IEC 62047-32

Edition 1.0 2019-01

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Semiconductor devices – Micro-electromechanical devices – Part 32: Test method for the nonlinear vibration of MEMS resonators

Dispositifs à semiconducteurs – Dispositifs microélectromécaniques – Partie 32: Méthode d'essai pour la vibration non linéaire des résonateurs MEMS



IEC 62047-32:2019-01(en-fr)



THIS PUBLICATION IS COPYRIGHT PROTECTED
Copyright © 2019 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de l'IEC ou du Comité national de l'IEC du pays du demandeur. Si vous avez des questions sur le copyright de l'IEC ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de l'IEC de votre pays de résidence.

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

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

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

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

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 It also gives information on projects, replaced and withdrawn publications.

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

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

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

A propos de l'IEC
La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC
Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Recherche de publications IEC - webstore.iec.ch/advsearchform
La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études,…). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished
Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et une fois par mois par email.

Service Clients - webstore.iec.ch/csc
Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: sales@iec.ch.

Electropedia - www.electropedia.org
Le premier dictionnaire d'électrotechnologie en ligne au monde, avec plus de 22 000 articles terminologiques en anglais et en français, ainsi que les termes équivalents dans 16 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

Glossaire IEC - std.iec.ch/glossary
67 000 entrées terminologiques électrotechniques, en anglais et en français, extraites des articles Termes et Définitions des publications IEC parues depuis 2002. Plus certaines entrées antérieures extraites des publications des CE 37, 77, 86 et CISPR de l'IEC.

IEC 62047-32

Edition 1.0 2019-01

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Semiconductor devices – Micro-electromechanical devices – Part 32: Test method for the nonlinear vibration of MEMS resonators

Dispositifs à semiconducteurs – Dispositifs microélectromécaniques – Partie 32: Méthode d'essai pour la vibration non linéaire des résonateurs MEMS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

ICS 31.080.99

ISBN 978-2-8322-6455-3

Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.

® Registered trademark of the International Electrotechnical Commission
Marque déposée de la Commission Electrotechnique Internationale

CONTENTS

FOREWORD 3
1 Scope 5
2 Normative references 5
3 Terms and definitions 5
4 Test parameters of nonlinear vibration of the resonators 5
5 Test method for the amplitude-frequency response and phase-frequency response of the nonlinear vibration 6
5.1 Test system 6
5.2 Test conditions 6
5.3 Test procedures 7
6 Test method for the bending factor of the nonlinear vibrating frequency response 7
7 Test method for the amplitude threshold for the nonlinear jump 7
8 Test method for the frequency deviation as a result of the nonlinear vibration 8
8.1 Frequency deviation of the self-excitation closed-loop system 8
8.2 Frequency deviation of the phase-locked closed-loop system 8
8.3 Frequency deviation of the burst-excited system 9
Annex A (normative) Model of nonlinear vibration of MEMS resonators and bending factor 10
A.1 Model of nonlinear vibration of MEMS resonators 10
A.2 Solution of the nonlinear vibration model 11
A.3 Bending factor of the amplitude-frequency response 11
Annex B (informative) Nonlinear jump of the frequency response of MEMS resonators 14
Annex C (normative) Frequency deviation of MEMS resonators in the closed-loop system 16
C.1 Effect of the frequency deviation of the MEMS resonator on the accuracy of the resonant sensor 16
C.2 Frequency deviation of the self-exciting closed-loop system 16
C.3 Frequency deviation of the phase-locked closed-loop system 16
C.4 Oscillation frequency deviation of the burst-excited closed-loop system 18

Figure 1 – Test system 6
Figure 2 – 3 dB bandwidth of the linear amplitude-frequency response 8
Figure A.1 – Typical amplitude-frequency response of the nonlinear vibration of the MEMS resonator 12
Figure A.2 – Change of the amplitude-frequency response with the bending factor 13
Figure B.1 – Jump phenomenon of the frequency response of a clamped-clamped MEMS bridge resonator 14
Figure B.2 – Three nonlinear amplitude-frequency responses with various amplitude level 15

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 32: Test method for the nonlinear vibration of MEMS resonators

FOREWORD

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

International Standard IEC 62047-32 has been prepared by subcommittee 47F: Micro-electromechanical systems, of IEC technical committee 47: Semiconductor devices.

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

FDIS	Report on voting
47F/322/FDIS	47F/325/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 62047 series, published under the general title *Semiconductor devices – Micro-electromechanical devices*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "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
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 32: Test method for the nonlinear vibration of MEMS resonators

1 Scope

This part of IEC 62047 specifies the test method and test condition for the nonlinear vibration of MEMS resonators. The statements made in this document apply to the development and manufacture for MEMS resonators.

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 62047-1, *Semiconductor devices – Micro-electromechanical devices – Part 1: Terms and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62047-1 and the following apply.

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

3.1
nonlinear vibration
vibration whose displacement has a nonlinear relationship with the elastic restoring force, with the change of the vibration amplitude

3.2
nonlinear jump
jump phenomenon of the frequency response curve when the vibration amplitude exceeds a certain threshold

3.3
frequency deviation
deviation of the vibration frequency of the resonator in a closed-loop system from the natural frequency of the resonator

4 Test parameters of nonlinear vibration of the resonators

Test parameters of nonlinear vibration of the resonators are:

a) amplitude-frequency response of the nonlinear vibration, $A(\omega)$;

b) phase-frequency response of the nonlinear vibration, $P(\omega)$;

c) bending factor of the amplitude-frequency response, b;

d) amplitude threshold for the nonlinear jump, a_c;

e) frequency deviation of the self-exciting closed-loop system, E_1;

f) frequency deviation of the phase-locked closed-loop system, E_2;

g) frequency deviation of the burst-exciting closed-loop system, E_3.

5 Test method for the amplitude-frequency response and phase-frequency response of the nonlinear vibration

5.1 Test system

A test system consists of the following equipments:

a) laser vibrometer;
b) micro-optical apparatus;
c) signal generator;
d) vacuum chamber;
e) mounting fixture;
f) vacuum pump;
g) angle valve.

The test system is illustrated in Figure 1.

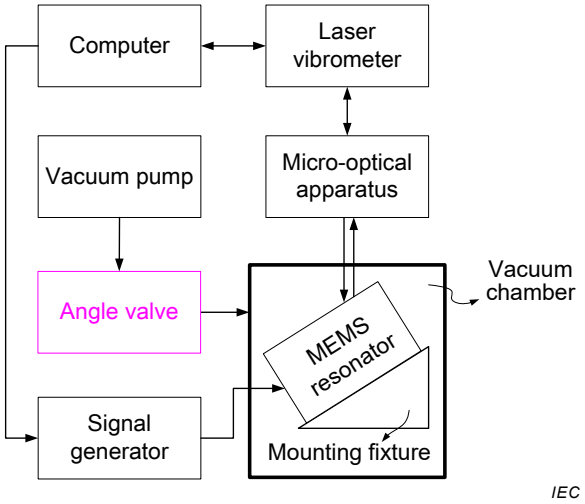


Figure 1 – Test system

5.2 Test conditions

a) Keep the ambient temperature within 23 °C ± 5 °C.
b) Maintain the vacuum degree of the vacuum chamber according to the actual operation of the resonator.
c) Adjust the micro-optical apparatus to restrict the laser spot within the surface of the resonator.
d) For transparent resonators, the laser beam should illuminate on the metal layer on the resonator to enhance the reflected laser intensity.
e) The connection of the resonator, the installing base and the vacuum chamber should be strong enough.

f) For out-of-plane vibrating resonators, the surface of the installing base should be parallel to the horizontal plane. For in-plane vibrating resonators, the surface of the installing base should be set to a certain angle about the horizon level, to ensure enough intensity of the reflected laser into the detector.

g) The vacuum pump and the vacuum chamber should be connected with flexible bellows in case of the vibration propagation from the pump to the chamber.

h) The angle valve should be tightly shut off to well maintain the vacuum level, and then the pump turned off before operating the test procedure.

5.3 Test procedures

a) Set the frequency of the vibration excitation according to the estimated value of the natural frequency of the resonator. And then implement the initial frequency scan around the natural frequency within a wide range. The amplitude frequency response and the phase frequency response can be measured according to the vibration displacement of the resonators. And record the resonant frequency of the resonator.

b) Reset the vibration excitation parameters to implement the frequency scan for the second time: reducing the interval of the frequency scan to half of that set in the initial frequency scan and reducing the range of the frequency scan to ten times of the half-power bandwidth of the amplitude frequency response. The amplitude frequency response and the phase frequency response can be measured according to the vibration displacement of the resonators. And record the resonant frequency of the resonator.

c) Compare the resonant frequencies obtained by the initial and the second tests. If the discrepancy in the resonant frequencies is smaller than 1 ppm[1] of the resonant frequency measured in the second test, either the initial or the second test result can be deemed as the accurate amplitude frequency response and the phase frequency response. If the discrepancy in the resonant frequencies exceeds 1 ppm of the resonant frequency measured in the second test, the third time frequency scan with further small frequency interval should be implemented, until the discrepancy in last tested resonant frequency and the previous one is smaller than that 1 ppm of the resonant frequency measured in the last test.

6 Test method for the bending factor of the nonlinear vibrating frequency response

a) Test the nonlinear vibrating amplitude frequency response of the MEMS resonator according to the method presented in Clause 5. And obtain the resonant frequency ω_{r} and the resonant amplitude a_{r}.

b) The bending factor can be calculated by substituting the resonant frequency ω_{r} and the resonant amplitude a_{r} into Formula (A.11) as provided in Annex A. The value of ω_{n} can be determined by its design value.

$$b = \frac{\omega_{\mathrm{r}} - \omega_{\mathrm{n}}}{a_{\mathrm{r}}^2} \tag{1}$$

7 Test method for the amplitude threshold for the nonlinear jump

a) Obtain the bending factor of the amplitude frequency response of the MEMS resonator by the method set out in Clause 6.

b) The nonlinear jump phenomenon is presented in Annex B. Figure B.1. The amplitude threshold for the nonlinear jump can be calculated by substituting the bending factor b into Formula (2).

---

[1] ppm = part per million

$$a_c = \sqrt{\frac{4\omega_n}{3\sqrt{3}Q|b|}} \tag{2}$$

where

a_c is the amplitude threshold for the nonlinear jump;

Q is the quality factor of the resonator with linear vibration.

The value of Q can be obtained by the following formula:

$$Q = \frac{\omega_n}{\omega_2 - \omega_1} \tag{3}$$

where

ω_1 and ω_2 are the boundary points of the -3 dB bandwidth of the linear amplitude-frequency response, which is shown in Figure 2.

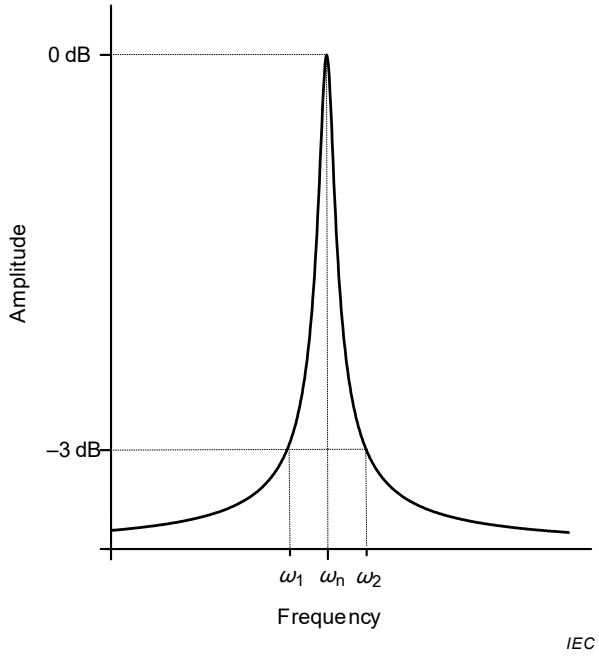


Figure 2 – 3 dB bandwidth of the linear amplitude-frequency response

8 Test method for the frequency deviation as a result of the nonlinear vibration

8.1 Frequency deviation of the self-excitation closed-loop system

a) Obtain the bending factor of the amplitude frequency response of the MEMS resonator by the method provided in Clause 6.

b) Frequency deviation of the self-excitation closed-loop system can be calculated by substituting the bending factor b into Formula (C.3).

$$E_1 = \frac{ba_s^2}{\omega_n} \times 100\ \% \tag{4}$$

8.2 Frequency deviation of the phase-locked closed-loop system

a) Obtain the bending factor of the amplitude frequency response of the MEMS resonator by the method provided in Clause 6.