LONGITUDINAL COUPLED SURFACE ACOUSTIC WAVE RESONATOR FILTER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to longitudinal coupling type surface acoustic wave resonator filters and, more particularly, to a longitudinal coupling type surface acoustic wave resonator filter in which the electrode structure is improved so that the selectivity is increased.

2. Description of the Related Art

Recently, surface acoustic wave (SAW) filters have been used as band-pass filters for various communication devices. Such band-pass filters require a suitable pass band width and high selectivity. In addition, SAW filters used in radio-frequency (RF) stages require that a pass band be within a desired range and that high selectivity be achieved.

In particular, in the case of SAW filters used for RF stages in cordless telephone sets in accordance with the CT-1, CT-1+ and CT-2 standards, it is important to achieve a sufficiently large attenuation at points ± 20 MHz and ± 40 MHz apart from a center frequency, although the desired attenuation varies depending upon intermediate frequency (IF) filters used in the telephone sets. Thus, filters having higher selectivity are required. Also with respect to IF

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☑ Description : paged ...1.... to paged ...36....
☑ Claim(s) : paged ...37.. to paged ...41.....
☑ Drawing(s) : paged ...1/1.. to paged ....1/1...
☑ Abstract : paged ...42.. to paged ....7.....
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filters, characteristics of selectivity between adjacent channels are important.

On the other hand, it is known that, among SAW filters, those using SAW resonators are particularly effective in reducing the insertion loss, in increasing the out-of-band attenuation and in reducing the size. For example, a filter has been proposed which includes longitudinal coupling type SAW resonator filters connected in a multi-stage arrangement. Each SAW resonator filter is formed by arranging three sets of interdigital (ID) electrodes at equal intervals in a surface wave propagation direction on a piezoelectric monocrystalline substrate formed of a 36° Y-cut X-propagation $LiTaO_3$ monocrystal or the like and by providing reflector electrodes at the opposite sides of the ID electrode arrangement region which extend in the surface wave propagation direction. The filter thus arranged can operate with a smaller insertion loss and can be smaller in size.

In the above-described conventional longitudinal coupling type SAW resonator filter, however, the attenuation in a stop band which is higher than the pass band cannot be sufficiently increased.

Fig. 7 shows an example of an insertion loss-frequency characteristic of a filter including the above-described

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conventional longitudinal coupling type SAW resonator filters connected in a two-stage arrangement. In Fig. 7, an essential portion of the characteristic represented by the solid line A is replotted as represented by the solid line B by enlarging the scale of the insertion loss, that is, using the scale on the right-hand side of the ordinate.

The characteristic curve shown in Fig. 7, representing the characteristic of the structure formed of the conventional longitudinal coupling type SAW resonator filters in a multi-stage connection having a pass band set at 864 to 868 MHz, has an increase at a frequency higher than the pass band due to a response of the ID electrodes (as indicated by arrow C in Fig. 7), which shows that the attenuation in the range of about 886 to 906 MHz is not sufficiently large.

The above-mentioned response of the ID electrodes is caused by internal reflection in the ID electrodes. Therefore, the level of the response depends upon the film thickness and line width of each of the ID electrodes. For this reason, the method of increasing the film thickness of electrode fingers or reducing the line width in a manufacturing process to set the desired attenuation in the above-mentioned range has been used as a method for reducing the level of undesirable response of the IC electrodes.

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However, if the film thickness of the electrode fingers is increased, the attenuation of surface waves propagating in the ID electrodes is increased, resulting in an increase in insertion loss. If the line width of the electrode fingers is increased, the electrical resistance through each electrode finger is increased, also resulting in an increase in insertion loss.

As conventional design methods for increasing the selectivity of SAW filters, a new phase weighting method (Shingaku Giho US81-22) and a method of forming a split structure in some of the ID electrodes to limit internal reflection in the ID electrodes are known.

Of these methods, however, the former method requires a troublesome operation for designing weighted ID electrodes and also requires that an increased number of electrode fingers be thinned out. Therefore, this method inherently experiences the problem of an increase in impedance or an increase in the length of the ID electrodes.

The latter method uses a split electrode having electrode fingers, the width of which is half the width of the ordinary electrode fingers, i.e., solid electrodes. Therefore, this method requires advanced processing techniques such as dry etching techniques if it is used for

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filters of 800 MHz or higher bands. It also experiences the problem of a reduction in yield mainly because it is difficult to control the width of electrode fingers of each ID electrode in the mixed arrangement of the solid electrodes and the split electrodes.

SUMMARY OF THE INVENTION

The preferred embodiments of the present invention overcome the problems described above by providing a longitudinal coupling type SAW resonator filter which achieves high selectivity without increasing the insertion loss and which is capable of being mass-produced much more easily than conventional devices.

According to one preferred embodiment of the present invention, there is provided a longitudinal coupling type SAW resonator filter comprising a substrate made of a piezoelectric material or a substrate having a piezoelectric thin film formed thereon, and first, second and third sets of ID electrodes disposed on the piezoelectric substrate or in contact with the piezoelectric thin film. The second and third sets of ID electrodes are preferably located on the opposite sides of the first set of ID electrodes and extend in a direction of propagation of surface waves excited and

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received by the first set of ID electrodes. The filter alsc comprises first and second reflectors located at the opposite sides in the surface wave propagation direction of the area in which the first to third sets of ID electrodes are provided. Each of the first to third sets of ID electrodes preferably includes a pair of comb electrodes each having at least one electrode finger. A center distance L_1 between centers of the electrode finger of the first set of ID electrodes and the electrode finger of the second set of ID electrodes located adjacent to each other and a center distance L_2 between centers of the electrode finger of the first set of ID electrodes and the electrode finger of the third set of ID electrodes located adjacent to each other are preferably set to different values.

In the longitudinal coupling type SAW resonator filter of the preferred embodiments of the present invention having the first to third sets of ID electrodes disposed on the substrate made of a piezoelectric material or the substrate having a piezoelectric film formed thereon and the first and second reflectors provided on the opposite side of the area in which the first to third ID electrode sets are provided, the center distances L_1 and L_2 are preferably set to different values. A high-selectivity characteristic can be

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achieved by using two resonant modes determined by the center distances L_1 and L_2. The reason for this effect will become apparent from the following detailed description of preferred embodiments of the present invention.

According to the preferred embodiments of the present invention, a piezoelectric monocrystal of $LiTaO_3$, $LiNbO_3$, quartz or the like or a lead titanate-zirconate piezoelectric ceramic may be used as the material for forming the above-mentioned piezoelectric substrate. On the other hand, as the above-mentioned substrate having a piezoelectric thin film formed thereon, a substrate may be provided by forming a piezoelectric thin film of ZnO, Ta_2O_5 or the like on a surface of an insulating member made of an insulating ceramic such as alumina or any other insulating material or on the upper surface of the above-described piezoelectric substrate.

The first to third sets of ID electrodes may be formed on the piezoelectric substrate or in contact with the piezoelectric thin film. The method of forming the ID electrodes in contact with the piezoelectric thin film preferably comprises a method of forming the first to third sets of ID electrodes on the piezoelectric thin film or a method of forming the first to third sets of ID electrodes between the substrate and the piezoelectric thin film.

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The first to third sets of ID electrodes may be formed of a suitable electroconductive material, e.g., Al or an Al alloy. Each of the first to third sets of ID electrodes includes a pair of comb electrodes each having at least one electrode finger. The electrode fingers of the comb electrodes are arranged in an interlocking manner.

The first and second reflectors are provided to confine surface acoustic waves in the region between the first and second reflectors. Ordinarily, each of the first and second reflectors has a plurality of electrode fingers arranged substantially perpendicularly to the surface wave propagation direction. The first and second reflectors may also be formed of a suitable electroconductive material. Preferably, they are formed of the same material as the first to third sets of ID electrodes, e.g., Al or an Al alloy.

The longitudinal coupling type SAW resonator filter of the preferred embodiments of the present invention is characterized by setting the center distances L_1 and L_2 to different values in the three-electrode-set type SAW resonator filter having first to third sets of ID electrodes and first and second reflectors arranged as described above. The selectivity of the filter is improved by utilizing two resonant modes determined by the two center distances, as

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will be apparent from the following description of the preferred embodiments of the present invention.

Preferably, according to the preferred embodiments of the present invention, if each of the first and second reflectors has a plurality of electrode fingers arranged substantially perpendicularly to the surface wave propagation direction, and if the wavelength of surface waves determined by the electrode pitch of the reflectors is λ, the center distances L_1 and L_2 are set to such values that the center distance L_1 satisfies an inequality (1):

$$0 + n\lambda \leq L_1 \leq 1/2\lambda + n\lambda \quad \ldots (1)$$

(n: an integer),

the center distance L_2 satisfies an inequality (2):

$$1/2\lambda + m\lambda \leq L_2 \leq (m + 1)\lambda \quad \ldots (2)$$

(m: an integer), and

the center distance L_1 and the center distance L_2 satisfy an inequality (3):

$$L_1 \neq L_2 - 1/2\lambda + k\lambda \quad \ldots (3)$$

(k: an integer).

Thus, as will be apparent from the following description of the preferred embodiments, a longitudinal coupling type SAW resonator filter reliably achieving a desired band width and having improved selectivity is provided.

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According to another preferred embodiment of the present invention, there is provided a multiple-electrode-set longitudinal coupling type surface acoustic wave resonator filter comprising a piezoelectric substrate made of a piezoelectric material or a substrate having a piezoelectric thin film disposed thereon, and first to Xth (X: an integer equal to or larger than 4) sets of interdigital electrodes disposed on the piezoelectric substrate or in contact with the piezoelectric thin film. The second to Xth sets of interdigital electrodes are arranged to extend along a direction of propagation of surface waves excited and received by the first set of interdigital electrodes. The filter also comprises first and second reflectors located on the opposite sides in the surface wave propagation direction of the area in which the first to Xth sets of interdigital electrodes are provided. Each of the sets of interdigital electrodes preferably includes a pair of comb electrodes each having at least one electrode finger. If the center distances between adjacent-end electrode fingers of adjacent pairs of the interdigital electrodes are L_1, L_2, ... L_{X-1}, the center distances satisfy equations (4) and (5):

$$L_3 = L_1 = L_3 = L_5 \cdots \quad \cdots (4)$$

$$L_A = L_2 = L_4 = L_6 \cdots \quad \cdots (5)$$

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If the wavelength of surface waves determined by the electrode finger pitch of the reflectors is λ, the center distances L_S and L_A satisfy inequalities (6) and (7):

$$0 + n\lambda \leq L_S \leq 1/2\lambda + n\lambda \quad \ldots (6)$$

(n: integer)

$$1/2\lambda + m\lambda \leq L_A \leq (m + 1)\lambda \quad \ldots (7)$$

(m: integer)

or inequalities (8) and (9):

$$1/2\lambda + n\lambda \leq L_S \leq (n + 1)\lambda \quad \ldots (8)$$

(n: integer)

$$0 + m\lambda \leq L_A \leq 1/2\lambda + m\lambda \quad \ldots (9)$$

(m: integer), and

the center distances L_S and L_A satisfy an inequality (10):

$$L_S \neq L_A - 1/2\lambda + k\lambda \quad \ldots (10)$$

(k: integer).

Thus, a longitudinal coupling type SAW resonator filter capable of reliably achieving the desired band width and having improved selectivity is provided.

According to still another preferred embodiment of the present invention, there is provided a longitudinal coupling type SAW resonator filter device comprising a substrate, and a plurality of longitudinal coupling type SAW resonator filters in accordance with the preferred embodiments of the

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present invention. The plurality of longitudinal coupling type SAW resonator filters are disposed on the substrate and connected in series to each other. That is, on one substrate, a plurality of longitudinal coupling type SAW resonator filters of the preferred embodiments of the present invention may be formed and may be connected in series. In this manner, a filter having further improved selectivity can be provided.

According to a further preferred embodiment of the present invention, there is provided a SAW resonator filter device comprising a longitudinal coupling type SAW resonator filter in accordance with a first preferred embodiment of the present invention described above, and at least one of another longitudinal coupling type SAW resonator filter, a lateral coupling type SAW resonator filter and a trap filter using a SAW resonator formed on the substrate of the longitudinal coupling type SAW resonator filter of the first preferred embodiment of the present invention and electrically connected to the longitudinal coupling type SAW resonator filter of the first preferred embodiment of the present invention.

As described above, the SAW resonator filter device of the preferred embodiments of the present invention may be electrically connected to any other SAW resonator filter, a

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trap filter and the like. Preferably, in such a case, other devices are constructed on the piezoelectric substrate constituting the SAW resonator filter device. In this manner, a smaller integrated SAW resonator filter device can be provided.

These and other elements, features, and advantages of the preferred embodiments of the present invention will be apparent from the following detailed description of the preferred embodiments of the present invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a plan view of the structure of a SAW resonator filter according to a first preferred embodiment of the present invention;

Fig. 2 is a diagram showing a frequency characteristic of a conventional SAW resonator filter having the structure shown in Fig. 1 but having equal center distances L_1 and L_2 and having the number of electrode fingers of the reflectors set to zero;

Fig. 3 is a diagram showing a center distance $L = L_1 = L_2$ and relative resonance frequencies in the SAW resonator filter having the structure shown in Fig. 1;

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Fig. 4 is a diagram for explaining the principle of operation of a SAW resonator filter having the electrode structure shown in Fig. 1 and arranged in accordance with the first preferred embodiment of the present invention;

Fig. 5 is a diagram showing an insertion loss-frequency characteristic of a SAW resonator filter device shown in Fig. 11A as a second preferred embodiment of the present invention;

Fig. 6 is a diagram showing an insertion loss-frequency characteristic of the SAW resonator filter device shown in Fig. 11A when a thinning-out and weighting method is used;

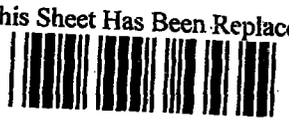
Fig. 7 is a diagram showing an example of an insertion loss-frequency characteristic of a conventional SAW resonator filter;

Figs. 8A and 8B are schematic plan views of a portion where ID electrodes are formed, showing cases where the center distance is apparently changed when an electrode finger is added;

Figs. 9A and 9B are schematic plan views of a portion where ID electrodes are formed, showing cases where the center distance is apparently changed when one of the electrode fingers is removed;

Fig. 10 is a schematic plan view of a case where the

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adjacent-end electrode fingers of an adjacent pair of ID electrode sets are connected by the electrode material;

Figs. 11A are 11B are plan views of SAW resonator filter devices according to second and third preferred embodiments of the present invention; and

Fig. 12 is a plan view of a SAW resonator filter device according to a fourth preferred embodiment of the present invention.

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DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention will be described below in detail with respect to preferred embodiments thereof.

Referring to Fig. 1, a SAW resonator filter 10 which illustrates a preferred embodiment of the present invention is constructed on a piezoelectric substrate 11 preferably having a substantially rectangular planar shape. In this preferred embodiment, the piezoelectric substrate 11 is preferably formed of 36° Y-cut X-propagation $LiTaO_3$.

A pair of comb electrodes 14a and 14b forming a first set of ID electrodes are disposed on a central portion of the piezoelectric substrate 11. The comb electrode 14a is connected to ground while the comb electrode 14b is connected to an input/output terminal 22. The comb electrodes 14a and 14b have electrode fingers arranged in an interlocking manner.

Second and third sets of ID electrodes are located on the opposite sides in the surface wave propagation direction of the first ID electrode set formed of the comb electrodes 14a and 14b. The second ID electrode set is formed of comb electrodes 12a and 12b while the third ID electrode set is formed of comb electrodes 13a and 13b.

Each of the pair of comb electrodes 12a and 12b and the

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pair of comb electrodes 13a and 13b have electrode fingers arranged in an interlocking manner, as do the comb electrodes 14a and 14b. However, the comb electrodes 12b and 13b having a smaller number of electrode fingers are disposed on the same side as the comb electrode 14a of the first ID electrode set having a larger number of electrode fingers.

The comb electrodes 12b and 13b are connected in common to an input/output terminal 21 while the comb electrodes 12a and 13a are connected to ground.

Reflectors 15a and 15b are disposed on the opposite sides in the surface wave propagation direction of the area in which the first to third ID electrode sets are formed. Each of the reflectors 15a and 15b preferably has electrode fingers arranged at equal pitches and each extending in a direction substantially perpendicular to the surface wave propagation direction.

The above-described comb electrodes 12a, 12b, 13a, 13b, 14a, and 14b and the reflectors 15a and 15b are preferably formed by forming an Al or Al alloy film on the piezoelectric substrate 11 and processing this film by photolithography and etching.

One of the novel features of this preferred embodiment resides in that the value of the distance L_1 between the

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centers of the electrode fingers at the adjacent ends of the first and second ID electrode sets is within the range defined by the above-mentioned inequality (1), that the value of the distance L_2 between the centers of the electrode fingers at the adjacent ends of the first and third ID electrode sets is set so as to satisfy the above-mentioned inequality (2), and that the center distances L_1 and L_2 are set so as to satisfy the above-mentioned inequality (3). The symbol λ in the inequality (3) represents the wavelength determined by the electrode fingers pitch of the reflectors 15a and 15b (see Fig. 1).

In the SAW resonator filter of this preferred embodiment, since the center distances L_1 and L_2 are set so as to satisfy the above-described conditions, the selectivity can be improved in comparison with the conventional SAW resonator filter. The principle of the operation and design conditions of the SAW resonator filter of this preferred embodiment will be described in the following paragraphs.

The principle of the operation of longitudinal coupling type SAW resonator filters generally used will first be described.

Conventional three-electrode-set longitudinal coupling type SAW resonator filters have generally the same structure

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as that of the SAW resonator filter shown in Fig. 1 illustrating a preferred embodiment of the present invention except for the above-described relationship between the center distances L_1 and L_2. Therefore, the principle of the operation of conventional longitudinal coupling type SAW resonator filters will be described with reference to Fig. 1. In conventional three-electrode-set longitudinal coupling type SAW resonator filters, the distance L_1 between the centers of the electrode fingers at the adjacent ends of the first ID electrode set (comb electrodes 14a and 14b) and the second ID electrode set (comb electrodes 12a and 12b) and the distance L_2 between the centers of the electrode fingers at the adjacent ends of the first ID electrode set (comb electrodes 14a and 14b) and the third ID electrode set (comb electrodes 13a and 13b) are equal to each other. That is, $L_1 = L_2 = L$.

Fig. 2 shows a frequency characteristic in the case where the number of electrode fingers of the reflector electrodes in the conventional three-electrode-set longitudinal coupling type SAW resonator filter having equal center distances L_1 and L_2 is set to zero. A peak indicated by the arrow D in Fig. 2 is considered to correspond to a resonant mode due to multiple reflection between the first

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and second ID electrode sets or multiple reflection between the first and third electrode sets, and a peak indicated by the arrow E is considered to be corresponding to an internal resonant mode of the ID electrodes.

As conventional longitudinal coupling type resonator filters, longitudinal coupling type double mode filters have been constructed by using the two resonant modes indicated by the arrows D and E. Longitudinal coupling type triple mode filters have also been realized by using these resonant modes and another resonant mode due to multiple reflection between the reflectors 15a and 15b at a frequency lower than the frequency of the resonant mode indicated by the arrow E in the case of adding the reflectors 15a and 15b.

Fig. 7 shows a typical characteristic of conventional longitudinal coupling type resonator filters in two-stage serial connection designed on the basis of the above-described principle. As described above, a filter having this structure has a small insertion loss but has unsatisfactory selectivity at frequencies higher than the pass band. That is, the attenuation in a frequency range higher than the center frequency by about + 20 to 30 MHz is at most 25 dB.

The resonance frequencies of the above-mentioned

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resonant modes D and E are determined by the value of the center distance L (= L_1 = L_2). Fig. 3 shows the relative positions of the resonant modes D and E with the center distance L used as a parameter. The characteristics shown in Fig. 3 are of a SAW filter arranged by setting the number of electrode fingers of the first ID electrode set, i.e., the sum of the numbers of electrode fingers of the comb electrodes 14a and 14b to 57, the number of electrode fingers of the second ID electrode set (comb electrodes 12a and 12b) to 31, the number of electrode fingers of the third ID electrode set (comb electrodes 13a and 13b) to 31, and the number of electrode fingers of each of the reflectors 15a and 15b to 0, and by using a 36° Y-cut X-propagation $LiTaO_3$ substrate as piezoelectric substrate 11, the SAW filter having a center frequency of 866 MHz.

As can be can be understood from Fig. 3, the resonance frequency the resonant mode E is not dependent on the value of the center distance L, but the resonance frequency of the resonant mode D decreases as the value of L increases. When the center distance L becomes equal to about 0.45λ, a mode conversion from the resonant mode D into the resonant mode E starts. As the value of the center distance L increases further, the resonant mode D is completely converted into the

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resonant mode E and new resonant mode D appears from the high-frequency side.

In contrast, in the above-described preferred embodiment of the present invention, resonance is excited in two resonant modes D by setting the center distances L_1 and L_2 to different values, as explained below with reference to Fig. 4.

Fig. 4 shows the results of one preferred embodiment constructed by setting the number of electrode fingers of the first ID electrode set, i.e., the sum of the numbers of electrode fingers of the comb electrodes 14a and 14b to 57, the number of electrode fingers of the second ID electrode set, i.e., the sum of the numbers of electrode fingers of the comb electrodes 12a and 12b to 31, the number of electrode fingers of the third ID electrode set to 31, and the number of electrode fingers of each of the reflectors 15a and 15b to 150.

Characteristics F and G shown in Fig. 4 are shown for comparison with the preferred embodiment of the present invention. Characteristic F was obtained by setting $L_1 = L_2 = 0.25\lambda$ and characteristic G was obtained by setting $L_1 = L_2 = 0.62\lambda$. On the other hand, characteristic H shown in Fig. 4 was obtained by setting the distances L_1 and L_2 to

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different values: L = 0.25λ, and L2 = 0.62λ.

Two resonant modes occurred with respect to each of the characteristics F and G shown in Fig. 4. The peak at a higher frequency corresponds to the above-described resonant mode D while the peak at a lower frequency corresponds to the above-described resonant mode E. In the characteristics F and G shown in Fig. 4, the resonant mode E occurs at the end of the stop band of the reflector, so that the peak is rugged.

In contrast, in the characteristic H shown in Fig. 4, substantially no resonant mode E is recognized but two resonant modes D appear. The resonant mode D of a higher frequency occurs due to multiple reflection between the first ID electrode set (comb electrodes 14a and 14b) and the third ID electrode set (comb electrodes 13a and 13b) determined by the center distance L_2 while the resonant mode D of a lower frequency occurs due to multiple reflection between the first ID electrode set (comb electrodes 14a and 14b) and the second ID electrode set (comb electrodes 12a and 12b) determined by the center distance L_1.

Also, a double mode filter having a favorable characteristic such as indicated by I in Fig. 4 can be provided by adjusting the electrode interlocking width of the first to third electrode sets and/or by adding an external

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matching circuit.

The band width of SAW resonator filters having characteristics such as indicated by H and I in Fig. 4 is determined by the difference between the values of the center distances L_1 and L_2 and can be freely selected by adjusting these distances, as described below with reference to Fig. 3.

For example, center distance $L_1 = 0.25\lambda$ is selected to set a reference resonance frequency (0 MHz in terms of relative value, indicated by the arrow J in Fig. 3), at which resonant mode D occurs between the comb electrodes 12a and 12b and the comb electrodes 14a and 14b. With respect to this frequency, if $L_2 = 0.62\lambda$ is selected, resonant mode D occurs between the comb electrodes 13a and 13b and the comb electrodes 14a and 14b at a frequency higher by 10 MHz as indicated by arrow K in Fig. 3. By using these two resonant modes D, a band filter having a band width of 10 MHz in the band from 800 to 900 MHz can be obtained.

To increase the band width, the center distance L_1 may be set to a value larger than the above-mentioned value or the center distance L_2 may be set to a value smaller than the above-mentioned value. Conversely, to reduce the band width, the center distance L_1 may be reduced or the center distance L_2 may be increased. Under the characteristic conditions

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shown in Fig. 3, it is theoretically possible to realize a filter having a band width of 40 MHz at the maximum.

With respect to the conditions shown in Fig. 3, a similar filer may be arranged by selecting center distance $L_1 = 0.12\lambda$ and center distance $L_2 = 0.25\lambda$. In this filter, however, resonant mode D corresponding to the center distance of 0.12λ and resonant mode D corresponding to the center distance of 0.25λ do not couple with each other because of the phase relationship therebetween. This filter is obtained as a double mode filter in which resonant mode D corresponding to the center distance of 0.25λ and resonant mode E couple with each other.

Accordingly, with respect to wavelength λ, it is necessary to select center distances L_1 and L_2 so as to satisfy the above-mentioned inequalities (1) and (2).

$$L_1 = L_2 - 1/2\lambda + k\lambda \quad \ldots (11)$$

(k: integer)

If equation (11) is satisfied, the difference between two resonant modes D is zero and the phase difference therebetween is 180°, so that a double mode filter cannot be formed. Therefore, it is necessary to determine center distances L_1 and L_2 to such values as to satisfy inequalities (1) to (3).

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The relationship between center distances L_1 and L_2 determines a certain phase. Therefore, if one of the electrode fingers of the comb electrodes at the outer ends in the surface wave propagation direction is removed or if an electrode finger is added, it is necessary to determine the relationship between center distances L_1 and L_2 by considering the phase determined by the relationship between center distances L_1 and L_2.

If the structure shown in Fig. 1 is changed by increasing the number of electrode fingers of the comb electrode 12b by one, as shown in Fig. 8A, or by increasing the number of electrode fingers of the comb electrode 14b by one, as shown in Fig. 8B, the center distance is apparently changed to L'_1 (= L_1 - 1/2λ). In such cases, however, the phase relationship of surface waves is not changed, so that there is no change in the resulting filter characteristic.

Fig. 9A shows an arrangement of removing one of the electrode fingers of the comb electrode 12a in the structure shown in Fig. 1, and Fig. 9B shows an arrangement of removing one of the electrode fingers of the comb electrode 14a in the same structure. In these arrangements, center distance L''_1 = (L_1 + 1/2λ). However, there is no change in the resulting filter characteristic.

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The cases where the center distance L_1 is apparently changed have been described with reference to Figs. 8 and 9. However, the same description can be made with respect to center distance L_2. That is, each of center distances L_1 and L_2 is set as the distance between the centers of the adjacent-end electrode fingers both of which are connected to ground, or one of which is connected to an input end while the other of which is connected to an output end.

While the center distances satisfy the conditions represented by the above-described equations (1) to (3), an electrical connection may be established between the electrode fingers of the comb electrode 12a and the comb electrode 14a at the adjacent ends of these electrodes and/or between the adjacent electrode fingers of the comb electrode 13a and the comb electrode 14a by using the same electroconductive material as the material of the comb electrodes. Fig. 10 shows an example of a structure in which the adjacent electrode fingers of the comb electrode 12a and 14a are connected to each other.

In the structure shown in Fig. 10, the gap between electrode fingers of the comb electrodes 12a and 14a at the adjacent ends of these electrodes is filled with an electrode material 17 which is the same electroconductive material as

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that of the comb electrodes.

As is apparent from Figs. 8A, 8B, 9A, 9B and Fig. 10, it is necessary to determine center distances L_1 and L_2 of the preferred embodiments of the present invention so as to maintain the same relationship between the phase of surface waves in the first ID electrode set and the phases of surface waves in the second and third ID electrode sets.

The SAW resonator filter of the preferred embodiments of the present invention will be described with respect to experimental examples thereof.

Fig. 5 shows an example of a characteristic of an RF filter arranged for use in a cordless telephone set of the CT-2 system in accordance with the preferred embodiments of the present invention and having a center frequency of about 866 MHz.

The filter having the characteristic shown in Fig. 5 is designed as a two-stage longitudinal coupling type SAW resonator filter device 31 shown in Fig. 11A. As shown in Fig. 11A, SAW resonator filters 32 and 33 are constructed on a substantially rectangular piezoelectric substrate 34. The SAW resonator filter 32 preferably has the same electrode structure as the SAW resonator filter 10 shown in Fig. 1. Therefore, the ID electrodes and reflectors corresponding to

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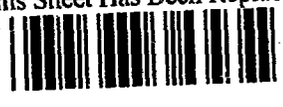
those shown in Fig. 1 are indicated by the same reference characters and the detailed description for them will not be repeated.

The SAW resonator filter 33 also preferably has the same electrode structure as the SAW resonator filter 32. Therefore, the electrodes of the SAW resonator filter 33 are indicated by adding 30 to each of the numbers designating the electrodes of the SAW resonator filter 32, and the description for them will not be repeated.

As shown in Fig. 11A, the comb electrode 14b of the SAW resonator filter 32 is connected to the comb electrode 44b of the SAW resonator filter 33, thereby connecting the SAW resonator filters 32 and 33 in series.

More specifically, each of the SAW resonator filters 32 and 33 was constructed by setting the film thickness of the electrode members made of Al and forming the comb electrodes and the reflectors to 3.6 % of λ which is the wavelength of surface waves, by setting the numbers of electrode fingers of the first to third ID electrode sets to 65, 37 and 37, respectively, by setting the numbers of electrode fingers of reflectors 15a, 15b, 45a, and 45b to 150, by setting center distance L_1 = 0.30λ and center distance L_2 = 0.64λ, and by using 36° Y-cut X-propagation $LiTaO_3$ for piezoelectric

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substrate 34.

In the two-stage longitudinal coupling type SAW resonator filter device 31, as can be read from Fig. 5, a -4 dB band width of about 13 MHz, i.e., 1.5 % in terms of relative band width was obtained and improved selectivity was achieved in a frequency range in the vicinity of the pass band. Also, at the point of 866 MHz + 20 MHz where a strong demand for a sufficiently large attenuation should be satisfied, a large attenuation of 30 dB was achieved.

The characteristic curve M shown in Fig. 5 represents an essential portion of the characteristic indicated by L, which is replotted by enlarging the insertion loss on the ordinate, that is, by using the scale on the right-hand side of the ordinate to represent the insertion loss.

Fig. 6 shows a characteristic improved by combining the well-known thinning-out and weighting method with the arrangement of the above-described SAW resonator filter device 31. The characteristic curve O represents an essential portion of the characteristic curve N with the insertion loss on the ordinate enlarged. As can be understood from Fig. 6, the attenuation in the stop band in the vicinity of the pass band could be further improved by combining the thinning-out and weighting method, and a large

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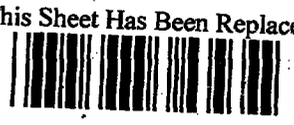
attenuation of 45 dB or more was achieved at the point of 866 MHz + 20 MHz.

As is apparent from the characteristics shown in Figs. 5 and 6, the preferred embodiments of the present invention can be utilized to improve the attenuation in the stop band higher than the pass band while the electrode fingers are still formed as solid electrodes, so that there is no need for manufacturing a split electrode structure requiring advanced processing techniques with respect to high frequencies. It is therefore possible to achieve adaptation for operation at higher radio frequencies without reducing the productivity.

While the SAW resonator filters 32 and 33 in the arrangement shown in Fig. 11A are connected in the above-described manner, comb electrodes 12b and 13b of the SAW resonator filter 32 may be connected to comb electrodes 43b and 42b of the SAW resonator filter 33 as shown in Fig. 11B.

Fig. 12 is a schematic plan view of a longitudinal coupling type SAW resonator filter which represents a preferred fourth embodiment of the present invention. As the first to third preferred embodiments of the present invention, examples of the application of the present invention to a longitudinal coupling type SAW resonator filter having three

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sets of ID electrodes have been described. However, the preferred embodiments of the present invention can also be applied to a multiple electrode set type SAW resonator filter, such as that shown in Fig. 12, having four or more sets of ID electrodes.

That is, in a SAW resonator filter 51 shown in Fig. 12, a plurality of sets of ID electrode sets 53 to 58 are arranged in the surface wave propagation direction, and reflectors 59 and 60 are disposed on the opposite sides in the surface wave propagation direction of the area in which the ID electrode sets 53 to 58 are formed. As materials for forming a piezoelectric substrate 52, ID electrodes 53 to 58 and reflectors 59 and 60, the same materials as those in the SAW resonator filters of the first to third preferred embodiments can be used.

In the longitudinal coupling type SAW resonator filter 51 having more than four sets of ID electrodes 53 to 58 formed in this manner, the ID electrodes and reflectors are formed so as to satisfy equations (4) and (5) and inequalities (6) to (10) shown below, thereby achieving the same advantages as those of the longitudinal coupling type SAW resonator filters of the first to third preferred embodiments.

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That is, ID electrode sets 53 to 58 are formed so that the distance between the centers of the adjacent-end electrode fingers of each adjacent pair of the ID electrode sets is selected so as to satisfy the following equations:

$$L_S = L_1 = L_3 = L_5 \quad \ldots (4)$$

$$L_A = L_2 = L_4 = L_6 \quad \ldots (5)$$

Also, if the wavelength of surface waves determined by the electrode finger pitch of reflectors 59 and 60 is λ, the center distances L_S and L_A are selected so as to satisfy the following inequalities:

$$0 + n\lambda \leq L_S \leq 1/2\lambda + n\lambda \quad \ldots (6)$$

(n: integer)

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$$1/2\lambda + m\lambda \leq L_A \leq (m + 1)\lambda \quad \ldots (7)$$

(m: integer)

or the following inequalities:

$$1/2\lambda + n\lambda \leq L_S \leq (n + 1)\lambda \quad \ldots (8)$$

(n: integer)

$$0 + m\lambda \leq L_A \leq 1/2\lambda + m\lambda \quad \ldots (9)$$

(m: integer)

Further, the center distances L_S and L_A are selected so as to satisfy the following inequality:

$$L_S \neq L_A - 1/2\lambda + k\lambda \quad \ldots (10)$$

(k: integer)

According to the preferred embodiments of the present invention, in the longitudinal coupling type SAW resonator filter using the first to third sets of ID electrodes, the center distances L_1 and L_2 are set to different values. This makes it possible to provide a double-mode longitudinal coupling type SAW resonator filter using two resonant modes determined by the center distances L_1 and L_2 and having improved selectivity.

That is, in the conventional longitudinal coupling type resonator filter, the attenuation in a stop band higher than the pass band is not sufficiently large because of a response of ID electrodes in the stop band. In contrast, in the

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above-described new double-mode longitudinal coupling type SAW resonator filter, the center distances L_1 and L_2 are set to different values, and two resonant modes determined by these center distances are excited, thereby effectively improving the attenuation in the stop band so that it is higher than the pass band.

According to the preferred embodiments of the present invention, only setting the center distances L_1 and L_2 between the electrode fingers to different values may suffice, as described above, and there is no need for advanced processing techniques. Therefore, the same productivity as that of the conventional SAW resonator filter can be maintained. If the well-known electrode thinning-out and weighting method is also used, further improved selectivity can be achieved.

Further, a longitudinal coupling type SAW resonator filter having four or more sets of ID electrodes may be constructed, as shown in Fig. 12, as well as the longitudinal coupling type SAW resonator filter having three sets of ID electrodes.

A plurality of SAW resonator filters according to at least one preferred embodiment of the present invention may be connected in series on one piezoelectric substrate or the

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SAW resonator filter of the preferred embodiments of the present invention may be connected to a different SAW element such as a SAW resonator filter or a trap filter on one substrate. In this manner, longitudinal coupling type SAW resonator filters adapted for various kinds of use can be provided as integrated devices. Also in such cases, the longitudinal coupling type SAW resonator filter of at least one preferred embodiment of the present invention can operate with sufficiently high selectivity no matter what the connection arrangement.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

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* C L M S *

WHAT IS CLAIMED IS:

1. A longitudinal coupling type surface acoustic wave resonator filter comprising:

a substrate;

first, second and third sets of interdigital electrodes disposed on a surface of said substrate;

said second and third sets of interdigital electrodes being located on opposite sides of said first set of interdigital electrodes in a direction of propagation of surface waves excited and received by said first set of interdigital electrodes;

each of said first, second and third sets of interdigital electrodes including a pair of comb electrodes each having at least one electrode finger;

a center distance L_1 between centers of the electrode finger of said first set of interdigital electrodes and the electrode finger of said second set of interdigital electrodes located adjacent to each other and a center distance L_2 between centers of the electrode finger of said first set of interdigital electrodes and the electrode finger of said third set of interdigital electrodes located adjacent to each other being set to different values; and

first and second reflectors located on said substrate at opposite ends of an area in which said first, second and third sets of interdigital electrodes are provided;

each of said first and second reflectors having a plurality of electrode fingers arranged substantially perpendicularly to

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the surface wave propagation direction, a wavelength of surface waves determined by an electrode pitch of the reflectors is 1 and said center distance L_1 satisfies an inequality (1):

$$0 + n\lambda \leq L_1 \leq 1/2\lambda + n\lambda \quad \ldots (1)$$

(n: an integer),

said center distance L_2 satisfies an inequality (2):

$$1/2\lambda + m\lambda \leq L_2 \leq (m+1)\lambda \quad \ldots (2)$$

(m: an integer), and

said center distance L_1 and said center distance L_2 satisfy an inequality (3):

$$L_1 \neq L_2 - 1/2\lambda + k\lambda \quad \ldots (3)$$

(k: an integer).

2. A longitudinal coupling type surface acoustic wave resonator filter according to claim 1, wherein said substrate comprises one of a piezoelectric substrate and a substrate including a piezoelectric thin film disposed thereon.

3. A multiple-electrode-set longitudinal coupling type surface acoustic wave resonator filter comprising:

a substrate;

first to Xth (X: an integer equal to or larger than 4) sets of interdigital electrodes disposed on a surface of said substrate;

said second to Xth sets of interdigital electrodes being arranged to extend along a direction of propagation of surface waves excited and received by said first set of interdigital

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electrodes;

first and second reflectors located on said substrate at opposite sides direction of an area in which said first to Xth sets of interdigital electrodes are provided; and

each of said sets of interdigital electrodes including a pair of comb electrodes each having at least one electrode finger; wherein

center distances between adjacent-end electrode fingers of adjacent pairs of said interdigital electrodes are L_1, L_2, ... L_{X-1} and the center distances satisfy equations (4) and (5):

$$L_S = L_1 = L_3 = L_5 \quad \ldots (4)$$

$$L_A = L_2 = L_4 = L_6, \quad \ldots (5)$$

wherein, a wavelength of surface waves determined by an electrode finger pitch of said reflectors is λ and said center distances L_S and L_A satisfy inequalities (6) and (7):

$$0 + n\lambda \leq L_S \leq 1/2\lambda + n\lambda \quad \ldots (6)$$

(n: integer),

$$1/2\lambda + m\lambda \leq L_A \leq (m+1)\lambda \quad \ldots (7)$$

(m: integer)

or inequalities (8) and (9):

$$1/2\lambda + n\lambda \leq L_S \leq (n+1)\lambda \quad \ldots (8)$$

(n: integer)

$$0 + m\lambda \leq L_A \leq 1/2\lambda + m\lambda \quad \ldots (9)$$

(m: integer), and

the center distances L_S and L_A satisfy an inequality (10):

$$L_S \neq L_A - 1/2\lambda + k\lambda \quad \ldots (3)$$

(k: integer).

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4. An electronic component comprising:

a substrate;

a plurality of longitudinal coupling type surface acoustic wave resonator filters located on said substrate and connected in series to each other, each of said plurality of longitudinal coupling type surface acoustic wave filters including:

first, second and third sets of interdigital electrodes disposed on a surface of said substrate;

said second and third sets of interdigital electrodes being located on opposite sides of said first set of interdigital electrodes in a direction of propagation of surface waves excited and received by said first set of interdigital electrodes;

first and second reflectors located on said substrate at opposite ends of an area in which said first, second and third sets of interdigital electrodes are provided;

each of said first, second and third sets of interdigital electrodes including a pair of comb electrodes each having at least one electrode finger; and

a center distance L_1 between centers of the electrode finger of said first set of interdigital electrodes and the electrode finger of said second set of interdigital electrodes located adjacent to each other and a center distance L_2 between centers of the electrode finger of said first set of interdigital electrodes and the electrode finger of said third set of interdigital electrodes located adjacent to each other being set to different values.

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5. A surface acoustic wave resonator filter device comprising:

a longitudinal coupling type surface acoustic wave resonator filter including first, second and third sets of interdigital electrodes disposed on a surface of said substrate, said second and third sets of interdigital electrodes being located on opposite sides of said first set of interdigital electrodes in a direction of propagation of surface waves excited and received by said first set of interdigital electrodes, first and second reflectors located on said substrate at opposite ends of an area in which said first, second and third sets of interdigital electrodes are provided, each of said first, second and third sets of interdigital electrodes including a pair of comb electrodes each having at least one electrode finger and a center distance L_1 between centers of the electrode finger of said first set of interdigital electrodes and the electrode finger of said second set of interdigital electrodes located adjacent to each other and a center distance L_2 between centers of the electrode finger of said first set of interdigital electrodes and the electrode finger of said third set of interdigital electrodes located adjacent to each other being set to different values; and

at least one of a longitudinal coupling type surface acoustic wave resonator filter, a lateral coupling type surface acoustic wave resonator filter and a trap filter including a surface acoustic wave resonator disposed on the substrate and electrically connected to said longitudinal coupling type surface acoustic wave resonator filter.

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