■ Terminology

Main terms used for surface acoustic wave (SAW) filters are explained below.

Nominal Frequency : The nominal value of the center frequency, and it is used as the standard frequency for the related standards.

Passband Width : The width of a band (passband) within which signals are transmitted by a filter with the center frequency as the midpoint. In practice this normally means a width (1- or 3-dB bandwidth) obtained by increasing attenuation by a constant amount (ex. 1 or 3 dB) from the minimal loss point in the band.

Ripple : When the maximal value of attenuation exists in the passband, the maximal value among the differences of the maximal loss and the minimal loss is called a ripple.

Insertion Loss (Insertion Attenuation) : The attenuation difference between the insertion of a filter and with no filter, and it is classified into three types: constant loss, minimal insertion loss, and maximal insertion loss. Constant loss is the value of insertion loss at the nominal frequency, and minimal and maximal insertion losses are the minimal and maximal values of the insertion loss band. IEC (International Electrotechnical Commission) stipulates that insertion loss should be called insertion attenuation, but the term insertion loss is more popular and preferred in the industry.

Attenuation : This normally refers to relative attenuation in the attenuation band with the minimal insertion loss used as a standard, but it may be used to mean absolute attenuation for radio equipment, etc. with the throughlevel (0 dB) used as a standard. Therefore, in context, it is important to clarify the true meaning of this word.

Attenuation Bandwidth : The frequency width when it is guaranteed that the value of relative attenuation is the same as or more than that of the specified attenuation.

Guaranteed Attenuation and Guaranteed Attenuation Band : Relative attenuation and its frequency band guaranteed in the attenuation band.

Terminating Impedance : The impedance on the used circuit side viewed from the filter side. Normally, terminating impedance is expressed as load impedance of the circuit as it is (50 or 150 Ω), but it is also expressed as a conjugate condition of the SAW-side impedance with a matching circuit placed toward the circuit. When expressed as the latter, it is generally expressed as resistance and parallel capacitance of the negative sign (conjugate condition).

Group Delay Time : A value obtained when the amount of phase change is differentiated by angular frequency.

Group Delay Time Ripple : The maximal value among differences between the maximal and the minimal values of the group delay time in a specified passband width.

■ Explanation

A surface acoustic wave (SAW) is a wave that occurs when energy concentrates near the surface of an elastic body, and electronic devices to which this wave is applied are called SAW devices.
NDK develops and manufactures filters, resonators, delay lines, oscillators, etc. as SAW devices.
Described here are a SAW filter and a SAW resonator.

● SAW Filter

Figure 1 shows the basic structure of a SAW filter.
A SAW filter has a structure of comb electrodes that excites and receives surface waves placed on a piezoelectric substrate.
The piezoelectric effect obtained when an AC voltage is applied to the comb electrodes causes the piezoelectric substrate between the adjacent electrodes to be distorted and a surface wave to be excited.
As shown in Figure 2, the teeth of the comb electrodes are arranged with a certain pitch between them, and a surface wave is excited most strongly when its wavelength λ is the same as the pitch of the electrode teeth. The equation $f_0 = v/\lambda$ describes the relation between the center frequency (f_0) and the propagation velocity (v) of a surface wave.
There are two types of SAW filters: a delayed-type electrode structure; and a resonance-type electrode structure.

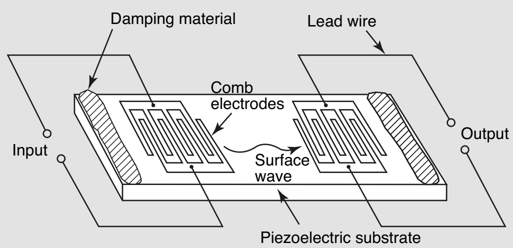

Figure 1 Basic structure of a SAW filter (transversal type)

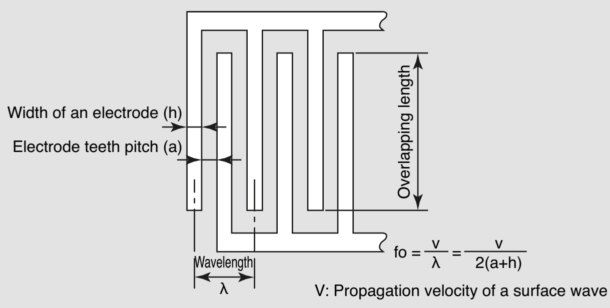

Figure 2 Basic structure of comb electrodes (transversal type)

■ Explanation

● SAW Resonator

Figure 3 shows the basic structure of a SAW resonator. A high-Q resonator can be realized by generating a standing wave between comb electrodes and increasing the number of electrode teeth.
As shown in Figure 4, there are two types of SAW resonators: (a) one-port resonator and (b) two-port resonator.
The one-port resonator has a structure of comb electrodes placed at the center and reflectors on both sides. A surface wave that has been excited by the comb electrodes is reflected by the reflectors, which then generates a standing wave. Therefore, this resonator uses high Q, and it is applied mainly to oscillators and narrowband filters. The two-port resonator because of its structure is a narrowband filter, but it does use a high Q, and is generally used for oscillators and narrowband filters with a higher frequency band than one-port resonators.

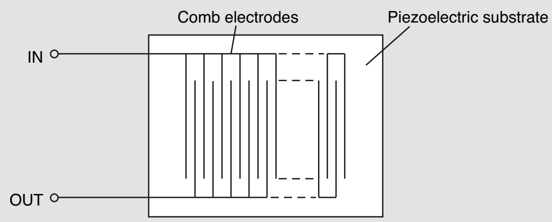

Figure 3 Basic structure of a SAW resonator

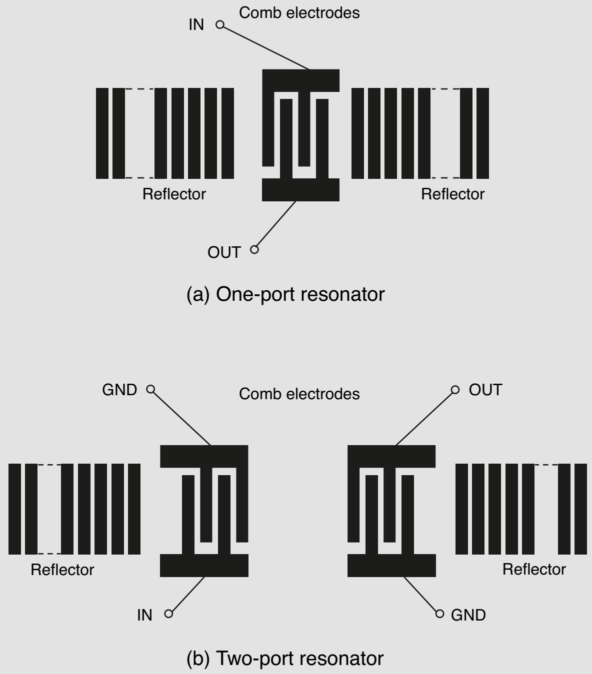

Figure 4 Basic structures of one-port and two-port resonators

● Materials for Piezoelectric Substrates

Depending on the methods used to design a device, NDK uses separate piezoelectric substrate materials for the SAW devices shown in the right handtable. Substrate materials are roughly divided into two types: one which has been used for a long time and with a high degree of freedom in design is used for Rayleigh wave substrates ; the other, with less freedom and limited in design, is for Leaky wave substrates with low loss characteristics and easily reaches the higher frequencies by high acoustic velocity; they are mainly used for mobile communications. Lithium niobate (LiNbO3) substrates and lithium tantalate (LiTaO3) substrates are used for broadband filters, etc., and according to the filter specifications the manufacturing materials and cutting angles differ. Products for mobile phones that require low loss mainly use Leaky wave materials, while Rayleigh wave materials are predominately used for communication equipment that requires low ripple and low group delay characteristics. Among Rayleigh wave materials, ST-cut crystal has the best temperature characteristics as a piezoelectric substrate material. In addition, its coupling coefficient is low and its frequency-temperature characteristics are expressed as a zero temperature coefficient around normal temperatures on a quadratic curve.

Undulation Mode	Material Name	Cutting Angle	Propagation Angle	Propagation Velocity m/s	Bonding k_s^2(%)	Temperature Coefficient Primary $10^{-9}/K^2$	Temperature Coefficient Secondary $10^{-9}/K^2$
Rayleigh wave	ST-quartz	42.75°Y	X	3 157	0.16	0	–34
	$LiTaO_3$	X	112°Y	3 295	0.64	–18	–
	$LiNbO_3$	Y	Z	3 488	4.82	–94	–
	$LiNbO_3$	128°Y	X	4 000	5.56	–74	–
Leaky wave	$LiNbO_3$	64°Y	X	4 742	11.3	–79	–
	$LiTaO_3$	36°Y	X	4 178	4.8	–33	–

● Frequency-Temperature Characteristic

Materials for piezoelectric substrates have their own frequency-temperature characteristics. Figure 5 shows the frequency-temperature characteristic of a crystal substrate.

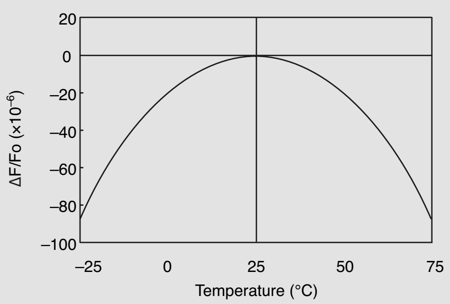

Figure 5 Frequency-temperature characteristic of a SAW device (piezoelectric substrate: crystal)

■ Manufacturing Process

The process for manufacturing SAW devices is similar to that used for ICs or LSIs. Ultrafine pattern processing is needed, and therefore SAW devices are manufactured in a clean room.