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Edition 2.0 2005-05

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

IEC 61019-2:2005-05(EN-FR)

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SURFACE ACOUSTIC WAVE (SAW) RESONATORS –

Part 2: Guide to the use

FOREWORD

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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 editon 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 $LiNbO_3$ (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- withdrawn;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).

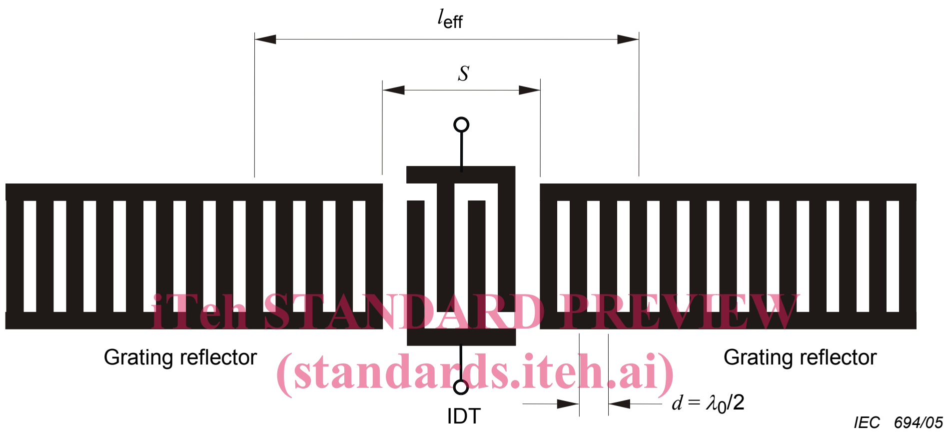


Figure 1 – One-port SAW resonator configuration

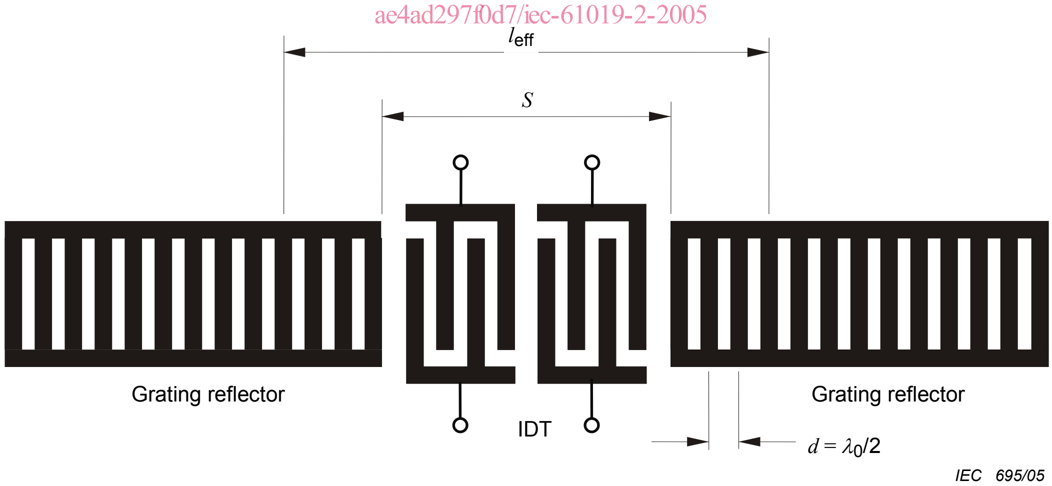


Figure 2 – Two-port SAW resonator configuration

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.

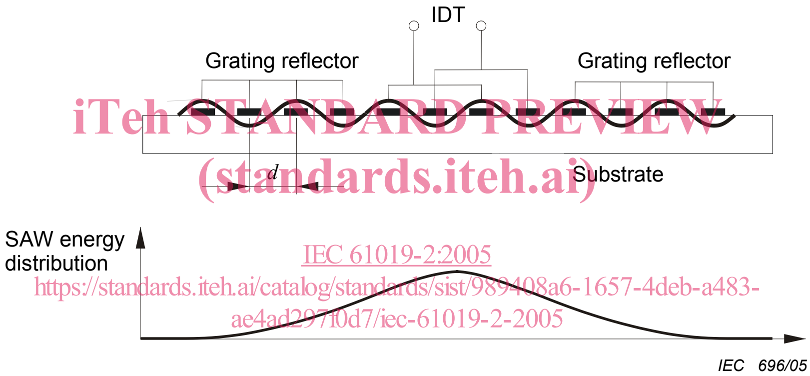


Figure 3 – Standing wave pattern and SAW energy distribution

5 SAW resonator characteristics

5.1 Reflector characteristics

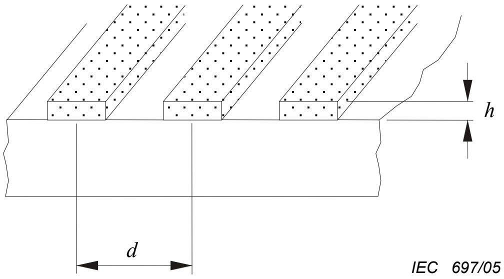
The reflector for SAW resonators consists of a periodically arranged array of reflective elements, called a grating reflector. As cross-sections show in Figure 4, possible array elements are:

a) metal strips or dielectric ridges;

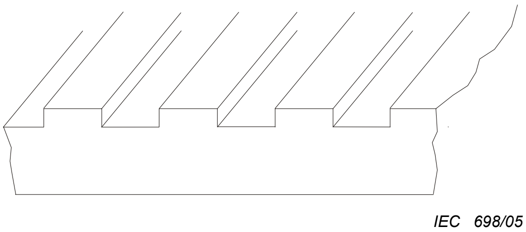
b) grooves;

c) ion-implanted or metal-diffused strips.

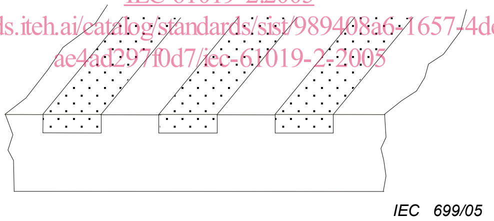
For example, an aluminum strip on ST-cut quartz, whose thickness h is 1 % of wave length $\lambda(h/\lambda_0)$ and whose width w is half the spatial period ($w = d/2 = \lambda_0/4$), has a small reflection coefficient ε of approximately 0,5 %. A groove with 1 % depth has almost the same ε. This periodic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

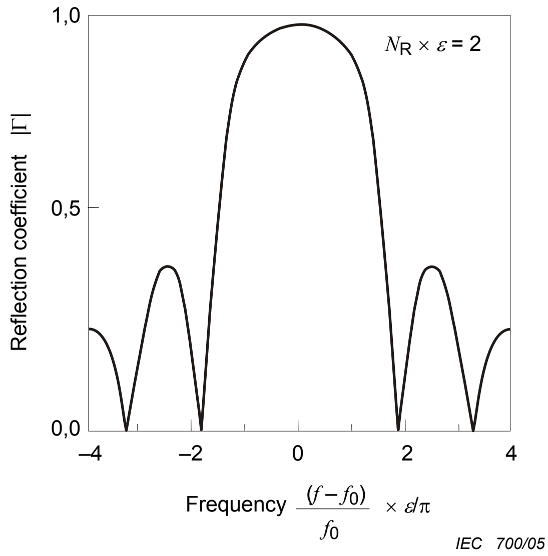


Figure 5 – Reflectivity response for grating reflection

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.

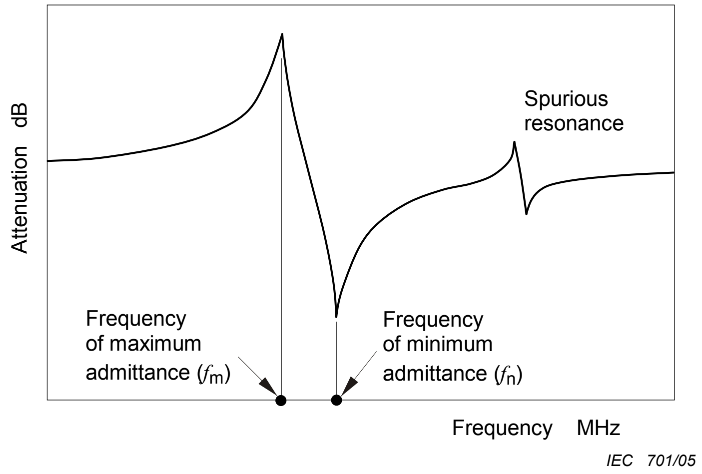
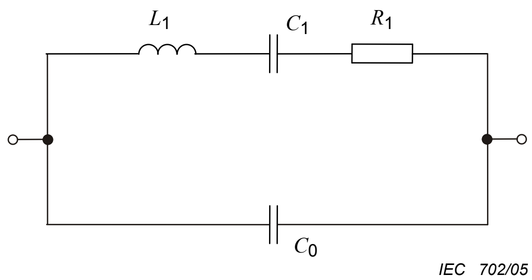


Figure 6 – Typical frequency characteristics for a one-port SAW resonator, inserted into a transmission line in series

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 $LiTaO_3$ 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.



$f_s = \dfrac{1}{2\pi\sqrt{L_1 \times C_1}}$	is the motional (series) resonance frequency;
$Q = 2\pi f_s \times L_1/R_1$	is the quality factor;
$r = C_0/C_1$	is the capacitance ratio;
$M = Q/r$	is the figure of merit;
L_1, C_1, R_1	are the motional inductance, motional capacitance and motional resistance respectively;
C_0	is the static capacitance.

Figure 7 – Equivalent circuit for a one-port resonator

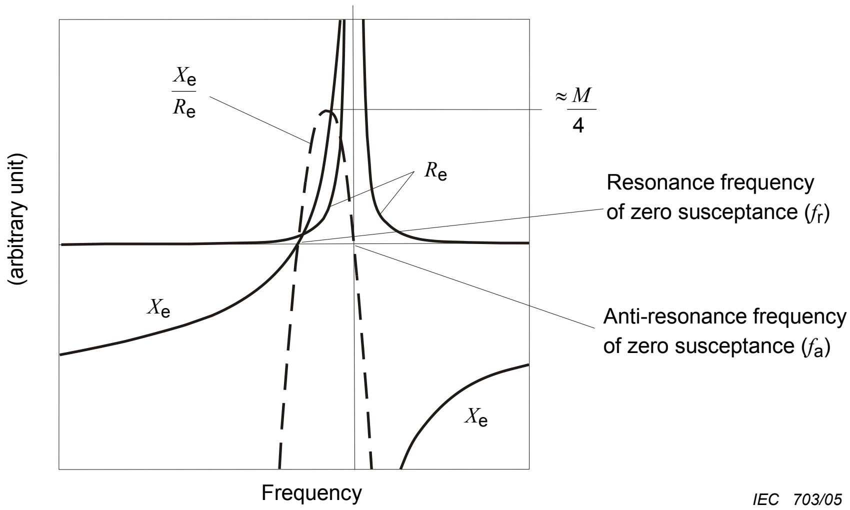


Figure 8 – Frequency response for series equivalent resistance (R_e), reactance (X_e) and X_e/R_e

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.

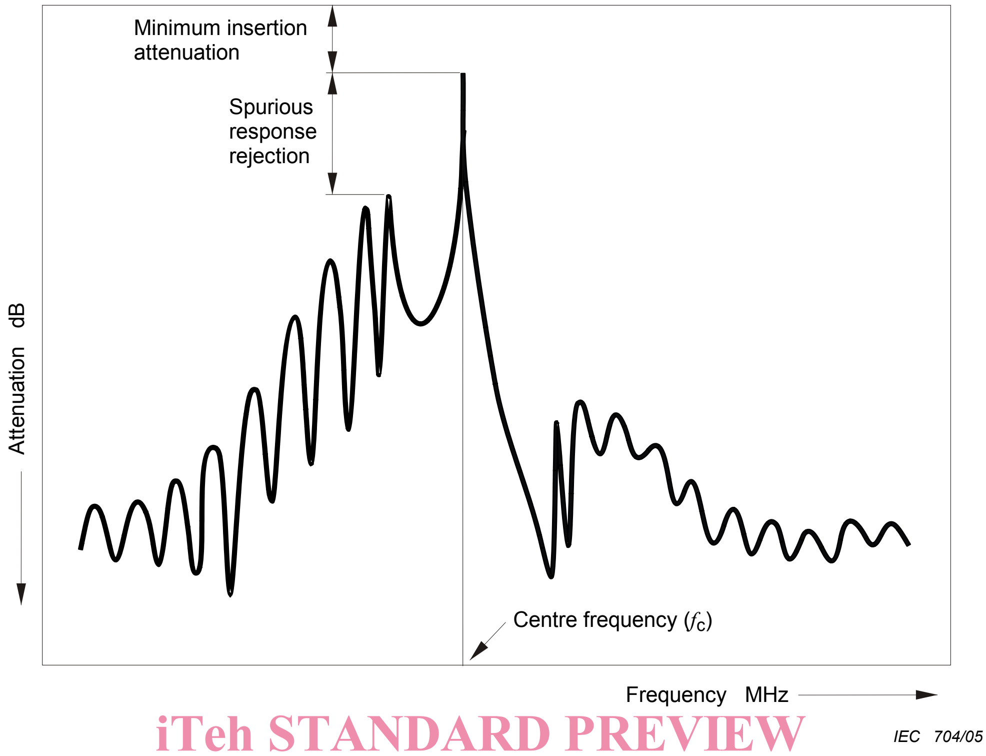
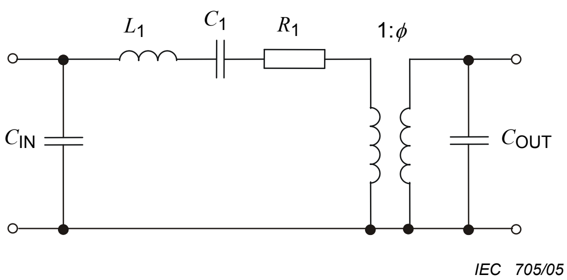


Figure 9 – Insertion attenuation and spurious response characteristics for a two-port resonator

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.