrique comprend une couche sensible ou réceptive (matériau de reconnaissance cible).

3.1.2
élément de capteur de type résonateur
composant de capteur piézoélectrique qui utilise les résonances acoustiques

3.1.3
élément de capteur de type à ligne à retard
composant de capteur piézoélectrique qui utilise une ligne à retard d'onde acoustique de surface (OAS) de type transversal

3.1.4
élément de capteur de type non acoustique
composant de capteur piézoélectrique qui utilise la charge électrique induite par une force quasi statique, un couple ou un élément analogue

Note 1 à l'article: Dans le cas présent, le terme "non acoustique" signifie "piézoélectrique quasi statique". Par conséquent, l'élément de capteur de type non acoustique (piézoélectrique) est un élément de capteur qui utilise l'effet piézoélectrique quasi statique.

3.1.5
cellule de capteur piézoélectrique
élément de capteur équipé des accessoires et fixations mécaniques nécessaires pour détecter correctement les paramètres à mesurer

3.1.6
module de capteur piézoélectrique
élément ou cellule de capteur équipé(e) d'accessoires électroniques qui assurent l'interface avec les acquisitions de données externes

3.1.7
système de capteur piézoélectrique
système organisé qui inclut la détection, l'amplification de la valeur détectée, la communication avec d'autres équipements et l'analyse de la valeur détectée

Note 1 à l'article: Dans le cas présent, ces fonctions coopèrent mutuellement.

3.1.8
capteur piézoélectrique
terme générique qui inclut un élément, une cellule, un module et un système de capteur

3.1.9
QCM
microbalance à quartz
une des familles de capteurs chimiques et biochimiques qui utilisent des résonateurs de cristal

Note 1 à l'article: Un capteur à mode de partage d'épaisseur (TSM – thickness share mode) s'apparente à un QCM.

Note 2 à l'article: L'abréviation "QCM" est dérivée du terme anglais développé correspondant "quartz crystal microbalance".

3.2 Types de capteurs chimiques

3.2.1
élément de capteur chimique piézoélectrique
composant de capteur piézoélectrique qui comprend une couche sensible (matériau de reconnaissance cible) nécessaire au mesurage pratique de molécules non biologiques simples en quantité, et qui fonctionne et détecte les substances chimiques essentiellement en phase gazeuse

Note 1 à l'article: Un élément de capteur de gaz est l'un des éléments de capteurs chimiques.

3.2.2
élément de capteur biochimique piézoélectrique
composant de capteur piézoélectrique qui comprend une couche réceptive (matériau de reconnaissance cible) nécessaire au mesurage pratique de molécules biologiques complexes en quantité, et qui fonctionne essentiellement en milieu aqueux et y détecte les biomolécules

3.3 Types de capteurs physiques

3.3.1
élément de capteur de force piézoélectrique
composant de capteur piézoélectrique dont la fréquence de résonance, le retard ou la charge/tension électrique est utilisé(e) pour mesurer la force

3.3.2
élément de capteur de pression piézoélectrique
composant de capteur piézoélectrique dont la fréquence de résonance, le retard ou la charge/tension électrique est utilisé(e) pour mesurer la pression

3.3.3
élément de capteur de couple piézoélectrique
composant de capteur piézoélectrique dont la fréquence de résonance, le retard ou la charge/tension électrique est utilisé(e) pour mesurer le couple

3.3.4
élément de capteur de viscosité piézoélectrique
composant de capteur piézoélectrique dont la fréquence de résonance, le retard ou la perte/le gain d'insertion est utilisé(e) pour mesurer la viscosité

3.3.5
élément de capteur de température piézoélectrique
composant de capteur piézoélectrique dont la fréquence de résonance ou le retard est utilisé(e) pour mesurer la température

3.3.6
élément de capteur d'épaisseur de film piézoélectrique
composant de capteur piézoélectrique dont la fréquence de résonance est utilisée pour mesurer l'épaisseur de film

3.4 Types de modules de capteurs

3.4.1
module de capteur à OAS sans fil
élément ou cellule de capteur piézoélectrique équipé(e) d'une antenne de connexion sans fil à une unité d'interrogation

Note 1 à l'article: Dans le cas présent, les éléments de type résonateur et de type à ligne à retard de l'OAS sont utilisés pour l'élément ou la cellule de capteur piézoélectrique.

3.4.2
module de capteur bimode
élément ou cellule de capteur bimode équipé(e) de circuits pour la compensation de température et d'accessoires électroniques qui assurent l'interface avec les acquisitions de données externes

Note 1 à l'article: Le capteur bimode est un capteur piézoélectrique capable de détecter des grandeurs physiques à partir d'une variation des fréquences de résonance de deux modes indépendants sur une même plaque piézoélectrique (voir l'IEC 63041-3:2020, 3.1.5).

3.5 Types de systèmes de capteurs

3.5.1
système de capteur à OAS sans fil
terme générique qui inclut des capteurs à OAS sans fil et un lecteur pour l'envoi et la réception des signaux de radiofréquence

VOIR: Annexe C.

3.5.2
système de capteur bimode
terme générique qui inclut des modules de capteurs à quartz, un dispositif électrique, un ordinateur personnel, une mémoire, des dispositifs avec ou sans fil, un logiciel et du matériel, etc.

4 Symboles des éléments de capteurs

4.1 Généralités

Les Figures 1 à 6 représentent les schémas conceptuels et les symboles définis pour les éléments de capteurs de type résonateur à onde acoustique de volume (OAV), de type résonateur à OAS et de type à ligne à retard à OAS. Les symboles sont essentiellement les mêmes que ceux indiqués dans l'IEC 60122-1, l'IEC 61019-1 et l'IEC 60862-1.

La Figure 7 et la Figure 8 représentent le schéma conceptuel et le symbole défini pour les éléments de capteurs de type non acoustique.

Les Figures 9 à 12 représentent le schéma conceptuel et le symbole défini pour les éléments de capteurs de type résonateur à OAS et de type à ligne à retard à OAS sans fil. Cette configuration est présentée à l'Annexe C.

NOTE La diagonale de la Figure 2, la Figure 4, la Figure 6, la Figure 8, la Figure 10 et la Figure 12 exprime les modifications apportées aux objets à mesurer.

Il convient que les symboles littéraux (voir 4.7) qui présentent les types de capteurs soient définis dans le cercle en haut à droite de la Figure 2, la Figure 4, la Figure 6, la Figure 8, la Figure 10 et la Figure 12, et pour chaque application de capteur.

4.2 Symbole des éléments de capteurs de type résonateur à OAV

La Figure 1 représente les schémas conceptuels des éléments de capteurs de type résonateur à OAV dont une partie du montage est ignorée. La Figure 2 représente le symbole des éléments de capteurs de type résonateur à OAV.

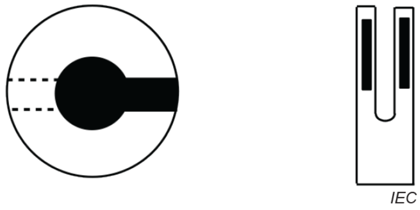

Figure 1 – Schémas conceptuels des éléments de capteurs de type résonateur à OAV

NOTE La Figure 1 présente des exemples d'éléments de capteurs de type à disque et de type à lyre.

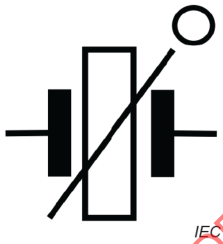

Figure 2 – Symbole des éléments de capteurs de type résonateur à OAV

4.3 Symbole des éléments de capteurs de type résonateur à OAS

La Figure 3 et la Figure 4 représentent respectivement le schéma conceptuel et le symbole pour les éléments de capteurs de type résonateur à OAS.

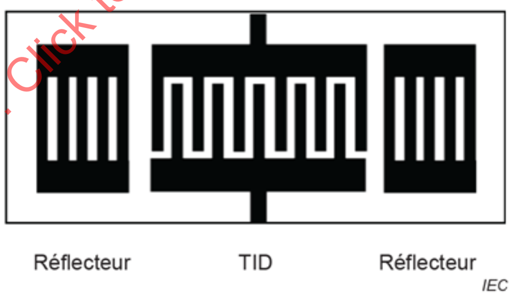

Figure 3 – Schéma conceptuel des éléments de capteurs de type résonateur à OAS

Figure 4 – Symbole des éléments de capteurs de type résonateur à OAS

4.4 Symbole des éléments de capteurs de type à ligne à retard à OAS

La Figure 5 et la Figure 6 représentent respectivement le schéma conceptuel et le symbole pour les éléments de capteurs de type à ligne à retard à OAS.

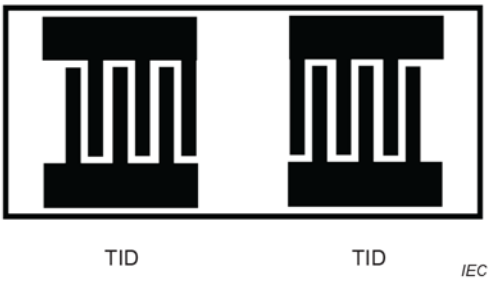

Figure 5 – Schéma conceptuel des éléments de capteurs de type à ligne à retard à OAS

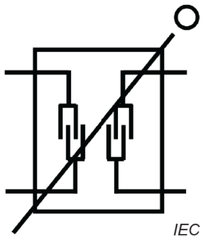

Figure 6 – Symbole des éléments de capteurs de type à ligne à retard à OAS

4.5 Symbole des éléments de capteurs de type non acoustique

La Figure 7 représente les schémas conceptuels des éléments de capteurs de type non acoustique dont une partie du montage est ignorée. La Figure 8 représente le symbole des éléments de capteurs de type non acoustique.

Figure 7 – Schémas conceptuels des éléments de capteurs de type non acoustique

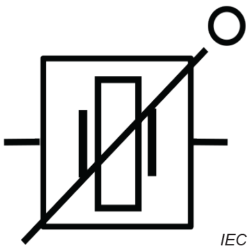

Figure 8 – Symbole des éléments de capteurs de type non acoustique

4.6 Symbole des éléments de capteur à OAS sans fil

Les Figures 9 à 12 représentent respectivement le schéma conceptuel et le symbole pour les éléments de capteurs de type résonateur à OAS et de type à ligne à retard sans fil.

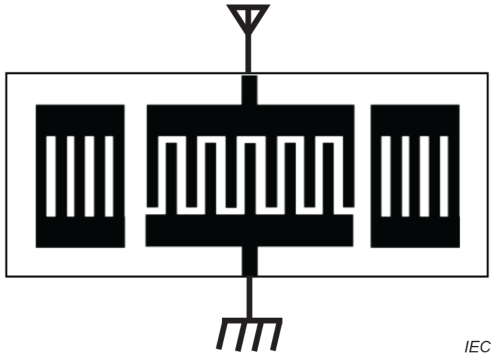

Figure 9 – Schéma conceptuel des éléments de capteurs fondamentaux de type résonateur à OAS sans fil

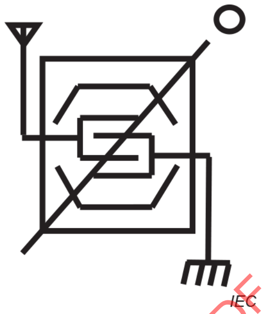

Figure 10 – Symbole des éléments de capteurs fondamentaux de type résonateur à OAS sans fil

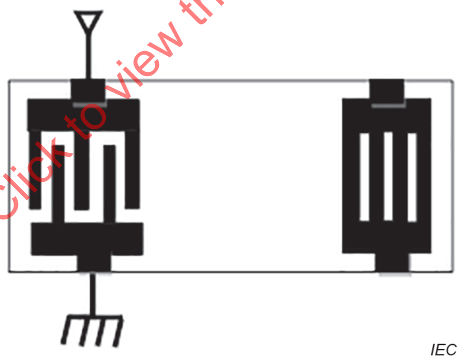

Figure 11 – Schéma conceptuel des éléments de capteurs fondamentaux de type à ligne à retard à réflexion d'OAS sans fil