

Surface acoustic wave (SAW) filters of assessed quality —

Part 2: Guidance on use

The European Standard EN 60862-2:2002 has the status of a
British Standard

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee EPL/49, Piezo-electric devices for frequency control and selection, which has the responsibility to:

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Surface acoustic wave (SAW) filters of assessed quality
Part 2: Guidance on use
(IEC 60862-2:2002)

Filtres à ondes acoustiques de surface
(OAS) sous assurance de la qualité
Partie 2: Guide d'utilisation
(CEI 60862-2:2002)

Oberflächenwellenfilter (OFW-Filter)
mit bewerteter Qualität
Teil 2: Leitfaden für die Anwendung
(IEC 60862-2:2002)

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Foreword

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Annexes designated "normative" are part of the body of the standard.
In this standard, annex ZA is normative.
Annex ZA has been added by CENELEC.

Endorsement notice

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INTRODUCTION

This part of IEC 60862 gives practical guidance on the use of SAW filters which are used in telecommunications, measuring equipment, radar systems and consumer products. IEC 60862-1 should be referred to for general information, standard values and test conditions.

The features of these SAW filters are their small size, light weight, adjustment-free, high stability and high reliability. SAW filters add new features and applications to the field of crystal filters and ceramic filters. At the beginning, SAW filters meant transversal filters which have two interdigital transducers (IDT). Although SAW transversal filters have a relatively higher minimum insertion attenuation, they have excellent amplitude and phase characteristics. Extensive studies have been made to reduce minimum insertion attenuation, such as resonator filter configurations, unidirectional interdigital transducers (UDT), interdigitated interdigital transducers (IIDT). Nowadays, various kinds of SAW filters with low insertion attenuation are widely used in various applications and SAW filters are available in the gigahertz range.

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

SURFACE ACOUSTIC WAVE (SAW) FILTERS OF ASSESSED QUALITY –

Part 2: Guidance on use

1 Scope

SAW filters are now widely used in a variety of applications such as TV, satellite communications, optical fibre communications, mobile communications and so on. While these SAW filters have various specifications, many of them can be classified within a few fundamental categories.

This part of IEC 60862 includes various kinds of filter configuration, of which the operating frequency range is from approximately 10 MHz to 3 GHz and the relative bandwidth is about 0,02 % to 100 % of the centre frequency.

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

Standard specifications, given in IEC 60862, and national specifications or detail specifications issued by manufacturers, define the available combinations of nominal frequency, pass bandwidth, ripple, shape factor, terminating impedance, etc. These specifications are compiled to include a wide range of SAW filters with standardized performances. It cannot be over-emphasized that the user should, wherever possible, select his SAW filters from these specifications, when available, even if it may lead to making small modifications to his circuit to enable standard filters to be used. 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 60368-2-1:1988, *Piezoelectric filters – Part 2: Guide to the use of piezoelectric filters – Section One: Quartz crystal filters*

IEC 60862 (all parts), *Surface acoustic wave (SAW) filters of assessed quality*

3 Terms and definitions

For the purpose of this part of IEC 60862, the following terms and definitions apply.

3.1 General terms

3.1.1

surface acoustic wave (SAW)

acoustic wave, propagating along a surface of an elastic substrate, whose amplitude decays exponentially with substrate depth

3.1.2

surface acoustic wave filter (SAW filter)

filter characterized by a surface acoustic wave which is usually generated by an interdigital transducer and propagates along a substrate surface to a receiving transducer

3.1.3

power flow vector

vector, analogous to a Poynting vector, characterizing energy propagation caused by a surface acoustic wave

3.1.4

propagation vector

vector characterizing the phase progression of a wave

3.1.5

power flow angle

angle between the direction of the power flow vector and the direction of the propagation vector

3.1.6

SAW beam steering

SAW propagation phenomenon in anisotropic materials described by an angle of power flow which is not zero

3.1.7

SAW diffraction

phenomenon (analogous to diffraction of light from a source of finite aperture) which causes SAW beam spreading and wavefront distortion

3.1.8

SAW coupling coefficient (k_s^2)

SAW electromechanical coupling coefficient is defined as follows:

$$k_s^2 = 2 \left| \frac{\Delta v_s}{v_s} \right|$$

where

$\Delta v_s/v_s$ is the relative velocity change produced by short-circuiting the surface potential from the open-circuit condition

3.1.9

interdigital transducer (IDT)

SAW transducer made of two comb-like conductive structures deposited on a piezoelectric substrate transforming electrical energy into acoustic energy or vice versa

3.1.10

unidirectional interdigital transducer (UDT)

transducer capable of radiating and receiving surface acoustic waves in or from a single direction

3.1.11

multiphase transducer

interdigital transducer having more than two inputs which are driven in different phases. Usually used as a unidirectional transducer

3.1.12

finger

element of the IDT comb electrode

3.1.13**dummy finger**

passive finger which may be included in order to suppress wavefront distortion

3.1.14**split finger**

finger formed of more than one element, so as to produce antireflection properties

3.1.15**bus bar**

common electrode which connects individual fingers together and also connects the filter to an external circuit

3.1.16**weighted-response transducer**

transducer intended to produce a specified impulse response by design of the structure (see, for example, 3.1.17 to 3.1.22)

3.1.17**finger overlap or source strength**

length of a finger pair between which only electromechanical interaction is generated

3.1.18**apodization**

weighting produced by the change of finger overlap over the length of the IDT

3.1.19**withdrawal weighting**

weighting by removal of fingers or sources

3.1.20**capacitive weighting**

weighting by change of capacitance between electrodes

3.1.21**series weighting**

weighting by separation of a finger into individual elements having capacitive coupling between them. The elements may be separated from the bus bar

3.1.22**phase weighting**

weighting by change in period of finger arrangement inside the IDT

3.1.23**aperture**

normalized beamwidth of the SAW generated at centre frequency and normalized to the corresponding wavelength

3.1.24**multistrip coupler (MSC)**

array of additional metal strips deposited on a piezoelectric substrate, in a direction transverse to the propagation direction, which transfers acoustic power from one acoustic track to an adjacent track

3.1.25

reflector

SAW reflecting component which normally makes use of the periodic discontinuity provided by a metal strip array or a grooved array

3.1.26

spurious reflections

unwanted signals caused by reflection of SAW or bulk waves from substrate edges or electrodes

3.1.27

triple transit echo (TTE)

unwanted signals in a SAW filter which have traversed three times the propagation path between input and output IDTs caused by reflections from output and input transducers

3.1.28

bulk-wave signals

unwanted signals caused by bulk-wave excitation, detected at the filter output

3.1.29

feed-through signals (signals of electromagnetic interference)

unwanted signals from the input appearing at the filter output due to stray capacitances and other electromagnetic couplings

3.1.30

suppression corrugation

grooves in the non-active side of a substrate for suppressing bulk-wave signals

3.1.31

acoustic absorber

material with high acoustic loss placed on any part of the substrate for acoustic absorption purposes

3.1.32

shielding electrode

electrode intended for the reduction of electromagnetic interference signals

3.1.33

interdigitated interdigital transducer (IIDT)

SAW transducer made of a combination of three or more interdigital transducers. Same as a multi-IDT

NOTE In this standard, IIDT (or multi-IDT) resonator filters are referred to as SAW resonator filters composed of a number of IDTs for input and output in a line alternating with grating reflectors confirming the IDT structure at both ends.

3.2 Response characteristics

3.2.1

nominal frequency

frequency given by the manufacturer or the specification to identify the filter

3.2.2

centre frequency

arithmetic mean of the cut-off frequencies

3.2.3**reference frequency**

frequency defined by the specification to which other frequencies may be referred

3.2.4**cut-off frequency**

frequency of the pass-band at which the relative attenuation reaches a specified value

3.2.5**total power loss**

logarithmic ratio of the available power at the given source to the power that the SAW filter delivers to a load impedance under specified operating conditions

3.2.6**insertion attenuation**

logarithmic ratio of the power delivered directly to the load impedance before insertion of the filter to the power delivered to the load impedance after insertion of the filter

3.2.7**nominal insertion attenuation**

insertion attenuation at a specified reference frequency

3.2.8**relative attenuation**

difference between the attenuation at a given frequency and the attenuation at the reference frequency

3.2.9**pass-band**

band of frequencies in which the relative attenuation is equal to, or less than, a specified value

3.2.10**pass bandwidth**

separation of frequencies between which the relative attenuation is equal to, or less than, a specified value

3.2.11**pass-band ripple**

variation in insertion attenuation within a specified pass-band

3.2.12**TTE ripple**

maximum variation in attenuation characteristics caused by TTE within a specified pass-band

3.2.13**minimum insertion attenuation**

minimum value of insertion attenuation in the pass-band

3.2.14**stop-band**

band of frequencies in which the relative attenuation is equal to, or greater than, a specified value

3.2.15

stop bandwidth

separation of frequencies between which the relative attenuation is equal to, or greater than, a specified value

3.2.16

shape factor

ratio of two bandwidths at specified values of the relative attenuation

3.2.17

group delay

time equal to the first derivative of the phase shift, in radians, with respect to the angular frequency

3.2.18

nominal group delay

group delay at a specified reference frequency

3.2.19

group delay distortion

difference between the lowest and highest value of group delay in a specified frequency band

3.2.20

trap frequency

specified frequency at which the relative attenuation is equal to, or greater than, a specified value

3.2.21

trap attenuation

relative attenuation at a specified trap frequency

3.2.22

transition band

band of frequencies between the cut-off frequency and the nearest point of the adjacent stop-band

3.2.23

reflection coefficient

dimensionless measure of the degree of mismatch between two impedances Z_a and Z_b , given by the expression

$$\left| \frac{Z_a - Z_b}{Z_a + Z_b} \right|$$

where

Z_a and Z_b represent respectively the input and source impedance or the output and load impedance

3.2.24

return attenuation

value of the reciprocal of the modulus of the reflection coefficient expressed in decibels. Quantitatively, it is equal to:

$$20 \log \left| \frac{Z_a + Z_b}{Z_a - Z_b} \right| \text{ dB}$$

3.2.25

reflected wave signal suppression

relative attenuation of unwanted signals caused by reflection of SAW or bulk waves from substrate edges or electrodes within a specified time window

3.2.26

feed-through signal suppression

relative attenuation which implies the suppression of directly coupled signals by the electromagnetic and electrostatic coupling between the input and output electrodes

3.2.27

unwanted response

response other than that associated with the mode of vibration intended for the application

3.2.28

input level

power, voltage or current value applied to the input terminal pair of a filter

3.2.29

output level

power, voltage or current value delivered to the load

3.2.30

nominal level

power, voltage or current value at which the performance measurement is specified

3.2.31

input impedance

impedance presented by the filter to the signal source when the output is terminated by a specified load impedance

3.2.32

output impedance

impedance presented by the filter to the load when the input is terminated by a specified source impedance

3.2.33

terminating impedance

either of the impedances presented to the filter by the source or by the load

3.2.34

available power

maximum power obtainable from a given source by suitable adjustment of the load impedance

3.2.35

roll-off rate

index describing the rise-up characteristics for digital communication SAW roll-off filters. It is a ratio of the transition band to the ideal cut-off frequency, which is equal to half of the sampling frequency, in the case of cosine roll-off frequency characteristics

3.2.36

intermodulation distortion

non-linear distortion of a SAW transducer or filter response characterized by the appearance of frequencies at the output equal to the differences (or sums) of integral multiples of the two or more component frequencies present at the input

3.3 SAW filter related terms

3.3.1

transversal filter

filter consisting of input and output interdigital transducers on a piezoelectric substrate. The frequency response of the filter is fundamentally given by the impulse response of the transducer

3.3.2

frequency symmetrical filter

filter having a symmetrical frequency characteristic in relation to the reference frequency

3.3.3

frequency asymmetrical filter

filter having a specified asymmetrical pass-band or stop-band characteristic in relation to the reference frequency

3.3.4

dispersive filter

filter designed so as to have group delay which is a function of frequency, usually by varying the finger periodicity

3.3.5

comb filter

filter having two or more pass-bands between three or more stop-bands

3.3.6

resonator filter

filter in which two or more SAW resonators are incorporated

3.3.7

ladder filter

filter having a cascade or tandem connection of alternating series and shunt SAW resonators

3.3.8

lattice filter

filter having at least four SAW resonators connected in series to form a mesh, two non-adjacent junction points are used as input terminals, while the remaining two junction points are used as output terminals (bridge circuit). Preferably it can be used for balanced circuits

4 Preliminary remarks of a technical nature

It is of prime interest to a user that the filter characteristics should satisfy a particular specification. The selection of tuning networks and SAW filters to meet that specification should be a matter of agreement between user and manufacturer.

Filter characteristics are usually expressed in terms of insertion attenuation and group delay as a function of frequency, as shown in figure 1. A standard method for measuring insertion attenuation and group delay is described in 4.5.2 of IEC 60862-1¹⁾. In some applications, such characteristics as phase distortion are also important.

Insertion attenuation characteristics are further specified by nominal frequency, minimum insertion attenuation or maximum insertion attenuation, pass-band ripple and shape factor. The specification is to be satisfied between the lowest and highest temperatures of the specified operating temperature range and before and after environmental tests.

¹⁾ To be published.

SAW filters are classified roughly into two types: transversal filters and resonator filters. Transversal filters are further classified into two types: bidirectional IDT filter and unidirectional IDT filter. Also resonator filters are further classified into three types i.e. ladder and lattice filters, coupled resonator filter and IIDT resonator filter. Fundamentals of SAW transversal filters and SAW resonator filters are described in clauses 5 and 6 of this standard, respectively. In figure 2, the applicable frequency range and relative bandwidth of the SAW filters are shown in comparison with those of ceramic, crystal, dielectric, helical and stripline filters.

5 Fundamentals of SAW transversal filters

5.1 Frequency response characteristics

A brief description of SAW filters is given here to help users unfamiliar with these filters to understand their operating principles and characteristics. The SAW filter uses a surface acoustic wave, usually the Rayleigh wave. The mechanical energy transported by the wave is concentrated in a surface region of the order of a wavelength in depth. The wave travels on a solid surface at a velocity, 10^3 m/s to 10^4 m/s, which offers the possibility of filtering operations in the VHF and UHF regions in practical SAW filters. The SAW filter has a planar structure, in which electrodes are formed on one surface of a piezoelectric substrate, incorporating a suitable configuration of electrodes as a means of conversion between surface acoustic waves and electrical signals.

Figure 3 is a diagram showing the signal flow through a transversal filter. The filter consists of N taps separated by delays D_n . Each tap is weighted by a coefficient A_n . Filtering is achieved by passing the signal through a number of delay paths and adding these delayed signals. The delays correspond to the positions of IDT fingers on a substrate. The coefficients correspond to weighting coefficients given to the IDT fingers. The frequency response of the filter $H(f)$ is given by a discrete Fourier transformation, expressed as the following equation at a frequency f :

$$H(f) = \sum_{n=1}^N A_n \exp(-j2\pi f T_n) \quad T_n = \sum_{i=1}^n D_i \quad (1)$$

where T_n is the accumulated delay at the n th tap.

Both amplitude and phase characteristics of the transversal filter are given by two sets of variables: weighting coefficients A_n and delays D_n of the sampling taps.

The SAW transversal filter is essentially constructed with a pair of transducers on a piezoelectric substrate as shown in figure 4. When an electrical signal is applied to the input IDT, the surface wave is generated by means of the piezoelectric effect and propagates in both directions along the substrate surface. The surface wave is converted again into an electrical signal at the output IDT. If the IDT spatial period $2d$ is uniform, maximum efficiency can be achieved at the frequency for which the surface wave propagates one transducer period synchronously in one RF signal period. The centre frequency f_0 of the IDT is given by this synchronization condition:

$$2df_0 = v_s \quad (2)$$

where v_s is the SAW velocity.

When the SAW transversal filter has two uniform identical transducers, its frequency response is as shown in figure 5. The transfer function $T(f)$ is approximately expressed as

$$T(f) = \left(\frac{\sin x}{x} \right)^2 \quad (3)$$

where

$$x = \frac{N\pi(f - f_0)}{f_0} \text{ and}$$

N is the number of finger pairs.

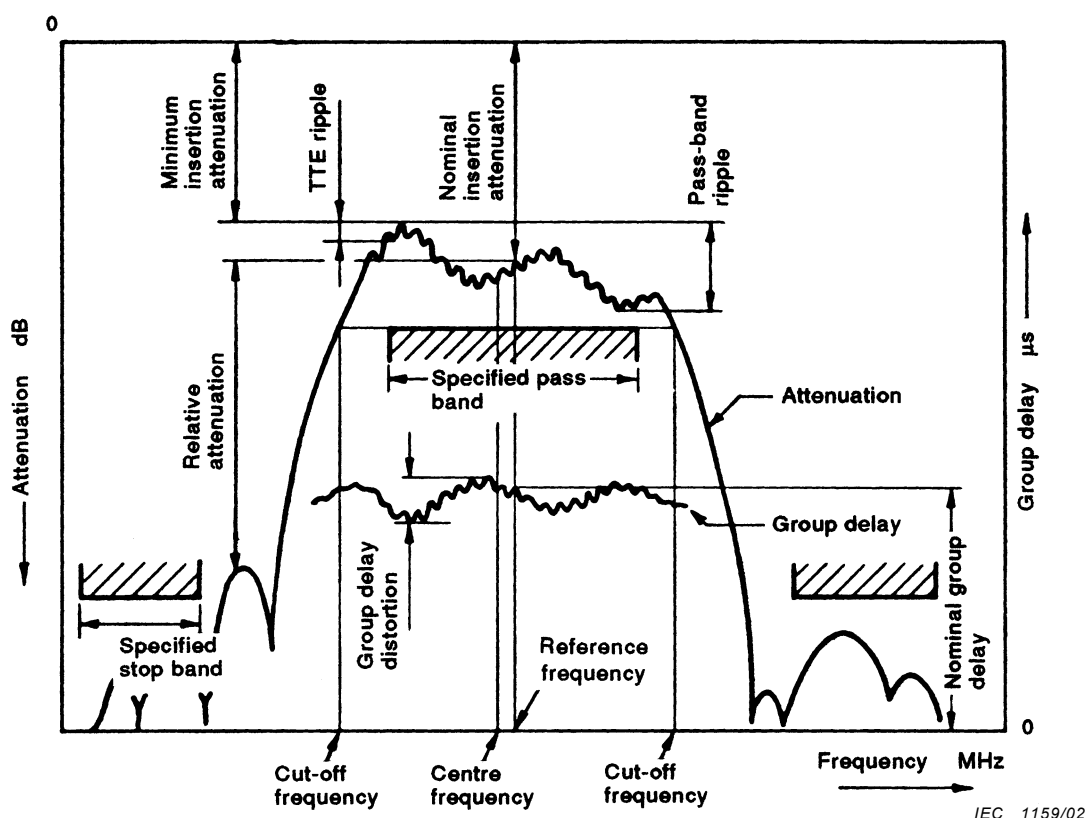


Figure 1 – Frequency response of a SAW filter

5.2 Weighting methods

The IDT operates as a kind of transversal filter with N taps for the weighting. A number of weighting methods are applicable, for example apodization, withdrawal and series (dog-leg) weighting.

a) Apodization weighting

An apodized transducer, as shown in figure 6, is most commonly used to achieve weighting. An acoustic wave is generated or detected only in regions where adjacent electrodes of opposite polarity overlap.

b) Withdrawal weighting

Weighting is achieved by selectively withdrawing electrodes, as illustrated in figure 7, to equate with the desired weighting function.

c) Series (dog-leg) weighting

Weighting is achieved by dividing the voltage by segmenting each electrode pair, as shown in figure 8.

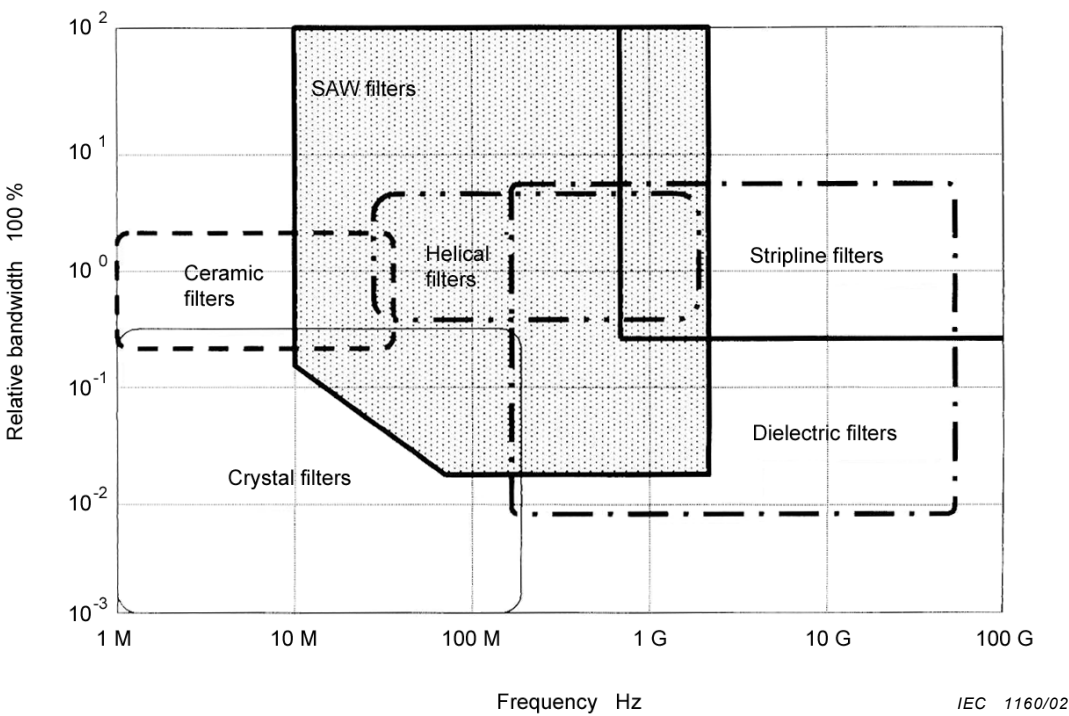


Figure 2 – Applicable range of frequency and relative bandwidth of the SAW filter and the other filters

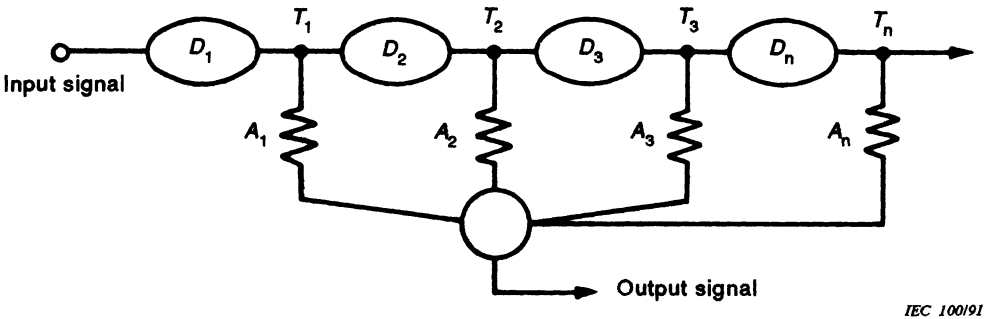


Figure 3 – Schematic diagram showing signal flow through a transversal filter

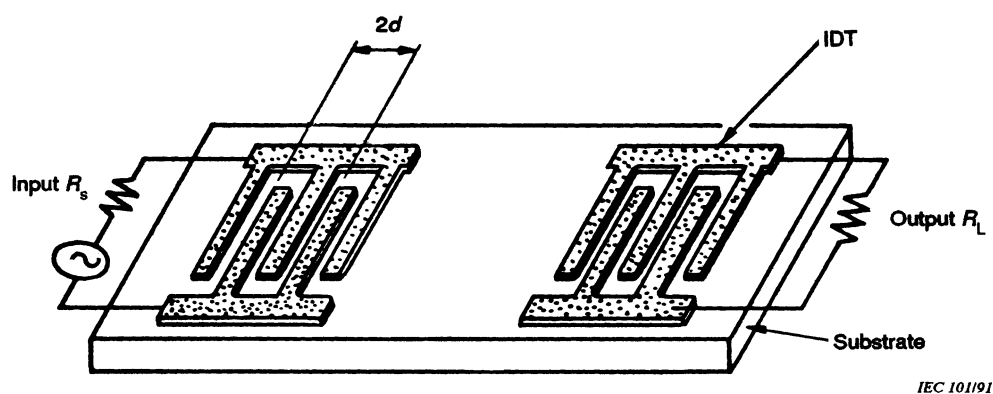


Figure 4 – Basic configuration of a SAW transversal filter

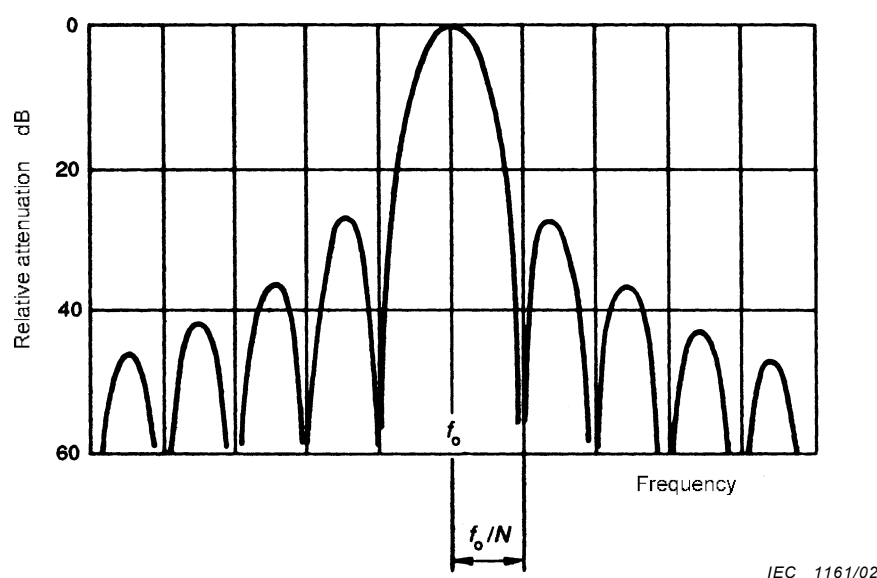


Figure 5 – Frequency response of the SAW transversal filter shown in figure 4, where f_0 is the centre frequency and N is the number of finger pairs of the IDT