IEC 62830-4

Edition 1.0 2019-02

INTERNATIONAL STANDARD

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Semiconductor devices – Semiconductor devices for energy harvesting and generation –
Part 4: Test and evaluation methods for flexible piezoelectric energy harvesting devices

Dispositifs à semiconducteurs – Dispositifs à semiconducteurs pour récupération et production d'énergie –
Partie 4: Méthodes d'essai et d'appréciation pour les dispositifs de récupération d'énergie piézoélectrique souples

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SEMICONDUCTOR DEVICES – SEMICONDUCTOR DEVICES FOR ENERGY HARVESTING AND GENERATION –

Part 4: Test and evaluation methods for flexible piezoelectric energy harvesting devices

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

FDIS	Report on voting
47/2530/FDIS	47/2551/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62830 series, published under the general title *Semiconductor devices – Semiconductor devices for energy harvesting and generation*, 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 "http://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- withdrawn,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
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SEMICONDUCTOR DEVICES – SEMICONDUCTOR DEVICES FOR ENERGY HARVESTING AND GENERATION –

Part 4: Test and evaluation methods for flexible piezoelectric energy harvesting devices

1 Scope

This part of IEC 62830 describes terms, definitions, symbols, configurations, and test methods that can be used to evaluate and determine the performance characteristics of flexible piezoelectric energy harvesting devices for practical use. This document is applicable to energy harvesting devices for consumers, general industries, wearable electronics, military, and biomedical applications without any limitations of device technology and size.

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 60749-5, *Semiconductor devices – Mechanical and climatic test methods – Part 5: Steady-state temperature humidity bias life test*

IEC 60749-12, *Semiconductor devices – Mechanical and climatic test methods – Part 12: Vibration, variable frequency*

3 Terms and definitions

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

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

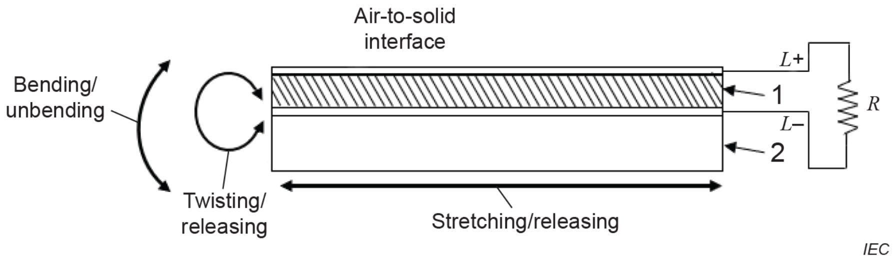
- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 General terms

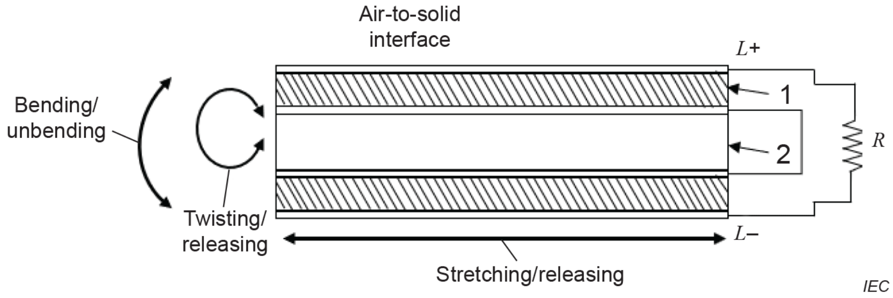
3.1.1
flexible
capability of being bent or flexed

3.1.2
flexible energy harvester
energy transducer that transforms bending, stretching, or twisting energy into electric energy

Note 1 to entry: A flexible energy harvester which converts applied stress by bending, stretching or twisting to electricity using a piezoelectric transducer is comprised of a spring and a piezoelectric transducer as shown in Figure 1. The piezoelectric transducer contains two electrodes and a piezoelectric film or nano wires. The induced external stress introduces the bending, stretching or twisting motion to the flexible substrate as shown in Annex C. The flexible substrate is bent and the bending of the spring introduces tension and compression of the piezoelectric film. The top and bottom electrodes of the piezoelectric film harvest the generated charges resulting from the piezoelectric effect.



1(a) Unimorph type



1(b) Bimorph type

Key

Configuration of energy harvester		**Components to operate energy harvester**	
1	Piezoelectric film which is the body layer of the piezoelectric transducer for energy harvesting	*R*	External load
2	Spring, to couple the induced bending, stretching or twisting to the flexible substrate by suspending it	*L*+, *L*–	Outputs of energy harvester

Figure 1 – Flexible energy harvester using a flexible substrate with a piezoelectric film

Note 2 to entry: The flexible piezoelectric energy harvester can be classified into four different types as shown in Annex B.

3.1.3
unimorph cantilever
cantilever that consists of one piezoelectric layer

Note 1 to entry: A unimorph cantilever consists of two layers where the piezoelectric layer is attached with the non-piezoelectric layer that works as a spring to introduce external stress to the piezoelectric layer.

3.1.4
bimorph cantilever
cantilever that consists of two piezoelectric layers

Note 1 to entry: In a bimorph cantilever, a non-piezoelectric layer is placed between two piezoelectric layers.

3.1.5
flexible substrate
substrate that is made from flexible materials, such as polyimide and PDMS

3.1.6
spring
elastic object to store mechanical energy with spring constant, k_{sp}

[SOURCE: IEC 62830-1:2017, 3.1.5]

3.2 Piezoelectric transducer

3.2.1
piezoelectric transducer
energy converter to generate electricity from mechanical energy by means of piezoelectric effect

[SOURCE: IEC 62830-1: 2017, 3.2.1]

3.2.2
piezoelectric effect
effect by which a mechanical deformation of piezoelectric material produces a proportional change in the electric polarization of that material

3.2.3
piezoelectric constant
d
quantifying value of the polarization in the piezoelectric material on application of a stress

3.2.4
electromechanical coupling coefficient
k
value to describe the conversion rate of electrical energy to mechanical form or vice versa

Note 1 to entry: The coefficient is a combination of elastic, dielectric and piezoelectric constants which appears naturally in the expression of the piezoelectric transducer.

$$k = \frac{d}{(s\varepsilon)^{1/2}} \tag{1}$$

where

d is the piezoelectric charge constant;

s is the elastic compliance (inverse of Young's modulus) at constant electric field;

ε is the permittivity of the piezoelectric material at constant stress.

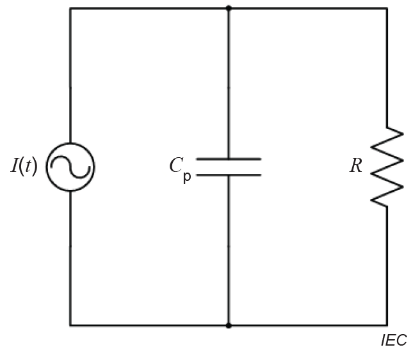
Note 2 to entry: Annexes A and D show additional information for the piezoelectric constant and electromechanical coupling.

3.2.5
capacitance
$\boldsymbol{C_p}$
capacitance between the two electrodes of the piezoelectric transducer

3.3 Characteristic parameters

3.3.1
equivalent circuit
<flexible piezoelectric energy harvester> electrical circuit which has the same output voltage from induced bending, stretching, or twisting motion as the piezoelectric flexible energy harvester in the immediate neighborhood of a resonance

Note 1 to entry: A flexible piezoelectric energy harvester can be divided into current source and capacitance parts as shown in Figure 2. The equivalent circuit is comprised of parallel connected C_p, of R, and of transformer ($I(t)$), where C_p and R represent the capacitance between the two electrodes of the piezoelectric transducer and external load.



Key

I(t)	current source of piezoelectric transducer
C_p	capacitance of piezoelectric transducer
R	external load

Figure 2 – Equivalent circuit of flexible piezoelectric energy harvester

3.3.2
open circuit voltage
V
electrical potential difference relative to a reference node of energy harvester when there is no external load connected to the terminals of the energy harvester

3.3.3
short circuit current
I
current through the external load connected to the terminal of an energy harvester

[SOURCE: IEC 62830-1:2017, 3.3.6, modified – the term "ouput current" has been replaced by "short circuit current".]

3.3.4
output power
P
electrical power transferred to the external load connected to the terminal of an energy harvester

[SOURCE: IEC 62830-1:2017, 3.3.5]

3.3.5
power density
electrical power per unit volume (including seismic mass and clamper) transferred to the external load connected to the terminals of the energy harvester

3.3.6
optimal load
R_{opt}
specified value of the external load for transferring the largest electrical energy from the energy harvester

[SOURCE: IEC 62830-1: 2017, 3.3.7]

3.3.7
temperature range
range of temperature as measured on the enclosure over which the energy harvester will not sustain permanent damage though not necessarily functioning within the specified tolerances

[SOURCE: IEC 62830-1: 2017, 3.3.9]

3.3.8
humidity range
range of humidity as measured in the enclosure over which the energy harvester will not sustain permanent damage though not necessarily functioning within the specified tolerances

3.3.9
input stress
range of stress induced by bending motion, stretching motion, and twisting motion to the energy harvester as measured on the enclosure over which the energy harvester will not sustain permanent damage under long term operation though not necessarily functioning within the specified tolerances

3.3.10
mean-time-to-failure
length of time the energy harvester is expected to last in operation without failure or disruption

4 Essential ratings and characteristic parameters

4.1 Limiting values and operating conditions

Specification and characteristic parameters should be listed as shown in Table 1. The manufacturer shall clearly announce the operating conditions and their limitation for energy harvesting. The limiting value is the maximum induced bending, stretching or twisting motion to ensure the long term operation of the flexible energy harvester for power generation without any damage.

Table 1 – Specification parameters for flexible piezoelectric energy harvesters

Parameters	Symbols	Min.	Max.	Unit	Measuring conditions
Insert name of characteristic parameters					

The information provided in Table 1 is the following:

– Parameters: name of the characteristic parameters;
– Symbols: symbol of the parameters;
– Min.: minimum value of the parameters;
– Max.: maximum value of the parameters;
– Unit: unit of the parameters;
– Measuring conditions: specified conditions for evaluation.

4.2 Additional information

Some additional information should be given such as equivalent circuits (e.g. resonant frequency, internal impedance, frequency response, output voltage and power, etc.), handling precautions, physical information (e.g. outline dimension, terminals, etc.), accessories, installation guide, package information, PCB interface and mounting information, and other information.

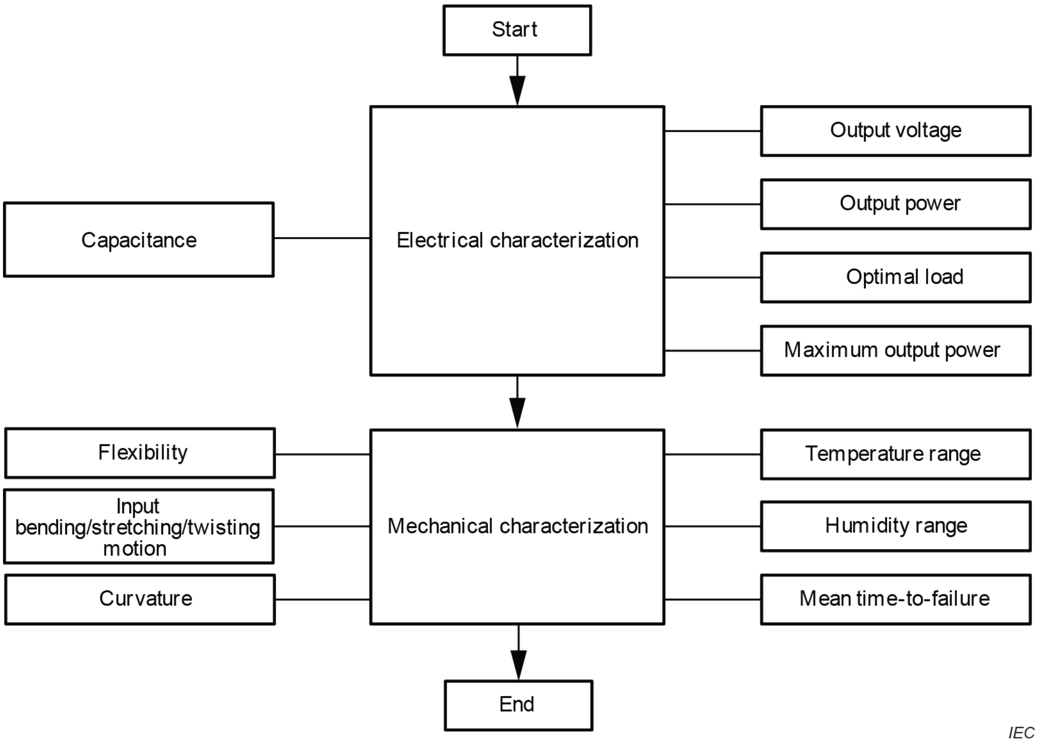
5 Test method

5.1 General

Basically, the general test procedures for a flexible energy harvester are performed as shown in Figure 3. After the flexible piezoelectric energy harvester is being mounted on a test fixture, it is measured by using voltage, current, and LCR meters. To measure and characterize these devices accurately, the ultra-high-impedance meters should be used.

After calibration of the measuring equipment, connect the test cable with the output terminals of the flexible energy harvester mounted on the test fixture such as a vibration exciter or linear motor. The readings of the output voltage or current on the display of the meters are carefully taken with the induced bending, stretching, or twisting motion measured by the accelerometer.

NOTE A flexible energy harvester can be measured as shown in Figure 3. After mounting the energy harvester onto a linear motor, the electrical characteristics are measured by using a meter or equivalent equipment. If the measurements are satisfactory, a reliability test for the temperature range with thermal cycling and mechanical failure with various bending, stretching or twisting motions, is performed for commercial use.



Key

Procedure	**Reference subclause**	**Procedure**	**Reference subclause**
Start		Mechanical characterization	
Electrical characterization		Flexibility	**3.1.1**
Capacitance	**3.2.5 and 5.2.2**	Input bending/stretching/twisting motion	**3.3.9 and 5.2.17 to 5.2.19**
Output voltage	**5.2.9**	Temperature range	**3.3.7 and 5.2.15**
Output power	**3.3.4 and 5.2.11**	Humidity range	**3.3.8 and 5.2.16**
Optimal load	**3.3.6 and 5.2.12**	Mean-time-to-failure	**3.3.10**
Maximum output power	**5.2.13**		

Figure 3 – Measurement procedure of flexible piezoelectric energy harvesters

5.2 Electrical characteristics

5.2.1 Test procedure

Figure 4 shows a test setup of the electrical characteristics of a flexible piezoelectric energy harvester. To measure the electrical characteristics of a flexible piezoelectric energy harvester, the device should be mounted on a linear motor/vibration exciter as shown in Figure 4. When periodic signal input waveforms (sinusoidal, rectangular, triangular, sawtooth, etc.) with specified frequency and acceleration are applied to the device at the condition of a continuous bending, stretching, or twisting motion, an output voltage across an external load and short current are measured. The input motion (stress) being used to characterize the devices can be selected as the possible applications of the devices. The direction of deformation depends on the geometrical structure of the harvester and direction of applied acceleration. A periodic sinusoidal waveform of 1 Hz frequency and 1 g acceleration is the input during all the experimental data presented here.

The following test procedure is performed:

a) A specified bending, stretching, or twisting motion is induced to the energy harvester.

b) The voltage across or current through the external load which is connected to the terminals of the energy harvester is measured using a voltage or current meter, respectively.

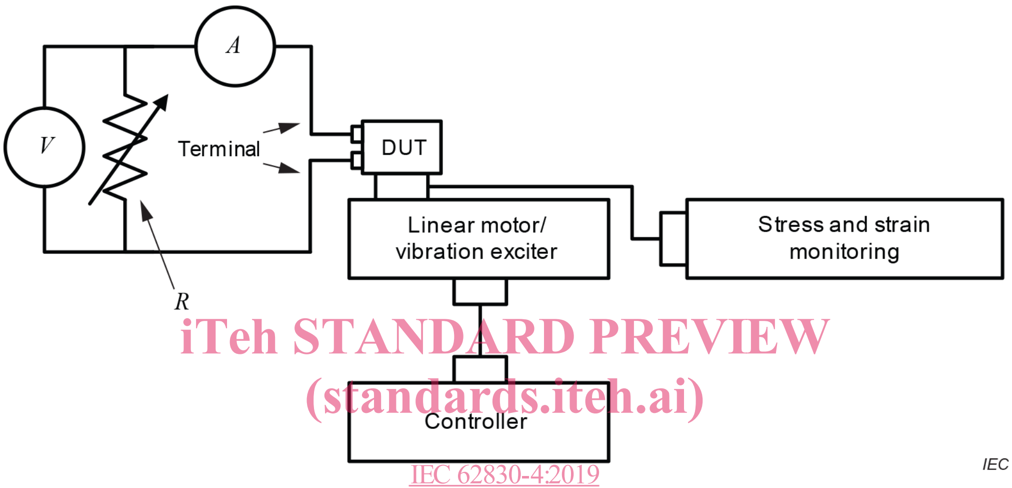
c) The voltage and current are measured under various accelerations of bending, stretching, or twisting motion by adjusting the amplifying ratio of the controller.

d) The voltage and current are measured between the top and bottom electrodes or comb structured electrode through forward and reverse connection at the specific range of strain.

e) The voltage and current are measured with various induced strain ranges and frequencies.

f) The voltage and current are derived from various external loads to find the optimal load.

NOTE In the random excitation experiments, the base excitation is intended to cover a broad range of excitation frequencies to be as close to white noise as possible within the limitations of the electromechanical shaker and other hardware.



Key

Component and meters to monitor		**Equipment and supplies**	
DUT: device under test	Piece of energy harvester	Controller	To supply a specified frequency of electrical signal to the linear motor
Voltage meter (*V*)	To detect a voltage across the external load	Linear motor/ vibration exciter	To supply a specified level and frequency of bending/stretching/twisting motion to a piece of DUT
Ampere meter (*A*)	To detect a current through the external load	Stress & strain monitoring	To detect an acceleration, force and strain of the linear motor
External load (*R*)	Load with specific impedance		

Figure 4 – Test setup for the electrical characteristics of a flexible piezoelectric energy harvester

5.2.2 Capacitance

It is a capacitance measured between two terminals of an energy harvesting device at a specified frequency and voltage. A calibration of an LCR meter should be made in order to eliminate systematic errors that have occurred in the LCR meter, cable, and connectors. When the device is connected to the LCR meter, its capacitance will be displayed. When measuring capacitance, the specified frequency and voltage for measurement should be recorded.