May 21, 1940. W. F. CURTIS 2,201,388

ELECTRIC ORGAN

Original Filed July 30, 1937 5 Sheets-Sheet 1

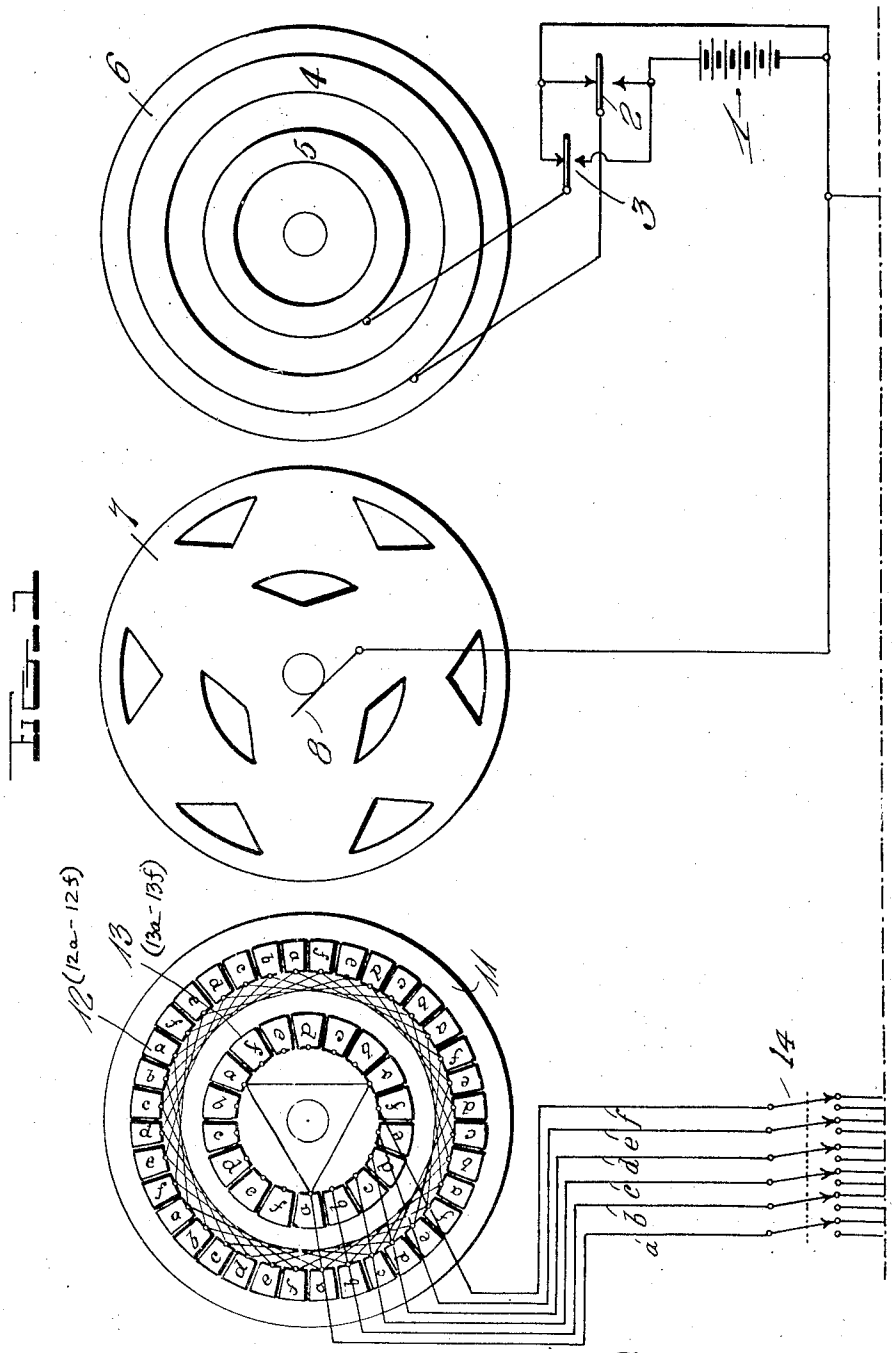


FIG. 1

Wesley F. Curtis, INVENTOR

John B. Brady

ATTORNEY

May 21, 1940. W. F. CURTIS 2,201,388

ELECTRIC ORGAN

Original Filed July 30, 1937 5 Sheets-Sheet 2

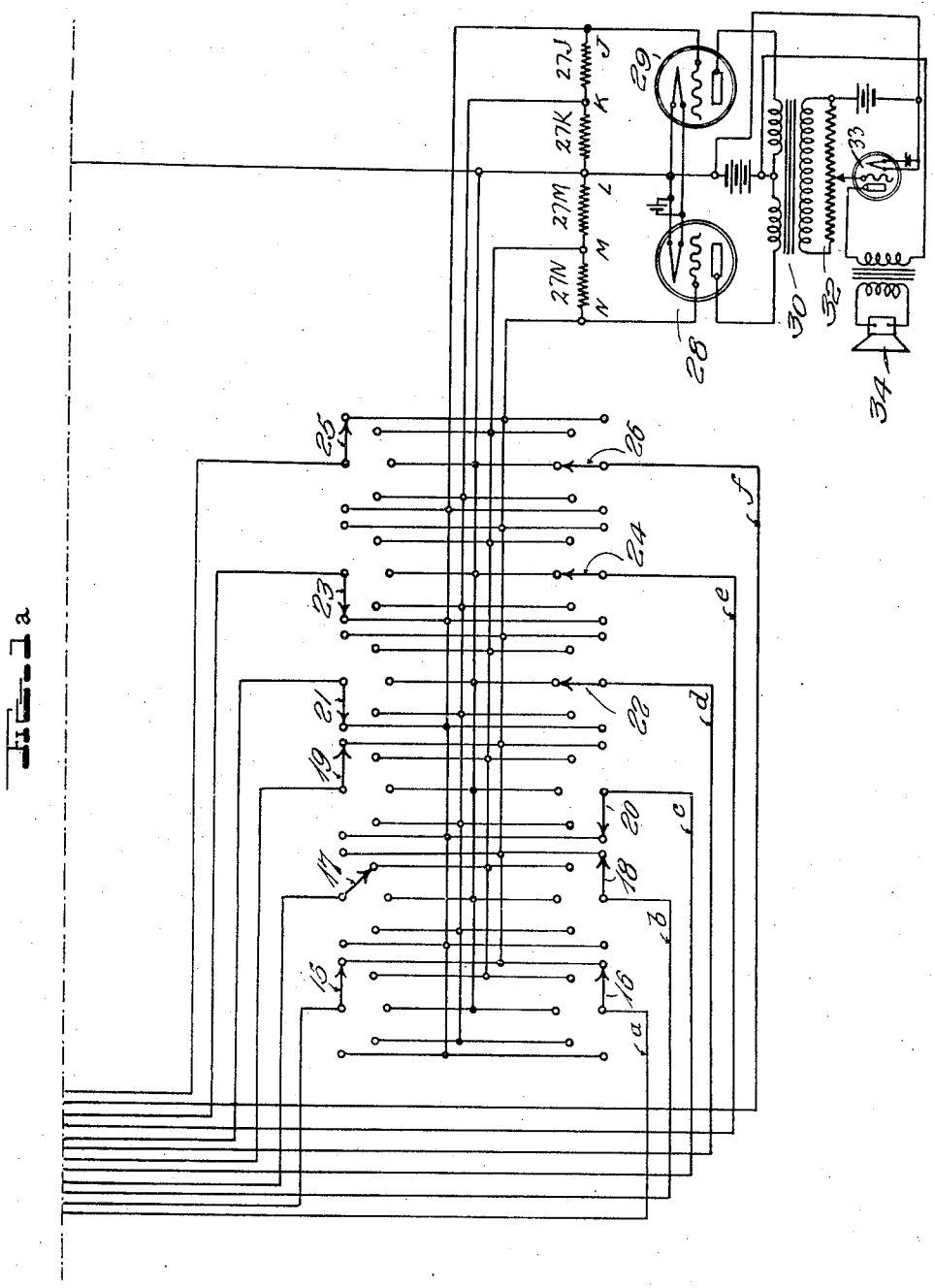


Fig. 1a

Westley F. Curtis, INVENTOR

John A Brady

ATTORNEY

May 21, 1940. W. F. CURTIS 2,201,388

ELECTRIC ORGAN

Original Filed July 30, 1937 5 Sheets-Sheet 3

Fig. 2

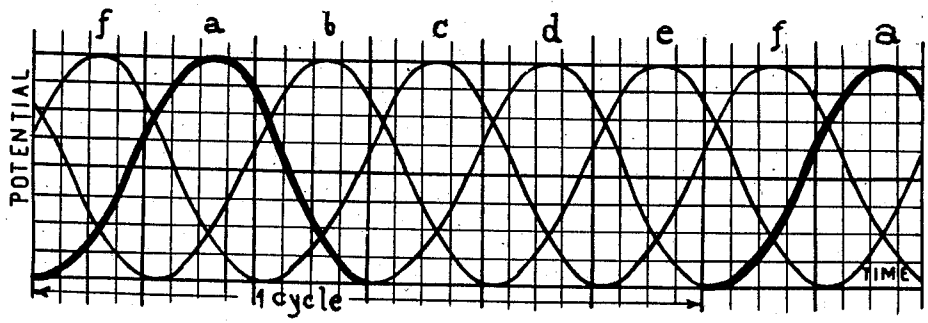
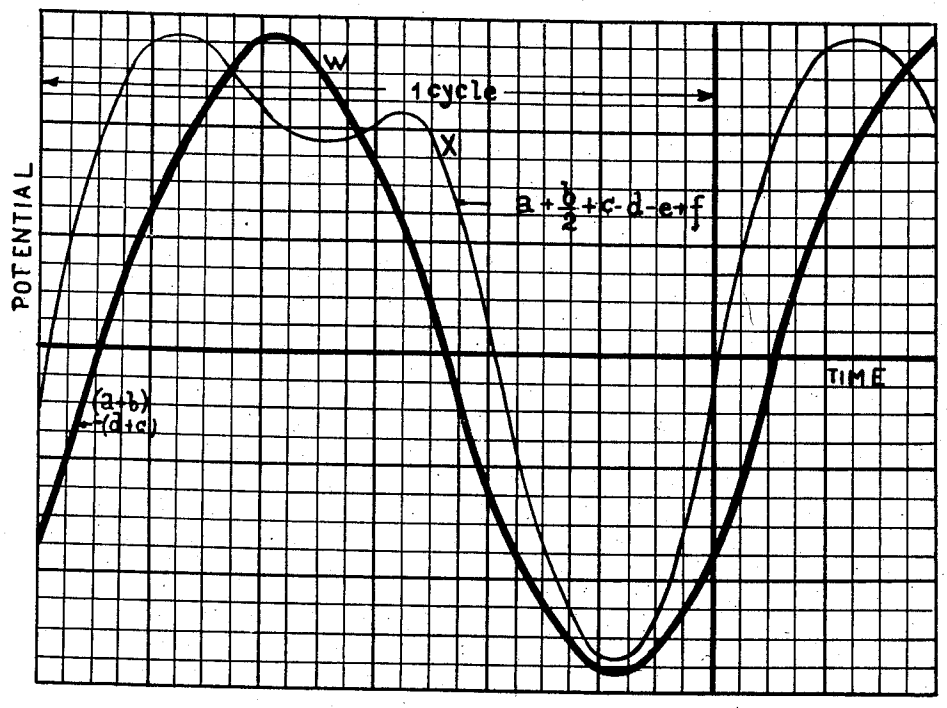


Fig. 3



Westley F. Curtis, INVENTOR

John B Brady ATTORNEY

May 21, 1940. W. F. CURTIS 2,201,388

ELECTRIC ORGAN

Original Filed July 30, 1937 5 Sheets-Sheet 4

FIG. 4

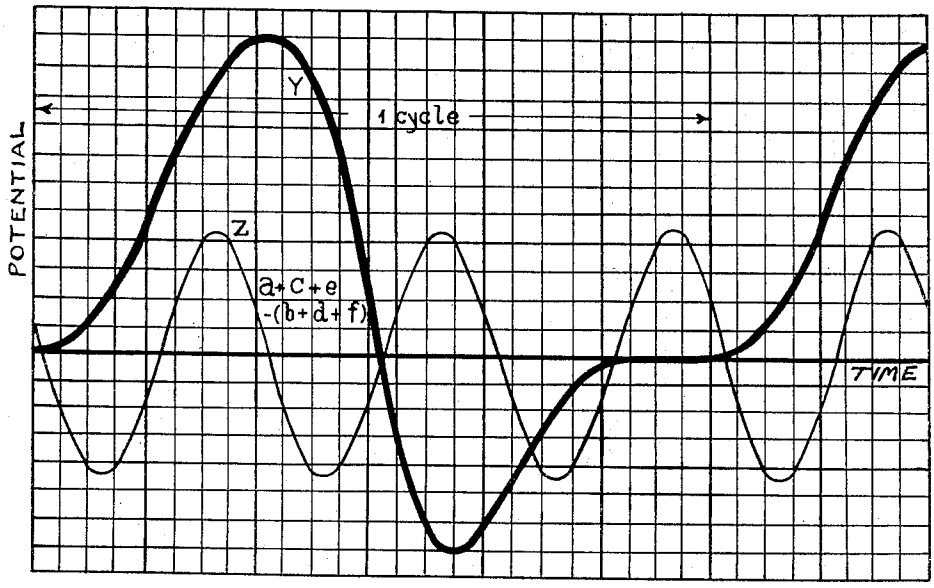


FIG. 5

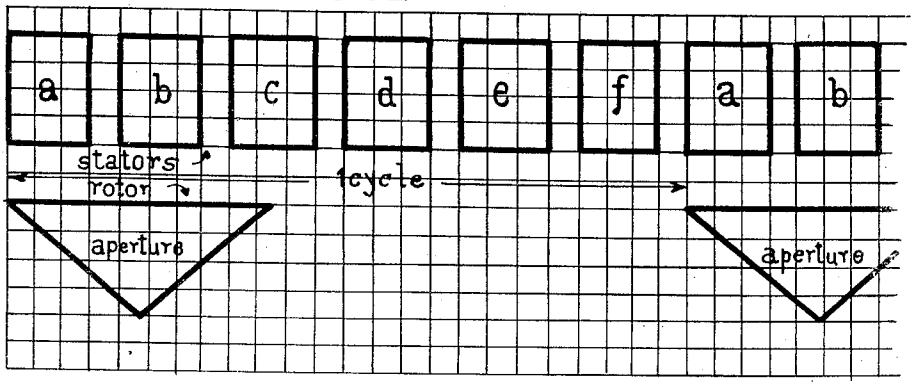
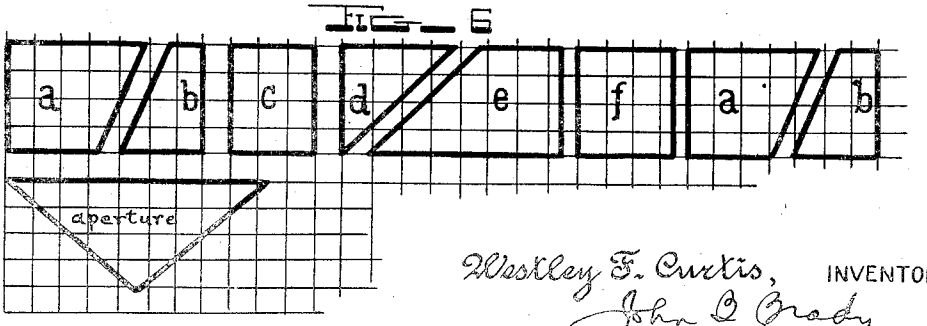


FIG. 6



Weskley F. Curtis, INVENTOR

John B. Brady

ATTORNEY

May 21, 1940. W. F. CURTIS 2,201,388

ELECTRIC ORGAN

Original Filed July 30, 1937 5 Sheets-Sheet 5

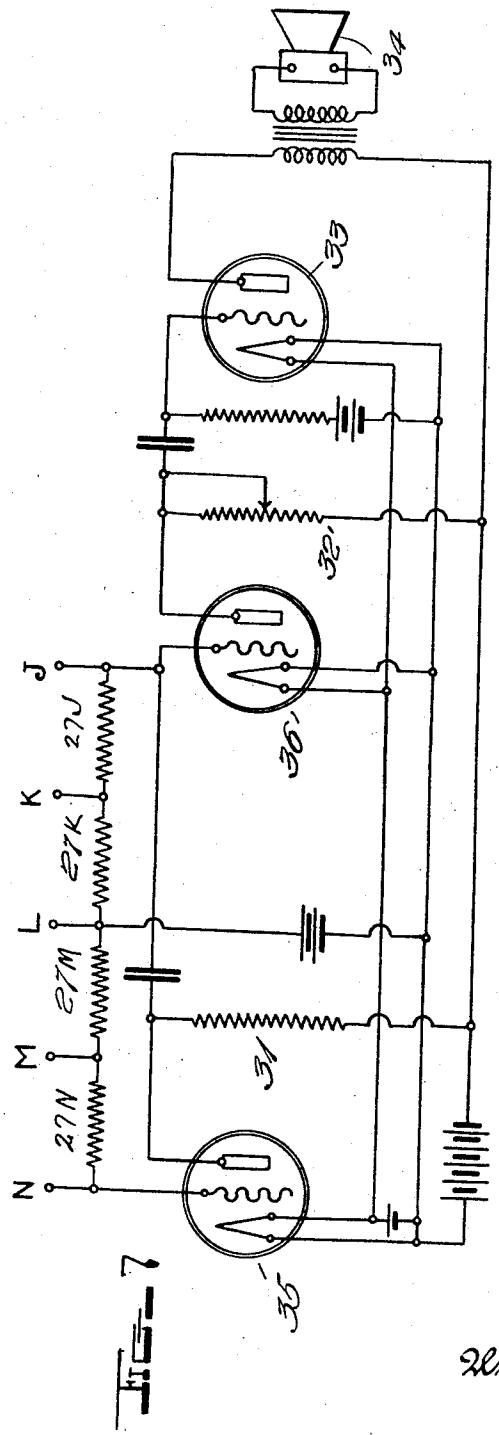


FIG. 7

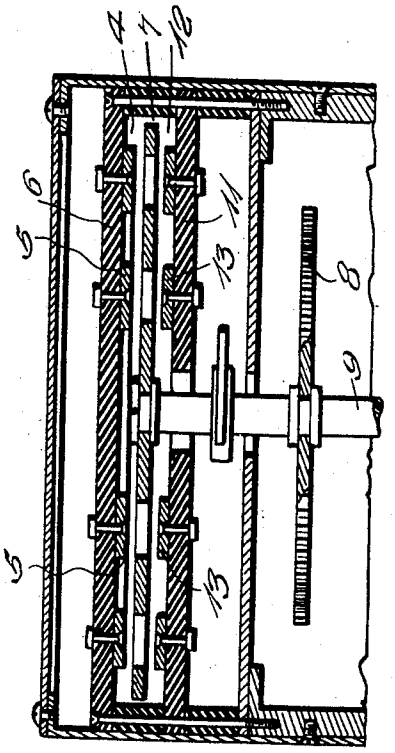


FIG. 8

Westley F. Curtis, INVENTOR

John C. Grady ATTORNEY

Patented May 21, 1940 2,201,388

UNITED STATES PATENT OFFICE

2,201,388

ELECTRIC ORGAN

Westley F. Curtis, Beaver Heights, Md.

Original application July 30, 1937, Serial No. 156,574. Divided and this application May 7, 1938, Serial No. 206,680

7 Claims. (Cl. 171—329)

My invention relates to electrical musical instruments in general, and in particular to those instruments employing rotating parts for the generation of tones, especially those classes of such instruments which depend upon electrostatic or photoelectric effects.

This application is a division of my application Serial No. 156,574, filed July 30, 1937, for Method of controlling the timbre of an electrical musical instrument.

The development of the type of musical instrument in which complex musical tones are synthesized from a number of simple components is today most seriously handicapped by two defects. One of these defects is the great complexity of all the instruments whose design has so far been made public. The other is that these instruments, complex as they are, yet do not have the degree of flexibility, the range of musical expressiveness, which the potentialities of such an instrument lead one to hope for. It is my contention that these twin difficulties arise from the same source; i. e. the attempt to control tone quality in too fine-grained a manner. To provide such a quality control system involves great trouble and expense, and yet there are great numbers of useful tone qualities which are unattainable by the instrument. The oboe, for example, often emits a very prominent ninth harmonic; organ tones often contain appreciable percentages of harmonics as high as the twelfth and sometimes as high as the twentieth, according to some authorities. Furthermore, in conventional acoustic instruments, the quality varies with pitch to a noteworthy degree. This feature, while regarded as a defect by some, adds variety to the music. It is this feature which lends color and attractiveness to the often-used musical device of repeating a passage an octave higher or lower. No way of obtaining this result is included in synthetic instruments of the class considered above.

One object of my invention is to provide an instrument which is capable of producing a wider variety of tone qualities or timbres than previous instruments.

Another object of my invention is to provide an instrument in which the tone quality emitted can be easily and rapidly altered to any one of a plurality of previously selected tone qualities.

Still another object is to control the tone quality of an electrical musical instrument by controlling the wave-forms produced by the individual tone generators.

A further object is to provide simplified means for so controlling the tone quality.

Another object is to provide a compact musical instrument of the type described by completely utilizing the surfaces of the rotating members, thus providing an instrument of minimum size which can be constructed at comparatively low cost.

A further object of my invention is to provide a musical instrument to be manually operated from a keyboard and having simple means for controlling the wave-form, the amplitudes of the individual partials, and the output volume at the discretion of the operator.

Other and further objects of my invention reside in the music producing system as set forth more fully in the specification hereinafter following by reference to the accompanying drawings, in which:

Figures 1 and 1*a* show schematically the circuit connections and the essential geometrical relationships between the working parts of two individual tone generators of an electrostatic instrument embodying my invention; Figs. 2, 3 and 4 show a few of the many possible wave-forms which can be derived from the apparatus shown in Fig. 1; Fig. 5 shows in greater detail than Fig. 1 the plate and opening proportions from which the wave-forms of Figs. 2 to 4 were calculated, the plates and the openings in Fig. 5 being shown in a rectilinear development of their actual forms as shown in Fig. 1 to facilitate calculation; the approximation thus introduced causes the calculated wave-forms to contain slightly less energy on the harmonic overtones than would actually be the case; Fig. 6 shows a modified arrangement of the stator plates in a view similar to Fig. 5; Fig. 7 shows an alternate circuit arrangement for the amplifier shown in Fig. 1; and Fig. 8 is a vertical cross-section view of the generator assembly shown schematically in Fig. 1.

Referring to Fig. 1, battery 1 represents a source of steady potential for exciting the tone generators (often referred to as the polarizing voltage). Keys 2 and 3 connect the input terminals of the generators to the polarizing potential of source 1 when depressed. They are provided with back-contacts which connect the input terminals to ground when the keys are not depressed, thus eliminating the production of sound by generator sections not in use at the instant. Each generator section comprises a continuous stator plate and a stator plate formed of a series of interrelated segments, with an in-

termediate grounded rotor plate having apertures of a predetermined form embracing more than one of the segments of the segmented stator plate. Two generator sections are shown in Fig. 1, controlled by the separate keys 2 and 3. The input plates 4 and 5 are conducting rings mounted on an insulating plate 6. Rotor plate 7 is a conducting disk pierced by appropriate apertures which are here shown as roughly triangular in shape. The rotor, which it is here convenient to represent to one side of plate 6, in the actual instrument is mounted as in Fig. 3. The rotor plate is connected to ground through the sliding contact or "brush" 8.

Output elements 12 and 13 comprise series of conducting plates mounted on an insulating base 11 which is placed as shown in Fig. 8. The output plates for each tone generator are divided into groups which number six in the instrument shown. The plates belonging to these groups are identified by the letters *a*, *b*, *c*, *d*, *e* and *f*, respectively, and the plates comprising different groups are insulated from each other. All of the plates belonging to one group, for instance group *a*, are connected together electrically, and are thence connected to a terminal of a multiple switch 14. That is, all the plates of groups *a*, regardless of the pitch of the tone generator section with which they are associated, are connected to the same movable switch arm of switch 14. Two coacting contacts are provided for each switch arm of switch 14, through which each group of stator plates, *a*, *b*, etc., may be connected to one of the wave-form control switches 15—26 and the input circuit of amplifier tubes 28 and 29. The outputs of tubes 28 and 29 are combined in transformer 30, which is so connected that pulsations coming through tube 28 appear in the secondary with polarity opposite to that of pulsations coming through tube 29. The wave resulting from combining the pulsations in transformer 30 is applied to the grid circuit of amplifier tube 33 through volume control 32, and is thence transmitted to loud-speaker 34 where it is converted into sound.

As a matter of economy of both materials and space, it is desirable that substantially all of the area swept over by the rotor apertures be covered with conductive plates. It is not necessary, however, to make the interstices between the plates so small that constructional and insulation problems become acute, as these interstices aid in producing waves which are rich in harmonics.

Considering the rotor plate 7 and the segmented stator plate in more detail, it will be noted that the outer annular series of plates 12, includes twice as many segments as the inner series 13, and the rotor plate is provided with twice as many apertures in correspondence with the outer plates as are provided for coaction with the inner series. As a result, the frequency of the currents generated are in the ratio of 1:2 for the inner and outer series, or in other words, the generator sections provide notes an octave apart in the tonal scale. The quality or timbre of each note is to be determined by the proportions and manner of combination of the partials generated by the several groups of plates, *a*, *b*, *c*, etc., in each generator section.

It will be understood that the speed of rotation of the rotor plate 7 determines the pitch of the tones generated so that if successive generators are driven in the speed ratio of one to the twelfth root of two, the various notes of the equitempered scale or produced. The range of the instrument, the number of octaves included, is determined by the number of annular series of plates provided in each generator, similar to the keyboard arrangement and circuits shown in my U. S. Patent No. 2,001,708, issued May 21, 1935.

Amplifier tubes 28, 29, Fig. 1*a*, are connected with a push-pull output circuit in transformer 30, the primary of which is center-tapped to provide a return lead to the cathodes of the tubes. The input circuits of the tubes include resistor 27 shunted across the grids and having a center tap providing a return connection to the cathodes. Input connections are tapped on resistor 27 at selected positions principally at its opposite terminals J, N, and the center tap L, and also at some intermediate point or points on both sides of the center tap, as at K and M indicated on Fig. 1*a*. These input connections are led to switch contacts on each of the wave-form control switches 17—26, the switch arms of which are connected with the several switch contacts of the multiple switch 14 which is constituted as a selector switch, functioning as follows:

When multiple switch 14 is moved to the right, plate groups *a*, *b*, *c*, *d*, *e* and *f* are connected to the switch arms or movable contactors of wave-form control switches 15, 17, 19, 21, 23 and 25 respectively, by means of which any group of plates can be connected to any one of the taps J, K, L, M, N, on resistor 27 in the input of the amplifier, and thus any tone quality within the scope of the instrument may be simply effected, as will be further described with reference to Figs. 2–4. Similarly, any such tone quality can be set up by properly adjusting wave-form control switches 16, 18, 20, 22, 24 and 26, without disturbing the settings of odd-numbered switches 15, 17, etc. Then when switch 14 is moved to the left, the tone-quality corresponding to the setting of the even-numbered switches is emitted; and the odd-numbered switches are inoperative. This feature corresponds to what is called "pre-set combinations" as applied to acoustic organs, and is necessary if present organ music is to be played. Further sets of wave-form control switches can be readily added by adding a corresponding number of fixed contacts to the multiple selector switch 14, the connections being precisely similar to those shown. Every set of wave-form control switches equivalent to 15, 17, 19, 21, 23, 25, broadens the flexibility of the instrument by providing an additional tone quality which can be established previously to playing a musical composition and instantaneously made effective by moving selector switch 14. A minimum of four such immediately available tone qualities is desirable, and hence, at least four sets of wave-form control switches will be required. Selector switch 14 may be subjected to push-button control, in the manner of an automatic radio tuner, if desired. As shown more clearly in Fig. 5, the apertures in the rotor plate 7 are adapted to embrace approximately one-half the distance moved by the rotor during the generation of one cycle. The aperture is shown as triangular, for example only, and is formed to produce a desirable wave shape as it progressively exposes more and less of the active plate areas in the generator. One or more apertures are provided for each annular series or generator section, the number of apertures preferably corresponding with the number of complete cycles generated by one revolution of the rotor plate.

The potential wave-forms derived separately from the several plate segments *a*—*f*, in the cycle or period of movement of the aperture across a

set of plate segments *a*—*f*, are shown in Fig. 2 as pulsations positive with reference to ground potential, which is the condition that might be observed at switch **14** with one of the keys **2**, **3**, closed to battery **1**. The resultant wave-form which is applied to the input circuit of the amplifier tubes **28**, **29**, however, is determined by the setting of the wave-form control switches so as to vary the intensity and relative polarity of each wave partial and its consequent effect on the resultant wave-form.

It will be noted in Fig. 2 that all of the pulsations or wave partials recur at the same frequency but differ in phase due to the physical arrangement of the segments in the annular series. The amplitude of the impulse is determined by its point of connection at resistor **27** with respect to the center tap L, and its relative polarity by its connection at one side or the other of the center tap, due to the manner of connection of the push-pull output transformer **30**.

It is seen then that the wave-form resulting from combining the different series of pulsations will depend on the relative polarity and amplitude of the pulsations entering into the combination. Curve W of Fig. 3 shows the wave-form resulting when the "*a*" and "*b*" pulses are given one polarity, the "*d*" and "*e*" pulses opposite polarity, and the amplitudes of all these pulses are the same, the "*c*" and "*f*" pulses not being used. This situation would arise if the wave-form control switches were set so that the plates *a* and *b* were connected to point N of the amplifier, the plates *c* and *f* to point L, and the plates *d* and *e* to point J.

The resulting wave is an excellent approximation to a sine wave.

Similarly, curve X of Fig. 3 results from connecting plates *a*, *c*, and *f*, to point N of the amplifier, plates *b* to point M, and plates *d* and *e* to point J, which is the setting shown on the odd-numbered switches **15**, **17**, etc., in Fig. 1*a*. The resulting wave contains low order harmonics of considerable amplitude. Curve Y of Fig. 4 results from connecting plates *a* and *b* to point N, plates *c* to J, and the others to L, which is the setting shown in the even-numbered switches **16**, **18**, etc., in Fig. 1*a*. As this curve has a discontinuity, the output is rich in high harmonics.

Curve Z of Fig. 4 presents some features of special interest. It is obtained by connecting plates *a*, *c* and *e* to point N and plates *b*, *d* and *f* to point J. In the first place, the amplitude is somewhat lower than that of most curves so derivable but this is not disturbing, as such an effect is to be expected and the difference is small enought so that it can readily be made up by changing volume control **32**, at least for most purposes. It will, however, be noted that curve Z repeats itself exactly three times as often as the other curves, and hence corresponds to a note of higher pitch—an octave and a fifth higher, in fact. This results from the fact that all the output plates are identical. If four or eight instead of six groups of plates were employed, it could, however, be utilized to raise the pitch of the entire instrument by one or two octaves at will. Also under this system there are several ways in which each wave-form can be produced: e. g., giving the "*b*" plates the connections the "*a*" formerly had and the "*c*" plates the connections the "*b*" formerly had, etc., the "*a*" plates winding up with the connections the "*f*" plates formerly had. This sort of process is well known to mathematicians as a "cyclic interchange." If all the plates are identical, any cyclic interchange which can be made in the connections does not change the wave-form.

For several reasons, therefore, I prefer that the plates of each group should differ in shape from the plates of other groups. A possible arrangement of output plates of different forms is shown in Fig. 6. The approximate sine wave represented by curve W of Fig. 3 can be produced as well with the arrangement shown in Fig. 6; as plates *a'* and *b'*, and plates *d'* and *e'*, when connected together, are substantially the same in effect as the corresponding plates shown in Fig. 5.

Fig. 7 shows an alternative method for controlling the polarity of the pulsations in the amplifier circuits, employing a well known property of vacuum tubes instead of transformers to accomplish the reversal. It is often said that a vacuum tube produces a "phase reversal." As far as symmetrical alternating currents are concerned, a reversal of polarity is the equivalent of a 180° change of phase, and thus the term "phase reversal" may be used. The term, however, is a misnomer, and should not be applied to the pulsating potentials which are considered here. Actually, if the grid potential of a vacuum tube is made more positive (or less negative, as the steady grid bias is usually negative) the plate current increases. This increases the drop in potential in the plate coupling impedance, and the potential of the plate electrode becomes less positive. It will thus be seen that the effect of a vacuum tube is to reverse the polarity of applied voltages, a more positive voltage applied to the grid appearing as a less positive plate voltage. No true change of phase—i. e., of the position in time of the potential pulsations—takes place, except a very small effect due to the reactances in the associated circuits.

In the circuit of Fig. 7 the input terminals J, K, L, M, N, on resistor **27** are designed to be connected to switches **15**—**26** in the manner shown in Fig. 1*a*, the circuit of Fig. 7 replacing the amplifier circuit shown in Fig. 1*a*. Tube **35** of Fig. 7 is employed as a polarity reversing tube as explained above. Plate resistor **31** is so adjusted that the voltage amplification of the amplifier stage of which tube **35** is the active member is substantially unity. The remainder of the circuit is merely a conventional amplifier including a first stage with tube **36** and an output stage similar to that shown in Fig. 1*a*, but resistance coupled to the first stage by means including volume control device **32'**.

It will be understood that the wave-forms illustrated in Figs. 3 and 4 are simple examples of the variations possible by means of the wave-form control system of my invention. The number of different wave-forms available is very large and entirely adequate to afford a practically inexhaustible variety of novel tone effects in quality and timbres of exceptional note. While I have disclosed my invention in certain preferred details, I do not intend to be limited thereby as the system of my invention is adaptable to other embodiments for the synthesis of a wave-form from a plurality of partials of like frequency but different phase characteristics, as will occur to persons skilled in the art. My invention therefore is limited only by the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States is as follows:

1. In an electrical musical instrument, wave-form control means comprising means for pro-

ducing a plurality of pulsating potentials in different phases, each potential having pulsations recurring at regular intervals with the duration of each pulsation substantially less than the interval between pulsations, a push-pull electron tube amplifier circuit, an input resistor element having a neutral connection and opposite terminal connections to said push-pull amplifier circuit, said resistor element being provided with tap connections for determining the amplitude and polarity relation of impulses applied thereto with respect to said neutral connection, and switching means connected with said tap connections and individually connected with producing means for each potential for regulating the amplitude and relative polarity of the respective potentials as applied to said amplifier circuit.

2. In an electrical musical instrument, waveform control means comprising means for producing a plurality of pulsating potentials in different phase, each potential having pulsations recurring at regular intervals with the duration of each pulsation substantially less than the interval between pulsations, an electron tube amplifier circuit having an input resistor element, means for connecting a portion of said element directly to said amplifier circuit, a polarity reversing device connected between the remaining portion of said element and said amplifier circuit, tap connections on said resistor element, and switching means connected with said tap connections and individually connected with the producing means for each potential for regulating the amplitude and relative polarity of the respective potentials as applied to said amplifier circuit.

3. In an electrical musical instrument, waveform control means including a device for producing a plurality of wave partials; said device comprising a series of electrostatic plate elements disposed in closely adjacent insulated relation, a unitary electrostatic plate element disposed in spaced parallel relation to said series of plate elements and a grounded intermediate movable element having an aperture adapted to vary progressively the electrostatic effect between each plate in said series and said unitary plate element in accordance with a predetermined wave pattern, the disposition of said plates in the series determining the relative phase relations of the wave partials produced therein; and means for combining the wave partials from the series of plate elements to produce a single cycle of a resultant wave having a wave form as determined by the relative phase characteristics of said wave partials and the amplitudes and polarities in which they are combined and a frequency which is a function of the velocity of said movable element.

4. In an electrical musical instrument, waveform control means including an electrostatic device for producing a plurality of wave partials; said device including a like plurality of electrostatic plate elements disposed in an insulated physical relation which determines the relative phases of the wave partials produced, and a shield plate element apertured and movable to vary progressively the effective electrostatic capacity of the plate elements, the relative shapes and sizes of said aperture and said plate elements being functions of the wave forms of the wave partials produced; and means for combining the wave partials from the plurality of plate elements to produce a single cycle of a resultant wave having a wave form as determined by the relative phase, wave form and amplitude characteristics of said wave partials and a frequency proportional to the velocity of said movable apertured plate element.

5. In an electrical musical instrument employing rotating condensers for causing fluctuations in electrical potential, scanning inductors constrained to move in a closed path, and a plurality of groups of stationary inductors, each stationary inductor being of such dimensions that it is scanned by a scanning inductor in a time that is substantially shorter than the fundamental period of the fluctuations produced by the rotating condensers, and all stationary inductors being arranged adjacent to said closed path; the members of each group of said stationary inductors being electrically connected with each other and electrically insulated from all members of all other groups and from the scanning inductors; the members of each group being interposed in a systematic manner among all the other stationary inductors around the path of the scanning inductors.

6. In an electrical musical instrument employing rotating condensers constructed as described in claim 4, means for combining the voltage fluctuations produced in the various groups of stationary inductors including connections from each of said groups and independent switching means in each of said connections for controlling the relative amplitude and polarity, in combination, of the fluctuations produced in each of said groups.

7. In an electrical musical instrument employing rotating condensers constructed as set forth in claim 4, thermionic vacuum tube means for combining the voltage fluctuations produced in the various groups of stationary inductors, and means for supplying said fluctuations to said combining means, each in selected relative polarity and amplitude.

WESTLEY F. CURTIS.