

Oct. 28, 1941.

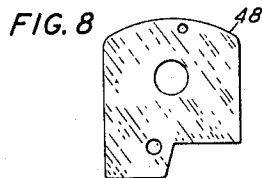
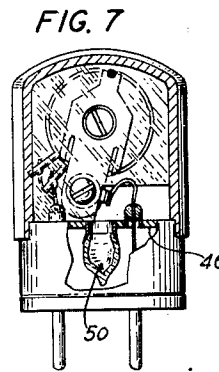
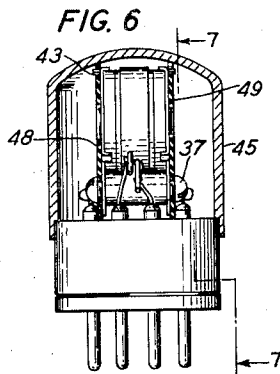
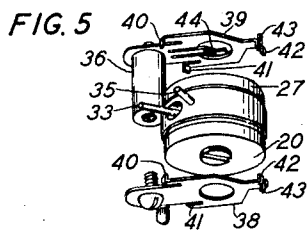
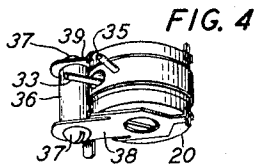
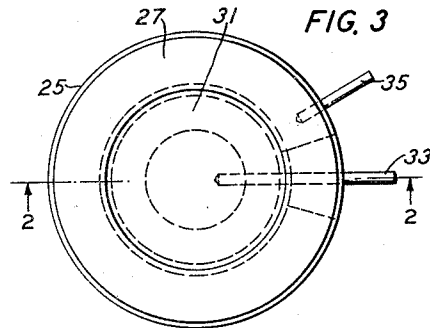
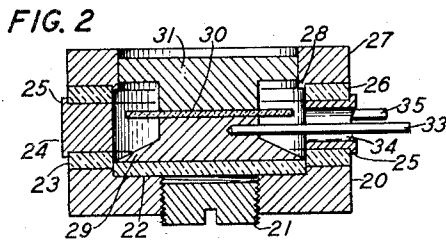
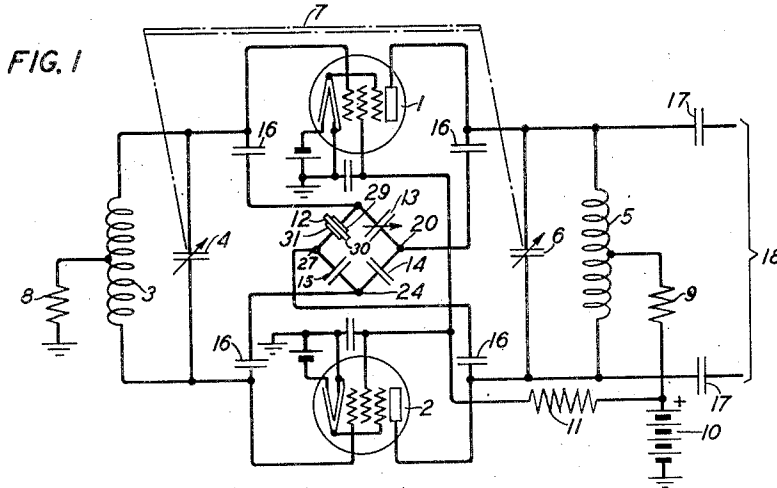
I. E. FAIR

2,260,707

CRYSTAL CONTROLLED OSCILLATOR FOR ULTRA-HIGH FREQUENCIES

Filed June 20, 1939

2 Sheets-Sheet 1



INVENTOR  
I. E. FAIR  
BY  
E. V. Snigge  
ATTORNEY

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I. E. FAIR

2,260,707

CRYSTAL CONTROLLED OSCILLATOR FOR ULTRA-HIGH FREQUENCIES

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2 Sheets-Sheet 2

FIG. 9

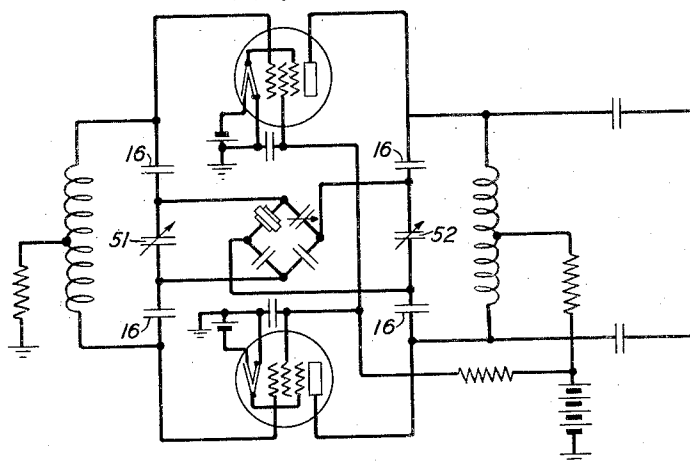
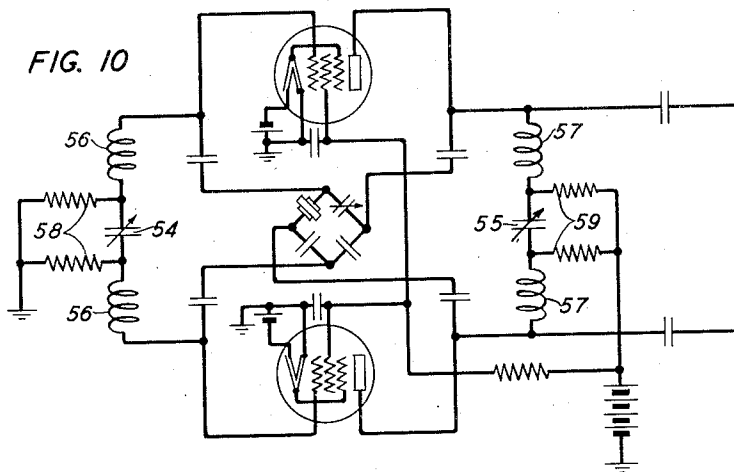


FIG. 10



INVENTOR  
I. E. FAIR  
BY  
E. V. Ligg  
ATTORNEY

## UNITED STATES PATENT OFFICE

2,260,707

CRYSTAL CONTROLLED OSCILLATOR FOR  
ULTRA-HIGH FREQUENCIES

Irvin E. Fair, Lyndhurst, N. J., assignor to Bell  
Telephone Laboratories, Incorporated, New  
York, N. Y., a corporation of New York

Application June 20, 1939, Serial No. 280,079

15 Claims. (Cl. 178-44)

This invention relates to improvements in vacuum tube oscillators and more particularly to feedback circuits of the bridge type for coupling the anode circuit of a vacuum tube oscillator to its impedance control circuit.

An object of the invention is to simplify and make more compact the construction of the bridge used in the feedback circuit.

Another object is to reduce the number of tuning adjustments required for piezoelectric controlled oscillators operating at very high frequencies and employing a bridge type feedback circuit.

Another object is to render the balance of a feedback bridge to be maintained substantially independent of the capacitances of the associated vacuum tube and the stray capacitances and inductances of the tube circuit and the bridge connections.

A further object is to eliminate impedances effectively introduced into the bridge by the conducting leads which connect the bridge elements to each other.

A still further object is to eliminate coupling coils ordinarily required for bridge type feedback circuits and to make it possible to employ ordinary variable condensers in lieu of the balanced tuning condensers customarily employed in balanced oscillator circuits.

An additional object is to reduce the length of leads to a feedback bridge in a push-pull oscillator to such an extent as to preclude parasitic oscillations of the parallel type.

Another object is to provide a more direct coupling between the feedback bridge circuit and the plate and grid circuits of a vacuum tube oscillator to enable an increased feedback effect to be obtained while, at the same time, maintaining the bridge balance at such a point as to prevent production of oscillations at unwanted frequencies.

Another object is to increase the coupling between the piezoelectric crystal and electrical circuit by eliminating practically all of the stray capacity of the crystal holder.

Another object is to provide a piezoelectric crystal mounting for the frequency controlling element of an electrical oscillator which will enable the element to oscillate efficiently at a high mechanical harmonic frequency.

Another object is to render the frequency of oscillations produced substantially independent of ambient temperature changes.

Piezoelectric crystal controlled oscillators may be operated at frequencies of the order of 120 megacycles by causing the piezoelectric element

to be operated at one of its harmonic frequencies. A stable oscillator capable of producing oscillations of that order of frequency and including an amplifying element of the balanced or push-pull type provided with a feedback circuit of the bridge type is disclosed in W. P. Mason application, Serial No. 249,388 filed January 5, 1939. This invention relates to improvements in the circuits and apparatus of oscillators of that type.

In accordance with the invention the feedback bridge is constructed as a unitary device which includes in a close compact assemblage the piezoelectric frequency control element and the other three reactances of the bridge. The bridge is connected in paths directly between the impedance control grids and the anodes of the two electron discharge devices of a push-pull oscillator thereby eliminating feedback circuit coupling coils, long bridge circuit leads, and the necessity for employing individually balanced tuning capacitances for the tuned grid and plate circuits of the oscillator.

In the drawings, Fig. 1 shows a circuit schematic of an improved oscillator embodying certain features of the invention;

Fig. 2 illustrates, in section, certain structural features of the bridge unit including the piezoelectric crystal holder and the three other capacitances of the bridge;

Fig. 3 is a top view of the structure of Fig. 2;

Fig. 4 shows the means for holding the structure of Figs. 2 and 3 in assembled position;

Fig. 5 illustrates the structure of Fig. 4 disassembled to show details;

Figs. 6 and 7 are sectional views of the complete bridge unit sealed in an evacuated container;

Fig. 8 shows a mica element used to hold the bridge structure in position within the container; and

Figs. 9 and 10 present alternative circuits embodying the invention.

Referring to the circuit of Fig. 1, which discloses one embodiment of the invention, two pentode type electron discharge devices 1 and 2 are shown with their grid circuits connected in push-pull relation to the closed tuned circuit consisting of inductance 3 and variable capacitance 4 and their output circuits likewise connected to the tuned circuit comprising inductance 5 and variable capacitance 6. The capacitances 5 and 6 are controlled by unitary tuning control device 7 to enable the tunings of the tuned circuits to be varied in similar manner simultaneously. The tuned circuits are preferably so constructed as to avoid any electromagnetic or electrostatic cou-

pling between their reactances. A grid leak path including a high resistance 8 connects the electrical mid-point of inductance 3 to ground. A high resistance 9 connects the electrical mid-point of inductance 5 to the positive terminal of a space current source 10, the negative terminal of which is also connected to ground. A path including a resistance element 11 connects the screen grids of the devices 1 and 2 to the positive terminal of source 10. The resistance element 11 serves to reduce the screen grid potential to the correct value for satisfactory operation of the discharge devices. The screen grids are connected by relatively large capacitances to their respective cathodes and the space charge grids are connected directly to the cathodes.

The feedback portion of the oscillator comprises a Wheatstone bridge consisting of four capacitances 12, 13, 14 and 15. Element 12 is a piezoelectric device and element 13 is a variable balancing capacity of any suitable type. As will be readily understood, the capacitances are of such magnitude as to effect a static capacity balance. Under these circumstances the two pairs of diagonally opposite junctions are electrically conjugate. The bridge will be found to be in a path extending directly from the grid of one discharge device to the grid of the other. It is also connected in a path extending directly from the plate of one discharge device to the plate of the other. Introduced into the connecting paths between the four terminals of the bridge and the two pairs of grids and anodes are four similar fixed capacity elements 16. Inasmuch as the diagonally opposite junctions of the bridge connected to the one path are electrically conjugate to the remaining two junctions of the bridge which are connected to the other path no feedback takes place through the bridge from the tuned plate circuit 5, 6 to the tuned grid circuit 3, 4. However, in the immediate frequency region of the resonance point of the piezoelectric device 12 that device no longer behaves as a static capacitance but rather as a resonant circuit thus permitting a relatively vigorous feedback at the sharply defined frequency to which it is resonant. With the tuning of circuits 3, 4 and 5, 6 so adjusted as to permit the oscillation system to oscillate at the resonance frequency of the piezoelectric device 12, the oscillator builds up oscillations in the tuned circuit 5, 6 and supplies them by way of coupling capacitances 17 to the antenna or high frequency transmission circuit 18.

Fig. 2 illustrates, in section, the structural details of the bridge 12, 13, 14, 15. The structure consists of a circular base member 20, consisting of brass or other suitable conducting material and having a threaded central aperture into which fits a circular screw-threaded plug 21 also of brass. The upper surface of the member 20 is provided with a circular recess in which a disc 22 of fused quartz or other suitable dielectric material closely fits. The disc 22 is somewhat thicker than the depth of the recess and, accordingly, projects above the upper surface of the base member 20. Also seated upon the base 20 is an annular dielectric member 23 provided with a central opening just large enough to enable it to fit over the member 22 which accordingly holds it in position. Surmounting the member 23 is an annular conducting ring 24 of brass provided with peripheral flanges 25 and having a central opening of the same diameter as that of the dielectric disc 23. The lower

flange 25 fits closely about the member 23 and accordingly holds the ring 24 in position while the upper flange 25 forms an outer boundary of the seat which the upper surface of the ring 24 provides for a dielectric disc 26 similar in every respect to disc 23. Seated upon the dielectric member 26 is an annular brass ring 27 provided with an interior peripheral flange 28 fitting closely within the annular member 26.

Resting upon the quartz disc 22 is a cylindrical brass electrode member 29, the lower portion of which is flared sufficiently to make its area co-extensive with the upper surface of the disc 22. Seated upon the electrode member 29 is a piezoelectric crystal plate 30 which, in turn, supports an upper electrode member 31. The member 31 has a cylindrical portion coextensive with the upper portion of electrode 29 to determine the effective electrode area of the crystal plate 30. The upper end of the electrode 31 has a diameter such as just to fit within the interior of the brass ring 27.

The structure of Fig. 2, as described, includes the three dielectric members 22, 23, 26 and the piezoelectric crystal plate 30. Each of these dielectric members with its adjacent conducting electrodes constitutes one of the capacitances of the bridge of the circuit of Fig. 1. For example, the capacitance 12 of the circuit is constituted by the piezoelectric plate 30 with its lower and upper electrodes 29 and 31 respectively which are insulated from each other. The variable capacitance 13 includes the dielectric 22 with its base electrode member 20 and its upper electrode 29. This capacitance may be varied by adjustment of the position of the screw-threaded plug 21 toward or away from the lower surface of the dielectric 22 as will be readily appreciated. Capacitance 14 consists of the annular dielectric member 23 with its lower base electrode 20 and upper electrode 24 while the capacitance 15 consists of the dielectric ring 26 with its lower electrode 24 and upper electrode 27.

An outstanding feature of the structure is the avoidance of leads between the electrically adjacent capacitance elements of the bridge. This result is attained by employing electrodes which are mutual to two of the capacitance elements. The base member 20 serves as an electrode for both the variable capacitance 13 and for the fixed capacitance 14. Electrode 24 is mutual to the capacitances 14 and 15. Member 29 forms an electrode for both the piezoelectric capacitance 12 and for the variable capacitance 13. Similarly the tightly interfitted members 27 and 31 cooperate with the capacitances 12 and 15.

The electrode member 29 may be connected to the circuit by a conducting lead or screw 33 extending laterally from the member 29 out through an aperture 34 in the ring 24. A similar laterally extending pin 35 forms a terminal for ring 24.

Fig. 4 shows the structure for holding together the assemblage of Figs. 2 and 3. It comprises a cylindrical post 36 of isolantite or other suitable ceramic insulating material threaded at each end to receive screws 37 which hold the clamping springs 38 and 39, preferably of phosphor-bronze, tightly against the ends of the bridge structure. Clamping spring 38, as shown in more detail in Fig. 5, has a central aperture through which the plug 21 may be introduced and adjusted to vary the capacitance of element 13. It also has three positioning tabs 40, 41 and 42 which are bent over to fit closely about base member 20 and hold

it accurately in position. Tab 42 is provided with an outwardly struck clip 43. Spring 39 is, in general, similar to spring 38 but has, in addition, a central spring or pressure member 44 to exert pressure upon the upper surface of the electrode 31. It is, therefore, adapted to compensate for slight variations in the thicknesses of the parts which may result in change of the relative positions of the upper surfaces of members 27 and 31.

The bridge structure is preferably mounted within a sealed container 45 to protect it against the effects of humidity, as shown in Fig. 6, which shows the apparatus mounted in a sealed container with portions of the container and its base ferrule cut away. The container 45 may be simply evacuated or it may first be evacuated and thereafter filled with a dry gas such as nitrogen. A metallic container may be employed and for that purpose a shell of the type commonly employed for electron discharge devices having its end closed by a circular metallic plate 46, soldered or welded in place may be used. In order to hold the bridge in fixed position within the container and to insulate it carefully from the container walls, mica sheets 48 and 49 are held in contact with the outer surfaces of springs 38 and 39 by the heads of screws 37 and by the clips 43 which engage them at their margins most remote from the clamping screws. The mica sheets, which may have a desired contour such as is shown in Fig. 8, are of such dimensions as to fit tightly within the circular container 45 and each sheet is apertured to permit the screws 37 to pass therethrough. The end plate 46 of the container is preferably provided with insulating seals of the type disclosed in U. S. patent to Ronci No. 2,125,315, granted August 2, 1938, through which pass the four leads to the bridge unit. The mica sheet adjacent clamping spring 38 is also centrally apertured to permit access to adjust element 21. The end plate 46 is also provided with a tubulation 50 for sealing.

The bridge structure fulfills two requirements necessary for the circuit of Fig. 1 to function properly but which could not be attained with electrical bridges of the prior art. The first requirement is that the bridge be very compact. This is necessitated by the fact that the loop path which the bridge forms from the grid to the plate of the same tube may, at extremely high frequencies, constitute an anti-resonant circuit which allows the tubes to oscillate in parallel relation substantially independently of the balance of the bridge and of the tuning of the tuned circuits 3, 4 and 5, 6. The bridge container of this invention is so compact that it may be mounted on the panel between the tubes or on the opposite side of the panel from the tubes which allows the plate and grid leads to be made very short and the resonant frequency of the loop to be raised beyond the point at which oscillations of the parallel type can be maintained.

The direct coupling of the bridge to the tube circuits affords an increased gain over that obtainable by the coupling coil arrangements of the prior art. This is the reason for the second requirement, namely, that a better balance of the bridge be had to prevent uncontrolled oscillations. The size and symmetry of the bridge are important because the effect of inductances and stray capacitances of the leads and in the elements themselves is to make the balance of the bridge dependent upon frequency. In such a circuit the bridge may be well balanced for the crystal frequency and yet may oscillate at a

widely different frequency determined by the associated circuits. By combining the bridge and crystal holder in one unit the effective length of the leads connecting the elements of the bridge together is made negligible since the electrode for one capacity is also the electrode for the physically and electrically adjacent one.

The average capacity of the piezoelectric elements used in oscillators of this type is very small and of the order of 5 micro microfarads. Therefore, an additional paralleling capacity, even if very small, reduces the coupling to the crystal appreciably and results in diminished output. Accordingly, the new bridge is so designed that the capacity of the piezoelectric holder itself has been largely eliminated by the shielding effect of the various electrodes. It will be observed that the bridge structure consists in effect of alternate layers of conducting and dielectric material. Accordingly, the capacitance between the electrodes 29 and 31 of the piezoelectric plate 30 is substantially confined to that existing between the faces of the electrodes immediately adjacent the crystal faces. The conducting ring 24 is interposed squarely between the members 20 and 27 which support the crystal electrodes and thus substantially eliminates any external or stray capacities between those electrodes. In a similar fashion each of the other capacitances of the bridge is shielded. This, together with a better coupling to the grid and plate circuits which the compact bridge makes possible, has increased the output energy of the oscillator.

A generally prevalent source of trouble with high frequency oscillators is instability of frequency in consequence of temperature effects. In prior piezoelectric controlled oscillators employing bridge feedback circuits this defect has been greatly reduced. Nevertheless, the use of piezoelectric quartz with bridge balancing condensers having appreciably different temperature coefficients of capacity has limited the temperature range within which high stability may be maintained. The use of quartz as the dielectric of the balancing capacitance of applicant's novel bridge eliminates the effects of temperature upon the unbalance. It also results in an equal loss factor in each arm thus additionally improving the balance.

Upon considering the tuned circuits of Fig. 1 it will be seen that the tuning capacitance of each is, in effect, shunted by the entire bridge structure in series with two of the capacitances 16. The bridge viewed as a single shunting reactance from the standpoint of either circuit may be made to have a positive coefficient of reactance with change in temperature by using a dielectric material which has a negative temperature coefficient of dielectric constant for members 23 and 26. One such dielectric material is Al Si Mag 190, made by the American Lava Corporation, Chattanooga, Tennessee. This material may be machined or otherwise worked in much the same manner as may quartz to construct the rings 23 and 26. Since the tuning condensers 4 and 6 have negative temperature coefficients of reactance it is possible to so proportion them that the resulting combination of tuned circuit and bridge has a low temperature coefficient. This also results in a substantial compensation of the temperature coefficient of the piezoelectric device and eliminates the necessity for temperature control of either the piezoelectric crystal or of the circuit. Of course, the piezo electric device will

preferably comprise a quartz or tourmaline plate having such an orientation as to render its temperature coefficient of frequency extremely low. It is advisable, however, to enclose the oscillator so that rapid temperature changes will not produce large unequal temperature gradients in its various constituent parts since this would cause a frequency deviation until an equilibrium is again reached.

The compact bridge not only simplifies the high frequency oscillator circuit by eliminating the coupling coil and enabling a single tuning device to be used: it also increases the frequency stability and the output energy. Such small shunt loss as is introduced by the ceramic insulating post 36 is effective only in the plate circuit where the energy loss is of less consequence. The bridge device may be mounted between and very close to the two electron discharge devices to make the external coupling leads of the bridge extremely short.

In order to produce very high frequency oscillations as, for example, of the order of 150 megacycles or higher, it is found necessary to operate the piezoelectric frequency control crystal at a harmonic of its natural oscillation frequency. For this purpose quartz crystals of the well-known AT cut, disclosed at page 459 of the Bell System Technical Journal, vol. 13, July 1934, and also at pages 250 to 254 of Bell Laboratories Record, April 1936, vol. XIV No. 8, may be used. The AT cut quartz crystal, which exhibits zero temperature coefficient of frequency when vibrated in a thickness mode of shear vibration, has its major faces substantially parallel to an X or electric axis of the virgin quartz and inclined at an angle of  $+35^{\circ}20'$  with respect to the Z or optical axis. With the compression positive end of the electric axis pointed toward the observer a positive rotation is clockwise for right-hand quartz and counter-clockwise for left-hand quartz. Right-hand quartz is that which rotates the plane of plane polarized light traveling along the Z axis in the quartz in a right-hand direction or clockwise when viewed by an observer located at the light source and facing the crystal. Left-hand quartz rotates such plane in the opposite or counter-clockwise direction. However, any thickness mode crystal plate appropriate to the operation desired may be employed as, for example, the BT cut or  $-49^{\circ}$  orientation crystal disclosed at page 459 in the Bell System Technical Journal publication to which reference has already been made.

It has been found important at high harmonics of such thickness mode crystals to have the crystal of either uniform thickness or slightly thicker in the center in order to obtain a large output and a single response at the desired harmonic frequency. The major surfaces of the crystal are polished to make them nearly or substantially flat and the degree of flatness determined by interference fringes. Any difference in thickness between the major faces will, of course, result in a difference in the fundamental mode of vibration as it tends to exist at that point. The difference in frequency between the harmonics of these fundamental modes will be correspondingly greater. Therefore, a crystal whose thickness varies irregularly will usually have more than one thickness response frequency, each of which corresponds to a particular active spot or small portion of the crystal which vibrates at a frequency corresponding to the thickness at the point. The active spots usually exist at points

where the crystal plate is slightly thicker than the surrounding portion. Since it is not possible to obtain absolute flatness or parallel faces, the number of active spots, and therefore response frequencies, may be reduced by making the plate slightly thicker in the center and with a gradual taper towards the edges. A crystal of this shape has one major response and the active portion is at the center.

The edges of high frequency crystals are usually not active since there is a tendency for them to become thinner than the rest of the plate during the process of grinding. To obtain as large an active area as possible the diameter of the finished crystal disc may be made approximately twice that of the electrode diameter. By ordinary grinding methods, the central portion of the plate may be made quite flat and with just enough taper to provide a single active spot.

Another advantage in using crystal plates of comparatively large area is that the coupling of the harmonic thickness vibrations with certain other modes is, in general, reduced as the area is increased.

The crystal electrodes may be made to have very flat surfaces and, as has been explained, may be mounted concentrically with the major faces, thus utilizing the flattest portion of the crystal. Maximum electromechanical coupling is obtained when the area of the electrodes is about equal to that of the active portion of the crystal plate. This depends upon the shape of the crystal plate, as previously explained, and also upon the frequency of the crystal response.

In one embodiment, a circular piezoelectric quartz plate of AT cut having a thickness of .210 millimeter and a fundamental thickness mode of oscillations of 8 megacycles per second and a 15th mechanical harmonic frequency of 120 megacycles was employed. The quartz plate had a diameter of 12 millimeters and it was held clamped by a circular centrally mounted electrode having a surface diameter of about 6 millimeters.

It also appears to be important in order to obtain high intensity oscillations of the higher harmonic frequencies to avoid air-gaps between the electrodes and the piezoelectric crystal face so as to obtain as nearly as possible maximum piezoelectric coupling.

In order to make the final adjustment of the frequency of piezoelectric plates intended to operate at high harmonic frequencies according to this invention, the following process may be used: Very fine emery dust as, for example, No. 304 may be mixed with water and after shaking allowed to stand for a few minutes. The heavier particles settle to the bottom and the top white liquid containing the fine particles may be used for grinding. A small amount of the liquid is poured on to a cast iron lap, the surface of which is finished to a fair polish and it may be well rubbed in with a second lap. The piezoelectric crystal may then be placed upon a small piece of flat plate glass and worked into such a degree of contiguity that no interference fringes appear between the crystal and the glass when viewed in ordinary white light. This holds the crystal flat while it is undergoing the final grinding. By lightly rubbing the crystal on the wet lap, its frequency may be changed by an amount of the order of .05 per cent to 1 per cent in one minute. If the lap is allowed to dry the change is much less. As an alternative, small frequency adjustments may be made by simply placing the crys-

tal on the dry lap and subjecting it to a few light grinding strokes with the finger pressed lightly against it at the back. A few light strokes will raise the frequency a kilocycle or two in 100 megacycles. Smaller frequency variations are obtained by circuit adjustment.

The coupling elements 16 may be small fixed type condensers of sufficiently large capacity to provide the required feedback but having a reactance large enough to reduce the coupling between the bridge and the tuned circuits so that adjustment of the tuned circuits will have little effect upon the oscillator frequency as controlled by the bridge.

Fig. 9 shows a modified form of circuit in which the condensers 16 are introduced into the tuned circuits with the bridge in shunt to the tuning condensers 51 and 52 at its conjugate connections. There is some disadvantage in having the coupling of the tuned circuits to the bridge vary with tuning of the tuned circuits. This may be reduced by making variable condenser 51 and the two adjacent condensers 16 as a three-part variable condenser with a single tuning control and, likewise, making condenser 52 and its adjacent condensers 16 as a single three-part variable condenser. Obviously, the condensers 51 and 52, as illustrated, or, in the three-part modification, may be operated by a unicontrol device similar to element 7 of Fig. 1.

Fig. 10 shows an alternative circuit in which the tuning condensers 54, 55 are placed between the sections of the two-part coils 56 and 57. Individual grid leak resistors 58, similar to element 8 of Fig. 1, and plate circuit resistors 59, similar to element 9 of Fig. 1, are required for the two tubes.

Oscillators embodying the principles of this invention and requiring only a single electron discharge device have been found very successful throughout the range of frequencies up to 150 megacycles. They are very stable in frequency and permit a wide range of tuning of the tuned circuits in order to obtain maximum voltage and output without substantial change of the frequency of the oscillations produced.

What is claimed is:

1. A feedback coupling unit comprising an insulating member, a laterally projecting spring attached to each end of the insulating member and an assemblage of three capacitances and a piezoelectric condenser stacked between the springs and held in proper relative positions thereby, the capacitances and the condenser each including electrically conducting elements separated by dielectric members with the conducting elements serving as the terminals of a four-arm bridge constituted by the capacitances and the condenser.

2. In an oscillator feedback unit comprising a central electrode member, a piezoelectric plate seated against one of its principal faces, a dielectric element of a balancing capacitance seated against its other face, upper and lower electrode members for the piezoelectric plate and for the dielectric member, respectively, and a spring clamp holding the assemblage together while maintaining the upper and lower electrode members insulated from each other.

3. In combination, a central electrode comprising a circular conducting element, an annular conducting element surrounding said central electrode and spaced therefrom, two conducting end electrodes each overlying both the central and annular electrodes and positioned respec-

tively at opposite sides thereof, and individual dielectric members clamped between the central electrode and each of the end electrodes and between the annular electrode and each of the end electrodes.

4. A unitary bridge for an oscillator feedback circuit comprising four capacitance elements each having a dielectric placed between two conducting elements, each conducting element serving as a common electrode of two electrically adjacent capacitances, and means for varying the magnitude of one capacitance without affecting the magnitudes of others.

5. A unitary capacitance bridge and piezoelectric crystal holder comprising a piezoelectric crystal and electrodes therefor, means for supporting the electrodes comprising alternate layers of conducting materials and dielectric materials which constitute the elements of an electrical bridge, and means for varying the electrostatic balance of the bridge.

6. A unitary capacitance bridge and piezoelectric crystal holder comprising a plurality of electrical condensers each having a dielectric and conducting elements, a piezoelectric crystal, electrodes therefor and electrostatic shielding means substantially surrounding the piezoelectric crystal, the shielding means comprising the conducting elements of the capacitance bridge.

7. A unitary capacitance bridge and piezoelectric crystal holder comprising a piezoelectric crystal, conducting electrodes adjacent the opposite sides of the crystal, supports for the electrodes, and a conducting element of the capacitance bridge interposed between the electrode supports to effectively shield the piezoelectric crystal and its holder from external electric fields.

8. A piezoelectric quartz crystal element adapted to vibrate in a shear mode at a mechanical harmonic frequency dependent mainly upon its thickness dimension perpendicular to its major faces, said major faces being substantially parallel to an X axis and inclined with respect to the Z axis at one of the angles of substantially  $+35^{\circ}20'$  and  $-49^{\circ}$  as measured in a plane perpendicular to said major faces, electrodes having clamping surfaces adjacent said major faces, and means for resiliently clamping said element between said electrodes, said major faces and said clamping surfaces being nearly flat and parallel with respect to each other, said crystal element being slightly thicker at the center and tapering towards the edges, and said clamping surfaces covering the central part only of the total area of said major faces at a major active portion of said element.

9. Apparatus in accordance with claim 8 wherein said major faces are circular, said electrode clamping surfaces are circular, and said mechanical harmonic is one of the odd order integers 3 to 27.

10. A unitary bridge for an oscillator feedback circuit comprising four capacity elements each having a dielectric placed between two conducting elements, each conducting element serving as a common electrode of two electrically adjacent capacitances, the substances of the dielectric being such that the reactances of the bridge as presented at each of the conjugate pairs of terminals have a positive coefficient with change in temperature.

11. In combination, a combined oscillator feedback bridge and frequency-determining element comprising a piezoelectric quartz crystal element

adapted to vibrate at a mechanical harmonic of a shear mode vibration comprising a pair of electrodes between which the quartz element is fixedly held, the area of the surface of the quartz element adjacent the electrodes being considerably larger than that of the engaging electrode face in order to reduce the coupling of the harmonic vibrations with undesired modes of vibration, three additional capacitances each comprising an individual dielectric member placed between conducting electrodes, the three capacitances together with the electrodes of the piezoelectric element being combined in a compact form to entirely surround and effectively shield the capacitance of the piezoelectric element from external influences.

12. In combination, a pair of tuned loop circuits tuned to substantially the same frequency, a selective wave energy transfer path having input leads connected between two points in one of the loop circuits which are electrically remote from each other to derive a driving electromotive force therefrom, and output leads connected to two points in the other tuned circuit which are electrically remote from each other to impress an electromagnetic force thereon, the energy transfer path comprising a bridge structure including four capacity elements, one of which is a piezoelectric device, the output leads and the input leads being connected to conjugate pairs of terminals in the bridge and reactances in the tuned circuits having temperature coefficients of opposite sign to those of the bridge and so related in magnitude as to substantially compensate the tendency of the tuned circuit tunings to change with change in temperature.

13. A bridge comprising four electrical reactance elements connected in series, input leads connected to the first and third junction points, output leads connected to the second and fourth junction points, the reactance elements having such magnitudes that for at least one frequency the input and output leads are conjugately re-

lated, and input and output circuit reactances connected to the input and output leads respectively, the temperature coefficients of reactance of the bridge reactances having a sign opposite to that of the temperature coefficients of the input and output reactances and being so related in magnitude thereto that the reactance between the input leads and the reactance between the output leads remain substantially unaffected with change in temperature.

14. In combination, a tuned input circuit, a tuned output circuit, a transmission path comprising a four-arm bridge, means connecting the input circuit to two points in the bridge and connecting the output circuits to two points of the bridge which are conjugate with respect to those to which the input circuit is connected, the bridge comprising reactance elements the temperature coefficients of which cause the shunt effect of the bridge to tend to vary the tuning of the tuned circuits and reactance elements in the tuned circuits having temperature coefficients which are of a sign opposite to and so related in magnitude to those of the bridge as to substantially compensate the tendency to change the tuned circuit tunings with change in temperature.

15. A bridge unit comprising four capacitance elements having individual dielectric members and a plurality of electrically conducting members, each of the conducting members serving as an electrode for two of the capacitance elements whereby a compact unit is attained, a container in which the unit is mounted, thin flexible sheets of supporting material shaped to fit snugly within the walls of the container to hold the unit in place therein and clamping means for resiliently holding the dielectric members and conducting members in assembled relation and for holding the bridge unit fixed to the flexible supporting sheets.

IRVIN E. FAIR.