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INTERNATIONAL STANDARD

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Semiconductor devices – Micro-electromechanical devices – Part 7: MEMS BAW filter and duplexer for radio frequency control and selection

Dispositifs à semiconducteurs – Dispositifs microélectromécaniques – Partie 7: Filtre et duplexeur BAW MEMS pour la commande et le choix des fréquences radioélectriques

IEC 62047-7:2011

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 7: MEMS BAW filter and duplexer for radio frequency control and selection

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

FDIS	Report on voting
47F/79/FDIS	47F/87/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.

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SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 7: MEMS BAW filter and duplexer for radio frequency control and selection

1 Scope

This part of IEC 62047 describes terms, definition, symbols, configurations, and test methods that can be used to evaluate and determine the performance characteristics of BAW resonator, filter, and duplexer devices as radio frequency control and selection devices. This standard specifies the methods of tests and general requirements for BAW resonator, filter, and duplexer devices of assessed quality using either capability or qualification approval procedures.

2 Normative references

Void.

3 Terms and definitions

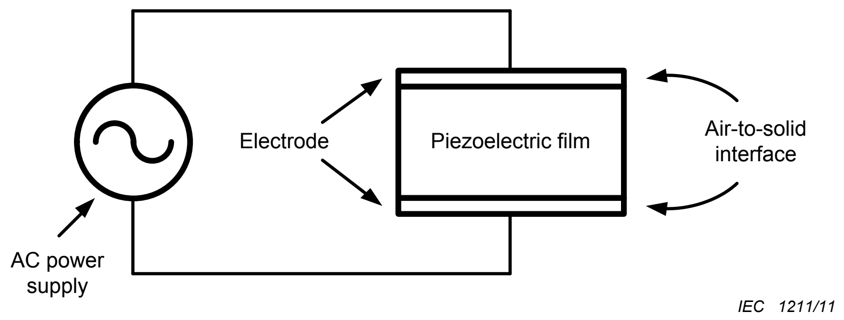
For the purposes of this document, the following terms and definitions apply.

3.1 General terms

3.1.1
bulk acoustic wave
BAW
acoustic wave propagating in a bulk body

3.1.2
BAW resonator
resonator employing bulk acoustic wave

NOTE BAW resonator consists of piezoelectric material between top and bottom electrodes, as shown in Figure 1. The top and bottom electrodes which can be made to vibrate in a vertical direction of the deposited piezoelectric film. The electrodes are either two air-to-solid interfaces or an acoustic Bragg reflector and an air-to-solid interface. The former is often called the film bulk acoustic resonator (FBAR), and the latter is called the solidly-mounted resonator (SMR).



Key

Layers of a piece of BAW resonator		Components to operate a BAW resonator	
Electrode	To provide electrical input to a body of piezoelectric film and electrical connections with a external circuit	AC power supply	Electric power supply to vibrate a BAW resonator
Piezoelectric film	Body layer of a kind of BAW resonator		
Air to solid interface			

Figure 1 – Basic structure of BAW resonator

3.1.3
electrode
electrically conductive plate in proximity to or film in contact with a face of the piezoelectric film by means of which a polarizing or driving field is applied to the element

[IEC/TS 61994-1, 3.21]

3.1.4
piezoelectric film
film which has piezoelectricity

NOTE Piezoelectric films can be distinguished as non-ferroelectric and ferroelectric materials. The non-ferroelectric materials, such as AlN (aluminium nitride) and ZnO (zinc oxide) have low dielectric constant, small dielectric loss, good hardness, and excellent insulating properties. Thus, they are good for microwave resonator and filter applications. The ferroelectric materials, such as PZT (lead-zirconate-titanate) and PLZT (lead-lanthanum-zirconate) have high dielectric constant, large dielectric loss, and fair insulating properties. Thus, they are good for memory and actuator applications.

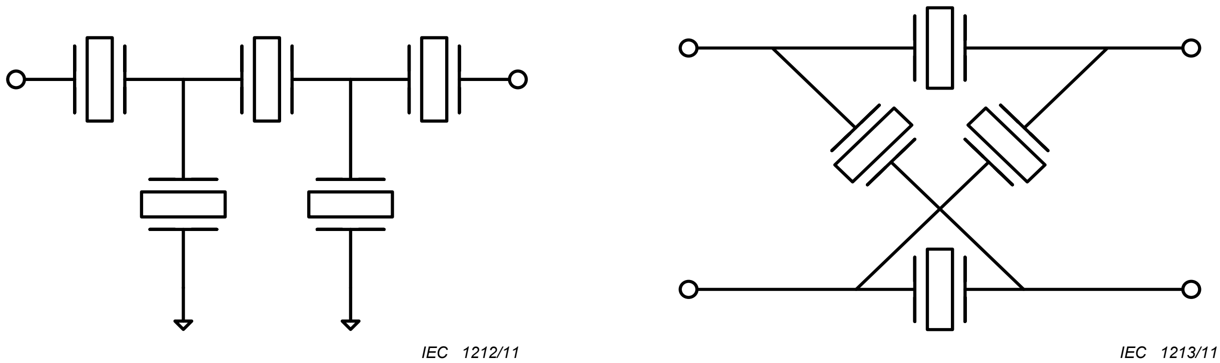
3.1.5
direct piezoelectric effect
effect which a mechanical deformation of piezoelectric material produces a proportional change in the electric polarization of that material

3.1.6
converse (or reverse) piezoelectric effect
effect which mechanical stress proportional to an acting external electric field is induced in the piezoelectric material

NOTE Converse piezoelectric effect is widely being used for acoustic wave resonators and filters, resonant sensors, oscillators, ultrasonic wave generators, and actuators. Direct piezoelectric effect is usually applied for various piezoelectric sensors and voltage generators.

3.2 Related with BAW filter

Figure 2 shows topologies for BAW filter design.



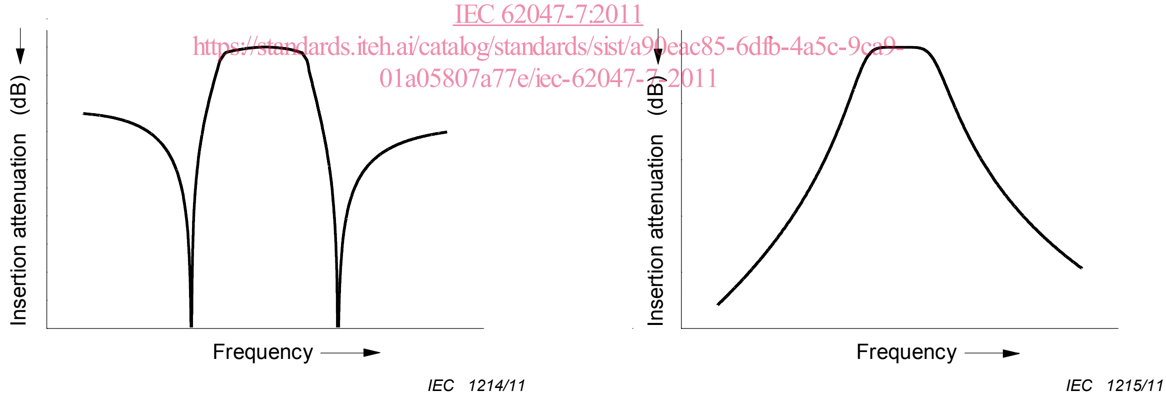
a) Ladder type b) Lattice type

Figure 2 – Topologies for BAW filter design

NOTE BAW resonators are connected in series and parallel for forming electrical filters, as shown in Figure 2. The resonant frequencies of series and parallel resonators should be different to secure the bandwidth of the BAW filter.

3.2.1
ladder filter
filter having a cascade or tandem connection of alternating series and shunt BAW resonators

NOTE BAW resonator connected in series should have slightly higher resonant frequency than that of a parallel BAW resonator. The parallel resonant frequency of the parallel BAW resonator needs to be equal to the series resonant frequency of the series BAW resonator in the filter geometry shown in Figure 2. It gives a steep roll-off, but poor stop-band rejection characteristics as shown in Figure 3a). Thus, helper inductors are usually given to improve the isolation, and in general, the out-of-band rejection far from the passband becomes worse.



a) Ladder type b) Lattice type

Figure 3 – Frequency responses of ladder and lattice type BAW filters

3.2.2
lattice filter
filter having two pairs of resonators electrically coupled in a bridge network, with one pair of resonators in a series arm and the other pair in a shunt arm

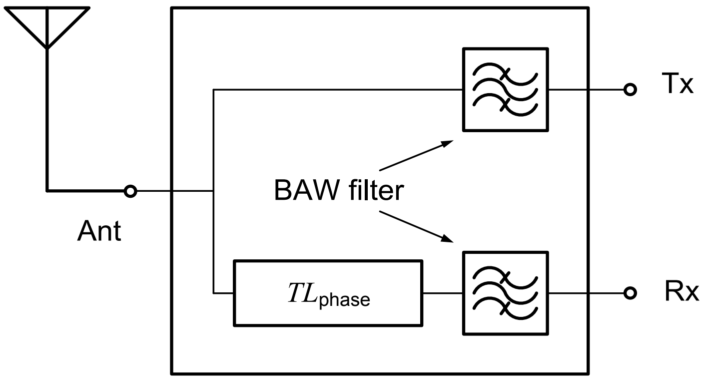
[IEC 60862-1: 2003, 2.2.3.8 modified]

NOTE Lattice type filter need more resonators than ladder type one, sine it needs two resonators to synthesize one pole and one transmission zero from the transfer function. The pass-band is obtained when one pair of resonators behaves inductive while the other pair of resonators behaves capacitive. Unlike the ladder type filter, it gives a deep stop-band rejection and good power handling capability, but smooth roll-off characteristics as shown in Figure 3 b).

3.2.3
helper inductor
inductor connected with shunt resonators of ladder BAW filter

3.3 Related with BAW duplexer

Figure 4 shows an example of BAW duplexer configuration.



IEC 1216/11

Key

*T*x	transmitting port	*R*x	receiving port
Ant	antenna port	TL_{phase}	phase delay line

Figure 4 – An example of BAW duplexer configuration

NOTE Two different BAW filters, transmitting and receiving band pass filters, are connected with a quarter wavelength phase shifter, phase delay line, or parallel inductor on a package substrate for forming a duplexer, as shown in Figure 4. In order to improve isolation characteristics between these transmitting and receiving filters, via grounds should be well formed onto the package substrate. Series and shunt inductors are added into the *T*x and *R*x filters in order to improve its attenuation, roll-off, and ripple characteristics.

3.3.1
transmitting band pass filter
*T*x
band pass filter used at the transmitter of the RF system which transmits a signal to the antenna

3.3.2
receiving band pass filter
*R*x
band pass filter used at the receiver of the RF system which receives a signal from the antenna

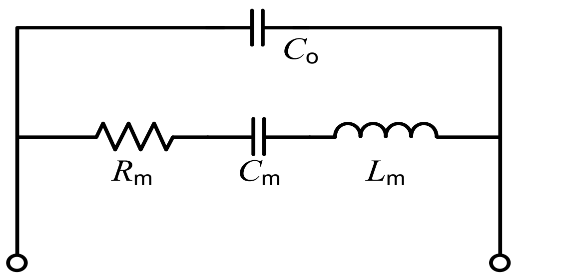
3.3.3
phase delay line
transmission line to delay a signal from a port to the antenna or isolate the transmitter and receiver

3.4 Characteristic parameters

3.4.1 BAW resonator

3.4.1.1
equivalent circuit (of BAW resonators)
electrical circuit which has the same impedance as a piezoelectric resonator in the immediate neighborhood of resonance

NOTE For example, one port BAW resonator consists of series elements L_m, C_m, R_m in parallel with C_o as shown in Figure 5, where L_m, C_m, R_m represent the motional inductance, capacitance, and resistance, respectively. C_o represents the shunt capacitance. Sometimes, another resistance R_s is added in series with an input terminal for taking account of electrode and interconnection resistance.



Key

C_0	shunt capacitance	R_m	motional resistance
C_m	motional capacitance	L_m	motional inductance

Figure 5 – Equivalent circuit of BAW resonator (one-port resonator)

[IEC/TS 61994-1: 2007, 3.25 modified]

3.4.1.2
nominal frequency
frequency assigned by the specification of the resonator

[IEC/TS 61994-1: 2007, 3.58 modified]

3.4.1.3
resonant frequency (or series resonant frequency)
f_r
lower frequency of the two frequencies of a piezoelectric resonator vibrating alone under specified conditions, at which the electrical impedance of the resonator is resistive

[IEC/TS 61994-1: 2007, 3.81 modified]

3.4.1.4
anti-resonant frequency (parallel resonant frequency, f_p)
f_a
the higher frequency of two frequencies of a piezoelectric resonator vibrating alone. An approximate value of this frequency is given by the expression

$$f_p = 1/2\pi\sqrt{L_m C_m C_0/(C_m + C_0)} \quad (1)$$

where

C_0 represents the shunt capacitance; and

L_m and C_m are the motional inductance and capacitance

[IEC/TS 61994-1: 2007, 3.3, 3.69 modified]

3.4.1.5
motional (series) resonant frequency
f_s
resonant frequency of the motional or series arm of the equivalent circuit of the resonator, it is defined by the following formula

$$f_s = \frac{1}{2\pi\sqrt{L_m C_m}} \qquad (2)$$

where

L_m and C_m represent the motional inductance and capacitance respectively .

[IEC/TS 61994-1: 2007, 3.55 modified]

3.4.1.6
fundamental resonance
lowest resonance mode in a given family of vibration

3.4.1.7
spurious resonance
state of resonance of a resonator other than that associated with the working frequency

[IEC/TS 61994-1: 2007, 3.86 modified]

3.4.1.8
spurious resonance rejection level
difference between the maximum level of spurious resonances and the minimum insertion attenuation

[IEC/TS 61994-1: 2007, 3.87 modified]

3.4.1.9
unwanted response
state of resonance of a resonator other than that associated with the mode of vibration intended for the application

[IEC/TS 61994-1: 2007, 3.99 modified]

3.4.1.10
capacitance ratio
r
ratio of the parallel capacitance C_0 to the motional capacitance C_m

[IEC/TS 61994-1: 2007, 3.7 modified]

3.4.1.11
motional capacitance
C_m
capacitance of the motional or series arm of the resonator equivalent circuit

3.4.1.12
motional inductance
L_m
inductance of the motional or series arm of the resonator equivalent circuit

3.4.1.13
motional resistance
R_m
resistance of the motional or series arm of the resonator equivalent circuit

[IEC/TS 61994-1: 2007, 3.52 modified]

3.4.1.14
shunt capacitance
C_0
capacitance in parallel with the motional arm of the resonator equivalent circuit which is caused by the energy leakage and dielectric loss of the piezoelectric film

3.4.1.15
figure of merit
FOM or M
factor indicating performance of the device, product of both k_{eff}^2 and Q, which indicates the activity of the resonator, and the value usually given by Q/r, where Q is the Q factor and r is the ratio of capacitances at low frequencies

[IEC/TS 61994-1: 2007 modified]

3.4.1.16
electromechanical coupling factor
certain combination of elastic, dielectric and piezoelectric constants which appears naturally in the expression of impedance of a resonator. A different factor arises in each particular family of mode of vibration. The factor is closely related to the relative frequency spacing and is a convenient measure of piezoelectric transduction. Alternatively, the coupling factor may be interpreted as the square root of the ratio of the electrical or mechanical work which can be accomplished to the total energy stored from a mechanical or electrical power source for a particular set of boundary conditions

[IEC/TS 61994-1: 2007, 3.22 modified]

3.4.1.17
relative frequency spacing
B_s
ratio of the difference between the parallel resonance frequency f_p and the series resonance frequency f_s in a given mode of vibration, to the series resonance frequency

$$B_s = (f_p - f_s) / f_p \qquad (3)$$

[IEC TS61994-1: 2007, 3.80 modified]

3.4.1.18
effective electromechanical coupling factor
k_{eff}^2
the effective electromechanical coupling factor for thickness-longitudinal vibration is defined as follows:

$$k_{eff}^2 = \left(\frac{\pi}{2}\frac{f_r}{f_a}\right) \Big/ \left\{\tan\left(\frac{\pi}{2}\frac{f_r}{f_a}\right)\right\} \qquad (4)$$

when the piezoelectric film is mechanically isolated from surroundings such as electrodes

3.4.1.19
electromechanical coupling factor (of piezoelectric material)
$\boldsymbol{K^2}$
figure indicating piezoelectric strength of piezoelectric material is defined as follows:

$$k_{\mathrm{eff}}^2 = \frac{K^2}{\left(1 + K^2\right)} \tag{5}$$

NOTE It depends not only materials but also the wave type and the wave propagation direction and polarization.

3.4.1.20
quality factor (for a series resonant circuit of BAW resonator)
$\boldsymbol{Q}$
factor how long stored energy is preserved in a device and is defined as follows:

$$Q = 2\pi f_{\mathrm{r}} L_{\mathrm{m}} / R_{\mathrm{m}} \tag{6}$$

where

f_{r} is the resonance frequency;

L_{m} is the motional inductance;

R_{m} is the motional resistance

[IEC/TS61994-1: 2007, 3.77 modified]

NOTE The Q of a resonator is a measure of the losses in the device. The possible dissipative losses are resistances in the electrodes, visco-acoustic loss in all of the materials, acoustic scattering from rough surfaces or material defects, and acoustic radiation into the surrounding areas of the BAW device.

3.4.1.21
long-term parameter variation
relationship which exists between any parameter (for example resonance frequency) and time

3.4.2 BAW filter and duplexer

3.4.2.1
shape factor
ratio of the two bandwidths limited by two specified attenuation value

3.4.2.2
transition band
band of frequencies between a cut-off frequency and the nearest point of the adjacent stop band

3.4.2.3
roll off rate
ratio of transition band to the ideal cut off frequency, which is an index describing the increasing characteristics of BAW filters

3.4.2.4
attenuation
decrease in intensity of a signal, beam, or wave as a result of absorption of energy and of scattering out of the path to the detector, but not including the reduction due to geometric spreading