

July 12, 1949.

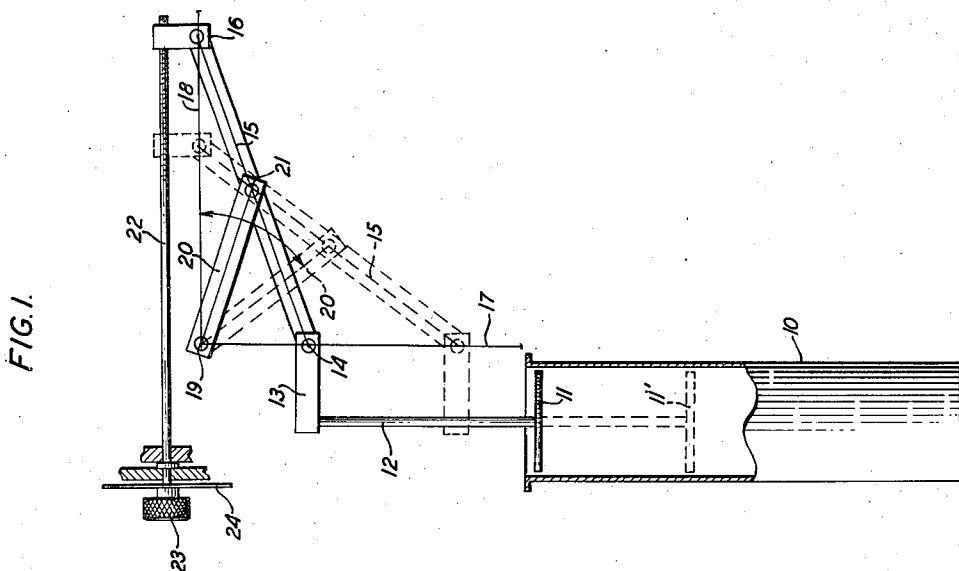
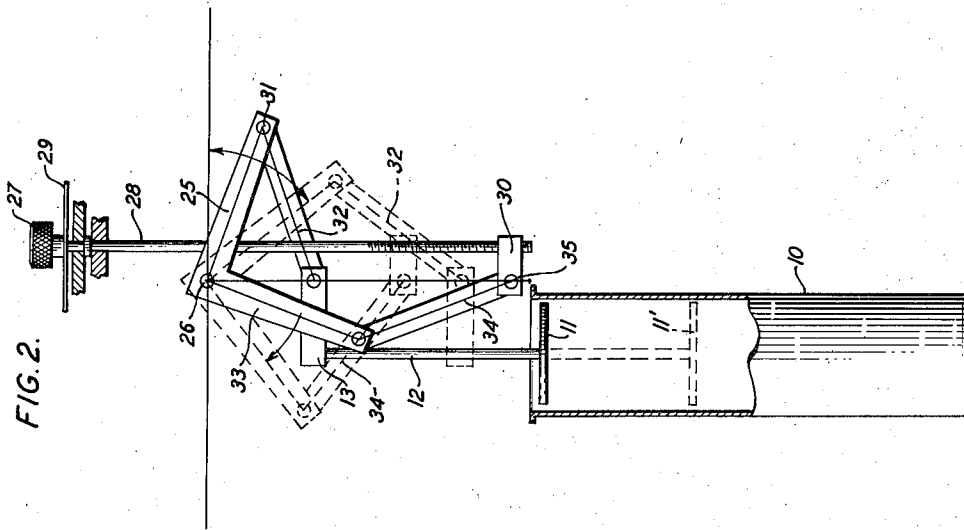
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2,475,778

ELECTRICAL CAVITY RESONATOR

Filed Oct. 17, 1946

4 Sheets-Sheet 1



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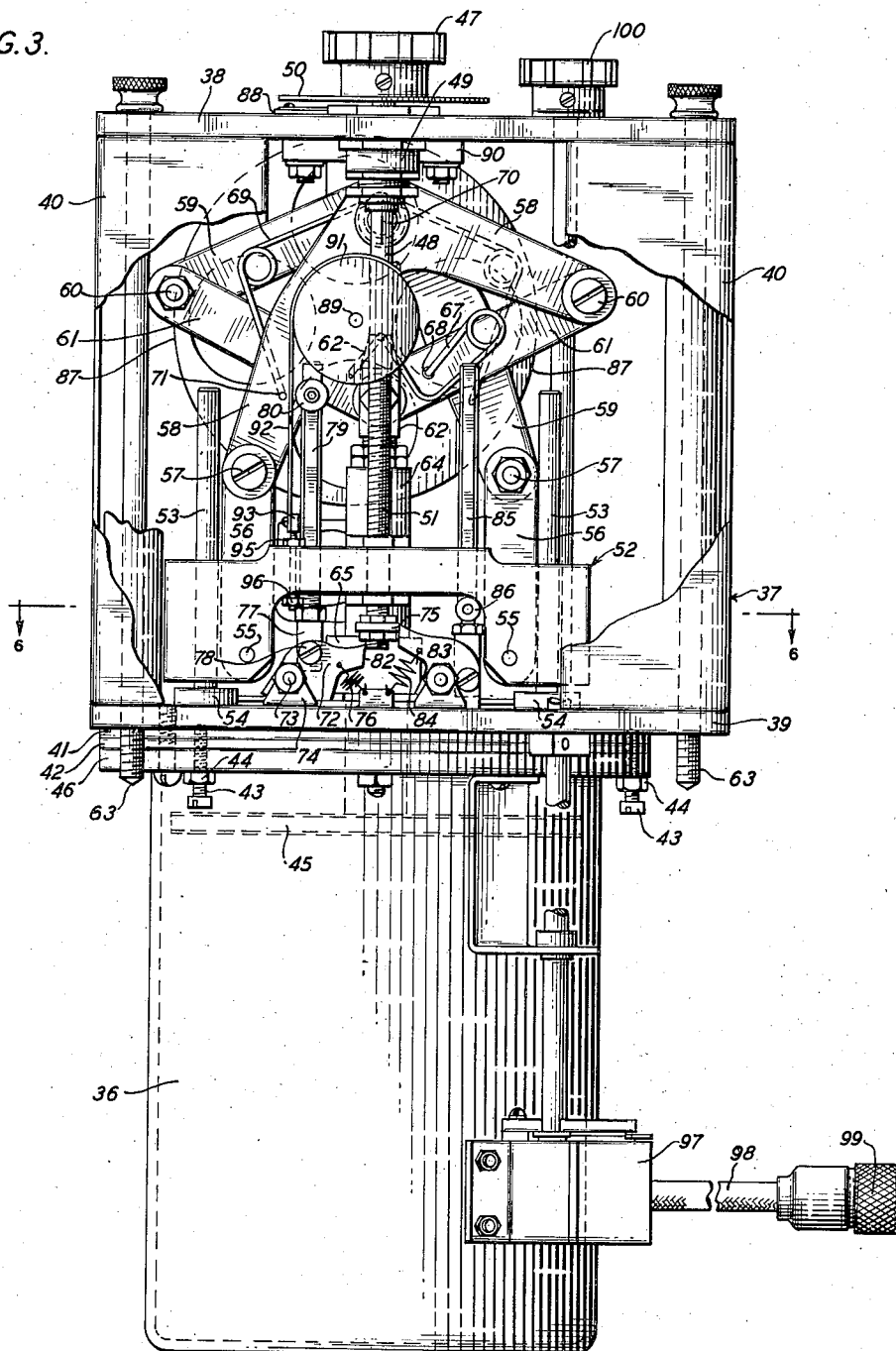
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FIG. 3.



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FIG. 4.

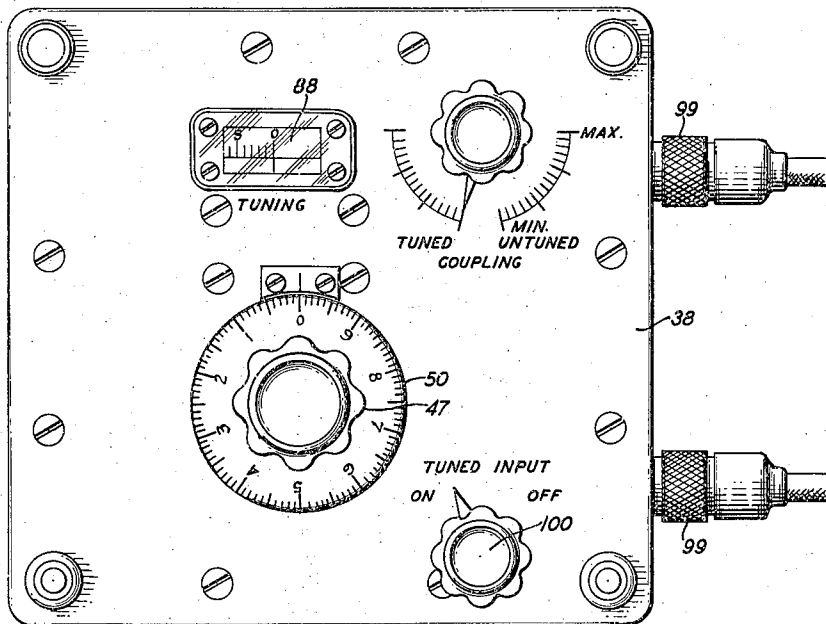
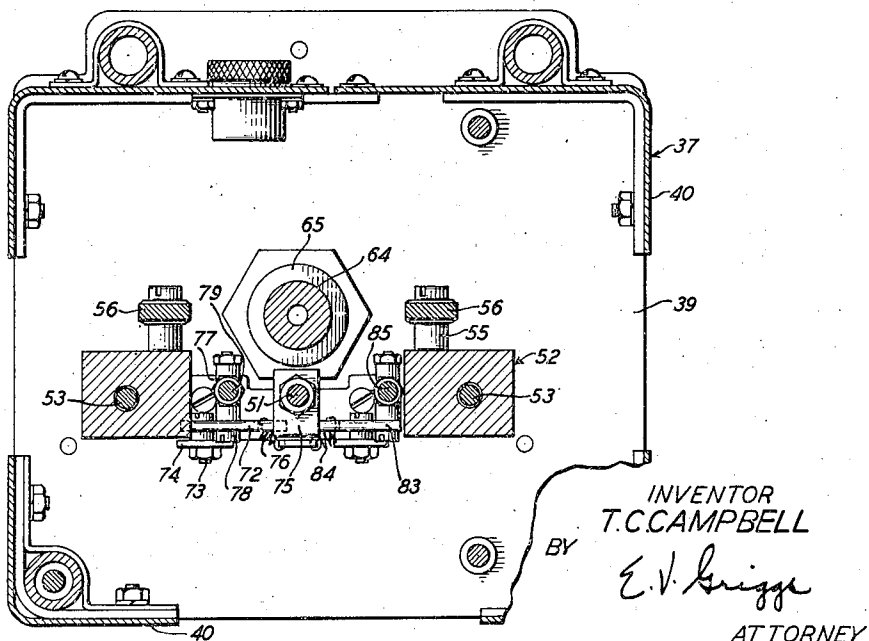


FIG. 6.



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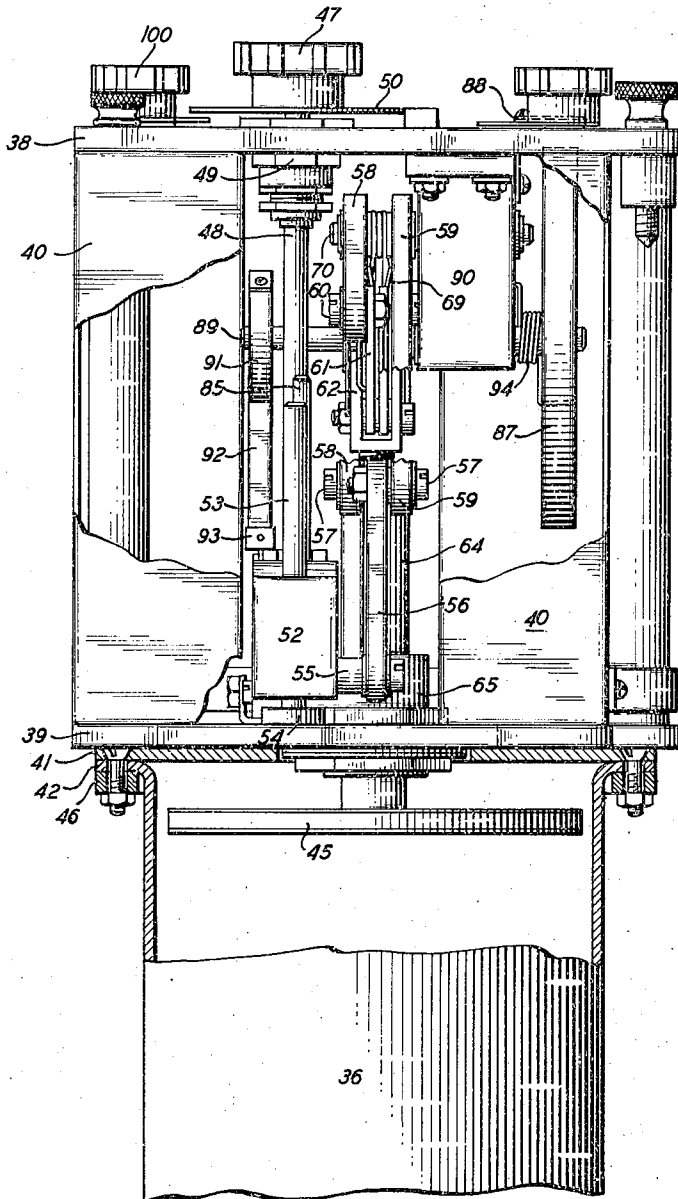
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ELECTRICAL CAVITY RESONATOR

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4 Sheets-Sheet 4

FIG. 5.



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ELECTRICAL CAVITY RESONATOR

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7 Claims. (Cl. 178-44)

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This invention relates to electrical cavity resonator and more particularly to a cavity resonator tuning device for use in electrical testing.

An object of the invention is to enable tuning of a cavity resonator over a very wide range of frequencies with a substantially linear relation between displacements of the tuning dial and changes in resonator frequency.

Another object of the invention is to equalize the accuracy of tuning of an electrically resonant system throughout its entire tuning range.

Another object of the invention is to render more compact a tuning operating mechanism for a variable frequency cavity resonator.

A feature of the invention is a mechanical linkage for converting rotary motion of a dial into straight line motion of a tuning element such that the resonant frequency of the system being tuned varies linearly with respect to rotary displacement of the dial.

Cavity resonators capable of variable tuning are well known in measurement of microwave frequency and for radar testing. For such purposes as in airborne apparatus it is particularly necessary to reduce the volume and the weight of cavity resonators so far as is compatible with other requirements. Ordinarily, tuning is effected by means of a piston in a cylindrical resonator which is operated at a particular natural mode of oscillation. This may be, for example, a TE_{01n} mode, in accordance with the designation of modes used by Schelkunoff in his treatise entitled "Electromagnetic Waves," D. Van Nostrand Company, first edition 1943, page 395. The tuning of such devices is complicated by the fact that the relation between displacement of the actuating device and displacement of the piston is non-linear and moreover the relation between displacement of the piston and frequency of the resonator is complex. It is therefore not convenient to manipulate such tuners by any simple dial arrangement having uniformly spaced graduations. This difficulty is greatly increased when, in addition to the other requirements, there are added those of extraordinarily wide tuning range with a large number of closely but evenly spaced subdivisions of that range and the ability to move both limits of the band upward or downward to meet special operating conditions or to relax manufacturing tolerances. It is to the problem of satisfying these requirements that the present invention is addressed.

In accordance with the invention the piston rod connected to the piston tuner of a cylindrical cavity resonator operating at a TE_{01n} natural

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resonance mode of oscillation is connected to one arm of a bell crank mechanism, another arm of which is linked to a crosshead mounted for travel in the same direction as the piston. The crosshead is provided with an interiorly threaded opening which engages with the threads on the outer surface of a rotating actuator rod to the free end of which an indicating dial is connected. A counter mechanism associated with the dial indicates the number of completed turns or dial rotations. The screw-driven crosshead is displaced an amount which is directly proportional to the number of turns of the dial. Linear displacement of the crosshead causes a rotational operation of the bell crank. The linkage between the bell crank and the crosshead on the one hand and between the bell crank and the piston rod on the other causes motion of the piston in the direction parallel to that of the crosshead but in an amount which varies with a sine function of the angle of displacement of the bell crank. Consequently, as the volume of the cavity resonator is reduced, equal movements of the dial cause successively diminishing displacements of the piston, while when the volume of the resonator is being increased, equal displacements of the dial cause successively increasing displacements of the piston. Thus, the motion of the dial is translated into change of the frequency of the cavity resonator in such manner that the changes in frequency are substantially equal for equal angular displacements of the dial throughout the entire tuning range.

Referring to the drawing, Fig. 1 is a schematic mechanical diagram for use in explaining the operation of the tuning mechanism of this invention;

Fig. 2 is a schematic diagram corresponding in general to the disclosure of Fig. 1, but with a bell crank interposed between the slider mechanism and the piston rod;

Fig. 3 is a front view of an embodiment of the invention incorporating the principles of Fig. 2;

Fig. 4 is a top plan view of the structure of Fig. 3;

Fig. 5 is a side view of the same structure;

Fig. 6 is a section along the transverse plane passing through the broken line 6-6 of Fig. 3.

Referring to Fig. 1, a cylindrical cavity resonator 10 closed at its lower end is provided with a loosely fitting tuner piston 11 rigidly connected to a piston rod 12, which is in turn connected to and driven by a crosshead 13. The piston rod and the crosshead are mounted on and supported by means not shown to permit the piston to move

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in a vertical direction only from the minimum frequency position in which it is shown in solid lines to the maximum frequency position 11 shown in broken lines. The crosshead 13 is pivotally connected at 14 to one end of a rigid link 15, not shown but represented by a line, the other end of which is pivotally connected to a second crosshead 16 mounted to slide along a horizontal guideway perpendicular to the vertical guideway of crosshead 13. The guideway of crosshead 13 may be represented by the line 17 extending through the center of the pivotal positions and the guideway of crosshead 16 may similarly be represented by the line 18 extending through the center positions of the pivotal connections to that crosshead.

The guideways 17 and 18 intersect at a point 19. It easily may be shown that the bisecting point of a fixed length hypotenuse of a right triangle with the hypotenuse moving so that the ends of the hypotenuse slide along the legs of the triangle, traverses a circular path about the vertex of the right angle. Accordingly, without otherwise modifying the system we may, for purposes of explanation of subsequent modifications, introduce into the structure of Fig. 1 a rigid link 20 with one end pivoted at 19 and the other end pivotally connected to the rigid link 15 at its central point 21. The central point of the link 15 moves with the link 15 to describe an arc of a circle about pivotal point 19. This principle is utilized in subsequent modifications of the structure of Fig. 1.

Crosshead 16 is provided with a threaded aperture closely engaging the threaded exterior surface of the actuator rod 22, the free end of which is connected to the knob 23 associated with the dial 24. Consequently, as the knob 23 is rotated the dial 24 rotates with it as does also the actuator rod 22. This carries the crosshead 16 in a horizontal direction and through the link 15 impels the crosshead 13 to move in a vertical direction.

A disadvantage of the structure of Fig. 1 is that it requires considerable space in the directions of motion of the two crossheads. This may be overcome by a transformation of the Fig. 1 structure utilizing the principle that the central point 21 of the link 15 follows the arc of a circle described about the junction point 19. We may first assume that the link 15 is divided at its central point 21 to constitute two separate links. The swinging link or rocker arm 20 may be replaced by two separate links pivoted at point 19, one of these links having its free end connected to the left-hand half of link 15 and the other link having its free end connected to the right-hand half of link 15. So long as the two links pivoted at 19 remain mechanically tied together motion of the two portions of link 15 will occur in the manner which has been described. If now, the links pivoted at 19 be free from each other, the link associated with crosshead 16 and the entire tuning actuating structure comprising elements 23, 24 and 22 may be rotated in a clockwise direction about the position 19 to a position in which the actuator rod 22 will lie parallel to the piston rod 12. If now, the two links pivoted at 19 be rigidly connected with each other at their pivot ends to swing as a unit about the pivot, they will constitute a bell crank rocker arm and the structure will be transformed into that of Fig. 2.

Referring to Fig. 2 in which the resonator 10, piston 11, piston rod 12 and crosshead 13 correspond to the similarly designated elements of

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Fig. 1, it will be apparent that operation of the tuning knob 27 to rotate the actuator rod 28 carrying the dial 29 will cause vertical displacement of the crosshead 30 in the same manner that operation of the knob 23 in Fig. 1 causes horizontal displacement of the crosshead at pivot 16. The link 34 pivoted to crosshead 30 at point 35 of Fig. 2 corresponds to the right-hand portion of the link 15 of Fig. 1. Consequently, being rigid, it causes angular motion of the bell crank arm 33 about the pivot 26 of the same magnitude as the motion of the arm 20 about the pivot 19 in Fig. 1. This same angular motion is transferred by the bell crank to its other arm 25, which operates upon rigid link 32, pivoted at 31, and crosshead 13 to produce vertical translation of the crosshead in precisely the same manner as the arm 20 of Fig. 1 may be deemed to operate upon the crosshead 13 by virtue of the left-hand portion of link 15.

It readily will be appreciated that in so far as translation of motion is concerned, the structure of Fig. 2 will cause piston 11 to move in response to the operation of the knob 27 in the identical manner and degree that equal angular motion of the knob 23 of Fig. 1 causes the piston 11 of that figure to move. It should be noted that the motions of the crossheads in the structure of Fig. 2 are in parallel directions, thus enabling the dimension of the apparatus in directions transverse to the motion of the piston to be greatly diminished. Moreover, the structural arrangement is such that the tuning actuator rod and the piston may be placed side by side to reduce the length of the structure and to make it very compact. This parallel arrangement of the piston rod and of the tuning actuator rod lends itself to embodiments in a device which is not only compact, but which may be made rigid so as to reduce the various errors which may occur in a less rigid structure designed for an extremely wide tuning range.

Fig. 3 presents an embodiment of the principles of the structure of Figs. 1 and 2 in which the cylindrical cavity resonator 36 is supported by a rigid rectangular frame 37 comprising a flat top plate 38, a flat lower plate 39 and four angle bar corner struts 40 connecting the plates. Plate 39 is attached by screws or bolts to a flat circular ring 41 connected to an outwardly extending flange 42 of the cavity resonator 36 and a clamping ring 46. A three-point adjusting screw connection consisting of threaded bolts 43 and locking nuts 44 permits adjustment of the plane of the supporting plate 39 with reference to the supporting disc 41 to enable the inner surface of the lower end of the resonator 36 to be brought into parallelism with the lower face of the tuning piston 45.

Although in the drawing the frame 37 and the supported cavity resonator 36 are shown in vertical alignment and are so described in the specification, it should be understood that the frame 37 may be attached by the connecting bolts 63 to the supporting structure or vehicle on which it is mounted without regard to the direction of travel of the piston 45 and that, therefore, the piston 45 may in actuality travel in a horizontal or in any other direction.

A dial knob 47 is attached to the upper end of a tuning shaft or actuator rod 48 supported for rotary motion in bearing 49 in the top plate 38. The shaft 48 at its upper end carries a flat circular dial 50 graduated at its outer periphery with tuning indications. The actuator rod 48 is threaded along its lower portion 51, where it

passes through a correspondingly internally threaded aperture in the central axis of a cross-head member 52 which may accordingly be raised or lowered by manipulation of the screw-threaded shaft in response to actuation of the knob 47. The crosshead 52 is held against lateral displacement by round guide rods 53, which fit closely in vertical holes near the opposite ends of the crosshead 52 and are supported by bases 54 attached in any desired manner to the lower plate 39 of the frame.

Near each end of the crosshead 52 there is pivotally connected to the crosshead at a point 55 a rigid link 56 which corresponds in function to the link 34 connected to the crosshead 30 in Fig. 2. In the structure of Fig. 3 the crosshead 52 is double-ended and two such links 56 are provided to constitute a symmetrical structure in which lateral thrust on the crosshead occasioned by the reaction of one link 56 is opposed and substantially neutralized by the equal and oppositely directed lateral thrust from the link 56 connected to the opposite end of the crosshead. Pivots 57 at the upper end of links 56 connect the links 56 to bell cranks 58 and 59, respectively. Each bell crank has a pivotal connection 60 at its outer end to a link 61 corresponding to the link 32 in Fig. 2 and having a pivotal connection to a vertical yoke 62, which serves the same function as the crosshead 13 of Figs. 1 and 2. The yoke 62 comprises two vertical portions through which passes a pintle providing the pivotal connection to the links 61. The yoke also has a downwardly projecting stem which is fastened by a screw-threaded connection to the upper end of piston rod 64 which provides a means for adjusting the piston height. The piston rod extends downwardly through the circular guide and supporting member 65 attached to the lower frame plate 39 and extends into the resonator 36 carrying at its lower end the piston 45.

It will readily be appreciated that the link and bell crank mechanism of Fig. 3 is analogous to that of Fig. 2 and differs therefrom in few respects. One of these differences resides in the duplication of the crank arm system of Fig. 2, so that by an arrangement of one right-hand crank arm and one left-hand crank arm the two working simultaneously to elevate or depress the piston 45 there is provided a symmetrical system which neutralizes the lateral thrust on the piston rod and correspondingly reduces mechanical load on the tuning system and liability of warping of the position of the piston.

A spring 67 which passes through a slot in the upper portion of the yoke 62 and is bent around as shown in the drawing to permit its outer ends to seat in apertures 68 near the lower ends of the respective links 61 is designed to push down on the upper end of the piston rod and to cause the links 61 to rotate in a direction which will cause downward displacement of the piston. Another spring 69 having its central portion wound around the crank arm axis 70 and having its outer extremities bent down and returned to engage apertures in the longer crank arms, as indicated at 71, serves to cause these longer crank arms to tend to rotate outwardly thereby breaking the almost straight line alignment between the longer crank arms and the immediately connected links 56. Accordingly, it will be appreciated that the springs 67 and 69 not only tend to take up any backlash in the linkage so as to maintain the indications of the dial accurate at all times but that their joint effect is such as to materially reduce the load on the

tuning mechanism at the time when the piston is moving upwardly. In fact, the mechanism may be regarded as one in which the screw-threaded actuating rod causes downward motion of the piston against the action of the springs and when reversed permits upward motion of the piston under the impelling action of the springs thus tending to equalize the stresses which are required in the two directions of operation of the tuning mechanism.

In order to limit the motion of the piston to the tuning range desired, the lower threaded portion 51 of the actuator rod 48 is provided with a stop lug 75 clamped between two nuts on the threaded rod. At one extreme of the tuning range the lug will engage a dog or locking member 72 pivotally connected at point 73 to a mounting plate 74 attached to the lower frame plate 39. The dog 72 is held in a downward retracted position by a spring 76. It supports a block 77 attached at the pivot point 78 and carrying an upstanding rod 79 which passes loosely through an opening in the crosshead 52. Near its upper end the rod 79 is encompassed by a cylindrical stop member 80 which is adjustably clamped thereto in any well-known manner to enable its position to be reset in the event that it should become necessary. When in the course of upward motion of the crosshead 52 the upper surface of the crosshead engages the cylindrical stop 80 it lifts the rod 79, swinging the dog 72 about its pivot 73 to cause its front end surface 82 to be projected up into the path of the lug 75 as it turns in a counter-clockwise direction. This stops rotation of the rod 48 at the upper limiting frequency of the resonator when the piston 45 is in its lowermost position. A second dog 83 at the opposite side of the lug 75 is likewise normally held in a downward retracted position by a spring 84 and carries a pivotally connected upstanding rod 85 similar to the rod 79 and similarly passing loosely through an aperture in the crosshead 52. A cylindrical stop member 86 encompassing the rod and adjustably clamped thereto is positioned beneath the crosshead 52 so that in the position shown in Fig. 3, in which the tuning mechanism is in the position corresponding to the lower limiting frequency of the resonator, the crosshead 52 bears down on the stop 86 to swing the dog 83 upwardly against the action of the spring 84 into a position such that it obstructs the counter-clockwise rotation of lug 75.

The stops 80 and 86 may be adjusted to change the length of the travel of the piston for a given number of turns of the dial or they may be adjusted to limit the useful length of the cavity resonator to any particular band selected. If the two stops are each moved upward by the same amount, the length of the piston stroke will be decreased. If, on the other hand, the two stops are moved downward by the same amount, the length of the piston stroke will be increased.

In the event that it is desired merely to restrict the band over which the apparatus may be operated to a portion of the band for which it was originally designed, it is only necessary to readjust the stops 80 and 86 to the new limits desired.

The dial indicator consists of two parts, one showing complete turns of the screw-threaded shaft 48 and the other indicating divisions of a turn. The full-turn indicator comprises a disc 87 of low density plastic or other structural material carrying indicia on its perimeter, a portion of which is exposed through a viewing window 88 in the top plate 38. The indicator disc 87 (see Fig.

5) is fixed to a horizontal rotatable shaft 89 which extends through a bearing block 90 supported by and projecting downwardly from the underside of the top plate 38. The block 90 also supports the crank arm axis shaft 70. On the other end of the shaft 89 is mounted a thick disc 91 to the periphery of which is attached a flexible metallic strip 92 adapted to wind on and unwind from the periphery of the disc and having its other end attached by an adjustable connection 93 to the crosshead 52. A spiral spring 94 encircling the shaft 89 in the region between the indicator disc 87 and the bearing block 90 has one end anchored to the indicator disc 87 and the other to the fixed bearing block 90 in such manner as to exert a torsional effect upon the shaft 89 pulling the flexible metallic strip 92 tight to give correct readings at all times. Rotating the tuning dial knob 47 to move the crosshead 52 upward allows spring 94 to rotate indicator disc 87, shaft 89 and disc 91 against the pull of the metallic strip 92. Accordingly the number of full turns of the shaft 48 may easily be read from the position of the indicator dial 87 which may be seen through the window 88. Likewise, that portion of a single turn through which the tuning shaft has rotated in excess of the integral number of turns read from dial 87 will be indicated by the graduations on the dial 50. With this arrangement and with indicator dial 87 graduated so as to show 66 turns of dial 50 it readily may be seen from Fig. 4 that the two dials may be read in conjunction to show the frequency of the resonator 36 in 0.1 megacycle steps. Instead of the graduations of the dial 88 showing the number of full turns of the dial 50 as in Fig. 4 may, as readily, be graduated to indicate tunings over an equivalent range as, for example, from 3320 megacycles to 3980 megacycles thus indicating directly the tuning of the apparatus over the range for which it is designed.

If it be necessary in assembling the device to adjust the zero position of the indicator dial this readily may be done by shifting the position of the lock nuts 95 and 96 which encompass the screw-threaded extension of the metallic strip 92 and abut against the upper and lower surfaces of the crosshead 52.

The cavity resonator 36 may be provided with input and output couplers 97 respectively, preferably of the rotatable loop type, disclosed in the United States Patent No. 2,414,456, issued January 21, 1947 to W. A. Edson, and positioned to operate through apertures in the vertical wall of the resonator 36 at positions which are displaced 90 degrees from each other along the peripheral surface of the resonator. These couplers may be connected to external input and output circuits through coaxial conductors 98 terminating in jacks 99 of conventional type. The degree of coupling of each coupler may be controlled by an individual coupling control knob 100 mounted on a shaft extending through and supported by the framework 37.

In one embodiment of the structure illustrated in Figs. 3, 4 and 5 the requirements are that the cavity resonator be tuned for a resonance mode of $TE_{0,1,5}$ type for a mid-frequency of 3650 megacycles and that it be capable of tuning over a range of 660 megacycles with dial readings correct to 0.1 megacycle. To meet these requirements the resonator 36 is given an interior diameter of 5.22 inches and the structure is designed to enable the effective cavity length to vary between useful limits of 4.11 inches and 6.39 inches. This requires a piston travel of 2.28

inches to correspond to the 6600 dial divisions. The screw-thread at 51 on actuator rod 48 is made with 40 threads per inch so that the crosshead 52 moves 0.025 inch per revolution of the actuator rod 48 or 1.65 inches for 66 turns of the dial. The bell cranks 58 and 59 measure 2.61 inches between the center of the pivot 60 and the crank arm axis 70 and 3.26 inches between the center of pivot 57 and the crank arm axis 70. The links 61 each measure 2.61 inches between the terminal pivot centers and the links 56, 2.14 inches also taken between their terminal pivot centers.

It will be apparent that the invention disclosed enables a microwave cavity resonator tuning apparatus to be constructed which is capable of frequency adjustment over an extraordinary tuning range and which is sufficiently rigid to maintain the tuning reasonably accurate over that entire range.

What is claimed is:

1. A cavity resonator comprising a substantially closed chamber having walls of electrically conducting substance, a tuning plate substantially coextensive with one of said walls and movable into the chamber to vary the tuning thereof, a rotatable actuator for varying the position of the tuning plate and a mechanical linkage connecting the actuator to the tuning plate to drive the latter at such a rate for each position of the actuator that equal motions of the actuator over a large number of turns of the actuator yield substantially equal frequency changes in the natural resonance frequency of the resonator over a wide range of frequency variation of the resonator, said mechanical linkage comprising a rocker arm pivotally connected at a point fixed with respect to said closed chamber, an element constrained to undergo linear motion connected to said rotatable actuator to be linearly moved thereby, a link pivotally connected to the tuning plate structure and to the rocker arm, a second link pivotally connected to the linearly movable element and to the rocker arm, said two links each being pivotally connected to the rocker arm at a point separated from the fixed pivot of the rocker arm by the same distance that separates the pivotal connections of each of said two links.

2. A cavity resonator tuning device comprising a piston, a plunger connected to the piston, a pair of equal length links each pivotally connected at one end to the free end of the piston rod, a pair of bell crank members centrally pivoted at a common point each having one arm connected to one of the pivoted links and equal thereto in length, and a crosshead member mounted for travel in a direction parallel to the length of the piston rod, said crosshead member being connected to the other arms of the bell crank members and means for moving the crosshead in either of the two opposite directions of movement of which it is capable to cause displacement of said piston.

3. A tunable electrical apparatus comprising a wide range tuning mechanism, said mechanism including a crosshead member mounted in a guiding structure to restrict it to a motion of translation, a tuning screw mounted for rotation and engaging a threaded aperture in said crosshead member to cause motion of said member, a pair of discs mounted on a shaft extending transversely to the direction of said translation motion, a flexible connector fixed to and wrapped around the periphery of one disc and having an end fixed to the crosshead member, a spiral spring

connected to the shaft and to said apparatus to impel the shaft in one direction so that the ensuing tensile force on the flexible connector tends to move the crosshead, indicia on the periphery of the second disc to show the number of turns of the tuning screw from its zero position and an auxiliary tuning indicator carried directly by the tuning screw to indicate the fraction of a turn by which it is displaced from its zero position.

4. In combination, a supporting structure, a tuning piston having a piston rod fixed thereto, a tuning shaft rotatably mounted on said structure and extending in a direction parallel to that of said piston rod, said tuning shaft having a threaded portion, a screw-threaded follower engaging said shaft to be impelled thereby in the direction of the shaft axis upon rotation of the shaft and a bell crank pivotally supported on said structure, said bell crank comprising two arms of equal length rigidly connected at right angles to each other and pivotally supported at the intersection of the arms said bell crank having one arm connected by a rigid link to said follower and a second arm connected by a rigid link to said piston rod, said rigid links having their respective pivotal points equally displaced from each other.

5. In a cavity resonator tuning apparatus, a supporting structure, a rotatably mounted screw carried thereby, a tuning piston having a piston rod connected thereto and supported by said supporting structure in a position parallel to that of the screw, a cavity resonator also mounted upon said supporting structure and within which said tuning piston is positioned to vary the effective volume of the resonator, and screw-threaded means engaging said screw, means connecting said screw to said piston rod to cause said rod to move in a direction parallel to its own axis, said connecting means comprising a bell crank having one crank arm pivotally connected to the screw-threaded means and the second arm pivotally connected to the piston rod to vary the displacement of the piston with reference to the rotation of the rotatably mounted screw in a non-linear manner such as to cause the tuning piston to effect equal increments of frequency of the resonant cavity for equal angular displacement of the rotatably mounted screw.

6. A tuning device comprising a tuning piston, a piston rod fixedly connected thereto, a tuning shaft mounted for rotation and extending in a di-

rection parallel to that of the piston rod and said tuning shaft and overlapping the piston rod throughout a portion of its length, said tuning shaft also being screw-threaded over a portion of its length near the end adjacent the tuning piston, a follower having a screw-threaded aperture engaging the threaded portion of the tuning shaft, means for guiding said follower to restrict it to a motion of translation, a pivotally mounted bell crank comprising two crank arms of equal length, one of said crank arms connected by a rigid link to said follower and the second of said arms, equal in length between its pivots to that of the aforementioned rigid link connected to the piston rod at the end remote from the piston.

7. A tunable apparatus and indicator therefor comprising a cavity resonator, a piston mounted to move therein to vary the effective resonance volume of the resonator, a piston rod rigidly connected to said piston and mounted in a closely fitted guide on said resonator to insure linear motion of the piston, a pair of bell cranks pivotally mounted on said resonator and having an arm of one and an arm of the other extending in opposite directions from the pivot point, one arm of each bell crank being connected respectively by rigid swinging links to the piston rod, a crosshead mounted on said resonator for linear motion parallel to that of said piston, the other arm of each bell crank being connected by a rigid swinging link to the crosshead, a tuning screw mounted for rotation without translation in a position parallel to the piston rod, said screw extending through an engaging screwthreaded aperture in the crosshead whereby rotation of the screw advances the crosshead in one direction and in consequence advances the tuning piston in the opposite direction.

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