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Semiconductor devices – Semiconductor devices for energy harvesting and generation –
Part 3: Vibration based electromagnetic energy harvesting

Dispositifs à semiconducteurs – Dispositifs à semiconducteurs pour récupération et génération d'énergie –
Partie 3: Récupération d'énergie électromagnétique basée sur des vibrations

IEC 62830-3:2017-03(en-fr)

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SEMICONDUCTOR DEVICES – SEMICONDUCTOR DEVICES FOR ENERGY HARVESTING AND GENERATION –

Part 3: Vibration based electromagnetic energy harvesting

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The text of this standard is based on the following documents:

FDIS	Report on voting
47/2363/FDIS	47/2380/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.

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SEMICONDUCTOR DEVICES – SEMICONDUCTOR DEVICES FOR ENERGY HARVESTING AND GENERATION –

Part 3: Vibration based electromagnetic energy harvesting

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 vibration based electromagnetic energy harvesting devices. This part of IEC 62830 specifies the methods of tests and the characteristic parameters of the vibration based electromagnetic energy harvesting devices for evaluating their performances accurately and practical use. This part of IEC 62830 is applicable to energy harvesting devices for consumer, general industries, military and aerospace applications without any limitations of device technology, shape 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 60749-5:2003, *Semiconductor devices – Mechanical and climatic test methods – Part 5: Steady-state temperature humidity bias life test*

IEC 60749-10:2002, *Semiconductor devices – Mechanical and climatic test methods – Part 10: Mechanical shock*

IEC 60749-12:2002, *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
vibration
mechanical oscillations occurring about an equilibrium point

[SOURCE: IEC 62830-1:2017, 3.1.1]

3.1.2
vibration based energy harvester
energy transducer that transforms vibration energy into electric energy

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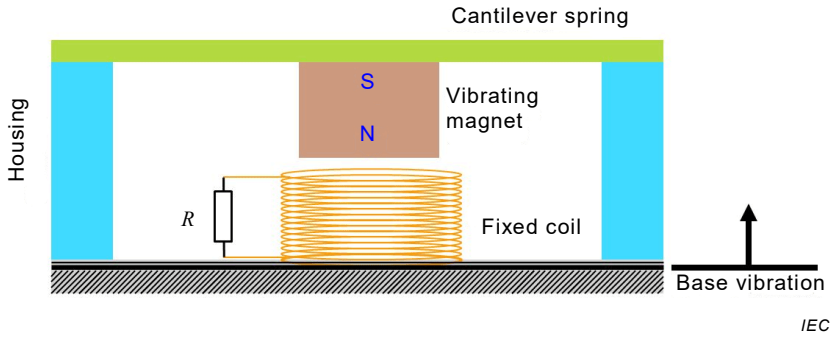
Note 1 to entry: A vibration based energy harvester to convert vibration to electricity by using electromagnetic transduction mechanism is comprised of magnet (inertial mass), cantilever spring, and coil as shown in Figure 1. The induced vibration introduces the reciprocating motion to the mass. The spring which suspends the magnetic mass is bended and the bending of spring introduces a relative displacement between the magnet and coil within the magnetic field and an e.m.f. is induced in the coil which is obtained across the coil terminals.

Note 2 to entry: A vibration based electromagnetic energy harvester can be represented as shown in Figure 2. It is configured by mass, spring, damping (mechanical and electrical), and electromagnetic transducer.



Key

Configuration of energy harvester		**Components to operate an energy harvester**	
Magnetic mass	Inertial mass with a field of magnetic force to introduce mechanical motion coupling from induced vibration	*R*	External load
Spring	To couple the induced vibration to the mass by suspending it		
Coil	Induces electric potential by cutting magnetic flux within vibrating magnetic field		

Figure 1 – General structure of a vibration based electromagnetic energy harvester

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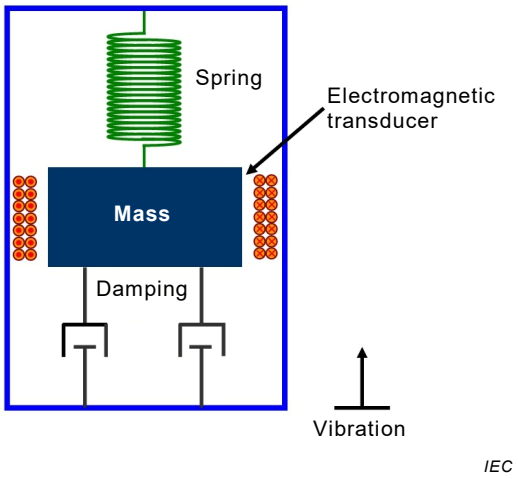

Key

Configuration of energy harvester		**Components to operate an energy harvester**	
Damping	Reduction of oscillation of the mass with time	Electromagnetic transducer	Functional device to operate as a transducer to transform vibration energy to electric energy via electromagnetic induction
Spring stiffness	a measure of the resistance offered by an elastic body to deformation		

Figure 2 – Conceptual diagram of a vibration based electromagnetic energy harvester

[SOURCE: IEC 62830-1:2017, 3.1.2]

3.1.3
mass-spring-damper system
system to derive the motion of the vibration energy harvester by using equivalent mass, spring and damper from that

[SOURCE: IEC 62830-1:2017, 3.1.3]

3.2 Electromagnetic transducer

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

3.2.2
electromagnetic induction
phenomenon in which an induced voltage or an induced current produced by relative motion between a permanent magnet and a coil winding

[SOURCE: IEC 60050-121:2008, 121-11-30, modified]

3.2.3
transformation factor
ϕ
measure of the performance of the electromagnetic transducer related to the flux density, B, the length of the coil, l and the number of turns per unit length of the coil, N, given by,

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$$\phi = NBl \tag{1}$$

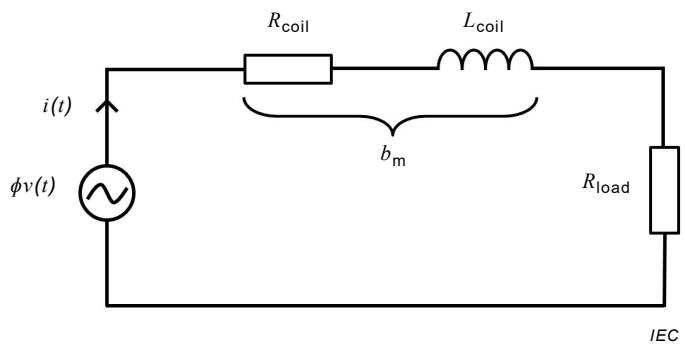
3.2.4
coil-resistance
R_{coil}
coil-resistance that is related to the resistivity of the coil material, length of the coil winding and diameter of the coil (circular)

3.2.5
coil-inductance
L_{coil}
coil-inductance that induces a proportional voltage across the coil due to a change in current in the coil

3.3 Characteristic parameters

3.3.1
equivalent circuit, <of a vibration based electromagnetic energy harvester>
electrical circuit which has the same output voltage from induced vibration as electromagnetic vibration energy harvester in the immediate neighborhood of resonance

Note 1 to entry: Electrical equivalent circuit representation of a vibration based electromagnetic energy harvester is shown in Figure 3. It consists of an e.m.f. source, $\phi v(t)$ that induces current, $i(t)$ and series inductance, L_{coil} and resistance R_{coil} with a load resistance, R_{load}. The damper is, typically a moving magnet linking flux with the stationary coil, the latter having series inductance and resistance. The operating principle is that voltage is induced in the coil due to the varying flux linkage, with the resultant currents causing forces which oppose the relative motion between the magnet and coil.



Key

$\phi v(t)$:	e.m.f. is induced due to the relative motion between the magnet and coil	b_m:	Damping occurs by the flux linkage between the magnet and the coil with series resistance R_{coil} and inductance L_{coil}
$i(t)$:	current starts flowing due to induced vibration	R_{load}:	external load

Figure 3 – Equivalent circuit of a vibration based electromagnetic energy harvester

3.3.2
resonant frequency
f_r
lowest frequency of the induced vibration of the energy harvester to generate largest output power

$$f_r = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \tag{2}$$

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where

k is the spring constant and m is the mass (of the magnet) attached to the cantilever spring

[SOURCE: IEC 62830-1:2017, 3.3.2]

3.3.3
bandwidth
Δf
separation of frequencies between which the output power shall be equal to or larger than a specified value (50 %)

3.3.4
damping ratio
ζ
dimensionless measure describing how oscillations in a system decay after a disturbance, expressing the level of damping in a system relative to critical damping

Note 1 to entry: For a damped harmonic oscillator with mass m, damping coefficient b, and spring constant k, it can be expressed as:

$$\zeta = \frac{b}{2\sqrt{km}} \tag{3}$$

3.3.5
quality factor,<vibration based energy harvesters>
Q
dimensionless parameter that describes how underdamped an oscillator or resonator, or equivalently, characterizes a resonator's bandwidth relative to its centre frequency

Note 1 to entry: In the context of resonators, Q is defined in terms of the ratio of the resonant frequency, f_r to the half-power bandwidth Δf of the resonator

$$Q = \frac{f_r}{\Delta f} = \frac{\omega_r}{\Delta \omega} \tag{4}$$

Note 2 to entry: For a single damped mass-spring system, the Q factor represents the effect of simplified viscous damping or drag, where the damping force or drag force is proportional to velocity. The formula for the Q factor is:

$$Q = \frac{1}{2\zeta} \tag{5}$$

where ζ is the damping ratio.

3.3.6
open circuit voltage
V
electrical potential difference relative to a reference node of an energy harvester when there is no external load connected to the terminal of the energy harvester

Note 1 to entry: V is defined as an open circuit voltage of the energy harvester.

[SOURCE: IEC 62830-1:2017, 3.3.4]

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3.3.7
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]

3.3.8
output current
I
current through the external load connected to the terminals of energy harvester

Note 1 to entry: I is defined as an output current of the energy harvester.

[SOURCE: IEC 62830-1:2017, 3.3.6]

3.3.9
optimal load
R_{opt}
specified value of the external load transferred to the largest electrical energy from energy harvester

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

3.3.10
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]

3.3.11
input vibration
range of acceleration of induced vibration to the energy harvester 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, 3.3.10]

3.3.12
mean-time-to-failure
the expectation of the time to failure in the operation of the energy harvester

[SOURCE: IEC 60050-192:2015, 192-05-11, modified]

4 Essential ratings and characteristic parameters

4.1 Identification and type

The vibration energy harvester shall be clearly and durably marked in the order given below:

a) year and week (or month) of manufacture;
b) manufacturer's name or trade-mark;
c) terminal identification (optional);
d) serial number;

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e) factory identification code (optional).

4.2 Limiting values and operating conditions

Characteristic parameters should be listed in as shown in Table 1. The manufacturer shall clearly announce the operating conditions and their limitation for energy harvesting. Limiting value is the maximum induced vibration to ensure the operation of vibration energy harvester for power generation without any damage.

Table 1 – Specification parameters for vibration based electromagnetic energy harvesters

Parameter	Symbol	Min.	Max.	Unit	Measuring conditions
Insert name of characteristic parameters					

4.3 Additional information

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

5 Test method

5.1 General

Basically, general test procedures for vibration energy harvester are performed as shown in Figure 4. After the vibration based electromagnetic energy harvester has been mounted on a test fixture, it is measured by using voltage, current, and LCR meters. Since the input impedances of these meters are usually 10 MΩ, miniaturized or micro sized energy harvesters may not be characterized accurately due to their large internal impedance. For measuring and characterizing these devices accurately, the ultra-high-impedance meters should be used. A digital storage oscilloscope is also used to observe and record the generated waveform of the electromagnetic energy harvester.

Before connecting the vibration energy harvester to the test fixture, meter, cable, vibration exciter and oscilloscope shall be calibrated according to their respective calibration method. After calibration, connect test cable with mounted vibration energy harvester test fixture on vibration exciter. The readings of output voltage or current on display of the meters and oscilloscope are carefully taken, together with induced vibration which is measured by the accelerometer.

It is to be noted that temperature affects the magnetic field strength of most magnets. As a result, generated electromotive force (e.m.f.) by an electromagnetic energy harvester has a temperature dependency. Electrical characterization of an electromagnetic energy harvester should be carried out at different temperatures.

NOTE Vibration based energy harvester can be measured as shown in Figure 4. After mounting the energy harvester onto a vibration exciter, electrical characteristic are measured by using a meter or equivalent equipment. If the measurements are satisfactory, the reliability test for the temperature range with thermal cycling and mechanical failure with various vibrations is performed for commercial use.

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