

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Surface acoustic wave (SAW) resonators –
Part 2: Guide to the use**

**Résonateurs à ondes acoustiques de surface (OAS) –
Partie 2: Guide d'emploi**



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2005 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 Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
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 corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue

The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub

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 It also gives information on projects, replaced and withdrawn publications.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 also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 30 000 terms and definitions in English and French, with equivalent terms in 14 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary

More than 55 000 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.

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: csc@iec.ch.

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.

Catalogue IEC - webstore.iec.ch/catalogue

Application autonome pour consulter tous les renseignements bibliographiques sur les Normes internationales, Spécifications techniques, Rapports techniques et autres documents de l'IEC. Disponible pour PC, Mac OS, tablettes Android et iPad.

Recherche de publications IEC - www.iec.ch/searchpub

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 aussi une fois par mois par email.

Electropedia - www.electropedia.org

Le premier dictionnaire en ligne de termes électroniques et électriques. Il contient plus de 30 000 termes et définitions en anglais et en français, ainsi que les termes équivalents dans 14 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

Glossaire IEC - std.iec.ch/glossary

Plus de 55 000 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.

Service Clients - webstore.iec.ch/csc

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

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Surface acoustic wave (SAW) resonators –
Part 2: Guide to the use**

**Résonateurs à ondes acoustiques de surface (OAS) –
Partie 2: Guide d'emploi**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX

U

ICS 31.140

ISBN 978-2-8322-1340-7

**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.**

CONTENTS

FOREWORD.....	3
INTRODUCTION.....	5
1 Scope.....	6
2 Normative references	6
3 Technical considerations	6
4 Fundamentals of SAW resonators.....	7
4.1 Basic structure	7
4.2 Principle of operation	7
5 SAW resonator characteristics.....	8
5.1 Reflector characteristics	8
5.2 SAW resonator characteristics.....	10
5.3 Spurious modes	14
5.4 Substrate materials and their characteristics	15
5.5 Available characteristics	17
6 Application guide	19
6.1 Oscillator circuits and oscillation condition	19
6.2 Practical remarks for oscillator applications	21
7 Checklist of SAW resonator parameters for drawing up specifications	22
Bibliography.....	25

INTERNATIONAL ELECTROTECHNICAL COMMISSION

SURFACE ACOUSTIC WAVE (SAW) RESONATORS –**Part 2: Guide to the use**

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 provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with an IEC Publication.
- 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 61019-2 has been prepared by IEC technical committee 49: Piezoelectric and dielectric devices for frequency control and selection.

This second edition cancels and replaces the first edition published in 1995. This edition constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

- at the end of 5.1, the edge reflector has been added. Its reference literature has been inserted in the bibliography;
- in Table 1, the propagation properties of LiNbO₃ (64° Y) have been added;
- in Table 3, the clause and subclause numbers have been corrected in order to be consistent with IEC 61019-1 (2004) which has replaced IEC 61019-1-1 (1990) and IEC 61019-1-2 (1993).

This bilingual version (2014-02) corresponds to the monolingual English version, published in 2005-05.

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

FDIS	Report on voting
49/714/FDIS	49/723/RVD

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

The French version of this standard has not been voted upon.

IEC 61019 consists of the following parts, under the general title *Surface acoustic wave (SAW) resonators*

Part 1: Generic information

Part 2: Guide to the use

Part 3: Standard outlines and lead connections

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

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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

INTRODUCTION

This part of IEC 61019 gives practical guidance to the use of SAW resonators which are used in telecommunications, radio equipments and consumer products. IEC 61019-1 can be referred to for general information, standard values and test conditions.

The features of these SAW resonators are small size, light weight, adjustment-free and high stability. In addition, the operating frequency of SAW resonators extends to the VHF and UHF ranges.

This part has been compiled in response to a generally expressed desire on the part of both users and manufacturers for a guide to the use of SAW resonators, so that the resonators may be used to their best advantage. To this end, general and fundamental characteristics have been explained in this guide.

SURFACE ACOUSTIC WAVE (SAW) RESONATORS –

Part 2: Guide to the use

1 Scope

SAW resonators are now widely used in a variety of applications: VCR RF-converters, CATV local oscillators, measuring equipment, remote control and so on. While SAW resonators are also applied to narrow bandwidth filters, the scope of this part of IEC 61019 is limited to SAW resonators for oscillator applications

It is not the aim of this guide to explain theory, nor to attempt to cover all the eventualities which may arise in practical circumstances. This guide draws attention to some of the more fundamental questions, which should be considered by the user before he places an order for a SAW resonator for a new application. Such a procedure will be the user's insurance against unsatisfactory performance.

Standard specifications, such as those of the IEC of which this guide forms a part, and national specifications or detail specifications issued by manufacturers, will define the available combinations of resonance frequency, quality factor, motional resistance, parallel capacitance, etc. These specifications are compiled to include a wide range of SAW resonators with standardized performances. It cannot be over-emphasized that the user should, wherever possible, select his SAW resonators from these specifications, when available, even if it may lead to making small modifications to his circuit to enable the use of standard resonators. This applies particularly to the selection of the nominal frequency.

2 Normative references

The following referenced documents are indispensable for the application 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 61019-1:2004, *Surface acoustic wave (SAW) resonators – Part 1: Generic specification*

IEC 61019-3:1991, *Surface acoustic wave (SAW) resonators – Part 3: Standard outlines and lead connections*

3 Technical considerations

It is of prime interest to a user that the resonator characteristics should satisfy particular specifications. The selection of oscillating circuits and SAW resonators to meet such specifications should be a matter of agreement between user and manufacturer.

Resonator characteristics are usually expressed in terms of resonance frequency, motional resistance, quality factor and parallel capacitance (for the one-port type) and centre frequency, insertion attenuation, loaded and unloaded quality factor, input capacitance and output capacitance (for the two-port type). A standard method for measuring resonator characteristics is described in 8.5 and 8.6 of IEC 61019-1. The specifications are to be satisfied between the lowest and highest temperatures of the specified operating temperature range and before and after environmental tests.

4 Fundamentals of SAW resonators

4.1 Basic structure

SAW resonators consist of interdigital transducers (IDT) and of grating reflectors, which are placed on the surface of a piezoelectric substrate. In most cases, the grating reflectors are made of thin metal (such as Al, Au) film while, in some cases, they are constructed with periodic grooves. The die is bonded by an adhesive agent into a sealed enclosure, and the IDT is electrically connected to the terminals with bonding wires. There are two SAW resonator configurations. One is a one-port SAW resonator. The other is a two-port SAW resonator. The former has a single IDT between two reflectors, as shown in Figure 1. The latter has two IDTs between two reflectors, as shown in Figure 2. In the figures, ℓ_{eff} is the resonator cavity length, as described in 5.2 c).

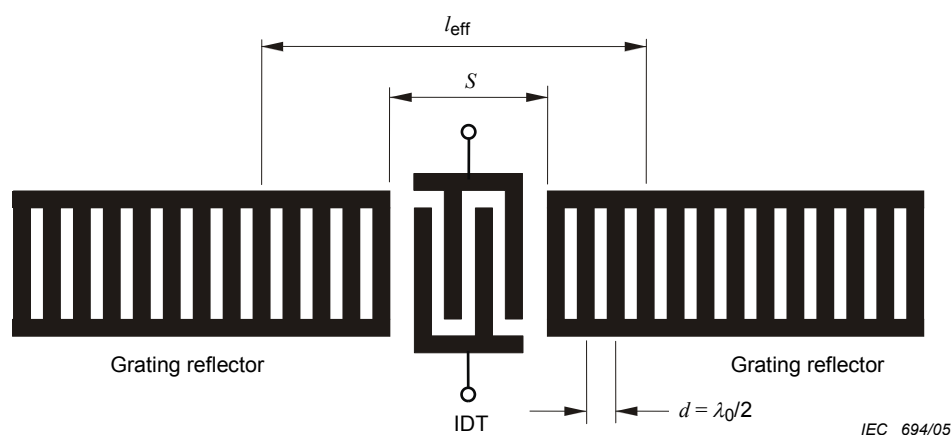


Figure 1 – One-port SAW resonator configuration

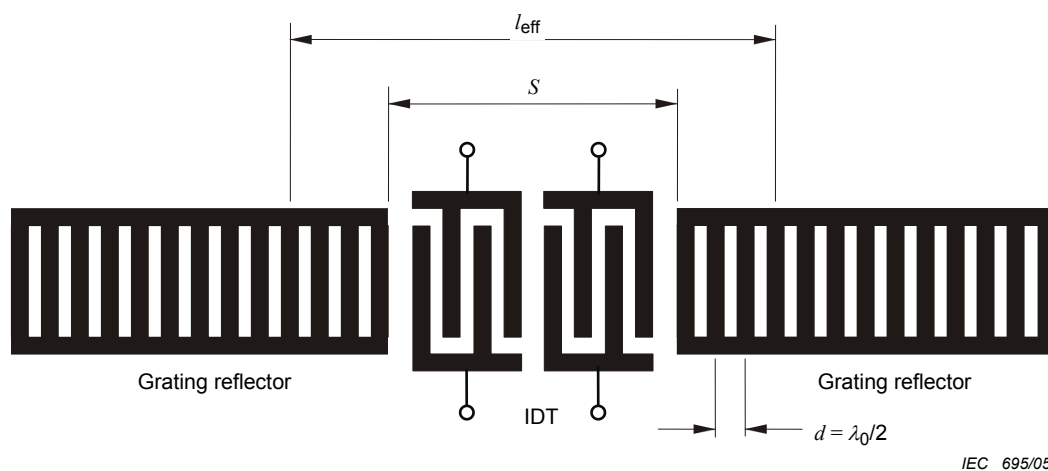


Figure 2 – Two-port SAW resonator configuration

4.2 Principle of operation

The resonance phenomenon for SAW resonators is achieved by confining the SAW vibration energy within grating reflectors. The SAW, excited by an alternating electrical field between IDT electrode fingers, propagates outside the IDT to be reflected by grating reflectors.

The grating reflectors feed the perturbation to the SAW, owing to the discontinuity in electrical or mechanical impedance. When the SAW is incident on such grating reflectors, the incident wave is gradually converted into a reflected wave. Although the amount of perturbation per unit reflective element may be very small, a large number of such elements, arranged periodically, reflect the SAW in phase, and maximize coherent reflection.

These grating configurations can form effective reflecting boundary, creating a standing wave between the reflectors and make resonance with a very high Q . Figure 3 shows the displacement distribution for this standing wave for a one-port SAW resonator. As shown in the figure, the SAW energy is maximum near the centre of the IDT, and gradually decays towards the edges of the grating reflectors. The resonance frequency, f_r , is approximately determined by

$$f_r \approx v_s / (2d) = v_s / \lambda_0$$

where

v_s is the SAW propagation velocity;

d is the distance between electrode centres;

λ_0 is the SAW wavelength at the stop band centre frequency.

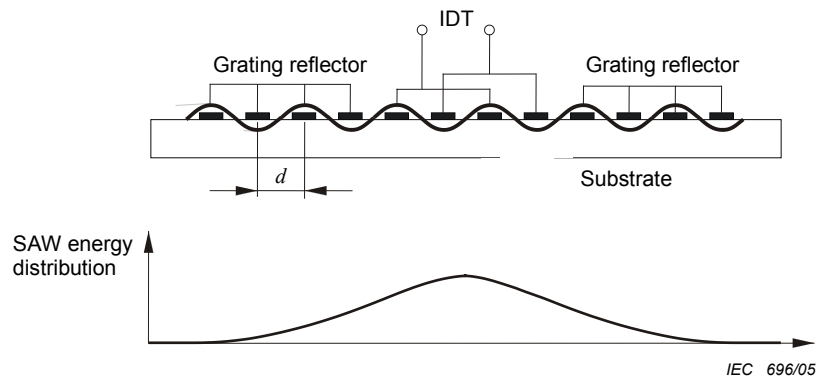


Figure 3 – Standing wave pattern and SAW energy distribution

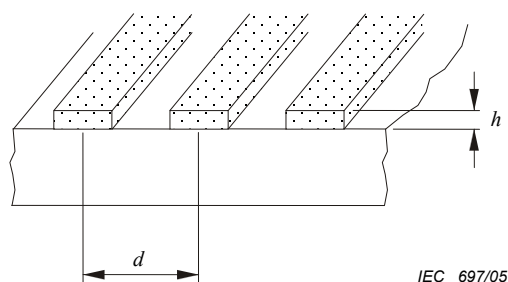
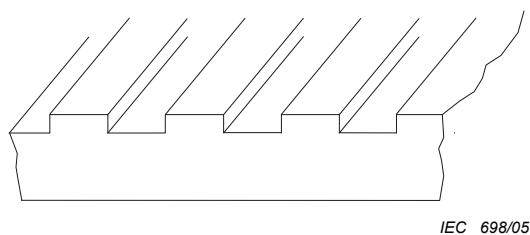
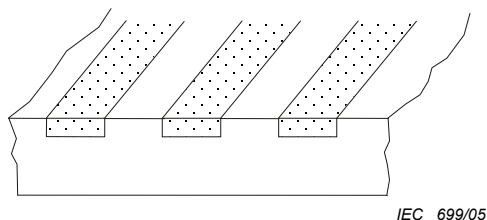
5 SAW resonator characteristics

5.1 Reflector characteristics

The reflector for SAW resonators consists of a periodically arranged array of reflective elements, called a grating reflector. As cross-sections show in Figure 4, possible array elements are:

- a) metal strips or dielectric ridges;
- b) grooves;
- c) ion-implanted or metal-diffused strips.

For example, an aluminum strip on ST-cut quartz, whose thickness h is 1 % of wave length $\lambda(h/\lambda_0)$ and whose width w is half the spatial period ($w = d/2 = \lambda_0/4$), has a small reflection coefficient ε of approximately 0,5 %. A groove with 1 % depth has almost the same ε . This periodic perturbation causes efficient reflection of SAW energy, if its wavelength equals twice its periodicity.

**4a – Metal strips or dielectric ridges****4b – Grooves****4c – Ion-implanted or metal diffused strips****Figure 4 – Grating reflector configurations**

A grating reflector without loss with a finite number of array elements has a frequency range of nearly total reflection called the stop band. The fractional stop bandwidth to centre frequency is $2\varepsilon/\pi$, where ε is the reflection coefficient for one element. Figure 5 indicates the frequency dependency on the total reflectivity $|\Gamma|$ for the grating reflector with a finite number N_R of array elements. Theoretically, the reflectivity maximum value is derived as:

$$|\Gamma|_{\max} = \tanh(N_R \times \varepsilon)$$

at the centre frequency f_0 of the stop band. A greater reflectivity makes SAW resonator Q value higher, due to decreasing the leakage of SAW energy stored in the cavity between two grating reflectors.

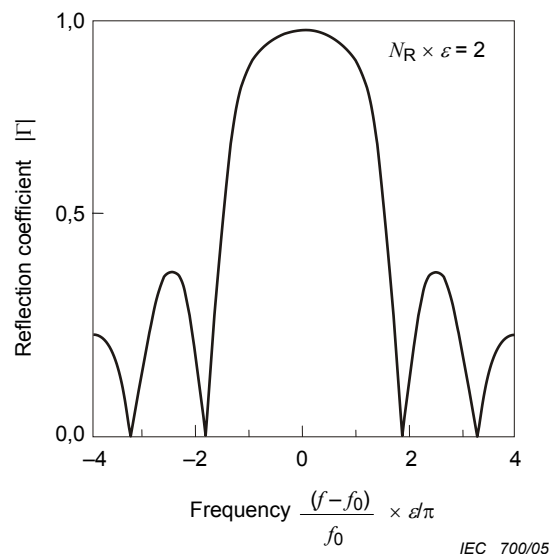


Figure 5 – Reflectivity response for grating reflection

For obtaining a greater reflectivity, it is clear, from the preceding equation, that $N_R \times \varepsilon$ should be larger. Increasing reflector element number N_R is the easiest way to obtain a higher reflectivity. However, in practice, a greater element number, i.e. longer reflector size, requires a larger SAW chip size and means an expensive SAW resonator. Generally, $N_R \times \varepsilon = 4$ is adequate for practical SAW resonators.

For obtaining greater reflectivity, increasing the reflection from one element is also effective. To accomplish this, strips should be thicker or grooves should be deeper. For the most part, ε is proportional to the thickness or the depth h/λ_0 . Thicker strips or deeper grooves require less element number N_R for the same reflection coefficient and realize greater stop bandwidth. However, a reflector with a large h/λ_0 has the following disadvantages:

- a) the mode conversion loss from SAW to bulk wave tends to increase, which may degrade the quality factor;
- b) stopband centre frequency deviation from the frequency $v_s/(2d)$ increases, because the centre frequency is a function of the square of h/λ_0 . This may cause mass production difficulties.

For a substrate material supporting shear wave, reflection at the edge of a substrate can be utilized as a substitute for a grating reflector. This gives the advantage of size reduction corresponding to the size of array elements.

5.2 SAW resonator characteristics

a) One-port SAW resonators

A one-port SAW resonator has the transmission characteristics shown in Figure 6.

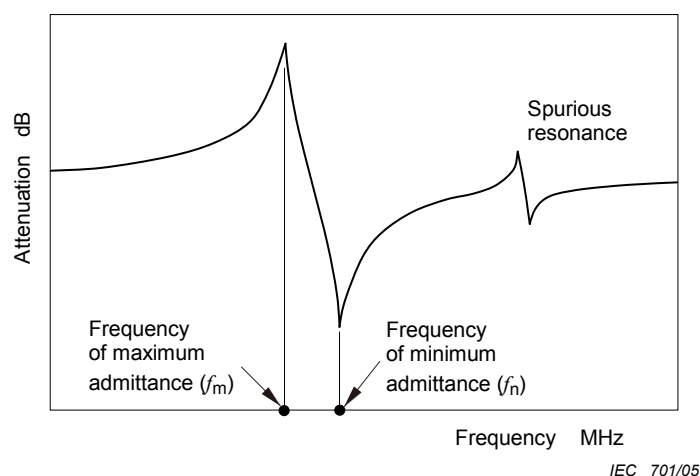
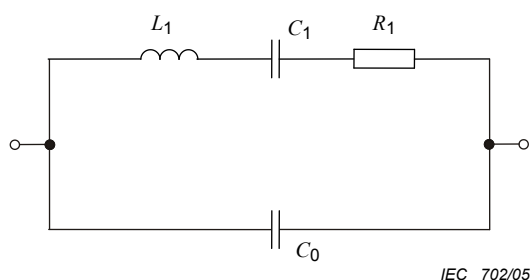


Figure 6 – Typical frequency characteristics for a one-port SAW resonator, inserted into a transmission line in series

The equivalent circuit in Figure 7 represents this one-port SAW resonator resonance. Comparing SAW resonators made from different piezoelectric materials, the figure of merit $M = Q/r$ derived from the equivalent circuit can be used. For example, SAW resonators on a quartz substrate have a high Q factor and a large r , while the values on X-cut LiTaO₃ are both smaller. Both resonators have similar figure of merit values. Considering only Q or the capacitance ratio r is insufficient for comparison purposes.

The equivalent circuit in Figure 7 can be replaced by a reactance with a series resistance: $R_e(f) + jX_e(f)$, where X_e and R_e are an equivalent series reactance and an equivalent series resistance, respectively. The frequency dependencies for these values are shown in Figure 8, where the value X_e/R_e reaches the maximum at the arithmetic mean of resonance and anti-resonance frequencies of zero susceptance.



$$f_s = \frac{1}{2\pi\sqrt{L_1 \times C_1}} \quad \text{is the motional (series) resonance frequency;}$$

$$Q = 2\pi f_s \times L_1 / R_1 \quad \text{is the quality factor;}$$

$$r = C_0 / C_1 \quad \text{is the capacitance ratio;}$$

$$M = Q/r \quad \text{is the figure of merit;}$$

$$L_1, C_1, R_1 \quad \text{are the motional inductance, motional capacitance and motional resistance respectively;}$$

$$C_0 \quad \text{is the static capacitance.}$$

Figure 7 – Equivalent circuit for a one-port resonator

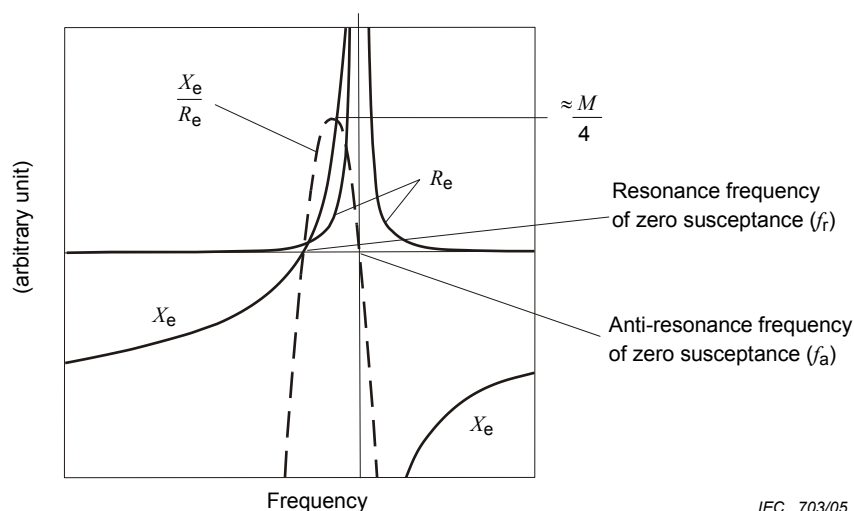


Figure 8 – Frequency response for series equivalent resistance (R_e), reactance (X_e) and X_e/R_e

The maximum value can be derived from the equivalent circuit as:

$$(X_e/R_e)_{\max} \approx (Q/r) / 4$$

In order to achieve oscillation more easily, resonators should show high Q reactance. Consequently, the figure of merit is adequate to compare SAW resonators.

Resonator impedance is inversely proportional to the aperture design. However, an over-narrow aperture resonator tends to increase r , due to the stray capacitance, and to degrade Q , due to the diffraction loss. On the other hand, an over-wide aperture resonator has a relatively low Q , due to electrode resistance.

b) *Two-port SAW resonators*

Two-port resonator transmission characteristics are shown in Figure 9.

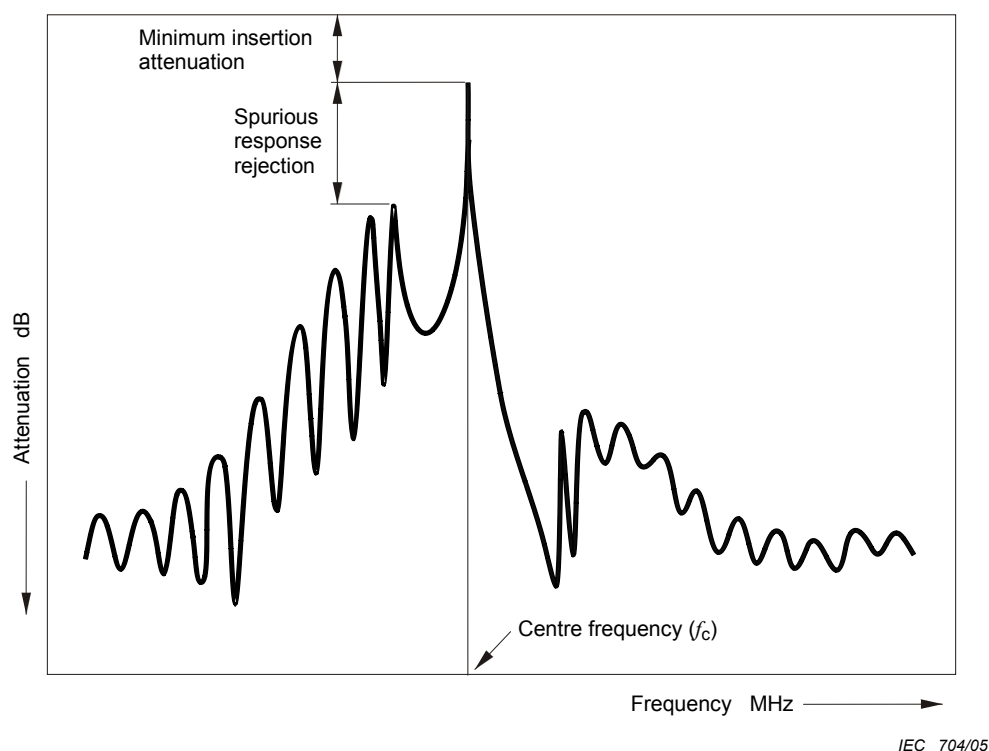
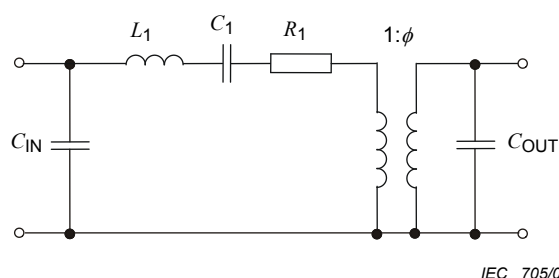


Figure 9 – Insertion attenuation and spurious response characteristics for a two-port resonator

An equivalent circuit for a two-port SAW resonator, in the vicinity of the centre frequency, is shown in Figure 10. It is constructed with a motional arm with motional inductance (L_1), capacitance (C_1), and resistance (R_1) in series, two parallel capacitances (C_{IN} and C_{OUT}) shunting the input and output ports and an ideal transformer. The turns ratio ϕ for the ideal transformer is derived from the input and output transducer structures. When both structures are the same, the ϕ value is unity; a 0° phase shift type is expressed as $\phi = 1$ and a 180° type is expressed as $\phi = -1$. Two-port SAW resonators, with different input and output impedances, have a $|\phi|$ value, which is not equal to unity.



Key

L_1	motional inductance	C_{IN}	input capacitance
C_1	motional capacitance	C_{OUT}	output capacitance
R_1	motional resistance	ϕ	turns ratio

Figure 10 – Equivalent circuit for a two-port resonator

For two-port resonators, there is no evident index as figure of merit as for one-port resonators. Easy-to-oscillate resonators are devices with low loss in the specific circuit and with the appropriate phase transition of 0° or 180° . Small motional resistance R_1 is essential for low loss. A lower impedance resonator (larger C_{IN} and C_{OUT}) has lower loss, in most cases.

c) *Equivalent circuit parameters*

Equivalent circuit parameters for a one-port SAW resonator can be represented as follows, when SAW reflection at IDT fingers is neglected:

$$L_1 = \frac{l_{\text{eff}}/\lambda_0}{4f_0|\Gamma|} \times R_a$$

$$R_1 = \frac{1-|\Gamma|}{2|\Gamma|} \times R_a$$

$$C_1 = \frac{1}{(2\pi f_0)^2 L_1}$$

$$C_0 = N \times w(1 + \varepsilon_r) \times \varepsilon_0$$

where

$R_a = \frac{1}{8k_s^2 f_0 N C_0}$ is the IDT radiation resistance at f_0 ;

$f_0 = v_s/(2d)$;

N is the IDT finger pair number;

w is the aperture;

k_s^2 is the SAW coupling coefficient;

ε_r is the relative permittivity of a piezoelectric substrate;

ε_0 is the permittivity of vacuum;

Γ is the reflection coefficient of a reflector;

λ_0 is the SAW wavelength at the centre frequency;

l_{eff} is the resonator cavity length shown in Figures 1 and 2 ($l_{\text{eff}} \approx S + \lambda_0/(2\varepsilon)$), where S is a separation of grating reflectors.

For two-port SAW resonators, C_0 shall be replaced by C_{IN} or C_{OUT} respectively. Other equations are the same as the above equations.

5.3 Spurious modes

SAW resonators have many kinds of spurious modes. One is higher-order SAW resonance modes, called longitudinal and transverse modes. Other types of SAW modes, such as leaky SAW, SSBW, Love waves, may be excited by the IDT. Another mode is bulk wave modes. Figures 6 and 9 show the typical spurious characteristics for one-port and two-port resonators, respectively. These spurious modes can be reduced by applying several techniques to the resonators.

When used in an oscillator circuit, these spurious modes rarely cause problems. However, should there be spurious responses near the main mode or responses with relatively large amplitude, oscillation problems at those spurious frequencies could occur.

These spurious responses could result in anomalous frequency-temperature, resistance-temperature and frequency pulling characteristics. Even very small perturbations of this type can have very deleterious effects for VCO (voltage controlled oscillator) applications. It is more difficult to eliminate these spurious responses from the resonators. However, these resonators seldom give trouble, because the spurious resonance resistance is in general larger than that for the main mode. Manufacturers' standard products involve design measures which minimize these effects when coupled with reasonable oscillator design.

In any application, where there are spurious responses, it should be considered that there is a possibility of the oscillator starting at the spurious responses. In a frequency range around the main response, one of the following ratios can be specified:

$\frac{\text{spurious resonance motional resistance}}{\text{main resonance motional resistance}}$ for a one-port resonator

$\frac{\text{spurious resonance response level}}{\text{main resonance response level}}$ for a two-port resonator

For two-port resonators, only spurious resonances which fulfil the phase condition of the oscillator feedback loop have to be considered.

5.4 Substrate materials and their characteristics

Various kinds of piezoelectric substrates are available for use in SAW resonators. Piezoelectric substrates for SAW resonators are selected, in consideration of the following items:

- 1) propagation velocity (v_s);
- 2) coupling coefficient (k_s^2);
- 3) temperature coefficient of frequency (TCF);
- 4) relative permittivity (ϵ_r);
- 5) material propagation loss;
- 6) reproducibility and reliability;
- 7) price.

Items 1) to 5) are constants concerned mainly with materials. Items 6) and 7) are conditions depending on both materials and substrate fabrication techniques. Several kinds of substrates have been developed and put into practical use.

Ideally, a high coupling coefficient and a zero temperature coefficient are desired. At present, this is not possible. Thus, a design trade-off is required. It is necessary to select a substrate according to the required specifications. Relationships between material constants and resonator characteristics are described below.

a) *Propagation velocity*

The propagation velocity v_s (m/s) is an important factor, which determines the frequency range. Resonance frequency f_r (MHz) is given approximately by:

$$f_r = v_s / (2d)$$

where d (μm) is the spatial period of the grating. For a specified resonance frequency, slower velocities require a shorter finger period and, consequently, a smaller chip size. Faster velocity is desirable for high frequency resonators, in order to make the IDT fabrication easier. Propagation velocity for a practical substrate is usually in the 2 000 m/s to 5 000 m/s range.

b) *Coupling coefficient*

SAW coupling coefficient k_s^2 is the transformation ratio between the electric energy and the mechanical (SAW) energy. The coupling coefficient is the principal factor that determines capacitance ratio r . When the coupling coefficient of the substrate is large enough, it is easy to design a low capacitance ratio SAW resonator. An achievable minimum capacitance ratio is represented as:

$$r_{\min} \approx \pi^2 / (8k_s^2)$$

c) *Temperature coefficient*

This characteristic is determined mainly by the piezoelectric material and crystal orientations. Rotated Y-cut (around ST-cut) quartz and $\text{Li}_2\text{B}_4\text{O}_7$ materials have parabolic frequency-temperature characteristics, but with other piezoelectric materials they are nearly linear. Figure 11 shows frequency-temperature characteristics for various common substrate materials.

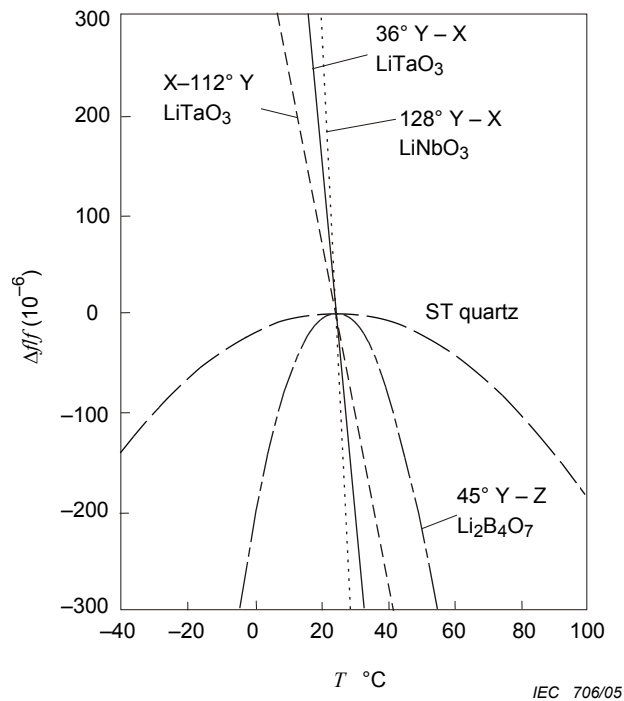


Figure 11 – Frequency-temperature characteristics for various common materials and their angles of cut

Typically the frequency-temperature dependence is:

$$\frac{\Delta f}{f} = a \times (T - T_0) + b \times (T - T_0)^2$$

where

$\frac{\Delta f}{f}$ is the fractional frequency change;

T_0 is the turnover temperature;

T is the operating temperature;

a is the first order temperature coefficient;

b is the second order temperature coefficient.

Typical temperature coefficient values are listed in Table 1.

d) *Relative permittivity*

The piezoelectric material permittivity is a second-order symmetric tensor. The static capacitance for the IDT, C_0 , directly depends on the substrate permittivity.