United States Patent [19]

Tanaka et al.

[11] **3,710,275**

[45] **Jan. 9, 1973**

[54] **LOW FREQUENCY OSCILLATOR EMPLOYING A PAIR OF U-SHAPED MECHANICAL VIBRATORS**

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[73] Assignee: **Shigeru Kakubari**, Tokyo, Japan

[22] Filed: **Nov. 5, 1970**

[21] Appl. No.: **87,305**

Related U.S. Application Data

[60] Division of Ser. No. 754,416, Aug. 21, 1968, abandoned, Continuation of Ser. No. 88,507, Nov. 10, 1970, Pat. No. 3,659,230.

[52] **U.S. Cl.**....................**331/37**, 58/23 TF, 318/128, 331/116 M, 331/156

[51] **Int. Cl.**...**H03b 5/30**

[58] **Field of Search**.............331/37, 41, 116 M, 156; 310/25; 318/128; 84/409; 58/23 TF; 333/71

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Primary Examiner—Roy Lake
Assistant Examiner—Siegfried H. Grimm
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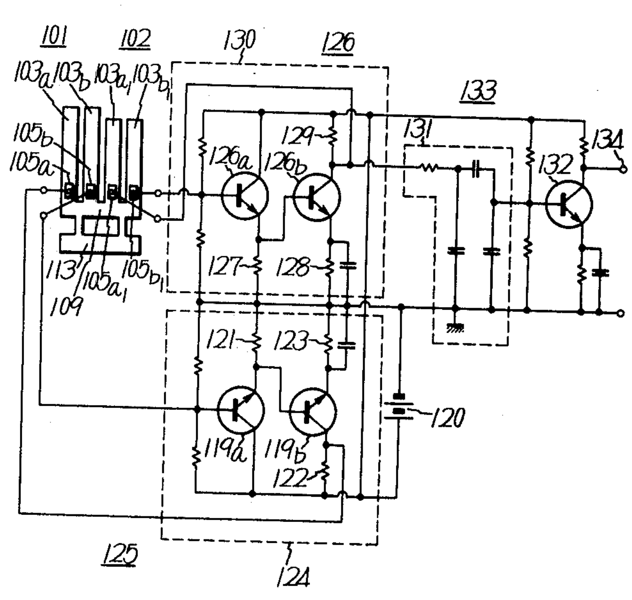
[57] **ABSTRACT**

A U-shaped mechanical vibrator having a pair of strip-like vibratory reeds of substantially the same configuration, and a base portion coupling together the pair of vibratory reeds at one end as a unitary structure, the width of each reed being selected greater than the thickness thereof, the vibratory reeds being arranged in a single plane including their surfaces in the widthwise direction in parallel and side-by-side relation, and the pair of vibratory reeds vibrating in antiphase relation to each other at right angles to the single plane.

3 Claims, 26 Drawing Figures



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SHEET 01 OF 12

Fig. 1

PRIOR ART

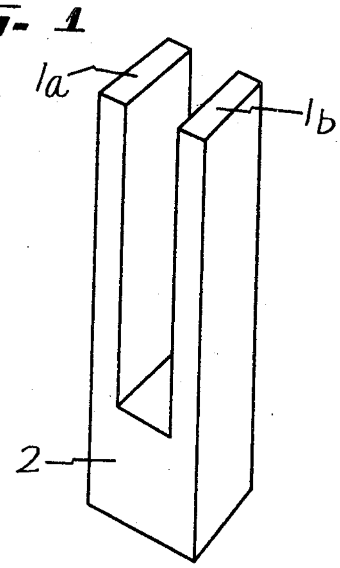


Fig. 2

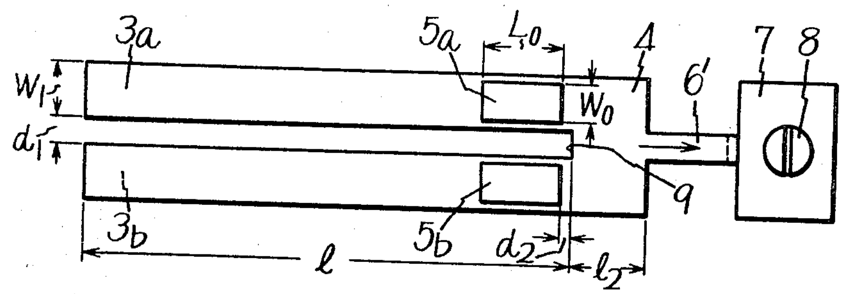


Fig. 3

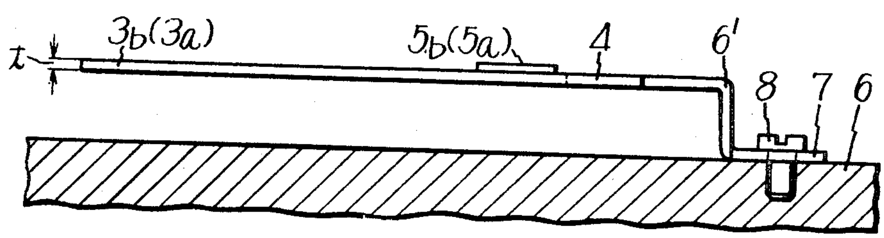


Fig. 4

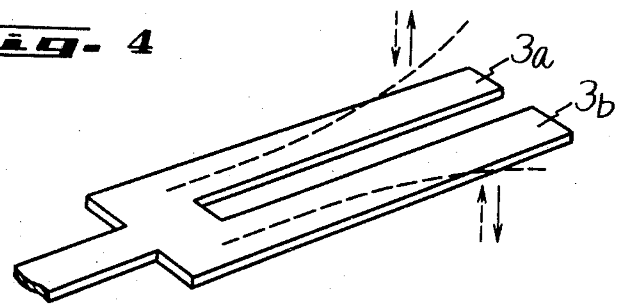
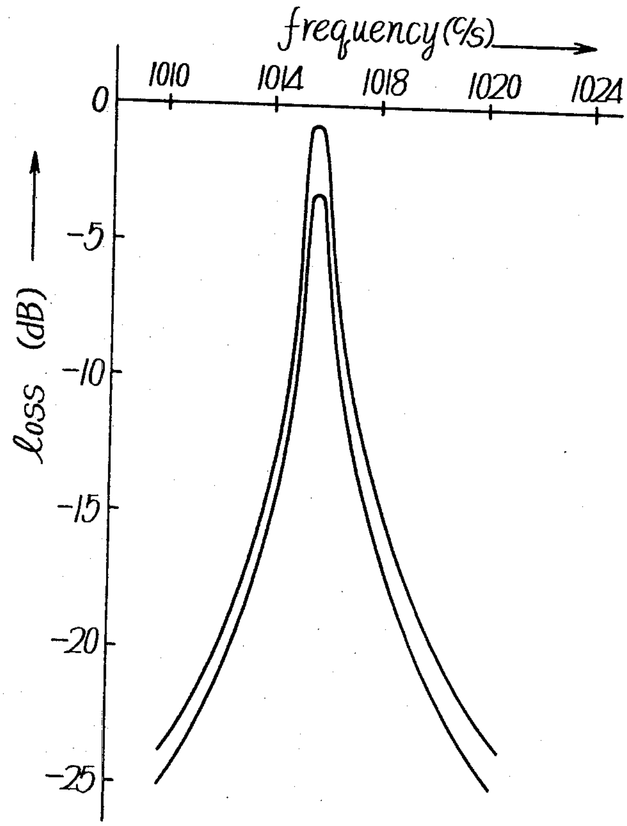

3a
3b

Fig. 6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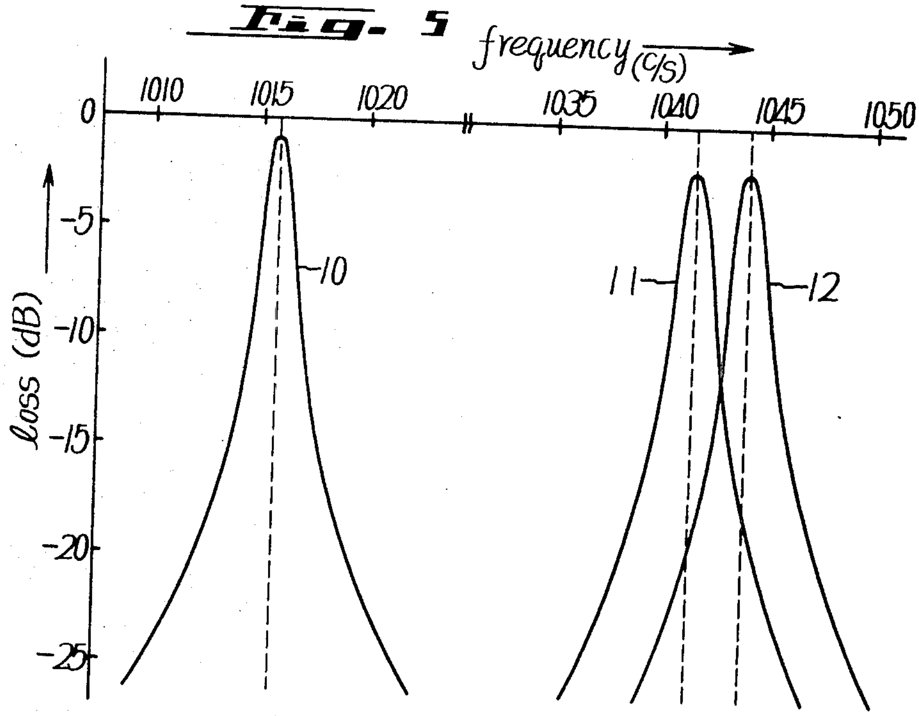
1010
1014
1018
1020
1024
0
-5
-10
-15
-20
-25
loss (dB)

Fig. 5


frequency (c/s)
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1015
1020
1035
1040
1045
1050
0
-5
-10
-15
-20
-25
loss (dB)
10
11
12

Fig. 7

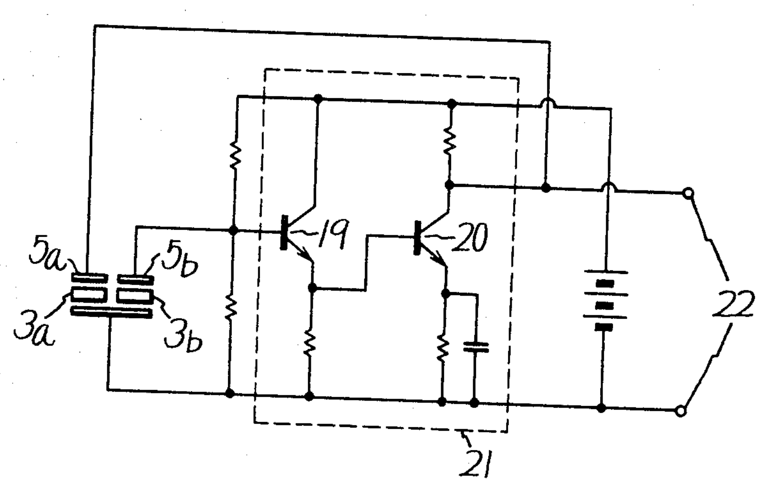

5a
5b
3a
3b
19
20
21
22

Fig. 8

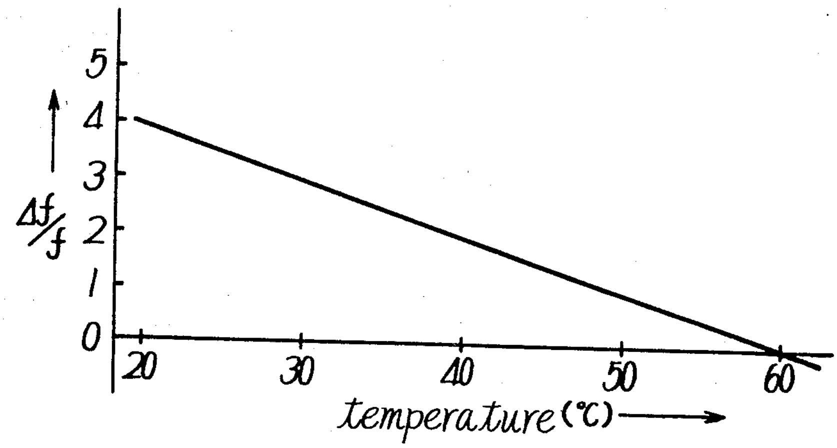


Fig. 9

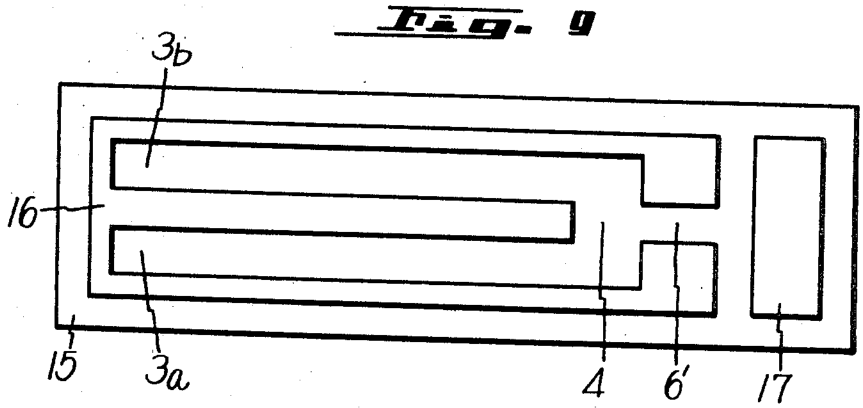


Fig. 10

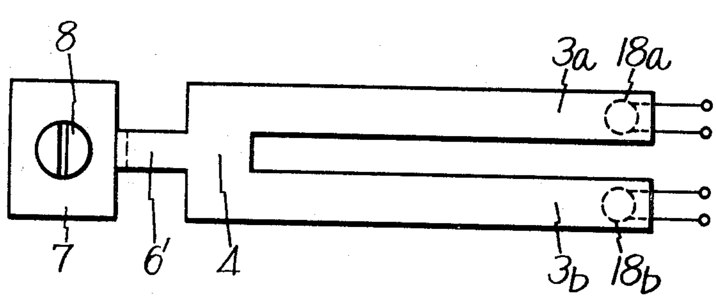


Fig. 11

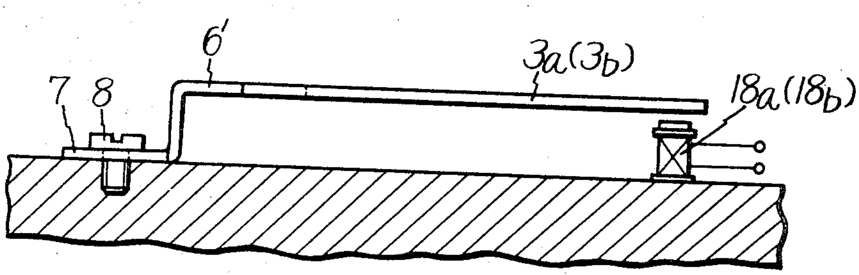


Fig. 12

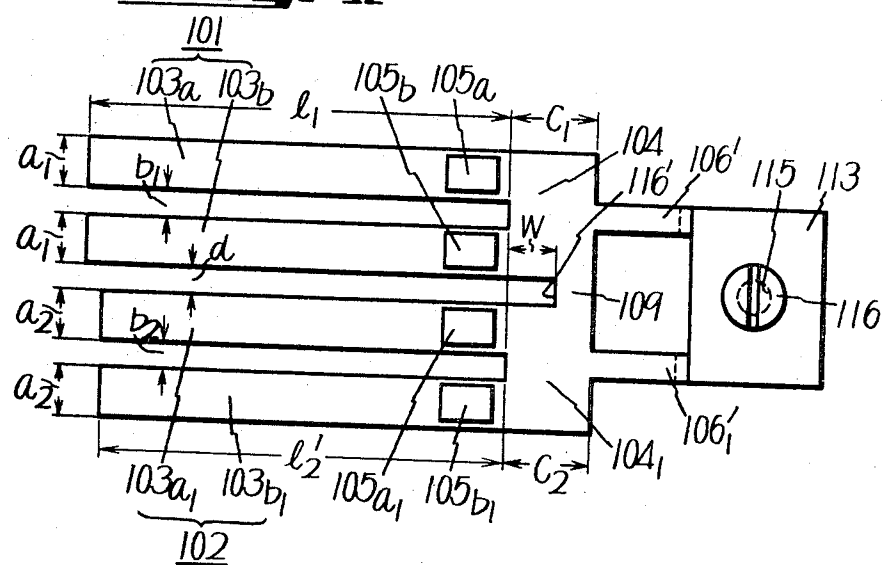


Fig. 13

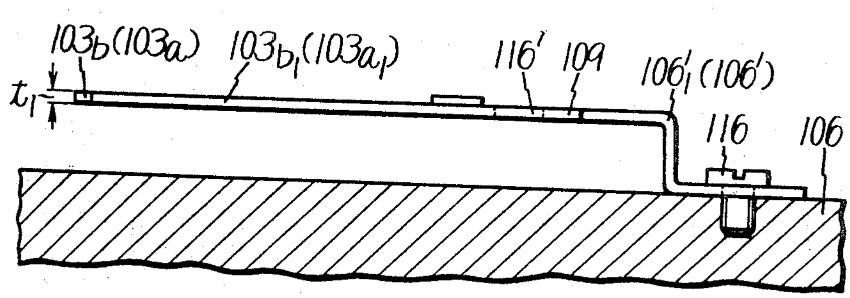


Fig. 14

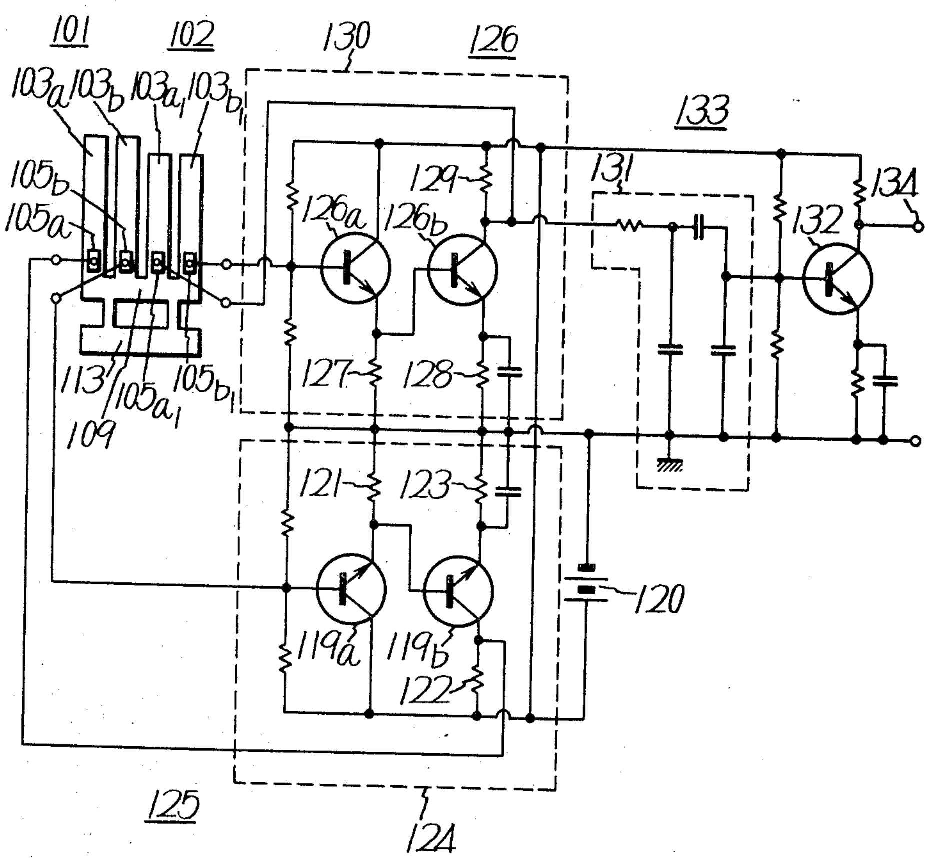

101
102
130
126
103a
103b
103a1
103b1
105b
105a
133
131
129
126a
126b
134
132
113
109
105a1
105b1
127
128
121
123
120
119a
119b
122
125
124

Fig. 15

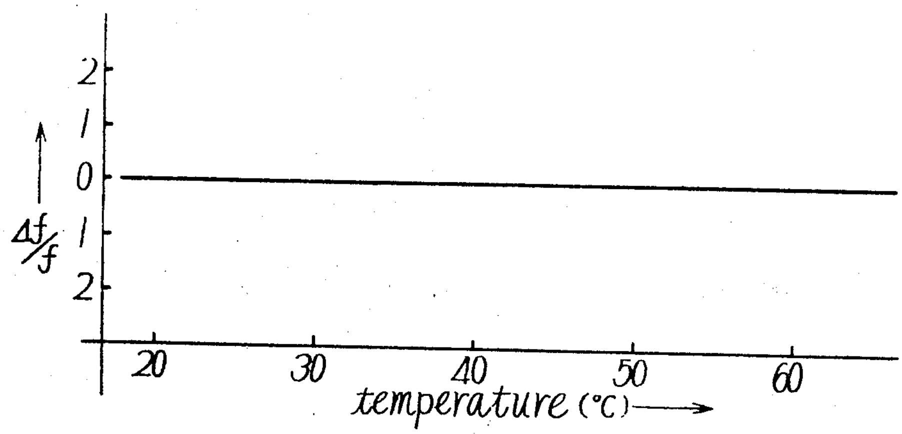


Fig. 16 A

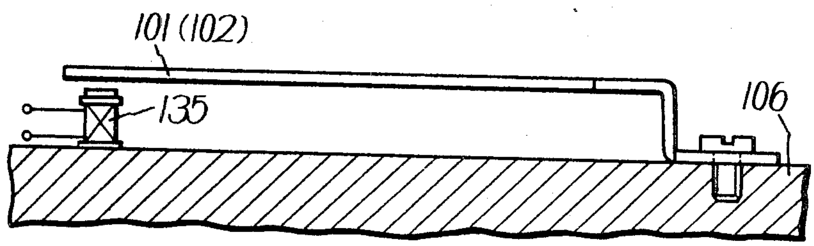


Fig. 16 B

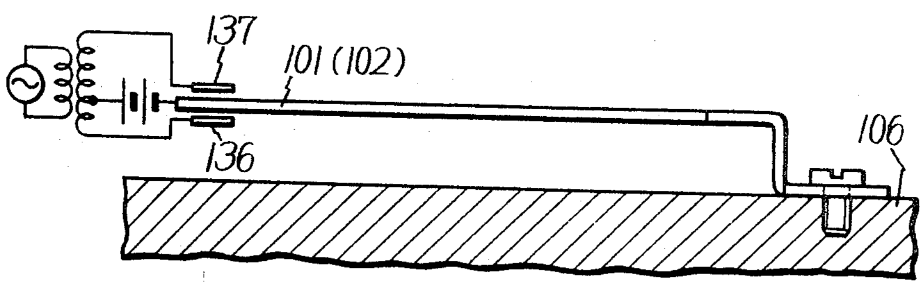


Fig. 17

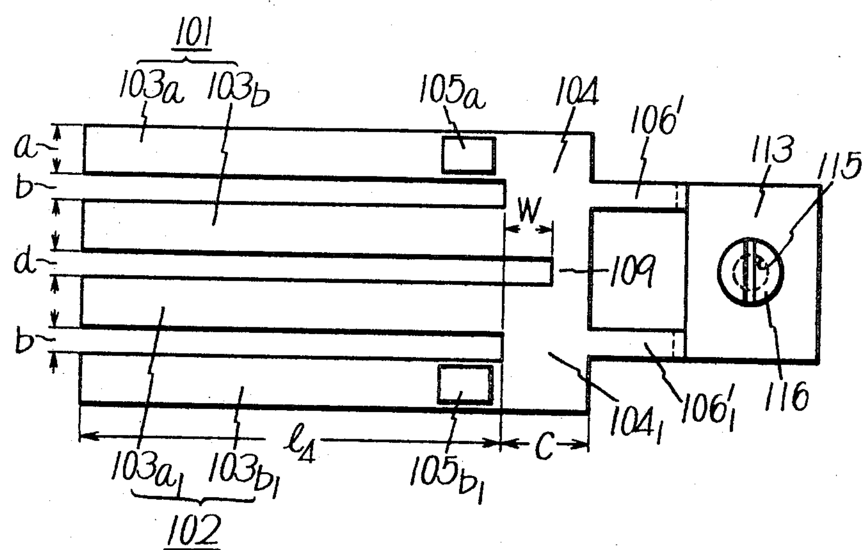

101
103a
103b
105a
104
106'
113
115
a
b
d
b
W
109
116
104_1
$106'_1$
l_4
C
$103a_1$
$103b_1$
$105b_1$
102

Fig. 18

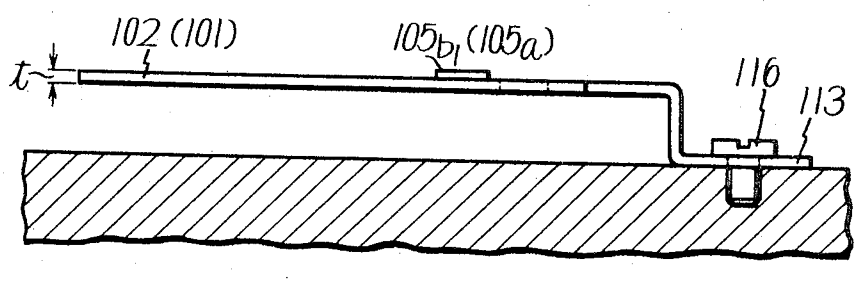
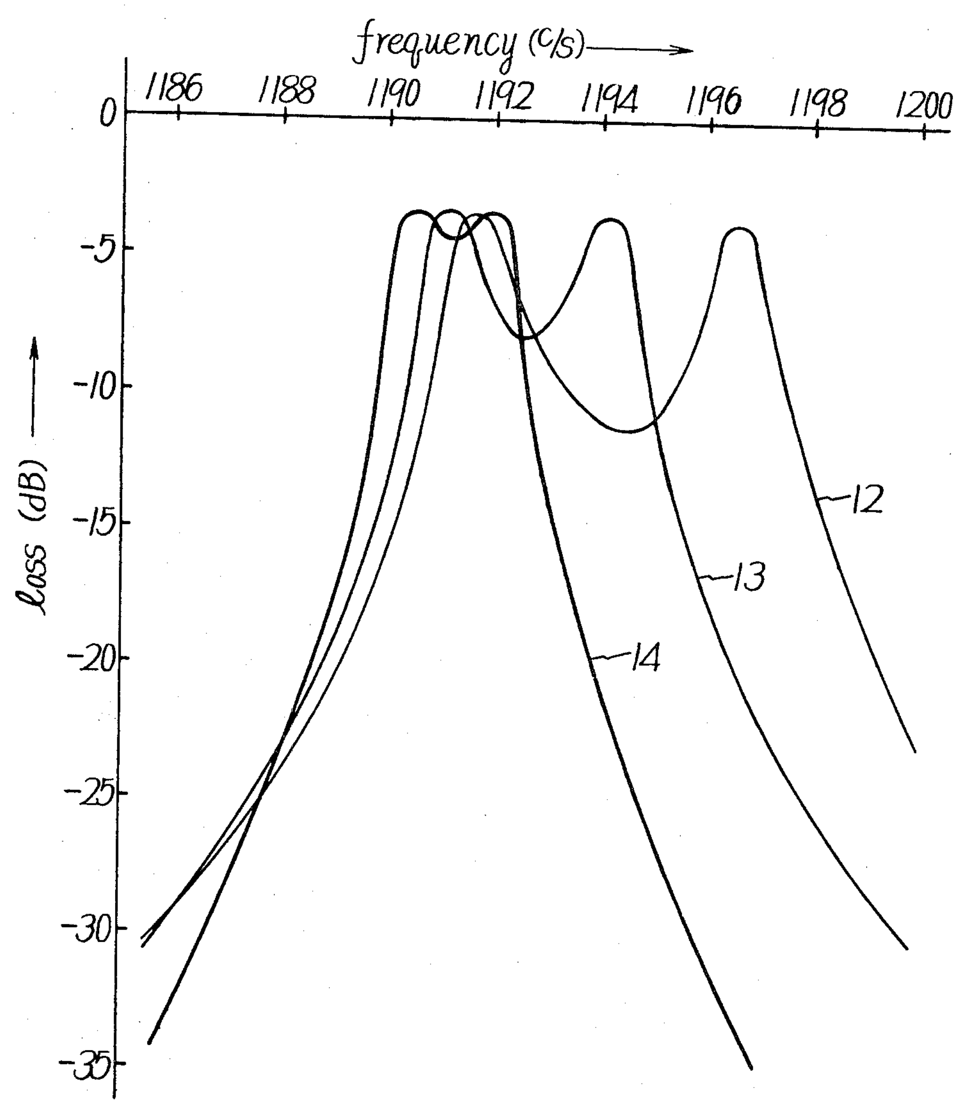

102 (101)
$105b_1$ (105a)
t
116
113

Fig. 19



frequency (c/s)
1186
1188
1190
1192
1194
1196
1198
1200
0
-5
-10
-15
-20
-25
-30
-35
loss (dB)
12
13
14

Fig. 23

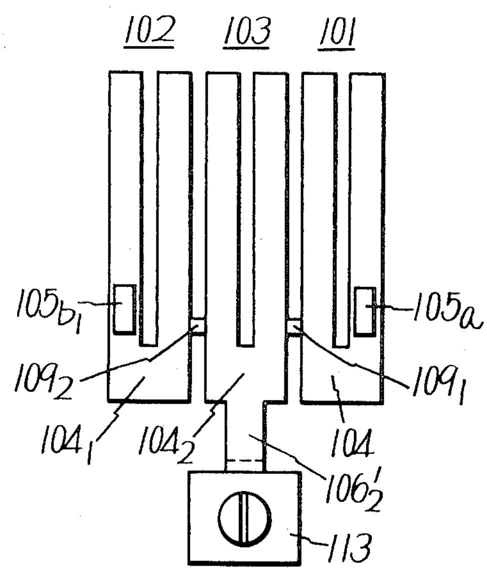


Fig. 20

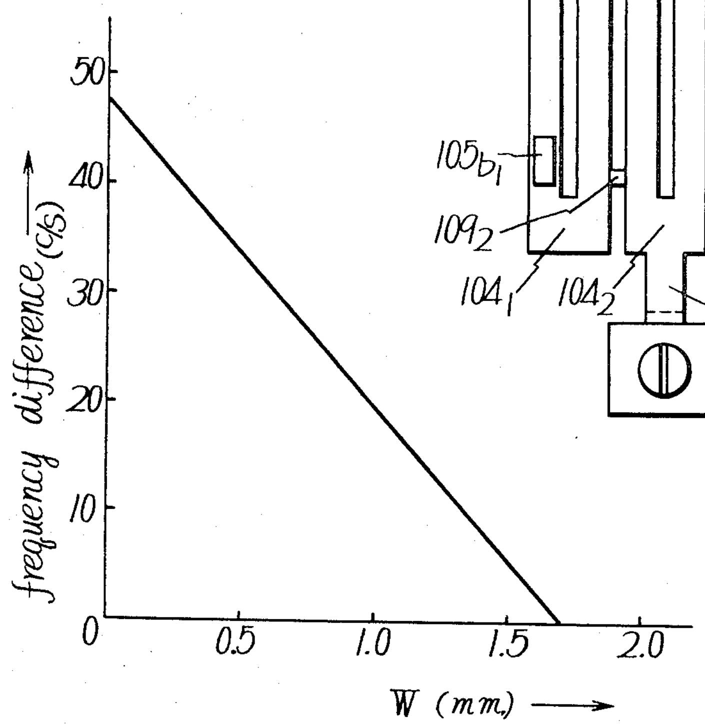


Fig. 24

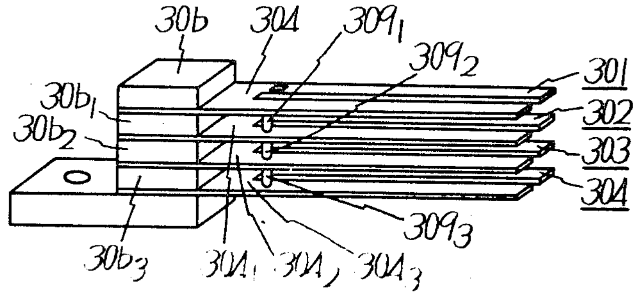


Fig. 21

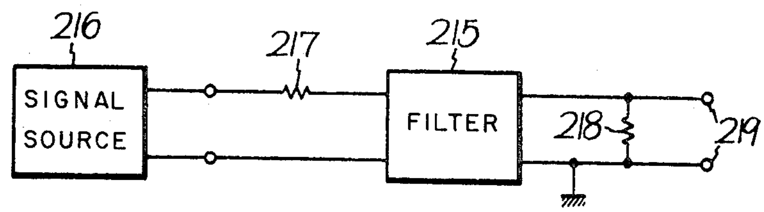

216
SIGNAL SOURCE
217
215
FILTER
218
219

Fig. 22

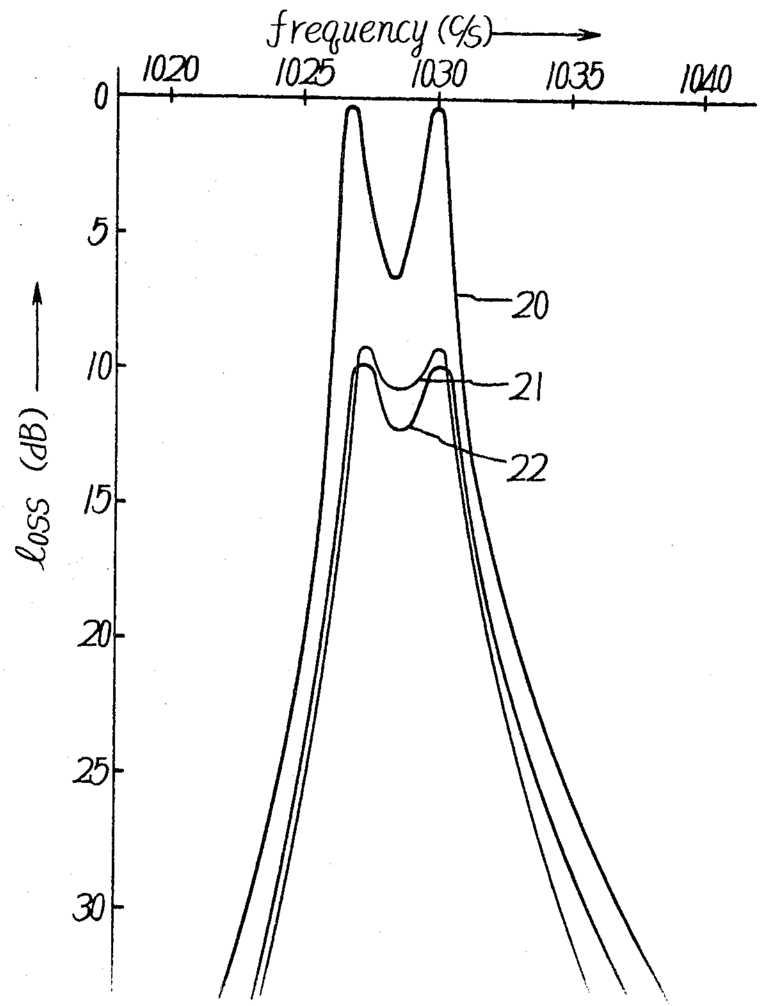
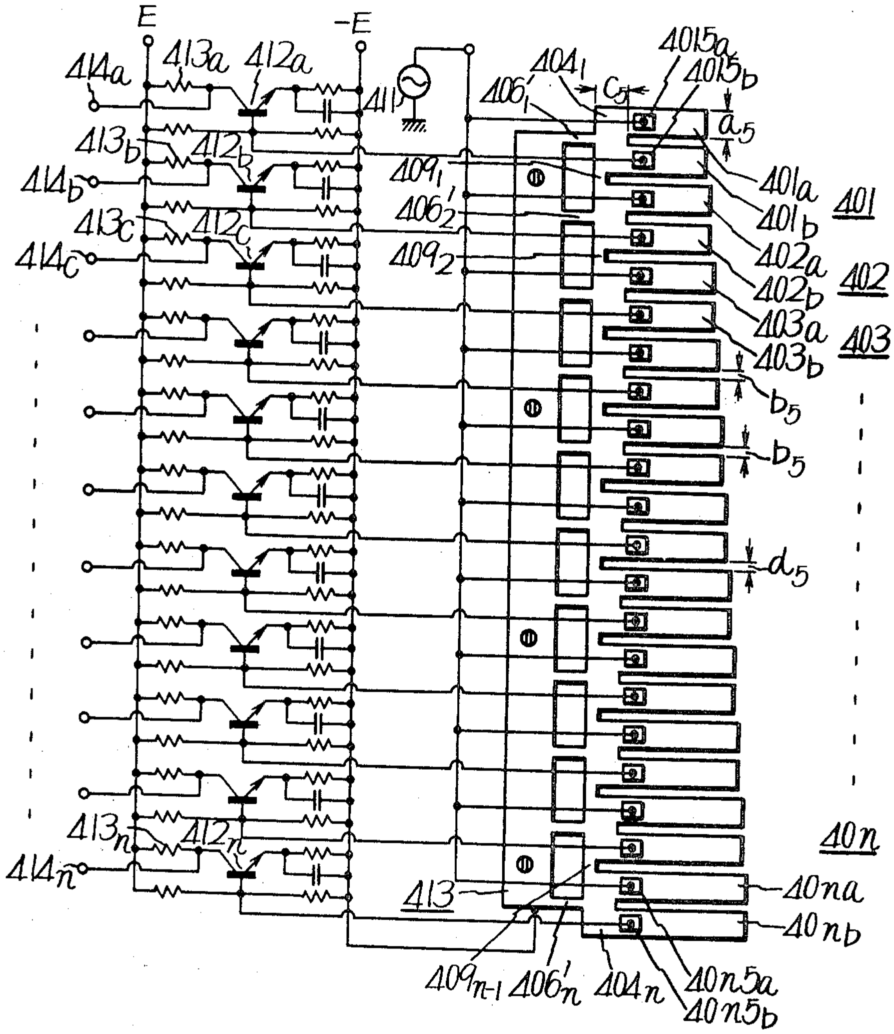

frequency (c/s)
1020
1025
1030
1035
1040
0
5
10
15
20
25
30
loss (dB)
20
21
22

Fig. 25


E
-E
414a
413a
412a
411
4061
4041
c5
4015a
4015b
a5
413b
412b
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4091
4062'
401a
401b
401
413c
412c
414c
4092
402a
402b
402
403a
403b
403
b5
b5
d5
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409n-1
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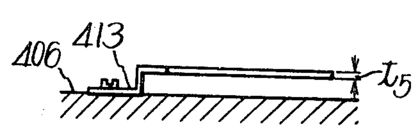
404n
40n5a
40n5b

Fig. 26


406
413
t5

LOW FREQUENCY OSCILLATOR EMPLOYING A PAIR OF U-SHAPED MECHANICAL VIBRATORS

REFERENCE TO RELATED APPLICATIONS

This application is a division of an application entitled "U-Shaped Mechanical Vibrator", Ser. No. 754,416, filed Aug. 21, 1968, and now abandoned in favor of a continuation application of that same title, Ser. No. 88,507, filed Nov. 10, 1970, which issued as U.S. Pat. No. 3,659,230 on Apr. 25, 1972.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a vibrator for use in oscillators, mechanical filters or the like, and more particularly to a vibrator which is small in size, easy to manufacture and suitable for mass production.

2. Description of the Prior Art

In the prior art the so-called tuning fork has been proposed as a vibrator but fabrication of such a conventional tuning fork involves an appreciable amount of time and high precision cannot be expected so that the prior art tuning fork is not suitable for mass production. Further, miniaturization is very difficult.

SUMMARY OF THE INVENTION

The principal object of this invention resides in the provision of a novel mechanical vibrator which is free from the drawbacks experienced in the prior art.

The mechanical vibrator of this invention can be produced by punching process or etching of a thin sheet metal, and hence is easy to manufacture, high in precision and suited for mass production. Further, the present invention allows ease in the production of extremely miniaturized vibrators.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a perspective view showing a conventional tuning fork;

FIG. 2 is a plan view showing one example of a planar tuning fork type mechanical vibrator produced according to this invention;

FIG. 3 is a side view of the vibrator depicted in FIG. 2;

FIG. 4 is a perspective view showing the manner in which the vibrator of FIG. 2 vibrates;

FIG. 5 is a graph showing loss-frequency characteristics relative to the position of electromechanical transducer elements;

FIG. 6 is a graph showing loss-frequency characteristics relative to the size of the electromechanical transducer elements;

FIG. 7 is a connection diagram illustrating one example of an oscillator circuit employing the vibrator of this invention;

FIG. 8 is a graph showing its frequency variation rate relative to temperature change;

FIG. 9 is a plan view illustrating, by way of example, one process for the manufacture of the vibrator of this invention;

FIG. 10 is a plan view showing still another example of the vibrator of this invention;

FIG. 11 is a side view of the vibrator depicted in FIG. 10;

FIG. 12 is a plan view illustrating one example of a planar compound vibrator consisting of two vibrators of this invention assembled in side-by-side relation;

FIG. 13 is a side view of the planar compound vibrator exemplified in FIG. 12;

FIG. 14 is a connection diagram illustrating one example of the planar compound vibrator as applied to an oscillator;

FIG. 15 is a graph showing its frequency variation rate relative to temperature change;

FIGS. 16A and 16B are side views respectively illustrating other examples of the planar compound vibrator of this invention;

FIG. 17 is a plan view showing one example of a filter employing two planar vibrators of this invention;

FIG. 18 is a side view of the filter shown in FIG. 17;

FIG. 19 is a graph showing loss frequency characteristic curves of the filter of FIG. 17 with the coupling degree of its vibrators being as a parameter;

FIG. 20 is a graphical representation of the relationship of the coupling degree to frequency deviation;

FIG. 21 is a schematic diagram showing the connections of a signal source, the filter and output terminals;

FIG. 22 is a graph showing loss-frequency characteristic curves with an external resistance being as a parameter;

FIG. 23 is a plan view illustrating another example of the filter of this invention;

FIG. 24 is a perspective view illustrating still another example of the filter of this invention;

FIG. 25 is a plan view illustrating one example of a frequency selector device employing a plurality of vibrators of this invention; and

FIG. 26 is a side view of the frequency selector device depicted in FIG. 25.

DESCRIPTION OF PREFERRED EMBODIMENTS

In FIG. 1 there is schematically illustrated one example of a conventional mechanical vibrator, commonly referred to as a tuning fork, which consists of a pair of vibratory reeds **1***a* and **1***b* arranged in opposing and predetermined spaced relation and a common base portion **2** interconnecting the reeds. Such a tuning fork is usually produced by machining of a metal block. However, the machining process presents a problem as it requires an appreciable amount of time and introduces a difficulty in obtaining the tuning fork with high precision and hence the prior art tuning fork is not suited for mass production with uniform characteristics. In particular, this imposes a severe limitation on the construction of small-sized tuning forks.

A detailed description will hereinafter be described in connection with a U-shaped mechanical vibrator of this invention which is free from the drawbacks encountered in the prior art.

In accordance with this invention the U-shaped mechanical vibrator consists of a pair of vibratory reeds **3***a* and **3***b* formed of resilient metal sheets in substantially the same configuration and arranged to extend in parallel with each other in the same plane, while being spaced a predetermined distance d_1, and a common plate-like base portion **4** joined contiguously to the vibratory reeds **3***a* and **3***b* and lying in the same plane as the reeds, as illustrated in FIGS. 2 and 3. On the vibratory reeds **3***a* and **3***b* there are fixedly mounted in close proximity to the base portion **4** electromechanical transducer elements such as piezoelectric elements **5a** and **5b** of, for example, PZT (zircon lead titanate). Further, one portion of the base portion **4** remote from the vibratory reeds **3a** and **3b** is extended and is bent substantially at right angles to the surface of the reeds **3a** and **3b** to provide a coupling portion **6'**. The free end portion of the coupling portion **6'** is bent substantially at right angles to be parallel with the reeds **3a** and **3b**, thus providing a mounting portion **7**. The mounting portion **7** is secured to a base plate **6** by means of, for example, a screw **8**, by which the U-shaped vibrator is mounted on the base plate **6**. The U-shaped vibrator may be formed, for example, by punching a thin metal sheet to have the vibratory reeds **3a** and **3b**, the base portion **4**, the coupling portion **6'** and the mounting portion **7** as a unitary structure. The vibrator may be made of a resilient material having small coefficient of thermal expansion such, for example, as ELINVAR. With such a vibrator (hereinafter referred to as a planar tuning fork) it has been ascertained that the vibratory reeds **3a** and **3b** vibrate opposite in phase in a direction at right angles to their surfaces (in this case the width W_1 of the vibratory reeds **3a** and **3b** is selected well greater than the thickness t thereof). Namely, the vibratory reeds **3a** and **3b** vibrate in such a mode that they first swing away from their common reference plane in opposite directions and then back to the reference plane, as depicted in FIG. **4**, in which manner the vibratory reeds **3a** and **3b** repeatedly vibrate.

The resonance frequency f of the planar tuning fork is given by the following equation:

$$f=(1/2\pi)=(\alpha_m 2/l^2)\cdot(t/\sqrt{12})\ \sqrt{(E/\rho)} \qquad (1)$$

where αm is a coefficient varying with vibrating conditions of the tuning fork and is 1.8751 in the case of basic vibration, namely m being equal to 1, l is the length of the vibratory reeds **3a** and **3b** in their longitudinal direction (refer to FIG. **2**), t their thickness (refer to FIG. **3**) , ρ the density of their material and E its Young's modulus.

For example, in the case where l is 18.5 mm., t is 0.5 mm., the width W_1 of the vibratory reeds **3a** and **3b** is 1.8 mm. and the distance d_1 between the vibratory reeds is 1 mm., the resonance frequency f of the tuning fork is 1,015 c/s from the above equation 1.

Now, a discussion will be made in connection with the influence exerted on the vibration of the vibratory reeds **3a** and **3b** by the position of the piezoelectric elements **5a** and **5b**. With the distance d_2 from the piezoelectric elements **5a** and **5b** to a demarcation line **9** between the vibratory reeds **3a** and **3b** and the base portion **4** being 1 mm., 0 and −1 mm., the elements **5a** and **5b** each being formed of PZT to have a length L_0 of 3.0 mm., a width W_0 of 1.7 mm. and a thickness of 0.25 mm., the insertion loss vs. frequency characteristics are respectively given as indicated by curves **10, 11** and **12** in FIG. **5** in which the ordinate represents loss in dB and the abscissa frequency in c/s and d_2 is employed as a parameter. As will be apparent from the graph, when $d_2 =$ 1 mm. the resonance frequency f is 1,015.5 c/s nearly equal to the aforementioned calculated value and when $d_2 = 0$ and −1 mm. the resonance frequencies are respectively as high as 1,041.5 c/s and 1,044.5 c/s. This is considered to result from the fact that the piezoelectric elements **5a** and **5b** act as stiffness on the vibratory reeds **3a** and **3b**, not as mass. The Q's of the planar tuning fork in the above three cases are 1,128 in the case of d_2 being 1 mm., 1,160 in the case of d_2 being 0 and 1,158 in the case of d_2 being −1 mm., and the Q in the first case is a little lower than the others. This implies that the Q lowers as the piezoelectric elements approach the side of the vibratory reeds **3a** and **3b** of large amplitude, that is, their free ends. Consequently, the insertion loss is most minimized with d_2 being 1 mm. The ratio of an output voltage to an input voltage, that is, the coupling factor is a little greater when $d_2 = 1$ mm. The foregoing numerical values are given in the following table 1.

TABLE 1

Position d_2 mm.	Resonance frequency (c/s)	Q	Insertion loss (dB)	Coupling factor
A_1	1015.5	1128	0.7	0.029
B_0	1041.5	1160	2.0	0.027
C–1	1044.0	1158	2.0	0.027

FIG. **6** is a graph showing the influence exerted upon the insertion loss by changing the size of the piezoelectric elements **5a** and **5b**, in which the ordinate represents the loss in dB and the abscissa frequency in c/s. In the figure the curve **13** indicates a case of the piezoelectric elements each having a length of 3 mm. and a width of 1.7 mm. and the curve **14** a case of the elements having a size of a length of 1.3 mm. and a width of 1.2 mm. It appears from the graph that the resonance frequencies are approximately equal to 1,015.5 c/s and Q's are also substantially equal to 1,128 but that the insertion losses are 0.7 dB and 3 dB. Further, the coupling factors are 0.027 and 0.025, namely the smaller piezoelectric elements slightly lower the coupling factor.

It is preferred that the distance d_1 between the vibratory reeds **3a** and **3b** be smaller than the width W_1 of each reed, for example, less than one-half thereof. This is because of the fact that with the distance d_1 being greater than the width W_1 of the reeds **3a** and **3b**, torsion or twist is yielded in the base portion **4**, that is, the coupling portion of the reeds which is likely to cause a variation in the resonance frequency. In addition, the width W_1 of the vibratory reeds is selected smaller than the length l_2 of the base portion **4** in the lengthwise direction of the vibratory reeds and the length l_2 is selected, for example, more than 1.5 times as great as the width W_1. The reason is that the length l_2 smaller than the width W_1 causes an increase in vibration rendered to the mounting portion **7** through the coupling portion **6'** from the base portion **4**.

Where the piezoelectric elements **5a** and **5b** are deposited on the same side of the vibratory reeds **3a** and **3b**, an input signal fed to either one of the piezoelectric elements and an output signal obtained from the other piezoelectric element are opposite in phase. Consequently, an output signal in phase with the input signal may be obtained by the use of piezoelectric elements of opposite polarities or by depositing the piezoelectric elements on different surfaces of the vibratory reeds.

FIG. **7** illustrates one example of a self-excited oscillator employing the planar tuning fork of this invention described above, which may be provided by the same connections as a self-excited oscillator using a conventional tuning fork except the use of the planar tuning fork of the present invention, as depicted in the figure. Namely, an amplifier **21** consisting of transistors **19** and **20** of cascade connection is provided and connections are made such that one portion of the output from the output terminal of the amplifier **21** is applied to the piezoelectric element, for example **5***a* of the vibratory reed **3***a* of the planar tuning fork and an output obtained by the other piezoelectric element **5***b* of the vibratory reed **3***b* is fed to the input side of the amplifier **21**, that is, to the base of the transistor **19**, thus providing an oscillator having an oscillation frequency determined by the resonance frequency of the planar tuning fork. In FIG. **8** there is depicted the frequency variation rate $\Delta f/f$ relative to temperature change (°C) in the above case, the ordinate representing the frequency variation and the abscissa temperature. This graph was obtained in the case where only the tuning fork was subjected to temperature change. From the graph it appears that the frequency variation is -1×10^{-5} deg.$^{-1}$ in a range of about 19°C to 59°C, which indicates an excellent characteristic.

Although the foregoing has stated that the planar tuning fork of this invention may be produced by press work (punching process), it may also be made of one base plate by means of chemical etching techniques. That is, grooves **16** are formed in a thin sheet **15** of ELINVAR by chemical etching in a manner to leave the vibratory reeds **3***a* and **3***b*, the base portion **4** and the coupling portion **6'**, as shown in FIG. **9**. In this case, it is preferred to form a groove **17** by chemical etching at a distance from the coupling portion **6'** on the opposite side from the vibratory reeds. With photoetching techniques used in the manufacture of semiconductor devices, smalled-sized tuning forks can be produced with high precision, and the planar tuning fork thus produced is suitable for use with, for example, semiconductor integrated circuit devices.

In the foregoing example the piezoelectric elements are used as electromechanical transducer elements but may be substituted with electromagnetic transducer elements. Namely, instead of mounting the piezoelectric elements **5***a* and **5***b* on the planar tuning fork, electromagnetic units **18***a* and **18***b* each consisting of a core and a coil wound thereon are disposed opposite the vibratory reeds **3***a* and **3***b* in the vicinity of the free ends where their amplitude of vibration is great. With an exciting signal being fed to, for example, the electromagnetic unit **18**a, the vibratory reed **3***a* is driven to vibrate and the vibratory reed **3***b* is thereby driven through the base portion **4**, by which an electric signal of the same frequency as the signal fed to the unit **18***a* is obtained from the electromagnetic unit **18***b*.

As has been described in the foregoing, this invention enables mass production of planar tuning forks of high precision and uniform characteristics without requiring such a troublesome machining of a metal block.

In FIG. **12** there is illustrated another example of this invention in which a plurality of, for example, two planar tuning forks such as depicted in FIG. **2** are jointed together at their base portions with their surfaces being flush with each other. A detailed description will hereinbelow be given of this example. Reference numerals **101** and **102** indicate two planar tuning forks, which are assembled together in the following manner. That is, vibratory reeds **103***a*, **103***b* and **103**a_1, **103**b_1 are disposed substantially in parallel at moderate intervals with their planar surfaces being substantially flush with one another, and coupling portions **106'** and **106**$_1$**'** extending from the base portions **104** and **104**$_1$ on the side remote from the vibratory reeds in parallel relation thereto are secured to a common support **113**, thereby providing an assembly of the tuning forks. In this case the base portions **104** and **104**$_1$ of the planar tuning forks **101** and **102** are jointed together through a joint portion **109**. Reference numerals **105***a*, **105***b*, **105**a_1 and **105**b_1 designate piezoelectric elements fixed mounted on the vibratory reeds of the planar tuning forks, which are identical with those exemplified in FIG. **2**. The planar tuning forks thus assembled together are mounted on a base plate **106** by clamping their common support **113** onto the base plate **106** by means of a screw **116** inserted through a hole **115** bored in the support **113**. It is a matter of course that such a compound tuning fork consisting of the two planar tuning forks **101** and **102** depicted in FIG. **12** may be produced from a sheet metal by means of punching or etching in the same manner as that described above with FIG. **2**.

The resonance frequency of each tuning fork is determined by the equation 1 as previously described but the frequencies of the two planar tuning forks are rendered different from each other by selecting the length of the vibratory reeds of either one of the tuning forks to be smaller or greater than that of the reeds of the other. In FIG. **12** the vibratory reeds **103**a_1 and **103**b_1 of the tuning fork **102** are shorter than those **103***a* and **103***b* of the other tuning fork **101**. It is preferred that the vibratory reeds of the same tuning forks, that is, **103***a* and **103***b* or **103**a_1 and **103**b_1 are identical in shape with each other.

Assuming that the widths of the vibratory reeds of the planar tuning forks **101** and **102** are taken as a_1 and a_2, the distance between the vibratory reeds **103***a* and **103***b* is b_1, the distance between the reeds **103**a_1 and **103**b_1 is b_2 and the lengths of the reeds **103***a*, **103***b* and **103**a_1, **103**b_1 are l_1 and l_2' respectively, a_1, b_1, a_2 and b_2 are selected such that $a_1 > b_1$ and $a_2 > b_2$. This is because of the fact that b_1 or b_2 exceeding a_1 or a_2 produce torsion in the base portion **104** or **104'** to cause a change in the resonance frequency. Further, if the lengths of the base portions **104** and **104**$_1$ in the lengthwise direction of the vibratory reeds are taken as c_1 and c_2 ($c_1 = c_2$ in the figure), c_1 and c_2 are selected greater than the widths a_1 and a_2 of the vibratory reeds. With c_1 being smaller than a_1 or a_2, vibration of the base portion **104** or **104**$_1$ in the direction of the coupling portions **106'** and **106**$_1$**'** increases, which is undesirable as set forth above.

In order to provide the coupling portion **109**, a slit **116'** is formed in the jointed portion of the base portions **104** and **104**$_1$ on the side of the vibratory reeds, in which case the depth W of the slit is selected great enough to permit the tuning forks **101** and **102** to function independently from each other.

For instance, a typical size is such that $a_1 = a_2 = 1.8$ mm., $b_1 = b_2 = 1.0$ mm., W = 1.6 mm., the thickness t_1

of the vibratory reeds **103***a*, **103***b* and **103***a*$_1$, **103***b*$_1$ = 0.5 mm. and the distance *d* between the adjacent vibratory reeds **103***b* and **103***a*$_1$ = 1.0 mm. In such a case, the resonance frequencies f_1 and f_2 of the planar tuning forks **101** and **102** are 1,377 c/s and 1,299 c/s respectively. To electrically drive the tuning forks **101** and **102** to obtain electric signals therefrom, piezoelectric elements **105***a*, **105***b* and **105***a*$_1$, **105***b*$_1$ of, for example, PZT may be deposited by an adhesive binder on the vibratory reeds **103***a*, **103***b* and **103***a*$_1$ and **103***b*$_1$ on the side of the base portions **104** and **104**$_1$.

In the example shown in FIG. **12** the planar tuning forks **101** and **102** are formed as a unitary structure but each of them performs the function of substantially an independent tuning fork. Consequently, it is possible that separate oscillators having the tuning forks as the reference frequency sources are provided and adapted to obtain an output of a frequency corresponding to a difference in their oscillation outputs, so that an oscillation output of low frequency can be obtained with relatively small tuning forks. FIG. **14** is a connection diagram illustrating one example of such construction. In the figure reference numeral **124** indicates an amplifier consisting of transistors **119***a* and **119***b*, the transistor **119***a* having its collector connected to a power source **120** and its emitter grounded through a resistor **121** and connected to the base of the transistor **119***b* and the transistor **119***b* having its collector connected to the power source **120** through a resistor **122** and its emitter grounded through a resistor **123**. Reference numeral **125** designates an oscillator circuit having incorporated therein the amplifier **124**. Namely, the input end of the amplifier **124**, that is, the base of the transistor **119***a* is connected to, for example, the piezoelectric element **105***b* of the vibratory reed **103***b* of the planar tuning fork **101**, and the output side of the amplifier, that is, the collector on the transistor **119***b* is connected to the piezoelectric element **105***a* of the vibratory reed **103***a*, by which the vibratory reed **103***a* is driven to drive the vibratory reed **103***b* and the transistor **119***b* is driven by an output of the piezoelectric element **105***b* of the vibratory reed **103***b* to permit oscillation of the oscillator circuit **125** at the resonance frequency of the planar tuning fork **101**. In a similar manner an amplifier **130** is constituted with transistors **126***a* and **126***b*, and the input side of the amplifier **130**, that is, the base of the transistor **126***a* is connected to the piezoelectric element **105***b*$_1$ of the other tuning fork **102** and the output side of the amplifier, that is, the collector of the transistor **126***b* is connected to the piezoelectric element **105***a*$_1$, thus providing an oscillator circuit **126** oscillating at the resonance frequency of the planar tuning fork **108**. Further, these oscillator circuits **125** and **126** are interconnected and their outputs are fed to a frequency converter. In the figure the oscillators **125** and **126** are coupled together by the mechanical coupling of the planar tuning forks **101** and **102** through the coupling portion **109**, under which conditions when the oscillator, for example, **126** is main, the oscillation frequency f_2 of the oscillator **126** is amplitude-modulated at the oscillation frequency f_1 of the oscillator **125**. Accordingly, the output of the oscillator **126**, that is, the collector output of the transistor **126***b* is fed through a low-pass filter **131** to an amplifier **133** consisting of a transistor **132** of emitter-grounded connection, from an output terminal **134** of which amplifier can be obtained a signal $f_2 - f_1 = f_0$ corresponding to a difference in the oscillation frequencies of the oscillators **125** and **126**. It is also possible in this case that the respective outputs of the oscillators **125** and **126**, that is, the output of the transistor **119**b and the collector output of the transistor **126***b* are separately applied to the common frequency converter circuit to obtain a beat frequency therebetween. In order to facilitate coupling of the planar tuning forks through the coupling portion **109** for obtaining an amplitude-modulated signal, it is preferred that in the planar tuning fork **102** of the main oscillator the outer vibratory reed **103***b*$_1$ (on the opposite side from the planar tuning fork **101**) is a drive side and the inner reed **103***a*$_1$ a pickup side and that in the other planar tuning fork **101** the inner vibratory reed **103***b* is a drive side and the outer reed **103***a* a pickup side. The planar tuning forks **101** and **102** for producing the reference frequencies of the oscillators **125** and **126** for obtaining a beat signal are produced as a unitary structure by punching of a resilient sheet of metal, for example, ELINVAR. Consequently, the frequency vs. temperature characteristics of the two oscillators are substantially the same and further since a difference frequency is obtained, a beat frequency output remarkedly stable in temperature can be produced. In FIG. **15** there is illustrated frequency change ratio $\Delta f/f$ relative to temperature change in the case where only the planar tuning forks **101** and **102** are subjected to temperature change. It appears from the graph that the temperature coefficient is substantially zero in a temperature range of 19°C to 65°C. In the illustrated example f_1 = 1,377 c/s, f_2 = 1,299 c/s and f_0 = 78 c/s at a temperature of 20°C. Since a signal corresponding to the difference in the oscillation frequency between the two oscillators is taken out as described above, even if the planar tuning forks **101** and **102** are miniaturized, a low-frequency signal can be obtained. In the prior art, a tuning fork oscillating, for instance, at 78 c/s is bulky and is difficult to drive. In the example depicted in FIG. **14** the piezoelectric elements are employed as electric transducer elements but they may be replaced with, for instance, electromagnetic transducer units or electrostatic transducer units, as will hereinbelow be described with FIG. **16**. That is, as depicted in FIG. **16**A an electromagnetic unit **135** consisting of a magnetic member and a coil wound thereon is disposed opposite the vibratory reed of the planar tuning fork, or fixed electrode **136** is placed as the electrostatic transducer unit in opposed relation to the vibratory reed, as illustrated in FIG. **16**B, in which case a high DC voltage source **137** is applied between the electrode **136** and the vibratory reed while at the same time applying or taking out an AC signal. It will be apparent that all or some of the piezoelectric elements **105***a*, **105***b*, **105***a*$_1$ and **105***b*$_1$ may be substituted with the electromagnetic or electrostatic transducer elements and that all these transducer elements may be used in combination. Although the foregoing description has been made in connection with the use of an assembly of two planar tuning forks, it is possible to use an assembly of three tuning forks, in which case a difference between the vibration frequencies of two tuning forks is first obtained and then a difference between the resulting difference frequency and the vibration frequency of the remaining tuning fork is obtained. Further, it is easy to produce an oscillator having oscillation frequencies corresponding to the differences in the vibration frequencies of more than four tuning forks.

In FIGS. **17** and **18** planar tuning forks of this invention such as depicted in FIG. **2** are mechanically coupled together in the same manner as in the example shown in FIGS. **12** and **13**. The similar parts to those in FIGS. **12** and **13** are identified by the similar reference numerals and no detailed description will be repeated for the sake of brevity. In this case the vibratory reeds **103***a*, **103***b*, **103***a*$_1$ and **103***b*$_1$ of the planar tuning forks **101** and **102** are substantially equal in length l_4 to one another. As driving and detecting elements of a filter, piezoelectric elements of, for example, PZT are used but in the present example the piezoelectric elements are mounted on the two outer vibratory reeds **103***a* and **103***b*$_1$ of the tuning forks **101** and **102** in proximity to the base portion **104** and **104**$_1$ thereof, as indicated by **105***a* and **105***b*$_1$.

The resonance frequency f of these planar tuning forks **101** and **102** is given by the aforementioned equation 1;

$$f=(1/2\pi)(\alpha_m 2/l^2)(t/\sqrt{12})\sqrt{(E/\rho)}$$

For example, where $l_4 = 1.85$ cm. and $t = 0.05$ cm., the resonance frequency f is 10,150 c/s.

Applying an electrical signal to the piezoelectric element **105***a* of the planar tuning fork **101**, the vibratory reed **103***a* is thereby vibrated, which leads to driving of the vibratory reed **103***b* in anti-phase relation to the reed **103***a*, thus rendering the planar tuning fork in its driven condition. This applies vibration to the planar tuning fork **102** through the coupling portion **109** to cause its vibratory reeds **103***a*$_1$ and **103***b*$_1$ to be driven at the same time, with the result that an electrical signal is taken out from the piezoelectric element **105***b*$_1$ of the vibratory reed **103***b*$_1$ of the planar tuning fork **102**. In such a case, the planar tuning forks **101** and **102** are caused to vibrate only by a signal having a particular frequency equal to their resonance frequency, and they hardly vibrate at other frequencies. Therefore, a filter having a pass band corresponding to the oscillation frequency of the planar tuning forks can be provided.

By the way, if the width of the vibratory reeds of each of the planar tuning forks **101** and **102** is taken as a and the distance between adjacent vibratory reeds is b, b is selected to be about one half of a. When b is greater than a pseudo-vibration is caused in the base portions **104** and **104**$_1$ to shift the resonance frequency. In addition, the length c of the base portion **104** or **104**$_1$ in the lengthwise direction of the vibratory reeds is selected greater than the width a of the vibratory reeds, for example, about 1.5 times as great as the width a. This is because of the fact that when c is smaller than a vibration is much transmitted to the support **113** through the coupling portions **106'** and **106**$_1$'. It is preferred to locate the piezoelectric elements **105***a* and **105***b*$_1$ a little further to the free end of the vibratory reeds than the demarcation between the reeds and the base portions **104** and **104**$_1$. In this case the resonance frequency of the planar tuning forks becomes approximately equal to the aforementioned equation 1. There is a tendency that shifting of the piezoelectric elements toward the free ends of the vibratory reeds causes their resonance frequencies to deviate higher. Now, the coupling portion **109** will be discussed. If the distance from the coupling portion **109** to the demarcation between the vibratory reeds **103***b* and **103***a*$_1$ and the base portions **104** and **104**$_1$ is taken as W, a loss characteristic curve with W varying as a parameter is as shown in FIG. **19**, in which the ordinate represents loss in dB and the abscissa frequency in c/s. That is, curves **12**, **13** and **14** respectively indicate the cases of W being 1.50 mm., 1.56 mm. and 1.62 mm. From the graph it appears that a decrease in W tightens the coupling of the two planar tuning forks **101** and **102** and causes the characteristic curve to be double-humped and widens its pass band, for example, up to about 8 c/s in the graph. In the case of the curve **13** the pass band is approximately 5 c/s. With the lowering of the coupling of the planar tuning forks, that is, with an increase in W, the characteristic curve becomes to be substantially single-humped and its pass band width becomes 2.5 c/s. The depths of the troughs of the curves **12**, **13** and **14** are respectively 8 dB, 5 dB and 1 dB. It will be understood from this that the band width can be widened by decreasing W to increase the coupling of the planar tuning forks **101** and **102** and that the band width can be narrowed by increasing W to decrease the coupling. In the above example the values of a, b, ...t are those previously mentioned and the piezoelectric elements of PZT are employed and are of a size of 3×2 mm^2. Further, it will be seen that the relation between the frequency difference of the peaks of the characteristic curves and W is such that an increase in W causes a linear decrease in the frequency difference as shown in FIG. **20**, the abscissa representing W in mm. and the ordinate the frequency difference in c/s.

The filter characteristic of the filter such as depicted in FIGS. **17** and **18** can be improved by input and output resistances. That is, as shown in FIG. **21**, a signal is applied to the filter **215** of this invention from a signal source through a resistor **217**, namely the signal is fed to the piezoelectric element **105a** of the filter **215**, and a resistor **218** is connected between the output side or the piezoelectric element **105b**$_1$ and ground, and output terminals **219** are led out from the both ends of the resistor **218**. This provides a maximum output when the resistance value R_2 of the resistor **218** on the output side is $(1/2\pi fc_1)$, c_1 being the capacitive component of the piezoelectric element PZT. Where the resonance frequency is 1,000 c/s and the capacitive component c_1 of PZT is 2,000 PF, $R_2 = 1$ megohm is a maximum output. In FIG. **22** there is illustrated a graph showing loss frequency characteristic curves obtained with the resistance values of the resistors **217** and **218** being altered, the ordinate representing loss in dB and the abscissa frequency in c/s. The curve **20** in the graph indicates the case where the resistance value R_1 of the resistor **217** is zero and R_2 is infinite, in which case the depth of the trough between peaks of the curve **20** is 6.5 dB and the insertion loss at the peaks is approximately zero. When $R_1 = 0$ and $R_2 = 1$ MΩ, the insertion loss at the peaks is about 9 dB but the characteristic curve becomes nearly single-humped and the depth of the trough is 3 dB. Further, when R_1 is 1 MΩ, the insertion loss is the same as in the above but the characteristic curve becomes further single-humped and the depth of the trough is about 1 dB. The band width does not vary with the resistance value R_2 but lowers from 5 c/s to 4.5 c/s when R_1 is altered from 0 to 1 MΩ.

As has been described above, this invention permits of fabrication of the tuning fork filter by means of punching a sheet metal and allows ease in mass production of miniature and highly precise filters. The band width can be adjusted by controlling the coupling degree of the coupling portion **109** of the two planar tuning forks **101** and **102**.

The filter described above exhibits excellent temperature characteristic such that the frequency change ratio relative to a temperature change is -1×10^{-5} or so. In addition, the cut-off characteristic of the filter is also excellent, as will be seen from the aforementioned loss characteristic.

The cut-off characteristic can be enhanced by further connecting the planar tuning forks in side-by-side relation, as exemplified in FIG. **23**. In the figure a planar tuning fork **103** identical with the forks **101** and **102** is interposed therebetween, and these tuning forks may be produced by punching of a sheet metal. In this case all the planar tuning forks are coupled integral with the support **113** through a coupling portion $\mathbf{106_2}'$ extending from a base portion $\mathbf{104_2}$ of the intermediate tuning fork **103**, while leaving out the coupling portions **106'** and $\mathbf{106_1}'$ of the other planar tuning forks depicted in FIG. **17**. In order to couple the three planar tuning forks, coupling beams $\mathbf{109_1}$ and $\mathbf{109_2}$ are fixedly disposed between the vibratory reeds of the intermediate planar tuning fork **103** and the inner ones of the adjacent tuning forks, thus providing a unitary structure of the planar tuning forks. With the three planar tuning forks **101**, **102** and **103** being coupled together in side-by-side relation, a filter of excellent selectivity can be obtained. It is possible to connect more planar tuning forks in side-by-side relation.

In the above example, the planar tuning forks are arranged with their vibratory reeds lying substantially in one plane but such arrangement is not always necessary. It is sufficient only to dispose a pair of vibratory reeds of at least one planar tuning fork in one plane. For example, it is possible that a plurality of planar tuning forks are assembled together by suitable coupling member in a manner to arrange their pairs of vibratory reeds one over another in spaced relation, as exemplified in FIG. **24**. In the figure, four planar tuning forks **301**, **302**, **303** and **304** each having their two vibratory reeds in one plane are employed and these planar tuning forks are assembled together to arrange their pairs of vibratory reeds one over another in opposed and moderately spaced relation, and base portions **304**, $\mathbf{304_1}$, $\mathbf{304_2}$ and $\mathbf{304_3}$ of the planar tuning forks **301**, **302**, **303** and **304** are extended in a direction remote from the vibratory reeds. The extended base portions are respectively put between block members $\mathbf{30}b$, $\mathbf{30}b_1$, $\mathbf{30}b_2$ and $\mathbf{30}b_3$ and bonded together, and coupling members $\mathbf{309_1}$, $\mathbf{309_2}$ and $\mathbf{309_3}$ are each interposed between adjacent planar tuning forks at a place on the base portions **304**, $\mathbf{304_1}$, $\mathbf{304_2}$ and $\mathbf{304_3}$, or on the vibratory reeds close to the portion, thus interconnecting the planar tuning forks. In this case it is preferred that the planar tuning forks are each produced by punching of a sheet metal and assembled together so as to ensure uniformity of their temperature characteristic. Also in this case piezoelectric elements are mounted on the vibratory reeds of the uppermost and lowermost tuning forks.

In the examples above described with FIGS. **17**, **23** and **24** the filters employ the plate-like planar tuning forks and hence they can be miniaturized in construction. Further, the planar tuning forks of high precision and uniform characteristics can be mass produced by punching process to ensure the fabrication of excellent filters. The use of the photoetching techniques employed in the manufacture of semiconductors allows ease in the production of small-sized planar tuning forks, which leads to further miniaturization of the filters.

In the above examples the piezoelectric elements are used as driving and detecting elements of the filters but they may be replaced with electromagnetic or electrostatic elements. It is of course possible to employ these three electromechanical transducer elements in combination.

FIGS. **25** and **26** illustrates a frequency selector unit which is applicable to an alarm device, a frequency analyzer or the like and in which a plurality of planar tuning forks of this invention are employed and signals are selectively picked up according to their frequencies from many input signals of different frequencies.

In the figure reference numerals **401**, **402**, **403**, ... **40**n respectively designate planar tuning forks such as exemplified in FIG. **2**. The tuning forks **401**, **402**, ...**40**n are respectively provided with a pair of vibratory reeds **401**a and **401**b, **402**a and **402**b, ... **40**na and **40**nb, in exactly the same manner as in the foregoing examples. All the planar tuning forks **401**, **402**, ...**40**n are assembled together as a unitary structure at their base portions $\mathbf{404_1}$, $\mathbf{404_2}$, ...$\mathbf{404}_n$ through coupling portions $\mathbf{409_1}$, $\mathbf{409_2}$, ...$\mathbf{409}_{n-l}$ in such a manner that their vibratory reeds **401**a, **401**b, ...**40**na, **40**nb may lie in the same plane at certain intervals. Free ends of coupling portions $\mathbf{406_1}'$, $\mathbf{406_2}'$ ....$\mathbf{406}_n'$ extending from the central portions of the base portions of the tuning forks in a direction opposite to the vibratory reeds are bent substantially at right angles and are secured to a support **413** parallel to a base plate **406** which support **413** extends substantially in parallel with the vibratory reeds. Further, electromechanical transducer elements such, for example, as piezoelectric elements **4015**a and **4015**b, **4025**a and **4025**b, ...**40**n**5**a and **40**n**5**b are deposited, by means of an adhesive binder, on the vibratory reeds **401**a and **401**b, **402**a and **402**b, ...**40**na and **40**nb of the planar tuning forks **401**, **402**, ...**40**n in proximity to the base portions $\mathbf{404_1}$, $\mathbf{404_2}$, ...**404**n thereof. The planar tuning forks **401**, **402**, **403**, ...**40**n are different in length of the vibratory reeds so as to obtain different resonance frequencies. The resonance frequencies f of the planar tuning forks are given by the aforementioned equation **1** as in the foregoing examples:

$$f=(1/2\pi)\cdot(\alpha_m 2/l^2)\cdot(t/\sqrt{12})\cdot\sqrt{(E/\rho)}$$

In FIG. **25** the planar tuning forks **401**, **402**, **403**, ...**40**n are adapted such that their resonance frequencies $f_{41}, f_{42}, f_{43}, ...f_{4n}$ gradually lower. Namely, the lengths of the vibratory reeds of the planar tuning forks are rendered sequentially greater. In each tuning fork the width a_5 of its vibratory reeds is selected greater than the space b_5 between the reeds, for example, $(a_5 12) \approx b_5$. With b_5 being greater than a_5 torsional vibration is yielded in the base portion to change the resonance frequency f and hence a stable resonance frequency cannot be obtained. Further, the length c_5 of the base portion in the lengthwise direction of the vibratory reeds is selected greater than the width a_5, for example, $1.5a_5 \approx c_5$. When c_5 is smaller than a_5, vibration of the vibratory reeds is much transmitted from the coupling portion to the support to cause loss. As in the foregoing examples, the vibratory reeds of each planar tuning fork vibrate in anti-phase relation to each other at right angles to their plane. That is, they vibrate in such a manner that they first go away from their plane in opposite directions and then back to the plane.

In FIG. 25 the coupling portions 409_1, 409_2, ...409_{n-1} are formed contiguous to adjacent ones at the ends of the base portions of the planar tuning forks remote from the vibratory reeds but coupling members may be formed contiguous directly to the vibratory reeds in proximity to the base portions thereof. These planar tuning forks, their coupling portions and the support may be produced by punching process of a sheet of a resilient alloyed metal such as ELINVAR. That is, they are produced successively from one material without interruption. Where the piezoelectric elements of PZT are employed as the electromechanical transducer elements, it is preferred to locate them on the vibratory reeds of the planar tuning forks in close but definitely spaced relation to the base portions so as to obtain resonance frequencies nearly equal to calculated values. Further, it is also preferred to form the coupling portions 409_1, 409_2, 409_3, ...409_{n-1} as small as possible to ensure the elimination of interference between adjacent planar tuning forks. The support **413** for mounting the planar tuning forks on the same base plate **406** may be formed in common to all the tuning forks but may be provided separately for each of them.

The electromechanical transducer elements **4015a**, **4025a**, **4035a**, ...**40n5a**, each being one of the elements in pairs, are connected to a common signal source **411**. Namely, signals are impressed from the common signal source **411** to the planar tuning forks in parallel relation. While, signals are separately led out from the other electromechanical transducer elements **4015b**, **4025b**, **4035b**, ...**40n5b**. In the figure transistors **412a**, **412b**, **412c**, ...**412n** are provided each for each of the planar tuning forks **401**, **402**, ...**40n** and are connected, for example, in am emitter grounded manner, the collectors of the transistors being respectively connected to one end of a power source E through resistors **413a**, **413b**, **413c** ......**413n** and the bases being respectively connected to the transducer elements **4015b**, **4025b**, ...**4025n** of the output side of the planar tuning forks. In addition, output terminals **414a**, **414b**, **414c**, ...**414n** are connected to the collectors of the transistors.

With such an arrangement as shown in FIG. **25**, upon application of a signal having a frequency f_{41} from the signal source **411** to the selector, only the planar tuning fork **401** vibrates to thereby feed a signal to the transistor **412a**, providing a signal of the frequency f_{41} at the output terminal **414a**. In a similar manner, only the planar tuning fork having a resonance frequency equal to the frequency of a signal fed from the signal source vibrates to provide a signal output at the terminal corresponding to the vibrated planar tuning fork, by which the frequency of the signal from the signal source **411** can be known. Even if a plurality of signals of different frequencies are simultaneously applied from the signal source **411** to the selector, only the planar tuning forks corresponding to the particular frequencies vibrate to produce signals at the corresponding output terminals. Thus, the selector unit of this example enables detection of the frequencies of the signals from the signal source **411** at the output terminals. Consequently, the unit can be used as a frequency analyzer unit, an alarm device or the like. In the case of the alarm device, a plurality of alarm signal sources placed at different locations are adapted to raise alarm signals of different frequencies, by which detection of an output produced at any of the output terminals **414a**, **414b**, **414c**, ...**414n** enables location of the source of the alarm signal being raised.

As described above, the selector unit employing the planar tuning forks of this invention enables discrimination of signal frequencies and in this case the planar tuning forks **401**, **402**, **403**, ...**40n** are formed as a unitary structure with their vibratory reeds lying in substantially the same plane, so that the entire structure can be produced by punching process of one sheet metal to facilitate the fabrication. Further, these planar tuning forks are of substantially the same temperature characteristic and hence a selector unit stable in temperature can be obtained. Even if the temperature characteristic is a little altered, the alterations of the planar tuning forks are rendered uniformly in the same direction and hence can easily be compensated for. If the punching template of high precision is made, highly precise selector unit can be mass produced.

In the foregoing the piezoelectric elements are used as the electromechanical transducer elements but they may be substituted with electromagnetic or electrostatic transducer elements. In addition, a high precise selector unit can be produced as described above, so that if input signal frequencies are extremely close to one another, the insertion loss can be held low because of sharp resonance frequency characteristic of the planar tuning forks. For example, when $a_5 = 1.8$ mm., $b_5 = 1.0$ mm., $c_5 = 1.35$ mm., $d_5 = 18.5$ mm. and $t_5 = 0.5$ mm., the resonance frequency is 1,015.0 c/s and Q is more than 1,100 and insertion loss can be held lower than 0 to several dB.

It will be apparent that many modifications and variations may be effected without departing from the scope of the novel concepts of this invention.

We claim as our invention:

1. A low frequency oscillator comprising two U-shaped mechanical vibrators, each including a pair of strip-like vibratory reeds of substantially the same configuration and a base portion coupling together the pair of vibratory reeds at one end as a unitary structure, the width of each of the vibratory reeds being selected fully greater than the thickness thereof, the pair of vibratory reeds being arranged in spaced and parallel relation to each other with their surfaces lying in substantially the same plane and vibrating in anti-phase relation to each other at right angles to the plane which includes their surfaces, the length of the vibratory reeds of one of said

U-shaped mechanical vibrators being selected shorter than that of the other vibrator so that said vibrators vibrate at the respective frequencies f_2 and f_1, a first electromechanical transducer element fixedly mounted on one of the vibratory reeds of said one U-shaped mechanical vibrator and a second electromechanical transducer element fixedly mounted on the other vibratory reed of said one U-shaped mechanical vibrator, a first amplifier having an input connected to said first transducer element and an output connected to said second transducer element, a third electromechanical transducer element fixedly mounted on one of the vibratory reeds of said other U-shaped mechanical vibrator, a fourth electromechanical transducer element fixedly mounted on the other vibratory reed of said other U-shaped mechanical vibrator, a second amplifier having an input connected to said third transducer element and an output connected to said fourth transducer element, a mechanical coupling connecting said base portions of said vibrators to effect amplitude modulation of the frequency f_2 at the frequency f_1, and a low pass filter connected to said output of said first amplifier to provide the low frequency $f_0=f_2-f_1$.

2. A low frequency oscillator according to claim 1, wherein each of said transducer elements is a piezoelectric element.

3. A low frequency oscillator according to claim 1, comprising a third amplifier connected to said low pass filter for receiving and amplifying oscillations at the low frequency f_0.

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