PATENT SPECIFICATION 981,014

981,014

DRAWINGS ATTACHED.

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Int. Cl.:—**G 04 c** //H 02 k, H 03 c, f.

COMPLETE SPECIFICATION.

Improvements in or relating to Electromagnetically Actuated Timepieces.

We, BULOVA WATCH COMPANY, INC., a Corporation organized under the laws of the State of New York, one of the United States of America, of 630 Fifth Avenue, City of New York, Zone 20, State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

Our invention relates generally to electromagnetically actuated timepieces, and more particularly to improved electromagnetic transducer arrangements and transistor drive circuits therefor to actuate a tuning fork timekeeping standard.

In Canadian Patent 609,691 of November 29, 1960, French Patent 74,802 of June 13, 1958, German Patent 1,124,433 of June 14, 1958, British Patent 854,196 of June 9, 1958, Italian Patent 591,162 of June 12, 1958, Japanese Patent 301,465 of October 30, 1962, and Swiss Patent 353,311 of June 19, 1953 entitled "Electrically Controlled Timepiece" and in Canadian Patent 583,728 of September 22, 1959, French Patent 1,153,306 of May 12, 1956, German Patent 1,095,747 of May 12, 1956, British Patent 840,086 of May 14, 1956, Italian Patent 552,682 of May 12, 1956, Japanese Patent 249,402 of February 16, 1959, Mexican Patent 59,196 of May 12, 1956, and Swiss Patent 342,171 of May 12, 1955, entitled "Electrical Timepiece" there are disclosed devices making use of a tuning fork having a predetermined natural frequency, the fork being pulsed electromagnetically by means of a battery-operated transistor circuit which excites the fork into vibration and sustains the motion thereof.

This motion is transferred to a rotary gear train by means of a pawl secured to one tine of the fork, the pawl advancing a ratchet or index wheel which drives the train.

The drive circuit for the tuning fork is constituted by a drive coil electromagnetically coupled to the tuning fork and connected to a transistor amplifier whose operation is controlled by a phase-sensing or pick-up coil similarly coupled to the tuning fork, the alternating voltage induced in the sensing coil by the vibration of the fork being applied to the transistor to render it conductive periodically and thereby produce drive pulses in the drive coil.

The tuning fork, which is operatively coupled to both coils, in effect acts as a feedback link for the transistor amplifier, and when the amplification factor of the amplifier exceeds the damping of this feedback element, under proper phase conditions the tuning fork is excited into vibration and the oscillation thereof is sustained by the amplifier.

In practical embodiments of this arrangement, it is difficult to separate or isolate the drive coil and pick-up coil transducers and as a consequence electromagnetic or electrostatic coupling between these transducers may lead to a higher degree of feedback than that brought about by the tuning fork. Hence the amplifier will be caused to oscillate parasitically at a frequency determined not by that of the tuning fork but by the unwanted stray feedback. When this occurs, vibration of the tuning fork may cease and the timepiece be rendered inoperative.

Such stray coupling is particularly acute in small electronic watch movements where, because of the limited space available, it becomes necessary to combine the sensing coil and a section of the drive coil on one transducer operatively coupled to one tine of the fork, the main section of the drive coil being placed on the second transducer operatively coupled to the other tine. For example, in one form of watch now in commercial use, 6,000 turns of the drive coil as well as 2,000 turns of sensing coil are both wound on one coil form, the remaining 8,000 turns of drive coil being wound on a second form. Thus while the resultant transducers have the same total number of turns and are therefore of equal size, a strong electromagnetic coupling is developed between the pick-up and drive systems. This gives rise in the circuit to parasitic oscillations having a frequency of several kilocycles.

While one may shunt out these high frequency oscillations with a by-pass capacitor whose reactance is relatively great at the lower frequency of the mechanical oscillations, the capacitor also acts to impart a phase shift which, however small, is nevertheless sufficient to bring about a change in timing amounting to an error of some seconds per day. Moreover since the phase shift varies somewhat with temperature, this introduces a further inaccuracy. The shunt capacitor not only impairs the accuracy of the watch, but because of its bulk it adds to the space requirements. This of course is a disadvantage in highly compact watch mechanisms where space is at a premium.

Accordingly, the principal object of the invention is to provide a transducer arrangement for an electronically actuated tuning fork in which feedback between the sensing and drive coils is obviated without the use of shields or a shunt capacitor, thereby avoiding the disadvantages incident to such expedients and improving the accuracy of the timepiece.

More specifically, it is a feature of the invention to provide a transducer wherein the sensing coil turns are so arranged and wound relative to the drive coil turns as to preclude unwanted coupling therebetween, without impairing the operative relationship between these coils and the tuning fork.

Another feature of the invention is to provide a transistor circuit for a timepiece of the above-described type which consumes less power and which operates effectively over a greater temperature range.

A further feature of the invention is to provide an electronically operated stop watch of high efficiency in which the start and stop delay is but a small fraction of a second.

The sensing coil is wound along the coil form in two series-connected halves, which are wound in opposing directions, the half sections of the sensing coil being symmetrically arranged with respect to the drive coil winding whereby the transfer inductivity therebetween is effectively zero. The divided sensing coil however is distributed within an annular air gap formed between a cylindrical magnet and a surrounding cup, the flux density in the air gap decreasing progressively as one moves inwardly from the open end of the cup. Hence the voltage induced in the one half of the sensing coil adjacent the open end is substantially greater than in the counterwound other half and the total output voltage of the series-connected halves is relatively large despite the bucking arrangement thereof.

A further significant feature of the invention resides in the use of a grounded collector silicon transistor drive circuit which has an extremely low leakage current, thereby minimizing power losses.

For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made to the accompanying drawings wherein:—

Fig. 1 is a schematic representation in perspective of the basic components of an electronic timepiece in accordance with the invention;

Fig. 2 is the electrical circuit diagram of the timepiece;

Fig. 3 is a sectional view of one transducer showing the winding arrangement of the pick-up and drive coils;

Fig. 4 is the equivalent circuit diagram transducer;

Fig. 5 shows a modified electrical circuit diagram for the timepiece which includes a stop watch arrangement; and

Fig. 6 is a modified coil carrier for the transducer.

Referring now to Fig. 1 of the drawings, the major components of the timepiece are a timekeeping standard constituted by a tuning fork 10 and an electronic drive circuit 11 therefor, and a rotary movement 12 of conventional design including a gear train for turning the hands of the timepiece which may be a clock, a watch or any other timing mechanism such as a time-delayed switch. Because of the exceptional accuracy of the device, a switching action may be caused to occur within predetermined months, days, hours or minutes or fractions thereof, spaced from a given starting instant. The gear train is driven by means of a pawl 13 connected to one tine of the fork and engaging a ratchet wheel 14 coupled to the rotary movement. The tuning fork has no pivots or bearings and its timekeeping action is therefore independent of the effects of friction.

Tuning fork 10 is provided with a pair of flexible tines 15 and 16 interconnected by a relatively inflexible base 17, the base having an upwardly extending stem 18 secured to the pillar plate of the timepiece by suitable screws 19 and 20. The central area of the pillar plate is cut out to permit unobstructed vibration of the tines.

The tuning fork is actuated by first and second transducer T_1 and T_2. Transducer T_1 is constituted by a magnetic element 21 secured to the free end of tine 15, the element coacting with a drive coil 22 and a pick-up or phase sensing coil 23. The two coils are wound in a manner to be later described on an open ended tubular carrier 24 affixed to a hub-assembly mounting form secured to the pillar plate. The second transducer T_2 includes a magnetic element 25 secured to the free end of tine 16 and coacting with a drive coil 26 wound on a tubular carrier 27.

The electronic drive circuit 11 comprises a transistor 28, a single cell battery 29 and an R-C biasing network formed by condenser 30 shunted by resistor 31. Transistor 28 which may be of the Germanium junction PNP type, is provided with base, emitter and collector electrodes designated B, E and C, respectively.

The base B is coupled through the R-C network 30—31 to one end of phase sensing coil 23, the other end of which is connected to one end of drive coil section 22. The main drive coil section 26 is connected in series with drive coil section 22 to collector electrode C of the transistor.

Emitter E is connected to the positive terminal of battery 29, the negative terminal thereof being connected to the junction of drive coil 22 and phase-sensing coil 23. Thus battery 29 is connected serially through both drive coils 22 and 26 between the emitter and collector of the transistor, the collector being negative relative to the emitter. Battery 29 should be of the type providing a highly stable voltage (i.e., 1.3 volts) for almost the full duration of its usable life.

The interaction of the electronic drive circuit 11 and the tuning fork is self-regulating and functions not only to cause the tines to oscillate at their natural frequency, but also to maintain oscillation at a substantially constant amplitude.

In operation, an energized pulse applied to the drive coils of the transducers will cause an axial thrust on the associated magnetic element in a direction determined by the polarity of the pulse in relation to the polarization of the permanent magnet therein and to an extent depending on the energy of the pulse. Since the magnetic element is attached to a tine of the tuning fork, the thrust on the element acts mechanically to excite the fork into vibration.

The resultant movement of the magnetic element relative to the fixed coils induces a back emf in the drive coils and in the case of transducer T_1 in the phase sensing coil as well. Since the magnetic element reciprocates in accordance with the fork motion, the back emf will take the form of an alternating voltage whose frequency corresponds to the fork frequency. The voltage picked up by the sensing coil is applied to the base of the transistor to control the instant during each cycle when the driving pulse is to be delivered to the drive coils. The behavior of the drive circuit is more fully exp'ained in the above-identified Patent Applications.

The two transducers are of like design except that transducers T_1 includes a phase-sensing coil 23 as well as a drive coil 22. The construction and behavior of the transducers is similar to that of a dynamic permanent magnet speaker save that the moving element is the magnet and not the coil.

The invention resides in the arrangement of the sensing coil and drive coil in transducer T_1 and as shown in Fig. 3 magnetic element 21 is constituted by a cylindrical cup 21*a*, of magnetic material, such as iron, and a permanent magnet rod 21*b* coaxially mounted therein. Magnet 21*b*, which may be made for example of Alnico, is supported on the end wall of the cup to provide a magnetic circuit in which the lines of magnetic flux extend across the annular air gap 21*c* defined by the inner magnet and the surrounding cup.

Magnet rod 21*b* is a cylinder of uniform circular cross section throughout its length, hence the cross-sectional area of the air gap throughout the length of the cup is also uniform. However, the magnetic field strength is greatest at the mouth of the cup adjacent the free pole of the permanent magnet and is weakest at the base of the cup inasmuch as the flux density progressively diminishes as one moves inwardly from the open end.

As best seen in Fig. 1, cylindrical cup 21*a* is cut out longitudinally along diametrically opposed planes to form slots. This effects a substantial reduction in transducer dimensions with relatively little flux leakage. The cut-outs act to reduce the space occupied by the cups in depth and they also prevent so-called dash-pot effects resulting from air compression of the magnet and cup assembly.

It will be seen that the fixed tubular carrier 24 is also cylindrical and is received concentrically within the annular air gap 21*c* in spaced relation both to the magnet rod and the surrounding cup whereby the magnetic element is free to reciprocate axially relative to the fixed coils.

The tubular coil carrier 24 is provided centrally with a circumferential ridge 24*a*, at the midpoint thereof, to provide separation between two halves of the sensing coil 23, one half 23*a* being wound on one side of the ridge and the remaining half 23*b* being wound in a counter direction on the other side. The two halves are connected in series. Wound about the two halves of the sensing coil are the turns of drive coil 22.

In lieu of a single ridge, it is also possible to use a pair of spaced ridges 24*b* and 24*c* centrally located on the carrier and providing a greater separation between coil halves 23*a* and 23*b*. The space between the two ridges, as shown in Fig. 6, may be used by the drive coil 22.

The operation of this arrangement is best understood with reference to Fig. 4. It will be seen that the drive coil 22 and the sensing coil halves are magnetically coupled, the two halves being symmetrically disposed relative to the drive coil and inductively coupled thereto. Since, however, the voltages induced by the drive coil in the sensing coil halves are of equal amplitude and in phase opposition, the voltages buck each other and cancel out.

On the other hand the voltages induced in the sensing coil halves by reciprocal movement of the magnetic element 21*a*, 21*b*, are not of equal amplitude, for the flux density in the air gap area in which coil half 23*b* lies is far greater than that for coil half 23*a*. Hence even though the two induced voltages are in phase opposition the resultant output is primarily the voltage induced in coil half 23*b* and this voltage is sufficient to control the transistor operation in the manner described previously.

While a symmetrical arrangement of the coil halves has been shown in order to reduce the inductive transfer between the sensing coil and drive coil to zero, such symmetry is not essential but preferred since it is only necessary to reduce such feedback substantially to prevent high frequency oscillation. It is to be understood that the specific number of turns given above are merely by way of example.

In the circuit shown in Figs. 1 and 2, the arrangement is of the grounded emitter type. In the alternative circuit shown in Fig. 5, the circuit is of the grounded collector type and makes use of a silicon high beta transistor 32. The advantage of the silicon transistor over the germanium type is that it is free of leakage current and works well from −60° to 110° C. with a power efficiency of 75% and more. This reduces the power consumption of the timepiece and also makes it operative in extremely hot and cold climates without loss of accuracy.

A very reliable start and stop feature can be incorporated in this circuit by the use of two silicon diodes 33 and 34 interposed between the negative terminal of battery 29 and drive coil 26, the diodes being serially connected tnd shunted by an on-off switch 35.

In the event the battery voltage applied to the transistor is lowered, a point will be reached at which the resultant amplitude of fork operation and pawl movement is insufficient to advance the ratchet wheel, even though the fork still vibrates. Assuming that the diodes each have a knee voltage of 0.4 volts, in series the diodes will begin to conduct at 0.8 volts. With switch 35 open (stop position), the voltage applied to the transistor oscillator is the battery voltage (1.3) minus .8 volts, which will ordinarily reduce the amplitude below the normal amount to a level at which the ratchet wheel will no longer be driven. When the switch is closed, the diodes are shunted out and normal operation is resumed.

Thus the operation of the fork is not arrested when stopping the watch but is only diminished somewhat in amplitude. The gear train however is decoupled from the tuning fork.

WHAT WE CLAIM IS:—

1. An electromagnetic transducer arrangement for an electromagnetically actuated timepiece having a tuning fork, comprising of first and second transducers for actuating the fork, each transducer including a magnetic element attached to a tine of the tuning fork, a pick-up coil operatively coacting with one of the magnetic elements, and a drive coil operatively coating with both of the magnetic elements, the pick-up coil being constituted by two serially connected portions wound in opposing directions to minimize stray coupling between the drive and pick-up coils.

2. A transducer arrangement as claimed in Claim 1, wherein one each of the magnetic elements is formed by a cylindrical cup having a magnetic rod supported coaxially therein to define an annular air gap of uniform cross-section, and a fixedly supported coil form received within the air gap of the one of the magnetic elements,

the pick-up and drive coils being wound on the form.

3. A transducer arrangement as claimed in Claim 2, wherein the form is provided with a central ridge to separate the two portions of the pick-up coil.

4. A transducer arrangement as claimed in Claim 2, wherein the form is provided with a pair of spaced centrally located ridges to separate the two portions of the pick-up coil, and a portion of the drive coil being wound in the space between the ridges.

5. A transducer arrangement as claimed in any one of the preceding claims, wherein the coils are equal halves symmetrically disposed relative to a portion of the drive coil.

6. A transducer arrangement for an electromagnetically actuated timepiece having its parts constructed, arranged and adapted to operate substantially as hereinbefore described with reference to the accompanying drawings.

7. A transistor drive circuit for the transducer arrangement as claimed in any one of the preceding claims, including an oscillator-amplifier coupled to the coils, the coils being linked by the magnetic elements to provide feedback in the oscillator-amplifier acting to sustain oscillation therein and cause vibration of the tuning fork.

8. A transistor drive circuit as claimed in Claim 7, wherein the oscillator-amplifier is constituted by a battery energized transistor.

9. A transistor drive circuit as claimed in Claim 8, including switch means to reduce the battery voltage below a predetermined value and to reduce the amplitude of fork vibration without cutting off the transistor oscillator.

10. A transistor drive circuit as claimed in Claim 8 or 9, wherein the transistor includes a grounded collector to silicon NPN transistor.

11. A transistor drive circuit for the transducer arrangement as claimed in Claim 6, having its parts constructed, arranged and adapted to operate substantially as hereinbefore described with reference to the accompanying drawings.

12. An electromagnetically-actuated timepiece including the transistor drive circuit of any one of Claims 7 to 11, including a rotary timepiece movement and a pawl and ratchet mechanism coupling one of the tines of the tuning fork to the rotary movement to convert the vibratory motion of the fork into rotary motion.

13. A timepiece as claimed in Claim 12, including the transistor drive circuit of Claim 9, wherein the reduction of the amplitude of fork vibration renders the pawl and ratchet mechanism inoperative decoupling the tuning fork and the rotary movement.

14. An electromagnetically-actuated timepiece having its parts constructed, arranged and adapted to operate substantially as hereinbefore described with reference to the accompanying drawings.

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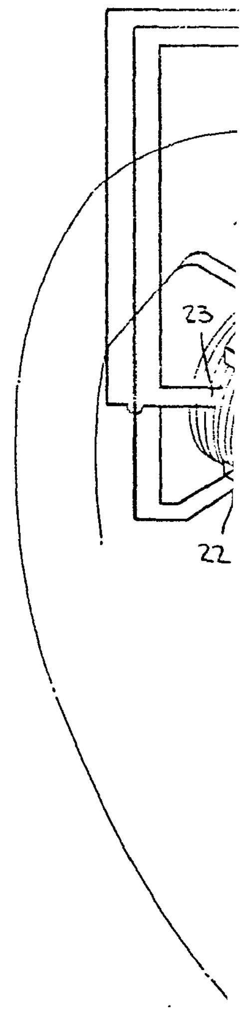
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981014 COMPLETE SPECIFICATION

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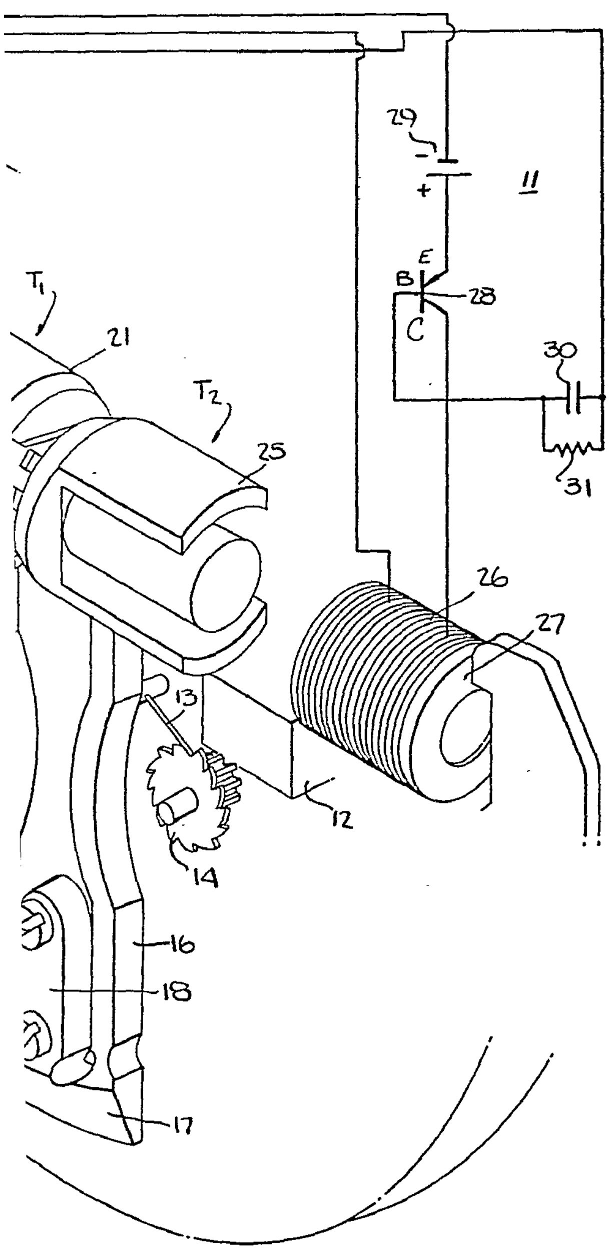
Sheet 1

Fig.1.



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Sheet 1

Fig. 1.

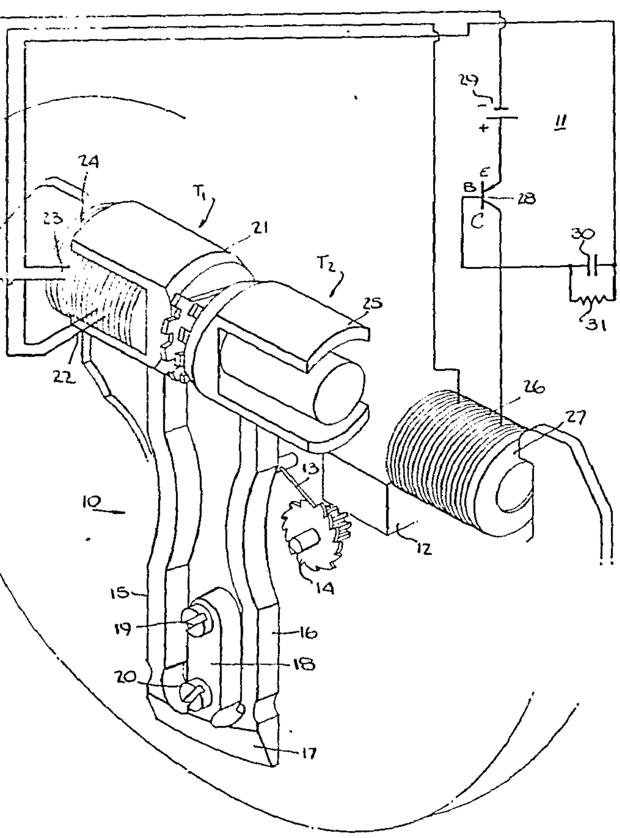


Fig.

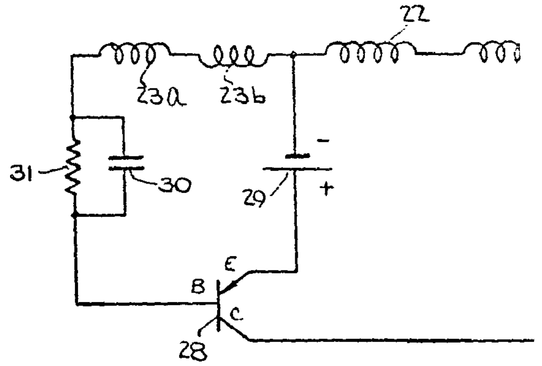


Fig. 3.

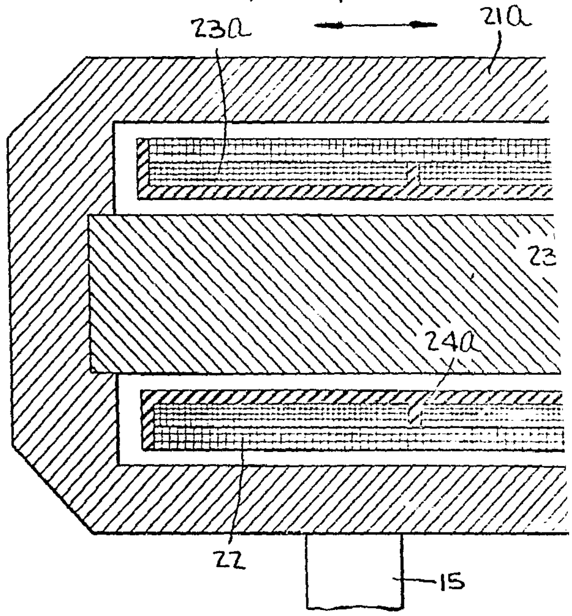


Fig.4.

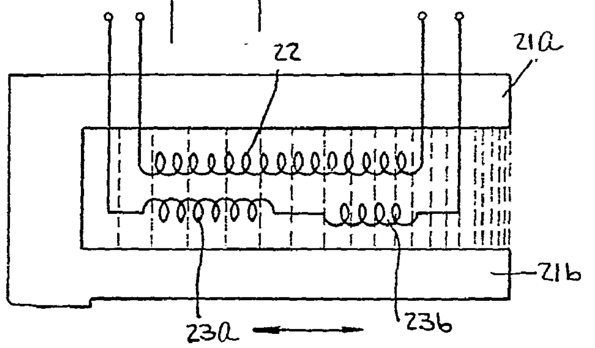
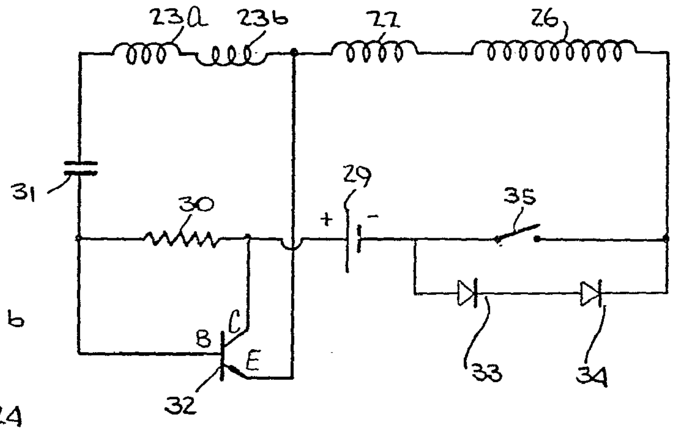


Fig.5.



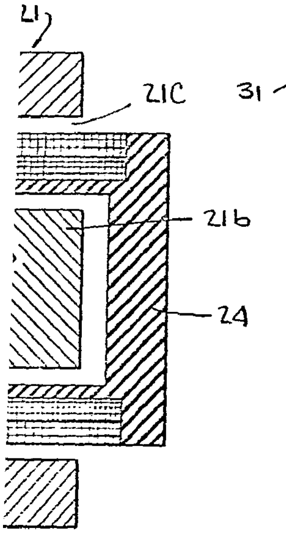
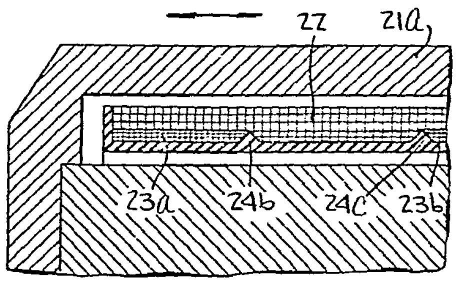


Fig.6.



981014 COMPLETE SPECIFICATION

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Sheet 2

Fig. 2.

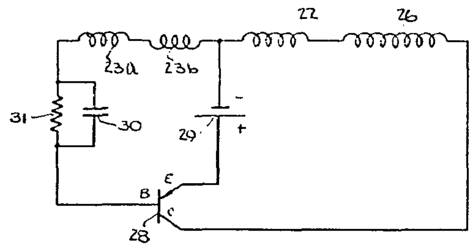

Fig. 4.

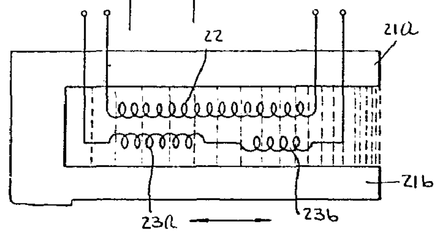

Fig. 3.

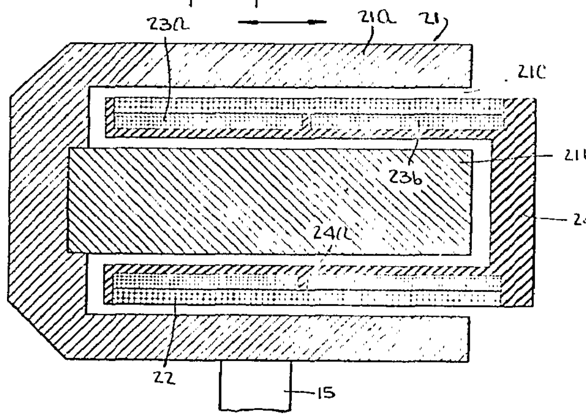

Fig. 5.

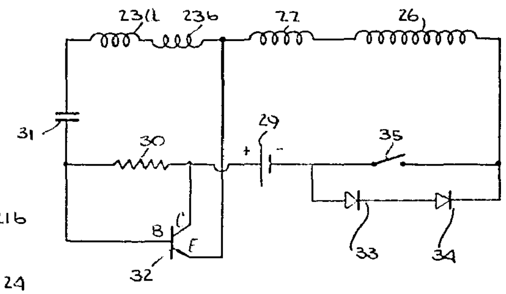

Fig. 6.