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PIEZOELECTRIC RESONATORS

BACKGROUND OF THE INVENTION

This invention relates to piezoelectric resonators
5 using SH type surface waves and more particularly to
such piezoelectric resonators having a plurality of
resonant characteristics. This invention also
relates to trap circuits comprising such
piezoelectric resonators using SH type surface waves
10 and more particularly to such trap circuits having
not only a plurality of trap frequencies but also
improved attenuation characteristics.

Trap circuits with characteristic as shown in Fig. 1
are used for the intermediate picture frequency
15 section in television video receivers and video tape
recorders in order to prevent beats due to
interference between adjacent channels. In other
words, signals must be sufficiently attenuated at the
adjacent-channel picture carrier frequency f_{ap} and
20 the adjacent-channel sound carrier frequency f_{as}
(respectively 39.75MHz and 47.25MHz according to the
National Television System Committee (NTSC) of the
United States).

In order to obtain such a trap characteristic, it has
25 been customary to make use of two traps, one having
an attenuation pole at the adjacent-channel picture

carrier frequency f_{ap} and the other having an
attenuation pole at the adjacent-channel sound
carrier frequency f_{as} , each trap being formed with an
LC resonant circuit or a piezoelectric resonator. As
5 piezoelectric resonators to be used for such a
purpose, attention is coming to be focused on those
which make use of SH-type surface waves such as the
BGS (Bleustein-Gulyaev-Shimizu) wave. Fig. 2 shows a
BGS wave resonator 1 utilizing the free-edge surface
10 reflection, comprised of a piezoelectric substrate 2
of a piezoelectric material such as piezoelectric
ceramics like lead zirconate titanate or
piezoelectric single crystals of LiNbO_3 or LiTaO_3 ,
having a quadrangular planar shape. If it is made of
15 a piezoelectric ceramic material, it is polarized in
the direction of arrow P. A pair of comb-shaped
electrodes 3 and 4, each having a plurality of
fingers 3a-3c and 4a-4c protruding interdigitatingly
toward each other, is formed on the upper surface 2a
20 of the piezoelectric substrate 2 to serve as an
interdigital transducer.

With the BGS wave resonator utilizing the free-edge
surface reflection type thus structured, BGS waves
are excited if an AC voltage is applied to the comb-
25 shaped electrodes 3 and 4. The BGS waves are
propagated in the direction shown by arrow X and is
reflected by the end surfaces of the piezoelectric
substrate 2. If the frequency spectrum determined by
this interdigital transducer and the frequency
30 determined by the dimension between the end surfaces
are matched, a useful resonant characteristic can be
obtained from the surface wave resonator 1. Fig. 3A
shows the attenuation-frequency characteristic of
this end surface reflection type surface wave
35 resonator, and Fig. 3B shows its impedance-frequency
characteristic. Figs. 3A and 3B clearly show that



the end surface reflection type surface wave resonator shown in Fig. 2, like the prior art LC resonance circuits and other kinds of piezoelectric resonators, have a single resonance characteristic.

5 As a result, it has been necessary to provide and connect two resonance circuits or piezoelectric resonators to obtain a trap characteristic as shown in Fig. 1, but the attenuation was not sufficient at each trap frequency even if two resonance circuits or
10 piezoelectric resonators were connected together.

Single surface acoustic wave resonators making use of the Rayleigh wave and having two resonance characteristics have been known. For example, Kanda, et al (Kokusai Denki Giho, No. 16, pages 1-7 (1992))
15 disclosed a surface wave resonant filter making use of the Rayleigh wave serving as a double-mode resonator making use of the zeroth-order longitudinal mode (the fundamental mode) and the second-order longitudinal mode. In order to obtain two resonance
20 characteristics, however, this double-mode resonator required more than two interdigital transducers and a reflector. Its resonance characteristics are determined by the reflectivity-frequency characteristic of the reflector but since the
25 reflectivity is large only in a small frequency range, the distance between the two resonant frequencies was as small as about 1MHz. In other words, a trap filter with characteristic as shown in Fig. 1 cannot be formed with such a double-mode
30 resonator alone.

SUMMARY OF THE INVENTION

It is therefore an object of this invention to provide a piezoelectric resonator using SH type



surface waves, capable of providing a plurality of attenuation poles by means of a single chip.

It is another object of this invention to provide a trap circuit capable of providing sufficiently large
5 attenuation at a plurality of trap frequencies.

A piezoelectric resonator of the kind using SH type surface waves, which embodies the present invention and with which the above and other objects can be achieved, may be characterized as comprising a
10 piezoelectric substrate and an interdigital transducer which is formed thereon and has at least two resonance characteristics. Such an interdigital transducer may comprise a pair of thinned-out comb-shaped electrodes with finger-shaped portions
15 protruding interlockingly towards each other, or a pair of comb-shaped electrodes with the lengths of their fingers varying such that the lengths of the regions between the fingers, where surface waves can be excited, will vary. Piezoelectric resonators thus
20 structured according to this invention have two resonance characteristics with the resonant frequencies separated by as much as about 8MHz. This is either because resonators can be designed such that the main lobe frequency determined by the
25 interdigital transducer and the frequency determined by the separation between the end surfaces are separated farther or because a plurality of main lobes can be designed. Because the present invention makes it possible to provide a plurality of trap
30 frequencies as shown in Fig. 1 by means of a single chip, the number of components and the cost of assembling these components can both be reduced.

A trap circuit embodying the present invention may be characterized as being formed with a piezoelectric

- resonator using SH type surface waves and comprising a piezoelectric substrate and two mutually connected interdigital transducers serving as two parallel-connected resonant units having two resonance
- 5 characteristics. In other words, only a single piezoelectric resonator is required according to this invention to form a trap circuit with two trap frequencies. When such a trap circuit is connected between an input terminal and an output terminal, an
- 10 inductor may be inserted between these two resonant units and/or between the input terminal and where the two resonant units are connected together in order to obtain more attenuation at adjacent-channel picture and sound carrier frequencies.
- 15 Alternatively, two piezoelectric resonators according to this invention may be used to provide two trap frequencies.

BRIEF DESCRIPTION OF THE DRAWING

- The accompanying drawings, which are incorporated in
- 20 and form a part of this specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention. In the drawings:

Fig. 1 is an attenuation-frequency characteristic of

25 a trap circuit having two traps;

Fig. 2 is diagonal view of a prior art BGS wave resonator utilizing the free-edge surface reflection;

Figs. 3a and 3b are graphs showing the attenuation-frequency and the impedance-frequency characteristics

30 of the surface wave resonator shown in Fig. 2;

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Fig. 4 is a plan view of a piezoelectric resonator according to a first embodiment of this invention;

Fig. 5 is a diagonal view of the piezoelectric resonator shown in Fig. 4;

- 5 Fig. 6 is a graph of the attenuation-frequency characteristic of the piezoelectric resonator shown in Figs. 4 and 5;

- Fig. 7 is a graph of the impedance-frequency characteristic of the piezoelectric resonator shown
10 in Figs. 4 and 5;

Fig. 8 is a plan view of a piezoelectric resonator according to a second embodiment of this invention;

Fig. 9 is a plan view of a piezoelectric resonator according to a third embodiment of this invention;

- 15 Fig. 10 is a plan view of a piezoelectric resonator according to a fourth embodiment of the invention for forming a trap circuit with improved attenuation;

Fig. 11 is a circuit diagram of a trap circuit using a piezoelectric resonator shown in Fig. 10;

- 20 Fig. 12 is a graph showing the attenuation-frequency characteristic of the trap circuit shown in Fig. 11;

Fig. 13 is a circuit diagram of another trap circuit using a piezoelectric resonator shown in Fig. 10;

- Fig. 14 is a graph showing the attenuation-frequency
25 characteristic of the trap circuit shown in Fig. 13;

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Fig. 15 is a circuit diagram of still another trap circuit using a piezoelectric resonator shown in Fig. 10; and

Fig. 16 is a graph showing the attenuation-frequency characteristic of the trap circuit shown in Fig. 15.

Throughout herein, components which are substantially the same or at least equivalent to each other are indicated by the same numerals and not described repetitiously.

10 DETAILED DESCRIPTION OF THE INVENTION

In what follows, the invention will be described by way of examples but these examples are not intended to limit the scope of the invention.

Figs. 4 and 5 show a piezoelectric resonator 11 according to a first embodiment of this invention, comprising a piezoelectric substrate 12 having a rectangular plane and made of an appropriate piezoelectric material such as piezoelectric ceramics like lead zirconate titanate. The piezoelectric substrate 12 is subjected to a polarization process in the direction shown by arrow P, parallel to its main surface and also to the direction in which electrode fingers, to be explained below, are extended.

25 An interdigital transducer (hereinafter abbreviated as IDT) 15 comprising a pair of mutually interlocking thinned-out comb-shaped electrodes 13 and 14 is formed on the upper surface of the piezoelectric substrate 12. The comb-shaped electrodes 13 and 14 respectively have a plurality of electrode fingers 13a-13d and 14a-14i opposite to and in the direction of P. It is to be noted in Figs. 4 and 5 that,



although these electrode fingers 13a-13d and 14a-14i are in a mutually interlocking formation, those 13a-13d extending from one of the electrodes (13) and those 14a-14i extending from the other (14) are not
5 designed to appear alternately as one moves transversely to the direction of extension of the fingers. In other words, the IDT 15 may be described as being formed by thinning out (or removing) some of the fingers from two regular comb-shaped electrodes
10 interlocked with each other such that the fingers extending therefrom are originally arranged alternately.

Described more in detail, the electrode 13 as shown in Figs. 4 and 5 may be considered to have its
15 fingers thinned out between the fingers 14c and 14g. Of the regions between two mutually adjacent fingers, let "1" denote those between two fingers adapted to be connected to different voltages and "0" denote those between two fingers adapted to be connected to
20 the same voltage. In other words, when different voltages are applied to the two comb-shaped electrodes 13 and 14, Regions 1 are where BGS waves are excited and Regions 0 are where BGS waves are not excited. The twelve regions between the fingers 14a
25 and 14i of the piezoelectric resonator 11 are denoted sequentially as 1, 1, 1, 1, 0, 0, 0, 0, 1, 1, 1, 1.

The fingers 13a-13d and 14a-14i are so designed that each region between a mutually adjacent pair of fingers has the same width equal to one quarter of
30 the wavelength λ of the BGS wave to be excited, that the width of every finger except the outermost fingers 14a and 14i is also $\lambda/4$, and that the width of the outermost fingers 14a and 14i is $\lambda/8$. The outermost fingers 14a and 14i are formed on the edges
35 of the upper surface and mutually opposite side end

surfaces 12a and 12b of the piezoelectric substrate 12. Comb-shaped electrodes as described above can be produced, for example, by forming many fingers of width $\lambda/4$ at a pitch of also $\lambda/4$ on a piezoelectric substrate which is wider than the required piezoelectric substrate 12 and dicing the piezoelectric substrate such that the width of the outermost electrodes 14a and 14i will be halved.

The piezoelectric resonator 11, as described above, excites BGS waves propagating perpendicularly to the direction of extension of the fingers 13a-13d and 14a-14i of its comb-shaped electrodes 13 and 14 when an AC voltage is applied to it through the electrodes 13 and 14. These BGS waves are reflected between the edge surfaces 12a and 12b. In other words, the piezoelectric resonator 11 is a surface wave resonator of an end surface reflection type using BGS waves, like the prior art resonator 1 shown in Fig. 2. Its attenuation-frequency characteristic and impedance-frequency characteristic are shown in Figs. 6 and 7, respectively. Figs. 6 and 7 clearly show that the piezoelectric resonator 11 has two resonant frequencies f_{r1} and f_{r2} , that is, it has two resonance characteristics. It is because the IDT 15 is formed with thinned-out electrodes. In other words, two main lobes can be provided, determined by such an IDT 15.

According to a preferred embodiment of this invention, the frequency difference between the two resonant frequencies f_{r1} and f_{r2} is about 8MHz. In other words, this invention makes it possible to obtain two resonance characteristics with a much larger frequency difference than in the case of double-mode resonator filters using the Rayleigh wave, as described above. This is probably because

two main lobes of the frequency spectrum determined by the IDT could be provided. Accordingly, the present invention makes it possible to provide piezoelectric resonators with two resonant
5 frequencies with a relatively large appropriate frequency difference by adjusting the material and the dimensions of the piezoelectric substrate, as well as the shape of the thinned-out electrodes and the dimensions of the fingers of the IDT. In short,
10 the piezoelectric resonator 11 can be used effectively as a trap filter in the intermediate picture frequency section for a television receiver or a video tape recorder. In other words, it can be used as a single trap chip having two trap
15 frequencies.

Fig. 8 shows another piezoelectric resonator 21 according to a second embodiment of the invention. It has an IDT 25 formed with two thinned-out comb-shaped electrodes 23 and 24. It is structured
20 substantially in the same way as the first embodiment described above except in the manner in which the "thinning out" is carried out. In what follows, therefore, only the structure of the IDT 25 will be described, the components which are the same as in
25 the first embodiment being indicated by the same numerals.

The electrodes 23 and 24 have two fingers 23a-23b and nine fingers 24a-24i, respectively, with a total of ten regions defined between mutually adjacent pairs
30 of these fingers 23a, 23b and 24a-24i. The types of these regions are sequentially 0, 0, 0, 1, 1, 1, 1, 0, 0, 0 from one end to the other.

By designing the piezoelectric resonator 21 such that the frequency of the main lobe determined by the IDT

25 and the frequency determined by the distance between the two side edge surfaces 12a and 12b are farther separated, it was determined not only that there were two resonant frequencies but that their
5 difference was 8.6MHz. The difference between the two resonant frequencies can be adjusted by thinning out the fingers differently from the two comb-shaped electrodes 23 and 24 forming the IDT 25, although the difference between the two resonant frequencies
10 cannot be uniquely determined because it depends not only on the manner in which fingers are thinned out from the comb-shaped electrodes but also on other factors such as the distance between the side edge surfaces 12a and 12b, the material of the
15 piezoelectric substrate and the size of the fingers. It is possible, however, to adjust such factors appropriately according to the purpose for which the resonator is to be used.

Fig. 9 shows still another piezoelectric resonator 31
20 according to a third embodiment of the invention, also using a piezoelectric substrate 32 with a rectangular planar surface to form a surface wave resonator using BGS waves reflected at its side edge surfaces 32a and 32b. The piezoelectric substrate 32
25 is uniformly polarized in the direction of arrow P and a pair of comb-shaped electrodes 33 and 34 are formed on its rectangular planar surface as according to the first and second embodiments of the invention described above.

30 The third embodiment is distinguishable from the first and second embodiments of the invention in that neither of the pair of comb-shaped electrodes 33 and 34 has its fingers "thinned out", that the fingers of the two electrodes 33 and 34 are aligned and protrude
35 directly towards each other and that the lengths of

these fingers vary such that the lengths (in the direction of the fingers) of the regions each sandwiched between a mutually adjacent pair of fingers of the different electrodes 33 and 34 (where surface waves are adapted to be excited) vary in the direction of propagation of the surface waves. Piezoelectric resonators thus structured, too, have been found to have two resonant frequencies. It was ascertained that the difference between the two resonant frequencies could be about 9.2MHz. The attenuation-frequency and impedance-frequency characteristics of a piezoelectric resonator according to the third embodiment of the invention was found to be similar to those shown in Figs. 6 and 7.

Although this invention has been described above with reference to examples using BGS waves as an example SH type surface waves, it is not intended to limit the scope of the invention. Use may be made equally well of other SH type surface waves, such as Love waves, to obtain a resonator with a plurality of resonant frequencies by forming an IDT with thinned-out electrodes or by varying the length of the regions where surface waves are excited.

With a piezoelectric resonator as described above, attenuation at the adjacent-channel picture carrier frequency f_{ap} and the adjacent-channel sound carrier frequency f_{as} is respectively about 13dB and 15dB. The present invention further relates to trap circuits using piezoelectric resonators according to this invention and having improved attenuation capabilities.

Fig. 10 shows still another piezoelectric resonator 51 according to a fourth embodiment of the invention

for forming a trap circuit with improved attenuation capability. Like the resonator described above with reference to Figs. 4 and 5, this piezoelectric resonator 51 is also comprised of a rectangular piezoelectric substrate 52 of a piezoelectric material such as piezoelectric ceramics like lead zirconate titanate or piezoelectric single crystals of LiNbO_3 or LiTaO_3 . If it is made of a piezoelectric ceramic material, it is polarized in the direction of arrow P. A pair of IDTs (herein referred to as "the first IDT 53" and "the second IDT 54") is formed on the upper surface of the piezoelectric substrate 52. Each of them is comprised of a pair of comb-shaped electrodes having a plurality of fingers extending in the direction of P or opposite thereto. One of the pair of comb-shaped electrodes of the first IDT 53 is comprised of a plurality of fingers 53a and a first connector electrode 55 which is formed along one of the side edges of the piezoelectric substrate 52. The other of the pair of comb-shaped electrodes of the first IDT 53 is comprised of a plurality of fingers 53b all connected to a common connector electrode 56. Another plurality of fingers 54a protrude from the common connector electrode 56 in a direction away from the first connector electrode 55 and form, together with the central connector electrode 56, one of the pair of comb-shaped electrodes of the second IDT 54. The other of the pair of comb-shaped electrodes of the second IDT 54 is comprised of a plurality of fingers 54b all connected to a second connector electrode 57 which is formed along the side edge of the piezoelectric substrate 52 opposite the first connector electrode 55. These three connector electrodes 55, 56 and 57 are connected to terminals a, b and c, respectively, for application of voltages.

Although the fingers 53a, 53b, 54a and 54b forming the two IDTs 53 and 54 are only schematically drawn in Fig. 10, it is to be understood that the fingers for each IDT are formed as explained above for the first embodiment of the invention with reference to Figs. 4 and 5. In other words, for example, the fingers 53a, 53b, 54a and 54b are each of width equal to $\lambda/4$ except that outermost ones of each of the IDTs 53 and 54 are of width equal to $\lambda/8$ and are arranged at a pitch of $\lambda/4$ on the piezoelectric substrate 52 where λ indicates the wavelength of the surface wave to be excited.

Each of the two resonant units formed by the two IDTs 53 and 54 functions like a piezoelectric resonator according to the first embodiment of the invention described above, having two resonance characteristics. In other words, it may be interpreted that resonators according to the fourth embodiment of the invention can be formed from a resonator according to the first embodiment of the invention by forming a central connector electrode 56 transversely to the fingers at the center. The lengths of the fingers in each IDT are adjusted such that the IDTs 53 and 54 will each have two resonance characteristics.

As shown in Fig. 11, a trap circuit for a television video receiver was formed by connecting the terminals a and c of Fig. 10 between an input terminal IN and an output terminal OUT and the terminal b to the ground. In Fig. 11, numerals 58 and 59 indicate resonant units formed by the two IDTs 53 and 54. Inserted between the aforementioned piezoelectric resonator 51 and the input terminal IN was a first resistor 61. Inserted between the ground potential and a point between the input terminal IN and the

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first resistor 61 was a second resistor 62. Inserted between the piezoelectric resonator 51 and the output terminal OUT was a third resistor 63. Inserted between the ground potential and a point between the output terminal OUT and the third resistor 63 was a fourth resistor 64. Fig. 12, which is a graph of the attenuation-frequency characteristic of a trap circuit thus structured, clearly shows that two traps were formed at two frequencies f_{ap} and f_{as} and that attenuation was as large as 15dB and 17dB at these frequencies. It is to be noted, however, that attenuation was undesirably large around the picture carrier frequency f_p which, as shown in Fig. 12, is between the two trap frequencies f_{ap} and f_{as} and closer to the one at the higher frequency.

Next, an inductor 65 was inserted between the terminals a and c as shown by broken lines in Fig. 10 to form another trap circuit embodying the present invention, the terminal b being again connected to the ground potential as shown in Fig. 13. In other words, this trap circuit is identical to the one described above with reference to Fig. 11 except for the insertion of the inductor 65. Thus, the same symbols as used in Fig. 11 are used to indicate corresponding components of the trap circuit of Fig. 13. Fig. 14 is a graph of the attenuation-frequency characteristic of a trap circuit thus formed, showing that attenuation was respectively 22dB and 27.5dB at its two trap frequencies f_{ap} and f_{as} . This clearly shows that insertion of the inductor 65 between the terminals a and c of the piezoelectric resonator 51 has the effect of increasing the attenuation at the adjacent-channel picture and sound frequencies by 9dB and 12.5dB. As can also be understood by comparing the graphs in Figs. 12 and 14, furthermore, the insertion of the inductor 65 has the effect of

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reducing attenuation at the picture carrier frequency, or that of preventing it from becoming large at the picture carrier frequency.

Still another trap circuit was formed as shown in Fig. 15, which is different from the circuit shown in Fig. 13 in that another inductor 60 was inserted between the terminal a and the input terminal IN. Fig. 16 is a graph of the attenuation-frequency characteristic of a trap circuit thus formed, showing that attenuation was respectively 26dB and 33dB at its two trap frequencies f_{ap} and f_{as} . This clearly shows that an insertion of the inductor 60 between the terminal a and the input terminal IN has the effect of further increasing the attenuation at the adjacent-channel picture and sound frequencies. Table 1 shows the magnitudes of attenuation by each of the three trap circuits described above (respectively with reference to Figs. 10-12, 13-14 and 15-16) at the adjacent-channel picture and sound carrier frequencies f_{ap} and f_{as} .

Table 1

	Attenuation at f_{ap} (dB)	Attenuation at f_{as} (dB)
Circuit of Fig. 11	15	17
Circuit of Fig. 13	22	27.5
Circuit of Fig. 15	26	33

Although only three trap circuits have been shown above as embodying the present invention, these embodiments are not intended to limit the scope of the invention. Many modifications and variations are possible within the scope of this invention. For

example, still another trap circuit was formed with an inductor (like the inductor 60 shown in Fig. 15) added between the terminal a and the input terminal IN of the circuit shown in Fig. 11 without any

5 inductor (such as the inductor 65 shown in Fig. 13 or 15) inserted between the terminals a and c of the resonator 51, and it was discovered by using such a trap circuit that the attenuation was 21dB and 24dB at the adjacent-channel picture and sound carrier

10 frequencies f_{ap} and f_{as} , respectively.

As another example, two piezoelectric resonators, as shown for example in Fig. 4, may be used in the examples given above in place of the piezoelectric resonator 51 according to the fourth embodiment of

15 the invention. In other words, two piezoelectric resonators 11 described above may be used to serve as the two resonant units 58 and 59 shown in Figs. 11, 13 and 15, an inductor being connected therebetween (like the inductor 65 shown in Figs. 13 and 15)

20 and/or another like the inductor 60 shown in Fig. 15. Attenuation at the two trap frequencies can be thereby effectively improved in a similar manner. Although the use of a piezoelectric resonator according to the fourth embodiment of the invention

25 is advantageous because the circuit structure can be thereby simplified because the resonant units are formed on a single chip, it is feasible according to



the present invention to use two resonators using SH type surface waves in order to form a trap circuit with greater attenuation than was possible with prior art LC resonance circuits.

5 When two resonators are used in place of a single resonator 51 according to the fourth embodiment of the invention, as discussed above, these two resonators need not be resonators according to the first embodiment of the invention described above
10 with reference to Figs. 4 and 5. Still another trap circuit was formed, similar to the one described above with reference to Fig. 11 but using two resonators 31 according to the third embodiment of the invention to serve as the two resonant units 58
15 and 59 of Fig. 11, and it was discovered that the difference between the two resonant frequencies could also be increased to about 8MHz.

In summary, all such modifications and variations that may be apparent to a person skilled in the art
20 are intended to be included within the scope of the invention.

As used herein the term 'SH type surface waves' means shear horizontal type surface waves.





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WHAT IS CLAIMED IS:

1. A piezoelectric resonator using SH type surface waves, said resonator comprising:
a piezoelectric substrate; and
5 an interdigital transducer which is formed on said substrate and has at least two resonance characteristics.
2. The piezoelectric resonator of claim 1 wherein said interdigital transducer comprises a pair
10 of thinned-out comb-shaped electrodes each having a plurality of fingers protruding towards the other electrode, said fingers from said pair of electrodes being in mutually interlocking formation, at least one mutually adjacent pair of the fingers of one of
15 said electrodes sandwiching therebetween two or more of the fingers of the other of said electrodes.
3. The piezoelectric resonator of claim 1 wherein said interdigital transducer comprises a pair of comb-shaped electrodes each having a plurality of
20 parallel fingers protruding in rows towards the other electrode, each of the fingers from one of the electrodes being aligned with one of the fingers from the other electrode, the lengths along said fingers of regions where surface waves can be excited upon
25 application of a voltage across said electrodes varying over said rows.

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4. The piezoelectric resonator of claim 2
wherein each of said fingers except those at both
ends of said piezoelectric substrate have width equal
to one-quarter of the wavelength of surface waves
5 excited in regions between said fingers and mutually
adjacent pairs of said fingers are separated by one-
quarter of said wavelength.
5. The piezoelectric resonator of claim 3
wherein each of said fingers except those at both
10 ends of said piezoelectric substrate have width equal
to one-quarter of the wavelength of surface waves
excited in regions between said fingers and mutually
adjacent pairs of said fingers are separated by one-
quarter of said wavelength.
- 15 6. The piezoelectric resonator of claim 1
comprising two interdigital transducers which are
formed on said piezoelectric substrate and are
connected to each other so as to form two resonant
units each having two resonance characteristics.
- 20 7. A trap circuit comprising a piezoelectric
resonator using SH type surface waves, said resonator
comprising:
a piezoelectric substrate; and
an interdigital transducer which is formed on
25 said substrate and has at least two trap frequencies.

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8. The trap circuit of claim 7 wherein said piezoelectric resonator comprises two interdigital transducers which are formed on said piezoelectric substrate and are connected to each other so as to
5 form two resonant units each having two resonance characteristics.

9. The trap circuit of claim 8 further comprising an inductor connected between said two resonant units.

10 10. The trap circuit of claim 8 wherein one of said interdigital transducers has a signal receiving terminal through which signals from an input terminal are adapted to be received by said trap circuit, said trap circuit further comprising an inductor connected
15 between said signal receiving terminal and said input terminal.

11. The trap circuit of claim 10 further comprising another inductor connected between said two resonant units.

20 12. The trap circuit of claim 7 comprising two piezoelectric resonators using SH type surface waves, said two resonators being both formed on said piezoelectric substrate, each having an interdigital

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transducer, being connected in parallel and providing two resonance characteristics.

13. The trap circuit of claim 12 further
5 comprising an inductor between said two piezoelectric resonators.

14. The trap circuit of claim 12 wherein one of said
two piezoelectric resonators has a signal receiving
10 terminal through which signals from an input terminal are adapted to be received by said trap circuit, said trap circuit further comprising an inductor connected between said signal receiving terminal and said input terminal.

15

15. The trap circuit of claim 14 further comprising another inductor connected between said two piezoelectric resonators.

20 16. A surface wave transducer device having at least two resonance characteristics.

17. A trap circuit comprising a surface wave transducer device in accordance with claim 16.

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18. A piezoelectric resonator substantially as hereinbefore described with reference to Figures 4 to 7,

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8, 9 or 10 of the accompanying drawings.



19. A trap circuit substantially as hereinbefore
described with reference to Figures 11 and 12, 13 and 14
5 or 15 and 16 of the accompanying drawings.

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ABSTRACT

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PIEZOELECTRIC RESONATORS

A single-chip piezoelectric resonator using SH type surface waves has an interdigital transducer formed on a piezoelectric substrate. The interdigital
5 transducer is designed to have two or more resonance characteristics, for example, by using a pair of thinned-out comb-shaped electrodes with mutually interlocking fingers protruding towards each other. Such an interdigital transducer may be formed also by
10 using a pair of comb-shaped electrodes with the lengths of their mutually pointing fingers varied. A trap circuit with two sufficiently separated trap frequencies and improved attenuation characteristics at these two trap frequencies can be formed by
15 two interdigital transducers of the kind described above on a single piezoelectric substrate so as to provide two resonant units each having two resonance characteristics.

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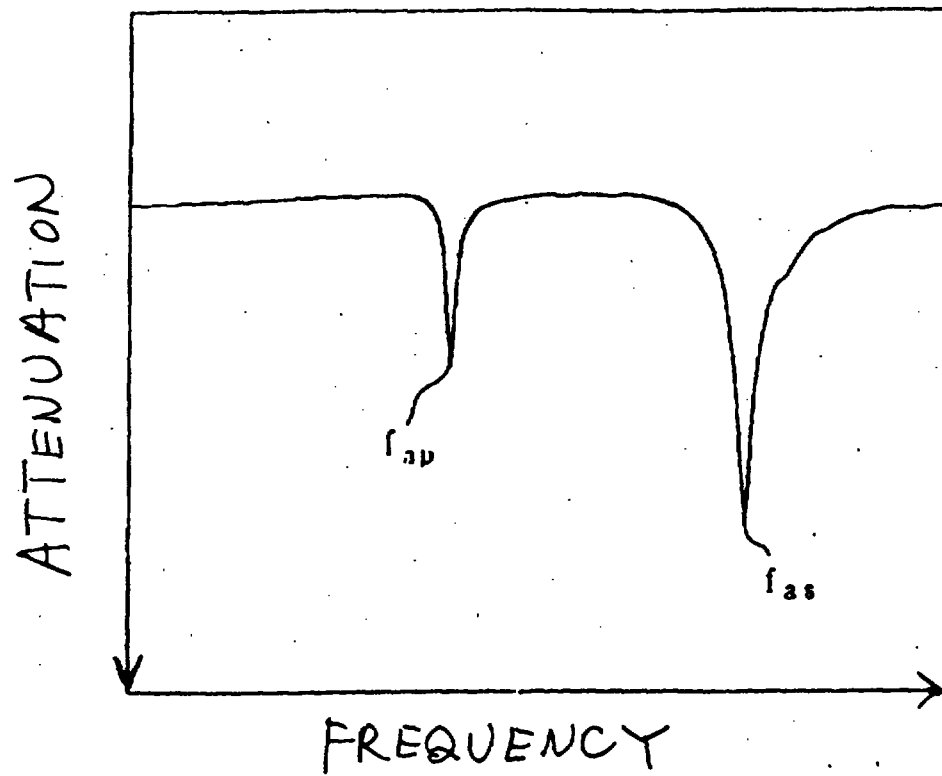
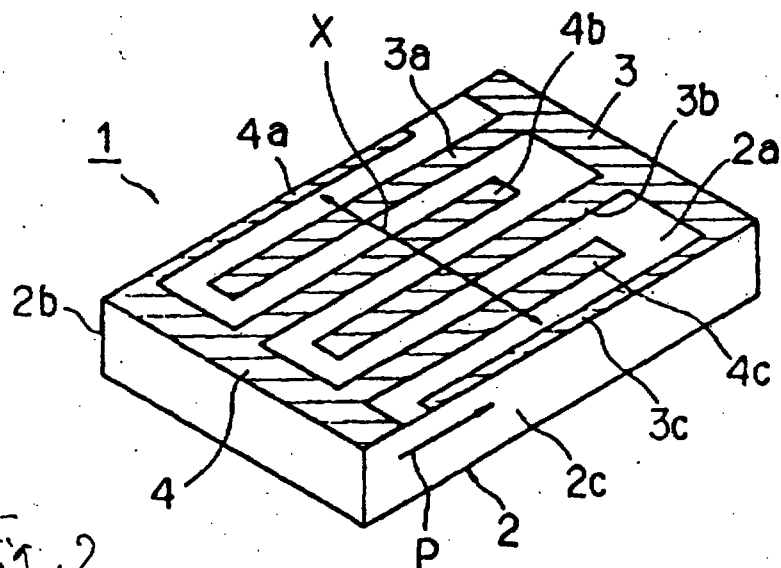
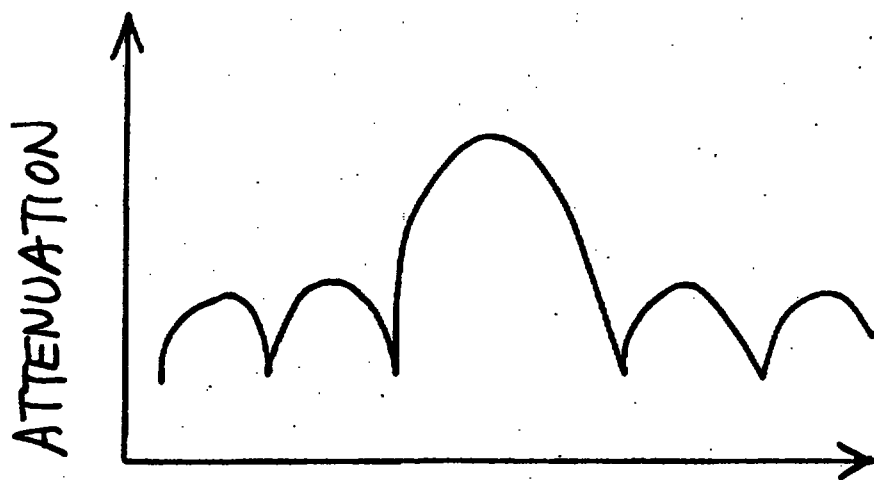


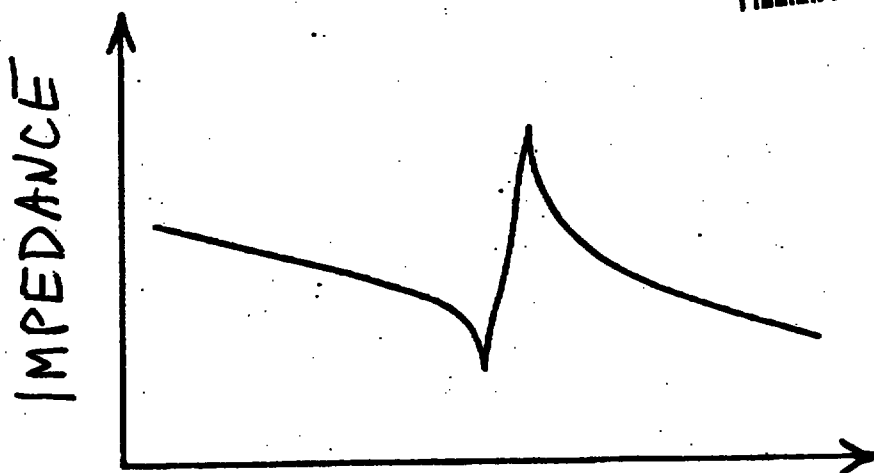
Fig. 1 (PRIOR ART)

Fig. 2
(PRIOR ART)



FREQUENCY

Fig. 3A (PRIOR ART)

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FREQUENCY

Fig. 3B (PRIOR ART)

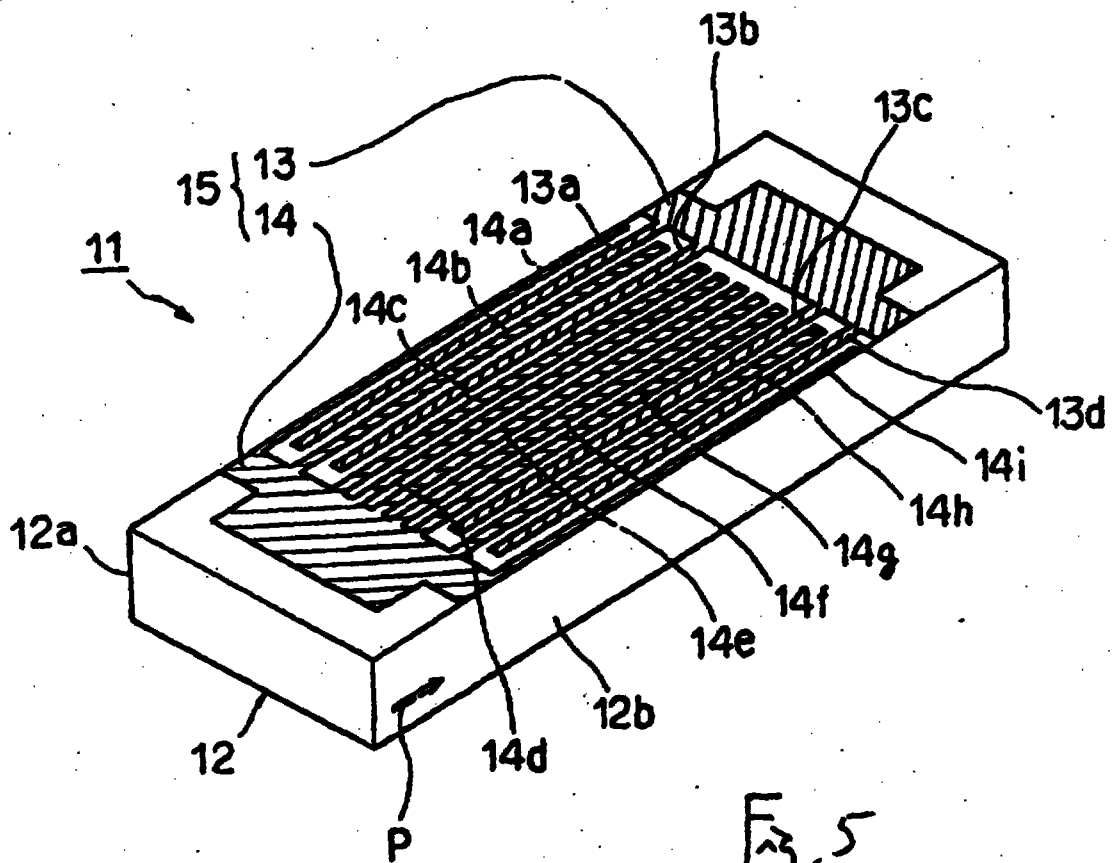


Fig. 5

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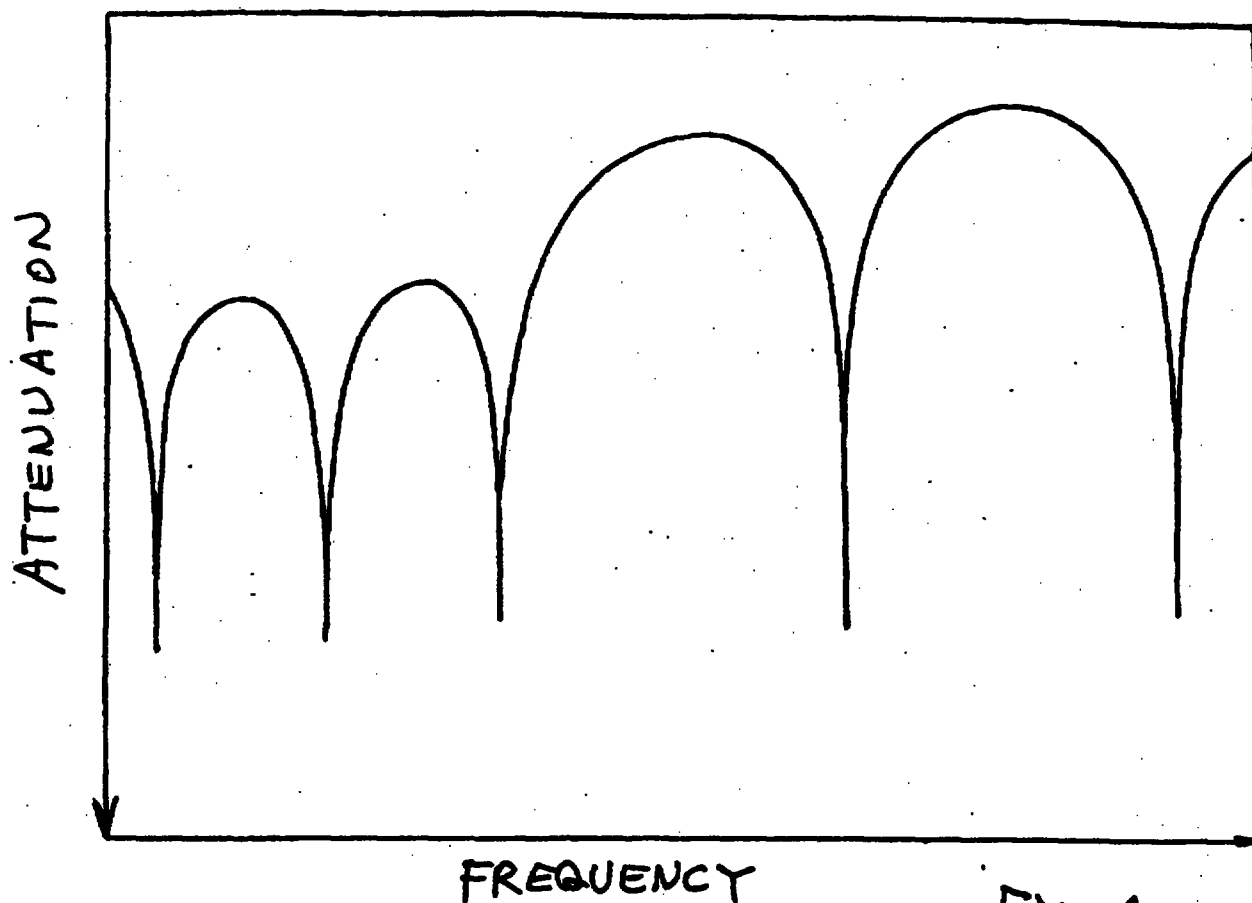
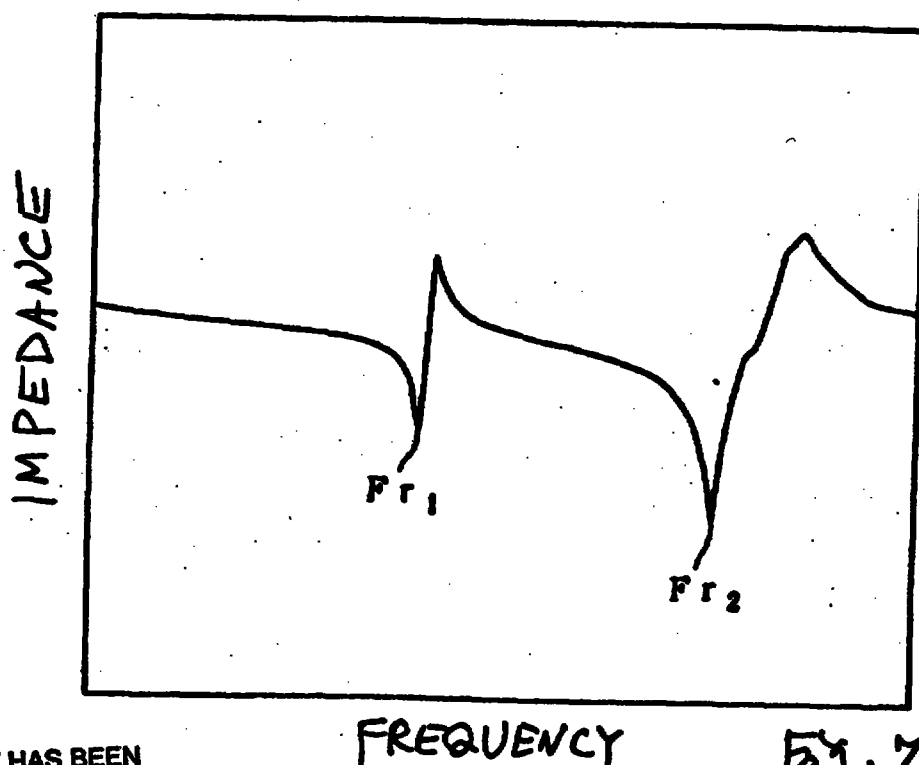


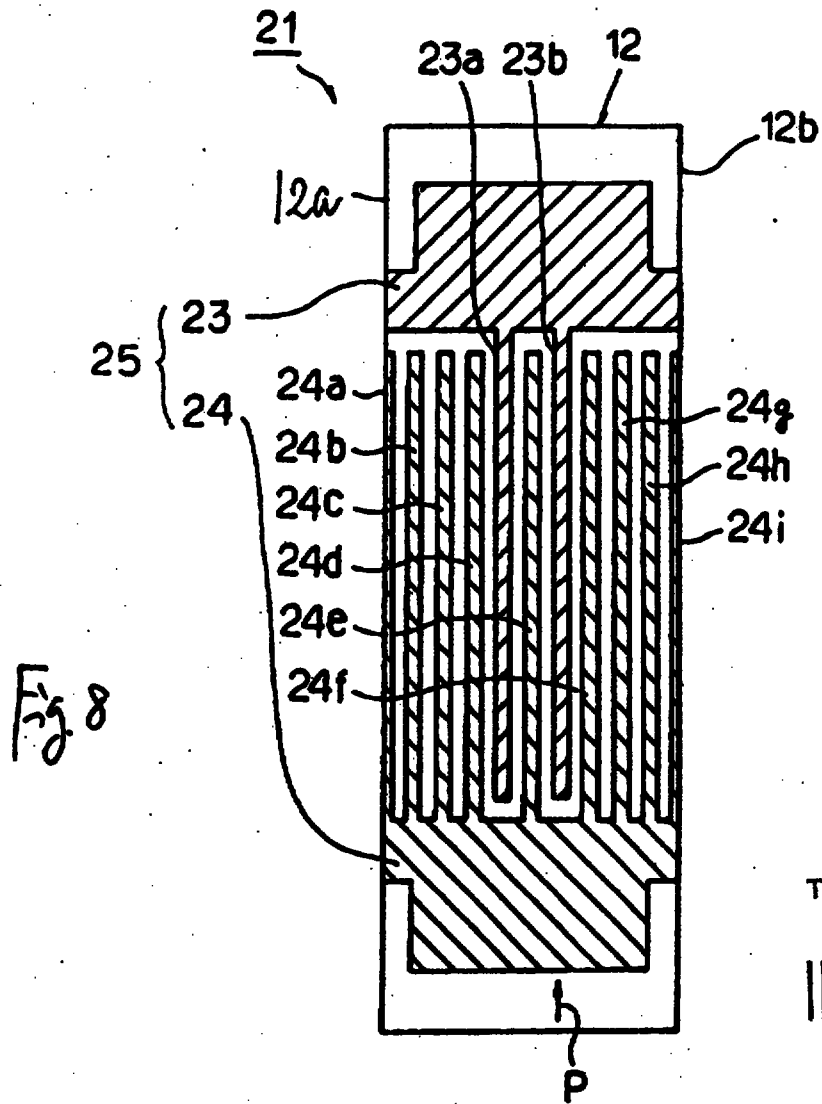
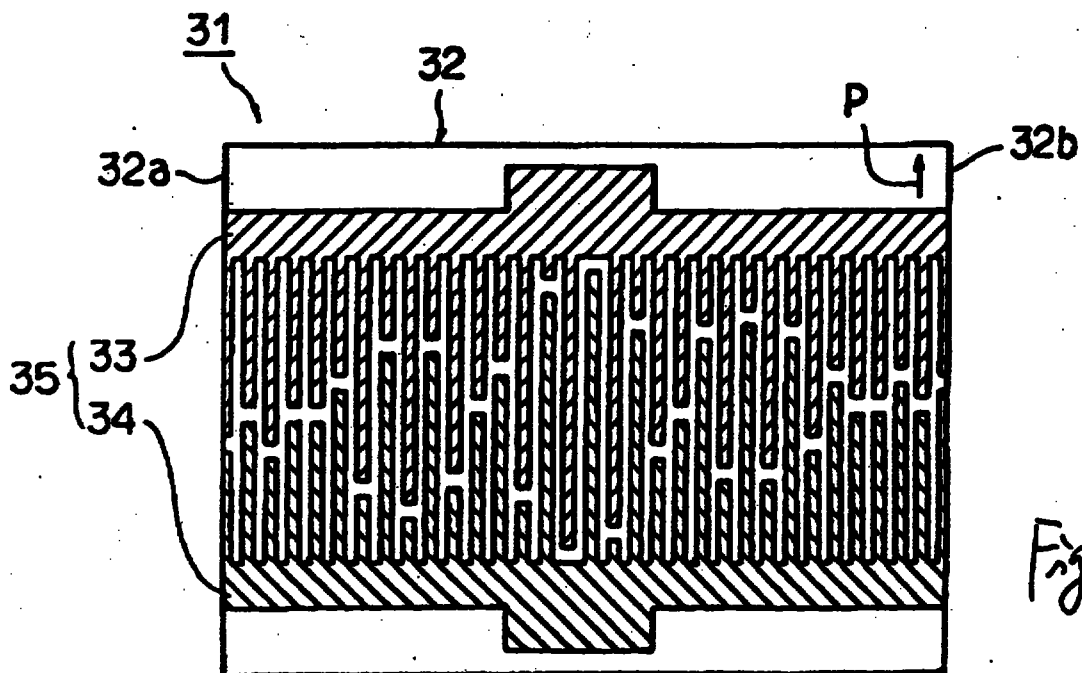
Fig. 6

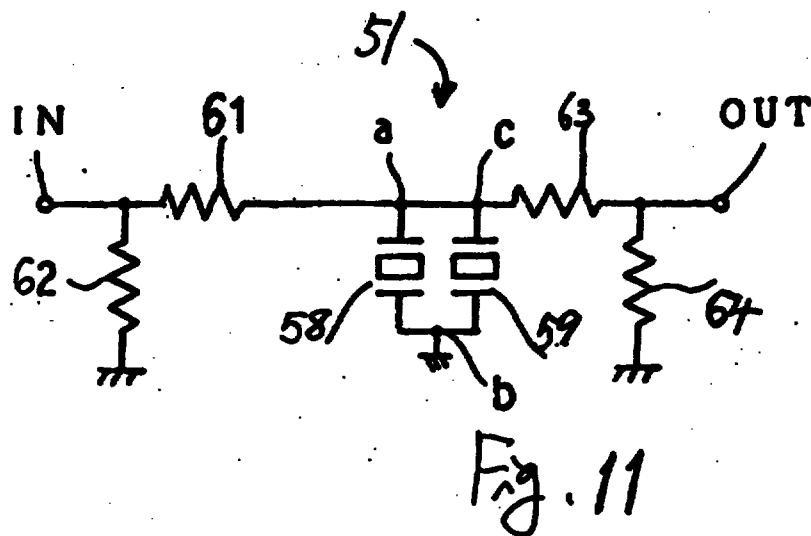
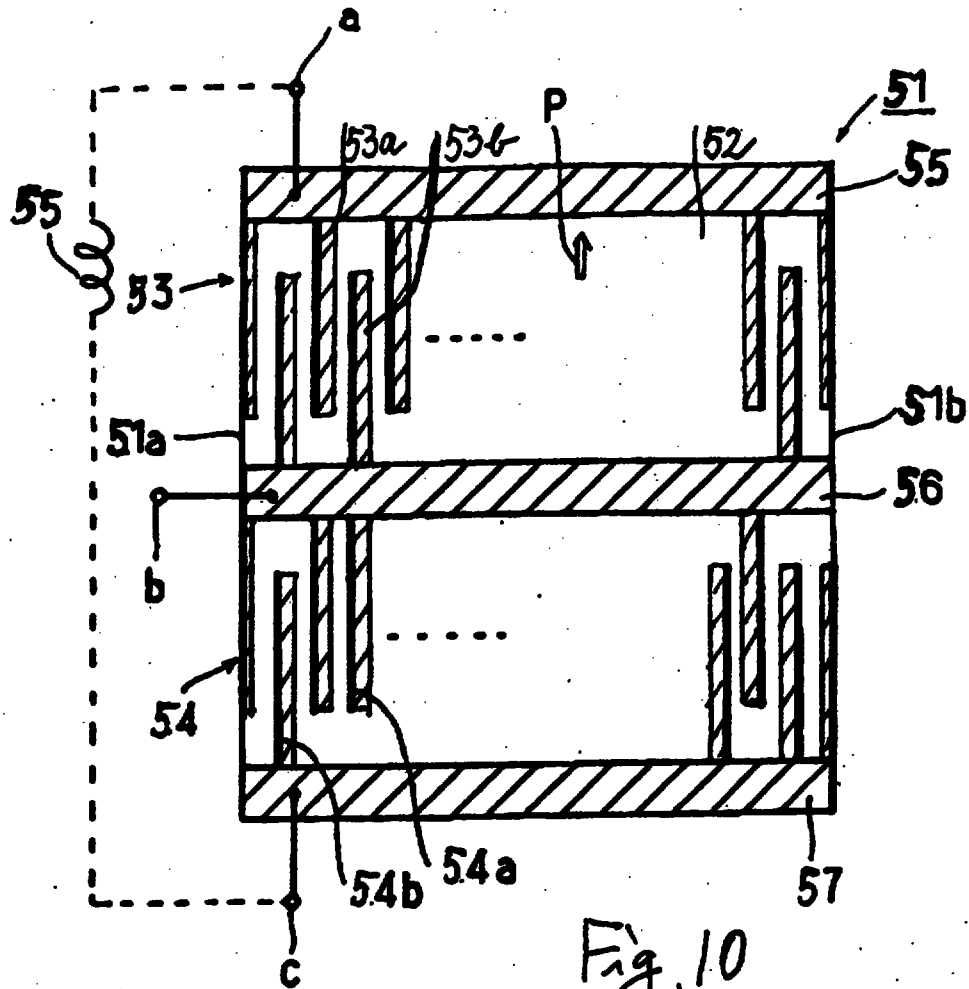


FREQUENCY

Fig. 7

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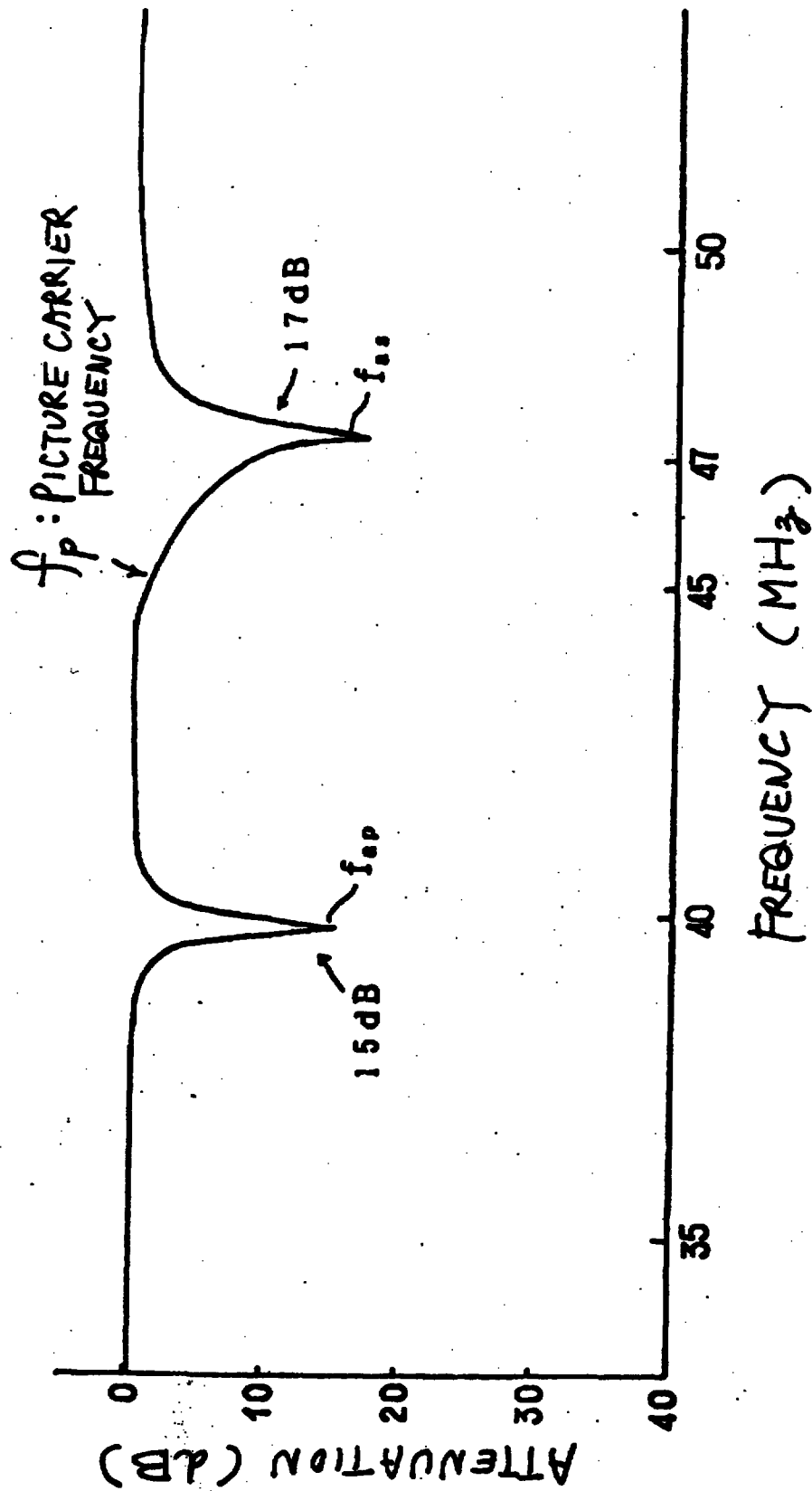


Fig. 12



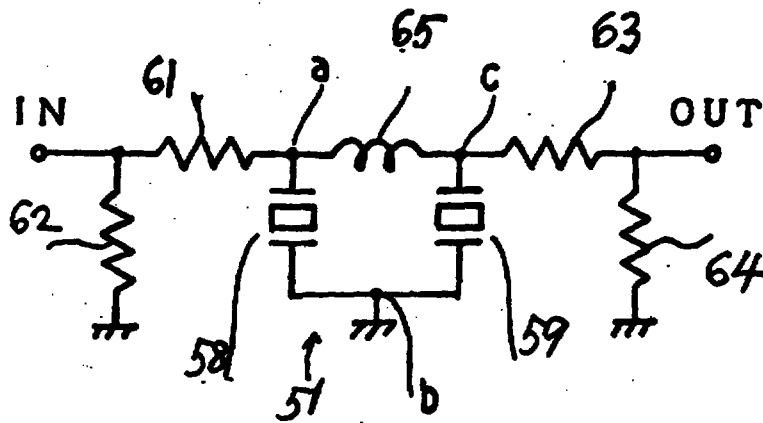


Fig 13

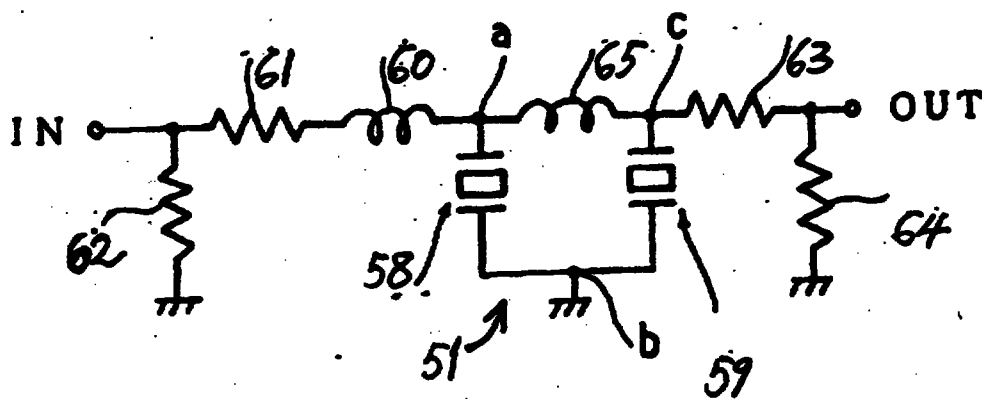


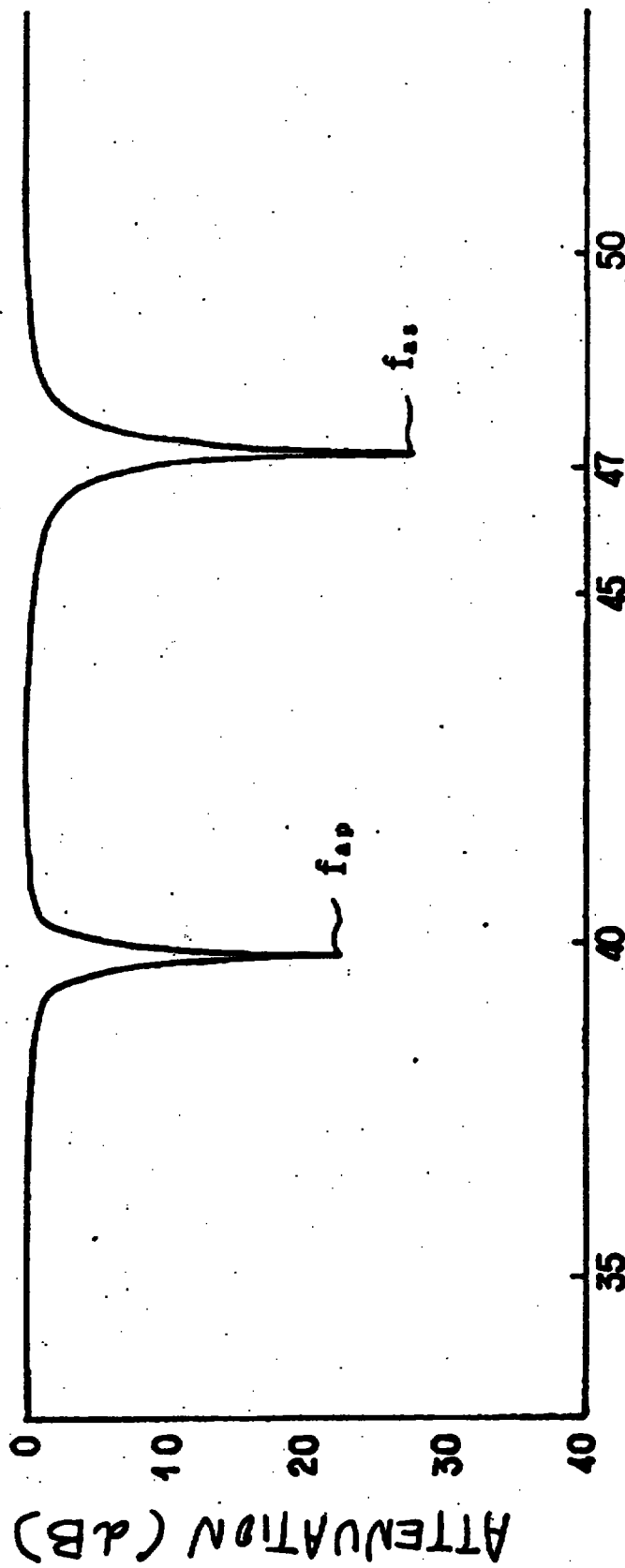
Fig - 15



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FREQUENCY (MHz)

Fig. 14

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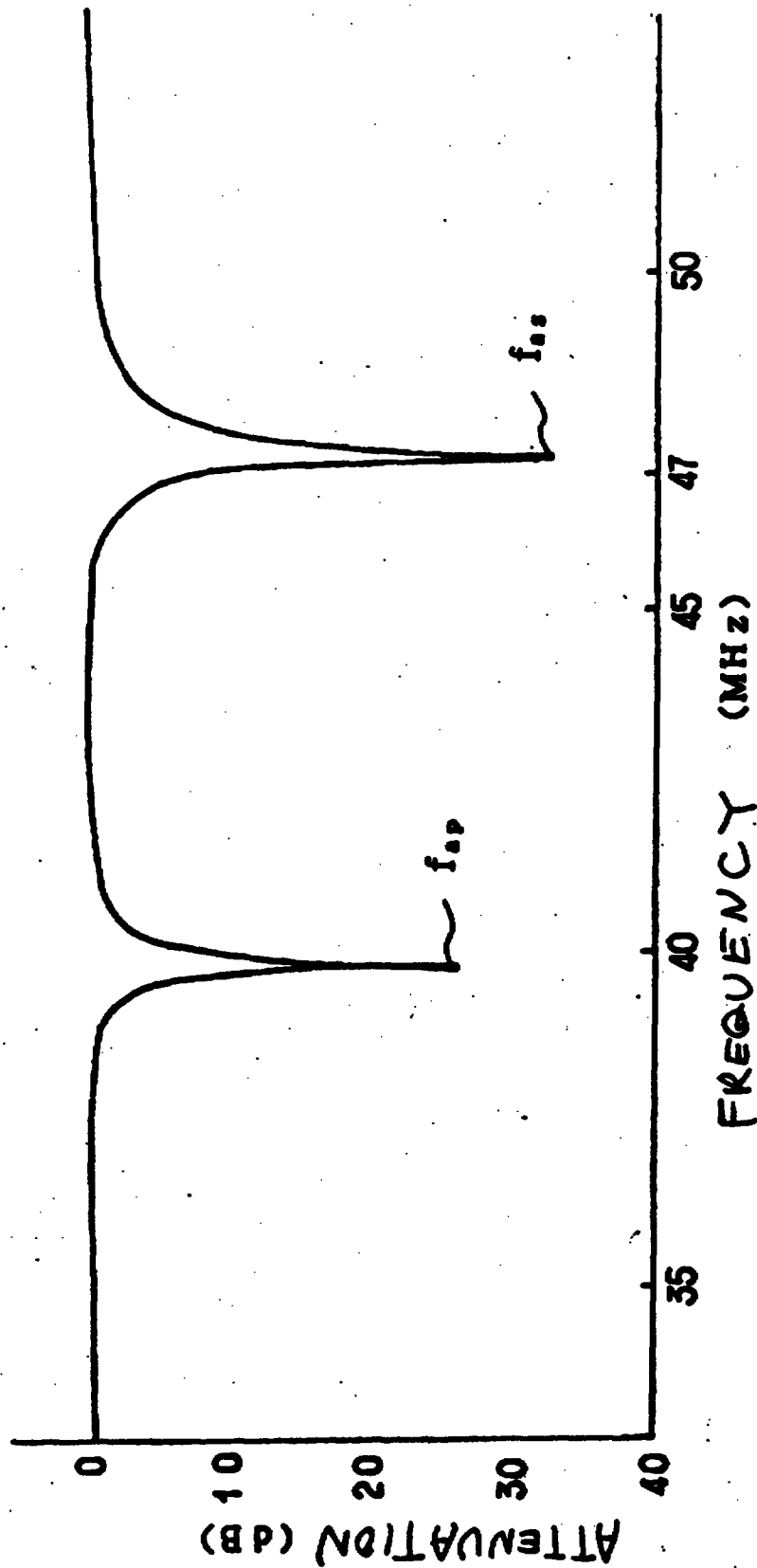


Fig-16

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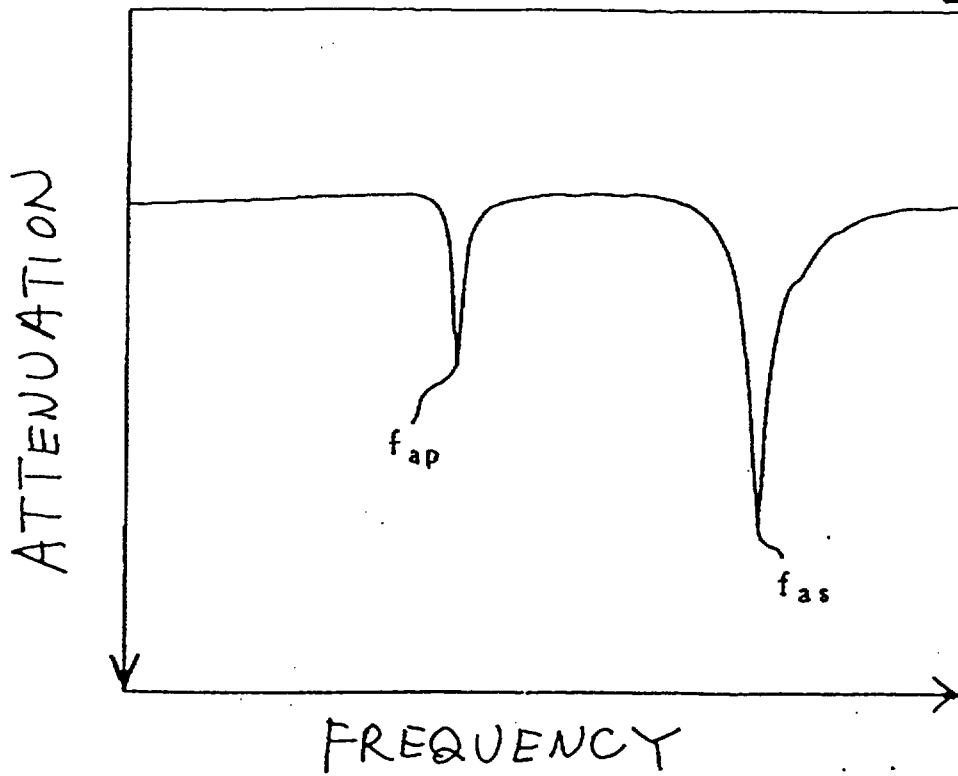


Fig. 1 (PRIOR ART)

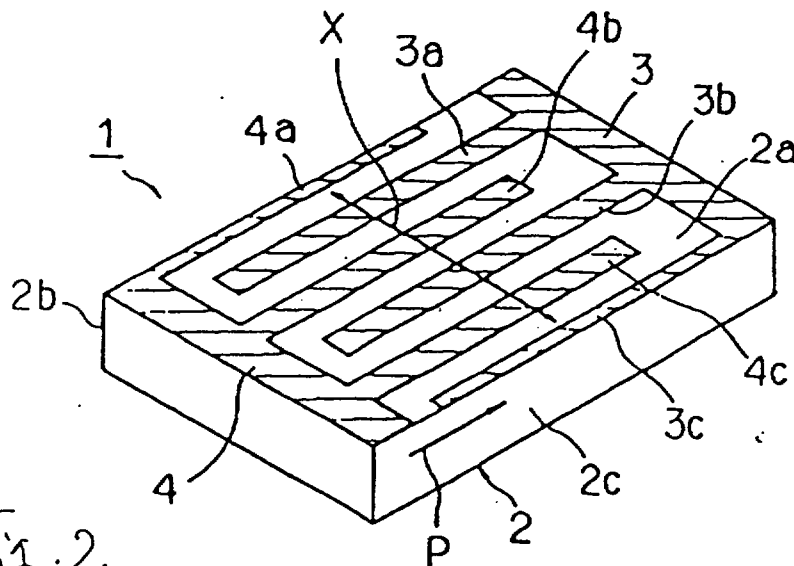


Fig. 2
(PRIOR ART)

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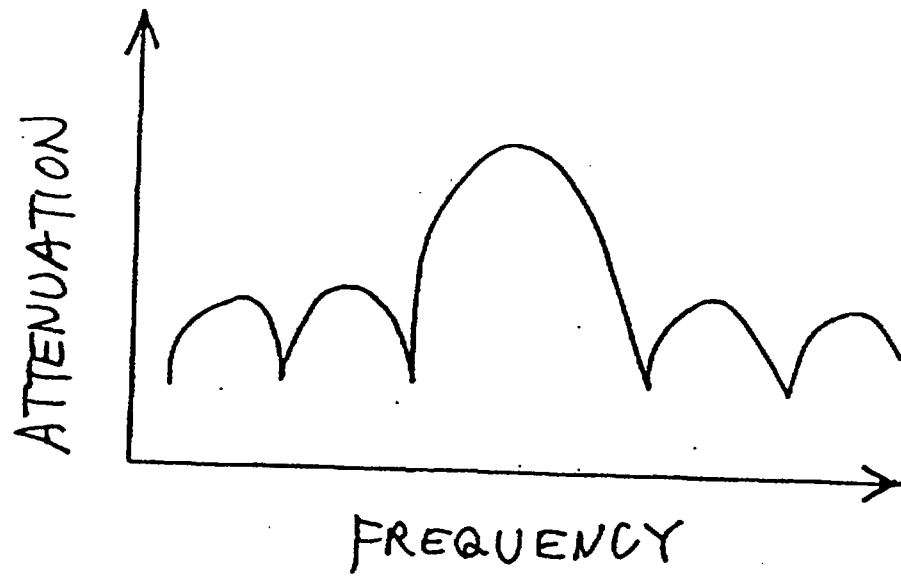


Fig. 3A (PRIOR ART)

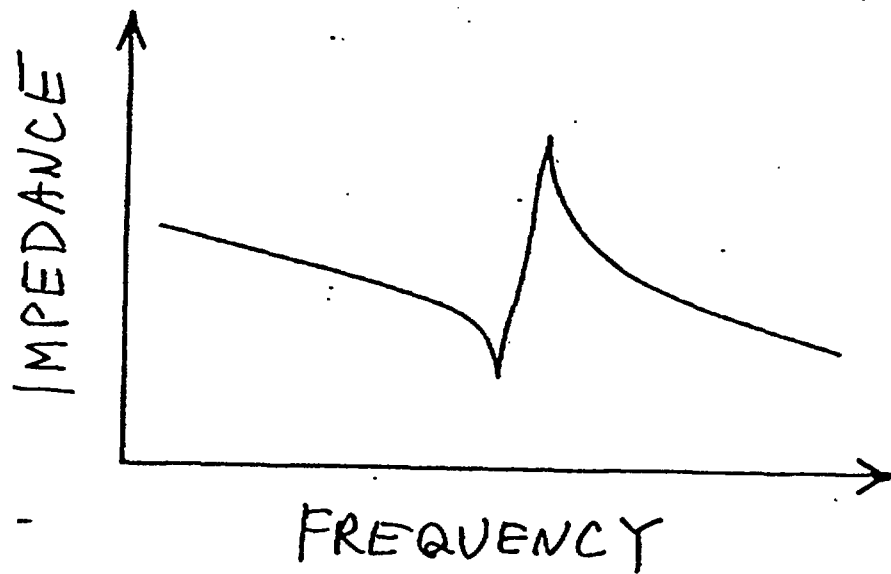


Fig. 3B (PRIOR ART)

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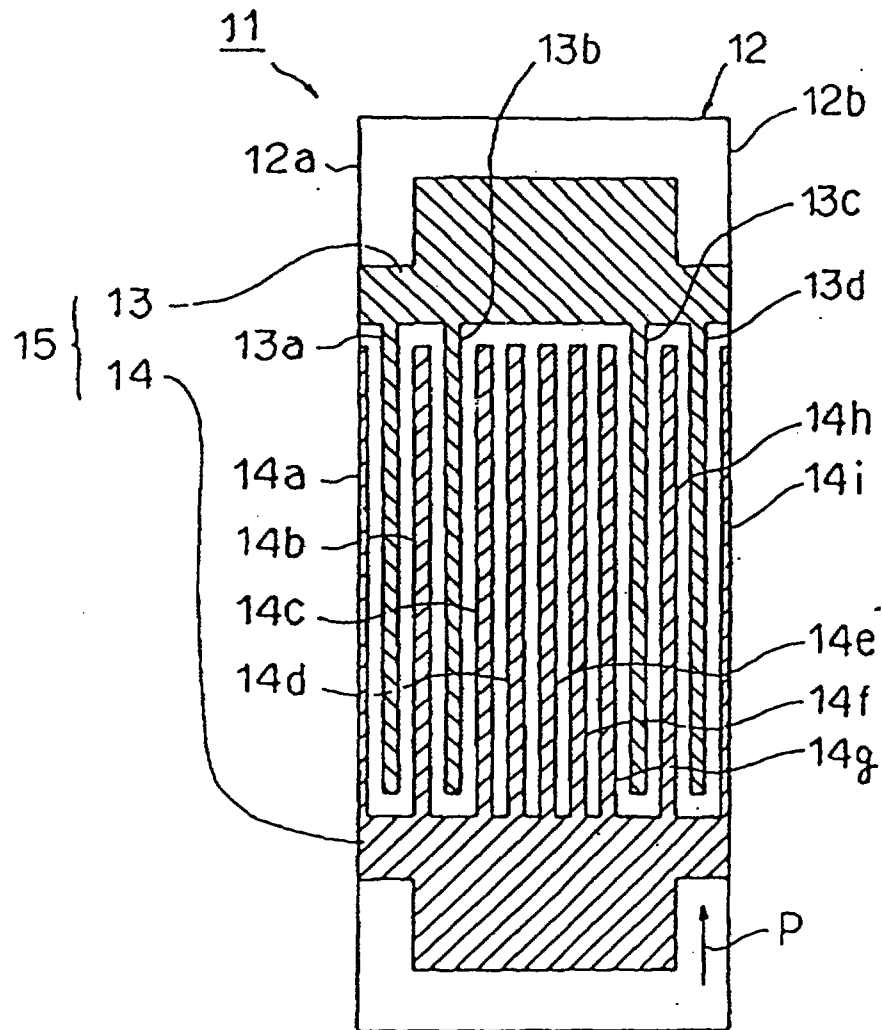


Fig. 4

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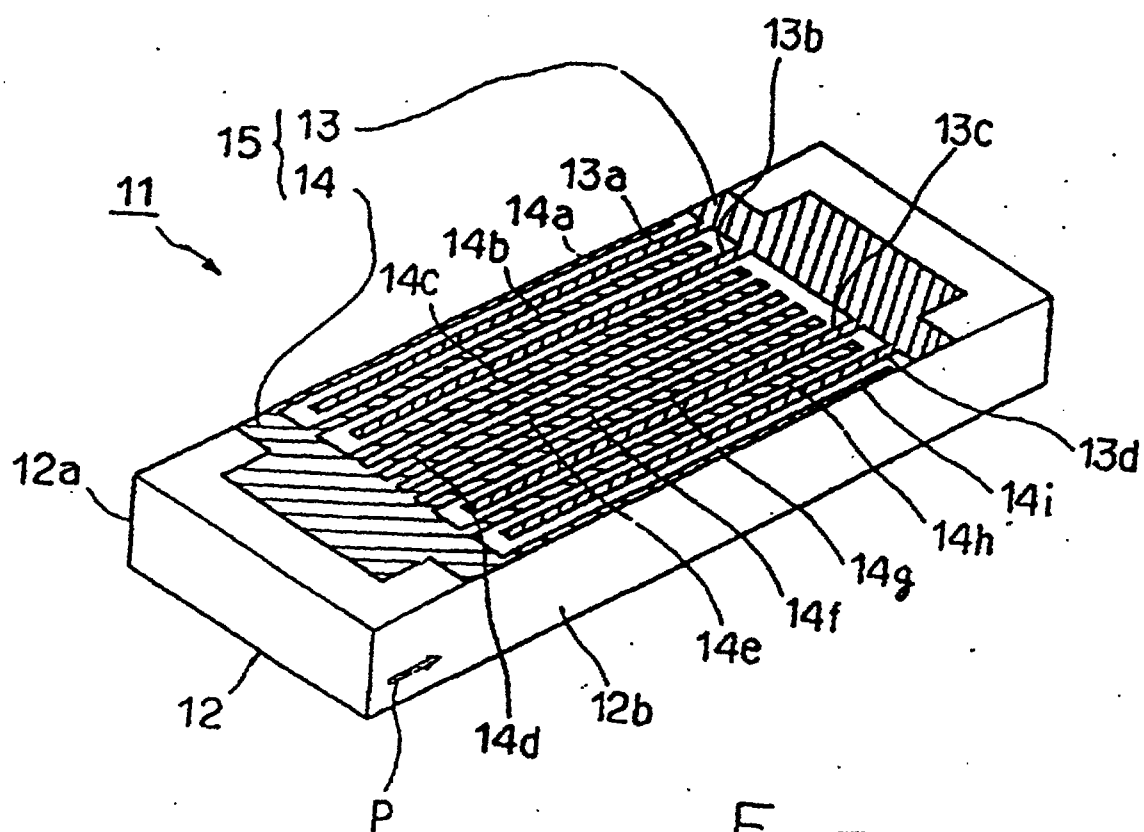


Fig. 5

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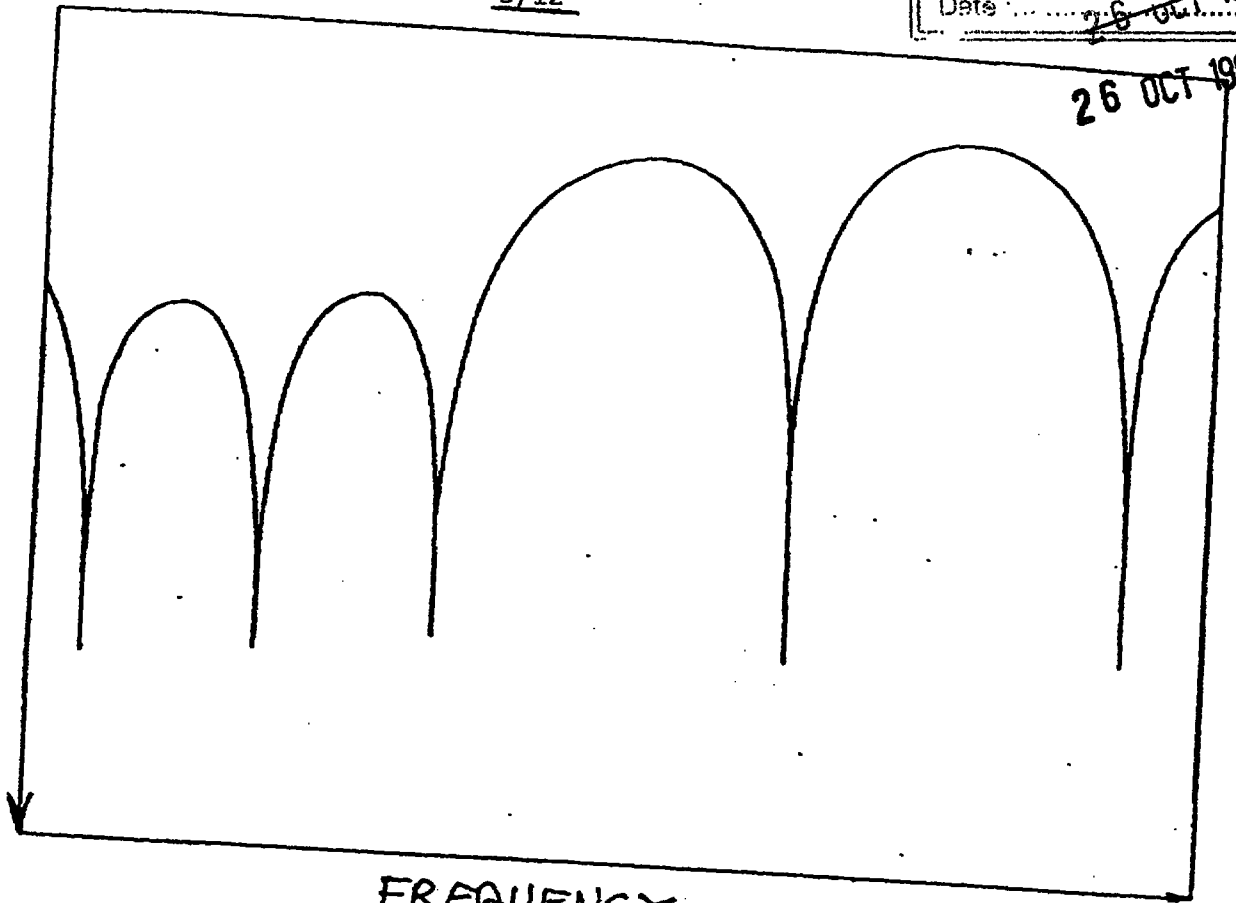
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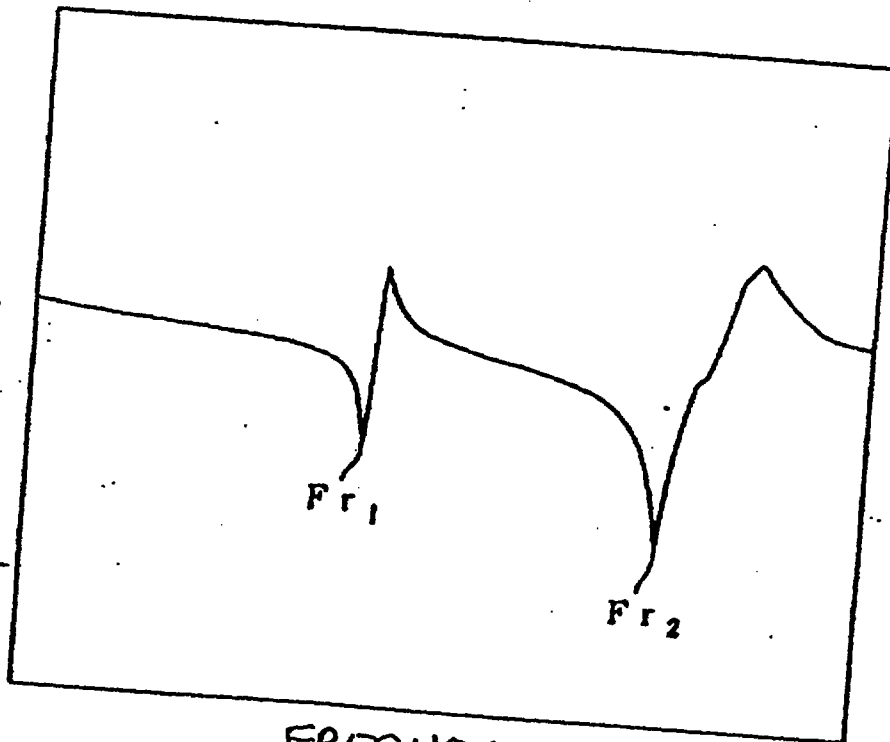
ATTENUATION



FREQUENCY

Fig. 6

IMPEDANCE



FREQUENCY

Fig. 7

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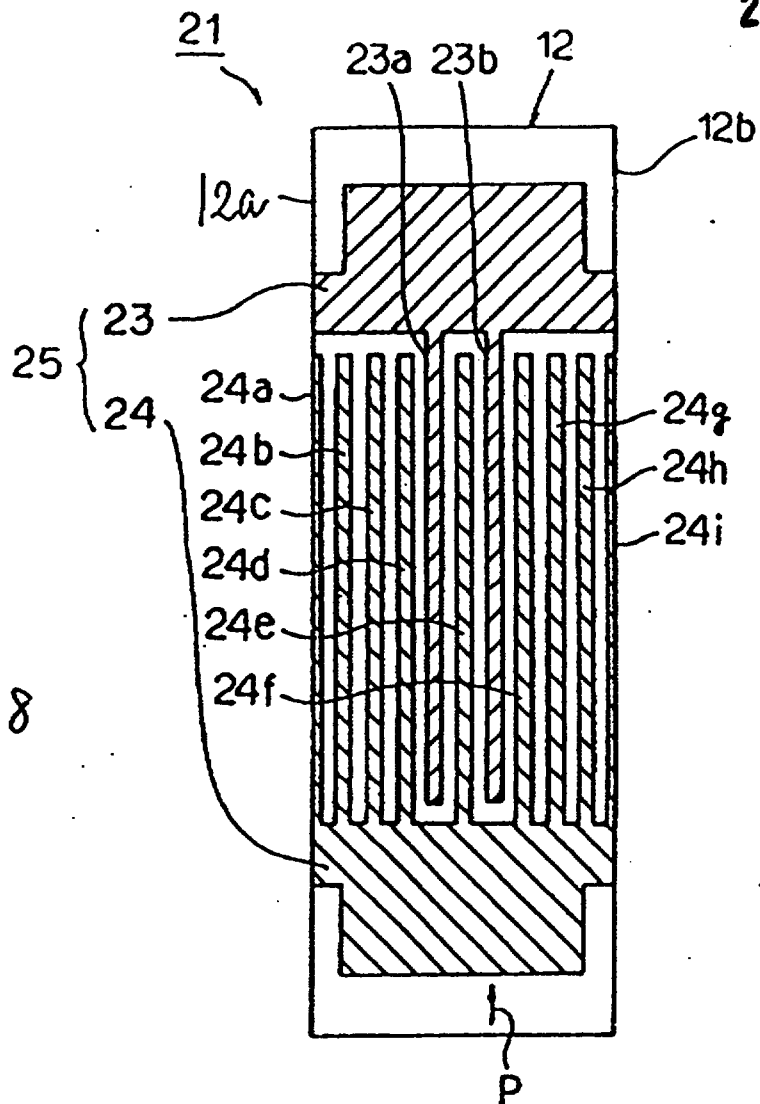


Fig. 8

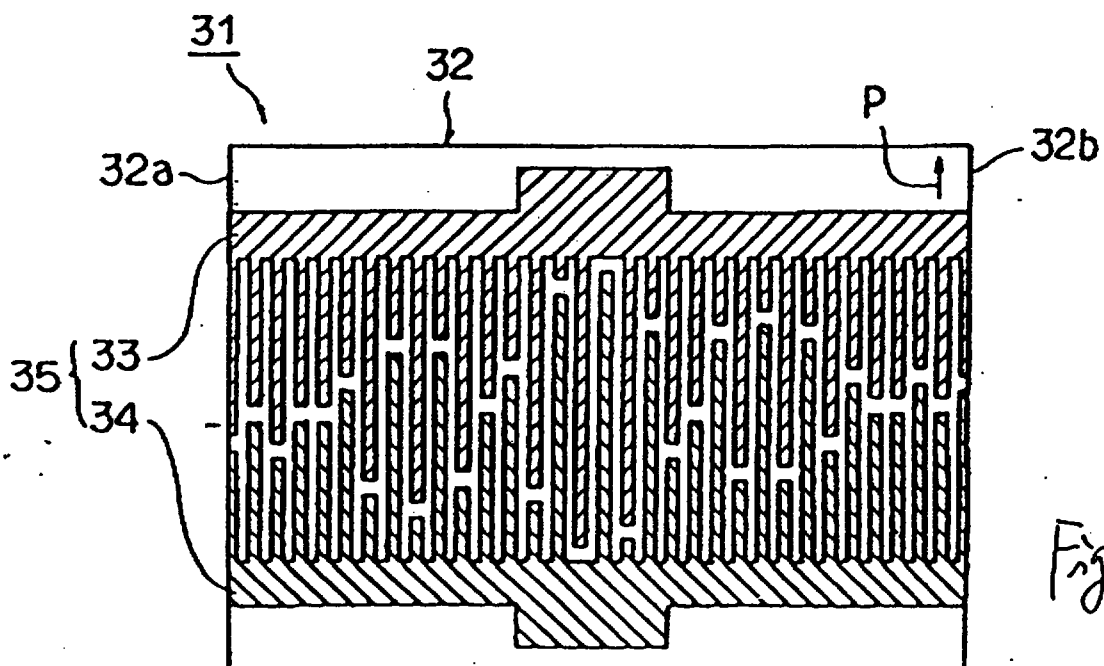


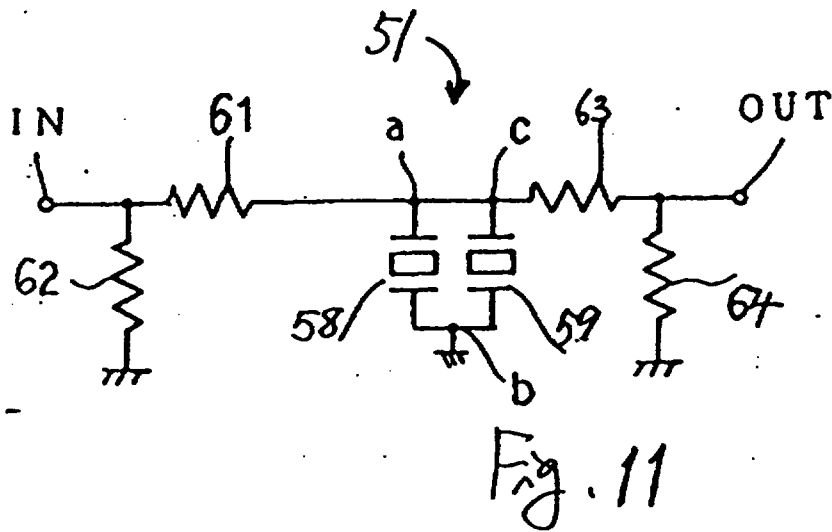
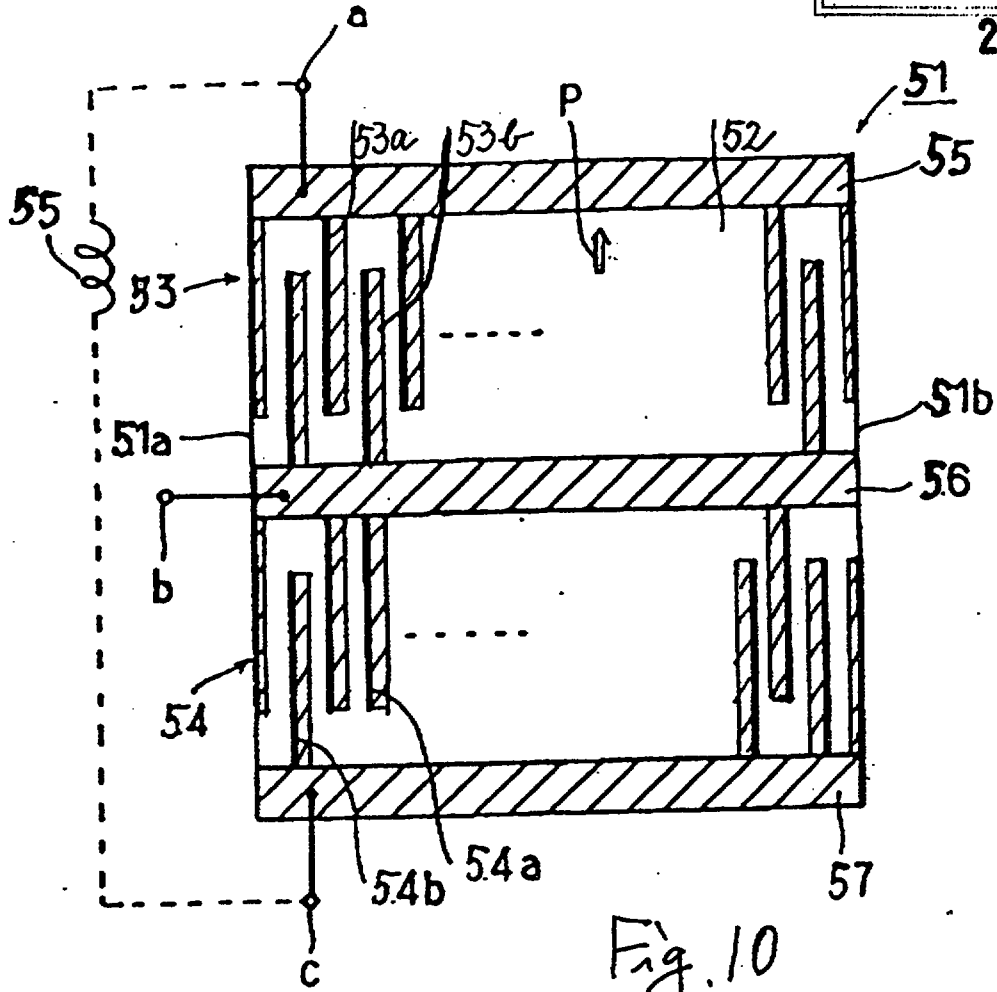
Fig. 9

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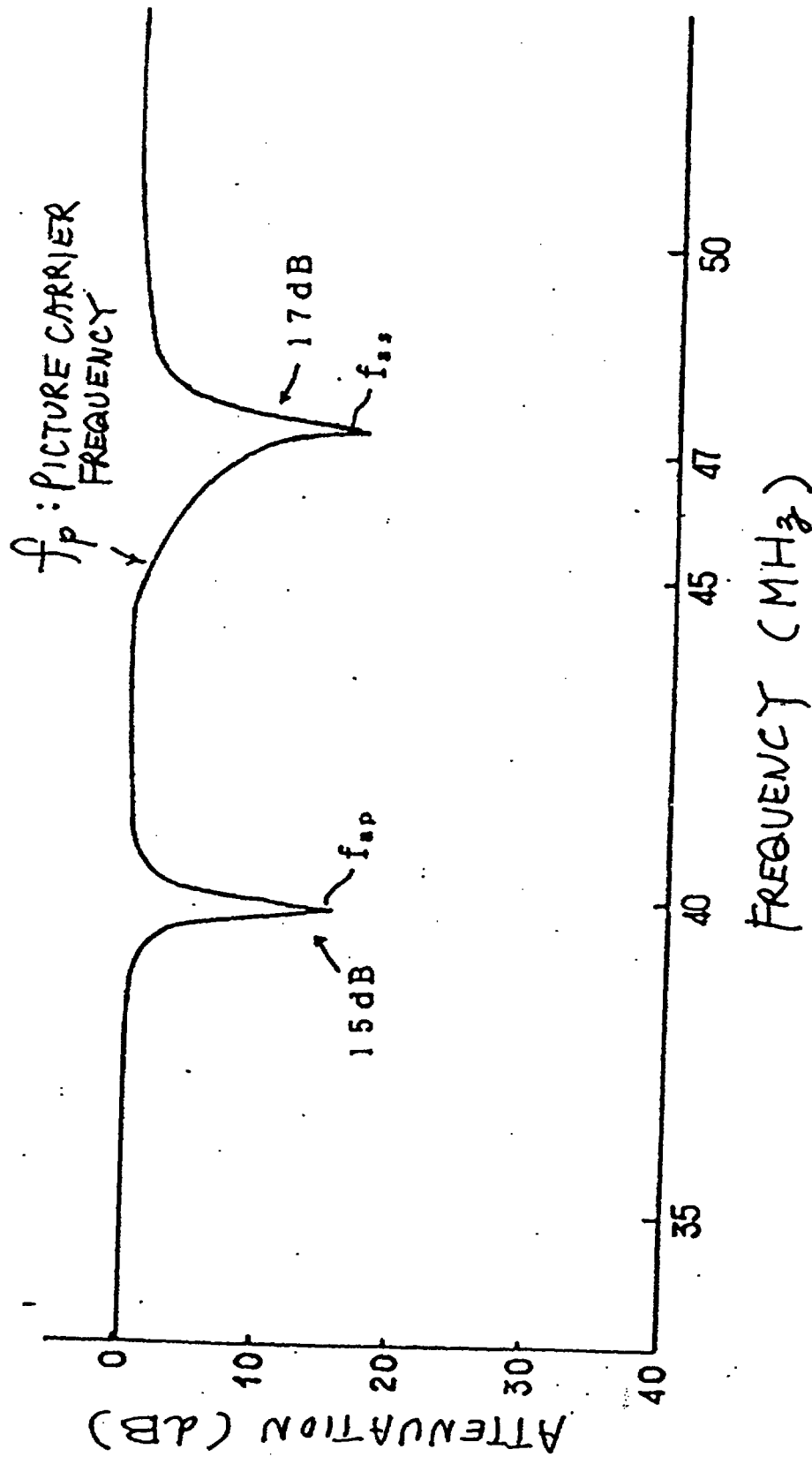


Fig. 12

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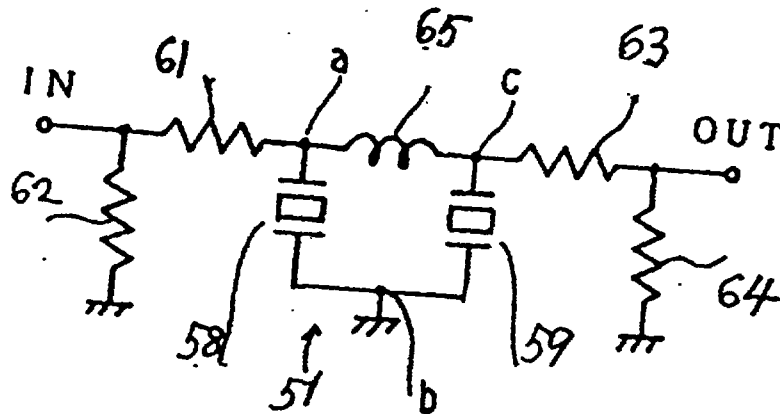


Fig 13

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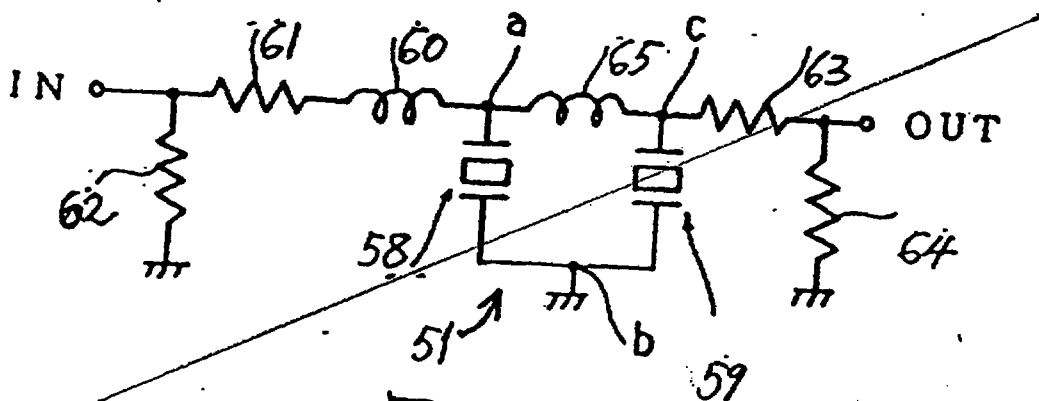


Fig - 15

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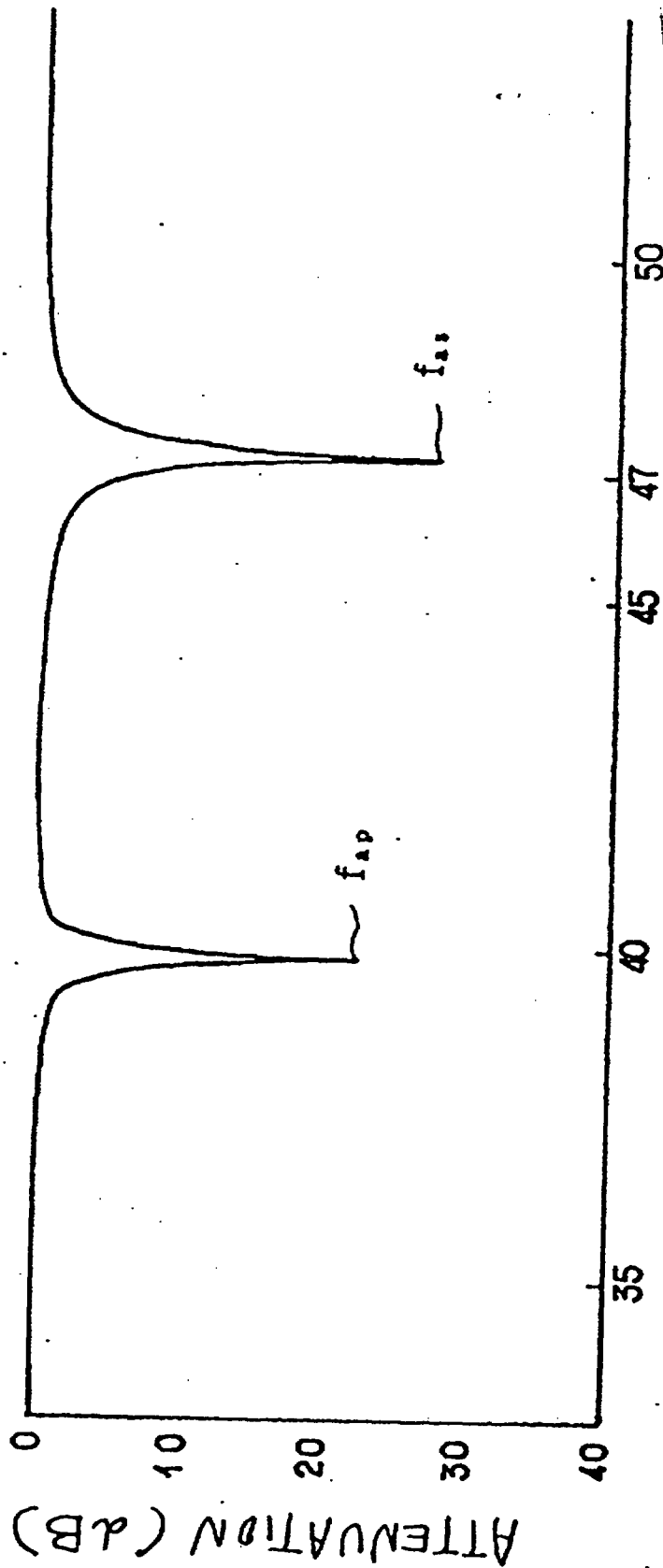


Fig. 14

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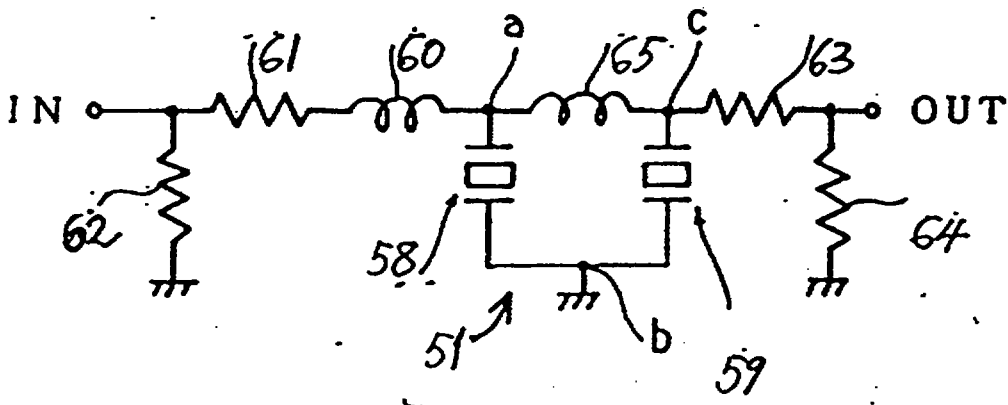


Fig - 15

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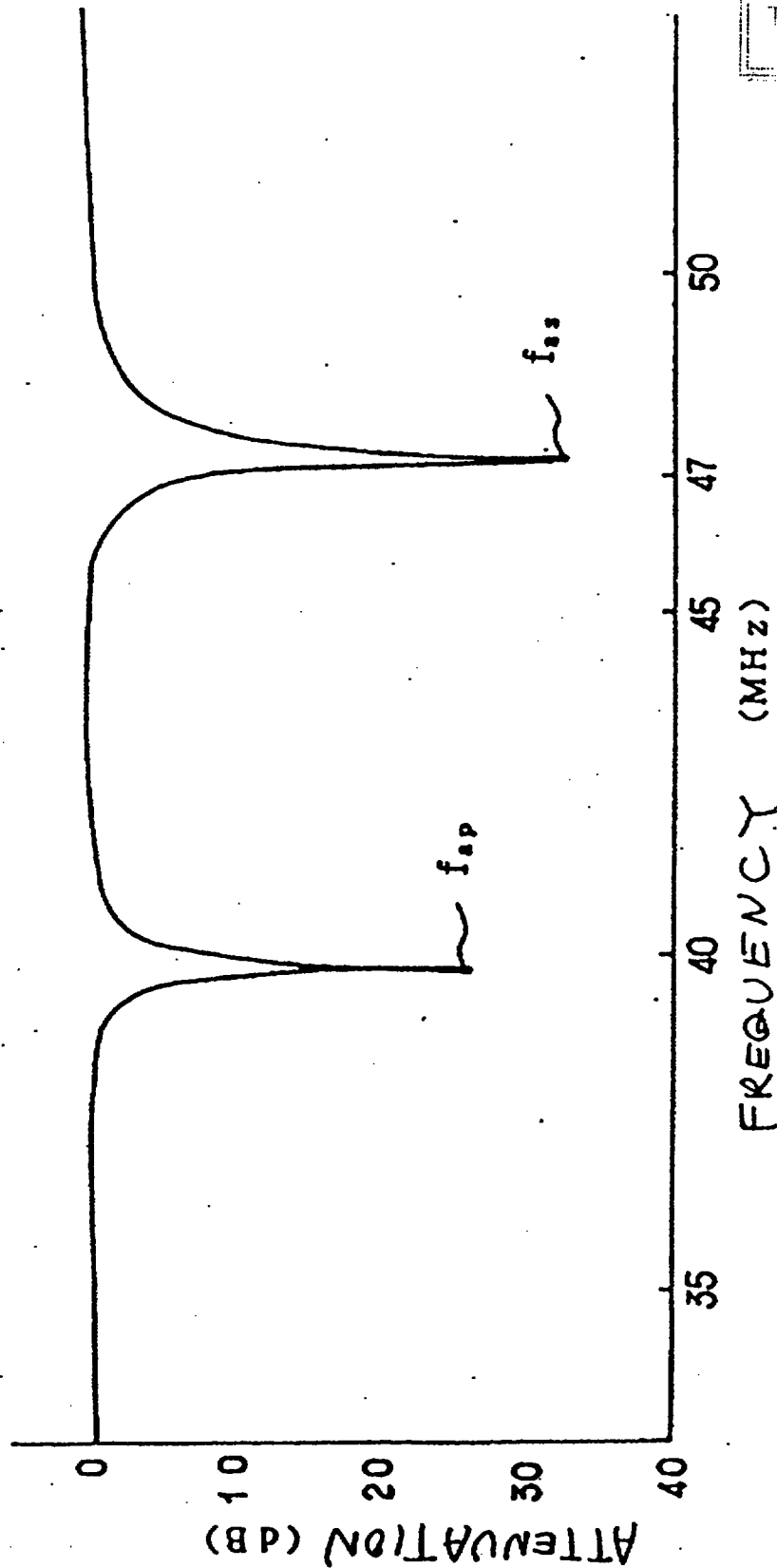


Fig. 16

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ABSTRACT

PIEZOELECTRIC RESONATORS

A single-chip piezoelectric resonator using SH type surface waves has an interdigital transducer formed on a piezoelectric substrate. The interdigital transducer is designed to have two or more resonance characteristics, for example, by using a pair of thinned-out comb-shaped electrodes with mutually interlocking fingers protruding towards each other. Such an interdigital transducer may be formed also by using a pair of comb-shaped electrodes with the lengths of their mutually pointing fingers varied. A trap circuit with two sufficiently separated trap frequencies and improved attenuation characteristics at these two trap frequencies can be formed by two interdigital transducers of the kind described above on a single piezoelectric substrate so as to provide two resonant units each having two resonance characteristics.

-2-

carrier frequency f_{ap} and the other having an attenuation pole at the adjacent-channel sound carrier frequency f_{as} , each trap being formed with an LC resonant circuit or a piezoelectric resonator. As
5 piezoelectric resonators to be used for such a purpose, attention is coming to be focused on those which make use of SH-type surface waves such as the BGS (Bleustein-Gulyaev-Shimizu) wave. Fig. 2 shows a BGS wave resonator 1 utilizing the free-edge surface
10 reflection, comprised of a piezoelectric substrate 2 of a piezoelectric material such as piezoelectric ceramics like lead zirconate titanate or piezoelectric single crystals of LiNbO_3 or LiTaO_3 , having a quadrangular planar shape. If it is made of
15 a piezoelectric ceramic material, it is polarized in the direction of arrow P. A pair of comb-shaped electrodes 3 and 4, each having a plurality of fingers 3a-3c and 4a-4c protruding interdigitatingly toward each other, is formed on the upper surface 2a
20 of the piezoelectric substrate 2 to serve as an interdigital transducer.

With the BGS wave resonator utilizing the free-edge surface reflection type thus structured, BGS waves are excited if an AC voltage is applied to the comb-
25 shaped electrodes 3 and 4. The BGS waves are propagated in the direction shown by arrow X and is reflected by the end surfaces of the piezoelectric substrate 2. If the frequency spectrum determined by this interdigital transducer and the frequency
30 determined by the dimension between the end surfaces are matched, a useful resonant characteristic can be obtained from the surface wave resonator 1. Fig. 3A shows the attenuation-frequency characteristic of this end surface reflection type surface wave
35 resonator, and Fig. 3B shows its impedance-frequency characteristic. Figs. 3A and 3B clearly show that

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the end surface reflection type surface wave resonator shown in Fig. 2, like the prior art LC resonance circuits and other kinds of piezoelectric resonators, has a single resonance characteristic.

5 As a result, it has been necessary to provide and connect two resonance circuits or piezoelectric resonators to obtain a trap characteristic as shown in Fig. 1, but the attenuation was not sufficient at each trap frequency even if two resonance circuits or
10 piezoelectric resonators were connected together.

Single surface acoustic wave resonators making use of the Rayleigh wave and having two resonance characteristics have been known. For example, Kanda, et al (Kokusai Denki Giho, No. 16, pages 1-7 (1992))
15 disclosed a surface wave resonant filter making use of the Rayleigh wave serving as a double-mode resonator making use of the zeroth-order longitudinal mode (the fundamental mode) and the second-order longitudinal mode. In order to obtain two resonance
20 characteristics, however, this double-mode resonator required more than two interdigital transducers and a reflector. Its resonance characteristics are determined by the reflectivity-frequency characteristic of the reflector but since the
25 reflectivity is large only in a small frequency range, the distance between the two resonant frequencies was as small as about 1MHz. In other words, a trap filter with characteristic as shown in Fig. 1 cannot be formed with such a double-mode
30 resonator alone.

SUMMARY OF THE INVENTION

It is therefore an object of this invention to provide a piezoelectric resonator using SH type

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Fig. 4 is a plan view of a piezoelectric resonator according to a first embodiment of this invention;

Fig. 5 is a diagonal view of the piezoelectric resonator shown in Fig. 4;

- 5 Fig. 6 is a graph of the attenuation-frequency characteristic of the piezoelectric resonator shown in Figs. 4 and 5;

- Fig. 7 is a graph of the impedance-frequency characteristic of the piezoelectric resonator shown
10 in Figs. 4 and 5;

Fig. 8 is a plan view of a piezoelectric resonator according to a second embodiment of this invention;

Fig. 9 is a plan view of a piezoelectric resonator according to a third embodiment of this invention;

- 15 Fig. 10 is a plan view of a piezoelectric resonator according to a fourth embodiment of the invention for forming a trap circuit with improved attenuation;

Fig. 11 is a circuit diagram of a trap circuit using a piezoelectric resonator shown in Fig. 10; and

- 20 Fig. 12 is a graph showing the attenuation-frequency characteristic of the trap circuit shown in Fig. 11.

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Throughout herein, components which are substantially the same or at least equivalent to each other are indicated by the same numerals and not described repetitiously.

10 DETAILED DESCRIPTION OF THE INVENTION

In what follows, the invention will be described by way of examples but these examples are not intended to limit the scope of the invention.

15 Figs. 4 and 5 show a piezoelectric resonator 11 according to a first embodiment of this invention, comprising a piezoelectric substrate 12 having a rectangular plane and made of an appropriate piezoelectric material such as piezoelectric ceramics like lead zirconate titanate. The piezoelectric
20 substrate 12 is subjected to a polarization process in the direction shown by arrow P, parallel to its main surface and also to the direction in which electrode fingers, to be explained below, are extended.

25 An interdigital transducer (hereinafter abbreviated as IDT) 15 comprising a pair of mutually interlocking thinned-out comb-shaped electrodes 13 and 14 is formed on the upper surface of the piezoelectric substrate 12. The comb-shaped electrodes 13 and 14
30 respectively have a plurality of electrode fingers 13a-13d and 14a-14i opposite to and in the direction of P. It is to be noted in Figs. 4 and 5 that,

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first resistor 61 was a second resistor 62. Inserted
between the piezoelectric resonator 51 and the output
terminal OUT was a third resistor 63. Inserted
5 between the ground potential and a point between the
output terminal OUT and the third resistor 63 was a
fourth resistor 64. Fig. 12, which is a graph of the
attenuation-frequency characteristic of a trap
circuit thus structured, clearly shows that two traps
10 were formed at two frequencies f_{ap} and f_{as} and that
attenuation was as large as 15dB and 17dB at these
frequencies. It is to be noted, however, that
attenuation was undesirably large around the picture
carrier frequency f_p which, as shown in Fig. 12, is
15 between the two trap frequencies f_{ap} and f_{as} and
closer to the one at the higher frequency.

Table 1 shows the magnitudes of attenuation of the trap
circuit described above at the adjacent-channel picture
and sound carrier frequencies f_{ap} and f_{as} .

20

Table 1

	Attenuation at f_{ap} (dB)	Attenuation at f_{as} (dB)
Circuit of Fig. 11	15	17

25

Although only one trap circuit has been shown above as
embodying the present invention, this embodiment is not
intended to limit the scope of the invention. Many
modifications and variations are possible within the
30 scope of this invention. For _____

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example, still another trap circuit was formed with
an inductor _____

added between the terminal a and the input terminal
IN of the circuit shown in Fig. 11 without any

5 inductor _____

inserted between the terminals a and c of the
resonator 51, and it was discovered by using such a
trap circuit that the attenuation was 21dB and 24dB
at the adjacent-channel picture and sound carrier
10 frequencies f_{ap} and f_{as} , respectively.

As another example, two piezoelectric resonators, as
shown for example in Fig. 4, may be used in the
examples given above in place of the piezoelectric
resonator 51,

15

20

Attenuation at the two trap frequencies can be
thereby effectively improved in a similar manner.
Although the use of a piezoelectric resonator

25 is advantageous because the circuit structure can be
thereby simplified because the resonant units are
formed on a single chip, it is feasible according to

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the present invention to use two resonators using SH type surface waves in order to form a trap circuit with greater attenuation than was possible with prior art LC resonance circuits.

5 When two resonators are used in place of a single resonator 51

, as discussed above, these two resonators need not be resonators according to the first embodiment of the invention described above with reference to Figs. 4 and 5. Still another trap
10 circuit was formed, similar to the one described above with reference to Fig. 11 but using two resonators 31 according to the third embodiment of the invention to serve as the two resonant units 58
15 and 59 of Fig. 11, and it was discovered that the difference between the two resonant frequencies could also be increased to about 8MHz.

In summary, all such modifications and variations that may be apparent to a person skilled in the art
20 are intended to be included within the scope of the invention.

As used herein the term 'SH type surface waves' means shear horizontal type surface waves.

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WHAT IS CLAIMED IS:

1. A piezoelectric resonator utilizing free-edge surface reflection said resonator comprising:
a piezoelectric substrate; and
5 an interdigital transducer which is formed on said substrate and has at least two resonance characteristics.
2. The piezoelectric resonator of claim 1 wherein said interdigital transducer comprises a pair
10 of thinned-out comb-shaped electrodes each having a plurality of fingers protruding towards the other electrode, said fingers from said pair of electrodes being in mutually interlocking formation, at least one mutually adjacent pair of the fingers of one of
15 said electrodes sandwiching therebetween two or more of the fingers of the other of said electrodes.
3. The piezoelectric resonator of claim 1 wherein said interdigital transducer comprises a pair of comb-shaped electrodes each having a plurality of
20 parallel fingers protruding in rows towards the other electrode, each of the fingers from one of the electrodes being aligned with one of the fingers from the other electrode, the lengths along said fingers of regions where surface waves can be excited upon
25 application of a voltage across said electrodes varying over said rows.

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4. The piezoelectric resonator of claim 2
wherein each of said fingers except those at both
ends of said piezoelectric substrate have width equal
to one-quarter of the wavelength of surface waves
5 excited in regions between said fingers and mutually
adjacent pairs of said fingers are separated by one-
quarter of said wavelength.

5. The piezoelectric resonator of claim 3
wherein each of said fingers except those at both
10 ends of said piezoelectric substrate have width equal
to one-quarter of the wavelength of surface waves
excited in regions between said fingers and mutually
adjacent pairs of said fingers are separated by one-
quarter of said wavelength.

15 6. The piezoelectric resonator of claim 1
comprising two interdigital transducers which are
formed on said piezoelectric substrate and are
connected to each other so as to form two resonant
units each having two resonance characteristics.

20 7. A trap circuit comprising a piezoelectric
resonator utilizing free-edge surface reflection, said
resonator comprising:

a piezoelectric substrate; and
an interdigital transducer which is formed on
25 said substrate and has at least two trap frequencies.

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8. The trap circuit of claim 7 wherein said piezoelectric resonator comprises two interdigital transducers which are formed on said piezoelectric substrate and are connected to each other so as to form
5 two resonant units each having two resonance characteristics.

9. The trap circuit of claim 7 comprising two piezoelectric resonators using SH type surface waves,
10 said two resonators being both formed on said piezoelectric substrate, each having an interdigital transducer, being connected in parallel and providing two resonance characteristics.

15 10. A surface wave transducer device having at least two resonance characteristics.

11. A trap circuit comprising a surface wave transducer device in accordance with claim 10.

20 12. A piezoelectric resonator substantially as hereinbefore described with reference to Figures 4 to 7, 8, 9 or 10 of the accompanying drawings.

25 13. A trap circuit substantially as hereinbefore described with reference to Figures 11 and 12 of the accompanying drawings.

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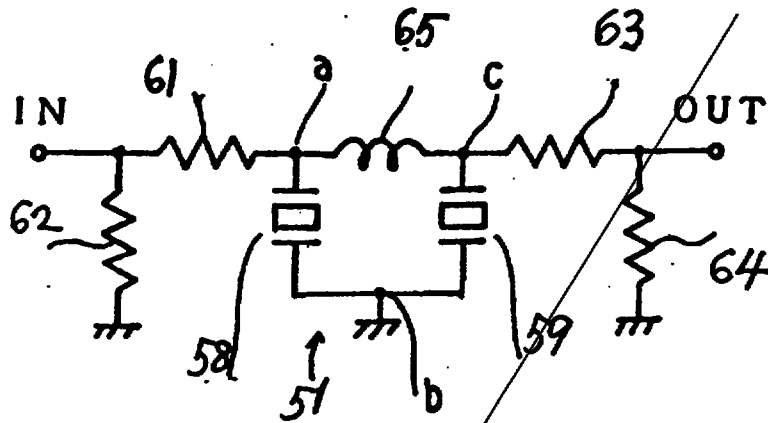


Fig 13

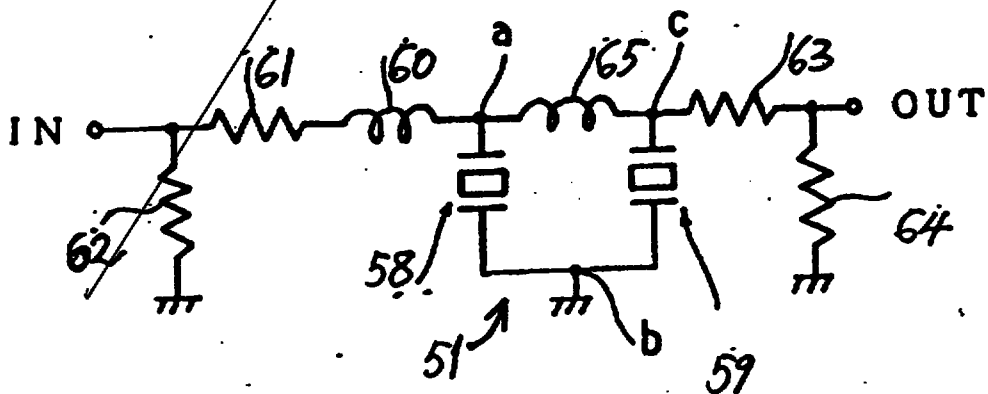


Fig - 15

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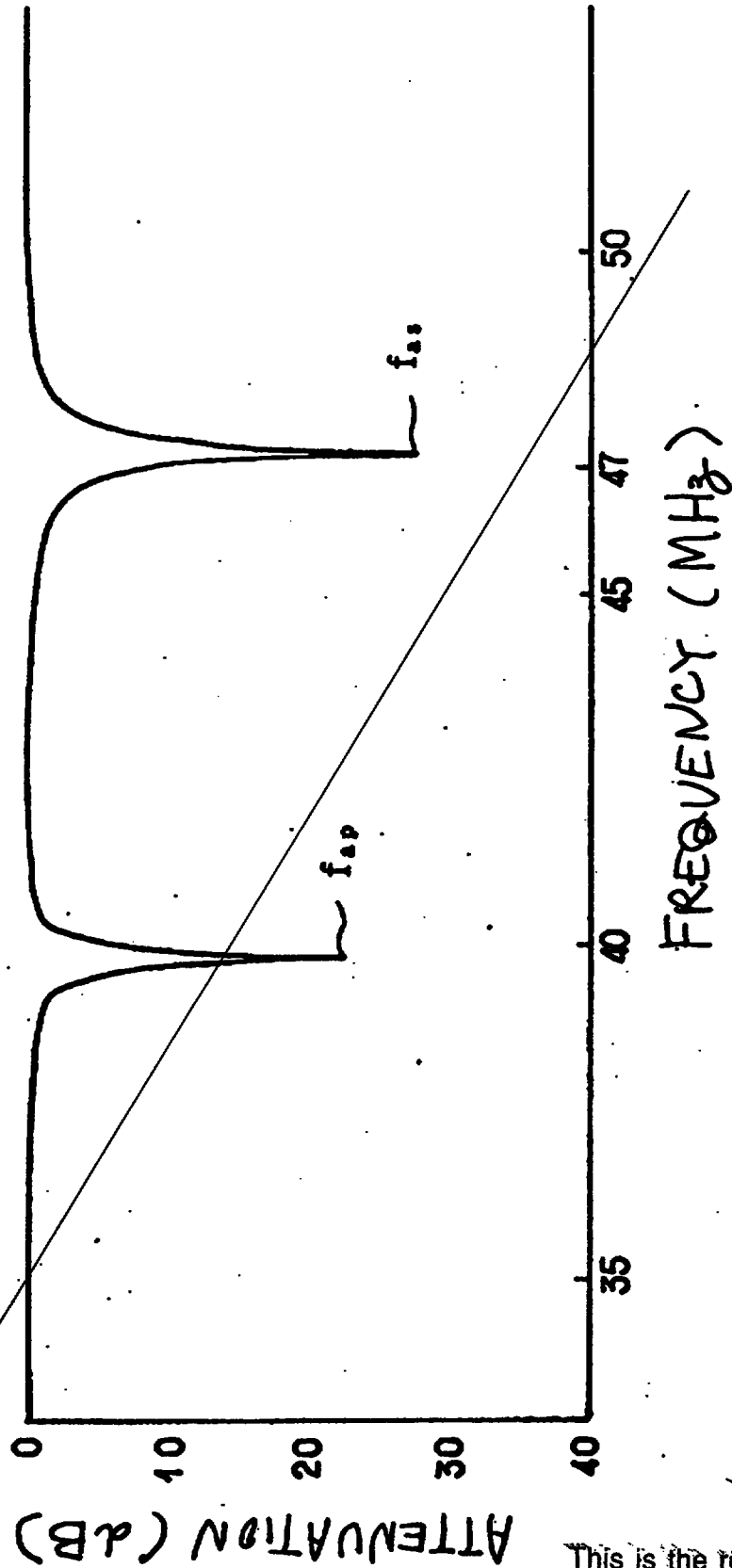


Fig. 14

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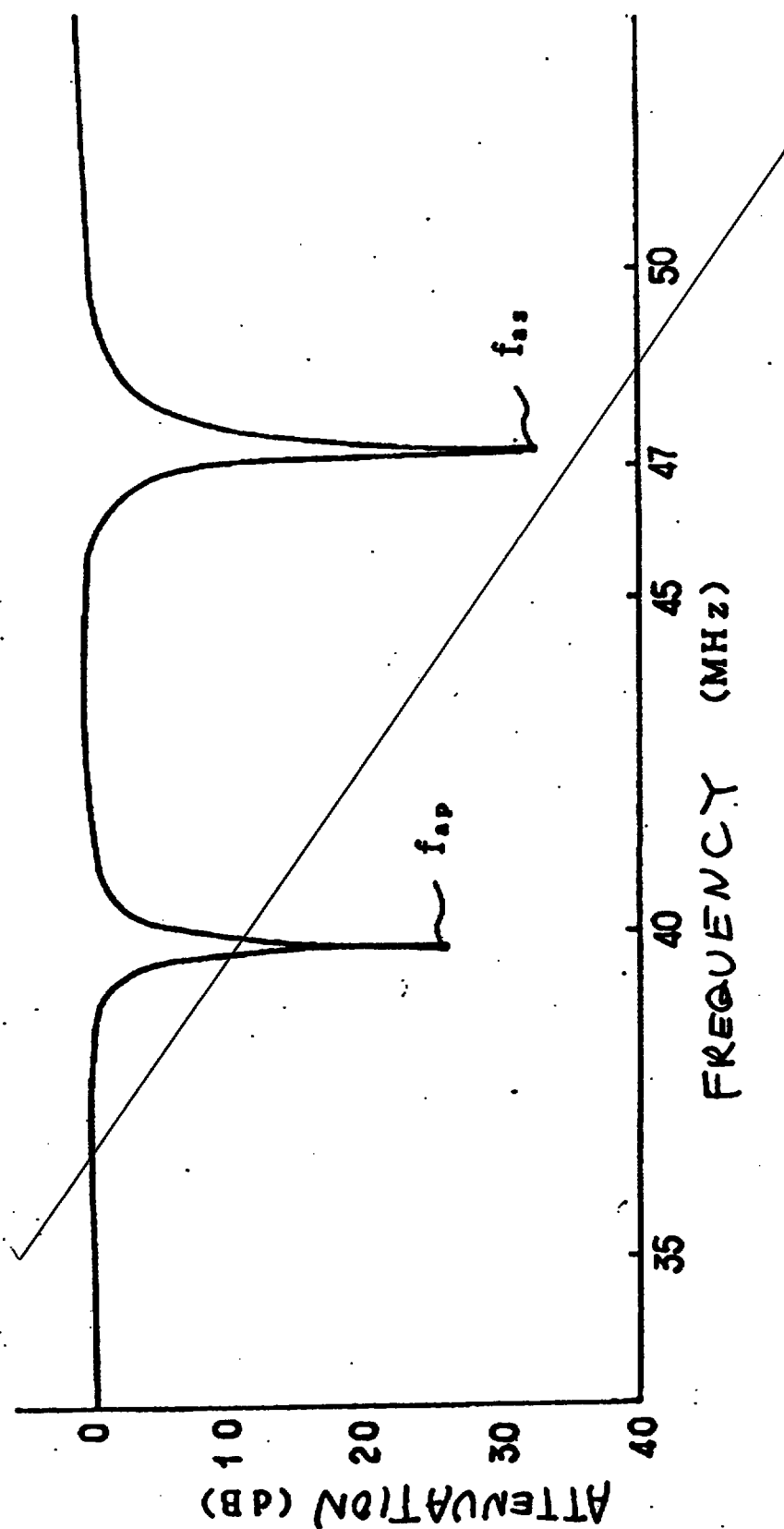


Fig. 16

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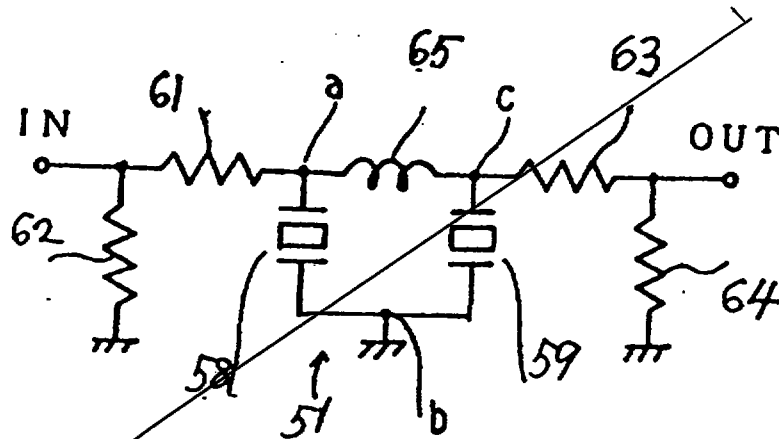


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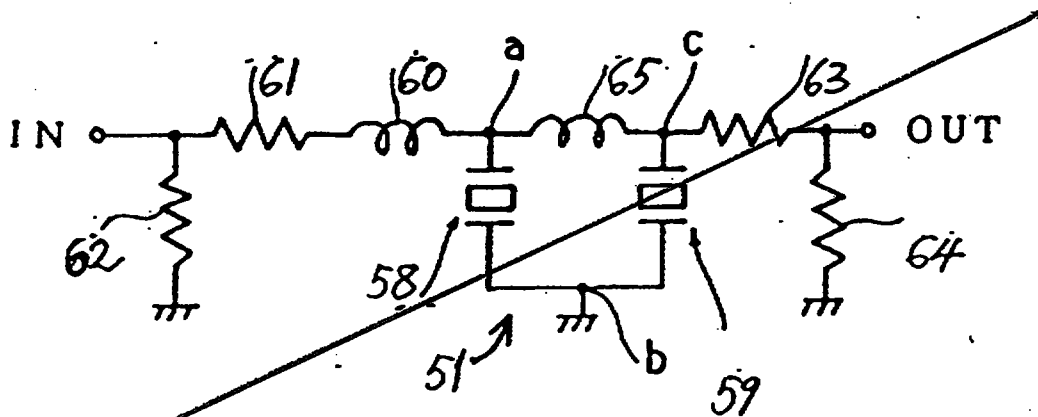


Fig - 15

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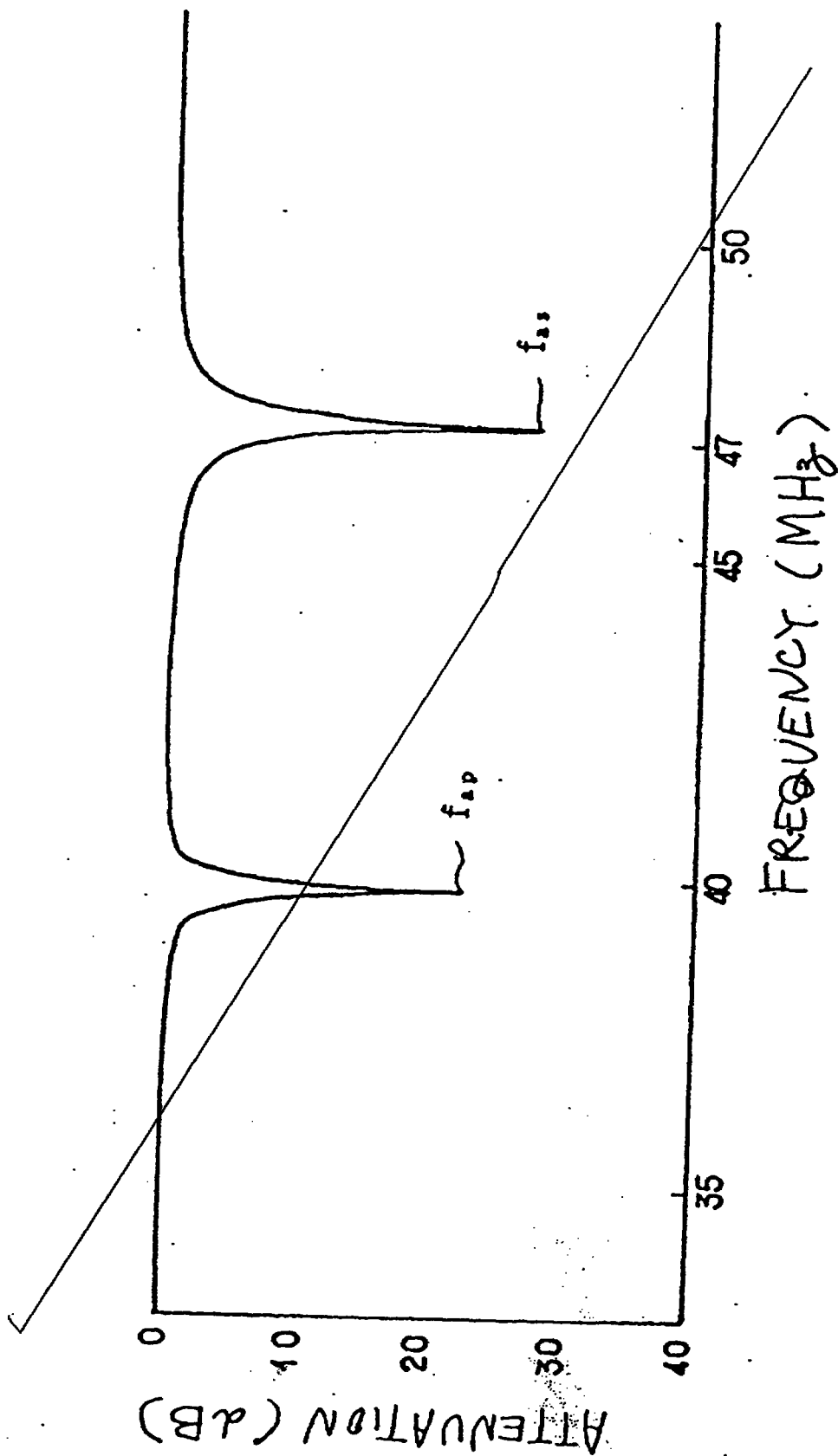


Fig. 14

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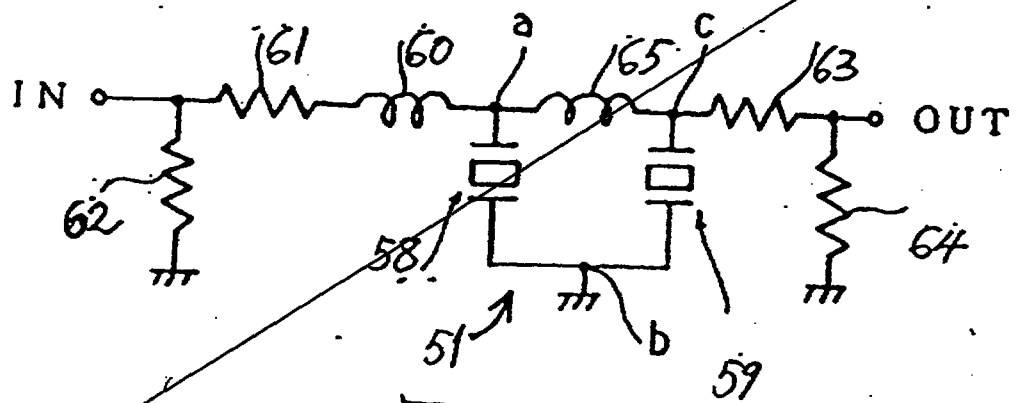


Fig - 15

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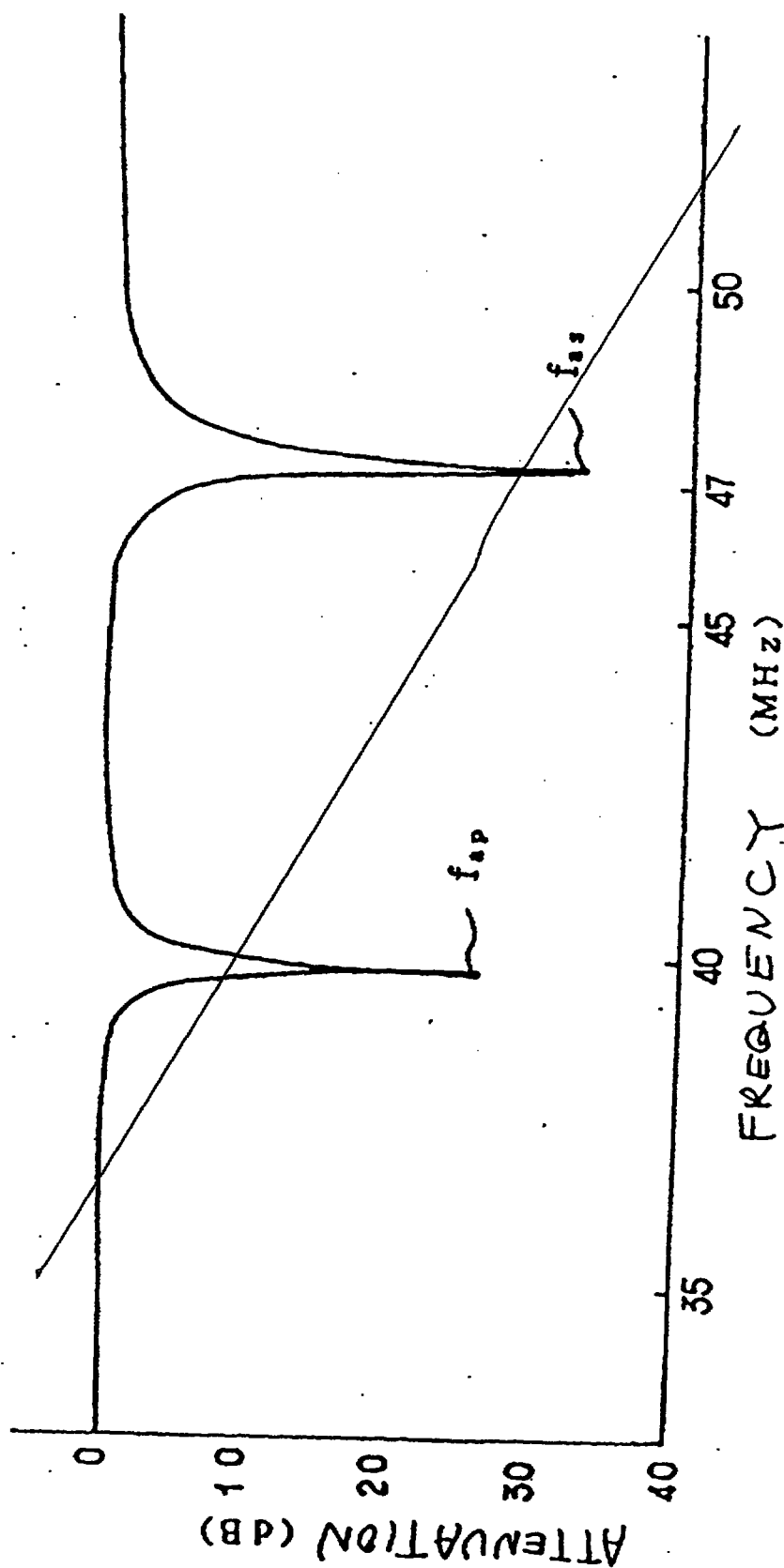


Fig. 16

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