

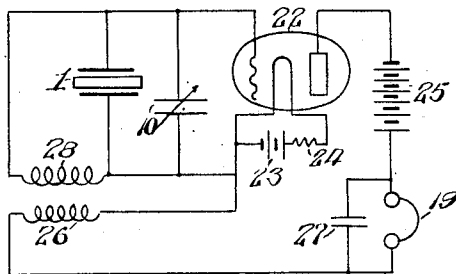
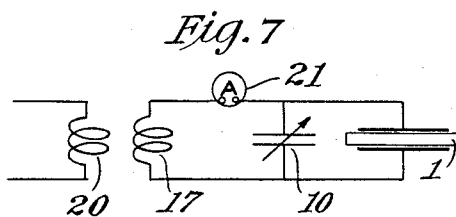
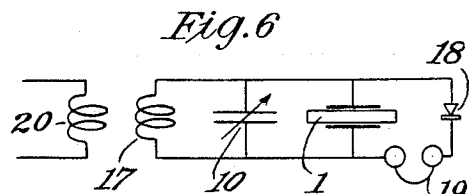
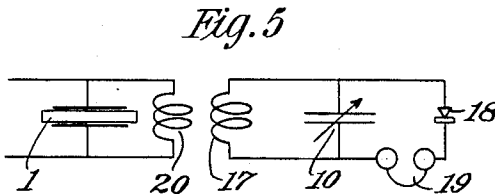
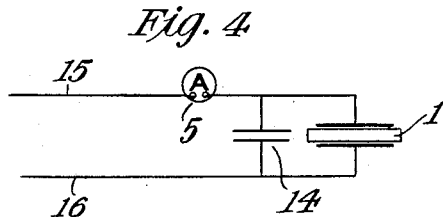
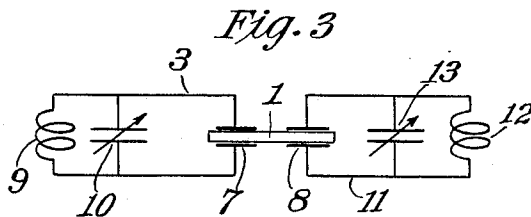
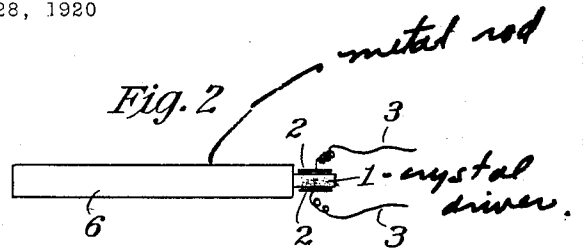
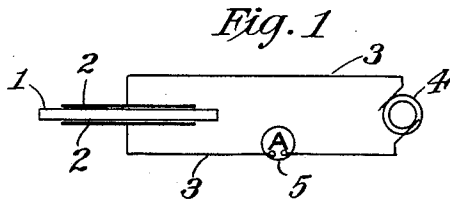
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W. G. CADY

1,450,246

PIEZO ELECTRIC RESONATOR

Filed Jan. 28, 1920

*Fig. 8.*

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UNITED STATES PATENT OFFICE.

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PIEZO-ELECTRIC RESONATOR.

REISSUED

Application filed January 28, 1920. Serial No. 354,659.

To all whom it may concern:

Be it known that I, WALTER G. CADY, a citizen of the United States of America, residing at Middletown, in the county of Middlesex, State of Connecticut, have invented certain new and useful Improvements in Piezo-Electric Resonators, of which the following is a full, clear, and exact description.

For many years it has been known that quartz, tourmaline and certain other crystals, if compressed in certain directions, exhibited positive and negative electrification in certain regions on their surfaces, and this phenomenon has been known as piezo-electricity.

Since this discovery it has been found that the converse effect obtains, that is to say, that such crystals when placed in an electric field become deformed, and a large number of both natural and artificial crystals have been found to possess this property, or in other words, to be piezo-electric. The general knowledge on the subject has so far developed that it is now possible to predict in advance whether a given crystal will show the piezo-electric effect, and in what manner a plate or rod should be cut from the crystal in order to exhibit this effect to the greatest possible degree.

As a rule, investigators, for the purpose of exhibiting these effects, have used flat plates coated on their opposite faces with tinfoil, and when such plates are compressed or otherwise deformed one of these coatings becomes charged positively, the other negatively, the signs of the charges having a definite relation to the principal axes of the crystals.

More recently, investigators, including myself, have experimented on the effects produced when the crystal plates, instead of being charged statically, are subjected to alternating electric fields of various frequencies, Nicolson, for example, having published a paper on the use of Rochelle salt crystals as receivers and transmitters in telephony. Following this line of investigation I have conducted experiments with different crystals exposed to the effect of higher frequencies such as are used in radio-telegraphy, and have studied, particularly, the periodic lengthening and shortening of rectangular plates when the tinfoil coatings were connected to a source of high frequency electro-motive force; and the inven-

tion upon which this application for Letters Patent is based has been the result of this study and the information obtained from such experiments.

It is evident that a crystal plate with tinfoil coatings, as above described, constitutes a true electric condenser, and possesses a certain electrostatic capacity. I have observed that the capacity and resistance of such a plate varied under different circumstances, and for this I have ascertained the cause and developed the mathematical theory.

The phenomenon may be thus briefly explained: A rectangular plate, like any elastic solid, is capable of being set into longitudinal vibration. If suddenly struck on one end, the vibrations are free and of a frequency dependent essentially upon the elastic modulus, the density of the material of which the plate is composed, and the length of the plate. The equation for such longitudinal vibrations is well known.

If, however, the vibrations are impressed on the plate by some outside agency, as occurs in these piezo-electric experiments, they are said to be forced, as distinguished from free. The amplitude of such forced vibrations is exceedingly minute except when the frequency of the impressed force approximates the natural frequency of the plate, or in other words, that of the free vibrations. If, for example, the impressed frequency is gradually raised from one less than the natural to one higher, the amplitude of vibration will be at first small, will rise to a large value as the resonant frequency is reached and will then fall again.

In further illustration, assume a plate of piezo-electric crystal having on its opposite faces tinfoil coatings connected to a source of high frequency electro-motive force. As the plate vibrates its length increases and diminishes alternately, and although such changes in length are so minute as to escape detection under ordinary conditions, they are sufficient to exert a marked reaction upon the electric circuit. An ammeter, for instance, connected with the circuit in series with the coatings on the plate will be found to pass through a maximum at a frequency slightly below resonance, followed by a minimum at the resonance frequency. In other words, the plate when in resonance vibration, reacts upon the circuit by virtue of the charges which

are being continually induced in the coatings as a result of the deformations of the plate, and this reaction chokes back the current. This reaction is, presumably, of two kinds; first, a capacity-reaction such that the apparent capacity of the plate passes through certain changes which may be either experimentally or theoretically determined; and second, a resistance-reaction, such that, owing to the absorption of energy from the circuit when the plate is vibrating, the apparent series resistance of the plate is greatly increased. It is this reaction that I utilize in the apparatus embodying my invention.

When the plate is made from a piezo-electric crystal of good elastic qualities, such as quartz, when its width is small in comparison with its length, and it is mounted in such manner that its vibrations will be damped as little as possible, the reaction is extremely sharp and very pronounced. Such a plate, connected to a source of electric oscillations of variable frequency, will respond when one and only one frequency—neglecting for the moment harmonics—is being generated. It forms a piezo-electric resonator, somewhat analogous to the acoustical resonators of Helmholtz. If the natural frequency of the plate has been determined by comparison with a standard wave-meter or otherwise, it may be in turn used as a standard for calibrating radio and other high frequency circuits, and a number of such plates of different lengths may be used for calibrating a high frequency circuit over as wide a range as desired.

It is not necessary that the device comprise a long, narrow plate, although this has its advantages in permitting greater sharpness in tuning, and resulting from the fact that resonance—still neglecting harmonics—occurs at one single frequency. The plate may have various shapes, or some other form than a plate may be used, including the entire native crystal itself. The only essential condition is that it shall be mounted and connected to an oscillating circuit of variable frequency in such a manner as to react electrically upon such circuit at a particular frequency. In general, the more complicated the form, the more numerous are the frequencies to which the unit will respond.

In the accompanying drawings I have illustrated graphically the nature of my invention and various ways of modifying the same and applying it to practical use; and to these drawings I now refer.

Fig. 1 is a diagrammatic illustration of the instrument in its simplest form.

Fig. 2 shows in a similar manner a modification of the same.

Figs. 3 to 8, inclusive, are diagrams il-

lustrating uses and applications of the invention which will be described in detail.

In Fig. 1 the piezo-electric plate is designated by the numeral 1. The conductive coatings 2 are connected with a source of high frequency current 4 by wires 3 and an ammeter 5 is shown in this circuit.

In Fig. 2 a modification of this instrument is shown. When the frequency of the source is relatively low, crystals of sufficient size may not be economically secured, in which case I use a thin rod 6 of any solid substance of good elastic properties, for example steel, as the vibrating element. It should be of such length that its natural period of vibration, calculable from the well known equation, is of the desired value. This rod is set into vibration by means of a piezo-electric plate 1 of relatively small dimensions, cemented or otherwise held in intimate contact with it. The shape, size and material of the plate 1 should be such as to excite as strong longitudinal vibration in the rod 6 as possible, when the metallic coatings 2 are connected to a source of high frequency electro-motive force, but in any event it should be small enough so that none of its own modes of vibration to which it may be piezo-electrically excited, are of a frequency sufficiently near the natural frequency of the rod 6 to be troublesome. The natural frequency of the rod 6 is, of course, slightly modified by the plate 1 attached thereto, but the combination of the two forms a unit of very constant frequency capable of reacting sharply on a high frequency circuit in exactly the same manner as the plates when used alone as in the preceding figure.

The rod 6 should be of such material that its natural frequency is as slightly as possible affected by changes of temperature, but in any case correction may readily be made for this. It need not be of solid material, which will probably be found best, for it is possible to use in place of a solid a column of liquid, for example mercury, in a long narrow tube, one end of the column being in contact with the piezo-electric plate or crystal. One advantage of this arrangement is the possibility of varying the frequency of vibration at will by adjustment of the length of the column of fluid.

The piezo-electric resonator may be used in various ways, as for example, to produce a large reactance in an alternating circuit at a certain particular frequency or frequencies, to serve as a standard of frequency or wave length in high frequency circuits, or even for such purposes as coupling one high frequency circuit to another, in order to transmit energy from one to the other circuit at a certain particular frequency. This latter application of the invention is shown in Fig. 3. In this Figure 1 is the piezo-

electric resonator having two pairs of coatings 7 and 8, one pair 7 of which is connected to the oscillating circuit 3, which contains also a coil 9 and a condenser 10, while the other pair of coatings 8 is connected to a similar oscillating circuit 11 containing a coil 12 and a condenser 13. The figure is intended merely to illustrate the general principles which applies to any of the numerous types of high frequency circuit.

In this case the following action takes place: Assuming that 3 represents the primary circuit, then whenever an alternating current of the critical frequency flows in that circuit, the plate 1 will be brought into energetic vibration through the agency of the alternating potential differences between the coatings 7. These alternations will in turn generate potential differences in the coatings 8, which will cause an alternating current of the same frequency to flow in the second circuit 11. At other frequencies the forced vibrations in the resonator 1 will be of very small amplitude, hence the induced current will be correspondingly small.

When it is desired to reduce the current in a high frequency circuit to as low a value as possible at a critical frequency, the arrangement shown in Fig. 4 may be employed. In this figure the piezo-electric resonator 1 is connected in parallel with a condenser 14 which may form part of any tuned oscillatory circuit in which alternating current of variable frequency is being generated. The wires 15 and 16 connect the condenser 14 with the remainder of the circuit through an ammeter 5. At the critical frequency, the absorption of energy in the piezo-electric resonator causes the current in the ammeter to pass through a minimum. This decrease in current is the greater, the smaller the capacity of the condenser with respect to that of the resonator.

This figure also indicates one way in which the piezo-electric resonator may be made to serve as a standard of frequency or of wave length in radio telegraphy. It is only necessary to connect several such resonators in succession in place of that shown, each time making note of the readings of the condenser or other apparatus at the critical frequency.

In Fig. 5 the piezo-electric resonator 1 forms part of an oscillatory circuit loosely coupled to a tuned circuit comprising a coil 17 and a condenser 10. In parallel with the latter is a detector 18 and a telephone receiver 19, or some other indicating device may be properly connected with the current. When the resonator is connected in parallel with the first circuit and coil 20 and the frequency of the alternating current is varied through the critical value, the sudden decrease in the current in 20 produces an audible click in the telephone 19. It is not gener-

ally necessary that the circuit of coil 17 should be in exact tune with that containing 20.

Fig. 6 illustrates the same plan as the preceding figure, but in this case the piezo-electric resonator is in parallel with the condenser 10 in the receiving circuit instead of being in parallel with coil 20.

Fig. 7 is similar to Figs. 5 and 6, except that instead of the detector and telephone there is shown a high frequency ammeter 21. By varying the frequency of the current in coil 20, and keeping the secondary circuit which comprises the coil 17 and a variable condenser 10 in electrical resonance with the current in 20, it is possible to observe quantitatively the manner in which the current in the ammeter passes through a minimum at the critical frequency, and to determine the settings of condensers and other instruments corresponding to this frequency, with a high degree of precision.

Fig. 8 represents a form of circuit in common use for generating high-frequency currents by means of a three element vacuum tube 22. In this figure 23 and 24 represent, respectively, the battery and regulating resistance in the filament circuit; and 25 is the plate battery. A telephone receiver 19 has a fixed capacity 27 in parallel with it and 26 is the feed back coil which is coupled to coil 28 in the grid circuit. Condenser 10 in parallel with coil 28 is used to control the frequency.

The piezo-electric resonator is in parallel with the condenser 10 and its capacity is so small as not to introduce a perceptible error. In many cases, moreover, it is possible to connect only one side of the resonator, or even to place the resonator near the apparatus without being actually connected to it, and still be able to detect the resonant frequency. When the frequency passes through the critical value, a click is heard in the telephone receiver.

In the description and illustrations given above, I have assumed that a supply of undamped alternating current was available. While the best results are obtained in this way, it is possible to use the resonator as a standard of wave length also when damped waves only are available, as for example, from a buzzer circuit. The reaction is then much less pronounced, owing to the fact that a damped train of waves contains, not a single frequency, but a combination of many frequencies. If, however, damped waves must be used, it is best to make the decrement as small as possible, for example by use of impact excitation. Some of the circuits above described, or proper modifications of them, may then be employed.

From the nature of the invention thus above described certain modifications are obviously possible. For example, to secure

piezo-electric resonators of various frequencies, weights may be attached to one or both ends of a piezo-electric plate which will have the effect of lowering the frequency. Again, instead of utilizing the longitudinal vibrations of a plate, the plate or rod may be so designed and mounted as to take advantage of the principle of flexural vibrations.

I have referred above to harmonic frequencies, but in this connection little need be added. While the fundamental frequency of the plate or rod will usually give the strongest reaction, the various harmonic vibrations can also be employed, giving reactions at frequencies two, three or more times the fundamental. Or, if the plate has other dimensions comparable with its length, some other mode of vibration, giving a still different frequency may be utilized. When the vibrating unit has once been suitably prepared and mounted, its resonant frequencies are, to a high degree of precision, fixed for all time.

What I claim as my invention is:

1. The combination with an alternating current circuit of high frequency, of a means for reducing the flow of current therein at any particular frequency comprising a body of piezo-electric character with conductive coatings over the regions thereof which exhibit opposite electrification, and connected with the alternating current circuit, the said body being so designed that its natural frequency of vibration will be in mechanical resonance with the said particular frequency of the alternating current.

2. The combination with an alternating current circuit of high frequency, of a means for reducing the flow of current therein at any particular frequency, comprising a body of piezo-electric character with conductive coatings over the regions thereof which exhibit opposite electrification and connected with the alternating current circuit, the said body being so designed and mounted that its mechanical vibrations will be damped to the least possible extent and so that its natural frequency of vibration will be in mechanical resonance with the said particular frequency of the alternating current.

3. The combination with an alternating circuit of high frequency and a resonator

consisting of a piezo-electric body with conductive coatings properly connected with such circuit, of a means for detecting the electrical reaction which occurs when a current of given frequency is impressed on the circuit, approximating the predetermined frequency of vibration of the piezo-electric resonator, included in the circuit which is capable of giving an audible indication of such reaction.

4. A piezo-electric resonator consisting of a plate or rod of piezo-electric crystal, a plurality of pairs of conductive coatings applied to the region of opposite electrification thereon, and means for connecting such pairs of coatings to a corresponding number of alternating current circuits, as herein described.

5. The combination with a tuned alternating current circuit, of a means for reducing the flow of current therein at any particular frequency with which the circuit is in electrical resonance, comprising a body of piezo-electric character with conductive coatings over the regions thereof which exhibit opposite electrification, and connected in parallel with the capacity or inductance of said alternating current circuit, the said body being so designed that its natural frequency of vibration will be in mechanical resonance with the said particular frequency of the alternating current.

6. The combination with a tuned alternating current circuit, of a means for reducing the flow of current therein at any particular frequency with which the circuit is in electrical resonance, comprising a body of piezo-electric character with conductive coatings over the regions thereof which exhibit opposite electrification and connected in parallel with the capacity or inductance of said alternating current circuit, the said body being so designed and mounted that its mechanical vibrations will be damped to the least possible extent and so that its natural frequency of vibrations will be in mechanical resonance with the said particular frequency of the alternating current.

In testimony whereof I hereunto affix my signature.

WALTER G. CADY.