

June 21, 1960

Filed Oct. 31, 1955

M. CLARK, JR  
PHOTOELECTRIC SCANNING DEVICE FOR  
GENERATING MUSICAL TONES

2,941,434

6 Sheets-Sheet 1

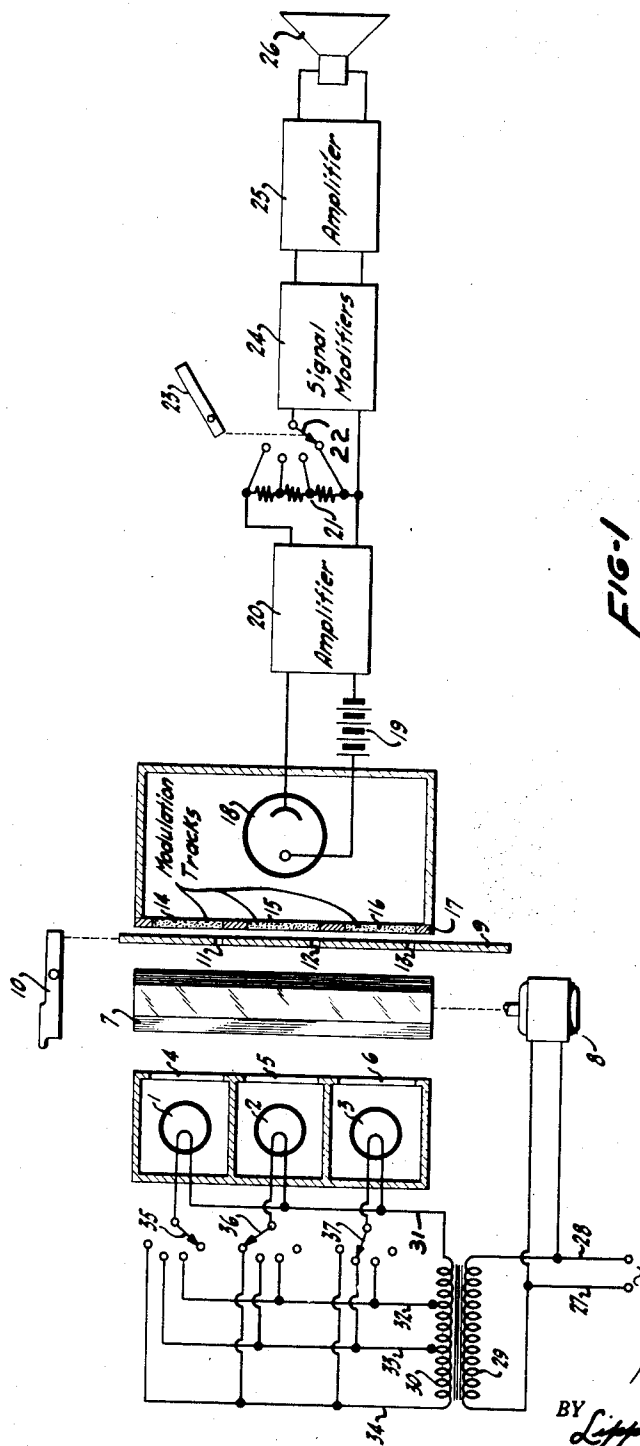


FIG-1

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6 Sheets-Sheet 2

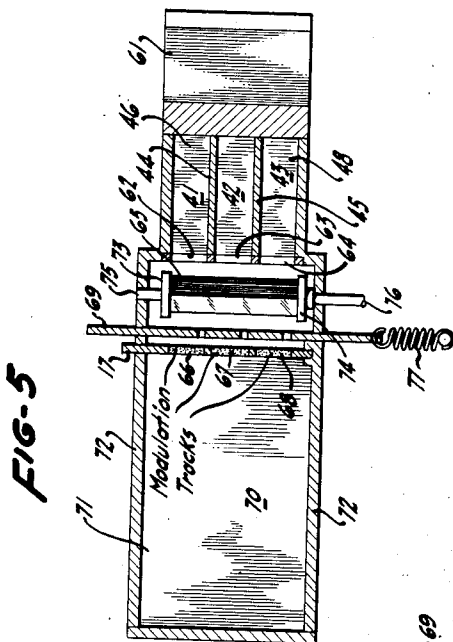


FIG-5

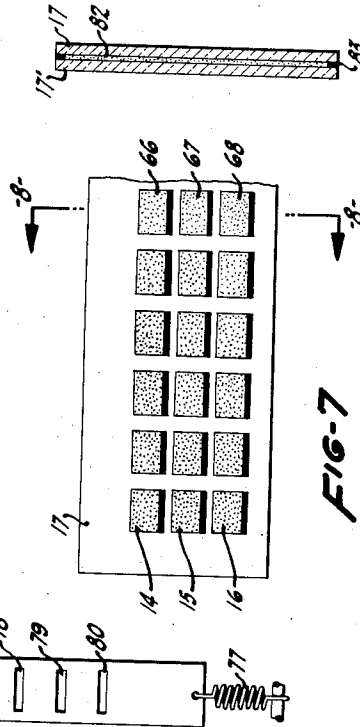


FIG-6

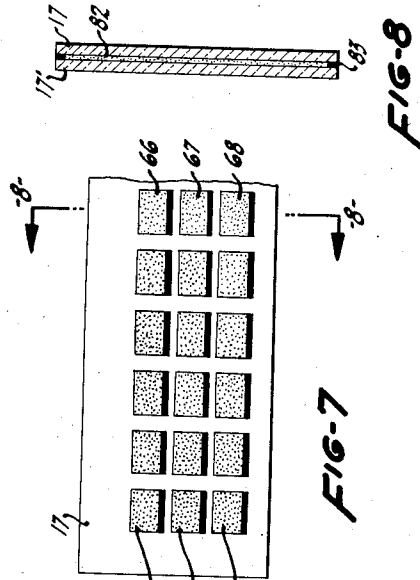


FIG-7

FIG-8

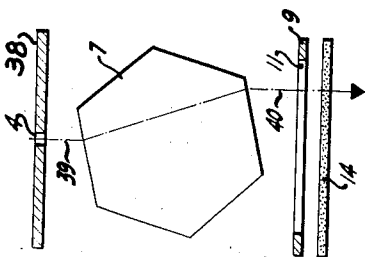


FIG-2

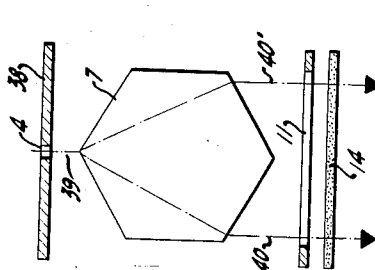


FIG-3

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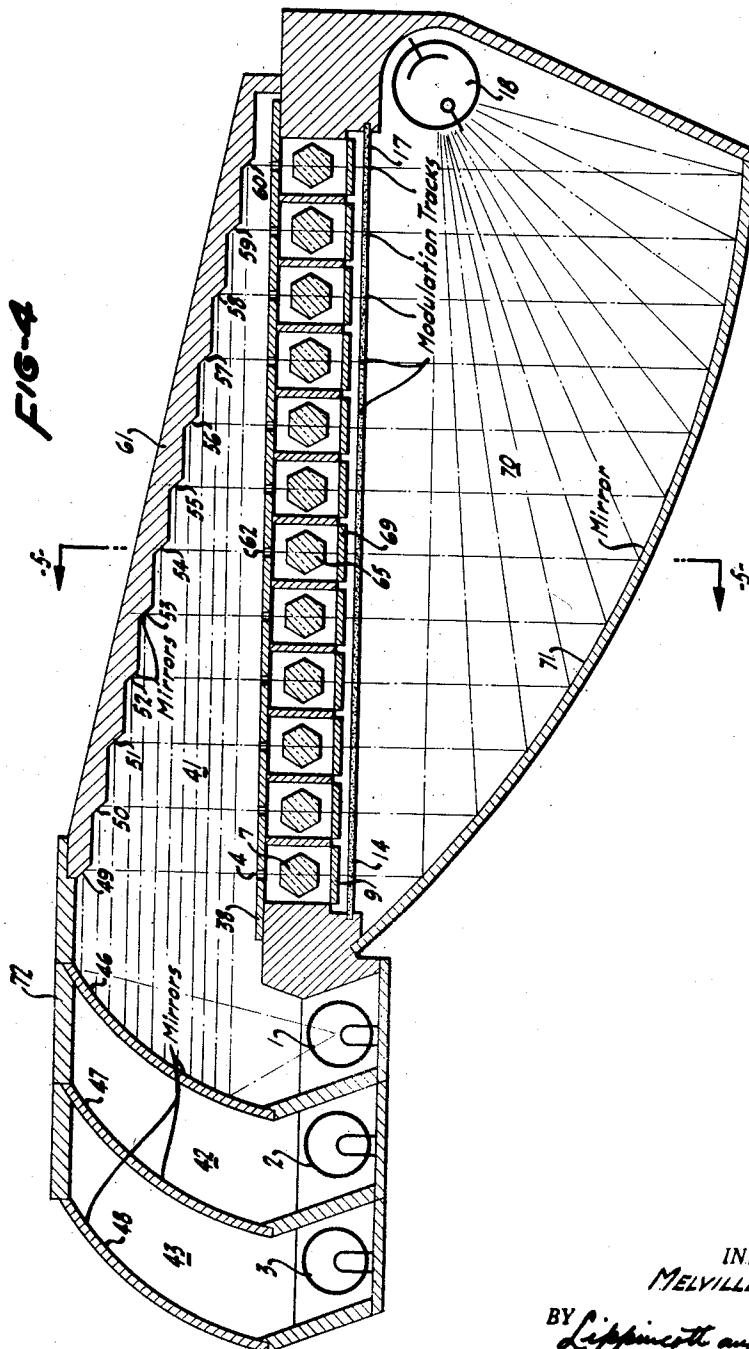
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6 Sheets-Sheet 3



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FIG-9

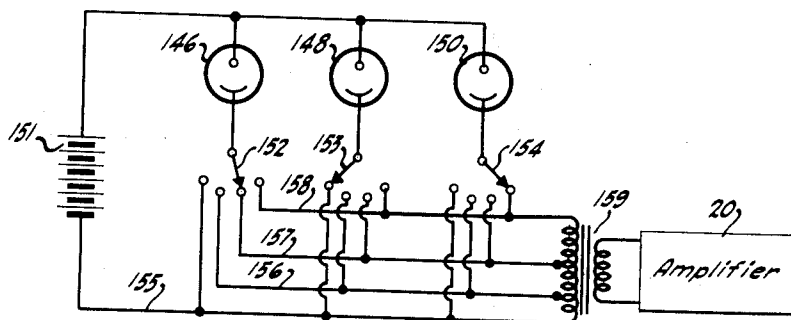
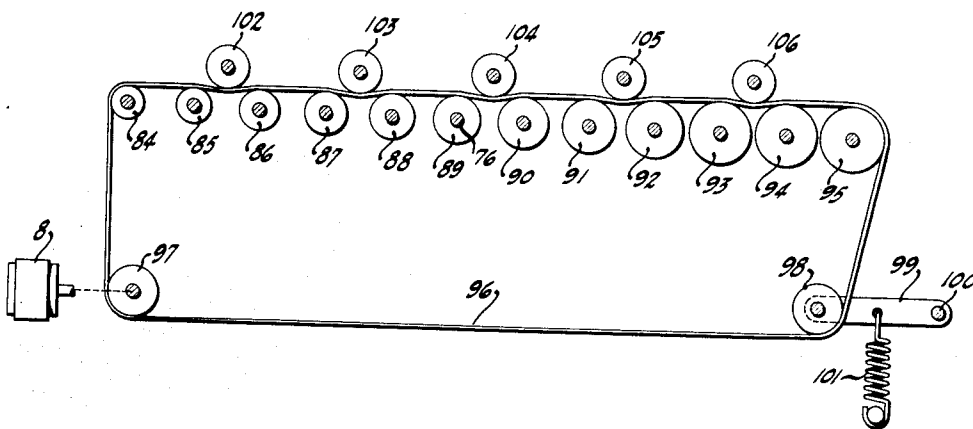


FIG-13

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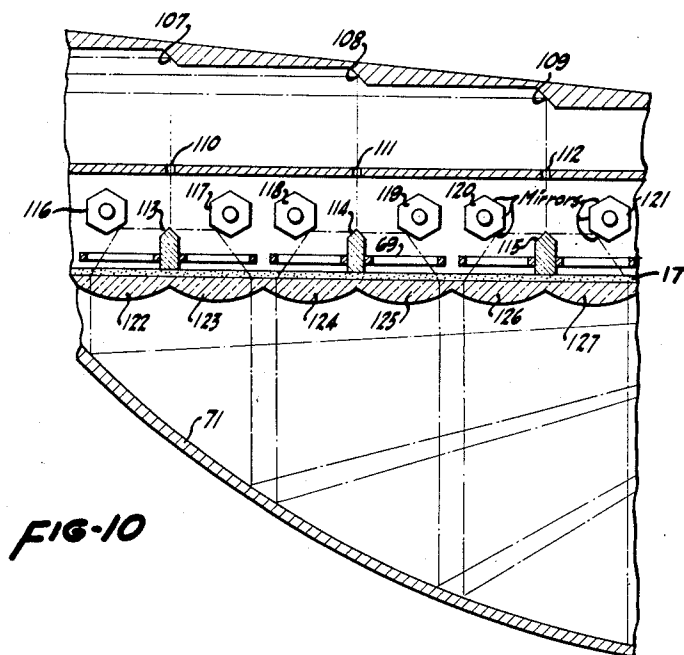


FIG-10

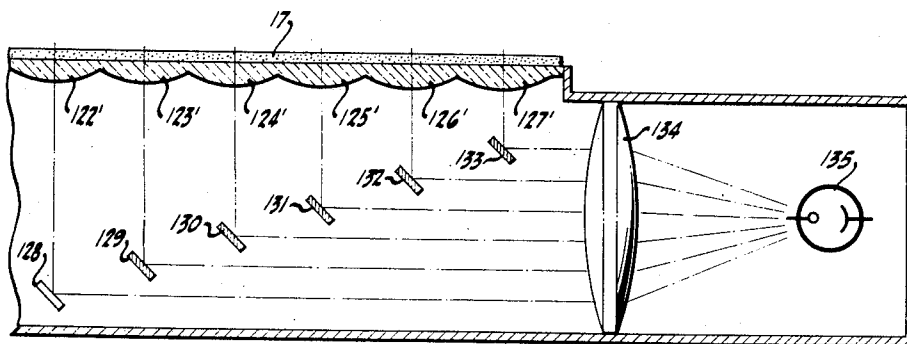


FIG-11

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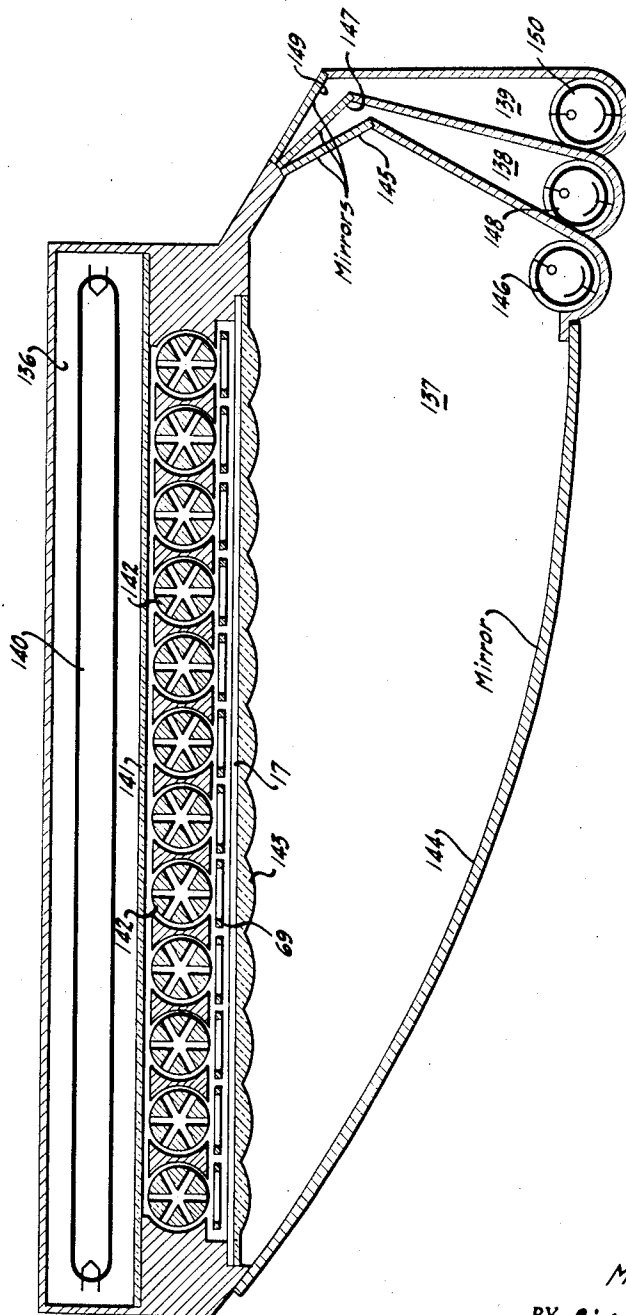
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PHOTOELECTRIC SCANNING DEVICE FOR  
GENERATING MUSICAL TONES

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Filed Oct. 31, 1955, Ser. No. 543,948

5 Claims. (Cl. 84—1.18)

This invention relates to electrical musical instruments, and in particular to photoelectric musical instruments having a plurality of stationary light-modulating tracks repetitively scanned by moving light beams.

An object of this invention is to provide an improved electrical musical instrument for faithfully simulating the tones of orchestral and other instruments.

Another object is to provide an exceptionally compact, easily manufactured photoelectric musical instrument.

Another object is to provide a photoelectric musical instrument having light-modulating tracks that can quickly and easily be interchanged for "voicing" the instrument—that is, for changing the timbres or tone colors which the instrument is capable of producing.

Still another object is to provide improved means for scanning the modulation tracks of a photoelectric musical instrument.

Other objects and advantages of the invention will appear as the description proceeds.

Briefly stated, in accordance with one aspect of this invention, a photoelectric musical instrument has a stationary member carrying a plurality of modulation tracks each having an optical transmittance that varies along its length in accordance with a musical tone. The modulation tracks are preferably arranged in a coplanar array consisting of rows of linearly aligned end-to-end tracks representing tones of similar timbre but different pitch, and of columns of parallel side-by-side tracks representing tones of similar pitch but different timbre. The instrument can produce as many different basic timbres as there are rows of modulation tracks, and it can produce a much larger number of composite timbres or tone colors by combining the basic timbres in different proportions. The stationary member may be removed and replaced by a similar member carrying a different set of modulation tracks for changing the basic timbres or tone colors of the instrument.

A plurality of cylindrical scanners are provided, one for each column of modulation tracks, which moves light beams repetitively along the lengths of the tracks to produce light modulated in accordance with musical tones. The scanning cylinders are rotated at different speeds so that the different rows of tracks produce tones of different pitches. A plurality of keying shutters are provided, one for each column of tracks, for selecting the pitch of the tone to be produced. Photoelectric transducer means convert the modulated light into electric signals, which may be used to produce sound waves.

The invention will be better understood from the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims. In the drawings,

Fig. 1 is a simplified schematic and circuit diagram of a photoelectric musical instrument embodying principles of this invention;

Fig. 2 is a schematic representation showing operating

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principles of a cylindrical scanner used in the same musical instrument;

Fig. 3 is another schematic representation showing operating principles of the same scanner;

Fig. 4 is a schematic plan view, partly in section, illustrating the optical system of the same musical instrument;

Fig. 5 is a section taken generally along the line 5—5 of Fig. 4;

Fig. 6 is a detail of one keying shutter in the same musical instrument;

Fig. 7 is a fragmentary detail showing schematically a portion of a stationary member carrying a plurality of modulation tracks for the same musical instrument;

Fig. 8 is a section taken generally along the line 8—8 of Fig. 7;

Fig. 9 is a schematic illustration of apparatus for rotating the scanning cylinders of the same musical instrument;

Fig. 10 is a schematic fragmentary plan view, partly in section, showing a portion of an alternative optical system using scanning cylinders of a different type;

Fig. 11 is a schematic fragmentary plan view, partly in section, showing a modification of the alternative optical system;

Fig. 12 is a schematic plan view, partly in section, showing another alternative optical system using scanning cylinders of still another type; and

Fig. 13 is a circuit diagram showing an electric circuit and timbre adjustment means associated with photoelectric transducers of the optical system shown in Fig. 12.

Reference is now made to Fig. 1 of the drawings, which is a schematic representation of a photoelectric musical instrument embodying principles of the present invention. In Fig. 1, only one cylindrical scanner and keying shutter is shown, but it will be understood that a plurality of such scanners and shutters will be provided in actual practice (as is shown in subsequent figures of this application) for producing tones of different pitch. A light source includes a plurality of electric lamps 1, 2 and 3, there being one lamp for each basic timbre to be produced by the instrument. Any desired number of such lamps may be provided to produce any desired number of basic timbres or tone colors. These lamps illuminate a plurality of optical apertures 4, 5 and 6, which preferably are linearly aligned, long, narrow optical slits. Apertures 4, 5 and 6 produce a plurality of light beams directed to a scanning cylinder 7 which may be a transparent prism continuously rotated at a constant speed by a motor 8. The rotational axis of cylinder 7 is parallel to slits 4, 5 and 6.

A keying shutter 9 is linked to a key 10 which may be one key in a piano or an organ-type manual keyboard, or may be a pedal in an organ-type pedal clavier. Keying shutter 9 carries a plurality of optical apertures 11, 12 and 13, which preferably are parallel optical slits each having a length extending normal to the plane of the drawing—that is, transverse to a projection of the axis of cylinder 7 upon the plane of the keying shutter 9. Light passing through apertures 11, 12 and 13 crosses a plurality of modulation tracks 14, 15 and 16 carried by a stationary member 17, and light transmitted by the modulation tracks reaches the cathode of a photoelectric transducer 18, preferably a phototube or a photo-multiplier tube, which converts modulated light into an electric signal.

Modulation tracks 14, 15 and 16 are coplanar and parallel, side-by-side, and each has a length extending in a direction normal to the plane of the drawing. Each track has an unmodulated section (preferably opaque) and at least one modulated section with an optical trans-

mittance which varies along its length in accordance with a musical tone. Each modulated section generally comprises a large integral number of wavelengths of the fundamental frequency. The modulation tracks may be multi-section tracks of the type described in my copending patent application entitled "Progressively Keyed Electrical Musical Instrument," Serial No. 543,949, filed October 31, 1955.

As scanning cylinder 7 rotates, the three light beams passing through apertures 4, 5 and 6 are moved repetitively along the lengths of tracks 14, 15 and 16. In the normal rest or unkeyed position of shutter 9, apertures 11, 12 and 13 are in alinement with unmodulated sections of the modulation tracks and no modulation of the light occurs. In other words, shutter 9 normally blocks the optical paths passing through modulated sections of the tracks 14, 15 and 16. When key 10 is depressed, shutter 9 moves upward and apertures 11, 12 and 13 are moved into alinement with modulated sections of tracks 14, 15 and 16 so that each light beam is modulated in accordance with the musical tone represented by a corresponding one of the modulation tracks.

Since light from all three beams reaches transducer 18, the electric signal produced by transducer 18 represents a composite tone that is the sum of the basic tone colors represented by the modulation of the tracks. The timbre or tone color of the composite tone is controlled by adjusting the relative amounts of light transmitted along the three scanning beams in a manner hereinafter more fully explained. Various modifications of the keying shutter 9 and preferred types of linkage between shutter 9 and key 10 are described in my copending patent application, Serial No. 543,949, hereinbefore identified. In a simple musical instrument, shutter 9 may be linked to key 10 by a direct mechanical connection.

Electric power is supplied to phototube 18 by any suitable means, such as battery 19. The electric signal produced by phototube 18 is amplified by an amplifier 20, and its amplitude is adjusted by a volume control which may, for example, consist of a resistance-type voltage divider 21 having an adjustable tap 22 linked to a swell pedal 23 for controlling the over-all loudness of the musical tone produced by the instrument.

Signal modifiers 24 may be provided if desired for adding various musical effects, such as reverberation, vibrato and tremolo effects, choral effects and the like. For this purpose, signal modifiers of types presently known to those skilled in the art may be employed. For example, a reverberation device may be constructed in accordance with principles disclosed on pages 522 and 523 of the book "Elements of Sound Recording" by John G. Frayne and Halley Wolfe, published by John Wiley and Sons, Inc., New York, 1949. After further amplification by an amplifier 25 the electric signal is supplied to one or more loudspeakers 26 which convert the electric signal into sound waves.

Individually adjustable amounts of electric current are supplied to each of the lamps 1, 2 and 3, by a lamp-energizing and stop or timbre-control system which will now be described. Alternating current is supplied to leads 27 and 28 by any suitable means such as a commercial 60-cycle electric outlet. Leads 27 and 28 supply electric current to motor 8, which may be a synchronous electric motor for rotating the scanning cylinders at constant predetermined speeds. Leads 27 and 28 are also connected to the primary 29 of a transformer having a tapped secondary 30 connected to a plurality of distribution lines 31, 32, 33 and 34. Distribution line 31 is a common line which is connected to one terminal of each of the lamps 1, 2 and 3. Lines 32, 33 and 34 are connected to different taps of secondary 30, so that different values of alternating voltages are present between line 31 and each of the lines 32, 33 and 34.

Other terminals of lamps 1, 2 and 3 are connected to a plurality of individually adjustable selector switches 35, 36 and 37, as shown. Each of the selector switches has

three taps which are connected to respective ones of the distribution line 31. Selector switches 35, 36 and 27 may either have no electrical connections or be connected to distribution line 31. Selector switches 35, 36 and 37 may be connected to drawbars, dials, or any other adjustment devices that can be operated conveniently by the musician, and are individually adjustable for controlling the relative amounts of electric current supplied to lamps 1, 2 and 3. These in turn control the relative brightnesses of the three lamps, and thus control the proportions of the three basic timbres that enter into the composite timbre of the musical tone produced by the instrument. Preferably, the transformer taps are so spaced as to provide equal loudness increments between successive adjustment positions at the selector switches.

The amount of hum produced by exciting the lamps with alternating current can be made negligible and other advantages can be obtained by using low voltage incandescent lamps—6 volt lamps, for example—which have relatively heavy filaments and consequently do not change in temperature or brightness appreciably during an alternation of the supply current. However, if desired, means may be provided for supplying lamps 1, 2 and 3 with direct current or with high frequency alternating current to eliminate any possibility of hum from this source.

The composite timbre or tone color of the tone produced by the instrument may be controlled in ways other than by controlling the relative amounts of current supplied to the lamps. For example, the three lamps may have constant brightnesses, or a single lamp may be used, and optical wedges or the like may be employed to control the relative amounts of light transmitted in the three beams. As another alternative, separate photoelectric transducers may be provided for each beam to produce separate signals for each of the basic timbres; and the relative amplitudes of these signals can then be controlled by any suitable volume control apparatus for adjusting the composite timbre of the tone. The latter alternative is illustrated in Figs. 11 and 12, and is more fully described hereinafter. The swell pedal 23 may also be linked to an optical wedge for controlling the over-all amount of light reaching transducer 18, or the swell pedal may control apparatus for varying the amount of current supplied to all of the lamps 1, 2 and 3.

Reference is now made to Figs. 2 and 3, which illustrate the principle of a transparent prism-type of cylindrical scanner. A mask 38 carries an entrance aperture 4 of the scanning system. Aperture 4 preferably is a long narrow optical slit parallel to the longitudinal or rotational axis of scanning cylinder 7. Aperture 4 is illuminated in a manner hereinafter more fully explained to form a narrow beam of light represented in the drawing by broken line 39. Scanning cylinder 7 is a regular prism of transparent material having a large refractive index, such as pure cast methyl methacrylate, although other transparent materials including glass may be employed. Cylinder 7 is continuously rotated at constant speed about its longitudinal axis by suitable coupling to a driving motor. The transverse section of cylinder 7 is a regular polygon having an even number of sides.

Referring particularly to Fig. 2, light beam 39 enters one face of cylinder 7 and is deflected laterally with respect to the cylinder by an amount and in a direction which is a function of the angular position of the scanning cylinder. The light beam emerges from the opposite face of the scanning cylinder, as is indicated at 40. Since the cylinder has a transverse section that is a regular polygon having an even number of sides, the opposite faces of cylinder 7 are parallel. Consequently, the light beam emerging from the cylinder at 40 is always substantially parallel to the light beam entering the cylinder at 39, but is moved repetitively from side to side as the cylinder rotates. For example, if cylinder 7 rotates in a clockwise direction, the emerging beam moves repetitively from right to left as viewed in Figs. 2 and 3.

Whenever cylinder 7 reaches an angular position such

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that beam 39 strikes the edge of a dihedral angle of the prism, as shown in Fig. 3, the beam is split into two parts 40 and 40'. Upon further clockwise rotation of cylinder 7, beam 40 is extinguished and beam 40' is moved in the right-to-left direction until beam 39 strikes the edge of the next dihedral angle of the prism.

As the scanning cylinder rotates, beam 40 moves transversely across the keying shutter 9 carrying an optical aperture 11 which preferably is a long narrow optical slit extending in a direction transverse to the longitudinal axis of cylinder 7. A small portion of beam 40 passes through aperture 11 and is moved repetitively along the length of modulation track 14.

When shutter 9 is in its normal rest or unkeyed position, the light passing through aperture 11 reaches an unmodulated section of track 14 and no modulation of the light is produced. However, when the key linked to shutter 9 is depressed, aperture 11 is moved transversely with respect to track 14, and the light beam is moved repetitively along the length of a modulated section of the track. As this happens, modulated light is transmitted to photoelectric transducer 18 which thereupon produces an electric signal corresponding to the musical tone represented by the modulation of the track.

Although the beam scans the modulation track in a somewhat non-linear manner, that is, the beam moves at a different speed along the center lengthwise portion of track 14 than it moves along end portions of the track, this non-linearity can be compensated by a corresponding non-linearity in the modulation of the track, by making the modulation tracks from recordings scanned by similar optical systems, for example. In this way distortion of the musical tones due to scanning non-linearities can be avoided.

Figs. 4 and 5 show the optical system of the improved photoelectric musical instrument. The optical system shown includes twelve scanning cylinders associated with twelve columns of modulation tracks, which may provide tones of twelve different pitches corresponding to the twelve semitones in one octave of the tempered musical scale. The number of different pitches that can be produced may be increased by a corresponding increase in the number of scanning cylinders and associated columns of modulation tracks, either by extending the length of the optical system shown or by adding other similar optical systems. Alternatively, the number of different pitches may be increased by providing modulation tracks representing more than one pitch in each column. For example, harmonically related pitches may be generated by a plurality of modulation tracks that are scanned at the same rate, but in which the optical transmittances of the several tracks are modulated with different integral numbers of the fundamental wavelength. For the latter alternative, the keying shutters would be divided into two or more parts connected to different keys.

A light source includes three lamps 1, 2 and 3 respectively associated with three different rows of modulation tracks for producing three different basic timbres of each pitch. By adding additional lamps and additional rows of modulation tracks, any desired number of basic timbres may be provided.

The three lamps 1, 2 and 3 are enclosed in separate lamp housings which communicate with respective ones of three input light chambers 41, 42 and 43, which are generally parallel and are arranged in a stack as is best shown in Fig. 5. Chambers 41, 42 and 43 are separated from one another by dividers 44 and 45. The spacing of the input light chambers corresponds to the spacing of the rows of modulation tracks. Preferably, each row of modulation tracks is approximately one centimeter wide, and accordingly each input light chamber has a depth of substantially one centimeter. Since lamps 1, 2 and 3 require a space larger than one centimeter in depth, the lamps are staggered in the manner shown in Fig. 4 so that the lamp housings may have a depth greater than that of the individual light chambers.

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The filament of lamp 1 is located at the principal focus of a substantially parabolic mirror 46 which collimates light produced by lamp 1 and directs it in a beam parallel to the row of scanning cylinders. In a similar manner, light produced by lamp 2 is collimated by a mirror 47, and light produced by lamp 3 is collimated by a mirror 48. Each of these collimated beams is reflected from a plurality of distribution mirrors, identified in the drawing by reference numerals 49 through 60, arranged in a step-wise array across and along the collimated beam, as shown in Fig. 4, and each oriented at an angle of substantially 45 degrees to the direction of the collimated light. Preferably these distribution mirrors are reflecting surfaces of an integral step-like member 61 and are similar to the distribution mirrors more fully described in my copending patent application entitled "Multi-Tone Electrical Musical Instrument," Serial No. 543,865, filed October 31, 1955.

The distribution mirrors reflect light from the collimated beams to illuminate a plurality of apertures, such as aperture 4, carried by a stationary mask 38. These apertures are the entrance apertures of the scanning system. In general, each input light chamber has one such aperture for each of the scanning cylinders. For example, there may be three vertical slit-like apertures 4, 5 and 6, linearly aligned end-to-end in mask 38, associated with scanning cylinder 7 in the manner indicated in Fig. 1, there being one of these apertures for each of the input light chambers 41, 42 and 43. Similarly, there are three apertures, 62, 63 and 64, associated with the scanning cylinder 65 as is shown in Fig. 5.

A stationary member 17, parallel to mask 38, carries a coplanar array of modulation tracks arranged in a plurality of rows of linearly aligned end-to-end tracks and a plurality of columns of parallel side-by-side tracks. There is one row of modulation tracks for each of the three input light chambers, and there is one column of modulation tracks for each of the twelve scanning cylinders. Each of these tracks has a modulated section with an optical transmittance that varies along its length in accordance with a different musical tone. In the preferred arrangement, each row of tracks represents similar timbres of different pitch, while each column of tracks represents different timbres of similar pitch. Accordingly, in the arrangement illustrated there are three different basic timbres for each of the twelve different pitches in a musical octave.

The twelve scanning cylinders, such as cylinders 7 and 65, are arranged in a row between mask 38 and the member 17 carrying the modulation tracks. These scanning cylinders are continuously rotated at different constant speeds so that the modulation tracks in different rows are repetitively scanned at different rates to produce musical tones of different pitch. There is a column of three modulation tracks associated with each scanning cylinder to produce musical tones having different basic timbres. For example, modulation tracks 14, 15 and 16 are associated with and optically scanned by cylinder 7, while modulation tracks 66, 67 and 68 are associated with and optically scanned by cylinder 65.

There is a keying shutter associated with each of the scanning cylinders. For example, keying shutter 9 is associated with cylinder 7, and keying shutter 69 is associated with cylinder 65. In their normal or unkeyed positions, these shutters block the optical paths through modulated sections of the tracks carried by member 17, so that no modulated light reaches the photo-electric transducer 18. However, each shutter is connected to an individually operable key of a keyboard, so that when any selected one of the keys is depressed a corresponding shutter is raised to bring a plurality of optical apertures simultaneously into alignment with modulated sections of the three modulation tracks in one row. Modulated light is thus produced that is modulated in accordance with three different basic timbres of a selected pitch,

and transducer 18 produces an electric signal representing a composite timbre of the selected pitch. The character of this composite timbre is controlled by adjusting the relative brightnesses of lamps 1, 2 and 3 in the manner hereinbefore explained.

Light transmitted by the modulation tracks enters a single output light chamber 70 and is collected by a mirror 71 which directs such light to a cathode of photoelectric transducer 18. For best optical efficiency, mirror 71 is arranged to form an image of all the modulation tracks upon the cathode of transducer 18.

The various optical parts are mounted within, and are held in position by, a rigid frame 72 which may, if desired, be hermetically sealed to exclude dust and other foreign materials. The light chambers may be filled up with any transparent material, such as air, other transparent fluids, or transparent solid materials. Light pipes, lenses, or other optical elements may be used in place of mirrors.

With particular reference to Fig. 5, each of the scanning cylinders—cylinder 65, for example—may be a prism of solid transparent material supported at each of its ends by end caps 73 and 74 connected to shafts 75 and 76 which rotate in bearings secured to frame 72. Shaft 76 may be the driving shaft for the scanning cylinder, and it is continuously rotated at a constant speed by means hereinafter described. Each of the keying shutters, shutter 69, for example, is biased to its normal or unkeyed position by a small spring 77, and is linked to a key that may be depressed to move the shutter upward for permitting light to pass through the shutter apertures to modulated sections of the modulation tracks.

Member 17, which carries the modulation tracks, may be lifted out of frame 72 and replaced with a similar member carrying different modulation tracks for changing the basic timbres which the instrument is capable of producing. In this way a small instrument capable of producing only a relatively small number of basic timbres can be very versatile, since the basic timbres, or "voicing," can be changed whenever desired by replacing the modulation tracks with other tracks representing a different set of musical tonalities.

A detail of keying shutter 69 is shown in Fig. 6. The shutter is generally opaque, but has three transparent optical apertures 78, 79, and 80. These apertures, as well as other apertures of the optical system, preferably are transparent portions of a generally opaque strip of photographic film or the like supported by a frame of metal or other durable rigid material, as is more fully discussed in my copending patent application Serial No. 543,865 hereinbefore identified. An upper portion 81 of the keying shutter is linked to a key in a keyboard of the instrument.

Fig. 7 is a schematic representation of a portion of the coplanar array of modulation tracks. Member 17 carries a plurality of modulation tracks, such as tracks 14, 15, 16, 66, 67 and 68. Preferably each track has an unmodulated section, presented in the drawings by heavy solid shading at the bottom of each track, with which the apertures of the keying shutter are aligned when the keying shutters are in their normal or unkeyed positions. Each track also has one or more modulated sections, represented in the drawing by stippled shading, in which the optical transmittance of the track varies along its length in accordance with a musical tone. Preferably these modulated sections are of the variable density type, although variable-area or other types of modulation tracks may be employed under certain circumstances. Generally, the use of variable-area tracks or the like requires more complex keying systems to avoid excessive distortion.

The modulation tracks are arranged in a plurality of rows and columns. For example, tracks 14 and 66 are in the same row, and tracks 14, 15, 16 are in the same column. Preferably each track in a given column rep-

resents a different timbre of similar pitch; and these timbres correspond to the timbres or tone colors of different musical instruments or groups of instruments. For example, one row of tracks may produce tones that

simulate the tones of a violin, another row of tracks may produce tones that simulate the tones of a trumpet, and a third row of tracks may produce tones that simulate tones of a flute. However, instead of simulating the tone colors of individual instruments, other tone colors may be represented and other arrangements of the tracks employed in a manner more fully described in my copending patent application Serial No. 543,865, hereinbefore identified, it being understood that each tone disc in the apparatus of said copending application corresponds to one column of modulation tracks in the apparatus of the present application.

Fig. 8 is a section showing a preferred construction of the stationary member carrying the modulation tracks. A flat transparent plate 17, of glass or other suitable material, is parallel to another similar plate 17'. Between these two plates, in a sandwich-like construction, is a film or photographic emulsion 82, different areas of which differ in optical transmittance to form the array of modulation tracks. In actual practice the tracks may be formed upon film 82 by photographic means, printing, or in any other suitable manner, and preferably they are photographically reproduced from a set of master tracks made, for example, using sound-on film recording techniques, from recordings of tones produced by the instruments that are to be simulated. To protect the film 82 and to prevent shrinkage or other damage, plates 17 and 17' are preferably hermetically sealed together by any suitable sealing means 83.

Reference is now made to Fig. 9 which shows a preferred arrangement for continuously rotating the scanning cylinders. Each cylinder is connected to a driving shaft, such as shaft 76, carrying a driving wheel. The twelve driving wheels which are connected to respective ones of twelve scanning cylinders are identified in the drawing by reference numerals 84 through 95 inclusive. These driving wheels have different diameters, so that the different scanning cylinders are driven at different constant speeds. Preferably the diameter of each driving wheel is related to the diameter of the next adjacent driving wheel by a ratio equal to the twelfth root of two, so that the fundamental frequencies of the tones produced by adjacent rows of modulation tracks have a ratio equal to the twelfth root of two. In this manner the twelve pitches of the instrument are properly related to the twelve semitones in an octave of the equal-tempered musical scale.

The driving wheels 84 through 95 are continuously rotated at different constant speeds by an endless belt 96, which is in contact with all twelve of the driving wheels and with a driving pulley 97 linked to the driving motor 8. To keep the belt taut, an idler pulley 98 is mounted on an arm 99 pivoted at 100 and urged downward by a spring 101. To keep the belt in good contact with all of the driving wheels a plurality of idler pulleys, identified in the drawing by reference numerals 102 through 106 are positioned between adjacent pairs of the driving wheels in the manner shown. In a large instrument covering many octaves, several such belt and pulley systems may be used, one for each of several groups of scanners, with driving pulleys driven at different speeds.

Reference is now made to Fig. 10, which shows a portion of an alternative optical system using mirror-type rotating scanning cylinders. Parts identical to those in the embodiment hereinbefore described are identified by the same reference numerals. The input light system is generally similar to that described in connection with Fig. 4 except that only half as many distribution mirrors are required. The distribution mirrors 107, 108, and 109 are positioned along and across a collimated light

beam from a light source (not shown), and illuminate a plurality of optical apertures 110, 111, and 112 which are entrance slits for the scanning system. It will be noted that only one entrance slit is provided for each pair of scanning cylinders. The entrance slits define beams of light that pass between the scanning cylinders of each pair, and are each divided into two parts by V-shaped beam-splitter mirrors 113, 114, and 115 which direct light to each of the scanning cylinders. For example, beam splitter 113 directs light to scanning cylinders 116 and 117, beam splitter 114 directs light to scanning cylinders 118 and 119, and beam splitter 115 directs light to scanning cylinders 120 and 121.

The transverse sections of the scanning cylinders are preferably regular polygons, and the surfaces of the scanning cylinders are mirrors or other reflecting surfaces. The scanning cylinders are continuously rotated at different constant speeds so that the modulation tracks carried by member 17 are repetitively scanned in the manner hereinbefore explained. A plurality of keying shutters, such as shutter 69, are provided, one for each scanning cylinder. The keying shutters may be identical to the keying shutters described in connection with Fig. 4.

Unlike the transparent-prism type scanners, the mirror type scanners produce emergent light beams which in general are not parallel to the entering beams or to each other. These beams can be collected more efficiently with a simpler optical system if they are first made parallel or collimated. For this purpose there is provided a plurality of cylindrical lenses identified in the drawing by reference numerals 122 through 127. For economy and convenience in manufacture and assembly of the instrument, lenses 122 through 127 preferably are molded from a continuous strip of transparent plastic so that all of the collimating lenses can be assembled in the optical system as an integral unit. The collimated light beams are collected by mirror 71 and directed to the cathode of a photoelectric transducer (not shown) in the same manner as with the apparatus illustrated in Fig. 4.

Alternatively, instead of the curved light-collecting mirror 71, a staggered array of mirrors may be used in the output light chamber, as shown in Fig. 11, in an arrangement analogous to the array of distribution mirrors in the input light chamber. Lenses 122' through 127', which correspond to and replace mirrors 122 through 127, are designed to focus light from the modulation tracks upon respective ones of the mirrors 128 through 133 in this staggered array, from which the light is directed through a collecting lens 134 or the like to the cathode of the phototube 135. Preferably the mirrors in array 128 through 133 most distant from the modulation tracks are also the ones most distant from the collecting lens so that the range of sweep of the light beams is minimized. The mirrors 128 through 133 are not necessarily oriented at exactly forty-five degrees relative to the plane of track-carrying member 17, but are oriented to direct the light to appropriate portions of lens 134 for transmitting the modulated light to the phototube cathode.

Reference is now made to Fig. 12 which illustrates another alternative optical system. In this system there is a single input light chamber 136 for all of the different timbres, and a plurality of output light chambers 137, 138 and 139, there being a separate output light chamber for each row of modulation tracks. A single light source is employed which may, for example, be an elongated tubular fluorescent lamp 140, or may be some other type of long distributed light source. The length of the light source is greater than the total distance between the first and the last scanning cylinders. As a further aid in securing a long distributed light source of uniform brightness, an optical diffusing plate 141 may be positioned in the input light chamber in the manner shown.

Each of the rotating scanning cylinders, such as cylinder 142, is a generally opaque drum, having a plurality of diametrically aligned optical apertures. These apertures may be formed, for example, by cutting a plurality of diametric slots in the opaque cylinders. Alternatively, the scanning cylinders may be in the form of hollow cylindrical drums having a generally opaque surface provided with a plurality of diametrically aligned transparent apertures. Diffused light from the input light chamber 136 can travel through the scanning system only along directions established by the diametrically aligned apertures of the scanning cylinders. Consequently, as each scanning cylinder rotates a light beam is moved repetitively along the length of one row of modulation tracks carried by stationary member 17.

A plurality of keying shutters, such as shutter 69, operate in the manner described in connection with Fig. 4 to direct these light beams either to unmodulated or to modulated sections of the modulation tracks, selectively. The light beams that pass through the modulation tracks are collimated by a plurality of cylindrical lenses, such as lens 143, and the collimated light is collected by a mirror 144.

Light passing through the upper row of modulation tracks enters output light chamber 137, and is directed by mirrors 144 and 145 to the cathode of a photoelectric transducer 146. Light passing through the center row of modulation tracks enters output light chamber 138 and is directed by mirrors 144 and 147 to the cathode of a photoelectric transducer 148. Light passing through the bottom row of modulation tracks enters output light chamber 139 and is directed by mirrors 144 and 149 to the cathode of a photoelectric transducer 150. Transducers 146, 148 and 150 respectively, produce three electric signals, each representing a different basic timbre of the selected pitch.

For controlling the timbre of the composite musical tone, a circuit such as that shown in Fig. 13 may be used to adjust the relative amplitudes of the three signals produced by transducers 146, 148 and 150. Transducers 146, 148 and 150, which may be phototubes or photo-multiplier tubes, receive direct current electric power from a suitable source such as battery 151. The phototubes are connected as shown to selector switches 152, 153 and 154, each of which has a plurality of contacts connected to respective ones of busses or lines 155, 156, 157 and 158 leading to exponentially-spaced taps on the primary of a transformer 159. The secondary of transformer 159 is connected to the input of amplifier 20 so that electric signals from different ones of the busses are transmitted with different degrees of amplification. The proportion of each basic timbre in the composite tone is controlled by individually adjusting the three selector switches 152, 153 and 154, which thus constitute a stop system of the musical instrument. The output of amplifier 20 may be connected to a circuit similar to that shown in Fig. 1.

In all of the embodiments described, various permutations in the order or positions of elements of the optical systems may be made. For example, the keying shutters may be placed on either side of the modulation tracks, and so may the strip or row of lenses. Also, the positions of light sources and photoelectric transducers may be transposed so that light travels through the optical systems in the reverse direction to that described.

It should be understood that this invention in its broader aspects is not limited to specific embodiments herein illustrated and described, and that the following claims are intended to cover all changes and modifications that do not depart from the true spirit and scope of the invention.

What is claimed is:

1. In an electrical musical instrument, the optically aligned combination of a stationary source of light, a stationary photoelectric transducer optically aligned with

said source for receiving such light and converting variations therein to electric signals, a stationary, light-transmissive, flat plate disposed optically in alinement between said source and said transducer, said plate carrying thereon, in parallel, side-by-side relation, a variable-density, photographic sound track and an unmodulated strip, said variable-density track being modulated in its longitudinal direction with a variable-density representation of a musical tone, a continuously rotative scanning device disposed optically in alinement between said source and said transducer, said scanning device being in optically alined operative association with said sound track and strip and being operable to scan in said longitudinal direction said sound track and said strip repetitively and continuously, a reciprocative shutter disposed optically in alinement with and between said source and said transducer, a playing key, and a mechanism linking said playing key to said shutter for direct control of the reciprocation thereof, said shutter being a generally opaque, flat ribbon parallel and adjacent to said plate, said ribbon containing a light-transmissive slit parallel to said longitudinal direction of the sound track and at least equal in length to the longitudinal dimension of said sound track, said ribbon and slit being reciprocatively movable transverse to said longitudinal dimension by action of said playing key, said slit being in optical alinement with said unmodulated strip when the playing key is released and being moved as the playing key is depressed into optical alinement with said sound track, said slit being parallel to said longitudinal direction of said sound track at all times so that the entire length of the track is always equally exposed to scanning by the scanning device, irrespective of whether said key is wholly or only partially depressed.

2. The combination claimed in claim 1, wherein said scanning device comprises a prism disposed optically between said source and said plate, with its longitudinal axis parallel to said plate and the projection of said axis on said plate perpendicular to the longitudinal direction of said sound track and said unmodulated strip, a generally opaque, stationary member having a light-transmissive slit disposed optically between said source and said prism with such slit parallel to the longitudinal axis of the prism, and mechanism for continuously rotating said prism at constant speed about its longitudinal axis.

3. The combination claimed in claim 1, wherein said scanning device comprises a prismatic mirror disposed optically between said source and said plate, with its longitudinal axis parallel to said plate and the projection of said axis on said plate perpendicular to the longitudinal direction of said sound track and said unmodulated strip, a generally opaque, stationary member having a light-transmissive slit disposed optically between said source and said mirror with such slit parallel to the longitudinal axis of the prismatic mirror, and mechanism for continuously rotating said prismatic mirror at constant speed about its longitudinal axis.

4. The combination claimed in claim 1, wherein said scanning device comprises a generally opaque drum having therein a plurality of light-transmissive, diametric slits, said drum being disposed optically between said source and said plate, with its longitudinal axis parallel to said plate and the projection of said axis on said plate perpendicular to the longitudinal direction of said sound track and said unmodulated strip, and mechanism

for continuously rotating said drum at constant speed about its longitudinal axis.

5. In an electrical musical instrument, the combination of a stationary, light-transmissive, flat plate carrying thereon a plurality of variable-density photographic sound tracks of equal longitudinal dimensions arranged in an array of rows and columns, said tracks being modulated in their longitudinal directions with representations of different musical tones, the tracks in each column being parallel and representing the same note in different timbres, the tracks in each row being in linear alinement and representing different notes of similar timbre, said plate also carrying thereon a plurality of unmodulated strips, one adjacent and in parallel, side-by-side relation to each of said sound tracks, a plurality of reciprocative shutters, one disposed adjacent to and in optical alinement with each column of said sound tracks, each shutter including a generally opaque, flat ribbon having therein a plurality of parallel, light-transmissive, transverse slits, each equal in length to the longitudinal dimension of each sound track, with the transverse spacing between said slits equal to the transverse spacing between the rows of sound tracks, whereby all slits of the shutter are movable into simultaneous optical alinement with the entire longitudinal lengths of all sound tracks of a column or all unmodulated strips of a column, selectively, a keyboard comprising a plurality of playing keys, means operatively linking each of said keys to a respective one of said shutters, so that depression of each key moves the associated shutter slits into optical alinement with the entire longitudinal lengths of all the sound tracks in a respective column, a plurality of lamps, one for each of said rows, a generally opaque, flat plate containing a plurality of parallel, light-transmissive slits disposed to be illuminated by said lamps, each lamp illuminating a different lengthwise portion of each slit, forming a plurality of ribbons of light each comprising light rays from each lamp, a plurality of continuously rotative scanning devices, one for each of said columns, for deflecting respective ones of said ribbons of light repetitively and continuously along the length of all the sound tracks in the respective one of said columns, the rays from each lamp being confined to the tracks in a respective one of said rows, means for rotating said scanning devices at different speeds respectively proportional to the fundamental frequencies of the notes of a musical scale, a photoelectric transducer disposed to receive light transmitted through said sound tracks and to convert variations thereof into electric signals, whereby the depression of any one of said playing keys results in the production of an electric signal corresponding to a musical tone having the pitch represented by the position of that key in the keyboard, and means for adjusting the relative brightness of said lamps for varying the timbre of the musical tone so produced.

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