Nov. 1, 1960 H. A. POEHLER 2,958,250

MUSICAL INSTRUMENT TUNING APPARATUS

Filed March 7, 1955 3 Sheets-Sheet 1

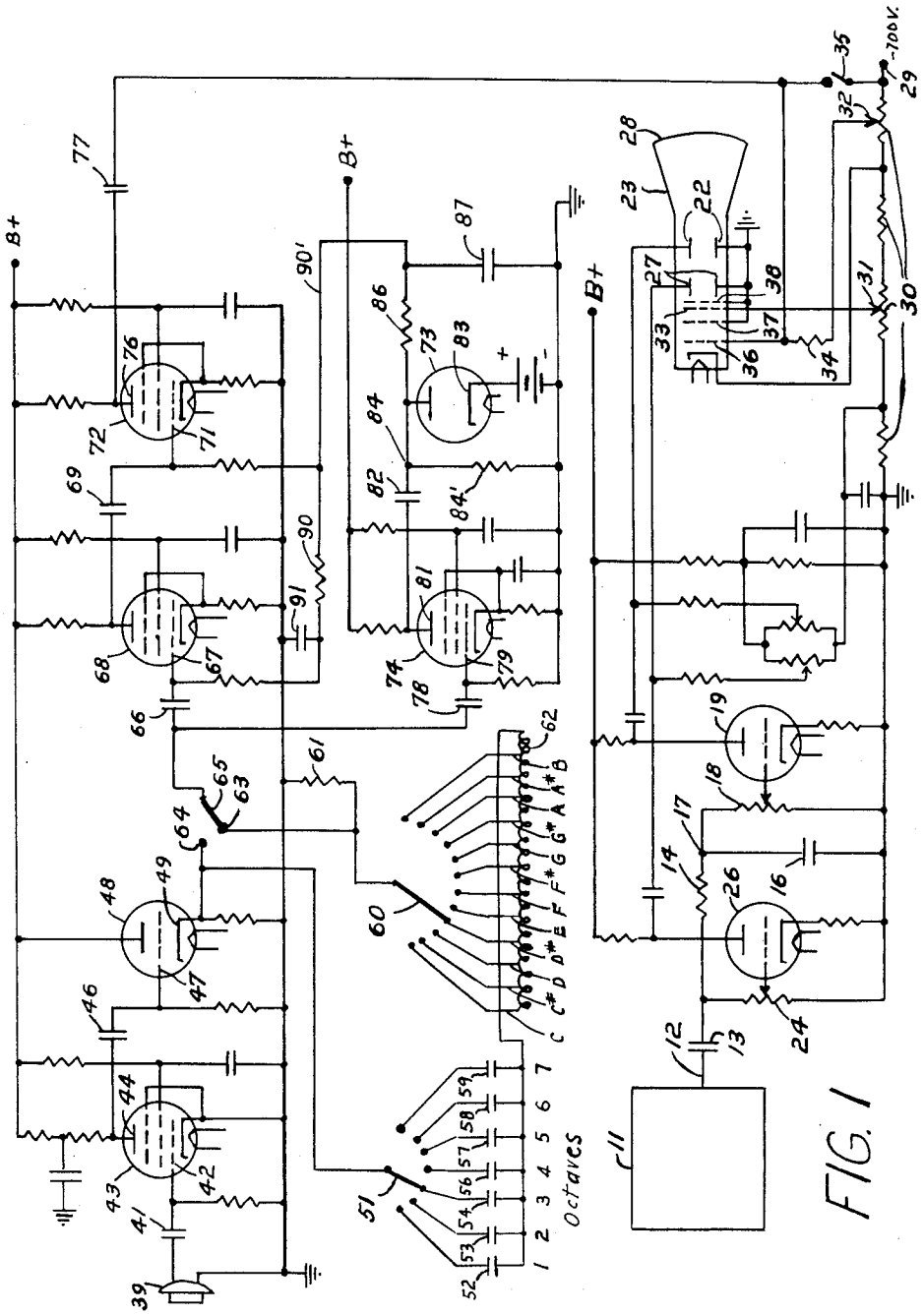


FIG. 1

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MUSICAL INSTRUMENT TUNING APPARATUS

Filed March 7, 1955 3 Sheets-Sheet 2

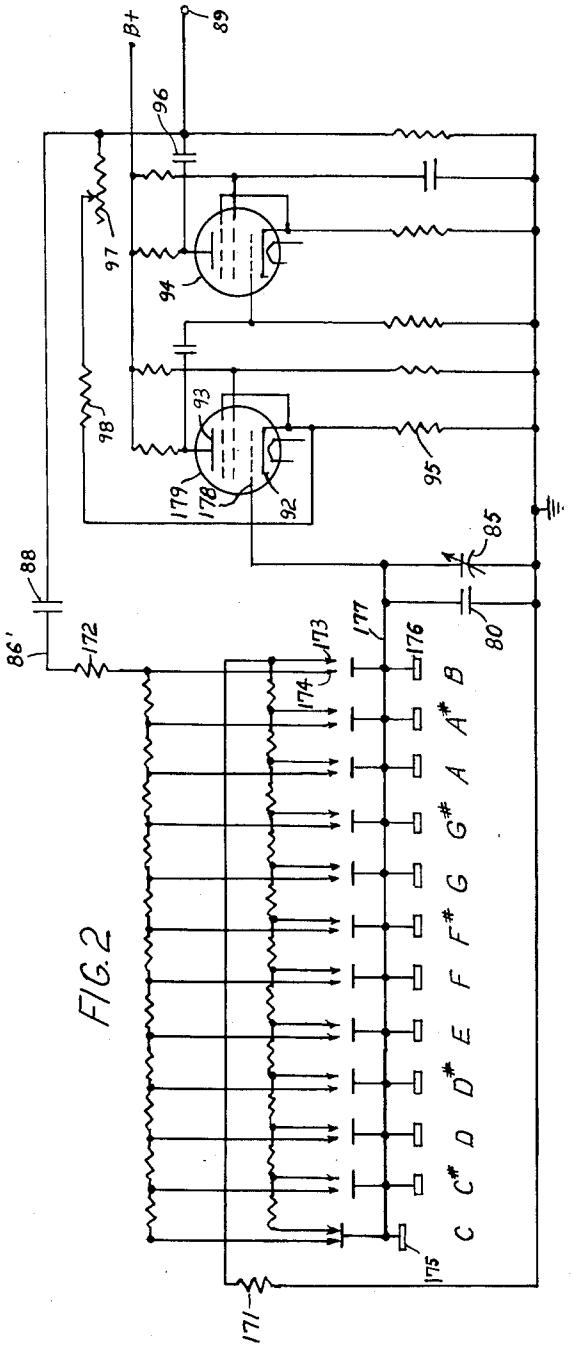


FIG. 2

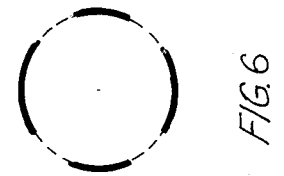


FIG. 6

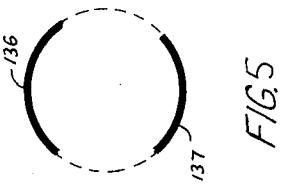


FIG. 5

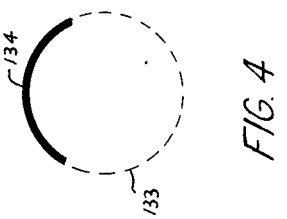


FIG. 4

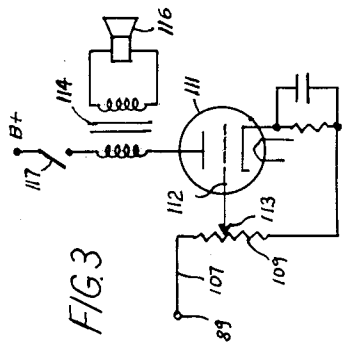


FIG. 3

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MUSICAL INSTRUMENT TUNING APPARATUS

Filed March 7, 1955 3 Sheets-Sheet 3

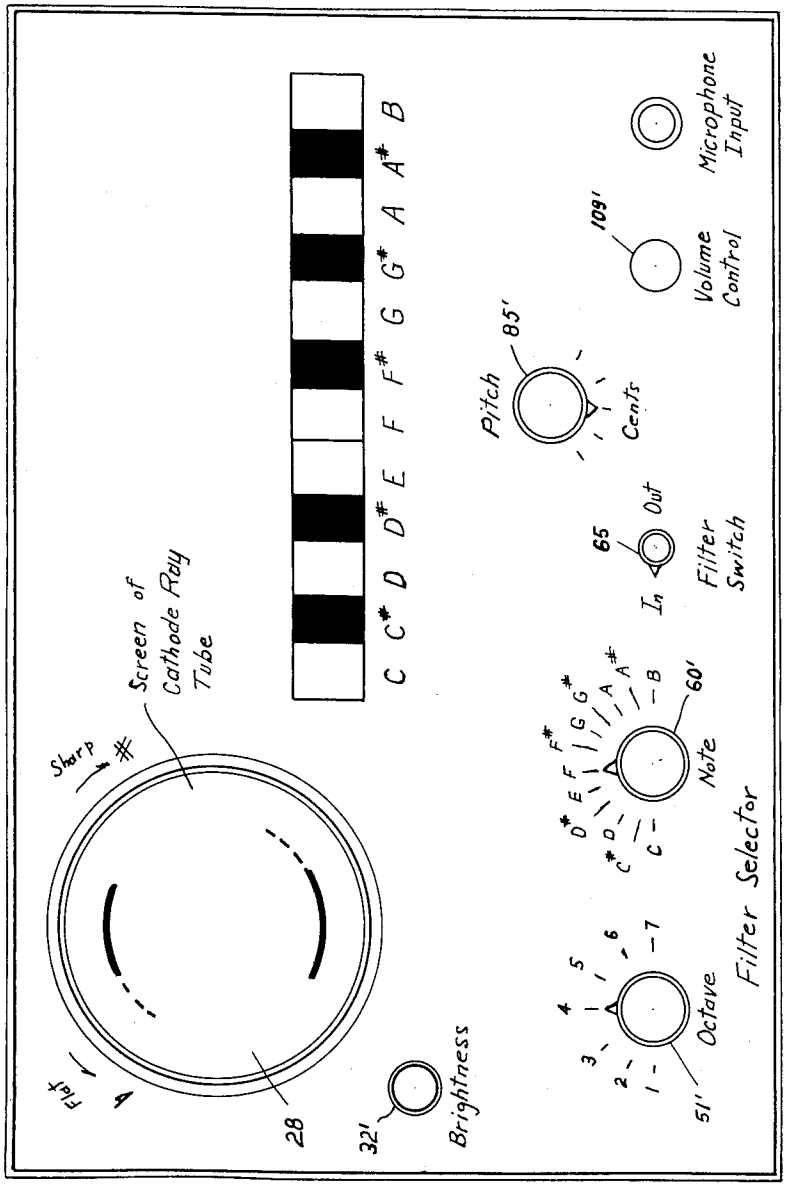


Fig. 7

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MUSICAL INSTRUMENT TUNING APPARATUS

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Filed Mar. 7, 1955, Ser. No. 492,467

9 Claims. (Cl. 84—454)

This invention relates to an improved device and a method for tuning musical instruments, and, more specifically, to a device which visually indicates the agreement of an audible note of a musical instrument with any audible standard of pitch.

This invention is applicable to the tuning or intonation of all presently-used musical instruments, as well as to musical-instrument research and design. In general, the invention is applicable to musical instruments emitting any audible note, whether the note be nearly pure, contains many partials, or contains other tones in addition to partials. In addition to operation on the fundamental of the tone, the device may be employed for the investigation of any of the harmonies or partials of the tone.

An object of this invention is to provide a simplified, visual indication of musical pitch.

Another object of this invention is to provide an improved method and apparatus for tuning pianos and, in particular, for "stretching the octaves."

Another object of this invention is to provide an apparatus that will give a visible indication of the presence, relative magnitude, and deviation from a true harmonic series, of the overtones of musical tones.

Another object of this invention is to provide a visual means for testing the intonation of instrumental and vocal tones.

Another object of this invention is to provide music teachers with an improved apparatus for teaching and illustrating musical intervals and the perception of beats.

Another object of this invention is to provide music teachers with an instrument that gives a simplified visual indication of vibrato.

While the invention is generally useful in the field of music, one application is the tuning of pianos. Tuning procedure, as generally practiced, requires a great skill, not possessed by all piano tuners. It involves tuning the temperament, or middle octave, by tuning one note to a standard pitch. The other notes of the temperament octave are then tuned relative to the first note, and relative to each other, by ear. In doing this the tuner must hear faint beats between second, third, or fourth harmonics of two notes of the temperament when struck together. This involves, for example, tuning D_4 to 293.66 vibrations per second. When A_4, having a fundamental frequency of 440.00 vibrations per second, is sounded simultaneously with D_4 at 293.66, the second harmonic of A_4, 880.00 and the third harmonic of D_4, 880.98, produce a beat whose frequency is 0.98 beats per second or 59 beats per minute. The tuner must judge the frequency of these beats. He must adjust the frequency of D_4 until the correct beat frequency is heard. Thus any error of judgment of the frequency of this hardly-discernible low beat between weak harmonic frequencies, in the presence of the strong fundamentals, will produce an error in the tones being tuned. Not only must the piano tuner operate as a human filter to fix

his attention on a single faint beat note to the exclusion of a number of much stronger masking tones, but he must also, and at the same time, be a precision timer in order to differentiate 59 cycles per minute from 57 or 61.

The piano tuner encounters still another difficulty in tuning pianos which are in poor condition. Sometimes, due to rusted or twisted strings, or some peculiarity of one or more of the hammers, a defect in the sounding board, or due to some other cause, a piano note is "ragged," having a peculiar tonal quality, which may make it nearly or quite impossible to pick out a desired higher harmonic by ear.

This invention avoids the difficulties inherent in detecting the beats between the harmonics of notes in the temperament. It provides twelve frequencies that are spaced in the same ratio as the chromatic musical scale, but that can be moved up and down in frequency as a group. With this device, tuning the temperament of a piano may be reduced simply to setting the notes of the temperament to coincide with the twelve frequencies supplied by the apparatus in accordance with this invention. Coincidence of the piano string vibration with the corresponding generated frequency is rendered by an improved, simple visual presentation. It has long been established that the second partial (or first overtone) of a piano string does not occur at twice the frequency of the fundamental, but has a somewhat higher pitch. This inharmonicity of the second partial of a vibrating piano string varies from piano to piano, and from string to string on a given piano, being more pronounced in the upper and lower registers of the piano keyboard, than in the middle. In the past, piano tuners have taken the inharmonicity into account, to a degree, by the common practice of tuning the upper register somewhat sharp and the lower register somewhat flat. This procedure is commonly referred to as "stretching the octave." However, the piano tuner, again, is faced with the difficult problem of detecting faint beats in the presence of stronger tones, which tend to obscure or "mask" weak beats. With this invention, "stretching of the octaves" can be accomplished in a rational manner, by enabling the tuner to tune a given note to the same frequency as the second partial of the note one octave below, or to the frequency of the fourth partial of the note two octaves below.

The objects and advantages of the invention discussed above, and others, will become more apparent from the following description and accompanying drawings, forming part of the application.

In the drawings:

Fig. 1 is a schematic circuit of one embodiment of the apparatus in accordance with the invention,

Fig. 2 is a schematic circuit of one form of oscillator that may be used as part of the apparatus of Fig. 1,

Fig. 3 schematically depicts an audio amplifier which may be used with the apparatus of Fig. 1,

Figs. 4, 5, and 6 represent various cathode ray tube screen patterns employed in tuning musical instruments by the use of the apparatus of the invention,

Fig. 7 is a front view of the control panel of the apparatus, in accordance with the invention.

Broadly, the invention, in one of its forms, comprises: a cathode ray tube whose deflected beam is swept circularly at any one of twelve discrete frequencies, whose spacing is exactly equal to the spacing of the twelve tones of the chromatic, equally-tempered, musical scale, but which frequencies may be moved up and down as a group, without altering said spacing, an oscillator to supply these frequencies, one audio amplifier to energize one pair of the cathode ray tube's deflection plates, a phase shifting network, a second audio amplifier to energize the other pair of the cathode ray tube's deflec-

tion plates, a preamplifier to amplify the weak electrical signals produced by the microphone and to lower the impedance level, a tunable bandpass filter, and, a delayed automatic gain control amplifier to control the intensity of the deflected beam.

In this form of the invention, a microphone is employed to pick up, through the air, the vibrations emitted by a selected musical tone. The electrical signal produced by the microphone is amplified in the preamplifier and passed, at a low impedance level, to an adjustable band-pass filter which rejects all frequencies except the fundamental, or any particular desired partial, of the musical tone. The electrical signal passed by the filter, is further amplified in the delayed automatic gain amplifier and applied to a control grid of the cathode ray tube, thereby modulating the intensity of the deflected beam. The delayed automatic gain control feature is useful, since it stretches the time interval during which tones that fade out rapidly are displayed for study. The biases of the cathode ray tube are so adjusted that in the absence of the control grid signal, the intensity of the deflected beam is such as to make the pattern on the screen of the cathode ray tube just barely visible. Positive portions of each cycle of the amplified tone signal brighten corresponding parts of the pattern; negative portions darken corresponding parts of the pattern. The circular pattern is produced by the action of the oscillator, the phase shift network, and the two audio amplifiers. The output of the oscillator is split into two channels. In the one channel, the oscillator output is amplified and applied to one pair of the cathode ray tube's deflection plates. In the other channel, the oscillator output is shifted approximately 90° in phase by the phase-shift network, amplified by the second audio amplifier and applied to the other pair of deflection plates, which are at right angles (90°) to the former pair. In a manner well known to the art, this application of signals, equal in amplitude, and differing in phase by 90° results in a circular pattern. If, then, the frequency of the musical tone be the same as the oscillator frequency, a stationary section of a circle will appear on the screen. If, however, the two frequencies are slightly different, the illuminated section of the circle will rotate in a direction indicating which frequency is the higher, and at a speed in revolutions per second corresponding to the frequency difference. If the frequency applied to the control grid be exactly double that of the oscillator, two opposite sections of the circle will be illuminated and stationary; and, in general, if the control grid frequency is n times the oscillator frequency, where n is an integer, the circle will have n illuminated sections at equal intervals. These sections will appear to rotate if the frequencies being compared do not have an integral relation. For control grid frequency $1/n$ times the oscillator frequency, the circle will have one illuminated section.

In tuning a piano note to the second partial of a note an octave lower, the filter selects and passes the second partial of the lower note and attenuates the fundamental. This has the effect of preventing the pattern of the fundamental of the tone from appearing on the cathode ray tube face to mask the fainter, second partial representation.

The apparatus of the invention is, not only, useful for tuning pianos and other musical instruments, but also constitutes a reliable and easily-used device for making adjustments in pitch and checking the intonation of any musical instrument.

Testing the intonation of a musical instrument is readily accomplished with the apparatus of this invention. The apparatus has twelve keys or push buttons, which correspond to the notes of the chromatic musical scale. The player sounds a note on his instrument and depresses the corresponding button of the apparatus, thereby circularly sweeping the screen of the cathode ray tube at the frequency corresponding to the button that is depressed. The frequency at which the circle is swept out is then adjusted to be exactly equal to the frequency of the musical tone that is being sounded and picked up by the microphone by tuning the fine frequency control until a stationary pattern appears on the face of the cathode ray tube. The player, then, plays each note of the instrument in sequence, depressing for each note the corresponding button of the apparatus, and avoiding any further adjustment of the frequency of the apparatus. If the intonation of the instrument is correct, a stationary pattern will be obtained for all the notes, and if not correct, the apparatus will indicate by the direction of the rotation of the visual pattern, whether the intonation of a particular note is flat or sharp.

A method of teaching tone perception with the apparatus of this invention is to sound a note on some musical instrument. The corresponding button on the apparatus is depressed, thereby circularly sweeping the face of the cathode ray tube at a frequency corresponding to the button that is depressed. The frequency at which the circle is swept out is then adjusted to be exactly equal to the frequency of the musical tone that is being sounded and picked up by the microphone by turning the fine frequency control until a stationary pattern appears on the face of the cathode ray tube. If the singer or instrument player, thereafter, sounds the required pitch exactly, a stationary pattern will be obtained, but a flat tone would be evidenced, for example, by a counter-clockwise rotation, and a sharp tone by a clockwise rotation.

In addition, the invention has several applications in connection with the teaching of music. For this purpose an audio output is useful. For example, in voice training the people may be required to sound and hold a tone. The same oscillation that sweeps out the circular trace on the cathode ray tube is fed through a volume control to an audio amplifier and, by means of a loud speaker, produces an audible tone. The tone is then turned off and the singer is required to sound the same tone, or a tone an octave higher or lower. A switch is provided to blank the cathode ray trace until the singer has established the tone. Otherwise, the watching singer would unconsciously vary her pitch until the pattern stands still. Releasing the switch brings the pattern into view; and, if the singer is on pitch, a stationary, single-segment pattern will be obtained. A stationary, two-segment pattern will be obtained if the singer correctly sings an octave higher. A flat tone would be apparent by a counterclockwise rotation, for example, and a sharp tone by a clockwise rotation.

In the use of wind instruments the position and tension of the lips often modifies the pitch. In the case of the flute a slight roll of the instrument against the lips changes the pitch. Students must have ear training to become conscious of the slight changes in pitch so caused, and to learn when the pitch is correct. The situation is complicated by additional pitch change caused by temperature as the wind instrument is used. The device of the invention provides a very simple indication to the student of the dependence of pitch on lip position and lip tension, for it affords a continuous visual demonstration of pitch.

More specifically, and with reference to Fig. 1, the oscillator 11 provides twelve distinct frequencies, having a separation corresponding to the separations of the twelve tones of the chromatic musical scale, but that can be moved up and down in frequency, as a group. Means are provided for the adjustment of the pitch so that the frequencies from B_3 (246.9 c.p.s.) to C_5 (523.3 c.p.s.) are covered. However, this adjustment is applied to all twelve so that, for each setting of the adjustment, the separation between the twelve distinct frequencies will always correspond to the separation of the notes of the

musical scale. The oscillator output is passed from conductor 12 through coupling capacitor 13 into two separate electrical channels, in one of which the output is phase shifted approximately 90° by a simple RC network, resistor 14 and capacitor 16 being provided for this purpose. The output at junction 17 is connected to a voltage divider 18 and through one amplifying triode 19 to one set of deflecting plates 22 of a cathode ray tube 23. The other oscillator output channel consists of a voltage divider 24 and a triode amplifier 26 connected to the other set of deflecting plates 27 of cathode ray tube 23. The two voltage dividers are required to equalize signal amplitudes fed to the cathode ray tube. This form of two-phase circuit produces a circular trace on the cathode ray tube screen 28.

A switch 35, when closed, biases the control grid 36 to cut off, thus blanking the screen of the cathode ray tube.

The cathode ray tube 23 is of the electrostatic deflection type but the electromagnetic type may be substituted with appropriate changes in the deflection circuits.

The bias circuits include a negative 700 volt source represented by terminal 29 and applied to a grounded voltage-dividing resistor 30. One slider 31 of the voltage dividing resistor 30 is connected to the focus grid 33, another slider 32 is connected through grid leak resistor 34 to the first or control grid 36 for brightness adjustment, and grids 37 and 38 are grounded. Potentials are so arranged that in the absence of a control grid signal the screen 28 is just slightly illuminated.

A microphone 39 is arranged to pick up the tone of a piano string, or other musical instrument which is to be tested. The microphone 39 is coupled through capacitor 41 to the grid 42 of the pentode amplifier 43, with output coupled from its anode 44 through a capacitor 46 to a grid 47 of a triode cathode follower 48. The purpose of the cathode follower is to lower the signal source impedance so that the signal may be fed into a series L—C filter, without degrading the high Q of the L—C filter circuit. The cathode 49 of the cathode follower is connected to a seven point switch 51, which permits any one of seven capacitors 52, 53, 54, 56, 57, 58, 59 to be selected. Since these capacitors correspond to the seven octaves of the piano, they are labeled octave 1, 2, 3, 4, 5, 6, 7. The series resonant circuit is connected in series with a resistor 61, whose resistance is low compared to the resistance of the tapped inductor 62. One end of resistor 61 is grounded and the other end is connected in series with the inductor and is connected to the contact 63 of switch 65. The voltage across the resistor 61 is proportional to the current through it. The current is maximum at the frequency for which L and C are resonant and falls off rapidly for frequencies higher or lower than the resonant frequency, provided the Q of the series L—C is high. This resonant frequency can be chosen to coincide with any of eighty four notes of the piano, since the switch 60 permits any of the twelve notes of the chromatic musical scale to be selected, while switch 51, independently, permits any of the seven octaves of the piano keyboard to be selected. The twelve taps of the inductor 62 are so chosen that the resonant frequency of the series L—C filter will coincide with the frequencies of the chromatic musical scale from C_4 (261.6 c.p.s.) to B_4 (493.9 c.p.s.) for the L—C combination made up of the center capacitor C 56 and the twelve inductances of the twelve taps of inductor 62. The twelve taps of the inductor are labeled, therefore, as C, C♯, D, D♯, E, F, F♯, G, G♯, A, A♯, B. The filter need only cover seventy six of the eighty eight notes of the keyboard, since only the partials, and not the fundamentals, of the lowest octave are used in tuning the notes of the lowest octave. The filter of Fig. 1 provides eighty four positions, hence eighty four frequencies may be selected. In the special case where eighty eight filter positions are required, it will suffice to add another capacitor and another contact to switch 51.

The output of the filter is applied to contact 63 of a single-pole, double-throw switch 65. The switch permits the signal to be used directly without being passed through the filter, since the cathode 49 is connected to terminal 64 of switch 65.

The output of switch 65 is coupled by capacitor 66 to the grid 67 of a remote-cutoff pentode 68. The output of pentode 68 is coupled by capacitor 69 to the grid 71 of another remote-cutoff pentode 72. The bias of both pentodes 68 and 72 is controlled by a negative, D.C. voltage developed by diode 73, from the signal amplified by the pentode 74.

The output of pentode 72 is coupled by means of capacitor 77 to the grid 36 of cathode ray tube 23.

Delayed automatic gain control of the amplified musical tone picked up by the microphone is desirable for most applications. Tones that die out rapidly, such as the tone of a struck piano string, for example, would otherwise not give an indication of sufficiently long duration to be useful for tuning. In effect, automatic gain control stretches the time that a musical tone can be studied. Initially, when the sound is loud, the amplifier has a low gain, due to the large negative bias developed by diode 73 and applied to the grids of pentodes 68 and 72. As the tone dies out, the bias developed by diode 73 decreases, and hence the gain of the amplifier increases. In practice, therefore, a useful signal is obtained at the grid 36 of the cathode ray tube 23, as long as the signal of the musical tone is above the noise level.

The automatic gain control consists of a separate pentode amplifier 74 and a diode rectifier 73. The same signal that is applied to the grid 67 of the remote-cutoff pentode 68 is applied by means of capacitor 78 to the grid 79 of pentode amplifier 74. The amplified output from this tube is taken from its plate 81 and coupled to one end of a resistor 84′ by means of capacitor 82. The automatic gain of the microphone amplifier should be delayed, since we do not wish to reduce gain, as the signal increases, for small input signals. Delayed automatic gain control is achieved by biasing the cathode 83 of diode 73 with a suitable positive voltage. Diode 73 conducts whenever the A.C. signal voltage developed at terminal 84 is sufficiently positive to overcome the positive bias applied to cathode 83. Current pulses which flow for positive-going signals cause terminal 84 to take on a pulsating negative potential. Resistor 86, together with capacitor 87, serves to filter out A.C. pulsations from the bias voltage developed by the rectification of diode 73. The bias is applied to bus 90′ which leads to the grid resistors of remote-cutoff pentodes 68 and 72. Further filtering is supplied by resistor 90 together with capacitor 91. The bias supplied by bus 90′ is negative and increases in amplitude as the signal at grid 67 increases. Hence, as the signal at grid 67 increases, the bias on bus 90′ also increases, becoming more negative. The increased negative bias produces a decreased transconductance in pentodes 68 and 72. Hence the signal output at the plate 76 remains relatively constant for a wide range of input signal amplitudes at grid 67. In this manner, automatic gain control is achieved.

One form of oscillator 11 which satisfies the requirements of the invention is the negative-feedback, resistance-capacitor oscillator shown in Fig. 2. It is significant to note that the apparatus, in accordance with the invention, does not require an oscillator that has absolute frequency stability. It requires merely an oscillator of good frequency stability. Absolute calibration is achieved by periodic checking against a suitable standard such as WWV or a precision tuning fork. It is important that the oscillator maintain the relative ratios of the twelve frequencies to a high degree of precision, the ratio of the frequencies being in the ratio of the chromatic musical scale. Further, it is desirable to be able to move the 12

frequencies up and down in frequency as a group, without disturbing their ratios to each other.

The above requirements are met by the particular form of the resistance-capacitance oscillator shown in Fig. 2. The requirements may also be met by other oscillators, such as a pentode negative-transconductance oscillator using a toroidal inductor with taps, that will provide frequencies in the ratio of the chromatic musical scale.

Frequency stability is achieved by the use of low temperature coefficient, wire-wound resistors for the frequency determining RC network. For the capacitor of this RC network, high-Q silver-mica condensers of low temperature coefficient are used. Since it is possible to obtain higher stability with resistors than with capacitors, a gang of resistors is used as the frequency selecting element. By using resistors of the same kind in the resistor gang, whatever small percentage change takes place in the value of one resistor will take place in all resistors, and hence even though the absolute value of frequency may vary slightly, the ratios of the twelve frequencies to each other are maintained to a high degree of precision.

In Fig. 2, two banks of resistors are connected to twelve interlocking key switches, one switch for each tone of the chromatic musical scale. End resistors **171** and **172** of the two gangs are connected to two separated, normally-open contacts **173** and **174** of a switch having a key **176**. When key **176** is depressed, it locks down, connecting both contacts **173** and **174** to the common bus bar **177**. The depression of key **176** also releases any other previously-depressed key. These twelve interlocking keys are designated C, C♯, D, D♯, E, F, F♯, G, G♯, A, A♯, and B. Oscillator **11** produces twelve frequencies which are merely nominally equal to, but which do have precisely the same spacing in the frequency domain as have the frequencies of the tones of the middle octave , or temperament of the piano, starting with middle C or C_4, which has a frequency of 261.6 c.p.s., and ranging to the first B above middle C, which is B_4 (493.9 c.p.s.). These twelve frequencies may be moved up and down as a group without altering their spacing.

Resistors of the first gang, including resistor **171** have one terminal grounded, the other terminal being connected through the key that is depressed through conductor **177** to the control grid **178** of the pentode oscillator tube **179**. Any one of these resistors, as connected into the circuit, is connected in shunt with capacitor **80**. The components thus constitute a shunt resistance-capacitance circuit between the grid **178** and ground, having a definite time constant. Adjustable capacitor **85** is used in tuning the oscillator frequency and effects the same percentage change in all of the twelve frequencies of the oscillator **11**. Hence the knob **85'** controlling condenser **85** may be calibrated in "cents" (one cent equals $\frac{1}{100}$ semitone). This is highly desirable, since it makes it possible to compensate for a sharp or flat tone by turning the knob **85'**, and thereafter to read the degree of sharpness or flatness in cents directly on the dial. Hence, adjustable capacitor **85** serves to move the twelve frequencies up and down as a group, without altering their spacing.

Resistors of the second bank including resistor **172** are connected through one terminal and the associated key, when depressed, to grid bus **177** and to control grid **178**. The other resistor terminals are joined to bus **86'** which is connected through a fixed capacitor **88** to the oscillator output terminal **89**. The selected resistor of this bank, therefore constitutes with capacitor **88** a series resistance-capacitance combination. A tungsten filament lamp **95** is connected between the cathode **92** of pentode **179** and ground, and serves as a cathode resistor for automatic control of oscillator output amplitude. The output of oscillator tube **179** is taken from its anode **93** and is amplified in pentode amplifier and phase inverter **94** before being coupled through capacitor **96** to the output terminal **89**. Regenerative coupling is provided, and the frequency is determined by the resistance-capacitance network composed of capacitors **88**, **80** and **85** and the resistor gangs of which resistors **171** and **172** are a part. Oscillation takes place at the frequency for which the voltage fed back is in phase with the input voltage. Adjustable resistor **97**, in series with fixed resistor **98** to the cathode **92**, is provided to allow compensation for differences in the tungsten lamp element **95**.

In order to train pupils in the perception of pitch, and for other purposes, an oscillator audio output is useful. The simple circuit of Figure 3 is suitable. Conductor **107**, is connected from the output terminal **89** of the oscillator to a volume-control potentiometer **109**. An amplifying tube **111** has its control grid **112** connected to the slider **113** of the volume control operated by knob **109'**, and has an output transformer **114** in its plate circuit, operating a loud speaker **116**. A switch **117** allows the audio output to be turned completely off.

Figure 7 shows a front view of the control panel of the apparatus, in accordance with the invention. The twelve black and white keys correspond to the notes of the chromatic musical scale, and are colored black and white in accordance with the piano keyboard, the accidentals being black. The panel is furnished with the following controls: pitch control knob **85'**, calibrated in "cents," two switches of the filter which consist of an octave-selector switch **51** and a note-selector switch **60** operated by knobs **51'** and **60'** respectively, a brightness control knob **32'**, a volume control knob **109'**, which is provided with an on-off switch **117**, and a filter switch **65**. In addition to the above controls, the front panel contains the face **28** of the cathode ray tube **23**.

In operating the apparatus of the invention, the oscillator, Fig. 2, is first calibrated with some suitable standard of frequency. As an example, we shall use a standard tuning fork, and shall calibrate the oscillator to middle C (C_4) in the following manner. With switch **65**, Figure 1, in the **63** position, the filter is tuned to the fundamental of C_4 by setting the switch **51** to the capacitor **56** position, and setting the switch **60** to the C tap. As a result the control grid **36** of cathode ray tube **23** will be actuated by the fundamental of the tone impinging on the microphone **39**. The oscillator key C, Fig. 2, is depressed. The C_4 tuning fork is struck, and the oscillator is adjusted by adjusting capacitor **85** until a stationary single segment **134**, Figure 4, of a circle is seen on the screen **28**, Fig. 1. The oscillator has now been calibrated, and will require no further adjustment unless the setting of capacitor **85** is changed. The dashed part **133** of the circle in Fig. 4, represents the darkened portions of the pattern. The brightened section, **134**, Fig. 4, represents the portion that is intensified during that part of each cycle when the control grid **36**, Fig. 1, is of positive polarity. A counterclockwise rotation of segment **134**, Fig. 4, for example, indicates that the tuning fork frequency is lower than that of the oscillator, and a clockwise rotation indicates that the frequency is higher.

The next step, and for a piano tuner the most important and difficult step, is the tuning of the middle octave, or temperament, of the piano. The note C_4 will be tuned first. The C_4 key of the piano is struck, which will again cause part of the circle pattern, Fig. 4, to be illuminated and, in general, to rotate rapidly. The three C_4 strings are now tuned, one after the other. In each case, the other two strings of the note are muted with a rubber wedge, and the tension on the string being tuned is adjusted until the rotation of segment **134**, Figure 4, is stopped.

To tune the next note, $C\sharp_4$, the oscillator key C♯, Fig. 2, is depressed. The calibration of the oscillator with a tuning fork is not required at this point, since the oscillator has the property that its twelve frequencies have a spacing exactly equal to the spacing of the twelve tones of the chromatic, equally-tempered, musical scale.

Hence, calibration of any one of the twelve frequencies of the oscillator will suffice. The filter is set to the $C\sharp_4$ position by setting the switch **51** to the capacitor **56** position and setting the switch **60** to the C♯ tap. The $C\sharp_4$ key of the piano is struck, which will again cause the **134** segment, of the circle pattern Figure 4 to appear and to rotate. The three strings of $C\sharp_4$ are then tuned, one at a time, until in each case the rotation of the segment **134** is stopped.

The operation of tuning the three strings, is then repeated in turn, with each of the ten remaining notes of the middle octave of the piano.

The two-position switch **65** may be kept connected to terminal **64** in tuning each note of the middle octave, thus omitting the filter. Although the filter is needed in the tuning of the higher and lower octaves, it may be dispensed with in the tuning of the middle octave. Its use for the middle octave, however, produces a clearer screen picture, because the numerous overtones that are generated when a string is struck would cause the darkened part **134**, Figure 4, to become partially illuminated.

To tune C_5, an octave higher, to C_4, employing the oscillator of Figure 2, set the filter of Figure 1 to C_5 by setting switch **51** to the capacitor **57** position, and switch **60** to the C tap, and set the oscillator, Figure 2, to C_4 by depressing the C key, **175**. The piano key C_4 is now struck. The microphone, filter, and amplifier will now apply the second partial, and not the fundamental, of C_4 to the control grid **36** of cathode ray tube **23**, Figure 1, making a second-partial pattern, composed of two opposite bright sections of circle **136** and **137**, as indicated in Figure 5. These segments will, in general, rotate. In filtering out the second partial, we have set the filter to the C_5 position. As we have pointed out, however, the second partial of C_4 is somewhat higher in pitch than C_5. Actually the second partial of C_4 is sufficiently close to C_5, that the filter will pass the second partial of C_4 when set to the C_5 position, while at the same time sufficiently attenuating the other partials. A similar explanation applies to the other filter positions. The oscillator is then adjusted to stop the rotation of the two segments, by readjusting the capacitor **84**, Figure 2. Piano key C_5 is now struck. The two-segment pattern that is seen will, in general, be rotating, and the three strings of C_5 are tuned, one at a time, with the other two muted, until the pattern stops rotating. This procedure is repeated with the other notes of the first octave above, and is repeated in an analogous manner with all the notes of the higher octaves. In each case the fine frequency capacitor **85** is readjusted so as to make the pattern stationary for the second partial of the note an octave below, and thereafter this adjustment of capacitor **84** is maintained while adjusting the fundamental of the upper note.

In tuning notes of the second octave above the middle octave, the pattern has four segments, as shown in Figure 6, and in tuning the notes of the third octave above, the pattern has eight segments.

In tuning the bass notes of the piano relative to the notes of the temperament, two methods are commonly employed by tuners. One method is to tune by octaves, and the other method is to tune by double octaves. In the former method, the second partial of the lower note should be made to zero beat with the fundamental of the upper note. In the latter method, the fourth partial of the lower note should be made to zero beat with the fundamental of the upper note. The apparatus and method described in this invention are applicable to either of the above methods of tuning, or, indeed, to any other methods where partials of tones are involved in tuning. Since the above two methods of tuning are identical except for the use of the fourth instead of the second partial in the tuning, only the first of the two methods, that of tuning to the second partials will be described in detail.

The tuning of the bass notes of the piano to the notes of the middle octave, or temperament, by octaves, will be illustrated in the following example. To tune C_3 one octave below C_4 to C_4, for example, the oscillator is set to C_4 by depressing the C key **175**, Figure 2. The filter is set to C_4 by setting the switch **51** to the capacitor **56** position, and the switch **60** to the C tap. The C_3 piano key is now struck. Since the filter is set to exclude the fundamental of C_3, and any other partials, only the second partial will pass the filter. This will produce a single-segment pattern on the screen. The pattern will in general, rotate. The C_3 strings are now tuned one at a time until the rotation of the pattern ceases. This procedure is followed with all the other notes one octave below the middle octave of the piano.

To tune the notes of the second octave below the middle octave, for example note C_2, the filter is set to C_3 by setting the switch **51** to the capacitor 54 position, and the switch **60** to the C tap. The oscillator is set to C_4 by depressing the C key **175**, Figure 2. A single-segment pattern will appear when C_3 is struck corresponding to the fundamental of C_3. The cathode ray tube control grid brightens the screen on alternate sweeps only. The oscillator is adjusted until the pattern is stationary, by adjusting the capacitor **85**, Figure 2. The piano note C_2 is now struck. A single segment pattern, representing its second partial, will be observed. The C_2 strings are then tuned, one at a time, until the pattern ceases its rotation. The remaining bass notes are then tuned in an analogous manner.

The invention, as described above, provides a highly-stable, dependable, and relatively inexpensive device that greatly facilitates the tuning of musical instruments, particularly pianos. With the improved oscillator, which has push button control for coordination with the piano keyboard, twelve frequencies are produced that will precisely maintain their spacing, in the frequency domain, which is equal to the spacing of the twelve tones of the chromatic musical scale, notwithstanding temperature differences, and within an accuracy greater than that which can be attained by any listening process as presently employed in the tuning of instruments. Moreover, a single frequency standard, such as a tuning fork, is all that is needed in order to properly adjust all twelve frequencies to an absolute standard. After this adjustment all the notes of the piano can be tuned without the aid of any additional standards, as previously described. Another important feature of the invention resides in the provision of the visual presentation of the correlation of the frequencies so that the operator can immediately ascertain whether or not the two frequencies are of the same pitch, and if not which one is flat.

The term "a simple closed curve," where used herein shall be understood to have the following definition: a simple closed curve is a curve that does not intersect itself, and, therefore, is one that divides the plane into exactly two domains, an inside and an outside.

While only one embodiment, of the invention has been illustrated and described, it is apparent that many modifications, alterations and changes may be made without departing from the true scope and spirit thereof.

What is claimed is:

1. In musical instrument tuning apparatus, the combination of an oscillator for producing a plurality of discrete oscillations whose spacing in the frequency domain is equal to the spacing of the tones of the chromatic musical scale, means for adjusting said oscillator to shift said frequencies over a range as a group to reproduce the fundamental tones of a musical scale of at least two octaves, a cathode ray tube having means to generate an electron beam and including a control grid for controlling the intensity of said beam, deflecting means for deflecting said beam, and a screen responsive to said beam, means for applying a selected frequency of said oscillator to said deflecting means for moving the said

beam to sweep out an ellipse on said screen at the periodicity of said selected frequency, a pick-up device for translating the sound wave produced by a musical instrument being tuned into electrical signals, means for amplifying said electrical signals, and means for applying the amplified electrical signals to said control grid of said cathode ray tube to intensity modulate the said electron beam as it moves to sweep out the said ellipse, whereby a non-rotating, visible pattern is produced on said screen when an integral relation exists between the frequency of the said sound wave and said selected frequency sweeping out the said ellipse.

2. In musical instrument tuning apparatus, the combination of an oscillator for producing a plurality of discrete oscillations whose spacing in the frequency domain is equal to the spacing of the tones of the chromatic musical scale, means for adjusting said oscillator to shift said frequencies in predetermined steps over a range as a group to reproduce the groups of tones of at least two octaves of the musical scale, a cathode ray tube having means to generate an electron beam, and including a control grid for controlling the intensity of said beam, deflecting means for deflecting said beam, and a screen responsive to said beam, means for applying a selected frequency of said oscillator to said deflecting means for moving the said beam to sweep out an ellipse on said screen at the periodicity of said selected frequency, a pick-up device for translating the sound waves produced by a musical instrument being tuned into electrical signals, amplifying means including a filter for amplifying and filtering the said electrical signals, and means for applying the amplified and filtered electrical signals to said control grid of said cathode ray tube to intensity modulate the said electron beam as it moves to sweep out the said ellipse, whereby a non-rotating, visible pattern is produced on said screen when an integral relation exists between the frequency of the filtered components of the said sound waves and said selected frequency sweeping out the said ellipse.

3. In musical instrument tuning apparatus, the combination of an oscillator for producing a plurality of discrete oscillations whose spacing in the frequency domain is equal to the spacing of the tones of the chromatic musical scale, means for adjusting said oscillator to shift said frequencies over a range as a group to reproduce the fundamental tones of a musical scale of at least two octaves, a cathode ray tube having means to generate an electron beam, and including a control grid for controlling the intensity of said beam, deflecting means for deflecting said beam, and a screen responsive to said beam, means for applying a selected frequency of said oscillator to said deflecting means for moving the said beam to sweep out an ellipse on said screen at the periodicity of said selected frequency, a pick-up device for translating the sound wave produced by a musical instrument being tuned into electrical signals, amplifying means including an adjustable bandpass filter for amplifying the said electrical signals and allowing only those components of the said electrical signal that lie within the pass region of the said adjustable bandpass filter to pass, and means for applying the amplified and filtered electrical signals to said control grid of said cathode ray tube to intensity modulate the said electron beam as it moves to sweep out the said ellipse, whereby a non-rotating, visible pattern is produced on said screen when an integral relation exists between the filtered frequency components of the said sound wave and said selected frequency sweeping out the said ellipse.

4. In musical instrument tuning apparatus, the combination of an oscillator for producing a plurality of discrete oscillations whose spacing in the frequency domain is equal to the spacing of the tones of the chromatic musical scale, means for adjusting said oscillator to shift said frequencies over a range as a group to reproduce the fundamental tones of a musical scale of at least two octaves, a cathode ray tube having means to generate an electron beam, and including a control grid for controlling the intensity of said beam, deflecting means for deflecting said beam, and a screen responsive to said beam, means for applying a selected frequency of said oscillator to said deflecting means for moving the said beam to sweep out an ellipse on said screen at the periodicity of said selected frequency, a pick-up device for translating the sound wave produced by a musical instrument being tuned into electrical signals, an amplifier including automatic gain control means for amplifying said electrical signals and maintaining the magnitude of the amplified signals at a substantially constant level in spite of variations in the magnitude of the said electrical signals, and means for applying the amplified electrical signals to said control grid of said cathode ray tube to intensity modulate the said electron beam as it moves to sweep out the said ellipse, whereby a non-rotating, visible pattern is produced on said screen when an integral relation exists between the frequency of the said sound wave and said selected frequency sweeping out the said ellipse.

5. In musical instrument tuning apparatus, the combination of an oscillator for producing a plurality of discrete oscillations whose spacing in the frequency domain is equal to the spacing of the tones of the chromatic musical scale, means for adjusting said oscillator to shift said frequencies over a range as a group to reproduce the fundamental tones of a musical scale of at least two octaves, a cathode ray tube having means to generate an electron beam, and including a control grid for controlling the intensity of said beam, deflecting means for deflecting said beam, and a screen responsive to said beam, means for applying a selected frequency of said oscillator to said deflecting means for moving the said beam to sweep out a simple closed curve on said screen at the periodicity of said selected frequency, a pick-up device for translating the sound wave produced by a musical instrument being tuned into electrical signals, means for amplifying said electrical signals, and means for applying the amplified electrical signals to said control grid of said cathode ray tube to intensity modulate the said electron beam as it moves to sweep out the said simple closed curve, whereby a non-rotating, visible pattern is produced on said screen when an integral relation exists between the frequency of the said sound wave and said selected frequency sweeping out the said simple closed curve.

6. In musical instrument tuning apparatus, the combination of an oscillator for producing twelve discrete oscillations whose spacing in the frequency domain is equal to the spacing of the tones of the chromatic musical scale, means for adjusting said oscillator to shift said frequencies over a range as a group to reproduce the fundamental tones of a musical scale of at least two octaves and including a calibration means to indicate the accuracy of said shift in "cents," a cathode ray tube having means to generate an electron beam, and including a control grid for controlling the intensity of said beam, deflecting means for deflecting said beam, and a screen responsive to said beam, means for applying a selected frequency of said oscillator to said deflecting means for moving the said beam to sweep out an ellipse on said screen at the periodicity of said selected frequency, a pick-up device for translating the sound wave produced by a musical instrument being tuned into electrical signals, means for amplifying said electrical signals, and means for applying the amplified electrical signals to said control grid of said cathode ray tube to intensity modulate the said electron beam as it moves to sweep out the said ellipse, whereby a non-rotating, visible pattern is produced on said screen when an integral relation exists between the frequency of the said sound wave and said selected frequency sweeping out the said ellipse.

7. In musical instrument tuning apparatus, the combination of an oscillator for producing a plurality of dis-

crete oscillations whose spacing in the frequency domain is equal to the spacing of the tones of the chromatic musical scale, means for adjusting said oscillator to shift said frequencies over a range as a group to reproduce the fundamental tones of a musical scale of at least two octaves and including calibration means to indicate the accuracy of said shift in "cents," a cathode ray tube having means to generate an electron beam, and including a control grid for controlling the intensity of said beam, deflecting means for deflecting said beam, and a screen responsive to said beam, means for applying a selected frequency of said oscillator to said deflecting means for moving the said beam to sweep out an ellipse on said screen at the periodicity of said selected frequency, a pick-up device for translating the sound wave produced by a musical instrument being tuned into electrical signals, an amplifier including automatic gain control means and an adjustable bandpass filter for amplifying, for maintaining the magnitude of the amplified signals at a substantially constant level, and for allowing only those components of the said electrical signals that lie within the pass band of the said adjustable bandpass filter to pass, and means for applying the amplified and filtered electrical signals to said control grid of said cathode ray tube to intensity modulate the said electron beam as it moves to sweep out the said ellipse, whereby a non-rotating, visible pattern is produced on said screen when an integral relation exists between the filtered frequency components of the said sound wave and said selected frequency sweeping out the said ellipse.

8. In apparatus for tuning musical instruments, an oscillator producing twelve different frequencies whose spacing in the frequency domain is equal to the spacing of the tones of the chromatic musical scale, independent switching means for selecting one of said frequencies, said switching means having control buttons for the operation thereof with buttons representing the tones of the scale being colored white and black in accordance with the piano keyboard, the accidentals being black, and display means connected with said oscillator including a cathode ray tube having electron beam generating and deflecting means, and a screen responsive to said beam, means connected between said beam deflecting means and said oscillator to sweep out a simple closed curve on said screen at the periodicity of the said selected frequency, said tube including means for the introduction of a signal for intensity modulating the electron beam as it sweeps out the simple closed curve on the screen, whereby a non-rotating, visible pattern is produced when an integral relation exists between the said selected frequency and the said signal.

9. In musical training apparatus, the combination of an oscillator for producing a plurality of discrete oscillations whose spacing in the frequency domain is equal to the spacing of the tones of the chromatic musical scale, means for adjusting said oscillator to shift said frequencies over a range as a group to reproduce the fundamental tones of a musical scale of at least two octaves, a cathode ray tube having means to generate an electron beam and including a control grid for controlling the intensity of said beam, deflecting means for deflecting said beam, and a screen responsive to said beam, means for applying a selected frequency of said oscillator to said deflecting means for moving the said beam to sweep out a simple closed figure on said screen at the periodicity of said selected frequency, a pick-up device for translating the sound wave of a musical sound into electrical signals, means for amplifying said electrical signals, means for applying the amplified electrical signals to said control grid of said cathode ray tube to intensity modulate the said electron beam as it moves to sweep out the said simple closed curve, whereby a non-rotating, visible pattern is produced on said screen when an integral relation exists between the frequency of the said sound wave and said selected frequency sweeping out the said simple closed curve, and an amplifier, connected to said oscillator, the last-said amplifier driving a loudspeaker to emit an audible tone having the periodicity of said selected frequency of the oscillator, and means to cut off the said electron beam in order to permit blanking of said screen of said cathode ray tube.

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