

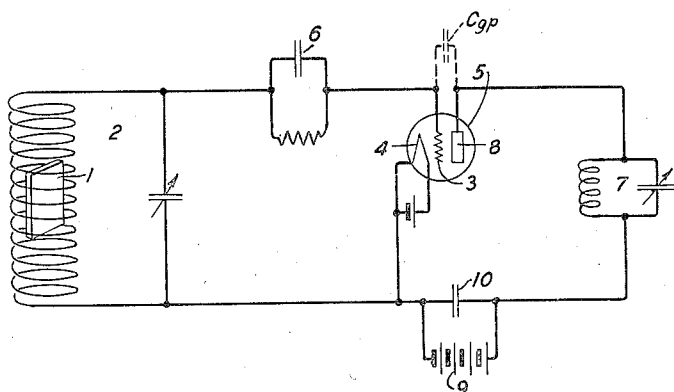
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COUPLING MEANS FOR PIEZOELECTRIC CRYSTAL ELEMENTS

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COUPLING MEANS FOR PIEZOELECTRIC
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This invention relates to coupling means for piezoelectric crystal elements and the association of a piezoelectric crystal element, so coupled, with an oscillation generating circuit so as to control the generated frequency as in accordance with the natural frequency of the crystal element.

As is well known, if two circuits are coupled in any desired manner and the characteristics of one of these circuits are examined during an interchange of energy therebetween, it is immediately evident that these characteristics, however measured, are affected to some degree by the other, that is, the coupled circuit, the extent of the effect being proportional to the degree of coupling. In the instance of an electrical oscillation generating means coupled to a control circuit, the effect exerted by the control circuit (passive circuit) on the controlled circuit (the driven circuit), as the frequency of the generated wave approaches the characteristic frequency of the control circuit, is a tendency for the control circuit to coerce the frequency of the generated wave to correspondence with its own characteristic frequency if the control circuit is adequately conditioned, with relation to the generator circuit, to achieve this function.

As an example, the control circuit may take the form of a piezoelectric crystal, the piezoelectric crystal being resolvable into a tuned circuit having special characteristics tending to give it great utility as a frequency control means. The principal characteristic, in this regard, and which it shares, although to a lesser degree, with comparable elastic, physical structures and with its electrical prototype if especially designed for that purpose, is its low decrement. The term "low decrement" expresses a condition tending toward the generation of comparatively persistent vibrations or oscillations of the element or circuit so described, when set into vibration, and it results from a relative absence of energy losses incident to the oscillations. A piezoelectric crystal can oscillate with relatively small energy loss because of its relatively great coefficient of elasticity. The corresponding characteristic of its analog, a tuned electric circuit, can approach quantitatively this piezoelectric crystal characteristic, only to the extent that it can be made devoid of resistance.

A piezoelectric crystal, or crystal element, has great utility, because of this characteristic, in exercising a frequency control over a coercible type of oscillation generating circuit to which it is coupled. The oscillation generating circuit might well be, as it usually is, a vacuum tube os-

cillator of any one of the conventional types. The crystal element may exercise its control purely as an accessory element, that is, under certain conditions such that the generator will function as such without the presence of the crystal element; or in such circuit relation that it, itself, effectively constitutes a frequency determining element of the generator circuit and an element necessary for the production of oscillations. A piezoelectric crystal element, as used in either of the above ways, is capable of controlling the frequency at its own characteristic frequency given adequate coupling and cooperative adjustment of electrical values of the associated circuit elements.

An adequate coupling for the crystal element requires, in the first instance, an effective means for impressing such a difference of potential on the crystal element in the direction of an electrical axis as will enable the crystal element to vibrate vigorously. By this means the crystal element is made effectively an element of a circuit. If necessary, or desired, this immediate crystal circuit may be related to the circuit of the generator as a whole through a variable coupling means. In any event it must be related thereto with a sufficient coupling to enable the immediate crystal circuit, and therefore the crystal itself, to constitute an integral part of the generator circuit as a whole.

The coupling means of the prior art has comprised a rather elaborate array of circuit and structural elements as compared with the alternative supplied by the present invention. Usually the crystal element has had to be related in a very definite way to electrode means for impressing the difference of potential on the crystal element, this requiring expensive and inconvenient physical layouts. The proportions of parts must be quite critical and easy changeability of crystal elements, even assuming the use of a common crystal element holder, cannot be achieved thereby.

It is an object of the present invention, having in mind especially the above comparative deficiencies of prior art circuits and structures, to couple a crystal element to its immediately associated electrical circuit in as simple a manner as possible, and with a minimum of circuits and structures exclusive of the crystal element itself; and, where the crystal element is used to control the frequency of an oscillation generator, to so control the generator in the simplest possible manner and with a minimum of auxiliary electri-

cal and physical apparatus, and with the utmost ease of changeability of crystal elements.

The means of the invention represents, it is believed, almost the acme in the above regard. Applicant has discovered that an oscillation generator, particularly of the vacuum tube type, may be controlled in frequency as in accordance with the characteristic frequency of a crystal element merely by positioning the crystal element in the magnetic field of a coil constituting a part of the oscillation generator. The coil may be a frequency determining reactance of an existent oscillation generator, in which case the invention involves merely the proper juxtaposition of a piezoelectric crystal element, with no other circuits or structure whatever, with relation to the oscillation generator. Or, the coil may be an adjunct of the crystal element coupling, so as to provide a means for coupling the crystal element to the remaining elements of the oscillation generator circuit. In order to be most effective the crystal element should be orientated with respect to the coil in such manner as to present as great a dimension as possible, in the direction of an electrical axis of the element, to the axis of the coil. The crystal element need not be positioned within the coil, although it perhaps functions most effectively when so positioned.

The novel features which characterize the invention are pointed out with particularity in the appended claims. The invention itself, however, will be best understood by reference to the following detailed description taken in connection with the accompanying drawing in which the single figure illustrates one way in which the invention may be carried into effect.

The figure as a whole illustrates the use of a crystal element 1 to control the frequency of an oscillation generator constituted by the remaining circuit elements shown. The oscillation generator here illustrated is a vacuum tube oscillator of the tuned-grid tuned-plate type. This is the type of vacuum tube oscillator circuit illustrated by Fig. 21 of the very well-known paper by R. A. Heising printed in the April and May 1920 issues of the Journal of the American Institute of Electrical Engineers. It is used in this application disclosure as being one of the most generalized vacuum tube oscillator circuits. The tuned grid circuit 2 is connected between the grid 3 and cathode 4 of the three-element vacuum tube 5, being separated from the grid by the blocking condenser 6 shunted by the grid leak resistance shown, these last two elements being adapted to fix the grid potential with respect to the cathode at an effective value, according to well-known practice. Alternative means for fixing, or establishing, this difference of potential could equally well be used. The tuned plate circuit 7 is similarly connected between the plate 8 and the cathode. The cathode may be of the filamentary type, as shown, and energized by any convenient source of potential. The plate-cathode circuit is supplied by direct current source 9, as in accordance with conventional practice. Although the current supply for the plate is here shown as adapted to traverse the plate tuned circuit, of course alternative plate supply circuits as used in the conventional practice in this art could equally well be used. In the specific circuit illustrated the condenser 10 is used to complete an alternating current path between the plate and cathode exclusive of the supply source.

As is pointed out in the above-identified Heising

paper the tuned input and tuned output circuits for this type of oscillator cooperate with the natural grid-plate capacitance C_{gp} of the tube, as shown in broken lines, to constitute the circuit as a whole a Hartley type of oscillator, the grid and plate tuned circuits each being resolvable into an equivalent inductance as in the more conventional showing of a Hartley type of oscillator. Accordingly, the grid and plate tuning condensers could be dispensed with without detriment to the effective operation of the oscillator although convenient as frequency adjusting means. The frequency determining circuit is that constituted by the interelectrode capacity C_{gp} in series with two tuned circuits as shown. As is pointed out by Heising in the above paper, the resonant frequency of this frequency determining circuit, and therefore the characteristic frequency of the oscillator as a whole, is never the resonant frequency of either component tuned circuit but is always lower than the resonant frequency of either one of them. The inherent grid-plate capacitance may be supplemented by a condenser connected between the grid and plate without significant change of effect. Analogously the effective grid-plate reactance may be that of an inductance by positioning an inductance coil having a sufficiently great inductance between these two tube elements. In that case the oscillator circuit as a whole would be that of a Colpitts oscillator, the tuned circuits in that case each having the effect of a capacitance.

The oscillator circuit, above described, in either of its variant forms, is capable of functioning entirely independently of the crystal. However, if its frequency is adjusted so as to be nearly identical with the natural frequency of the crystal element the coupling between the crystal element, treated if convenient as a coupled electrical circuit, and said oscillator results in a control or coercion effected by the crystal element so that the frequency of the oscillator as a whole becomes the characteristic frequency of vibration of the crystal element.

In the specific embodiment of the invention illustrated by the drawing, the crystal element functions as a control means for a self-contained oscillation generating circuit. As has been indicated in the Statement of Invention, the crystal element could equally well combine its function as a control means with its function as an equivalent reactive element, the crystal therefore replacing one of the conventional reactive elements in the frequency determining circuit of the oscillation generator, the same type of coupling being used as here shown, the coil within which the crystal element is contained being adapted either to couple the crystal with associated elements or to constitute this function together with the secondary function as another element of the overall frequency determining circuit.

The crystal element may be positioned within the confines of the coil, as shown, or outside of the coil although in its field. The crystal element appears to be most effective, that is, have the strongest coupling, when it is orientated so that an electrical axis has a large component extending in a direction parallel with the axis of the coil. This optimum orientation of the crystal element permits the use either of the so-called perpendicular cut or parallel cut crystal element since either of these cuts is characterized by having one or more electrical axes con-

tained therein. In the example illustrated a parallel cut crystal is presumed, its dimension parallel with the axis of the coil corresponding to that dimension which includes the electrical axis. In one example of a circuit which was found effective in practice, a parallel cut crystal was used having a characteristic frequency of 1988.5 kilocycles and the following dimensions: length, 1.025 inches; width, 1.020 inches; and thickness, 0.0403 inch. Applicant has also employed a perpendicular cut crystal of 3960 kilocycles frequency, orientated analogously as in the example illustrated, with its principal electrical axis (here in the direction of its thickness) parallel with the axis of the coil. It is recognized that a crystal (that is, a crystal element) of either the parallel or perpendicular cut has another electrical axis at 30 degrees from the principal electrical axis above indicated. Such axes may be made parallel with the axis of the coil, and therefore in the most effective relation to the associated circuits, by correspondingly offsetting the crystal element from the coil axis. In the instance of a perpendicular cut crystal, whose principal electrical axis, in the direction of thickness, would necessarily be rather short, this other electrical axis would have a greater length. Applicant has demonstrated the effectiveness of using this other axis by variably positioning the crystal with reference to the coil axis and noting the corresponding variation of coupling and therefore of the crystal's controlling effect.

Although it is recognized that the invention has been disclosed completely, within the spirit of the patent statutes, in the above text, and that it is not necessary to expound a theory of operation of the invention, assuming that an accurate statement of the theory may be made, nevertheless, it may be useful to note that a crystal element positioned in the manner described would be positioned in such a way as to intercept a maximum number of equi-potential electrostatic lines of force, this in turn meaning that this position represents a maximum difference of electrostatic potential across the crystal element in the direction of an electrical axis and therefore in the direction representing a maximum response of the crystal element. According to this theory the crystal element would be energized by electrostatic difference of potential, as in the instances of all piezoelectric crystals, but as derived in a quite novel and non-obvious manner. Because the electrostatic differences of

potential, if to them the crystal element coupling of the invention may be attributed, are derivable from an electromagnetic coil by the mere juxtaposition of the crystal element in the magnetic field of the coil, the invention has the unique utility of permitting a crystal element to control the frequency of an oscillator without any accessory circuits or structure whatever, and in such a manner as to permit the maximum facility of substitution of one crystal for another to correspondingly change the frequency.

What is claimed is:

1. In combination, a piezoelectric crystal element and means for exciting said crystal element comprised wholly by an electromagnetic coil.
2. In combination, a piezoelectric element and an electromagnetic coil, said element and coil being so related that the electrostatic coupling therebetween is substantially only through the intermediation of the magnetic field of said coil.
3. In combination, a helical coil, means impressing an alternating difference of potential on the terminals of said coil, and a piezoelectric crystal element within the circumscribing boundaries of said coil.
4. In combination, an electromagnetic coil, means for impressing an alternating difference of potential on the terminals of said coil, and a piezoelectric crystal element positioned within the circumscribing boundaries of said coil and so orientated with respect to said coil that an electrical axis of the crystal element has a substantial intercept in the direction of axial extension of said coil.
5. In combination, an oscillation generating circuit comprising a piezoelectric crystal element, said crystal element being coupled to the remaining elements of the circuit by being positioned in the magnetic field of a coil constituting an element thereof.
6. In combination, an oscillation generating circuit comprising an inductance coil and a frequency control means for said generator circuit comprising a piezoelectric crystal element in the magnetic field of said inductance coil.
7. A piezoelectric crystal controlled oscillator comprising in combination, an electron discharge tube having input and output electrodes, circuit means comprising an inductance coil for regeneratively coupling said input and output electrodes and a piezoelectric crystal element coupled to said inductance coil only through the intermediation of the magnetic field thereof.

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