Aug. 14, 1945. J. M. HANERT 2,382,413

ELECTRICAL MUSICAL APPARATUS

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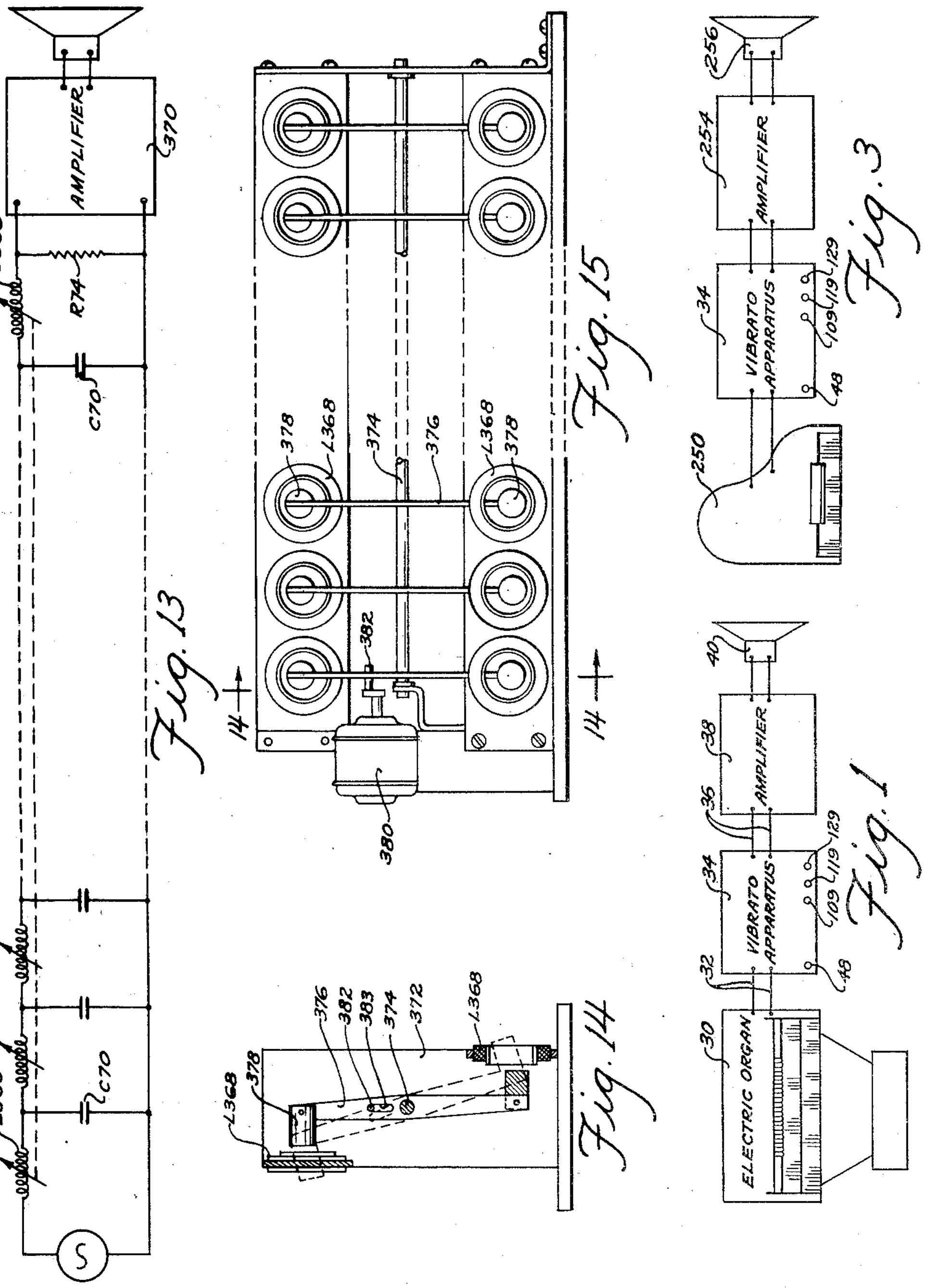

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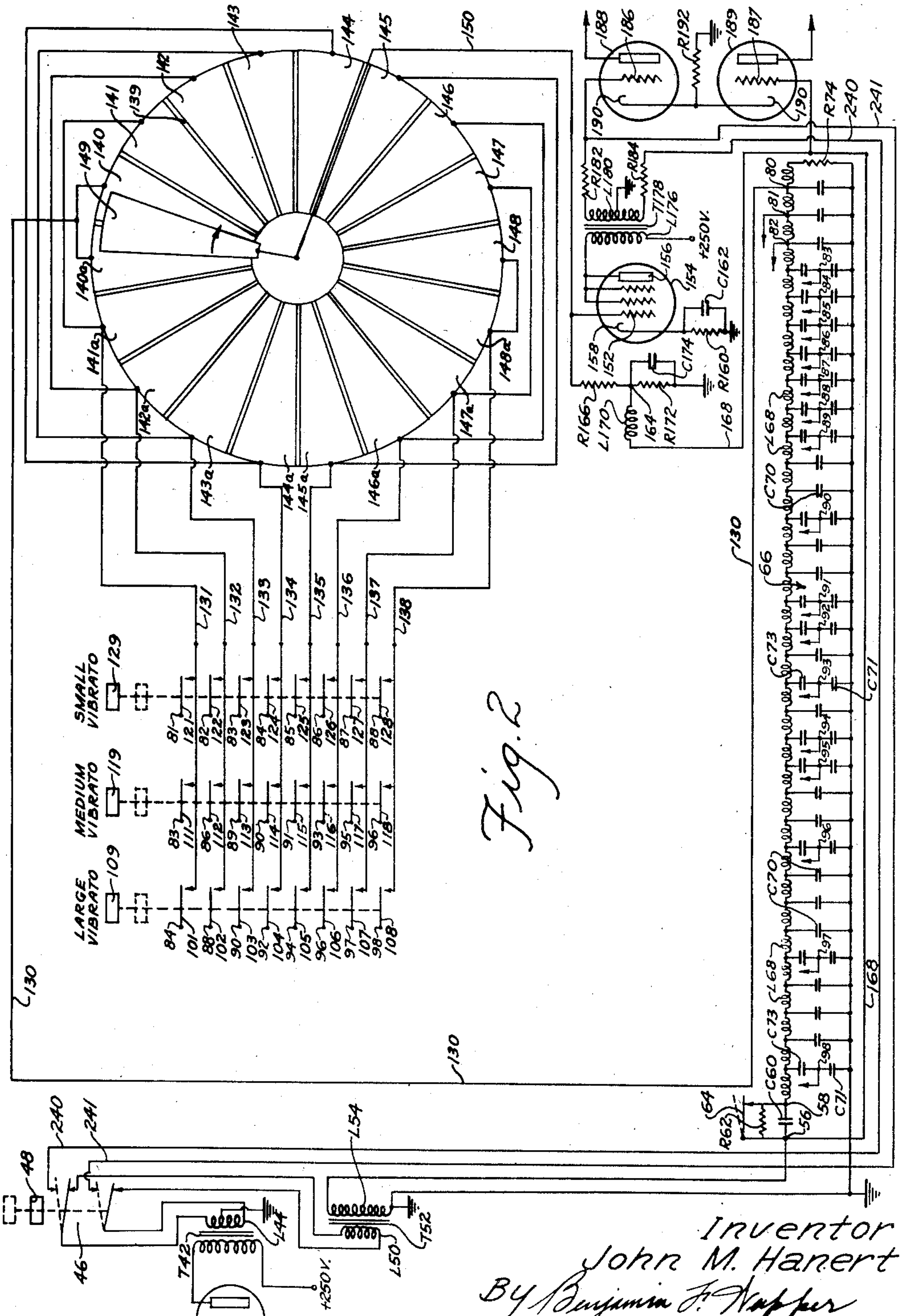
ELECTRICAL MUSICAL APPARATUS

Filed May 10, 1943 7 Sheets-Sheet 2



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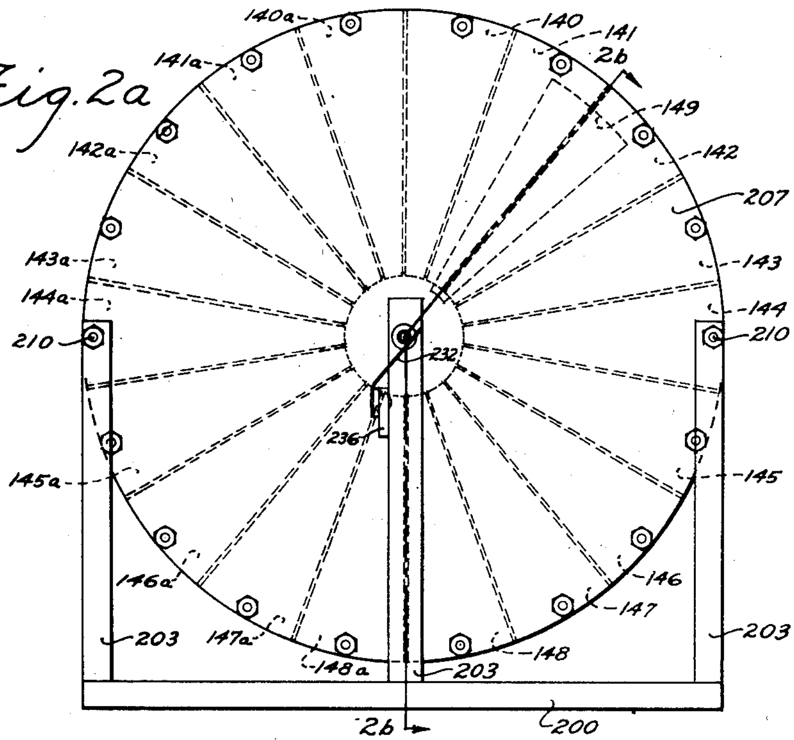
ELECTRICAL MUSICAL APPARATUS

Filed May 10, 1943 7 Sheets-Sheet 3

Fig. 2a



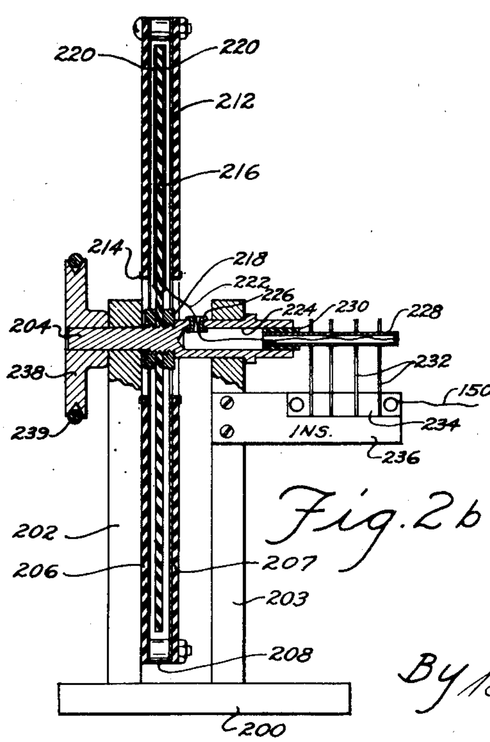


Fig. 2b

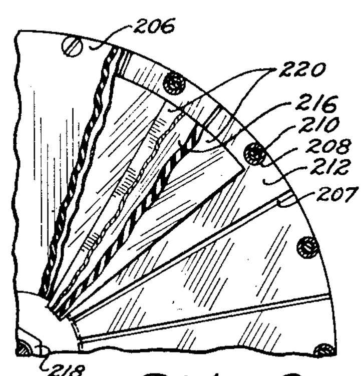


Fig. 2c

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ELECTRICAL MUSICAL APPARATUS

Filed May 10, 1943 7 Sheets-Sheet 4

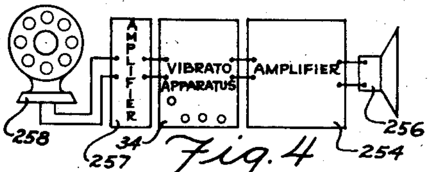

Fig. 4

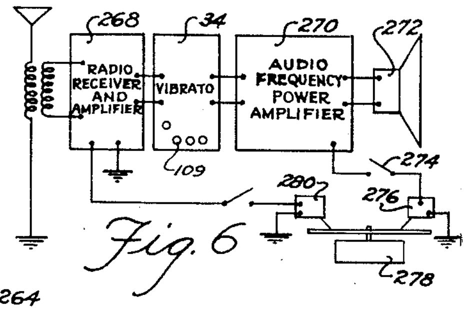

Fig. 6

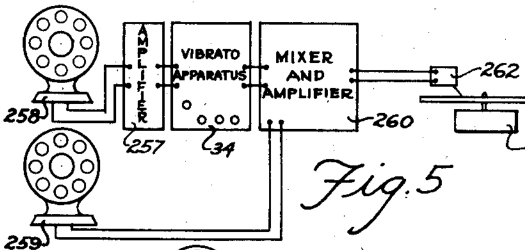

Fig. 5

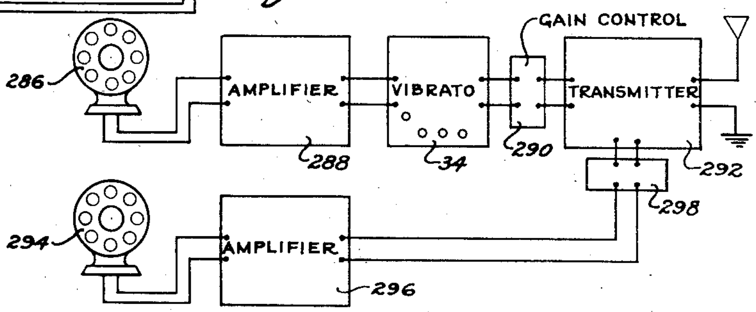

Fig. 7

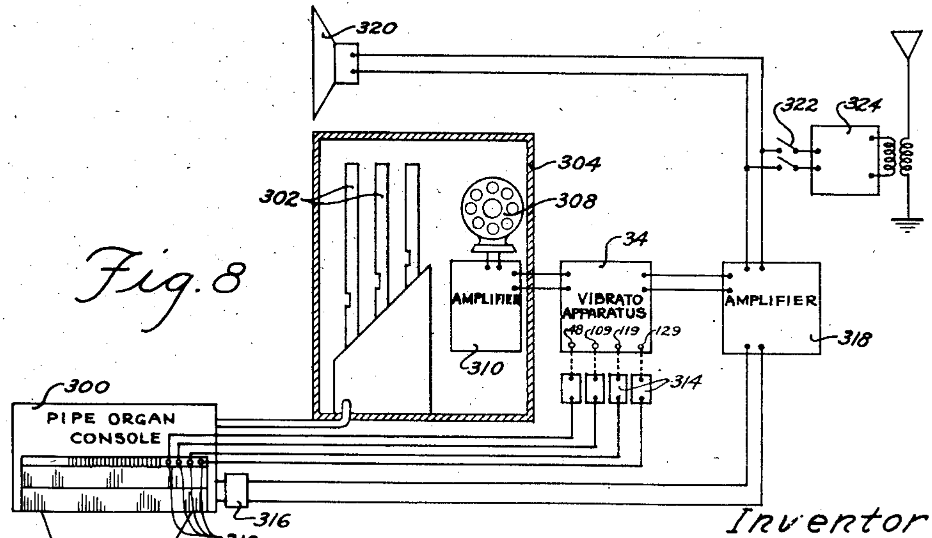

Fig. 8

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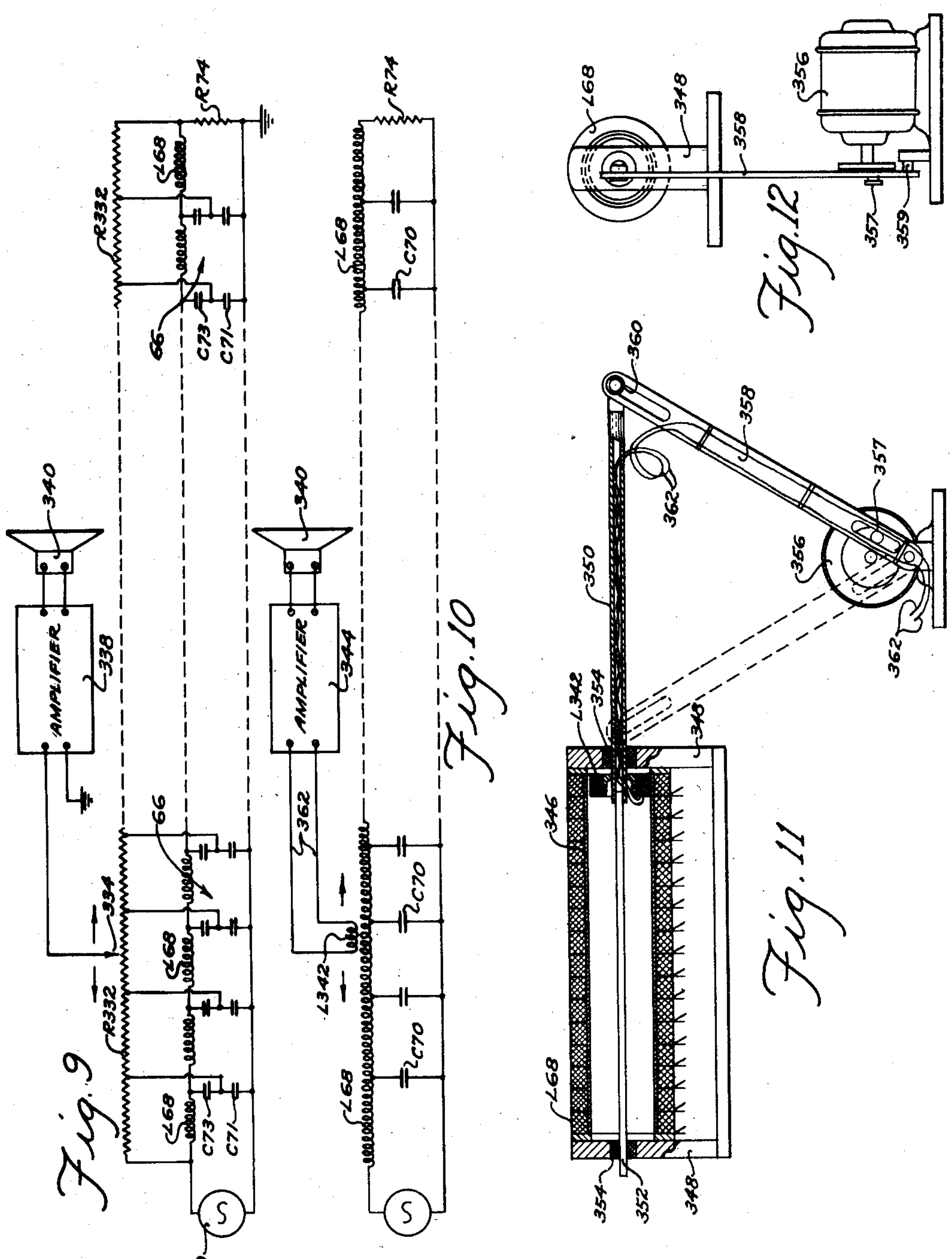
Aug. 14, 1945. J. M. HANERT 2,382,413

ELECTRICAL MUSICAL APPARATUS

Filed May 10, 1943 7 Sheets-Sheet 5



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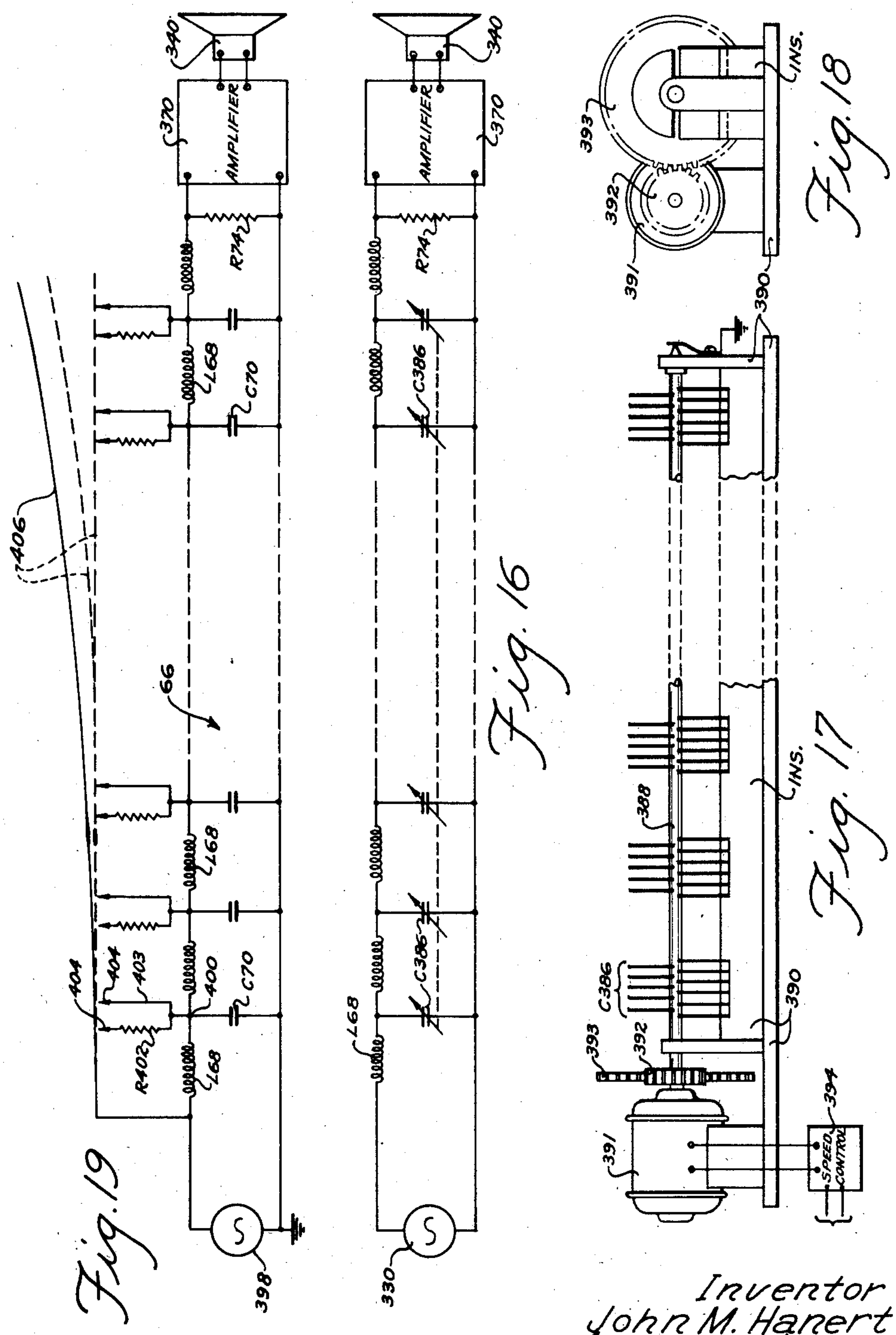
ELECTRICAL MUSICAL APPARATUS

Filed May 10, 1943 7 Sheets-Sheet 6



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ELECTRICAL MUSICAL APPARATUS

Filed May 10, 1943

7 Sheets-Sheet 7

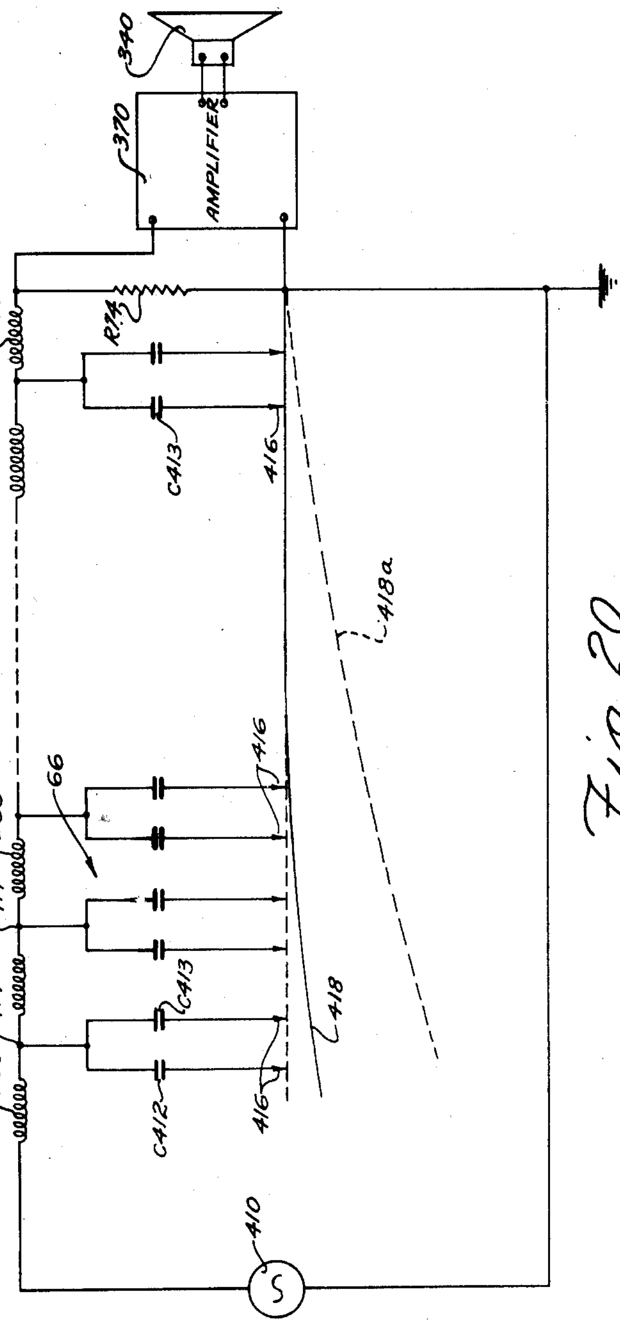

Fig. 20

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2,382,413

UNITED STATES PATENT OFFICE

2,382,413

ELECTRICAL MUSICAL APPARATUS

John M. Hanert, Wilmette, Ill., assignor to Hammond Instrument Company, Chicago, Ill., a corporation of Delaware

Application May 10, 1943, Serial No. 486,409

22 Claims. (Cl. 179—1)

My invention relates generally to electrical musical apparatus and more particularly to electrical means for introducing a vibrato effect in a musical tone or audio frequency signal.

Musical tones are characterized by their pitch, intensity envelopes, quality, and by the degree of, or absence of, vibrato. Of these characteristics many musicians consider the vibrato effect more important than the quality. There is probably a physiological and psychological basis for this opinion because a musical tone without vibrato continuously excites but one or a certain small group of the elemental sensory organs of the ear, and these elemental organs, such as the nerve endings at the bases of the arches of Corti, thus tend to become fatigued upon the continuous reception of a musical tone of fixed frequency.

On the other hand, a musical tone containing a vibrato, that is, a cyclical shift in frequency of approximately 1.5%, at a rate of about 6 per second, results in the intermittent excitation of a large number of different groups of sensory elements of the ear, so that these elements have an opportunity to relax or recuperate during intervals between the instants they are being excited. Furthermore, natural sounds, and the sound of the human voice, are not characterized by fixed frequencies, but contain a large number of frequencies, or comprise tones which are continuously changing in frequency. The human ear has thus developed as an organ which prefers constantly changing frequencies, or tones in which the total energy is distributed over a wide band of frequencies with the intensity of each frequency relatively low. As a corollary, the human ear tends to perceive loud tones of fixed frequency, or sounds in which the energy is concentrated in a few frequencies, as being harsh and tiresome.

Whether or not the foregoing physiological and psychological reasons advanced are the correct explanation of the accepted desirability of the vibrato, the fact is that musicians, and the public generally, greatly favor musical tones having a vibrato. For example, the most generally accepted musical tone is that of the violin (representative of the bowed string instruments), since the violinist has the ability to impart a true vibrato to the tone, that is, a periodic shift in frequency without any substantial change in energy level during the vibrato cycle. Since many musical instruments are inherently of fixed pitch and provide no means for introducing the vibrato effect, many attempts have been made to simulate this effect by producing periodic changes in intensity of the tones produced. Such changes in intensity, or energy, are tremulants—and are inferior substitutes for a vibrato in that the attention of the listener is drawn to the effect through the periodic change in intensity level, whereas in the true vibrato the attention of the listener is not particularly concerned with the periodic change in frequency, but instead perceives the vibrato as an over-all effect in some respects similar to the effect produced by a chorus of instruments playing the same tone on slight off-pitch frequencies, such as the musical effect of a string section in a symphony orchestra.

In order fully to appreciate the effect produced by the vibrato apparatus of the invention, it is necessary to have a clear understanding of the energy and frequency characteristics of the vibrato, particularly as contrasted with the corresponding characteristics of the tremulant.

The vibrato may be defined as a condition in which the instantaneous frequency of the generated signal is caused to vary between certain frequency limits at a rate slow enough for the ear to perceive the over-all effect as a sound of constant intensity but of varying pitch. The tremulant may be defined as a condition in which the instantaneous intensity of the generated signal is caused to vary between certain amplitude limits at a rate slow enough for the ear to perceive the over-all effect as a sound of constant pitch but of varying intensity or loudness. Unfortunately, if this variation in loudness is at all pronounced, the ear will interpret it as a "shake" in the over-all energy level of the music. This "energy shake," peculiar only to the tremulant, may easily become undesirably obtrusive to the listener and, under such conditions, draw the listener's attention to the modulating frequency or "beat" at which the tremulant occurs. Obviously, this steady modulation rate persists whenever any tones are sounded, and, being unrelated to both the frequencies of the musical tones and to the rhythm beats, tends to be foreign to the music and consequently sounds "mechanical." Furthermore, after the listener is initially conscious of the tremulant modulation rate he finds it difficult thereafter mentally to discount the effect even though it be reduced in extent. From that time on, its presence distracts from the artistry of the musical selection being rendered.

Considering the vibrato, however, the signal energy level of the music is perceived to be constant, and consequently, the listener's attention is not particularly drawn to the pitch modulating periodicity. Most listeners are not aware of the modulating rate, but rather perceive the vibrato effect merely as a pleasing undulation particularly agreeable to the ear, apparently for the physiological reasons heretofore set forth.

If the vibrato periodicity exceeds 7 c. p. s., the ear no longer senses the resulting effect as one of varying pitch, but rather hears the original signal plus other discreet new frequencies which are the so-called "side band" frequencies. These new frequencies, as is well known in the communication art, comprise the signal frequency plus a relatively long series of sum and difference frequencies, taken with respect to the modulating frequency, all of which may be represented mathematically by a Bessel series of side band component frequencies.

At such excessively high modulating rates these new frequencies, which are harmonically unrelated to the signal frequency, produce an effect of distortion and musical discord. It is for this reason that music does not sound agreeable if the modulation rate exceeds 7 c. p. s. When the modulating rate is less than 5 c. p. s., the relative pitches of a sequence of staccato chords become indeterminate (depending upon the instantaneous pitch of the signal at the particular moment that the staccato chord is struck), and may at times sound as if the chords were "out of tune" relative to each other, even though the individual tonal components of each chord taken separately sound perfectly "in tune" with each other. Thus, for fast staccato music the vibrato rate should be nearer the 7 c. p. s. rate, but for slow legato music may lie nearer the 5 c. p. s. rate.

Similarly, if the tremulant rate materially exceeds 7 c. p. s., the ear no longer translates the effect as that of a signal of fixed frequency rising and falling in loudness, but rather hears the introduction of additional side band frequencies. In the case of a sinusoidal tremulant modulating envelope, there are only two new side band frequencies produced which are the signal frequency plus and minus the modulating frequency. Thus, the difference between the vibrato and tremulant, taken from a mathematical viewpoint, lies in the greater number and extent of side band frequencies in the former as compared with the relatively small number and extent of side band frequencies for the latter. However, when the modulating frequency is less than 7 c. p. s. the sound is no longer perceived in accordance with the mathematical side band concept, as represented by the Bessel series, but instead, the ear resolves the sound into its pitch and modulating frequency, namely, as a cyclically changing pitch in the case of the vibrato, and as a cyclically changing loudness in the case of the tremulant.

In the apparatus of the invention the vibrato effect is achieved by advancing and retarding the phase of the signal transmitted to the electroacoustic translating means relative to the phase of the generated signal, which latter may be of a relatively constant frequency. This method of producing a vibrato is to be distinguished from the customary method, namely, alternately sharping and flating the tuning of the primary tone generator.

For example, in the musical instrument disclosed in my prior Patent No. 2,254,284, the vibrato effect was produced by a periodically opening and closing switch which, when closed, caused the oscillator to generate a frequency slightly higher than its nominal frequency and which, when open, caused the oscillator to generate a frequency slightly lower than the nominal frequency. Thus, the oscillator generated a signal which alternated between these two frequencies at intervals of $\frac{1}{12}$ of a second duration. Thus, in this type of vibrato apparatus the phase of the signal was not shifted, but instead, frequency modulation was accomplished directly by changing the tuning of the oscillator.

The apparatus of the present invention is particularly designed for use with tone generators operating at relatively fixed frequencies. It will be appreciated by those skilled in the art that when a signal of constant frequency is phase modulated, the resulting signal is no longer of a constant frequency. Instead, the instantaneous frequency is related to the original generated frequency by a positive or negative increment, which increment is a function of the rate and direction in which the phase is being shifted.

For instance, if the primary generator supplies a steady frequency of 440 c. p. s. and means are provided for advancing the phase at a rate of 360 electrical degrees per second, the time interval between pulses of the transmitted frequency would no longer be $^1/_{440}$ of a second, but would be $^1/_{441}$ of a second. Similarly, if the phase were being retarded at a rate of 360 electrical degrees per second, the frequency would drop to 439 c. p. s. during this interval of retarding phase.

In the apparatus of the invention a phase shifting network is provided in the output circuit of an electrical musical instrument such, for example, as an electrical organ, which network may be extended to produce several thousand electrical degrees of phase shift at relatively high audio frequencies. This apparatus preferably takes the form of an artificial transmission line having a finite cutoff frequency which preferably lies in the range of 13,000 c. p. s. Such transmission line passes most musical tones because the frequencies involved usually lie below the 13,000 c. p. s. upper limit. This artificial transmission line may comprise a plurality of low pass filter circuit meshes having series inductive elements and shunt capacitative elements. With such electrical network arranged in T sections, the phase shift per section is 180 electrical degrees at the cutoff frequency. At one half of the cutoff frequency the phase shift is approximately 90° and at one quarter the cutoff frequency the phase shift will be approximately 45°, etc. The amount of phase shift per section varies with frequency in an approximately linear manner.

Considered from the equivalent frequency modulation viewpoint, this means that the amount of frequency shift imparted through scanning such transmission line is a constant percentage of the signal frequency. In the apparatus and circuits to be described, several scanning means and modifications thereof are disclosed, but the fundamental principle underlying this invention resides in providing an artificial transmission line of sufficient length to effect a phase shift which, when taken at a scanning or modulating periodicity in the order of 6 c. p. s., produces a frequency modulation of sufficient extent to simulate the vibrato. It is evident that the extent of frequency modulation introduced by the apparatus is a direct function of the rate at which the phase is shifted. The extent of frequency modulation produced will be reduced if the modulating rate is reduced, and will be increased if the vibrato modulating rate is increased. This is to be distinguished from the case of direct generator frequency modulation exemplified in my aforesaid patent, in which the two instantaneous frequencies are independent of the rate at which such modulation takes place.

It will also be evident that if the phase modulation scanning means is operated very slowly, the ear will hear no change whatsoever in the sound except a slow shift in the intensities of individual frequencies because of the shifting standing wave pattern occurring in the room in which the person is listening. The over-all energy will be constant. If the vibrato switch in the apparatus of my aforesaid patent is slowly connected and disconnected, the listener will be aware of a sudden shift in frequency. Thus, we see that frequency modulation is a derivative function of phase modulation taken with respect to time.

As a further example, suppose there were provided a transmission line having a length sufficient to produce 300 electrical degrees of phase shift at a frequency of 440 c. p. s. Assume that the modulating or scanning frequency be 6 complete scannings (up the line and back) per second. Under these conditions the phase would be shifted 300 degrees during a time interval of 1/12 second or at the rate of 3600 electrical degrees per second.

Assuming the phase is shifting uniformly at a rate of 3600 electrical degrees per second, the instantaneous frequency suddenly shifts from the steady state frequency of 440 c. p. s. to a new frequency of 450 c. p. s., and remains at this value for 1/12 of a second. When the scanning means reverses its direction the phase is retarded at the rate of 3600 electrical degrees per second, thus causing the frequency modulation to shift suddenly and thereby produce an instantaneous pitch of 430 c. p. s. for the remaining 1/12 second of the modulating cycle. This same effect could have been achieved, as shown in the aforesaid patent, by shifting the oscillator frequency at a periodicity of 6 c. p. s. and by changing its tuning—first sharping the tuning to 450 c. p. s. for the first half of the cycle and then flating to 430 c. p. s. during the remaining half of the vibrato cycle. From this example it is apparent that, at a given modulation rate, a phase modulation apparatus produces exactly the same results as the direct generator frequency modulation apparatus.

At any other modulation rate for the phase shift apparatus the frequency shift will correspondingly vary, but in the case of the variable frequency oscillator, the modulation rate is not a factor in determining the instantaneous frequencies which are produced.

The shape of the modulating envelope also influences the instantaneous vibrato frequencies generated. For the apparatus shown in my aforesaid patent, the modulating wave shape is of square contour, that is, the instantaneous frequency is maintained at one value for one half of the cycle and another value for the other half of the cycle. In the apparatus of the present invention the modulating wave shape may also be of square contour, that is, the phase may be uniformly advanced during one half of the cycle and uniformly retarded during the remaining half cycle.

For obtaining the most pleasing effects, it appears that the contour of the modulating envelope should be generally of such shape that each instantaneous frequency shall be heard during a portion of the modulating cycle which is the reciprocal of the number of such instantaneous frequencies heard. Stated in the terms of phase shift, each change in phase should persist throughout a portion of the modulating cycle which is the reciprocal of the total number of phase shifts produced.

It is the primary object of my invention to provide electrical apparatus for introducing a vibrato effect into electrical musical tone and voice signals irrespective of their source. The invention is thus of general application to musical apparatus in which the music is, in one stage of its transmission from the source to the ear of the listener, in the form of an electrical signal. Thus, for example, the apparatus of my invention is applicable to the introduction of a vibrato effect in the electrical output signal of instruments such as electric organs and electronic pianos having generating systems incapable of producing a vibrato. As a further illustration, the apparatus of my invention may be used to introduce a vibrato effect in the music produced by a phonograph record, or in the music being recorded upon a record or film. Similarly, it may be used to produce vibrato effects in orchestral music, in which the orchestra is provided with microphones or similar pickups, and in which the signal is electrically amplified and translated into sound.

A further object is to provide an improved vibrato apparatus of general application for polyphonic music, which does not introduce cross-modulation frequencies in its output.

A further object is to provide an electrical vibrato apparatus in which the degree or periodicity of the vibrato may be readily controlled.

A further object is to provide an improved electrical vibrato apparatus in which the percentage of vibrato shift in frequency is substantially uniform throughout the range of frequencies in which the vibrato is a desirable effect.

A further object is to provide an electric vibrato apparatus in which the vibrato effect is limited to frequencies above the bass tone range.

A further object is to provide an improved means for introducing a vibrato effect in the musical output of instruments such as the electronic piano and pipe organ in which the vibrato is normally absent or of negligible effect.

A further object is to provide an improved vibrato apparatus of general application which is simple in construction, reliable in operation, and which may be economically manufactured.

Other objects will appear from the following description, reference being had to the accompanying drawings in which:

Figure 1 is a block diagram showing a system incorporating the invention;

Figure 2 is a wiring diagram of a preferred form of the invention;

Figure 2*a* is a side elevational view of the rotary condenser mechanism shown in Fig. 2;

Figure 2*b* is a central vertical sectional view thereof taken on the line 2*b*—2*b* of Fig. 2*a*;

Figure 2*c* is a fragmentary sectional view of the rotary condenser of Fig. 2;

Figure 3 is a block diagram illustrating the use of the apparatus in conjunction with a tone signal produced by an electric piano,

Figure 4 is a block diagram of the apparatus used in public address or similar systems introducing vibrato;

Figure 5 is a block diagram illustrating the use of the apparatus in a system for making recordings;

Figure 6 is a block diagram illustrating the use of the apparatus in a radio receiving, recording and reproducing system whereby the vibrato may be optionally introduced in any of the three uses of the apparatus;

Figure 7 is a block diagram illustrating the use of the apparatus of the invention in a broadcasting system or for making recordings in which two microphones are employed;

Figure 8 is a diagrammatic illustration of the use of the apparatus in a system for introducing the vibrato effect for music with the pipe organ;

Figure 9 is a wiring diagram of a modified form of the invention included to illustrate the principle of operation of the apparatus;

Figure 10 is a wiring diagram of a modified form of the invention using an inductive pickup;

Figure 11 is a fragmentary sectional view of the inductive pickup mechanism utilized in the apparatus of Fig. 10;

Figure 12 is a side elevational view of the mechanism shown in Fig. 11;

Figure 13 is a wiring diagram of a further modified form of the invention employing variable inductances to obtain the vibrato effect;

Figure 14 is a fragmentary sectional view of the variable inductance mechanism, being substantially a section taken on the line 14—14 of Fig. 15;

Figure 15 is a side elevational view of the variable inductance mechanism used in the form of the invention shown in Fig. 13;

Figure 16 is a circuit diagram of a further modification of the invention;

Figure 17 is a side elevational view of the variable condenser mechanism utilized in the circuit of Fig. 16;

Figure 18 is an end elevational view of the condenser mechanism of Fig. 17; and,

Figures 19 and 20 are circuit diagrams of further modified forms of the invention.

As previously indicated, the invention may be utilized in various systems, one such system being disclosed in Fig. 1 and comprising an electric organ **30** which may be of any suitable construction, such, for example, as shown in the patent to Laurens Hammond No. 1,956,350. The output of the organ is supplied through conductors **32** to a vibrato apparatus **34** hereinafter to be described, and the output of the latter is transmitted through conductors **36** to an amplifier **38** which is coupled to a speaker **40**.

The output of the organ which is assumed to provide musical tones of fixed frequency is modified by means of the vibrato apparatus **34** to phase modulate the output signals.

The preferred apparatus represented by the box **34** of Fig. 1 is shown in detail in Figs. 2, 2*a*, 2*b* and 2*c*. Referring to Fig. 2, the signal is supplied to the apparatus through an output transformer **T42**, the secondary winding **L44** of which has a grounded center tap and has its end terminals connected respectively to a double-pole double-throw switch **46**. The latter is adapted to be operated by a knob **48**, this knob being normally in the position shown in the full lines for utilizing the vibrato apparatus. When the switch **46** is in full line position, the primary winding **L50** of a voltage step-up transformer **T52** is connected to the secondary **L44**. The secondary **L54** of the transformer **T52** has one terminal grounded, and its other terminal connected to a junction point **56**.

Between the junction point **56** and the junction point **58** are connected in parallel a condenser **C60**, a resistor **R62** and a switch **64**. When the switch **64** is closed, the condenser **C60** and resistance **R62** are rendered ineffective, and when the switch is open, this resistor and condenser provide an input impedance for the lower audio frequencies. Between the terminal **58** and ground is an artificial line designated generally by the reference character **66** and constituting a phase shifting network.

This artificial line **66** comprises a plurality of T sections including inductances **L68** and condensers **C70**. In some of the sections the condenser **C70** is replaced by a pair of condensers **C71** and **C73** connected in series. The artificial line terminates in a resistance **R74** which constitutes the characteristic terminating impedance for the line, and thus does not provide a point for reflection of the signal, but instead, constitutes a "sink" in which the signal is lost.

The purpose of substituting the condensers **C71** and **C73** for the condensers **C70** in some of the networks is to provide a voltage division so that at terminals **83** to **96** between these pairs of condensers the amplitude of the signal voltage will be substantially the same as it is at a terminal **80** associated with the last section of the line, and thus make compensation for dissipation effects in the line.

The terminals **84**, **88**, **90**, **92**, **94**, **96**, **97** and **98** are respectively connected with a group of single-pole single-throw switches **101** to **108**, these switches being adapted to be closed by a push button **109**. A second group of switches **111** to **118** are adapted to be operated by a push button **119** and are respectively connected to terminals **83**, **86**, **89**, **90**, **91**, **93**, **95** and **96**, while a third similar group of switches **121** to **128** is adapted to be operated by a push button **129** and are respectively connected to terminals **81**, **82**, **83**, **84**, **85**, **86**, **87** and **88**.

Switches **101**, **111** and **121** are adapted respectively to make connection with a conductor **131**; switches **102**, **112** and **122** are adapted to make connection with a conductor **132**; switches **103**, **113** and **123** make connection with conductor **133**, and similarly, the remaining corresponding switches of the three groups respectively make connection with conductors **134** to **138**. The terminal **80** has a conductor **130** connected thereto.

A disc **139** of insulating material has a plurality of condenser plates **140** to **148** and **140*a*** to **148*a*** secured thereto. The condenser plates **140** to **148** are respectively connected with the condenser plates **140*a*** to **148*a*** and to the conductors **130** to **138**.

A condenser plate **149** rotates about the center of the disc **139** and is thus successively brought into capacitative relation with condenser plates **140** to **148** and **148*a*** to **140*a***. This condenser plate **149** thus constitutes a pickup element for effectively scanning the transmission line **66** first in one direction and then in the opposite direction. The condenser plate **149** is connected by a conductor **150** with the control grid **152** of a preamplifier tube **154** which may be of the 6J7 type. This tube **154** is a pentode in which the screen and suppressor grids are connected to the plate **156** so that the tube operates as a triode. The cathode **158** is connected to ground through a self-bias resistor **R160** shunted by a condenser **C162**.

The conductor **150** is connected to a junction point **164** through a high value grid resistor **R166**. The junction point **56** is connected by a conductor **168** and an inductance **L170** to the junction point **164**, and the latter is connected to ground through a resistor **R172** shunted by a condenser **C174**.

The inductance L170 and condenser C174 are of values relative to resistor R172 such as to afford low pass filtering on signals present at the junction point 164, for example, by cutting off frequencies above 80 c. p. s.

The plate 156 is connected to a suitable source of plate current, indicated as a terminal +250 v., through the primary L176 of a line transformer T178. The secondary L180 of this transformer has its center tap grounded and its terminals connected through decoupling resistors R182 and R184 to the grids 186 and 187 respectively of push-pull driver tubes 188 and 189. The cathodes 190 of the tubes 188 and 189 are connected to ground through a common self-biasing resistor R192.

The tubes 188, 189 form the driver stage of the amplifier represented by the block 38 in Fig. 1 and thus serve as the means for transmitting the signal which is ultimately translated into sound by the loud speaker 40.

The artificial line 66, as shown in Fig. 2, comprises 32 low pass T sections which may be designed to have a high frequency cutoff of 13,700 c. p. s. This is sufficiently high to transmit frequencies encountered in ordinary music, and is sufficiently high so that the frequency response at the various portions along the transmission line is substantially linear within the range of the musical frequencies transmitted. At 13,700 c. p. s. the phase shift per section is substantially 180 electrical degrees, thus making the total phase shift in the 32 section line 5760 electrical degrees. Thus, at 6850 c. p. s. the phase shift will be approximately 2880 electrical degrees; at 3425 c. p. s. the phase shift will be approximately 1440 electrical degrees; at 1712.5 c. p. s., 720 degrees; at 856.25 c. p. s., 360 degrees; and at 428.25 c. p. s., 180 electrical degrees. These values of the phase shift are computed on the assumption that the artificial line 66 is distortionless and has no dissipation. Since such theoretical transmission line cannot be built economically, the phase shift actually obtained by a practical apparatus does not quite attain the values set forth above.

In order to determine the characteristic impedance of the artificial line air core inductances of suitable values are selected. Let us assume that an inductance of .186 henries is selected, and since the desired cutoff frequency is selected to be 13,700 c. p. s., the characteristic impedance of the line may be computed from the formula $R=\pi L f_c$, in which L is the value, in henries, of each of the series inductive elements, except for the first and last sections—which are of one half section impedance; in which R is the characteristic impedance in ohms; and f_c is the cutoff frequency in c. p. s. Using the assumed values of L and f_c we find that the characteristic impedance of the line selected for illustration is 8,000 ohms.

The capacitance, C, in farads, of each of the condensers C70 and each pair of condensers C71, C73 may be computed according to the formula:

$$C=\frac{1}{\pi f_c R}$$

Substituting the assumed and computed values in this formula we find that each of the condensers C70 and pairs of condensers C71 and C73 shall have a value of .00290 mfd. The half sections at the beginning and end of the line will have inductances of one half the values of the remaining inductances.

For an artificial line of the above assumed values, the condenser C60 may have a value of .008 mfd.; the resistor R62, 40,000 ohms; the inductance L170, 4.72 henries; the resistor R172, 40,000 ohms; the condenser C174, .5 mfd.; and the resistor R166, 25 megohms.

The resistor R166 should have an impedance high with respect to the capacitance between the condenser plate 149 and the condenser plates 140 to 148 and 140a to 148a and the capacitance of condensers C71, in order to obtain a proper load impedance for the signals impressed upon the grid of tube 154 through the rotary condenser mechanism.

As further illustrative of the values of the circuit elements which may be employed, the resistor R160 may have a value of 1,000 ohms; the condenser C162, 30 mfd., and resistors R182, R184, 600 ohms each.

In the operation of the apparatus one of the knobs 109, 119 or 129 is depressed to close its associated switches. Assuming that the push button 109 has been depressed, the terminals 80, 84, 88, 90, 92, 94, 96, 97, and 98 will be connected respectively to the pairs of condenser plates 140—140a to 148—148a respectively. Thus, the input signal will appear as a voltage on the condenser plates 140 to 148 and 140a to 148a, but the phase of the signal will differ on each pair of plates. Thus, assuming a signal of 440 c. p. s. on plate 140 as having zero phase shift, the signal on plates 141 and 141a will have its phase advanced by 23.1°, the cutoff frequency of 13,700 c. p. s., and the signal on plates 142 and 142a will have its phase advanced by 46.2° etc., so that the phase of the signal on the plates 148 and 148a will be advanced by a phase angle of 184.8°.

Thus, as the scanning condenser plate 149 moves clockwise from a position adjacent the plates 140 and 140a to a position adjacent the plates 148 and 148a, the phase angle of the signal appearing on the scanning plate 149 will be advanced through 184.8 electrical degrees, and while it rotates through the remaining portion of a revolution (i. e. from the position adjacent plates 148 and 148a to a position adjacent plates 140 and 140a), the phase of the signal picked up will be retarded by 184.8 electrical degrees, and be returned to its original zero phase shift condition.

Assuming that the scanning condenser is rotating at 6 c. p. s., it will effect its phase shift of 184.8° in 1/12 of a second and hence the phase shift will be at a rate of 2,217.6 electrical degrees per second, thus alternately producing two instantaneous frequencies of 446.2 and 433.8 c. p. s., namely a frequency shift of about 2.8% at the frequency of 440 c. p. s. In musical terms this may be stated as corresponding approximately to a vibrato in which the frequency shift is between about one-fourth of a semitone above and below the nominal frequency. It will be noted that the percentage of frequency shift thus depends upon the speed of rotation of the scanning condenser plate 149.

The width, or degree, of the vibrato effect may be varied by releasing the knob 109 and depressing one or the other of the knobs 119, 129. When, for example, the "medium vibrato" knob 119 is depressed to close its associated switches, the scanning condenser plate 149 is successively coupled to the junction points 80, 83, 86, 89, 90, 91, 93, 95, and 96 as it scans from plate 140 to plate 148.

The operation of the knob 119 thus effectively shortens the artificial line to one of 24 sections instead of 32 sections, and hence at the assumed frequency of 440 c. p. s. would be capable of causing a maximum phase shift of 138.6 electrical degrees. Thus, the phase shift is at the rate of 1,663.2 electrical degrees per second, or the instantaneous frequency change is plus and minus 4.62 c. p. s. In other words the over-all frequency shift is through approximately 2.1%, or in musical terms, a vibrato between frequencies approximately three-sixteenths of a semitone above and below the nominal frequency.

When the "small vibrato" knob 129 is depressed (knobs 109, 119 being in their normal positions with their switches open), the condenser plates 140 to 148 are respectively connected to terminals 30 to 88. Thus, the sections of the artificial line beyond the junction point 88 are not utilized and the maximum phase shift produced is that which is obtained by the eight sections of the line preceding the junction 80, and the maximum phase shift obtainable from these eight sections will be 46.15 electrical degrees at 440 c. p. s. Therefore, with the scanning condenser rotating at 6 revolutions per second, the phase of the signal impressed on this scanning condenser will be alternately advanced and retarded at a rate of 554.4 electrical degrees per second, or, the instantaneous frequency change is plus and minus 1.54 c. p. s. Thus, with the knob 129 for the small vibrato depressed, the vibrato shift will be between 441.54 c. p. s. and 438.46 c. p. s. which constitutes a percentage change of approximately .7% which, in musical terms, constitutes a vibrato with a frequency shift between frequencies one-sixteenth of a semitone above and one-sixteenth of a semitone below the normal frequency.

The rotary pickup condenser mechanism may assume the form shown in Figs. 2*a*, 2*b*, and 2*c*. In these figures there is disclosed a base 200 having vertical supports 202 and 203 secured thereto, two of the latter forming bearings for a shaft 204. Rigidly secured to the supports 202 by bolts 210 are a pair of discs 206, 207 which are of insulating material, such as Bakelite, and which are held in spaced relation by separators 208 of conducting material. A plurality of pairs of sector shaped plates 212 are secured to the insulating discs 206 and 207 by the bolts 210, being electrically connected through the separators 208. These sector plates 212 may have their inner ends bent over and fitting in notches formed around the central opening in the discs 206 and 207, as indicated at 214 in Fig. 2*b*.

A rotor 216 is rigidly secured to the shaft 204, for example by being clamped thereto by nuts 218. The rotor 216 carries a pair of similar sector shaped plates 220, which together constitute the pickup condenser plate 149 of Fig. 2, and which are suitably secured on opposite sides of the rotor in superposed relation. These plates 220 are electrically connected to an insulated conductor 222 which projects through a Bakelite grommet 226 into a counterbore 224 formed in the end of the shaft. The other end of the conductor 222 is soldered to a conducting tube 228 which projects from the end of the shaft 204, being suitably insulated therefrom by a press-fit sleeve 230. A plurality of wire brushes 232 are secured to a plate 234 mounted on an insulating bracket 236 carried by one of the vertical supports 203. The conductor 150 (Fig. 2) is electrically connected to the plate 234 which is mounted on the insulating support 236.

A pulley 238 is secured to the shaft 204 and is driven by a belt 239 from a suitable motor which rotates the shaft 204 at a vibrato speed, in the order of 6 r. p. s.

In lieu of having sector shaped plates 212 and 220, the condenser may be formed by applying a coat of colloidal graphite, such as Aquadag. In making the plates 212 the appropriate surfaces of the discs 206, 207 may be painted with the colloidal graphite and the separate plates formed by scoring lines through the graphite coating, to separate the painted surface into sector shaped areas. A protective coating of a suitable varnish or shellac may then be applied to the whole inner surfaces of the discs.

The operation of the circuits and apparatus shown in Figs. 2*a*, 2*b* and 2*c* will now be described on the assumption that this apparatus is incorporated in the system of Fig. 1. Assuming that the organist desires to introduce a vibrato effect in the music being rendered, he will operate the switch knob 48 from the dotted line to the full line position shown in Fig. 2, thereby coupling the output of the organ 30 effectively across the input to the artificial line 66. The signal thus appears between the terminal 56 and ground. The lower audio frequencies, for example, below 80 c. p. s., are transmitted directly from the terminal 56 through the conductor 168 and impressed upon the control grid 152 of the amplifier tube 154.

As above pointed out in greater detail the frequencies above the assumed frequency of 80 c. p. s. will be transmitted through the artificial line in a well known manner and will be prevented from reflection at the end of this line because of the utilization of the characteristic line impedance R74. Assuming that the musician desires a wide or large vibrato he will depress the knob 109 whereupon the condenser plates 140, 140*a* to 148, 148*a* will be respectively connected to junction points substantially equally distributed along the full length of the artificial line, thus making use of the full extent of the phase shift characteristics thereof. As the rotor 216 revolves at approximately 6 r. p. s., it successively scans the artificial line 66, sequentially picking up the signal appearing thereon, commencing near the end of the line (at the junction point 80) and traversing the line to the beginning thereof and then returning over the line to the junction 80. It will be noted that while the artificial line 66 comprises 32 sections (plus two terminal half-sections) the signal is picked up at only nine spaced sections for the large vibrato. It has been found that the effect upon the ear of picking up the signal successively from each of the sections and picking it up from nine equally spaced sections of the line is substantially identical.

Since the pickup condenser plates 220 are in capacitative relation with two adjacent plates 140 to 148 and 140*a* to 148*a* as the plates 220 are rotated, the transition from a signal derived from one of the junction points to the signal at another of the junction points is gradual rather than abrupt. This is a contributing factor which makes it unnecessary to pick up the signal at each of the sections of the artificial line.

For certain musical selections the organist may, for the purpose of contrast, desire to eliminate the vibrato effect. This is accomplished by moving the knob 48 from the full line to the dotted line position, whereupon the output of the organ is coupled directly to the input of push-pull driver tubes 188 and 189 through conductors 240, 241.

The extent of the vibrato, that is, the determination of which of the knobs 109, 119 or 129 is to be operated depends upon the character of the musical selection to be rendered. For instance, for music of an ecclesiastical character or for hymn playing the small vibrato is found most useful, whereas for music of a theatrical and orchestral character the large vibrato is particularly well adapted. It is sometimes found that in playing very fast music of an orchestral nature the large vibrato is excessive and for this purpose the medium vibrato is provided. The extent of the medium vibrato is three-fourths that of the large vibrato whereas the extent of the small vibrato is one-fourth that of the large vibrato.

Switch 64 may be used either in the full line closed position shown, in which case the over-all frequency response is approximately linear, or it may be open, in which case the frequency response is relatively reduced in the middle register. This latter setting is particularly useful under conditions in which the organist is playing with both hands upon one manual with the melody part being carried as the highest note played. Due to the rising frequency response for the high frequencies this melody note will tend to predominate over and above the accompaniment. In music of a homophonic character this emphasis of the melody is particularly desirable.

In lieu of the use of the apparatus to produce a vibrato effect in the organ it may be utilized to improve the music produced by an electronic piano. Such system is shown in Fig. 3 as comprising a piano 250 electrically coupled to a vibrato apparatus 34, the latter being coupled to an output amplifier 254 feeding a speaker 256. The electronic piano 250 may be of any suitable type such as those employing direct electric pickup of the mechanical vibrations from the strings, those utilizing microphonic pickup of the mechanical vibration from within the sounding board of the piano, as by means of a vibration microphone, or by microphonic pickup of the sound vibrations within the case of a piano which may have been sound-proofed. The system of Fig. 3 is of particular utility because the tones produced through the vibration of the piano strings are entirely devoid of vibrato, and their vibration is of relatively constant frequency. When the vibrato effect is introduced into the tones of a piano, the quality and character of the music is vitally changed, the change being so pronounced that the effect is that of a marvelously improved piano.

In the system of Fig. 4 the vibrato apparatus 34 has its input coupled through a preamplifier 257 to a microphone 258 and its output coupled through an amplifier 254 to a speaker 256. The microphone may, of course, be utilized to pick up any sound virbations into which it is desired to introduce a vibrato effect. For example, in public address systems the microphones may be utilized to pick up the sound produced by various orchestral instruments, and for special effects, such as dramatic readings, it may be utilized to introduce the vibrato effect into speech. It is also particularly useful in imparting a vibrato effect to the tones produced by fretted instruments, such as guitars.

In the system of Fig. 5 the microphone 258 is coupled through a preamplifier 257 to the vibrato apparatus 34. A second microphone 259 is directly coupled to a mixer and amplifier 260 to which the vibrato apparatus 34 is also coupled. The output of the amplifier 260 is fed to a recording head 262, the stylus of which operates upon a record carried by a turntable 264 driven by a motor 265.

By judicious and artistic use of the vibrato apparatus in recording orchestral selections, that is, by properly balancing the strength of the signals derived from the microphones 258 and 259, the music recorded may be greatly improved. This is because the vibrato effect may thus be readily introduced into the music produced by instruments inherently incapable of generating the vibrato signal, while the vibrato is not introduced in the music produced by such instruments, as the violin, which are adequately capable of generating a satisfactory vibrato.

Under some circumstances, it may be desirable to utilize the vibrato apparatus in conjunction with a radio receiving, recording, and playback apparatus of the type shown in Fig. 6, wherein the output of a radio receiver and amplifier 268 is coupled through the vibrato apparatus 34 to an audio frequency power amplifier 270. The output of the amplifier 270 may be utilized to supply a signal to a speaker 272, or upon closure of the switch 274, may optionally or additionally be supplied to a recording head 276 of a phonograph recording apparatus 278. Thus the record may incorporate music having a vibrato effect even though this effect was absent from the music received by the radio receiver.

A further system in which the invention may be effectively used is illustrated in Fig. 7. This system is intended as a part of the broadcasting station in which the sound pickup from the microphone 286 is coupled to an amplifier 288, the output of the latter being transmitted through a vibrato apparatus 34, and a gain control 290, to a radio transmitter 292. The output of a second microphone 294 may likewise be coupled to the transmitter preferably through an amplifier 296 and a separate gain control 298. With this system the sound or music being broadcast may be picked up simultaneously by both microphones and by proper manipulation of the gain controls 290 and 298, using them as a mixer, the signal may have the vibrato incorporated or not, or incorporated to any desired degree. This system is particularly useful in broadcasting pipe organ music.

Pipe organs are generally incapable of producing a true vibrato effect, the closest approach to a vibrato on the pipe organ being accomplished by the use of the tremulant stops. Pipe organ music may therefore be greatly improved by the addition of the vibrato effect. An additional system for accomplishing this purpose is shown in Fig. 8.

In Fig. 8 a pipe organ console 300 is adapted, through electrical or other control, to cause pipes 302 to speak. The pipes 302 are mounted within a closed chamber 304 which is substantially soundproof.

In this system the sound produced by the pipes is picked up by a microphone 308 which is coupled through an amplifier 310 to a vibrato apparatus 34.

On the console 300 are located four stops 312 for respectively controlling the operation of solenoids 314 which are adapted to operate the control knobs 48, 109, 119 and 129 respectively of the vibrato apparatus shown in Fig. 2. The expression or swell pedal of the organ, instead of controlling swell shutters operates a gain control 316 which will effectively vary the gain of an amplifier 318 to which the output of the vibrato apparatus 34 is coupled. The amplifier 318 supplies a speaker 320, or, upon closure of switch 322, may additionally be coupled to a broadcast transmitter 324.

The pipe organ 300, in addition to having pipes

302, may have percussion stops, such as chimes, harp, glockenspiel, celeste, marimba and xylophone. The addition of the vibrato to the tones produced by these stops greatly enhances their musical effectiveness. In this system the usual pipe organ tremulant apparatus may be eliminated since it would have little, if any, musical utility. In systems incorporating large pipe organs having two separate pipe chambers, as for example pipe organs having separate swell chambers for the great and swell manuals, the microphone pickup and vibrato apparatus may be duplicated and the console provided with individual controls so that the vibrato effect may be produced in the tones controlled by one manual only, or both manuals, at the will of the organist. Under the latter circumstances, it would be preferable to have the modulating rates of operation of the vibrato apparatus differ, as for example, 5.8 and 6.2 c. p. s.

The system of Fig. 8 would also be useful in improving the tonal output of reed organs in which the signal vibrations are picked up either acoustically, by a microphone, or electrically, by a capacitative or electromagnetic pickup from the reeds.

The apparatus shown in Figs. 2, 2*a*, 2*b* and 2*c* is representative of but one of three general types of apparatus by which a vibrato effect may be introduced in a signal through the use of a phase shifting transmission network. These three types may be generally described as: (1) Systems in which the network or artificial line remains unchanged and in which the input signal is impressed upon the line and the output picked up from the line, at coupling points which, in effect, have relative oscillatory motion at a vibrator rate; (2) systems in which the points of coupling between the artificial line and the input and output respectively are fixed, and in which the effective length of the artificial line (as measured in electrical degrees of phase shift) is varied at a vibrato rate by sequentially rendering a greater or lesser number of sections of the line effective to transmit the signal; (3) systems in which the points of coupling of the input and output to the artificial line are fixed, and in which the phase shifting characteristics of the individual sections of the artificial line are simultaneously varied at a vibrato rate.

The apparatus of Figs. 2, 2*a*, 2*b* and 2*c* is representative of group (1) as above defined. Figs. 9 to 12 are also examples of apparatus of the first group. The apparatus of Figs. 19 and 20 are representative of group (2), while apparatus of Figs. 13 and 18 are representative of group (3).

In Fig. 9 the artificial line may be of the same design as in Fig. 2, and such parts thereof as are similar to those previously described have corresponding reference characters applied thereto. The input signal is derived from a conventionally illustrated generator 330 connected to the input of the line. In this figure each of the shunt legs of the sections comprises a pair of series condensers C71 and C73, and the junction points between the condensers of each pair are connected in equally spaced relation along a resistor R332 which has a sliding contact 334 cooperable therewith. Each of the individual sections of the resistor R332 is of sufficiently high value as not appreciably to effect the phase shifting characteristics of the artificial line. The sliding contactor 334 picks up a phase modulated signal for an amplifier 338, through which the signal is transmitted to a speaker 340.

It will be apparent that as the sliding contactor 334 is shifted back and forth along the resistor R332 in an oscillatory manner at a vibrato rate, the phase of the signal transmitted to the amplifier 338 will smoothly and gradually shift in a manner comparable to that occurring in the apparatus in Figs. 2, 2*a* and 2*b*. It is not essential that the contactor 334 make contact with each incremental section of the resistor R332, but instead, the resistor could have taps at uniform intervals throughout its length, and the contactor 334 could contact these taps sequentially without opening the circuit. In general it is rather difficult to construct a sliding contactor or a series of sequentially operating switches which will not introduce undesirable phase shift transients in the output signal. It is for this reason that the construction of Figs. 2, 2*a* and 2*b* is ordinarily preferred to that shown in Fig. 9, especially when a large angular phase shift is required. Furthermore, sliding contactors and switches are subject to undesirable mechanical wear.

A modified form of the invention in which there are no sliding contactors or switches is shown in Fig. 10 in which the artificial line, as before, comprises series inductances L68 and shunt condensers C70, but in which the signal is electromagnetically picked up by means of a coil L342 oscillated along the inductances L68 so as successively to couple with them. The pickup coil L342 is preferably connected to an indefinitely high impedance, such as the grid of an amplifier tube forming part of an amplifier 344. Thus the line 66 will have its phase shifting characteristics unaffected by the motion of the pickup coil L342.

Physical embodiments of parts of the system of Fig. 10 are shown in Figs. 11 and 12. The inductances L68 are illustrated as coils mounted upon a non-magnetic tube 346 carried by suitable supports 348. The pickup coil L342 is secured to the end of a tube 350 of non-magnetic material which has a guide rod 352 likewise of non-magnetic material projecting from the end thereof. The rod 352 and tube 350 are suitably guided in bearings 354 mounted in the supports 348. The pickup coil L342 is oscillated (successively coupling with the windings L68) by a motor 356 which, through a crank pin 357, oscillates an arm 358. The lower end of the latter is pivoted on a fixed pin 359. The outer end of the arm 358 has a pin and slot connection 360 with the end of the tube 350. Conductors 362, connected to the terminals of the pickup coil L342, are preferably led through the tube 350 and are attached near the point of pivot of the arm 358 so as to avoid the necessity of using any sliding contact arrangement.

It will be clear that if the motor 356 (which may include a suitable speed reducing gearing) drives the crank pin 357 at approximately 6 r. p. s., the pickup coil 342, will, in effect scan the artificial line at the vibrato frequency by successively coupling with the inductances L68. In order to prevent undesirable linking between adjacent inductances L68, the physical length of the tube 344 (that is, the total width of the inductance coils L68) should be large in comparison with their diameters.

A modification of the invention shown in Figs. 13, 14 and 15 is representative of a vibrato apparatus of type (3) defined above. In this apparatus the artificial line comprises a plurality of variable inductances L368 connected in series, with the usual condensers C70 in the shunt paths. An amplifier 370 is connected directly across the terminating impedance R74. The value of the terminating impedance R74 is such that it constitutes the characteristic impedance of the artificial line when the inductances L368 are at their intermediate or average values. The physical construction of the apparatus of Fig. 13 is shown in Figs. 14 and 15 as comprising a suitable supporting structure 372 upon which the inductance windings L368 are rigidly mounted. A shaft 374 is pivotally mounted on the supporting structure 372 and has a plurality of levers 376 secured thereto. Powdered iron cores 378 are secured to the ends of the levers 376 and so arranged that, as the shaft 374 is oscillated, the cores enter their associated inductance windings L368. The shaft 374 is oscillated by a motor 380 (which may include a speed reducing gearing) through a crank pin 382 operating in a slot 383 formed in one of the levers 376.

It may be seen that, as the motor 380 oscillates the shaft 374, all of the inductances L368 are simultaneously varied, thus effectively increasing and decreasing the length of the artificial line as measured in electrical degrees. The phase of the signal supplied to the amplifier 370 is thus modulated at the vibrato rate with the same ultimate results as are obtained by the forms of the invention previously described. It will be noted, however, that as the values of the inductances L68 are varied the cutoff frequency of the artificial line changes.

In the modification of the invention shown in Figs. 16, 17 and 18 the capacitances of the shunt path condensers are simultaneously varied. Thus the artificial line comprises inductances L68 and variable shunt path condensers C386. As in Fig. 13, the amplifier 370 is connected across the terminating impedance R74. In this case the value of R74 is such as to constitute the characteristic impedance of the line when the condensers C386 are at their average values.

The condensers C368 are preferably multi-plate gang condensers having a common operating shaft 388. By making the inductances L68 of relatively high value, such as 6 henries, the condensers C386 may be of relatively small capacitance, such as .000264 mfd. and R74 may then have a value of 151,000 ohms for a cutoff frequency of 8,000 c. p. s. The shaft 388 is mounted in suitable bearings on a supporting structure 390 and is driven by a motor 391 through a pinion 392 and gear 393. The motor 391 is preferably provided with a manually operable speed control 394 whereby the speed of the motor may be adjusted to rotate the shaft 388 at any desired speeds in the vibrato range, for example between 5.5 and 7 r. p. s.

In the embodiment of the invention disclosed in Fig. 19, a conventionally illustrated low impedance signal source 398 is coupled to the artificial line 66, comprising series inductances L68 and shunt condensers C70, the line terminating in its characteristic impedance in the form of resistance R74. Amplifier 370 is coupled across the resistor R74 and supplies the amplified signal to a loudspeaker 340. Resistors R402 and conductors 403 are connected between switch contacts 404 and junction points 400, the latter being between successive inductances L68. A contactor 406 has one end connected to the ungrounded terminal of the signal source 398 and is illustrated as being flexible and arranged to make contact successively with the contact points 404, commencing at the end of the artificial line adjacent the signal source.

The contactor 406 is operated at a vibrato rate. As it successively engages the contact points 404 it cumulatively short circuits the series inductances L68, thereby varying the length of the line as measured in electrical degrees of phase shift. When the contactor 406 is in engagement with all of the contacts 404 the condensers C70 are connected in parallel with the source 398, and the source 398 must therefore be of low impedance in comparison with the total impedance of the condensers C70, and thus prevent attenuation of the high frequencies through the shunt paths provided by these condensers. If desired, inductances could be substituted for the resistors R402, but for reasons of economy it is preferred to use resistors.

In the modification of the invention shown in Fig. 20 the artificial line is coupled to a high impedance signal source 410, the artificial line comprising the series inductances L68 and pairs of shunt condensers C412 and C413. One terminal of each of the condensers C412 and C413 is connected to a junction point 414 between successive inductances L68 while the other terminals of each of these condensers are connected to contact points 416. A contactor is connected to the grounded end of the characteristic impedance R74 and is illustrated as capable of being flexed to engage the contacts 416 successively, commencing at the output end of the artificial line and sequentially closing the circuits, and commencing at the input end of the line, opening these circuits.

An amplifier 370 is coupled across the terminating impedance R74 and supplies a speaker 340. When the flexible contactor 418 is in its fully opened position as shown by dotted line 418*a* the phase shift provided by the artificial line 66 will be negligible. Under these conditions series inductances L68 are still in series with the generator 410. By making the internal impedance of the audio frequency signal source 410 high compared with that of the inductances L68, the signal supplied to the amplifier 370 will be substantially unaffected by the presence of the series inductances L68, and thus the attenuation of the high frequencies by this series inductance path will be prevented. By making condensers C412 and C413 of equal value the extent of phase shift caused by successively closing the contacts 416 is made substantially uniform.

It will be seen that in each of the embodiments of the invention there is provided a signal transmission line which includes inductive and capacitative reactances for producing an electrical phase shift of the signal, the signal input and output being coupled to this signal transmission line, and the extent of phase shift of the signal produced by the transmission line varried at a vibrato rate to cause phase modulation of the signal. This phase modulation is perceived as a frequency modulation or vibrato effect.

From the foregoing description it will be clear that the principles of the invention may be incorporated in a variety of forms and that the circuits and apparatus disclosed are merely illustrative of suitable embodiments of the invention. The invention may be embodied in many other forms, all coming within the scope of the claims which follow.

I claim:

1. In an apparatus for improving sounds derived from a source in the form of electrical

waves, the combination of a multi-section artificial line, means to couple the sound signal source to said line, a plurality of junction points substantially uniformly distributed along said line, a condenser plate connected to each of said junction points, a scanning condenser plate cooperable with said first condenser plates effectively to scan said junction points in an oscillatory manner at a vibrato rate, and means to amplify and translate into sound the electrical signal appearing on said scanning condenser plate.

2. In an apparatus for improving sound derived from a source in which the sound is in the form of an electrical signal, the combination of an artificial line having substantial phase shift characteristics in the audio frequency band and coupled to said source, an output system including means for translating electrical signals into sound, and means for successively coupling said output system to said artificial line at successive points throughout the length thereof in an effectively oscillatory manner at a vibrato rate.

3. In an electrical system for the production of vibrato, the combination of a source of audio frequency signals, an output system, an electrical network having substantial phase shifting characteristics for frequencies in the audio spectrum, said network comprising a plurality of reactive elements connected to couple said audio frequency source with said output system, thereby to modify the phase of the signal transmitted to said output system with respect to the phase of the signal received from said source, and means for producing a frequency vibrato in the signal transmitted to said output system by causing a periodic change in the extent of phase shift produced by said network, said change being effected at a rate in the order of 6 c. p. s.

4. In an apparatus for improving sound derived from a source in which the sound is in the form of an electrical signal, the combination of an artificial line having substantial phase shift characteristics in the audio frequency band and having one end coupled to said source, an output system coupled to said artificial line at a point spaced from said end, and means for varying the phase shift characteristics of said artificial line at a vibrato periodicity.

5. The combination set forth in claim 4 in which said artificial line includes a plurality of inductance coils and condensers, and in which said means for varying the phase transmission characteristics of said line comprises means for varying the effective inductance of said coils.

6. The combination set forth in claim 4 in which said artificial line includes a plurality of inductance coils and condensers, and in which said means for varying the phase transmission characteristics of said line comprises means for varying the effective capacity of said condensers.

7. In an apparatus for improving sound derived from a source in which the sound is in the form of an electrical signal, the combination of an artificial line having substantial phase shift characteristics in the audio frequency band and having one end thereof coupled to said source, an output system for utilizing the signal and coupled to the other end of said line, said means for effectively varying the length of said artificial line at a vibrato rate.

8. The combination set forth in claim 7 in which said artificial line comprises a plurality of sections having series inductances and junction points between successive sections, and means for varying the effective length of said line comprising a switch mechanism for alternately decreasing and increasing the angular phase shift effected by said sections, said alternate increase and decrease being at a vibrato rate.

9. The combination set forth in claim 7 in which said artificial line comprises a plurality of condensers, and in which the means for varying the effective length of said artificial line comprises apparatus for successively increasing and decreasing the effective capacitances of said condensers along said line at a vibrato rate.

10. The combination set forth in claim 7 in which said artificial line comprises a plurality of inductance coils connected in series by junction points and in which said means for varying the effect of length of said artificial line comprises a conductor connected to the input end of said line, and switch means for successively connecting said conductor to junction points of said artificial line, traversing from the input end to the output end and returning to the input end thereof in a cyclical manner at a vibrato rate.

11. The combination set forth in claim 7 in which said artificial line comprises a plurality of sections each including a series inductance coil and a shunt condenser, and in which said means for varying the effective length of said artificial line comprises a conductor connected to the output end of said line, and periodically operating switch means for successively disconnecting said condensers from said conductor, commencing at the input end of said artificial line, proceeding to the output end thereof, and returning to the input end, thus, in effect, decreasing and increasing the length of said artificial line in a cyclical manner and at a vibrato rate.

12. The combination set forth in claim 2 in which said artificial line comprises a plurality of sections, each section having a parallel high resistance, and in which the means for successively coupling the output system to said artificial line comprises a contactor successively making contact along said resistors at a vibrato rate.

13. The combination set forth in claim 2 in which said artifical line includes a plurality of series inductance elements, and in which said means for succesively coupling the output system to said artificial line comprises an inductive pickup successively coupled to said series inductance elements.

14. In an apparatus for improving the sound derived from a source in which the sound is in the form of an electrical signal, the combination of an artificial line having substantial phase shift characteristics in the audio frequency band and coupled to said source, an output system for utilizing the electrical sound signal and also coupled to said line, and means for effectively relatively shifting the points of coupling of said line, said source, and said output system in a cyclical manner at a vibrato rate, thereby effectively to change the length of the artificial line through which the signal is transmitted.

15. The combination set forth in claim 14 in which said line includes a plurality of junction points at which the signal amplitudes are substantially the same, and in which the said points of coupling are at said junction points, whereby compensation is made for signal dissipation in the line.

16. In an electrical system for the production of vibrato, the combination of a source of audio frequency signals, an output system, electrical means having substantial phase shifting characteristics for frequencies in the audio spectrum,

said electrical means comprising reactive elements connected to couple said audio frequency source with said output system, thereby to modify the phase of the signal transmitted to said output system with respect to the phase of the signal received from said source, and means for producing a frequency vibrato in the signal transmitted to said output system by causing a periodic change in the extent of phase shift produced by said electrical means, said change being effected at a rate in the order of 6 c. p. s.

17. In an apparatus for improving the sound derived from a source in which the sound is in the form of an electrical signal, the combination of an artificial electrical transmission line having substantial phase shift characteristics in the audio frequency band, an output system for utilizing the electrical signal, means for coupling said source and said output system to said artificial line, and means for effectively changing at a vibrato rate the degree of phase shift produced by said artificial line upon the signal transmitted thereby to said output system.

18. In an apparatus for improving sound signals derived from a source in the form of electrical waves, the combination of a multi-section artificial line, means to couple said source to one end of said line, said artificial line including a plurality of terminals in different sections at which the signal appears at substantially the same amplitude, a plurality of condenser segments positioned adjacent each other in circular arrangement, means for respectively connecting said plates to said terminals in a predetermined order, a rotatable condenser plate successively cooperable with said condenser segments to pick up the electrical signals appearing on the latter, means to rotate said plate at a speed in the order of 6 c. p. s., and electroacoustic translating means coupled to said rotary condenser plate.

19. In an electrical system for the production of vibrato, the combination of a source of audio frequency signals, an output system, a plurality of electrical networks comprising reactive elements, said networks being effective to produce substantial electrical phase shifts in the audio frequency spectrum, means for coupling said source and said output system to said electrical networks, and means for effectively changing at a vibrato rate the degree of phase shift produced by said electrical networks.

20. In an apparatus for introducing a vibrato effect into music derived from a source in which the music is in the form of an electrical signal; an artificial line comprising a plurality of inductances connected in series, shunt capacitors, and a terminating impedance, said artificial line having a plurality of junction points at which the signal amplitude is substantially the same; means coupling the input end of said artificial line to the source of musical signals; a plurality of capacitor plates; means for connecting said plates to said junction points respectively, a scanner plate movable past said capacitor plates in capacitative relation therewith so as to be affected by the signal voltages appearing on the latter; means for moving said scanner plate relative to said capacitor plates in a cyclical manner at a frequency in the order of 7 c. p. s. to cause said scanner plate to be affected by the signals appearing at the junction points effectively in an oscillatory manner, and an output circuit coupled to said scanner plate.

21. In an apparatus for introducing a vibrato effect into music derived from a source in which the music is in the form of an electrical signal; an artificial line comprising a plurality of inductances connected in series, shunt capacitors, and a terminating impedance, said artificial line having a plurality of junction points at which the signal amplitude is substantially the same; means coupling the input end of said artificial line to the source of musical signals; a plurality of capacitor plates; selectively operable switching means for connecting said plates to said junction points respectively, either to junction points distributed along substantially the full length of the artificial line or to junction points distributed along a portion only of said artificial line; a scanner plate movable past said capacitor plates in capacitative relation therewith so as to be affected by the signal voltages appearing on the latter; means for moving said scanner plate relative to said capacitor plates in a cyclical manner at a frequency in the order of 7 c. p. s. to cause said scanner plate to be affected by the signals appearing at the junction points, effectively in an oscillatory sequence; and an output circuit coupled to said scanner plate.

22. In an apparatus for introducing a vibrato effect into music from a source in which the music is in the form of an electrical signal, a conductor, a plurality of inductances connected in series, a plurality of capacitors connected in shunt between the junctions of said inductances and said conductor, a terminating impedance connected between said conductor and the last of the series of inductances, said inductances, capacitors, and terminating impedances forming an artificial line means providing a plurality of junction joints in said line at which the signal transmitted therethrough is of substantially equal amplitude, means coupling the input end of said line to the source of musical signals, a plurality of capacitor plates respectively connected to said junction points, a scanner plate cooperable successively with said capacitor plates, means for moving said scanner plate relative to said capacitor plates in a manner to pick up the signals appearing on said capacitor plates effectively commencing with the beginning of the artificial line proceeding to the end of the artificial line and returning to the beginning thereof in a cyclical manner at a periodicity within the range of 5 to 8 c. p. s., and means to amplify and translate into sound the signal appearing on said scanner plate.

JOHN M. HANERT.

CERTIFICATE OF CORRECTION.

Patent No. 2,382,413. August 14, 1945.

JOHN M. HANERT.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 7, first column, line 55, for "virbations" read --vibrations--; page 8, first column, line 35, after the word "output" insert --signal--; line 38, for "vibrator" read --vibrato--; page 9, second column, line 61, for "varried" read --varied--; page 10, first column, line 68, for "said" second occurrence, read --and--; and second column, line 47, for "succesively" read --successively--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 1st day of January, A. D. 1946.

Leslie Frazer

(Seal) First Assistant Commissioner of Patents.