



BSI Standards Publication

Surface acoustic wave (SAW) filters of assessed quality

Part 2: Guidelines for the use

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW

raising standards worldwide™

Full document details: BS EN 60862-2:2012

National foreword

This British Standard is the UK implementation of EN 60862-2:2012. It is identical to IEC 60862-2:2012. It supersedes BS EN 60862-2:2002, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EPL/49, Piezoelectric devices for frequency control and selection.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2012

Published by BSI Standards Limited 2012

ISBN 978 0 580 66988 0

ICS 31.160

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 August 2012.

Amendments issued since publication

Amd. No.	Date	Text affected
----------	------	---------------

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 60862-2

August 2012

ICS 31.140

Supersedes EN 60862-2:2002

English version

Surface acoustic wave (SAW) filters of assessed quality - Part 2: Guidelines for the use (IEC 60862-2:2012)

Filtres à ondes acoustiques de surface
(OAS) sous assurance de la qualité -
Partie 2: lignes directrices d'utilisation
(CEI 60862-2:2012)

Oberflächenwellenfilter (OFW-Filter)
mit bewerteter Qualität -
Teil 2: Leitfaden für die Anwendung
(IEC 60862-2:2012)

This European Standard was approved by CENELEC on 2012-06-11. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Management Centre: Avenue Marnix 17, B - 1000 Brussels

© 2012 CENELEC - All rights of exploitation in any form and by any means reserved worldwide for CENELEC members.

Ref. No. EN 60862-2:2012 E

 **Documents**
Document Sharing Hub

Foreword

The text of document 49/933/CDV, future edition 3 of IEC 60862-2, prepared by IEC/TC 49 "Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60862-2:2012.

The following dates are fixed:

- latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2013-03-11
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2015-06-11

This document supersedes EN 60862-2:2002.

EN 60862-2:2012 includes the following significant technical changes with respect to EN 60862-2:2002:

- Clause 3 "Terms and definitions" has been deleted to be included in the next edition of EN 60862-1;
- the tapered IDT filter and the RSPUDT filter have been added to the clause of SAW transversal filters. Also DART, DWSF and EWC have been added as variations of SPUDT;
- the balanced connection has been added to the subclause of coupled resonator filters;
- recent substrate materials have been described;
- a subclause about packaging of SAW filters has been added.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 60862-2:2012 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60862 Series	NOTE	Harmonised as EN 60862 Series (not modified).
IEC 60862-1:2003	NOTE	Harmonised as EN 60862-1:2003 (not modified).
IEC 61019-2:2005	NOTE	Harmonised as EN 61019-2:2005 (not modified).

CONTENTS

INTRODUCTION	7
1 Scope	8
2 Normative references	8
3 Technical considerations	8
4 Fundamentals of SAW transversal filters	9
4.1 Frequency response characteristics	9
4.2 Weighting methods	10
4.3 Filter configurations and their general characteristics	13
4.3.1 General	13
4.3.2 Bidirectional IDT filters	14
4.3.3 Unidirectional IDT (UDT) filters	15
4.3.4 Tapered IDT filters	22
4.3.5 Reflector filters	23
4.3.6 RSPUDT filters	27
5 Fundamentals of SAW resonator filters	30
5.1 Classification of SAW resonator filters	30
5.2 Ladder and lattice filters	30
5.2.1 Basic structure	30
5.2.2 Principle of operation	31
5.2.3 Characteristics of ladder and lattice filters	32
5.3 Coupled resonator filters	35
5.3.1 General	35
5.3.2 Transversely coupled type	36
5.3.3 Longitudinally coupled type	36
5.3.4 Other characteristics of coupled resonator filters	36
5.3.5 Balanced connection	41
5.4 Interdigitated interdigital transducer (IIDT) resonator filters	45
5.4.1 Configuration	45
5.4.2 Principle	45
5.4.3 Characteristics	45
6 Application guidelines	46
6.1 Substrate materials and their characteristics	46
6.2 Application to electronics circuits	50
6.3 Availability and limitations	52
6.4 Input levels	53
6.5 Packaging of SAW filters	54
7 Practical remarks	56
7.1 General	56
7.2 Feed-through signals	56
7.3 Impedance matching condition	57
7.4 Miscellaneous	57
7.4.1 Soldering conditions	57
7.4.2 Static electricity	57
8 Ordering procedure	58

Bibliography.....	61
Figure 1 – Frequency response of a SAW filter	10
Figure 2 – Applicable range of frequency and relative bandwidth of the SAW filter and the other filters	11
Figure 3 – Schematic diagram showing signal flow through a transversal filter	11
Figure 4 – Basic configuration of a SAW transversal filter	12
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	12
Figure 6 – Apodization weighting obtained by apodizing fingers	13
Figure 7 – Withdrawal weighting obtained by selective withdrawal of the fingers	13
Figure 8 – Series weighting obtained by the dog-leg structure	13
Figure 9 – Split-finger configuration	14
Figure 10 – Typical characteristics of a SAW IF filter for radio transmission equipment (nominal frequency of 70,0 MHz)	17
Figure 11 – Typical characteristics of a frequency asymmetrical SAW filter (nominal frequency of 58,75 MHz for TV-IF use)	17
Figure 12 – SAW three-IDT filter	18
Figure 13 – Typical frequency response of a 900 MHz range SAW filter for communication (mobile telephone use)	18
Figure 14 – Schematic of the IIDT (multi-IDT) filter	19
Figure 15 – Multi-phase unidirectional transducer	19
Figure 16 – Single-phase unidirectional transducers	20
Figure 17 – Frequency characteristics of a filter using multi-phase unidirectional transducers.....	21
Figure 18 – Frequency characteristics of a filter using single-phase unidirectional transducers.	21
Figure 19 – Tapered IDT filter	22
Figure 20 – Frequency response of a 140 MHz tapered IDT filter	22
Figure 21 – Various reflector filter configurations	24
Figure 22 – Z-path filter configuration	25
Figure 23 – Dual-track reflector filter configuration	25
Figure 24 – SPUDT-based dual-track filter	26
Figure 25 – Frequency characteristics of Z-path filter	26
Figure 26 – Frequency characteristics of dual-track reflector filter	27
Figure 27 – Frequency characteristics of SPUDT-based reflector filter	27
Figure 28 – A part of DART electrode in RSPUDT filter	28
Figure 29 – Distribution of internal reflection and detection inside RSPUDT filter	28
Figure 30 – Frequency and time responses of a 456 MHz RSPUDT filter	29
Figure 31 – Structure of ladder and lattice filters	32
Figure 32 – Equivalent circuit of basic section of ladder and lattice filter	33
Figure 33 – Pattern layout of ladder filter	33
Figure 34 – Basic concept of ladder and lattice filter	34
Figure 35 – Typical characteristics of a 1,5 GHz range ladder filter	35

Figure 36 – SAW energy distribution and equivalent circuit of transversely coupled resonator filter .	37
Figure 37 – Typical characteristics of a transversely coupled resonator filter .	38
Figure 38 – Basic configuration and SAW energy distribution of longitudinally coupled resonator filter .	39
Figure 39 – Typical characteristics of a longitudinally coupled resonator filter .	40
Figure 40 – Configuration of balanced type transversely coupled resonator filter .	41
Figure 41 – Frequency characteristics of balanced type transversely coupled resonator filter .	42
Figure 42 – Configuration of balanced type longitudinally coupled resonator filter .	43
Figure 43 – Typical characteristics of a balanced type longitudinally coupled resonator filter .	45
Figure 44 – Schematic of IIDT resonator filter .	46
Figure 45 – Frequency characteristics of a 820 MHz range IIDT resonator filter .	46
Figure 46 – Minimum theoretical conversion losses for various substrates .	48
Figure 47 – Relationship between relative bandwidth and insertion attenuation for various SAW filters, with the practical SAW filters' bandwidth for their typical applications .	52
Figure 48 – Ripples in the characteristics of a SAW filter caused by TTE or feed-through signal: $\delta f = 1/(2t)$ for the TTE, and $\delta f = 1/t$ for the feed-through, where t is the delay of the SAW main signal .	53
Figure 49 – Example of SAW metal package .	54
Figure 50 – Example of SAW ceramic package .	55
Figure 51 – Example of SAW resin package .	55
Figure 52 – Example of SAW CSP .	56
Table 1 – Properties of typical single-crystal substrate materials .	50
Table 2 – Properties of typical thin-film substrate materials .	50
Table 3 – Properties of typical ceramic substrate materials .	50

INTRODUCTION

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.

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.

SURFACE ACOUSTIC WAVE (SAW) FILTERS OF ASSESSED QUALITY –

Part 2: Guidelines for the use

1 Scope

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.

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 50 % 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 series, 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 documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

None.

3 Technical considerations

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 the user and the 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 60862-1:2003. 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.

SAW filters are classified roughly into two types: transversal filters and resonator filters. Transversal filters are further classified into five types: bidirectional IDT filter, unidirectional IDT filter, tapered IDT filter, reflector filter and RSPUDT (resonant single-phase unidirectional transducer) 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 4 and 5 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.

4 Fundamentals of SAW transversal filters

4.1 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 (1) 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 conversion 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.

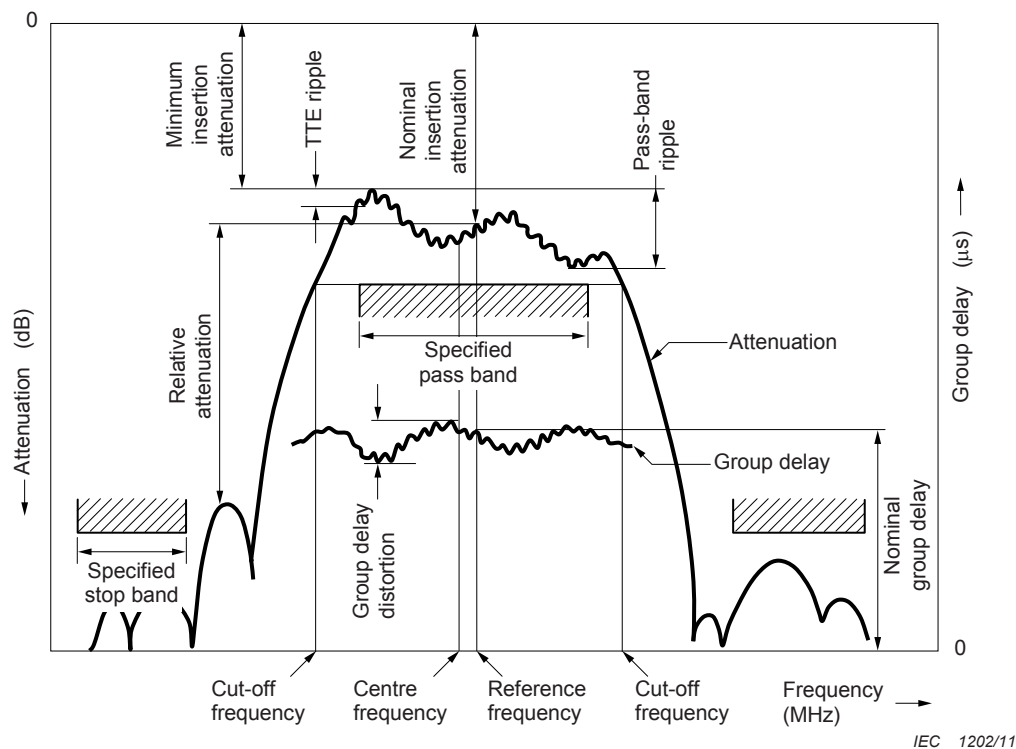


Figure 1 – Frequency response of a SAW filter

4.2 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.

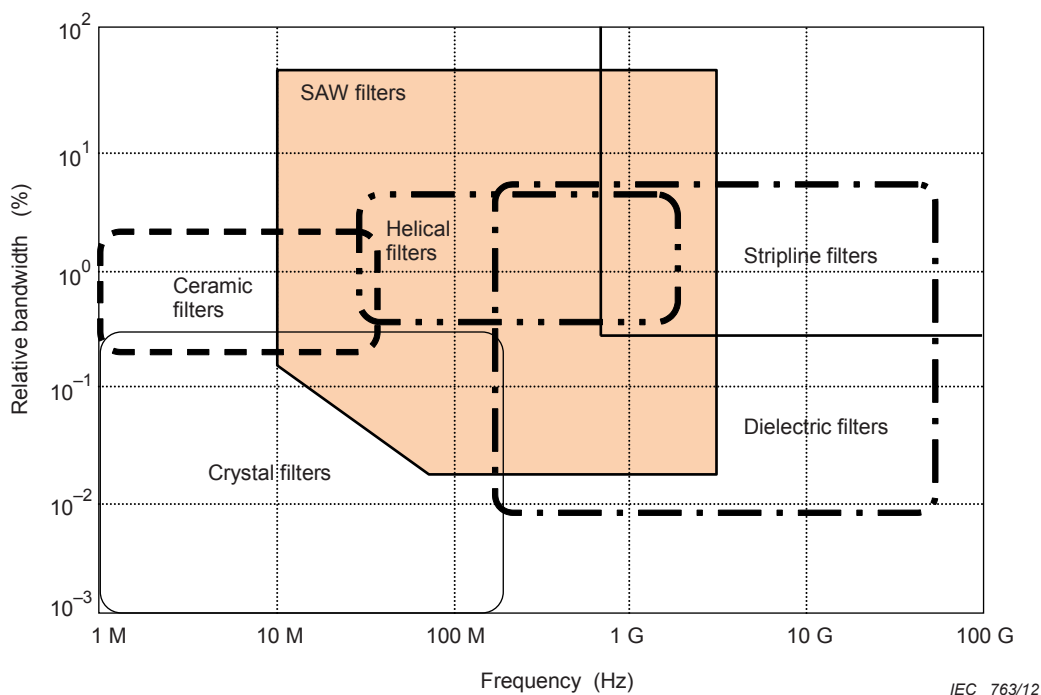


Figure 2 – Applicable range of frequency and relative bandwidth of the SAW filter and the other filters

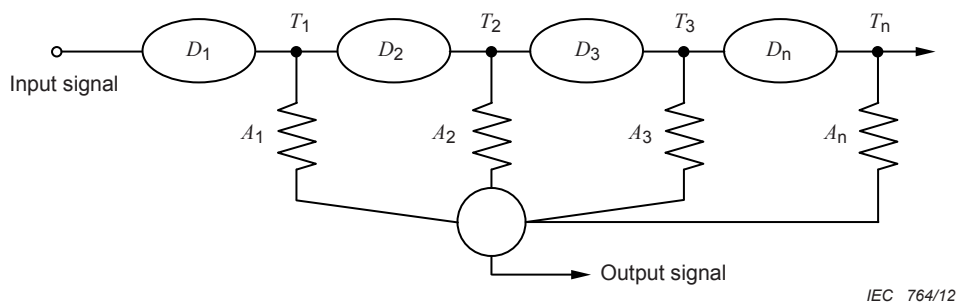


Figure 3 – Schematic diagram showing signal flow through a transversal filter

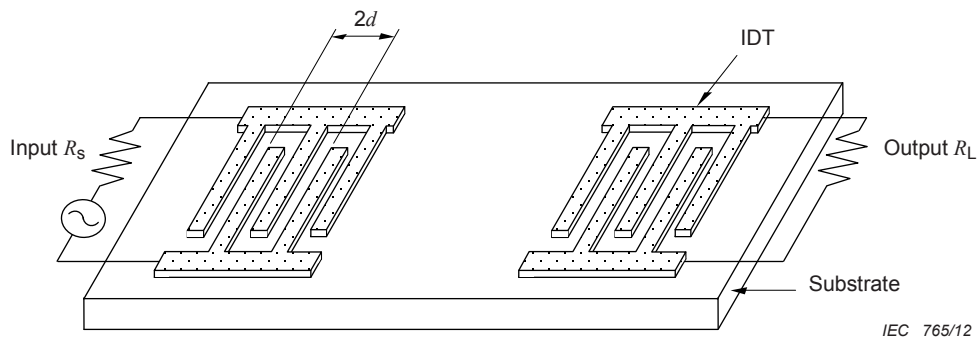


Figure 4 – Basic configuration of a SAW transversal filter

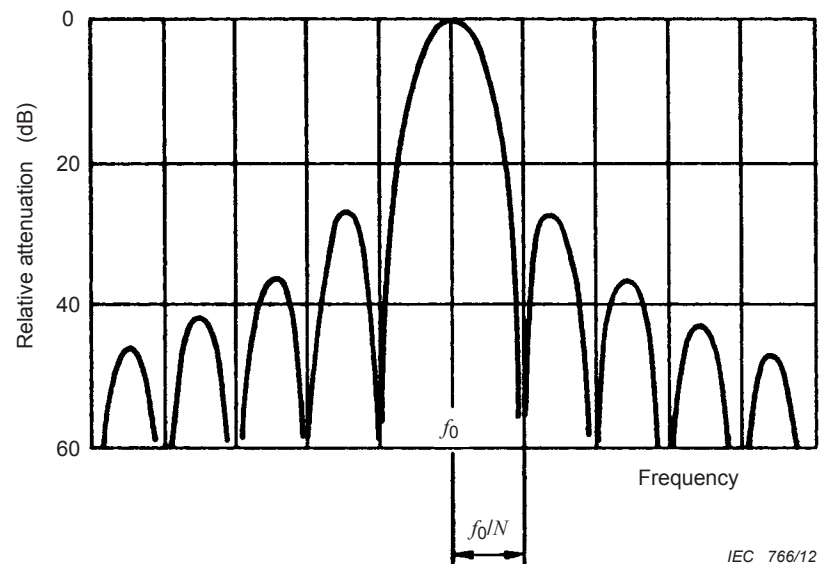
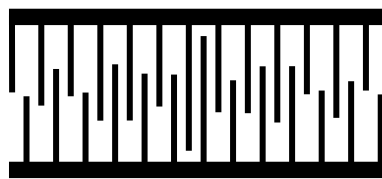
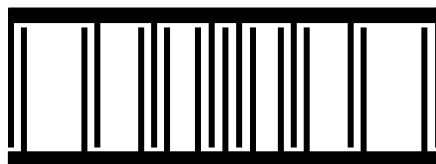


Figure 5 – Frequency response of the SAW transversal filter shown in Figure 4, where f_0 is the centre frequency and N is the number of finger pairs of the IDT



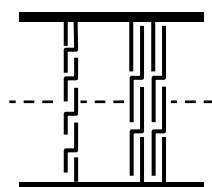
IEC 767/12

Figure 6 – Apodization weighting obtained by apodizing fingers



IEC 768/12

Figure 7 – Withdrawal weighting obtained by selective withdrawal of the fingers



IEC 769/12

Figure 8 – Series weighting obtained by the dog-leg structure

4.3 Filter configurations and their general characteristics

4.3.1 General

In some cases, the split-finger configuration, as shown in Figure 9, is used as the replacement of the solid-finger configuration shown in Figure 4 to reduce SAW reflections at the metal electrodes. With this geometry, the individual reflections, caused by the discontinuity in acoustic impedances on the surface, are cancelled in each finger pair. This finger configuration is now popular in SAW TV-IF filters, etc.

Ordinary IDTs show bidirectional property. These bidirectional IDTs transmit and receive SAWs to and from two directions respectively. For instance, a transmitting IDT converts an electric signal into SAWs. The SAW propagates both forwards and backwards with the same intensities. A receiving IDT will receive either of them with the same efficiency. This means that bidirectional loss values can be estimated at 3 dB each at the transmitting and receiving IDT. Therefore, the bidirectional loss of 6 dB is inherent and is the minimum insertion attenuation in a bidirectional two-transducer SAW filter. Moreover, in these ordinary SAW filters accompanying the bidirectionality, strong pass-band ripple is induced by the triple transit echo (TTE) when the impedances of transmitting IDT and the receiving IDT are matched to the outer loads.

In order to reduce the bidirectional loss and the triple transit echo (TTE) in SAW transversal filters, multi-IDT (IIDT) filters (including three-IDT SAW filters) and unidirectional IDT filters (including tapered IDT filters) are utilized.

Additionally, reflector filters (see Figures 21 and 22) can be included as one type of the transversal filters. Grating technology is widely used as a reflector which changes SAW's propagation direction with some reflection frequency response. The reflector filters utilize not

only their own transversal filter characteristics which are derived from the transducers but also the reflection frequency responses of the reflector in various grating constitutions in order to actively shape the filter transfer function and to reduce their chip length by folding the SAW propagation. And the studies of these various reflector filters have brought new filter technologies called resonant single-phase unidirectional transducer (RSPUDT) filters.

A brief summary of the configurations, the principles and/or the characteristics of individual types of SAW filters is given in the following subclauses.

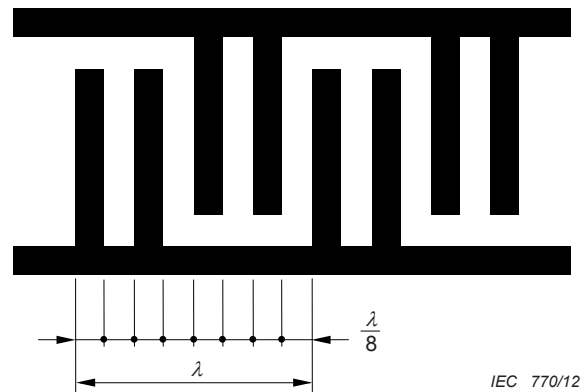


Figure 9 – Split-finger configuration

4.3.2 Bidirectional IDT filters

4.3.2.1 Bidirectional two-IDT filters

In the ordinary bidirectional two-IDT filters, as shown in Figure 4, the TTE is reduced to a sufficiently low level at the sacrifice of the insertion attenuation, by mis-matching the IDTs to the outer loads.

a) Frequency symmetrical band-pass filter

The centre frequency and bandwidth for an IDT are given by the periods of the fingers and the number of finger pairs of the IDT, respectively. In phase characteristics, phase lag increases proportionally with frequency. Therefore, group delay is invariant in the pass-band. One typical application of a frequency symmetric band-pass filter is as an IF filter for radio transmission equipment. Linear-phase characteristics and flat pass-band amplitude characteristics are preferable for the system requirement. Figure 10 shows a typical frequency response of a SAW filter whose nominal frequency is 70,0 MHz. High-frequency SAW filters are also available with higher selectivity.

b) Frequency asymmetrical band-pass filter

In the SAW transversal filters, the amplitude and phase characteristics can be designed independently. Asymmetrical pass-band, stop-band and/or group delay characteristics in relation to the reference frequency are obtainable by means of a sophisticated design technique. SAW TV-IF filters have frequency asymmetrical characteristics, as shown in Figure 11.

c) Other filter categories

Comb filters have also been proposed and are available. SAW matched filters are applied to recent civil spread spectrum (SS) systems, for example wireless LAN, etc. SAW filters with Nyquist characteristics have been developed for recent communication systems.

4.3.2.2 Multi IDT/interdigitated interdigital transducer (IIDT) SAW filters

Multi-IDT or interdigitated interdigital transducer filters have been developed from three-IDT filters, as demand for low-loss filtering increased. For this reason, a brief explanation for three-IDT filters is given.

a) Three-IDT filters

A three-IDT type SAW filter provides two identical receiving IDTs, symmetrically placed to the central transmitting IDT, as shown in Figure 12. When the symmetric central transducer is tuned and matched at the centre frequency, the two opposite directed SAWs are completely absorbed, this being the inverse process to the generation of the two SAWs by a tuned and matched transducer. At the same time, when the two receiving transducers connected are tuned and matched at the centre frequency, the insertion attenuation can be improved to 3 dB, and the TTE is eliminated. A typical frequency response of a 900 MHz range SAW three-IDT filter is shown in Figure 13.

This operation principle is extended to the multi-IDT filters.

b) Multi-IDT/Interdigitated interdigital transducer filters

Multi-IDT or interdigitated interdigital transducer filters provide input IDTs inter-digitally placed to output IDTs. This filter, as an example, schematically illustrated in Figure 14 comprises $(N + 1)$ input transducers and N output transducers. By this configuration, the bidirectional 6 dB loss in two-IDT filters is reduced to a much smaller value, and the triple transit echo is eliminated when the input and output port are matched to the outer loads.

When the input transducers and output transducers are tuned and matched to the circuit, the insertion attenuation of the filter shown in Figure 14 is reduced to the residual bidirectional loss caused by the outermost input transducers, which is inversely proportional to the number of transducers, as follows:

$$10 \log \{(N + 1)/N\} \text{ dB}$$

4.3.3 Unidirectional IDT (UDT) filters

4.3.3.1 Configuration

Both low insertion attenuation and excellent frequency characteristics in unidirectional filters are based upon directivity of surface wave propagation. Ideally, the filters have insertion attenuation of less than 1 dB, and both amplitude and phase characteristics can be controlled independently. They are divided roughly into two categories. One of them is the multi-phase unidirectional transducer, to which electrical fields with various phase differences are applied. The other category is the single-phase unidirectional transducer applied with the same phase field.

a) Multi-phase unidirectional transducers

The three-phase unidirectional and group-type unidirectional transducers are representative of the class. The unidirectionality of the three-phase transducers arises from applying three voltages with phase differences of 120° each. In this case, however, a third electrode shall cross over one of the other electrodes using an insulated bridge, making the filter no longer truly planar and less reliable.

The group-type unidirectional transducer shown in Figure 15 is capable of overcoming the above-mentioned shortcomings. The unidirectional transducer with only a few pairs of electrodes, excited with an electrical phase shift of 90° , is thought of as one group. Many groups can then be collinearly arranged, the signal of each group adding in phase with the signals of all the other groups so as to yield a filter with a low insertion attenuation. Conventional weighting techniques are also applicable in this transducer.

b) Single-phase unidirectional transducers (SPUDTs)

These single-phase unidirectional transducers (SPUDTs) utilize internal reflections within the transducer to achieve unidirectional behavior. The basic arrangement of a uni-

directional transducer using internal floating electrode reflection, which is called floating electrode unidirectional transducer (FEUDT), is shown schematically in Figures 16a-16c. The transducer shown in Figure 16a can obtain unidirectionality, caused by the offset arrangement of floating open metal strips from the centre of positive and negative electrodes. Similarly, there are other cases of floating short metal strips and combinations of them, which are shown in Figures 16b and 16c respectively. Other SPUDTs using internal reflection not by floating electrode are shown in Figures 16d and 16e. Figure 16d is called a distributed acoustic reflective transducer (DART), and Figure 16e is called a different width split finger (DWSF). Similar transducer to DART is called as an electrode width controlled (EWC) SPUDT, and the difference between DART and EWC is only thick finger width. Its width of DART and EWC is $3/8\lambda$ and $1/4\lambda$. DWSF is based on the conventional split finger transducer. In DWSF, one finger's width of one split finger pair and another finger's width of the pair are different, but the period of the pair keeps a half wavelength. And this configuration brings unidirectionality.

4.3.3.2 Principle

a) Multi-phase unidirectional transducers

In a group of multi-phase unidirectional transducers, the phase difference between the wave excited by the sending electrodes (applied 90° shifted electrical field in Figure 15) and the wave excited by the reflecting electrodes is zero (in phase) in the forward direction and is 180° (opposite-phase) in the reverse direction. The simple and experimental filter configuration shows a minimum insertion attenuation of 1,0 dB and a pass-band ripple of less than 0,2 dB at the centre frequency of 99,2 MHz. Here, the transducer has four pairs and eleven group electrodes. A 128° rotated Y-cut X-propagated LiNbO_3 substrate and a $50\ \Omega$ coaxial cable have been used as a SAW propagation medium and a 90° phase shifter respectively.

Figure 17 shows an experimental attenuation-frequency characteristic of a 70 MHz SAW IF filter for a digital-cellular base-station. Here, the input transducer is an unapodized multi-phase unidirectional transducer, while the output transducer is an apodized bidirectional transducer. These transducers are on a 128° rotated Y-cut X-propagated LiNbO_3 single crystalline substrate. This filter shows insertion attenuation of 8 dB and pass-band ripple of 0,2 dB peak-to-peak in the frequency range of $70\ \text{MHz} \pm 1,6\ \text{MHz}$.

b) Single-phase unidirectional transducers

In a single-phase unidirectional transducer, the phase difference between excited and reflected waves is zero (in phase) in the forward direction and is 180° (opposite phase) in the reverse direction due to the bilateral asymmetry of the internal structure of the transducer. Mass-loading effect, reflector array, change of the electromechanical coupling coefficient and internal floating electrode reflection are used to obtain asymmetry. These transducers are fabricated in one photolithographic process and do not need any phase shifter in the external circuit. Figure 18 shows the experimental result of a single-phase unidirectional transducer using internal floating, short and open strips, which is shown in Figure 16c. Tuning is achieved for each transducer with a shunt wire wound inductor of 200 nH. The resulting insertion attenuation of 2,3 dB at 97,3 MHz is obtained. The bandwidth of the filter is about 3,0 %.

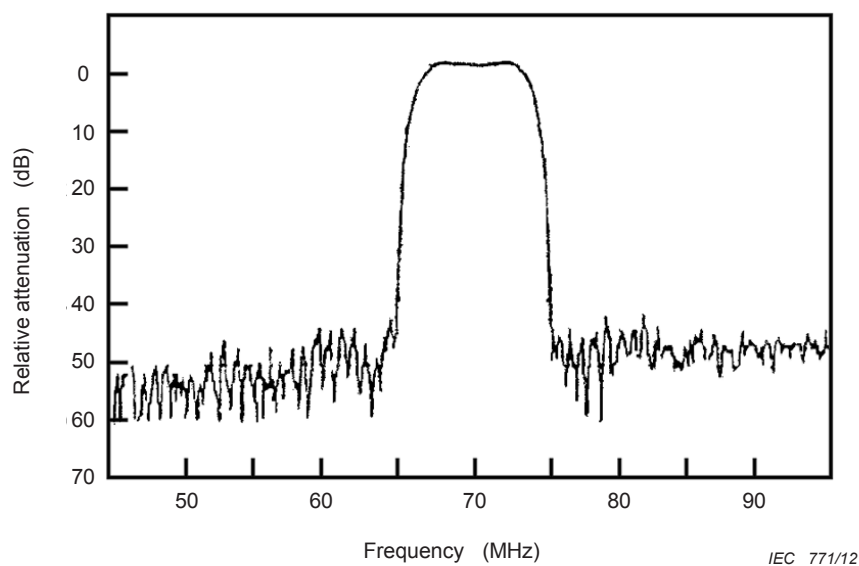


Figure 10 – Typical characteristics of a SAW IF filter for radio transmission equipment (nominal frequency of 70,0 MHz)

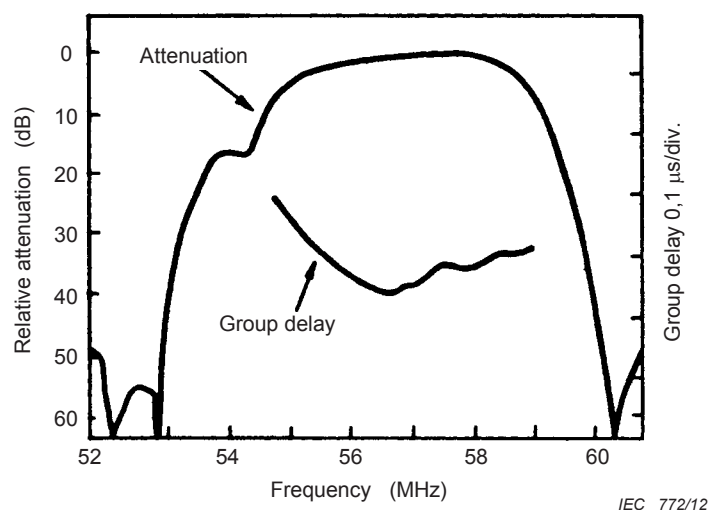


Figure 11 – Typical characteristics of a frequency asymmetrical SAW filter (nominal frequency of 58,75 MHz for TV-IF use)

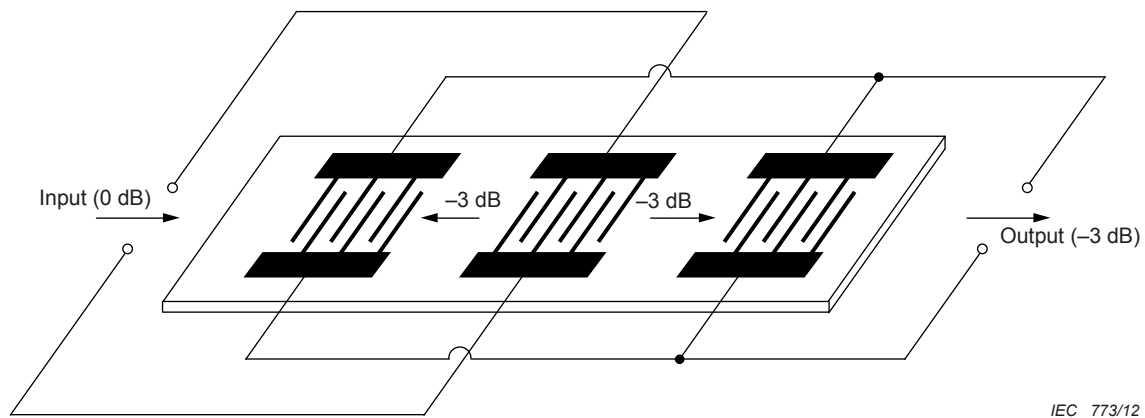


Figure 12 – SAW three-IDT filter

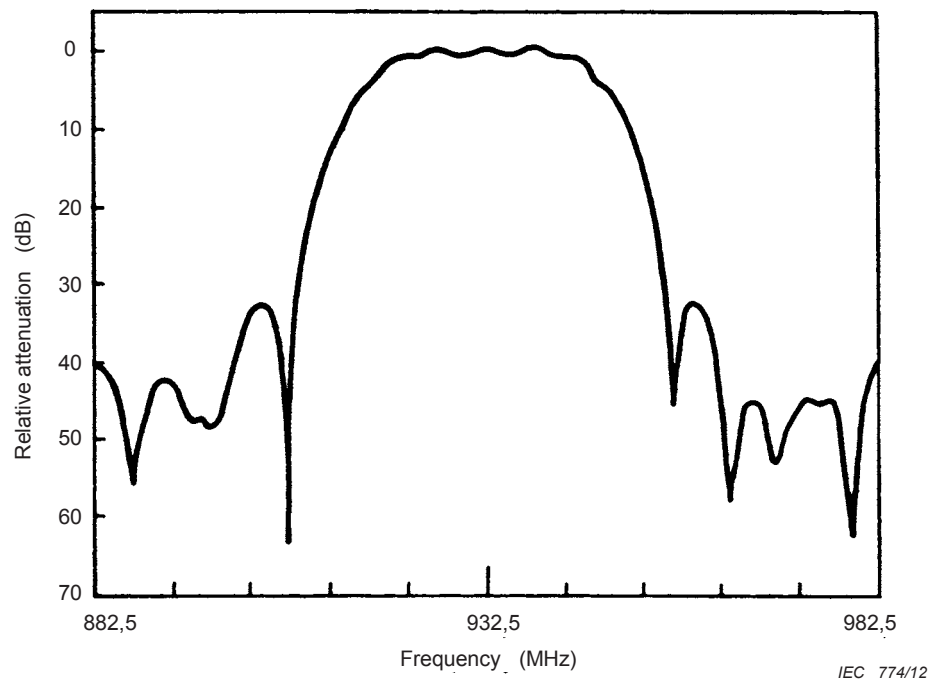


Figure 13 – Typical frequency response of a 900 MHz range
SAW filter for communication (mobile telephone use)

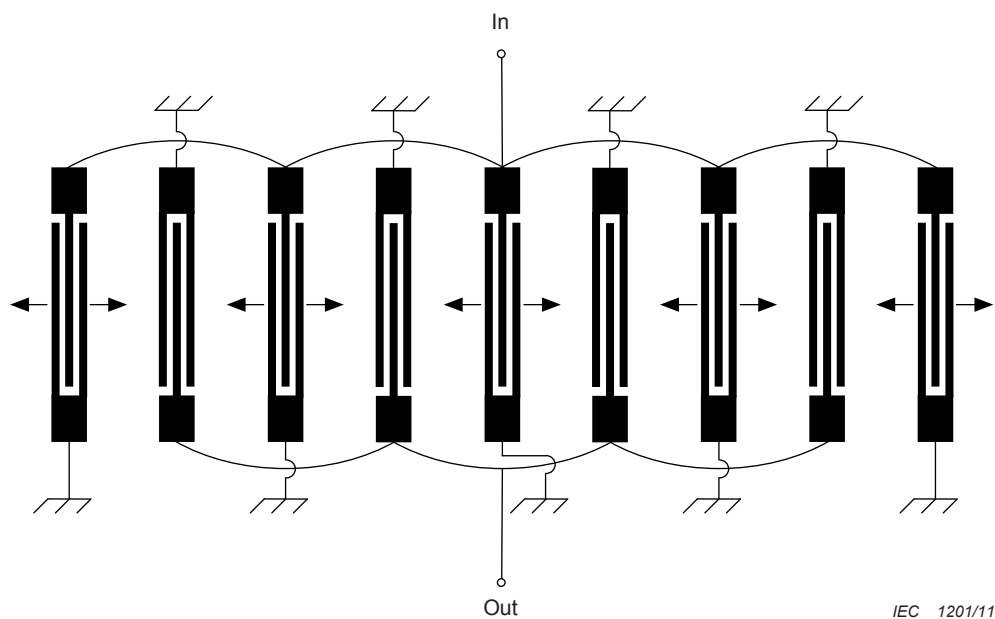


Figure 14 – Schematic of the IIDT (multi-IDT) filter

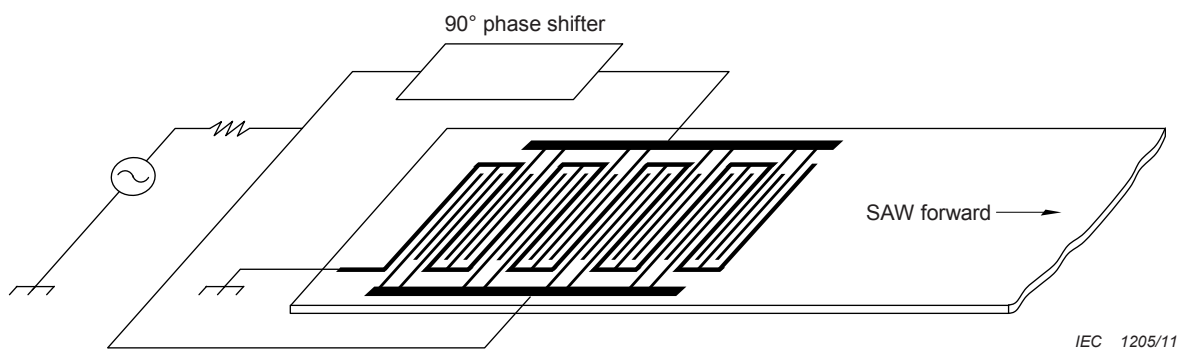


Figure 15 – Multi-phase unidirectional transducer