

May 6, 1941.

R. W. BUMSTEAD

2,241,027

ELECTRONIC MUSICAL INSTRUMENT

Filed Nov. 30, 1939

4 Sheets-Sheet 1

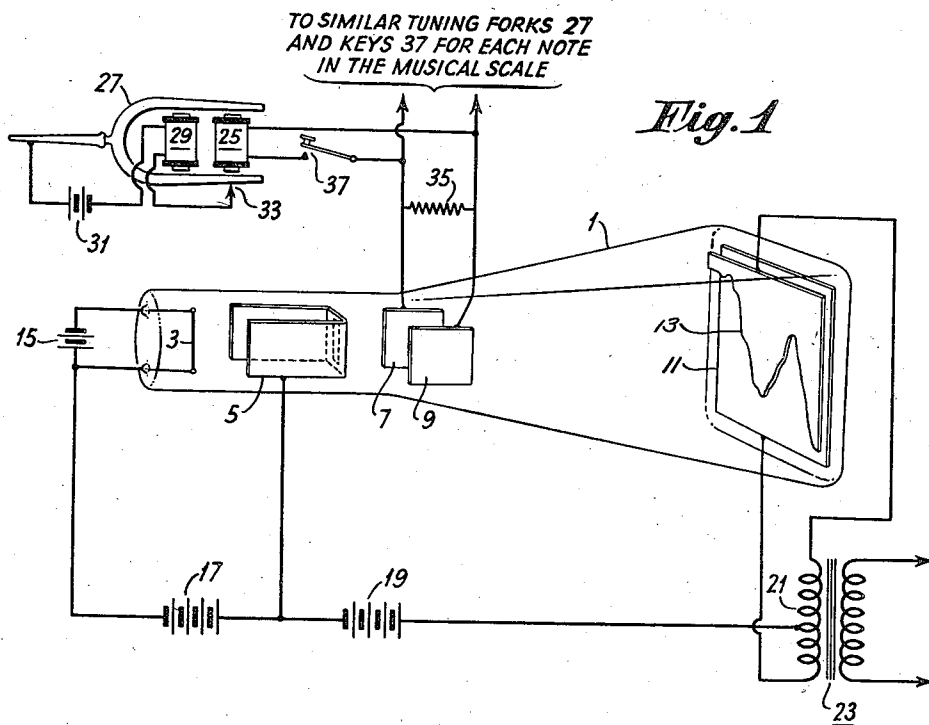


Fig. 2

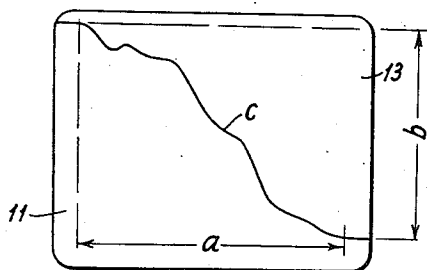
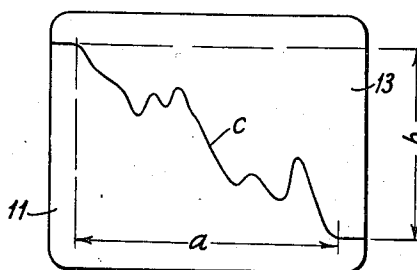


Fig. 3



INVENTOR
RALPH W. BUMSTEAD
BY *H. S. Snover*
ATTORNEY

May 6, 1941.

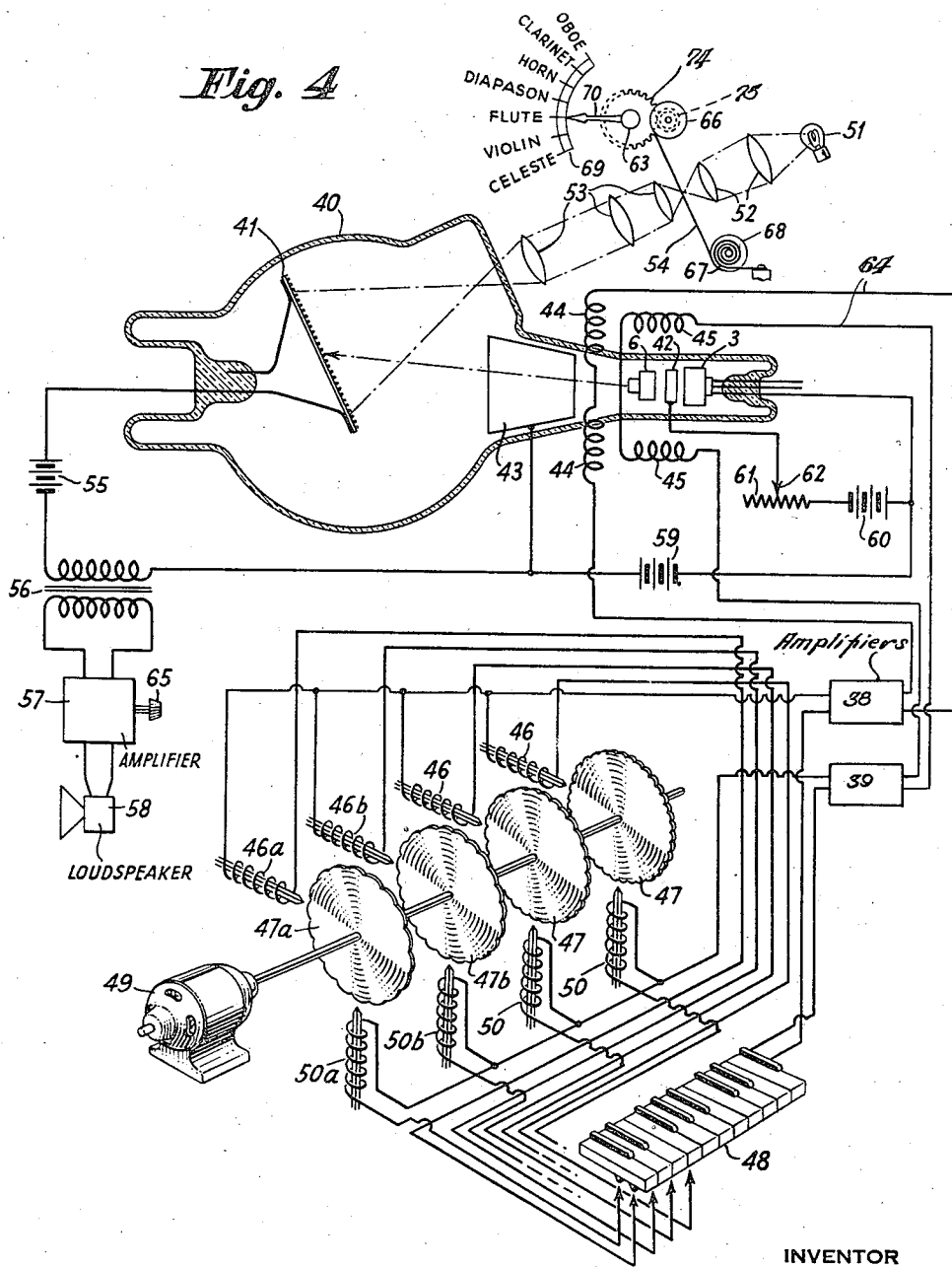
R. W. BUMSTEAD

2,241,027

ELECTRONIC MUSICAL INSTRUMENT

Filed Nov. 30, 1939

4 Sheets-Sheet 2



INVENTOR
RALPH W. BUMSTEAD
BY *H.S. Swier*
ATTORNEY

May 6, 1941.

R. W. BUMSTEAD

2,241,027

ELECTRONIC MUSICAL INSTRUMENT

Filed Nov. 30, 1939

4 Sheets-Sheet 3

Fig. 5

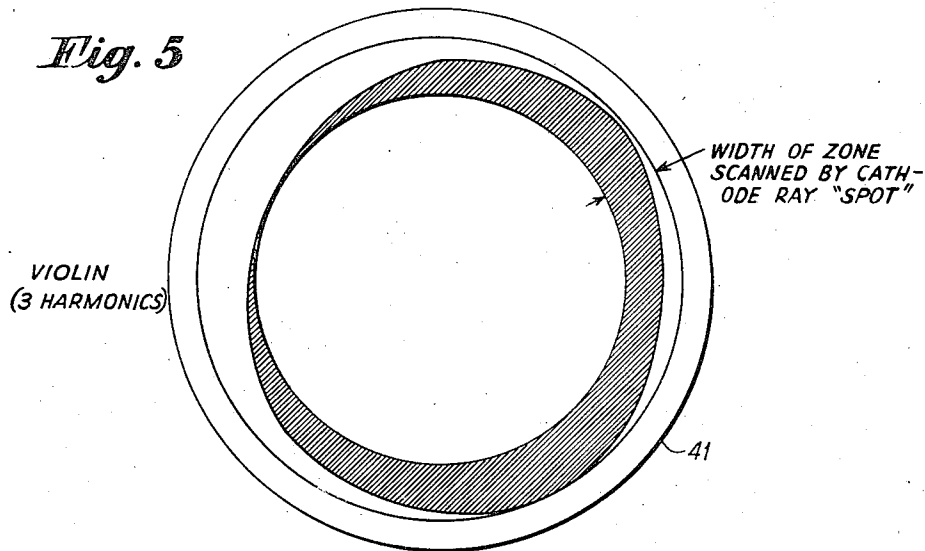
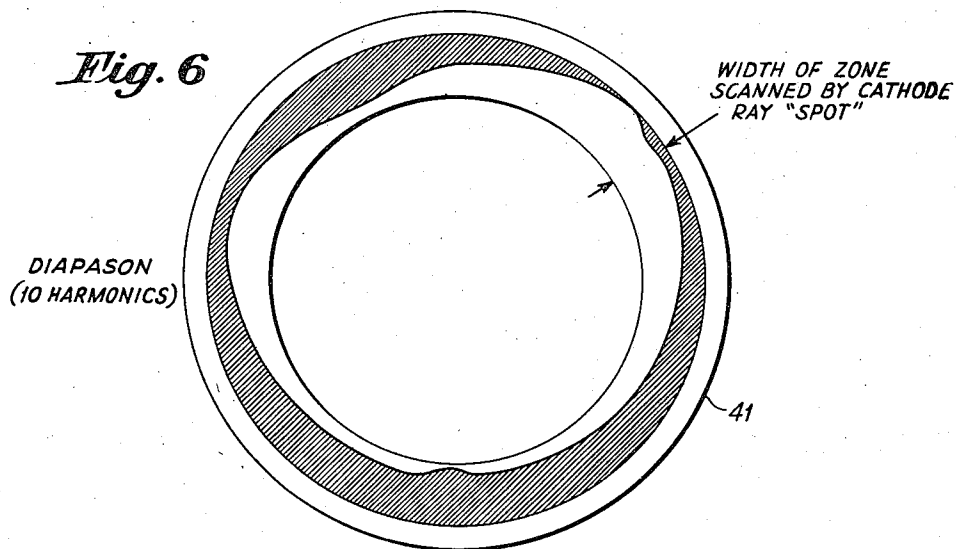


Fig. 6



INVENTOR
RALPH W. BUMSTEAD
BY *H.S. Snover*
ATTORNEY

May 6, 1941.

R. W. BUMSTEAD

2,241,027

ELECTRONIC MUSICAL INSTRUMENT

Filed Nov. 30, 1939

4 Sheets-Sheet 4

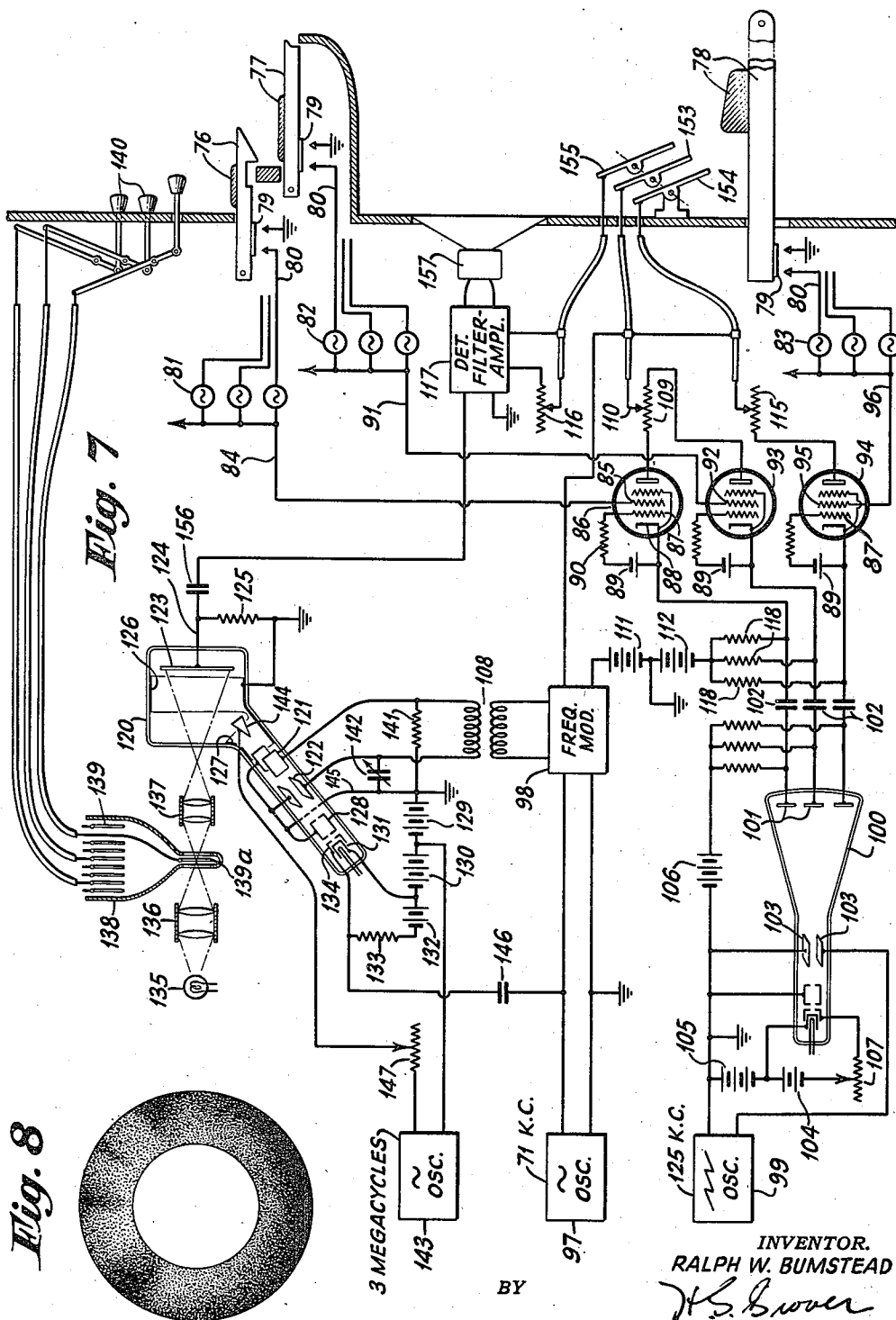


Fig. 8

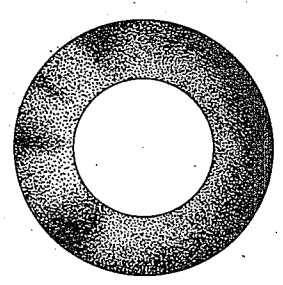


Fig. 7

INVENTOR.
RALPH W. BUMSTEAD
R. W. Bumstead
ATTORNEY.

UNITED STATES PATENT OFFICE

2,241,027

ELECTRONIC MUSICAL INSTRUMENT

Ralph W. Bumstead, Westfield, N. J., assignor to
Radio Corporation of America, a corporation of
Delaware

Application November 30, 1939, Serial No. 306,942

19 Claims. (Cl. 84—1.28)

This invention relates to electronic musical instruments and more particularly to a device for controlling the modulation of electric waves in accordance with the playing of keys on one or more keyboards, such as are comprised in a console of an organ. The methods employed are such as to superimpose selected harmonics or overtones upon the fundamental frequencies which are appropriate to the different keys of the keyboard.

The instant application is a continuation-in-part of my co-pending application Serial No. 86,740, which was filed June 23, 1936.

My invention has particular utility in musical instruments, such, for example, as an electronic organ. It is well known that musical sounds may be produced synthetically for simulating different orchestral instruments. The procedure heretofore practiced is to generate fundamental tones together with a number of the harmonics thereof and to amplify the resultant of the waves so combined, and to impress the output energy from an amplifier on any convenient sound reproducing device.

One of the difficulties encountered in the synthetic generation of complex sound waves is that it is very difficult to introduce the various harmonics in their correct amplitudes for simulating a desired orchestral instrument or organ stop. The difficulty is that musical tones to which we have accustomed our ears are of a very complex nature. Often times the tone of an organ pipe or an orchestral instrument includes as many as thirty significant harmonics of a given fundamental tone. The combination of so many harmonics with the fundamental in their correct proportions by prior known methods involves the use of very cumbersome apparatus and intricate circuits. Furthermore, the controls which would need to be provided in place of "organ stops" would be multitudinous and difficult for a musician to manipulate.

Accordingly, it is among the objects of my invention to provide a multiple harmonic generator in which one element only is necessary for compounding the required harmonics of every tone in the musical scale in order to give the tone quality of the fundamental notes a given timbre characteristic. The duplication of such elements in order to provide a range of tone qualities in the output of an electric organ would, therefore, correspond with the number of stops which it may be desired to provide.

It is another object of my invention to provide electrical apparatus in combination with the manual and pedal keyboards of an organ console, such as will enable an organist to play a musical selection using the different manuals and pedal keyboard in the usual manner for emphasizing certain notes, which represent a solo passage in

comparison with other notes which are simultaneously played as an accompaniment.

It is another object of my invention to provide an electronic musical instrument which comprises an iconoscope tube of the general type heretofore used in television systems, this tube being operative to modulate the fundamental frequency tones of the keys which are played, so as to give these tones a desired timbre characteristic.

It is a still further object of my invention to provide electronic apparatus such as will properly correlate the harmonic content of tones with their fundamental frequencies. In making this correlation it appears to be desirable that the phase relationships existing between different overtones or harmonics of a given fundamental frequency shall be consistently maintained and not periodically reversed, as would be the case when utilizing certain of the devices heretofore employed. Thus, instead of scanning a characteristic wave pattern back and forth in order to modulate a fundamental frequency by superimposed odd harmonics, the phase of which would be reversed with each half cycle of the fundamental frequency, I preferably provide scanning means which is rotational in character so that these phase relationships may be properly maintained.

In carrying out my invention I propose to use for the synthesis of harmonics, such as to produce tones of a given quality or timbre, a cathode ray tube having the usual cathode, focussing anode and deflecting plates and a novel form of anodes against which the cathode ray beam may be projected. Such a cathode ray tube is not of the type having a fluorescent screen, but in place of the fluorescent screen and within the envelope of the tube, a flat plate may be used as one of the anodes connected to one terminal of an output transformer, while another plate insulated from the first and mounted as closely as possible in front of the first mentioned anode has one of its edges shaped according to the contour of a composite sine wave constituting the algebraic sum of a fundamental wave and any number of harmonics thereof. This second plate is connected to the other terminal of said transformer.

My invention will now be described in more detail, reference being made to the accompanying drawings, in which

Figure 1 shows diagrammatically a preferred embodiment of the invention including a cathode ray tube of the type hereinbefore mentioned and operating circuits therefor;

Fig. 2 shows a plan view of the anode plates against which the electron beam is projected;

Fig. 3 shows a view similar to that of Fig. 2 but representing the composite wave formation for producing a tone of different quality from

that which is produced by the wave formation of one of the plates of Fig. 2;

Fig. 4 shows a modification of the invention including a cathode ray tube having a photo-electric screen and means for illuminating such a screen with a light and dark shaded pattern representative of a complex sound wave;

Figs. 5 and 6 show in plan view typical patterns of wave graphs such as may be projected upon the photo-electric screen of a cathode ray tube for modulation purposes;

Fig. 7 shows a further modification which includes certain details of structure not shown in the other figures, and which may preferably be employed as a complete electronic organ having a plurality of manual and pedal keyboards; and

Fig. 8 is a representation of a characteristic image having a variable density pattern of light and dark areas, this image being suitable for projection upon the photo-electric mosaic screen of a cathode ray tube.

Referring to Fig. 1, I show a cathode ray tube having an envelope 1, a cathode 3, a focussing anode 5, deflecting plates 7 and 9, an anode 11 preferably of substantially rectangular formation, and another anode plate 13 one edge of which has a contour of complex wave formation. The cathode may be heated by any suitable source 15. The focussing anode 5 is preferably of such formation as to focus the electron beam in a narrow web. As shown in the drawings, such a web would be vertically disposed and would be projected between the deflecting plates 7 and 9. A source of potential 17 is connected between the cathode and the focussing anode 5. Another source of direct current potential 19 is connected between the lead to the focussing anode 5 and a mid-point on the primary winding 21 of an output transformer 23. The two terminals of the winding 21 are connected respectively to the two anode plates 11 and 13.

In order to deflect the cathode ray beam laterally across the faces of the anode plates 11 and 13, I may provide any suitable source of alternating current such as the coil 25 within which a pure sine wave may be generated by means of a tuning fork 27. The tuning fork may be kept in vibration by means of a driving coil 29 in circuit with a direct current source 31 and having an interrupter contact 33.

In place of the tuning fork generator I may, of course, employ a plurality of phonic wheels with pick-up coils mounted adjacent thereto. Such a construction usually has a phonic wheel disc for each note in the musical scale and these discs are mounted on a single shaft for rotation at a constant speed.

The control circuits to the deflecting plates 7 and 9 may include a resistor 35 bridged across the leads to the respective deflecting plates in order that a suitable load may be provided. The key 37 enables one to instantly start and stop the impress of deflecting impulses upon the deflecting plates 7 and 9, even though the tuning fork 27 is kept under a state of constant vibration.

Fig. 2 shows in plan view the plates 11 and 13 when the latter is conformed to a suitable composite wave for simulating the tone quality of an organ pipe.

Fig. 3 makes a similar showing of the anode plates 11 and 13 when the latter is conformed to the composite wave produced by a clarinet. Other wave formations may, of course, be uti-

lized for simulating the different orchestral instruments and various organ pipes having different characteristic voicings.

It will be noted that in the illustrations of composite wave formation given in Figs. 2 and 3, the graph of a fundamental half wave extends over the distance marked a . It is contemplated, therefore, that the deflecting force applied to the plates 7 and 9 will be such as to deflect the electron beam back and forth over the entire area comprehended by the dimension a and having a height b corresponding to the vertical dimension of the webbed beam. Assuming, therefore, that the pure fundamental tone as produced by the tuning fork 27 is allowed to generate a deflecting force upon the plates 7 and 9, with the key 37 closed, then it will be seen that this fundamental wave will have such amplitude as to cause the electron beam to scan the area ab .

When the tines of the tuning fork 27 are approaching the poles of the pick-up magnet 25 current will be generated in one direction of the coil thereof. This current will be reversed as the tines of the tuning fork 27 move outwardly so as to increase the air gaps at the extremities of the core of the magnet 25. Accordingly, a full cycle of the fundamental tone frequency will result in the impress of charges on the deflecting plates 7 and 9 such as to move the electron beam forward and back over the area ab of the anode plates. It is for this reason that the contour c of the plate 13 is made to extend over only one half wave of the fundamental tone. The proportions of electrons simultaneously impinging upon the plates 11 and 13 will be equal at an intermediate point of the traverse of the beam back and forth. At the extremities of the deflection peaks of potential difference will be produced between the two anodes 11 and 13. The instantaneous values of the integrated harmonic forces will, therefore, be defined by the shape of the curve extending from one side to the other of the plate 13.

The periodic deflection of the electron beam causes the relative proportions of electrons impinging upon the two plates 11 and 13 to vary not only according to the fundamental tone of the tuning fork 27 but also in accordance with the various harmonics of this tone which are algebraically integrated for producing the complex wave c at the lower edge of the plate 13.

Referring now to Fig. 4 which illustrates a modification of my invention, a well known type of cathode ray tube 40 having a photo-electric anode 41 is therein shown. This cathode ray tube is provided with the usual electron emitting cathode 3, control electrode 42, focussing anode 6 and accelerating anode 43. Deflecting coils 44 and 45 may be employed for causing the beam to describe a more or less circular path as it impinges upon the photo-electric anode 41. In place of the deflecting coils, however, electrostatic plates may be used, if desired. Such plates would ordinarily consist of two pairs, one pair being for deflecting the beam according to a vertical component and another pair according to the horizontal component of its deflection.

The output circuit of an amplifier 38 includes the deflecting coils 44 for the vertical component. On the input side of amplifier 38 is a parallel circuit arrangement of pick-up coils 46a, 46b, etc., these pick-up coils being disposed suitably to be acted upon under the magnetic influence of phonic wheels 47a, 47b, etc. As these phonic wheels rotate, electric waves will be generated in

the coils whose circuits are closed through the key switches 48. Another amplifier 39 derives its control energy from the pick-up coils 50a, 50b, etc. when selected by the keys 48, and the amplifier output circuit includes the cathode ray deflecting coils 45.

The phonic wheels 47 may be synchronously rotated in any suitable manner as by means of a motor 49. Each of the phonic wheels 47 has a periphery of wavy formation, the number of scallops therein having a relation to the speed of rotation such as to produce a desired fundamental tone of the musical scale. It has been shown in Patent #1,956,350 to Hammond that a very close approximation to the equally tempered musical scale can be had by using these phonic wheels as herein shown and by rotating the same under control of a single synchronous motor.

In order to provide a horizontal component for the deflection of the cathode ray beam which shall be displaced 90° in phase from the vertical component of the desired fundamental wave, the deflecting coils 45 may be fed with energy generated by any of the pick-up coils 50a, 50b, etc., depending upon the particular key switch 48 which is depressed. These pick-up coils 50 are disposed with their axes in a substantially 90° relationship to those of the pick-up coils 46. That is to say, at any instant, the two pick-up coils 46 and 50 of a single pair are respectively opposed to points on the wave pattern of the periphery of the rotor 47 corresponding to a 90° phase displacement of one cycle of said pattern. Thus for each and every rotor 47 there will be a 90° phase displacement between the energies generated in its cooperating pick-up coils 46, 50.

With the deflecting circuits provided as shown it will be understood that a cathode ray beam may be caused to describe an arcuate path about a circular area on the photo-electric anode 41. The anode 41 may be ring-shaped, if desired, in order not to attract electrons into the center zone. A single revolution of the beam will be completed within a single cycle of a fundamental note corresponding to one of the keys 48 when it is depressed.

The principles involved in supplying suitable potentials to the deflecting circuits for a cathode ray tube for producing a rotary deflection of the electron beam are well known in the art. Patent 1,882,850 to Marrison is illustrative of the art. In that patent the circular path of the spot traced by the electron beam as it impinges upon the anode is explained on page 2, lines 31 to 34, inclusive.

If, however, a chord is to be played by depressing several of the keys 48, then the rotation-velocity as produced by the deflecting coils 44 and 45 will vary according to the resultant of the various electrical forces generated by different ones of the pick-up coils 46 and 50. Such a condition corresponds with variations in the instantaneous air pressure at a given point in a room where sound waves are being propagated. It is, therefore, evident that on the photo-electric screen of a cathode ray tube I may cause an electron beam to traverse different portions with different velocities so as to simulate the resultant of as many of the fundamental tones as it is desired to sound simultaneously, the same as in playing chords on any musical instrument of the keyboard type.

These different velocities are obtained by varying the radius of the beam in its deflection from

the axis of the cathode ray tube. The angular velocity remains constant so long as a given algebraic summation of rotation velocity components of the different tones of a chord persist. The wave motion, however, can be shown to be in exact correspondence with a resultant wave representing the instantaneous air pressures of the sound of a chord.

Now in order to give the fundamental tone as produced by the phonic wheel generator a desired timbre characteristic, I have shown means and a method for illuminating the photo-electric anode 41 with light and dark shaded patterns corresponding to complex sound waves, that is, sound waves made up of different harmonics of a given fundamental tone, where each harmonic has a desired amplitude in relation to the others. Suitably disposed in relation to the anode 41 is an optical system consisting of a light source 51, condensing lenses 52 and focussing lenses 53. Between the condensing lenses and the focussing lenses I may provide a film or mask 54. Different portions of the film 54 may be used for casting silhouette pictures on the anode 41. Silhouettes representative of different tonal qualities may be obtained from oscillographs of the sounds actually produced by different orchestral instruments.

An oscillogram of a single note will serve as a permanent record for modulating all of the notes in the musical scale, according to the methods herein disclosed. Each silhouette picture when projected onto the photo-electric anode 41 will give a predetermined tone characteristic to the fundamental tones when played on the keyboard. The silhouette images shown in Figs. 5 and 6 are merely illustrative of many different forms that may be used for simulating different instruments.

In place of the silhouette images as shown in Figs. 5 and 6, I may, if desired, produce equivalent results in modulating the fundamental tones of the musical scale by varying the light intensity along different radii from the center of rotation of the electron beam as it impinges upon the photo-electric anode 41. Thus, one may elect to use "variable density" sound films or "variable translucent area" sound films, as well known in the art.

It is well known that the anode 41 of a cathode ray tube such as herein shown may be arranged to respond to different degrees of illumination, thereby to generate a current of variable amplitude in the output circuit of the tube. Such an output circuit is herein shown as including a source of potential 55 for obtaining the desired polarity on the anode 41 more positive than on the accelerating anode 43. In circuit between the source 55 and the cathode 3 is a primary winding of a suitable transformer 56. The secondary winding of this transformer may be fed to an amplifier 57 and thence to a loud speaker 58. The anode-to-cathode circuit may also include an additional source of potential 59 for producing a voltage on the accelerating electrode 43 more positive than that of the cathode 3.

A biasing source 60 is connected between the cathode and the control electrode 42. By means of a variable tap 62 on the potentiometer 61, the bias on the control electrode may be suitably adjusted to obtain a desired flow of electrons. Means (not shown) may also be provided for varying the potential on the focussing anode 6 in order to control the diameter of the "spot"

where the beam impinges upon the anode 41.

In the operation of my invention as illustrated in Fig. 4, it will be noted that various modulations of the fundamental waves may be derived from the cathode ray tube according to the particular wave pattern which is projected as a picture on the photo-sensitive anode 41. Variations in the wave pattern may well be provided on a single film 54 or on a plurality of such films selectively introduced into the path of the light beam from the lamp 51. Furthermore, it may be seen that different films and different sources of light may be arranged so as to throw different images selectively upon the photo-electric anode 41.

Merely for the purpose of illustration, and for the sake of simplicity of showing means to an end, I have indicated the use of a control knob 63 on the same shaft with a gear 74 meshed with another gear 75 on the shaft of one of the reels 68 whereby the film 54 may be wound or unwound in order to bring different sound pictures into the path of the light beam. Tension may be had on the film 54 for rewinding purposes by the aid of a coiled spring 67 connected with the winding spool 68. A suitable indicator scale 69 may be disposed for cooperation with a pointer 70 whereby the turning of the control knob 63 will indicate what particular sound record and hence what particular tone quality is to be had by placing the film 54 in a given position. In practice, a musical instrument suitable for an organist would be provided with the usual "stops" whereby the selection of different sound films would be remotely controlled.

Still another modification of my invention contemplates the use of target anodes such as shown in Fig. 1 but with the outline of the complex wave following an arcuate path such as shown in either Fig. 5 or Fig. 6. In this case two sets of deflecting plates or two sets of deflecting coils would be required in order that the electron beam may be caused to describe a more or less circular path and thus to impinge upon the front and back anodes 12 and 11 respectively in varying proportions.

In order to provide an organist with means for playing a melody passage having one tonal characteristic, simultaneously with an accompaniment having a different tonal characteristic or combination of characteristics, it is within the scope of my invention to utilize a plurality of manuals together with a pedal keyboard. It is, therefore, contemplated that each manual will be connected through different conductors 84 to appropriate deflecting circuits for respectively different cathode ray tubes. Each cathode ray tube will then have its own optical system and set of sound record films corresponding to the "stops" that are to be selected for a given manual. A duplication of apparatus as thus suggested will also be found useful in combination with a pedal keyboard. Furthermore, each cathode ray tube, as controlled by a separate keyboard, may be provided with an independent output circuit and amplifier, the amplifier having its own volume control device 65, whereby the relative intensities of volume of a solo passage and its accompaniment may be regulated at the discretion of the organist.

Referring now to Fig. 7, I show another modification of my invention which is particularly adapted to an electronic musical instrument having two or more manuals and a pedal keyboard. The figure shows in elevation keys 76 and 77 of

two different manual keyboards and keys 78 of a pedal keyboard. Each of these keys, both of the manual and pedal keyboards, is provided with a contact plate 79 which, when a key is depressed, puts ground potential on an appropriate key circuit 80 leading to a given fundamental frequency oscillator 81, 82 or 83.

The oscillators 81, 82 and 83 may be of any desired type. For example, they may be tuning forks like the fork 27 shown in Fig. 1, or they may be rotating discs like the discs 47 in Fig. 4, or again they may be in the form of electron discharge tubes having tuned circuits for maintaining a given pitch corresponding to the note of each appropriate manual or pedal key.

All of the oscillators 81 for the full range of notes in the upper manual keyboard are connected in parallel to an output circuit conductor 84 leading to the screen grid 85 in a control tube 86. This tube preferably is of the pentode type and is normally biased to cut-off by a suitable source 89, connected in circuit between the cathode 88 and a bias resistor 90 leading to the control grid 87.

The output circuits of the oscillators 82 (appropriate to the lower manual) are similarly connected in parallel to a conductor 91 leading to the screen grid 92 of a control tube 93. This tube and the tube 94 are the equivalents of the tube 86. Tube 94, however, is provided with a screen grid 95 which is connected by conductor 96 to the respective output circuits of the oscillators 83 for the pedal keyboard.

The tubes 86, 93 and 94 are used to impress modulations upon the output of a supersonic frequency oscillator 97 which delivers preferably a sine wave of, for example, 71 kilocycles to a frequency modulator 98. Frequency modulators are well known in the art and need no further description in this application.

In order that the effects of playing a musical piece on different manuals and the pedal keyboard may be additive with respect to the portions played on different keyboards, I provide means for allotting small mutually exclusive intervals of time to each keyboard successively. The rate of shift of control from one manual to the other, and to the pedal keyboard, must, of course, be at a supersonic frequency. Accordingly, I preferably provide a saw-tooth wave oscillator 99 for controlling a cathode ray tube 100 having a plurality of anode targets 101 each coupled by means of a capacitor 102 to the cathode of a respective tube 86, 93 or 94. The cathode ray tube is provided with beam deflecting means such as the deflector plates 103, each connected to its respective output lead from the oscillator 99. The cathode ray tube 100 is provided with the usual electrodes constituting an electron gun. Suitable potentials for these electrodes are obtained from the direct current sources 104, 105 and 106. The source 104 biases the control grid negatively with respect to the cathode, the bias being made adjustable by means of a variable resistor 107. A positive potential from source 105 is impressed upon a focussing anode and also upon one of the deflecting plates 103. The opposed deflector plate 103 is also maintained at this potential plus or minus the output potential from the oscillator 99. The source 106 renders the targets 101 positive with respect to all other electrodes of the electron gun. As the electrons impinge upon each target, the positive potential thereon is reduced, thus putting a negative charge on the associated ca-

pacitor 102 which is coupled to the cathode of one of the tubes 86, 93 and 94. These tubes, therefore, become conductive one at a time and in rapid succession, say for periods of $\frac{1}{375,000}$ second.

While each key depression causes an appropriate tone frequency to be impressed upon the screen grid in one of the tubes 86, 93 and 94, the conductive time intervals of each tube recur with such rapidity as to form well defined envelopes of the tone frequency waves from the oscillators 81, 82 and 83. When solo passages are played on one keyboard these envelopes have a sine wave characteristic and a frequency corresponding to the fundamental tone of each key. When chords are played, the tone frequency envelopes become complex just like the sound waves which are propagated in air. The composite action resulting from playing the keys of one or more keyboards simultaneously will, therefore, be to impress these different frequencies from the oscillators 81, 82 and 83 selectively upon the frequency modulator 98, the output from which develops frequency modulated supersonic waves across the primary of a transformer 108.

It is perfectly feasible, in accordance with the embodiment of my invention shown in Fig. 7, to simultaneously apply the tone frequencies of different keys to the control tubes, and thence to the frequency modulator 98, as when playing chords. What happens in this case is that the frequency of the oscillator 97 is modulated over any part of the audible frequency band from the lowest to the highest notes in the keyboards.

In order to provide variations in the dynamic relationship between the notes played on the upper and lower manuals, I may, if desired, employ a potentiometer 109 having a movable tap 110 for feeding output potentials from the tubes 86 and 93 to the modulator 98. It will be understood that these output potentials are determined by the conductivity of the discharge tubes 86 and 93, and by the direct current potential from the source 111 feeding through the control circuit for the modulator 98.

If it is desired that the notes played on the two manuals shall have the same modulation depth, then the potentiometer tap 110 may be placed mid-way between the terminals of the potentiometer resistance 109. In this position impulses of equal amplitude will be derived from the two tubes 86 and 93 to be impressed upon the frequency modulator 98. If, however, it is desired that the notes of the upper manual 76 be emphasized over those of the lower manual 77, then, by operation of a tilting pedal 153, the potentiometer tap 110 may be moved to the left, thus reducing the impedance offered to the currents passed through the tube 86 while increasing that impedance which is offered to the current passed through the tube 93. The reverse action may, of course, be obtained by tilting the pedal 153 in the other direction.

The dynamic effects of the pedal keyboard oscillators 83 may likewise be controlled independently of the other oscillators by employing still another tilting pedal 154 to control a potentiometer 115 in circuit between the anode of the tube 94 and the common modulator circuit leading through the unit 98. A volume control device for the entire output from the musical instrument may be in the form of still another tilting pedal 155 connected to a potentiometer 116 for controlling the audio output from amplifier 117. The energy from this amplifier is fed to a loud

speaker 157. Each of these tilting pedals 153, 154 and 155, may, if desired, be connected to its appropriate potentiometer by either electrical or mechanical means. For the sake of simplicity in illustrating a complete operative device, however, I have shown such connections as in the form of Bowden-wires which are guided by flexible tubes and are moved longitudinally.

The screen grid potentials for the tubes 86, 93 and 94 are a composite of the potentials derived from the oscillators 81, 82 and 83 and the superposed potential from the source 112, the positive end of which is grounded and the negative end of which is connected through resistors 113 to the respective cathodes of these tubes. The keys 76, 77 and 78, as has been stated, operate to complete different circuits selectively which may now be traced from ground, through an appropriate oscillator such as 81 and common conductor 84 to the screen grid 85, thence through the discharge path of the tube 86 to its cathode, through the resistor 113 to the negative end of the source 112, the positive end of this source being grounded.

From the above description it will be seen that output currents from the tubes 86, 93 and 94 will be derived from the anodes of these tubes and will be fed to the frequency modulator 98, anode potential being supplied by the source 111 in series with the source 112. These modulating potentials will possess all of the characteristics of the fundamental tones appropriate to the depressed keys, whether they be played in chords or in solo. The output energy from the frequency modulator 98, when impressed upon the transformer 108, operates to control the deflection of an electron beam in the cathode ray tube 120.

This tube is preferably of the type known as an iconoscope and possesses, in addition to the usual electrodes of an electron gun, horizontal deflecting plates 121 and vertical deflecting plates 122. The tube 120 also possesses a photo-electric screen 123 having a conductive film in back thereof which is connected in an output circuit 124 leading through a load resistor 125 to ground. This tube also possesses collector electrodes 126 and 127, which may be in the form of metallic deposits on the inside walls of the tube and which may, if desired, be carried at different potentials, although, for the sake of simplicity, I have shown them both connected to ground. The focussing electrode of the electron gun is indicated at 128 and this also is grounded. A negative potential with respect to the focussing anode 128 is derived from the sources 129 and 130 for impress upon the cathode 131 of the electron gun. A suitable negative bias may be obtained from the source 132 for impress, across a resistor 133, upon a control grid 134. The mosaic screen 123 is arranged to receive a light image from an optical system consisting of a source of light 135 and lens systems 136 and 137. Between these lens systems and at the focus thereof I preferably interpose any one of a multiplicity of films 139, each carrying a ring-shaped image, such as shown in Figs. 5 and 6, for example. These images, as has been previously stated, are graphic representations of a single fundamental frequency cycle having superposed thereon a predetermined family of harmonics suitable for simulating the timbre quality of any desired musical instrument.

In order to vary the timbre of the tones played on the manuals and the pedals, I may employ

any selected one of a number of these films as shown in a magazine 133. The films 133 are indicated in cross section and each may be pushed into operative position in the optical system. One of these films is shown at 133a held in place by a gateway of the magazine 133, this gateway having an opening for admitting light from the source 135. The light beam, after it traverses the film and the lens arrangement 137, will focus an image upon the mosaic screen 123 in accordance with the light and dark areas of the selected film. Each film selection may be obtained by means of a suitable stop 140 which is conveniently disposed to be pulled out at will by the organ player. When a stop is pulled out it operates some suitable mechanical or electrical control system for lowering a selected film into the film gate, so that the image of the film may be used to modulate the fundamental waves which are impressed upon the deflecting plates 121 and 122 within the cathode ray tube 120.

It will be noted that the rotation frequency applied to the deflecting plates 121 and 122 is varied between two supersonic limits, one of which may, for example, be considered as 71 kilocycles, and the other of which may be the same number of cycles plus the highest frequency of any of the oscillators 81, 82 and 83.

The rotative action upon the electron beam in the iconoscope tube 120 may be produced by any suitable phase splitting device such as will impress on the horizontal deflecting plates 121 a potential having a substantially 90° phase relation to the potential which is applied to the vertical deflecting plates 122. For the sake of simplicity, such a phase splitting device is represented as a combination of a resistor 141 and a capacitor 142. The impedances of these two elements should be equalized at the mean frequency, that is, at the frequency of the oscillator 97 plus the frequency of the middle note in the keyboard. It is true that this arrangement will for higher and lower notes of the keyboard produce departures from the 90° phase relationship which is desired for rotative scanning. However, the frequency of the oscillator 97 is made sufficiently high so that these departures over the audible range will be slight and not undesirable. In fact, such departures as may occur unavoidably will tend to deflect the electron beam in an elliptical path so as to produce a vibrato effect in the output energy, and thus to simulate the sound of a stringed instrument which is played in a vibrato manner. If, however, the particular arrangement of resistor 141 and capacitor 142 is found inadequate to meet the phase splitting requirements, then other phase displacing apparatus well known in the art may be employed.

Since it is desirable that all of the minute variations in the curvature of the image derived from the characteristic film may be scanned by the electron beam, it is one of the features of my invention that the deflecting forces shall include a very rapid radial component. Such a radial deflection may be obtained from an oscillator 143 which delivers preferably a sine wave of the order of 3 megacycles. Several different methods of radial beam deflection are available. The method shown in the figure is one in which I employ a conical shaped electrode 144 whose axis is coincident with the central axis of the electron gun. This electrode is connected to one terminal of the output circuit of an oscillator 143, the other terminal of this oscillator being preferably connected to the junction between the

sources 129 and 130. The relative potentials of the sources 129 and 130 are such that a suitable bias may be impressed upon the electrode 144 for producing a centrifugal deflection of the electron beam. This deflection will vary in extent in accordance with the oscillation energy which is delivered by the oscillator 143. The action will be so rapid, however, that a great many radial movements will be given to the electron beam while it circumscribes only once the ring-shaped pattern of light and dark areas on the mosaic screen 123.

If it is not desired to employ such an electrode 144, then, by a more conventional method, the output circuit of the oscillator 143 may be interposed in circuit between the focussing electrode 128 and ground, that is, in circuit with the conductor 145.

If desired, the characteristic images such as shown in Figs. 5 and 6, for example, and which are composed of sharply contrasted light and dark areas, may be replaced by ring-shaped patterns having variable translucence around the ring-shaped area. A representation of a variable density film in accordance with this feature is shown in Fig. 8. Where such a film is used it may be unnecessary to employ the very high frequency oscillator 143, since even an elliptical path which the beam may circumscribe will not cause any appreciable distortion of the harmonic components which are to be impressed upon the fundamental frequencies.

It will be noted that the sum-frequencies representing different audio waves impressed upon the supersonic frequency output from the oscillator 97 will be still further modulated by the characteristic wave shaping action produced by one of the films 130, when the image thereof is projected on the iconoscope screen 123. It is necessary, however, to provide a stroboscopic effect in order to apply these timbre characteristics to the audio frequencies alone. This is accomplished, according to the invention, by varying the density of the electron bundle in the cathode ray under control of the high frequency from the oscillator 97. Accordingly, I employ a capacitor 146 to take off a component of the high frequency from the oscillator 97 and to impress it upon the control grid 134. This causes the number of electrons in the electron stream to vary at the same rate as the cyclic rotation frequency applied to the deflecting plates 121 and 122 when no audible frequencies are imposed upon the modulator 98. In the absence of fundamental audio frequency modulation, therefore, the mosaic screen 123 will be rotationally scanned at the same frequency by which the electron stream is varied in intensity. When, however, modulations are applied through the unit 98, the position of maximum emission from the electron gun will rotate about the periphery of the screen 123 at variable velocities dependent upon the fundamental tone frequencies which are derived from the oscillators 81, 82 and 83.

Although the amplitude of the carrier wave delivered by the oscillator 97 is constant, the amplitudes of the audio waves as delivered by the respective tubes 86, 93 and 94 may be varied by means of the volume control pedals 153 and 154 so as to vary the modulation depth, and hence to vary the dynamic content of the output from the modulator 98. The result of this volume control action is to vary the mean radius of curvature of the path described by the beam-"spot" on the mosaic screen 123. This

is true for the reason that the deflecting potentials applied to the plates 121 and 122 will be dynamically varied. In order, therefore, to give effect to these dynamic variations and to differentiate between the energies representing tones played on different manuals, and on the pedal keyboard, it is desirable that the range of shading of the light and dark areas imaged upon the screen 123 should be graduated between the outer and inner margins of the ring. Where the ring area is illuminated around substantially the entire outer periphery as in Fig. 5, and is darkened around substantially the entire inner margin, this effect may be produced automatically. This is true despite the action of the oscillator 143 to swing the electron beam in accordance with a radial component. If the resultant deflection tends to seek the inner margin of the ring, then the scanning action will cover a predominantly dark area. On the other hand, with higher amplitudes and greater deflection, the light areas on the outer margin of the ring will be predominantly scanned. In order to provide suitable regulation of the dynamic effect of the radial deflection from the oscillator 143 a potentiometer 147 may be employed.

When the image projected upon the screen 123 is of the variable density type as shown in Fig. 8, this image should preferably be formed so as to provide maximum contrast of shading, say, on the outer margin of the ring and minimum contrast of shading around the inner margin thereof. The arcuate variation of shading represents the composite characteristic of the various harmonic frequencies which are to be applied to give each fundamental frequency its desired timbre. The amplitude variations which are to be derived from the scanning action will, however, be determined by the extent of the deflection due to the deflecting plates 121 and 122, so that smaller amplitudes will be developed in the output from the cathode ray tube when the beam seeks the inner margin of the scanning ring and larger amplitudes when it seeks the outer margin thereof.

The output energy from the tube 120 is impressed across a load resistor 125 so as to produce voltage variations therein. These voltage variations are also impressed upon a capacitor 156 for the purpose of actuating suitable demodulating, filtering and amplifying apparatus indicated conventionally at 117. The details of the apparatus 117 are not shown as they are well known to those skilled in the art of radio reception. Generally speaking, however, such apparatus will include a detector for converting the modulated high frequency signals into either an audio signal or an intermediate frequency signal, as when heterodyning is used. The apparatus will also include suitable filtering means for eliminating undesirable frequency components. Furthermore, the apparatus will require sufficient amplification means to produce usable audio waves in a loud speaker 157.

In operation the signal derived from the conductive film on the back of the mosaic screen 123 may be accounted for as follows:

Consider first the action of the tube when the mosaic is scanned by the beam with no illumination on the mosaic. When the electron beam strikes a globule, the globule emits secondary electrons, the number of secondaries being several times larger than the number of beam electrons striking the globule. Some of these secondaries return almost immediately to the globule, the

rest escape and go either to the collector or to other parts of the mosaic. Because the globule is insulated, its potential will change in the positive direction if the number of electrons escaping from it is greater than the number of electrons flowing to it. The number of electrons which escape depends on the potential of the globule, the number being less, of course, the more positive the globule is. Hence, if the beam is on the globule a sufficiently long time, the globule will be driven to a positive potential. The value of this potential for typical operating conditions is about 3 volts positive with respect to the collector.

After the beam passes the globule, some of the secondary electrons emitted from the rest of the mosaic fall on the globule. The arrival of these electrons changes the globule potential in the negative direction to a new value. In a typical operating condition, this value is about $1\frac{1}{2}$ volts negative with respect to the collector. With no light on the globule, the globule stays at this negative potential until the next time the beam strikes, when the globule again releases electrons and rises to its maximum positive potential of approximately 3 volts.

Consider now the action of the tube when the mosaic is scanned with part of it illuminated. During the time between contacts with the beam, both an illuminated globule and an unilluminated one receive electrons from the rest of the mosaic. Both globules, therefore, charge in the negative direction during this time. The illuminated globule, however, at the same time emits electrons, the emission being caused by the light on this globule. The illuminated globule, therefore, does not fall to as negative a potential as the unilluminated one does. Hence, the next time the beam strikes, the illuminated globule does not have as far to rise to reach 3 volts. As a result, less charge is released to the collector when the beam strikes the illuminated globule than when the beam strikes the unilluminated one.

As the "spot" moves over the mosaic, varying amounts of charge flow from the individual elements of the mosaic to the collectors 126 and 127. The amount of charge flowing at any instant is a measure of the light on the globules where the beam is at that instant. In other words, a signal current flows between the mosaic and the collector. Although the beam current in an ordinary iconoscope tube is constant, in this case it is varied by the control action upon the electrode 134. The resultant signal current across the resistor 125 is, therefore, a composite of the control action by the control electrode 134 and of the photo-electric response to the light energy derived from the image impressed upon the mosaic screen 123. The voltage developed across the load resistor 125 will vary in accordance with the audio frequencies impressed upon the frequency modulator 98, since the respective components of the oscillator 97 impressed upon the control grid 134 and upon the transformer 108 are such that no variation in the signal output would result except for the photo-electric action of the image on the screen 123. The stroboscopic effect is such as to vary the angular velocity of the beam scanning action, while the frequency applied to the control grid 134 remains constant. This enables me to derive suitable timbre-characterized audio frequencies from the output circuit of the tube 120.

It is apparent that numerous advantages may

be obtained by carrying out my invention in the manner hereinbefore set forth. The timbre characteristics of any number of solo instruments, as well as any orchestral group of instruments, may be transcribed from actual renditions on these instruments. The permanent records thus obtained are usable at will in an instrument of relatively low cost and one which occupies a space not appreciably greater than an ordinary organ console. The exact simulation of tone qualities of notes produced by costly instruments and by differently voiced organ pipes is made possible. The flexibility of control by shifting alternative records into service provides the utmost of convenience to an organist and a very great range of possibilities for artistic interpretation of a musical composition.

Various modifications of the invention other than those herein shown and described may suggest themselves to those skilled in the art. Accordingly the invention is limited only in accordance with the scope of the claims.

I claim:

1. A musical instrument having keys to be played, a tuned audio frequency oscillator under control of each key, a cathode ray tube comprising an electron gun, beam deflecting means, and a photo-electric screen; means for projecting on said screen an image graphically depicting the timbre characteristics of a tone to be reproduced, said image constituting light and dark portions of an annular area, means for impressing supersonic frequency potentials upon said deflecting means thereby to scan said annular area rotatively, and means for causing said potentials to be frequency-modulated by output energy from the key-actuated audio frequency oscillators.

2. A musical instrument according to claim 1 and having detector and amplifier means receptive of output energy from said cathode ray tube, and a loud speaker controlled by the last said means.

3. A musical instrument according to claim 1 and having a beam-intensity control circuit connected between the cathode and control grid of said cathode ray tube, and means including a supersonic frequency generator coupled to said control circuit for varying the electronic density of the cathode ray at a predetermined periodicity.

4. A musical instrument according to claim 1 and having means for injecting alternate centrifugal and centripetal components into the scanning of said screen by the said beam, said components alternating at a frequency considerably higher than that of said supersonic frequency potentials.

5. A musical instrument according to claim 1 and having said keys grouped in different keyboards, and means for causing the modulations impressed on said supersonic frequency potentials to be constituted by an integration of brief impulses occupying mutually-exclusive time intervals, successive impulses being derived from different oscillators appropriate to respectively different keyboards.

6. A musical instrument having at least one keyboard and a plurality of electric tone frequency generators each under control of a different key in said keyboard, a supersonic frequency source, means for frequency-modulating the output energy from said source by impulses from said tone-frequency generators, a cathode ray tube having rotative scanning means characterized in that it produces rotative scanning cycles of the electron beam and spot in synchro-

nism with the frequency-modulated cycles from said source, a photo-electric mosaic screen in said tube having an annular area on which to trace the path of the scanning spot, luminous projection means adapted to focus an image on said mosaic screen, said image being so characterized as to produce variations in the output energy from said tube when scanned by said spot, means for demodulating said output energy thereby to derive electric audio waves having the same fundamental frequency components as those of the output energy from the key-actuated tone frequency generators and having superimposed harmonic components of which said image is a graphic representation of one fundamental frequency cycle, and means for translating said electric audio waves into corresponding sound waves having a desired timbre characteristic.

7. A musical instrument according to claim 6 and having a plurality of films cooperatively associated with said luminous projection means, each film bearing an appropriate circular image to be projected upon said mosaic screen, and a plurality of selectively operable stops arranged to be manipulated by an organist, each stop having means connected thereto for interjecting one of said films into the luminous path of said projection means.

8. A musical instrument having electric switches each operable by an appropriate key of a keyboard, sources of electric wave energy of musical scale frequencies, each source being operable to deliver its output in response to the actuation of an appropriate one of said switches by its respective key, a cathode ray tube having rotative deflecting means, a supersonic frequency source connected to said deflecting means and operative to rotate the beam cyclically, means for frequency-modulating the energy from the last said source by energy from the first said sources, means interposed between the modulating means and the deflecting means for phase-splitting the modulated energy, means including a target electrode in said cathode ray tube operative when scanned by the beam spot to produce a wave-shaping action upon each cycle of output energy from said cathode ray tube, means for heterodyning the frequency-modulated and wave-shaped energy with a fixed supersonic frequency, means for detecting and amplifying the heterodyned energy, and a sound reproducing device under control of the last said means.

9. In a musical instrument, means for producing an electron stream, deflector means for imparting rotary movement of said stream in cycles of a supersonic frequency, means capable of producing oscillations at different musical scale frequencies, means for frequency modulating the supersonic cycles by said oscillations, a wave-shaping element adapted to be variably excited when scanned by said stream, means for obtaining a heterodyned audio frequency derivative from the cooperation of said wave-shaping element with the scanning thereof, and means controlled by the last said means for producing musical sounds.

10. The device according to claim 9 in which said wave-shaping element is constituted by a photo-electric mosaic screen in combination with an optical system comprising means for projecting a characteristic wave-shaping image thereon.

11. In a device for introducing timbre-characteristics into fundamental frequency tones, means for producing oscillations representing said tones,

means for producing a directed beam of electrons, a target for said beam, means for causing said target to be rotatably scanned in cycles of a supersonic frequency, means for causing the instantaneous velocity of said cycles to be modulated by selected single trains of said tonal oscillations and by concurrent combinations of said trains, means for modulating the electronic density of said beam at a fixed supersonic frequency, means rendering said target operative when scanned by the beam to effect amplitude modulation of an output current derivative of the scanning action, and means to utilize said output current derivative for the production of timbre-characterized musical tones.

12. In a musical instrument, a cathode ray tube having a photo-electric target electrode, means for contrastingly illuminating different areas of said electrode, the margin line separating light and dark areas being endlessly conformed to the vector graph of a complex sound wave, means for causing the electron beam in said tube to rotatively scan said light and dark areas at different velocities in dependence upon the frequencies of selected musical scale notes to be played, an output circuit for said tube, and means controlled by said output circuit for reproducing a train of sound waves corresponding to said musical scale notes when modulated by said complex wave.

13. A device in accordance with claim 12 and including means for superposing a supersonic frequency radial deflection component on the scanning action of said electron beam.

14. In a musical instrument, an electron discharge tube having an electron gun and means for rotatively deflecting the electron beam emitted by said gun, means for controlling the scanning velocity of the deflecting means in dependence upon the succession of notes and chords of a musical rendition, means including a circuit for utilizing output energy from said tube, a target in said tube adapted to be scanned by said beam, said target being effected when different areas thereof are scanned for modulating the amplitude of said output energy, and means to reproduce said succession of notes and chords with a predetermined timbre characteristic, the last said means being controlled by said output energy.

15. A device in accordance with claim 14 in which said means for controlling the scanning velocity includes a supersonic frequency oscillator, a quadrature phase-splitting device interposed in circuit between said oscillator and said beam deflecting means, and means for frequency modulating the output energy from said oscillator.

16. A musical instrument of the class described comprising a cathode ray tube having an electron gun, a target, and electron beam deflecting means; means for so characterizing said target that, when rotatively scanned at cyclic frequencies which are a function of selected fundamental frequencies representing musical notes, potentials are produced having a desired timbre effect, means for applying operating potentials to said

beam deflecting means, and means controlled by output energy from said tube for reproducing said musical notes embellished by said timbre effect.

17. A musical instrument having a plurality of manual keyboards and a pedal keyboard, means for producing fundamental frequencies in response to the playing of the keys of said keyboards, means for separately controlling the relative amplitudes of the frequency products appropriate to each keyboard, sound producing apparatus comprising an electronic device for superposing complex harmonic frequency components upon said fundamental frequencies, and means including an electronic distributor operative at a supersonic switching frequency for applying said fundamental frequencies appropriate to the played keys of each separate keyboard in succession during mutually exclusive time intervals.

18. A musical instrument having a plurality of keyboards, a fundamental frequency electric generator for each key of the musical scale in each keyboard, cyclically operable switching means for rendering the generators of different keyboards effective in mutually exclusive time intervals, an oscillator for controlling the cycles of said switching means at a supersonic rate, a volume control device for varying the energies delivered by said generators in accordance with the relative amplitudes to be derived from playing the keys of different keyboards, an element carrying a graphic representation of a single cycle of a sound wave having harmonics thereof superimposed, thereby to simulate a tone of given timbre, means under control of said record for causing the output energy from said generators to be modulated in accordance with the wave formation of said graphic representation, and means for translating the modulated energy into musical sound waves.

19. In an electronic musical instrument, means for producing electric waves of different audio frequencies corresponding to the fundamental tones of a musical scale, a cathode ray tube having electron emitting and beam focussing means and a target electrode to be scanned by an electronic "spot", said target electrode constituting means for superimposing harmonic frequency modulations upon the output energy from said tube which modulations are correlated with selected fundamental frequencies of the first mentioned waves, means providing a complex scanning path for said spot such that one component is oscillatory at a supersonic frequency in a radial direction while another component is rotative at a cyclic frequency dependent upon selected waves derived from the first said means, and means under control of output energy from said cathode ray tube for producing complex tones which are characterized by said fundamental frequencies and by said harmonic frequency modulations.

RALPH W. BUMSTEAD.