

July 26, 1960

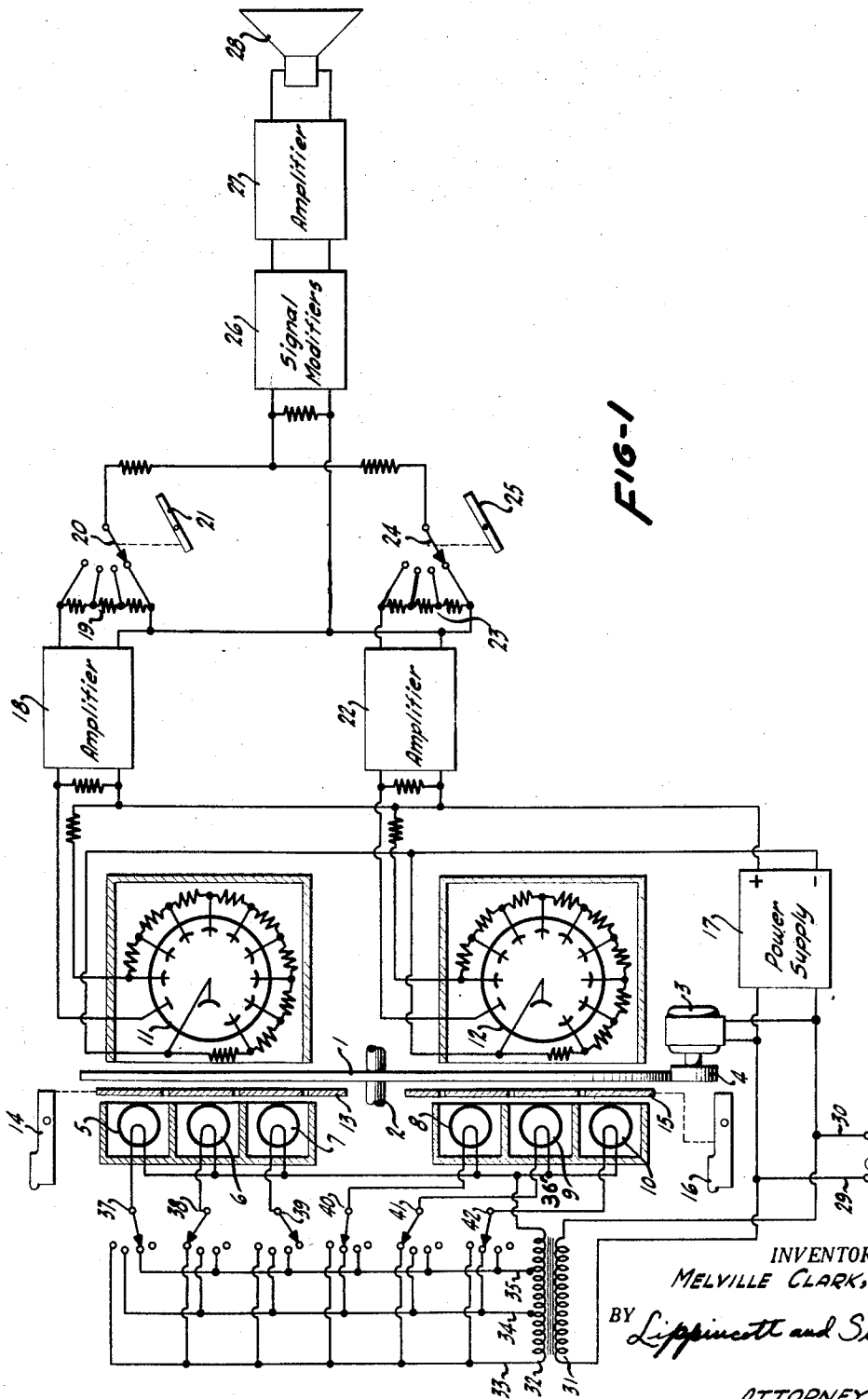
M. CLARK, JR

2,946,253

PHOTOELECTRIC APPARATUS FOR GENERATING MUSICAL TONES

Filed Oct. 31, 1955

7 Sheets-Sheet 1



July 26, 1960

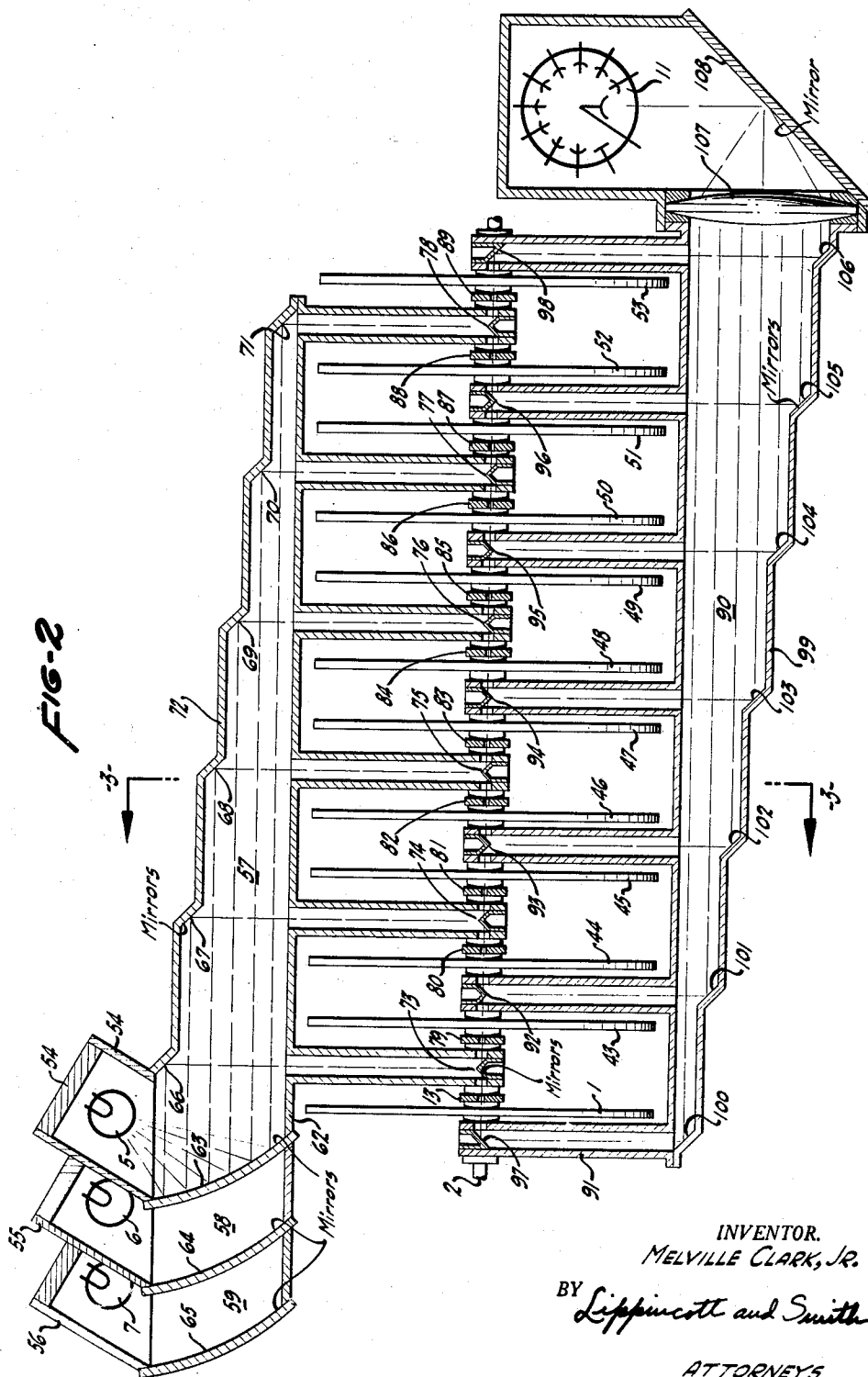
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PHOTOELECTRIC APPARATUS FOR GENERATING MUSICAL TONES

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PHOTOELECTRIC APPARATUS FOR GENERATING MUSICAL TONES

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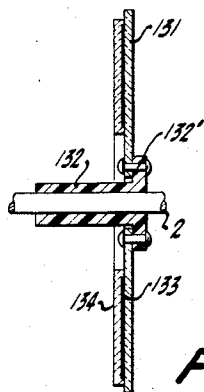
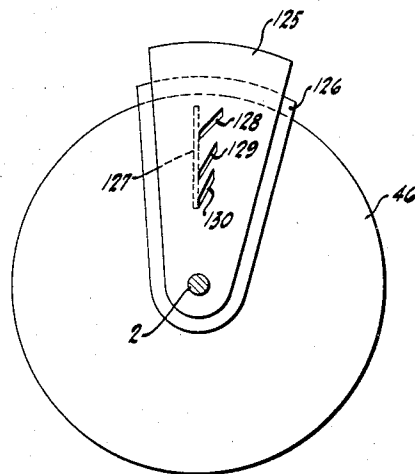
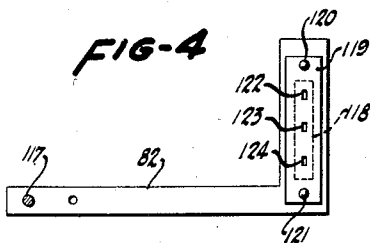
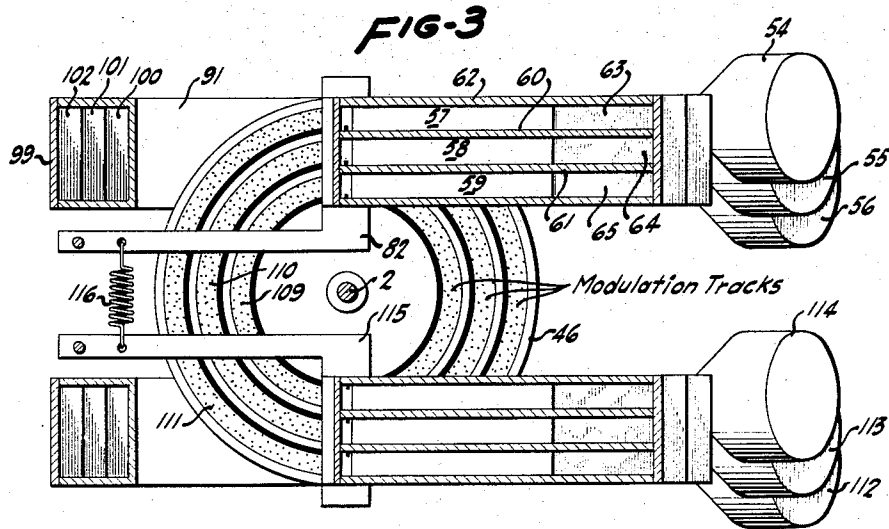


FIG-5

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PHOTOELECTRIC APPARATUS FOR GENERATING MUSICAL TONES

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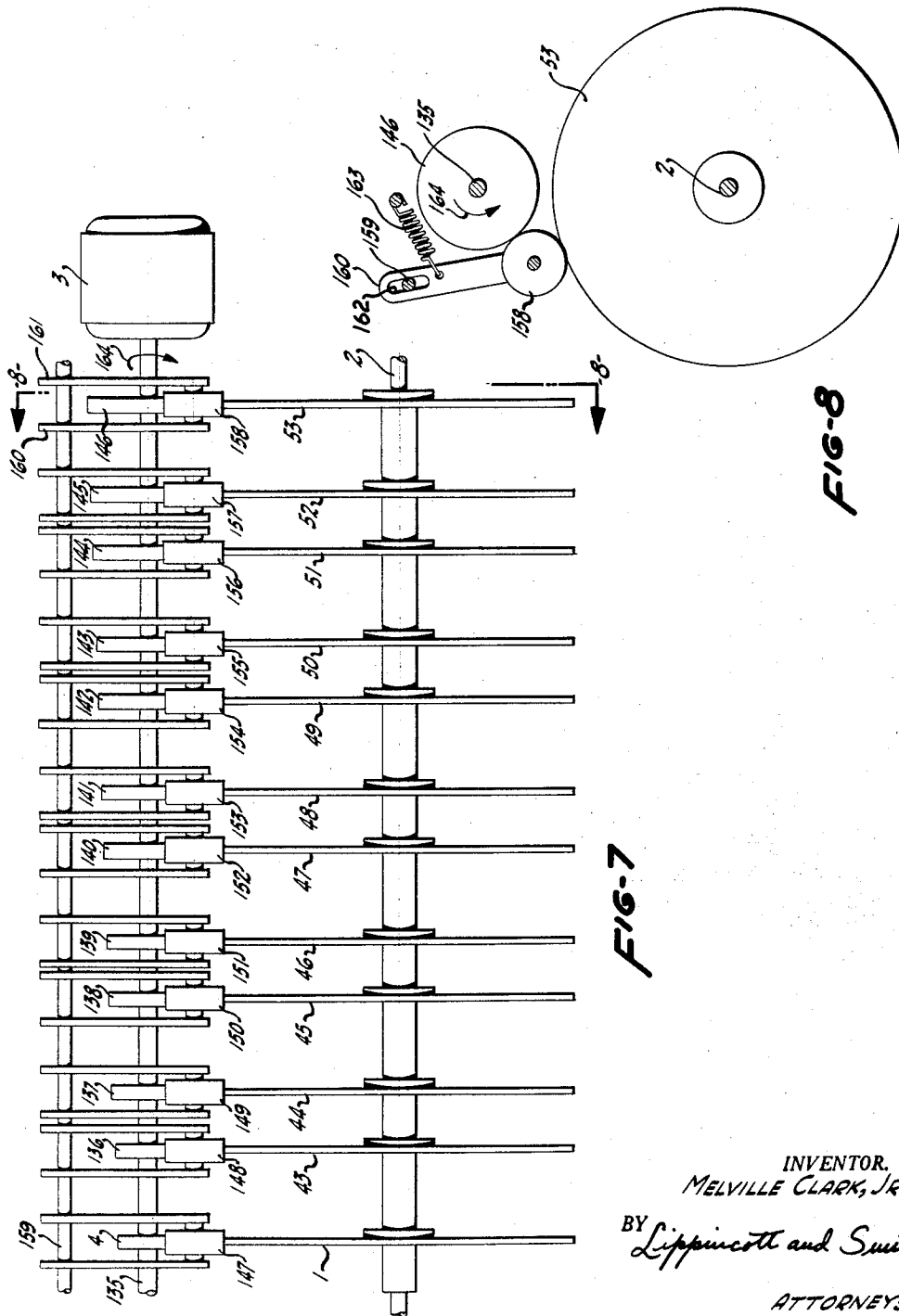


FIG-7

FIG-8

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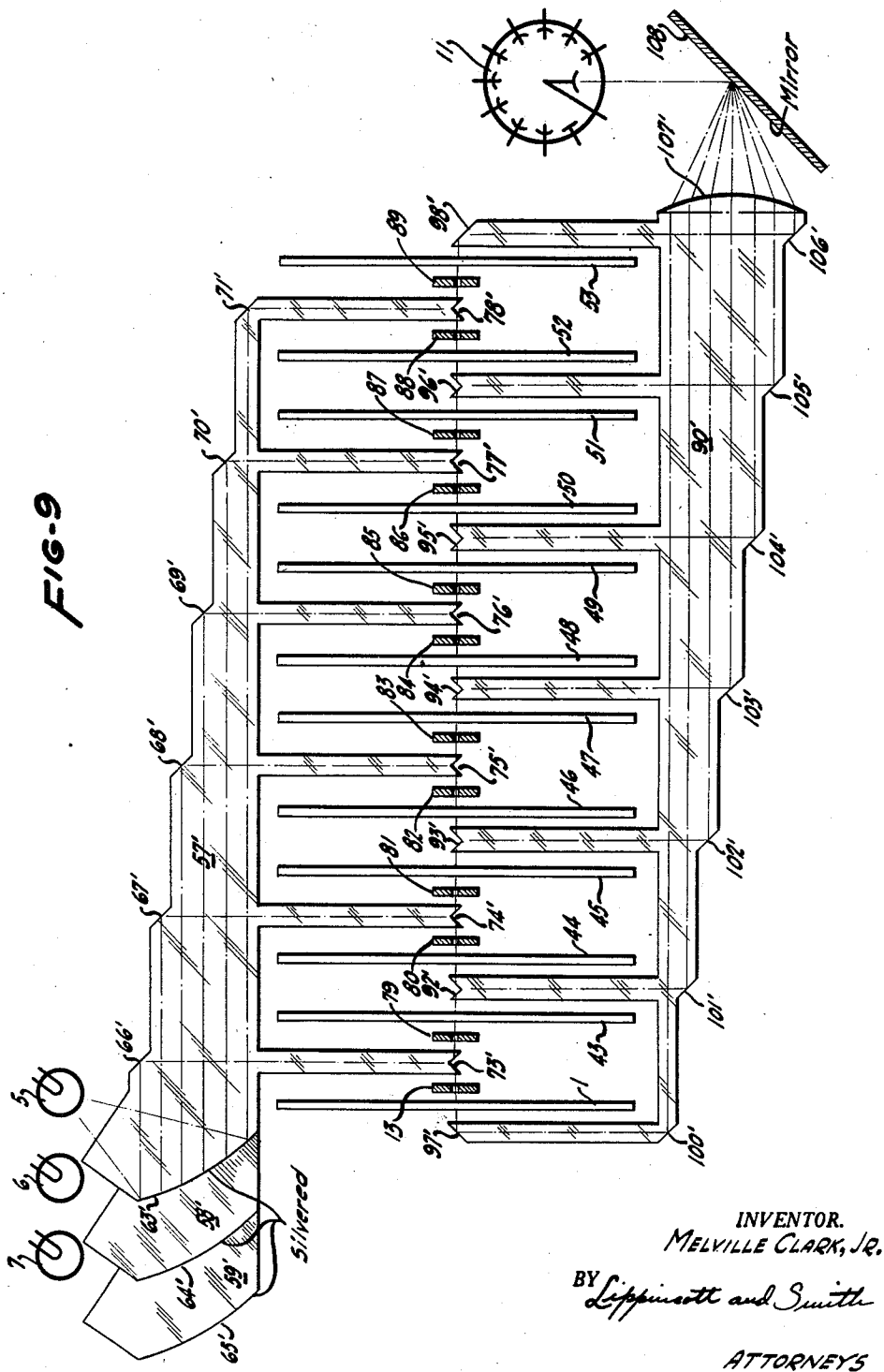
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PHOTOELECTRIC APPARATUS FOR GENERATING MUSICAL TONES

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PHOTOELECTRIC APPARATUS FOR GENERATING MUSICAL TONES

Filed Oct. 31, 1955

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FIG-11

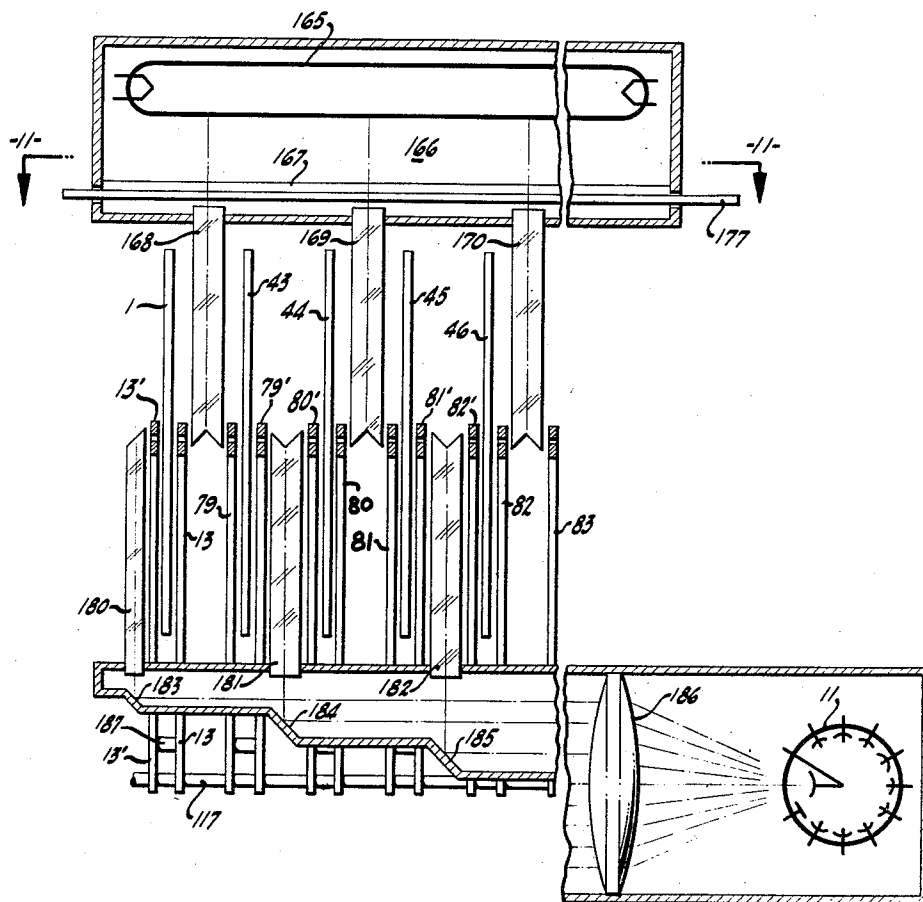
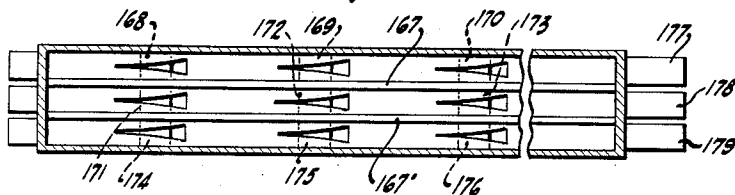


FIG-10

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PHOTOELECTRIC APPARATUS FOR GENERATING MUSICAL TONES

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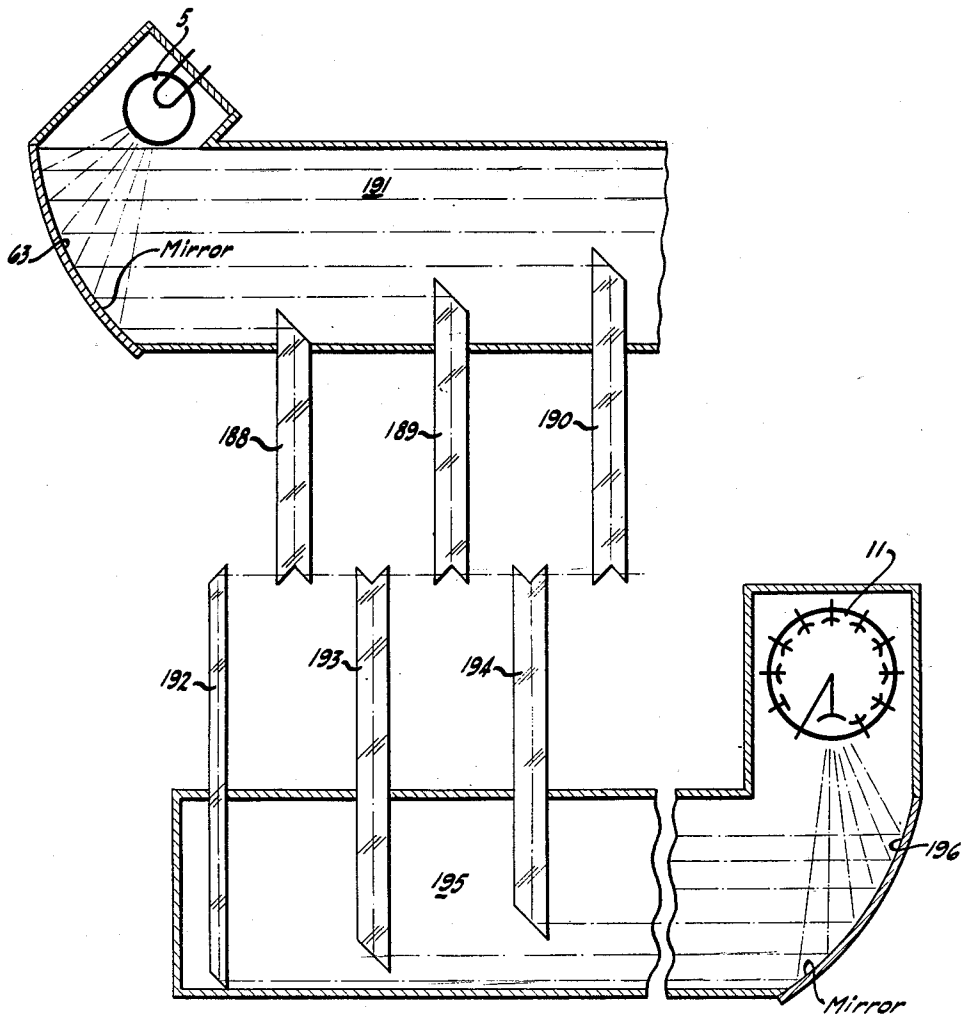


FIG-12

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PHOTOELECTRIC APPARATUS FOR GENERATING MUSICAL TONES

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Filed Oct. 31, 1955, Ser. No. 543,865

6 Claims. (Cl. 84—1.18)

This invention relates to electrical musical instruments; and in particular to improved means in such instruments for producing complex tonalities simulating orchestral music; to improvements in optical systems for photoelectric musical instruments, preferably of the rotating disc type; and to improvements in driving mechanisms for rotating the modulation discs in such instruments.

An object of this invention is to provide an improved electrical musical instrument for simulating the tones of orchestral and other instruments more faithfully than has been possible heretofore.

Another object is to provide an electrical musical instrument for simulating the composite tonalities produced by groups of orchestral or other instruments, including entire symphony orchestras or orchestral sections.

Another object is to provide an electrical musical instrument having great musical resources, particularly with respect to the number and variety of complex tonalities that may be produced, which is sufficiently simple and convenient to operate that such resources can be effectively utilized by a musician of reasonable proficiency.

Another object is to provide a musical instrument on which a person with modest training and ability can produce tones which can be produced on conventional instruments only after long practice by able musicians.

Another object is to provide an electrical musical instrument having a stop or timbre-control system for simulating a plurality of different instruments simultaneously, in which the stop adjustments are additive so that an adjustment for simulating one instrument can be made without disturbing previously-made adjustments for simulating other instruments, and without "robbing" the tones representing such other instruments.

Another object is to provide an electrical musical instrument in which the timbre or tone color may vary as a function of pitch.

Another object is to provide an improved musical instrument that may be constructed in a variety of sizes, ranging from small inexpensive accordion-size portable instruments having limited musical resources to large console instruments for simulating organ and symphonic music.

Another object is to provide an improved electrical musical instrument that is exceptionally compact, light and economical to manufacture, considering its musical capabilities.

Another object is to provide an improved electrical musical instrument that is rugged, that does not require tuning, and that requires a minimum amount of service and maintenance.

Another object is to provide a photoelectric musical instrument having an improved optical system that permits a compact and economical construction, that is easily linked to the keys of piano and organ type keyboards by simple mechanical linkages, and that consumes but a small amount of electric power.

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Another object is to provide an improved photoelectric musical instrument that is substantially free from difficulties due to the presence of dust and other foreign substances, and is unaffected by temperature and humidity changes.

Another object is to provide a musical instrument having an exceptionally wide dynamic range with a large signal-to-noise ratio.

Still another object is to provide a rotating-disc type of musical instrument having an improved driving mechanism for rotating the discs.

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

Briefly stated, in accordance with one aspect of this invention, signals representing different basic complex tonalities are generated simultaneously and are combined to produce a composite musical tone. Preferably, each basic tonality simulates a different orchestral instrument or a group of instruments, and the composite tone may simulate an entire orchestra. The timbre or character of the composite tone is controlled by a stop or timbre-control system for adjusting the relative amplitudes of the basic signals. For example, a signal simulating the tonality of a violin or orchestral string section may be controlled by a single stop adjustment mechanism, so that the musician can provide more or less of the violin tonality by changing a single stop adjustment. The stop adjustments can be changed individually.

This arrangement has many advantages over harmonic synthesis methods for complex tone generation often used in electric organs; especially with respect to playing convenience and the demands made upon the capabilities of the musician, which are limited even in the case of the most accomplished musicians by limitations of the human body. Since instruments embodying principles of this invention have stop systems that can be adjusted much more quickly and conveniently than is the case with instruments using harmonic synthesis methods, stop or timbre changes can be made with much less interruption of the musical composition. The stop adjustments are additive, so that the adjustment controlling tones simulating one instrument or group of instruments can be changed without affecting previously-made stop adjustments or the tones simulating other instruments for which the stops have previously been set. Furthermore, the selection of unpleasant or undesirable tone combinations is automatically made difficult.

A different basic tone signal can be provided to simulate each individual instrument of an orchestra or orchestral section. To a limited extent this may be desirable to provide facilities for simulating solo renditions. However, the structure and playing of the electrical musical instrument can be greatly simplified by providing basic signals that simulate groups or families of instruments. According to another aspect of this invention, the orchestral instruments are grouped into families in which each family consists of a plurality of instruments having tonalities which are similar in quality or timbre, but which differ chiefly in register. A basic signal is provided with a timbre representative of a family of instruments, such as the string family. This basic signal closely approximates the timbre of any instrument within the family. The musician can produce more or less of the string-section tonality by changing a single stop adjustment. With this arrangement, all of the undamped or non percussive tones of a symphony orchestra can be produced with as few as six basic timbres.

It should be realized, however, that certain principles of this invention can be used in instruments using harmonic synthesis methods of complex tone generation. When harmonic synthesis is employed, a signal may be

provided having the fundamental frequency of a selected pitch, and other signals may be provided having frequencies corresponding to different overtones of the same pitch. The improved photoelectric tone generation apparatus herein described provides significant advantages in such a system—for example, the basic signals generated may be combined optically in a truly additive manner without the “robbing” difficulties often encountered in other electrical musical instruments. Also, properly pitched harmonic and non-harmonic overtones can be provided in a relatively simple and convenient manner.

A modified harmonic synthesis system may be especially advantageous in small, low-cost instruments. One signal may be used to represent the fundamental, and one or more other signals may be used to represent selected combinations of overtones, with or without a fundamental frequency component in each overtone signal.

In addition to the basic timbres or signals used to simulate the undamped tonalities of orchestral music, other signals may be provided if desired to simulate damped or percussive tones, and also to produce novel or unconventional tones not usually produced by presently-known orchestral instruments.

In accordance with another aspect of this invention, an improved photoelectric musical instrument is provided in which basic tones are produced by the modulation of light beams, preferably by a plurality of parallel coaxial rotative tone discs each carrying a plurality of concentric circular modulating tracks each having an optical transmittance that varies along the length of the track. These tracks preferably are of the variable-density type, although variable-area or other types of modulating tracks may sometimes be used. In a preferred embodiment, there is a tone disc for each different pitch, and the discs are rotated at different constant speeds by driving mechanisms hereinafter described. On each disc there is a light-modulating track for each basic timbre. Electric lamps are used as a light source or light sources, and one or more photoelectric transducers are provided to convert modulated light into electric signals.

Novel light-transmitting systems herein described define a plurality of light beam paths passing between the parallel discs and crossing respective ones of the modulation tracks, so that a plurality of modulated light signals are provided to represent the different basic timbres of each pitch. The quality or timbre of a composite tone is preferably controlled by adjusting the relative amounts of light transmitted through tracks representing different basic timbres.

The improved optical systems are sufficiently compact that the average spacing between tone discs is equal to the average spacing between keys of a standard piano or organ-type keyboard, so that a simple and fast-acting keying system is made possible. In the improved optical system, each electric lamp supplies light to a plurality of tracks carried by different tone discs, so that the number of lamps required is small, which is particularly advantageous in simplifying maintenance and in reducing the electric power consumption and the attendant production of heat.

In accordance with still other aspects of this invention, a step-like array of distribution mirrors is used to provide parallel light beams passing through alternate ones of the spaces between the rotative tone discs, and V-shaped mirrors positioned between the tone discs are employed to split each of these beams into two parts passing in opposite directions through tracks carried by adjacent ones of the discs. Other V-shaped mirrors and a similar step-like array of mirrors may be used in collecting the modulated light transmitted by the modulation tracks. Adverse effects of dust and the like are minimized by the use of photographically produced transparent optical

apertures, and, if desired, by enclosing and sealing the optical system.

In accordance with still another aspect of this invention, a plurality of modulation tracks are provided to simulate the musical tones of different pitch that may be produced by an orchestral instrument or group of instruments. The modulation tracks for different pitches are similar in that they simulate tones produced by the same instrument or group of instruments, but they differ in timbre or harmonic content to simulate the variations of tone color as a function of pitch that are found in actual orchestral instruments.

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 an electrical musical instrument embodying principles of this invention;

Fig. 2 is a schematic plan view, partly in section, of a novel optical system for the same musical instrument;

Fig. 3 is a section taken generally along the line 3—3 of Fig. 2;

Fig. 4 is a detail showing one of the keying shutters of the same instrument;

Fig. 5 is a detail showing an alternative keying shutter;

Fig. 6 is a transverse section of a tone disc of the same musical instrument;

Fig. 7 is a schematic plan view illustrating a preferred drive mechanism for rotating the tone discs;

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

Fig. 9 is a schematic plan view showing an alternative optical system for the improved musical instrument;

Fig. 10 is a schematic plan view, partly in section, showing another alternative optical system for the improved musical instrument;

Fig. 11 is a section taken along the line 11—11 of Fig. 10; and

Fig. 12 is a schematic plan view, partly in section, showing still another alternative optical system for the improved musical instrument.

Reference is now made to Fig. 1 of the drawing, which is a simplified schematic and circuit diagram of the improved musical instrument, including one tone disc for producing one musical pitch of various timbres. Other tone discs are provided (as is shown in subsequent figures of this application) for producing other pitches; there being, in general, one or more tone discs for each pitch. For example, an instrument for simulating organ pitch will generally cover a range of sixty-one different pitches or semitones, and will have sixty-one or more tone discs, although in certain circumstances tones of two or more different pitches may be placed upon each disc so that a smaller number of discs may be used. A larger number of discs is employed when the number of different timbres or tonalities of each pitch, or the number of keyboards used in the instrument, is sufficiently great that more than one tone disc may more conveniently be used for each pitch.

The instrument illustrated in Fig. 1 has two standard piano or organ-type keyboards, and is capable of producing three different timbres of each pitch. However, a larger number of timbres may be provided by adding additional modulation tracks to each disc, or by increasing the number of discs, and ten or more different timbres of a given pitch may easily be accommodated on a single tone disc of reasonable size.

The tone disc 1 is rotative about a shaft 2, and is driven at constant speed by suitable means such as a motor 3 and a driving wheel 4. Tone disc 1 carries three concentric circular modulations tracks each having a circular modulated section with an optical transmittance that varies along its length in accordance with a different

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musical tone, preferably three different timbres of the same musical pitch. The tracks may also have unmodulated—opaque, for example—sections for purposes hereinafter described.

Light is produced by six electric lamps, identified in the drawing by reference numerals 5, 6, 7, 8, 9 and 10. There is also provided two photoelectric transducers 11 and 12, which preferably are photomultiplier tubes, for converting modulated light into electric signals.

An optical transmission system hereinafter described defines a plurality of optical paths between each of the lamps 5, 6 and 7 and the transducer 11. These paths cross modulated sections of respective ones of the modulation tracks carried by tone disc 1, and are normally blocked by a keying shutter 13. Shutter 13 has three optical apertures as shown, and is mechanically linked to a playing key 14 in one keyboard of the instrument. Key 14 may be a key of a manual keyboard, or it may be a pedal of a pedal clavier.

When key 14 is depressed, the apertures of shutter 13 are simultaneously moved into alinement with optical paths from lamps 5, 6 and 7 that cross modulated sections of the three modulation tracks carried by disc 1, so that these three paths are simultaneously unblocked and modulated light of three different basic timbres or tonalities reaches transducer 11 when all three of the lamps 5, 6 and 7 are lit. The amount of light transmitted in each of these three paths can be adjusted in a manner hereinafter described, by adjusting the relative amounts of electric current flowing through lamps 5, 6 and 7 for example, to control the relative intensities of the three basic tonalities that make up a composite timbre of the musical tone produced by the instrument.

A similar optical transmission system defines optical paths between lamps 8, 9 and 10 and the transducer 12, which paths preferably cross the same modulated sections of the tracks carried by disc 1. These latter paths are normally blocked by a shutter 15 which has three apertures, as shown, and which is linked to a playing key 16 in a second manual keyboard or pedal clavier. The current supplied to lamps 8, 9 and 10 may be adjusted individually so that a different composite timbre or combination of basic tonalities is produced when key 16 is depressed than is produced when key 14 is depressed.

Operating voltages for the photomultiplier transducers 11 and 12 are supplied by a power supply 17 through conventional resistance-type voltage dividers as shown. The anode or photomultiplier 11 is connected to an amplifier 18 and supplies thereto an electric signal corresponding to the composite modulation of the light received by photomultiplier 11. The output of amplifier 18 is connected to a volume control 19, which may be a resistance-type voltage divider having a movable tap 20 linked to a swell pedal 21 which may be operated to control the over-all volume of sound produced when key 14 is depressed. Similarly the anode of photomultiplier 12 is connected to an amplifier 22 which supplies an electric signal to a volume control 23 having an adjustable tap 24 linked to a second swell pedal 25 which may be operated to control the over-all volume of sound produced when key 16 is depressed.

The two volume controls may be connected as shown to any signal modifiers 26 that it may be desired to incorporate in the instrument. The signal modifiers may include reverberation devices, vibrato and tremolo producing apparatus, formant circuits, and the like. Such signal modifiers are known to those skilled in the art, and need not be described for an understanding of the present invention. For example, a reverberation device which may be employed is described 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 passing through the signal modifiers, the composite electric signal is further amplified by an amplifier 27 and supplied to one or more

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loud-speakers 28 which convert the electric signals into sound waves.

The composite timbre or tonality produced when either or both of the keys 14 and 16 are depressed is controlled by a stop system that preferably includes means for individually adjusting the relative amounts of electric current supplied to the lamps 5, 6, 7, 8, 9 and 10. Alternating electric current is supplied to leads 29 and 30 from any suitable source such as a commercial 60-cycle electric outlet. Connections are made to leads 29 and 30 for supplying electric power to the power supply 17 and to other power supplies, not shown, for the amplifiers and other electrical components of the musical instrument.

Electric current is supplied to the lamps 5 through 10 by means of a transformer having a primary 31 connected to leads 29 and 30, as shown. This transformer has a tapped secondary 32 connected to a plurality of distribution lines 33, 34, 35 and 36, of which line 36 is a common line connected to one terminal of all the lamps 5 through 10. In this way different alternating voltages are supplied between line 36 and each of the lines 33, 34, and 35. Preferably the secondary taps are so spaced as to provide equal increments in loudness between successive taps.

The second terminal of each lamp is connected to a respective one of a plurality of individually adjustable selector switches 37, 38, 39, 40, 41 and 42, each having three terminals connected to respective ones of the distribution lines 33, 34 and 35 and having a fourth terminal that is connected to none of the distribution lines, or alternatively is connected to line 36. By means of these selector switches, the voltage supplied to each lamp can be adjusted individually to zero or to any one of the voltage values appearing between line 36 and the distribution lines 33, 34, and 35.

In this way the voltage supplied to each lamp, and hence the current supplied through each lamp and the amount of light produced by the lamp, can be individually adjusted to control the relative amounts of light transmitted through different ones of the optical paths. Selector switches 37 through 42 are parts of a stop system for controlling the composite timbre of musical tones produced by the instrument. They may be mechanically connected to drawbars, dials or any other convenient adjustment mechanism placed in position readily accessible to the musician.

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 the lamps with direct current or with high frequency alternating current to eliminate any possibility of hum from this source.

Since an optical path from each of the lamps 5, 6, and 7 crosses a different one of the three light-modulating tracks carried by disc 1, which tracks are modulated in accordance with different timbres, the composite timbre of the tone produced when key 14 is depressed can be controlled by adjusting the switches 37, 38 and 39. In the same way, the composite timbre of the tone produced when key 16 is depressed can be controlled by adjusting the switches 40, 41 and 42. The loudness of each of these tones is individually controlled by the two swell pedals 21 and 25, so that the musician can produce at will a great variety of composite timbres from the three basic timbres represented by the modulation of the three tracks.

Numerous modifications of the instrument are possible without departing from the broader principles of this invention. The stop system may be modified, for example,

by the use of optical wedges and the like to adjust the relative amounts of light transmitted through the different optical paths instead of using the selector switches 37 through 42 for adjusting the relative amounts of current supplied to the various lamps.

According to another alternative, separate photoelectric transducers may be provided to receive the light from each path, and the timbre of the composite tone can be controlled by adjusting the relative amplitudes of the different electric signals so produced. The swell pedals can also operate optical wedges for adjusting the amount of light reaching photoelectric transducers 11 and 12 instead of adjusting the taps of voltage dividers 19 and 23. As still another alternative, other means for controlling the amplitudes of the electrical signals may be used in place of the resistance-type voltage dividers, such as variable capacitances in feedback circuits of amplifiers 18 and 22.

If desired, the signals from amplifiers 18 and 22 may be combined before such signals are supplied to the volume control operated by the swell pedal, in which case a single swell pedal may be used to control the overall amplitude of the composite signal, and hence to control the over-all loudness of the musical tone. Alternatively, signals may be combined by using a single photoelectric transducer receiving light from all six of the lamps 5 through 10.

In a simple instrument having only a single keyboard, lamps 8 through 10, photoelectric transducer 12, and circuit elements associated therewith, may be omitted. Conversely, if more than two keyboards are desired, additional lamps and transducers may be provided using, if necessary, additional rotative discs carrying modulation tracks which may be identical to, or different from, the modulation tracks carried by disc 1.

Within the broader aspects of this invention, the tone discs may be replaced by other moving parts carrying endless modulation tracks, such as rotating drums, endless loops of film, or the like; or rotating discs may be used in arrangements other than the parallel, coaxial arrangement herein specifically described, and with optical systems other than those herein disclosed. Certain of the inventive principles herein disclosed and claimed, especially those principles relating to the production of composite timbres from selected basic timbres and to the choice and arrangement of modulation tracks, are equally applicable to photoelectric musical instruments having stationary tracks scanned by moving light beams, such as those disclosed in my copending patent application entitled "Moving-Beam Photoelectric Musical Instrument," Serial Number 543,948, filed October 31, 1955 and to other musical instruments not necessarily of the photoelectric type.

The light-modulating tracks carried by disc 1 are endless concentric circular tracks which may each have a width of about one centimeter, so that ten such tracks may conveniently be carried by a disc having a radius of about five inches. Modulated sections of the tracks have an optical transmittance that varies along their lengths, and preferably are of the variable-density type well known in sound-on-film recording, although modulation tracks of other types such as variable-area tracks may be used under certain circumstances. Variable density tracks are preferred, since with variable-area tracks distortion due to peak-clipping may occur during keying unless more elaborate keying systems are employed to uncover the entire width of a modulated section simultaneously. Each track is generally modulated with a large integral number of wavelengths of the fundamental frequency. Preferably each track is of the multi-section type described in my copending patent application entitled "Progressively Keyed Electrical Musical Instrument," Serial Number 543,949, filed October 31, 1955.

Various forms of shutters 13 and 15, and various means for linking these shutters to the keys 14 and 16,

may be employed, as is more fully described in my copending patent application Serial Number 543,949 above identified. In a simple musical instrument, the shutters may be linked to the keys by direct mechanical connections. The apertures of shutters 13 and 15 are normally, in the unkeyed or rest positions of the shutters, in alignment with circular unmodulated sections of the modulation tracks carried by disc 1. Whenever either of the keys 14 and 16 is depressed, the apertures of the shutter linked thereto are moved into alignment with modulated sections of the modulation tracks so that a plurality of optical paths passing through respective ones of the modulated track sections are unblocked simultaneously.

In a preferred arrangement of the tracks, all of the tracks upon any one disc, such as disc 1, are modulated in accordance with various timbres of the same musical pitch—that is, all of the tracks carried by any one disc represent musical tones having the same pitch or fundamental frequency, but having different timbres or harmonic contents. For example, one track may be modulated in accordance with the musical tone produced by playing a selected note on a violin, while another track carried by the same disc may be modulated in accordance with the tone produced by playing the same note on a trumpet, while a third track upon the same disc may be modulated in accordance with the tone produced by playing the same note on a flute. Corresponding tracks carried by other rotative discs are modulated in accordance with the musical tones produced by playing some other note on a violin, a trumpet, and a flute, respectively. Other instruments may be represented in the same way by adding additional modulation tracks, lamps, and associated parts.

Whenever either of the keys 14 and 16 is depressed, optical paths through tracks modulated in accordance with violin, trumpet and flute tones of similar pitch are unblocked simultaneously. The relative amplitudes of the violin, trumpet and flute tones produced when key 14 is depressed are controlled by adjustment of selector switches 37, 38 and 39. Similarly, the relative amplitude of the violin, trumpet and flute tones produced when key 16 is depressed are controlled by adjustment of selector switches 40, 41 and 42.

The total amount of modulated light reaching the transducer 11 or the transducer 12 is the sum of the modulated light passing through the violin, trumpet and flute modulation tracks, so that an additive tone system is provided for producing a signal having a composite timbre similar to that produced when a violin, a trumpet and a flute are played simultaneously. Since the modulated sections of the tracks are modulated in accordance with the tones produced by actual orchestral instruments, a very good simulation of orchestral music can be produced. By providing a sufficient number of modulation tracks, every instrument of a symphony orchestra can be represented. If desired, non-orchestral instruments may be represented by certain of the modulation tracks, and tracks may be provided for producing tones that do not correspond to those of any presently-known instrument.

To provide a separate modulation track for each pitch of every instrument represented in a large symphony orchestra would require the use of a large number of tracks, as well as a large number of lamps and other components. To reduce the number of tracks required, advantage may be taken of the fact that the many instruments represented in a symphony orchestra can be grouped into families of instruments having similar characteristics of tone color and the like, and differing from one another chiefly in register. Consequently a very good simulation of orchestral music can be produced by an electrical musical instrument of the type herein described having a relatively small number of light-modulating tracks, each of which is modulated in accordance with a tone representative of a family of instruments.

In a preferred grouping of orchestral instruments in accordance with this invention, the orchestral instruments

which produce undamped tonalities are grouped into six families, as follows:

- (1) String family:
 - (a) Violins and violas
 - (b) Cellos and double basses
- (2) Flute family: Flutes and piccolos
- (3) Single reed family: Clarinets
- (4) Double reed family:
 - (a) Oboes and English horns
 - (b) Bassoon
- (5) Mellow brass family: French horn
- (6) Brilliant brass family:
 - (a) Trumpets and cornets
 - (b) Trombones and tubas

A seventh family may be added for the tonality produced by an organ diapason, but this tonality can be formed by combinations of other timbres, and consequently it is not essential that separate modulation tracks be provided to produce the organ diapason tonality.

By classifying orchestral instruments into families as above described, and by providing modulation tracks modulated in accordance with timbres representative of each family, all of the undamped tonalities of symphonic orchestral music can be simulated with an electrical musical instrument having only six modulation tracks per note.

With reference to the instrument illustrated in Fig. 1, for example, the innermost track carried by tone disc 1 may have a section modulated with a tone color or timbre representative of the flute family, the middle track may have a section modulated with a tone color or timbre representative of the single reed family, and the outermost track may have a tone color or timbre representative of the string family. Another similar instrument, or additional tracks carried by each tone disc of the same instrument, may simulate the double reed, mellow brass and brilliant brass families.

In addition to simplifying the construction of the instrument, this classification also simplifies the musician's task in operating it, since stop settings are required only for whole families of instruments, rather than for individual instruments.

If an even better simulation of orchestral music is desired, the string, double reed, and brilliant brass families may each be further sub-divided into two sub-families, as is indicated by the subparagraphs (a) and (b) under each of these family classifications in the listing hereinbefore given. With this subdivision, nine modulation tracks per note are needed to reproduce all of the undamped tonalities of an orchestra.

Other modulation tracks may be added, if desired, to represent the tonalities of the organ diapason and the damped tonalities produced by the percussive instruments such as the piano, harp, kettle drum, and the like, as well as the tonalities of non-orchestral instruments and novel tonalities not produced by presently-known musical instruments.

Although principles of this invention may be used to construct an electrical musical instrument capable of simulating an entire orchestra, it may in some cases be desirable to construct electrical musical instruments for simulating only a single orchestral instrument or a relatively small group of such instruments. For example, one electrical musical instrument may be made to simulate all of the different orchestral instruments in the string family, while another electrical musical instrument may be made to simulate all of the orchestral instruments in the flute and reed families, and yet another electrical instrument may be made to simulate the orchestral musical instruments in the brass families. A very few musicians playing together might then produce music comparable to that produced by a symphonic orchestra employing a much larger number of musicians. These electrical musical instruments can be substantially identical except for their modulation tracks, so that a

musician can switch from one instrument to another, or can alter his instrument by substituting a different set of tone discs with no impairment of his musical proficiency.

- 5 Modulation tracks may be provided to produce tones similar to those produced by solo instruments, or tracks may be provided for producing choral effects or tonalities similar to those produced by many instruments playing the same note at the same time. If desired, both
- 10 solo and choral modulation tracks may be provided in the same electrical musical instrument. Alternatively, all of the modulation tracks may represent solo instruments. Similarly, modulation tracks may be provided for producing tonalities including vibrato or tremolo effects, or vibrato effects and the like may be produced
- 15 by signal modifiers connected in the circuit at 26.

Various other arrangements of the modulation tracks are possible. For example, tracks modulated with pure sine-wave tones may be provided in which the tracks on

- 20 each disc represent different partials or harmonics of a note. The innermost track, for example, could be sine-wave modulated at the fundamental frequency, while other tracks are modulated in accordance with different overtones of the fundamental frequency. By adjusting
- 25 the selector switches 37 through 39 and 40 through 42, any desired timbre can then be formed by the well-known method of harmonic synthesis.

Instead of providing a separate modulation track for each overtone, groups of overtones may be combined on a single modulation track. In a small instrument,

- 30 for example, three tracks may be used for each pitch, in which the inner track is modulated at the fundamental frequency, the next track is modulated with a plurality of odd harmonics of the fundamental, and the third track
- 35 is modulated with a plurality of even harmonics of the fundamental. Although such a simple instrument would not simulate the tonalities of actual orchestral instruments as faithfully as larger and more complex instruments herein described, it would still provide resources
- 40 for producing a fairly large variety of interesting tonalities.

In a simple instrument, particularly in an instrument having only one keyboard, the number of rotative discs and other parts required may be reduced by placing

- 45 tracks representing more than one pitch upon the same disc. For example, the rotative disc 1 might carry six tracks, three of which represent tones of a given pitch, and the other three of which represent tones one octave higher in pitch. Shutter 13 could then be arranged to
- 50 key the tracks corresponding to one pitch, while shutter 15 could be arranged to key the tracks corresponding to the other pitch. Keys 14 and 16 would then be parts of the same keyboard, spaced one octave apart.

Conversely, in a large instrument having more basic

- 55 timbres or tonalities of each pitch than can conveniently be placed upon a single rotative disc, a plurality of discs may be provided for each pitch and each key may be linked to a plurality of shutters associated with different discs. Furthermore, extenders and couplers may be provided
- 60 for coupling together octavely related keys of the same keyboard, or for coupling together keys of different keyboards. In instruments having a large number of keyboards, including manual keyboards and pedal
- 65 claviars, separate tone generators may be provided for each keyboard or set of keyboards so that such an instrument is in effect a combination of several instruments which may be played from a single organ-type console.

Even in very large instruments, it may sometimes be desirable to place tracks representing tones of different

- 70 pitch upon the same tone disc. For example, a tone disc may carry tracks representing instruments playing in different registers—an octave apart, for example. Extenders and couplers linking different keys together may be used for the same purpose.

Reference is now made to Figs. 2 and 3, which show

a novel light-transmission circuit defining a plurality of optical paths from each of the lamps 5, 6 and 7 to the photoelectric transducer 11. The optical system shown in Figs. 2 and 3 provides twelve different pitches that preferably correspond to the twelve semitones in an octave of the equal-tempered musical scale. Additional pitches may be provided by extending the optical system shown to include a larger number of tone discs; by placing tracks representing a plurality of pitches on each disc; or by providing a plurality of optical systems similar to that shown in Figs. 2 and 3, one such system being provided for each group of pitches, which collectively cover a plurality of octaves. The instrument can be made in a variety of models of different size, ranging from small portable instruments having a relatively small number of tone discs and one keyboard to large concert instruments having a large number of tone discs and many keyboards.

Preferably one tone disc is provided for each pitch which is to be produced by the instrument. To provide the twelve pitches needed in a one-octave instrument, there are twelve tone discs, identified in the drawing by reference numerals 1, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, and 53. The tone discs are parallel and coaxial, and are rotated at different constant speeds by driving means hereinafter described. Each of the tone discs carries a plurality of modulation tracks, as hereinbefore explained, the different tracks on each disc being modulated in accordance with different timbers or tone colors of the same pitch.

The three lamps 5, 6 and 7 are enclosed in three lamp housings, 54, 55, and 56. These housings communicate with three input light chambers 57, 58, and 59, which are separated from one another by dividers 60 and 61, as is best shown in Fig. 3. The input light chambers 57, 58 and 59 are stacked in depth, as is best shown in Fig. 3, with a spacing corresponding to the spacing of the modulation tracks on the tone discs. With tracks one centimeter wide, for example, each of the input light chambers is approximately one centimeter deep. Since lamps 5, 6 and 7 ordinarily occupy a space greater than one centimeter in depth, the lamp housings 54, 55 and 56 are somewhat larger than the depth of the input light chambers, and to accommodate this larger size of the lamp housings the housings are staggered in the manner shown in Fig. 2. If desired, curved mirrors may be placed in the rear portions of the lamp housings which focus the lamp filaments upon themselves.

The various parts of the input light chambers are supported by a frame 62 having tongues extending parallel to the tone discs within alternate ones of the spaces between the discs, as shown. Light produced by lamp 5 is collimated by a mirror 63, which preferably is a segment of a parabolic cylinder with the filament of lamp 5 located at or near its principal focus. In actual practice, however, a segment of a right circular cylinder or other approximation of the parabolic form may be satisfactory for mirror 63. In a similar manner, light from lamp 6 is collimated by a mirror 64, and light produced by lamp 7 is collimated by a mirror 65. After leaving mirrors 63, 64 and 65, the collimated light travels in a direction substantially parallel to the common axis of the tone discs 1 and 43 through 53.

A plurality of distribution mirrors 66, 67, 68, 69, 70 and 71 are positioned in a stepwise staggered array, as shown, across and along the path of the collimated light beams, and are oriented at an angle substantially 45° to the direction of the collimated light so that a plurality of light beams are directed parallel to the tone discs within alternate ones of the spaces between the discs. To facilitate manufacture and optical alinement of the distribution mirrors, these mirrors preferably are made as parts of a single integral step-like member 72 having inclined risers which may be polished and silvered to

make reflecting surfaces. Alternatively, the distribution mirrors may be separate individual parts held in place by slots punched in the dividers 60 and 61 and in the frame 62. The same distribution mirrors preferably extend through all three of the input light chambers and thus form similar parallel beams in each of the light chamber tongues extending between the tone discs.

Mirror 66 directs a beam of collimated light parallel to and between the tone discs 1 and 43. A V-shaped beam-splitter mirror 73 positioned in the path of this beam and between discs 1 and 43 splits the beam into two parts and directs one such part through a modulation track carried by disc 1 and directs the other part through a modulation track carried by disc 43. Preferably, the V-shaped mirror 73 also extends into all three of the input light chambers, and it may consist of reflecting surfaces on a metal inset that fits within the frame 62. Alternatively, mirror 73 may be supported by V-shaped slots in dividers 60 and 61 and frame 62. Frame 62 has exit apertures adjacent to the beam-splitter mirrors to permit light to pass to the tone discs.

The beams directed through disc 1 are partially blocked by a keying shutter 13, so that only those portions of the light beams that pass through apertures of shutter 13 reach the modulation tracks of disc 1. Shutter 13 in its normal or rest position blocks the optical path through the modulated sections of the tracks, and permits light to pass only to unmodulated track sections. In other words, in the rest position of a keying shutter, its apertures are alined with unmodulated track sections, or, alternatively are alined with a mask to block the light beams.

When a key linked to shutter 13 is depressed, the apertures of shutter 13 are moved into alinement with modulated sections of the modulation tracks, and light thereupon passes through the tracks and is modulated in accordance with the musical tones represented by the variations in transmittance of the modulation tracks.

In a similar way, light is directed along a plurality of optical paths passing through each of the other tone discs and crossing respective ones of the modulation tracks carried thereby. For this purpose, other V-shaped mirrors 74, 75, 76, 77, 78 are positioned within alternate ones of the spaces between the tone discs in the manner shown. The paths through the modulated track sections are normally blocked by keying shutters 79, 80, 81, 82, 83, 84, 85, 86, 87, 88 and 89, each of which is linked to a different key of the keyboard and each of which has a plurality of apertures that become alined with and thus unblock the optical paths through modulated track sections when the associated key is depressed.

After passing through the modulation tracks, light enters an output light chamber 90, which is generally similar to the input light chambers 57, 58 and 59 except that the output light chamber does not have dividers corresponding to dividers 60 and 61 of the input light chambers. Consequently, there is only one output chamber, and this chamber has a depth equal to the combined depth of the three input light chambers. Light from the modulation tracks enters entrance apertures in the frame 91 and is directed along a plurality of paths parallel to the tone discs by a plurality of V-shaped mirrors 92, 93, 94, 95 and 96 positioned within other alternate ones of the spaces between the discs. The mirrors 97 and 98 at each end of the array of tone discs need be only half of a V, although V-shaped mirrors could be used in these positions for the purpose of reducing the number of different-shaped parts to be manufactured.

A steplike member 99 provides a plurality of mirrors or reflecting surfaces 100, 101, 102, 103, 104, 105 and 106 which combine the beams coming from between the tone discs into a beam traveling substantially parallel to the common axis of the tone discs. A condensing lens

107 and a mirror 108 direct this light to the cathode of photoelectric transducer 11.

As is best shown in Fig. 3, each of the tone discs, disc 46 for example, carries a plurality of concentric circular modulation tracks 109, 110 and 111 which are modulated in accordance with different timbres of similar pitch. The inner portion of each circular modulation track is an unmodulated, preferably opaque section, as is indicated by solid shading. Outer portions of each track, indicated by stippled shading, have an optical transmittance that varies or is modulated along the length of the track in accordance with the musical tone to be produced.

All of the tone discs may be identical, since notes of different pitch are produced by rotating the discs at different speeds in a manner hereinafter explained. Preferably, however, the corresponding tracks of different tone discs are modulated with somewhat different harmonic contents so that the timbre or quality of the tone produced varies somewhat from one pitch to another. Consequently, corresponding tracks represent similar timbres in that they simulate the same instrument or group of instruments, although the timbres are not identical. This corresponds to the variations in tone color from note to note that are found in conventional musical instruments; in consequence of which the electrical musical instrument embodying the principles of the present invention simulates the tonalities of other instruments more faithfully than can be accomplished with conventional prior-art electric organs.

Illustrative examples of the variations in harmonic content as a function of frequency encountered with orchestral instruments may be found, for example, on pages 216 through 230 of the book "Musical Engineering" by Harry F. Olson, 1st edition, McGraw-Hill Book Co., Inc., New York, 1952, and means are described on pages 214 through 216 of the same book whereby the frequency spectrum of any pitch of any instrument may be obtained. For purposes of the present invention, however, analysis of the frequency spectra is not necessary since the modulation tracks may be made from recordings of different notes played on orchestral instruments.

The keying shutter 82 carries a plurality of optical apertures that normally are alined with unmodulated sections of the tracks carried by tone disc 46. These apertures are also alined with the exit aperture in frame 62 through which light is directed toward the tone disc. When a key linked to shutter 82 is depressed, shutter 82 is moved upward, or radially outward with respect to disc 46, and the apertures carried by the shutter are moved into alinement with modulated sections of the tone disc tracks so that optical paths crossing a plurality of the modulated track sections are unblocked simultaneously. Consequently, when a key is depressed to move keying shutter 82 upward, light passes through the modulated sections of tone disc 46 into the entrance slit of the output light chamber 90, whereupon modulated light reaches transducer 11 to produce an electric signal corresponding to a desired musical tone. Chords may be played in the conventional manner by simultaneously depressing two or more keys of the same keyboard, or extenders may be used for linking two or more keys together.

A plurality of similar optical systems, usually two such systems, may be associated with one set of tone discs. The second optical system includes housings 112, 113 and 114 for the lamps 8, 9, and 10 shown in Fig. 1. A keying shutter 115 is linked to a key in the second keyboard, which may be either a second manual or a pedal clavier. When the key to which it is linked is depressed, shutter 115 moves downward, or radially outward with respect to disc 46, to bring its optical apertures into alinement with modulated sections of the tracks carried by tone disc 46.

Selector switches 37 through 42 of the stop system can be adjusted so that different composite timbres are pro-

duced when keys of the first and second keyboards, respectively, are depressed. Accordingly, the musician can set his stop system for two different composite timbres, and can produce either of these timbres at will by depressing a key in either the first or the second keyboard, or both composite timbres can be produced simultaneously to form a third composite timbre by simultaneously depressing keys in both keyboards. To hold the keying shutters in their normal rest or inward position when the keys are not depressed, a small spring 116 may be connected between the two keying shutters 82 and 115, as shown.

To exclude dust and other foreign substances, the optical systems may be enclosed and hermetically sealed. Bellows or the like may be provided to permit expansion and contraction of the gas within the system. The optical systems may be filled with air or any other transparent fluid. Alternatively, solid transparent materials may fill all or parts of the optical systems, as is herein-
after more fully explained.

The instrument described is exceptionally rugged, can be manufactured at reasonable cost, does not require tuning, and requires a minimum amount of service and maintenance.

Reference is now made to Fig. 4, which is a detail of the keying shutter 82. In a preferred form, a keying shutter includes an L-shaped metal supporting member or frame which is pivotally supported on a shaft 117. The metal frame has a relatively large rectangular aperture 118 which is covered by a strip 119 of photographic film or the like held upon the metal frame by suitable means such as rivets 120 and 121. Strip 119 is generally opaque, but has a plurality of small transparent areas forming optical apertures 122, 123 and 124 through which light passes to the modulation tracks carried by the tone disc. This arrangement is preferable to having optical apertures formed by cutting small holes in the shutter, since dust cannot enter the transparent apertures and consequently the light paths are less likely to be obstructed by dust or other foreign substances. The transparent apertures may be made photographically, by printing, or by any other suitable method of manufacture. Alternatively, small holes filled with transparent plastic may be used as optical apertures. In addition to the keying shutter apertures, other optical apertures of the instrument can be made in a similar manner.

Reference now is made to Fig. 5, which shows an alternative keying shutter mechanism. The keying shutter 125 is rotative about the shaft 2 which supports tone disc 46. A stationary mask 126 has a long narrow aperture 127 preferably extending in a direction radial to the tone disc 46. Keying shutter 125 has a plurality of diagonal apertures 128, 129 and 130. Light passes through shutter 125 and mask 126 only at the points where the keying shutter apertures are alined with the aperture 127 in the mask. In the normal rest or unkeyed position of shutter 125, the apertures 128, 129, and 130 are either completely out of alinement with aperture 127, or alternatively only the lower ends of the keying shutter apertures are alined with the mask aperture, so that light is transmitted only to unmodulated sections of the modulation tracks carried by the tone disc. Shutter 125 is linked to a playing key so that when the key is depressed shutter 125 moves counterclockwise and thus brings a different portion of the apertures 128, 129 and 130 into alinement with aperture 127. This is equivalent to moving a small aperture in the radial direction with respect to disc 46 in the manner of keying shutter 82, and permits light to cross modulated sections of the tone disc tracks.

Fig. 6 is a detail diametric section showing a preferred construction of a tone disc. A transparent disc 131 may be made of glass or other transparent material such as Mylar, polystyrene, or cellulose acetate. Disc 131 is secured to a hub 132 which may be made of metal, nylon

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or other suitable material, by a plurality of rivets 132'. Hub 132 is freely rotative on the metal shaft 2 which supports all of the tone discs. The modulation tracks are printed or are formed photographically on a film 133 carried by the disc 131. If desired, instead of using a film 133, a photographic emulsion may be coated directly upon the surface of disc 131. To inhibit shrinkage, buckling and other damage to the film 133, it may be covered by a coating 134 of cellulose acetate or other suitable material, preferably applied as a liquid and drying to a hard transparent solid. Hub 132 may be made sufficiently long to contact the opposite end of the hub of the next adjacent tone disc for the purpose of keeping the discs in the desired axially-spaced relation. Alternatively, the disc hubs may be somewhat shorter, and spacers, bearing supports, or other means may be used to position the discs on shaft 2.

The modulation tracks carried by film 133 preferably are photographic reproductions of a master tone disc which may be made, for example, using sound-on-film recording techniques, from recordings of tones played on the orchestral instruments that are to be simulated. Once a set of master tone discs has been prepared, reproductions in large quantities may be made at little expense for the economical mass production of electrical musical instruments embodying principles of the present invention. Alternatively, photoengraving techniques may be employed for making printed reproductions of the master tone discs, or other methods of tone disc manufacture may be used.

Reference is now made to Figs. 7 and 8 which shows a preferred driving mechanism for rotating the tone discs. The tone discs 1 and 43 through 53 are coaxial and axially spaced apart as hereinbefore explained. The average spacing between discs is preferably 0.55 inch, which corresponds to the average spacing between keys on a conventional piano or organ-type keyboard. In actual practice, some of the discs are spaced somewhat closer together than the average spacing, while others are spaced somewhat farther apart, to accommodate the optical system shown in Fig. 2 more conveniently.

A motor 3 is linked to a drive shaft 135 and rotates shaft 135 at a constant speed. Shaft 135 carries a plurality of driving wheels 4, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145 and 146, there being one driving wheel for each tone disc. Each of the driving wheels is of a slightly different diameter from the others so that the tone discs, which preferably are all of the same diameter, are driven at different constant speeds. Preferably, the diameter of one driving wheel is related to that of the next adjacent driving wheel by a factor equal to the twelfth root of two, which corresponds to the frequency spacing between adjacent semitones in the equal-tempered musical scale. It will be understood that tones of different pitches—for example, tones spaced one or more octaves apart—can be generated by tone discs rotated at equal speeds, but having tracks modulated with different, integral numbers of wavelengths.

The driving wheels are connected to the tone discs by a plurality of idler wheels, represented by reference numerals 147 through 158, which frictionally engage the driving wheels and the tone discs. Since the ratio of a tone disc speed to the speed of shaft 135 depends only upon the relative diameters of the tone disc and the associated driving wheel, and not upon the diameter of the idler wheel, so long as it is circular, the materials used are so chosen that most of the wear that occurs during operation of the instrument is upon the idler wheels rather than upon the driving wheels and the tone discs. The tone discs may be glass or a hard transparent plastic, and the driving wheels may be steel or other hard metal. The rims of the idler wheels may advantageously be covered with rubber or some other elastomer.

Each idler wheel is supported by arms loosely pivoted on a rod 159. Idler wheel 158, for example, is supported

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by a pair of arms 160 and 161 having slots as indicated at 162, Fig. 8, through which rod 159 passes. A spring 163 urges arm 160 downward to bring idler wheel 158 into firm frictional engagement with driving wheel 146 and into light frictional engagement with tone disc 53. Shaft 135 rotates in the direction indicated by arrow 164, so that rotation of the driving wheel also urges idler wheel 158 into engagement with the tone disc. However, the arrangement is such that idler 158 exerts only a small amount of force against tone disc 53, so that there is negligible tendency for the tone disc to bend or buckle.

Various changes and modifications can be made in the driving mechanism, including the use of gears and the like in place of frictionally engaged wheels. Frictionally engaged wheels have an advantage, however, in damping oscillations excited by fluctuations and vibrations in the driving mechanism. Modification can also be made in other parts of the instrument, and in particular with respect to the light chambers and optical systems. For example, a row of partially-reflecting mirrors might replace the stop-like array of distribution mirrors. If desired, the optical system shown in Figs. 2 and 3 may be enclosed in an hermetically sealed container, and may be filled with some other transparent fluid in place of air. Such sealing is especially advantageous in excluding dust, moisture and other substances that might affect the optics adversely.

Alternatively, solid transparent light-transmitting materials may be used in the light chambers in place of fluid fillings. For example, the light chambers shown in Figs. 2 and 3 may be completely filled with a transparent solid, as is illustrated in Fig. 9, for example, and the mirrors of the optical system may be reflecting surfaces formed on such solid material. The mirrors may be formed by polishing and silvering the desired surfaces of the solid light-transmitting material, or unsilvered surfaces may be employed with materials having a high refractive index such that substantially complete internal reflection occurs in rays having an angle of incidence to the surface of substantially 45°. The use of solid transparent materials for the light chambers has the advantage that such material may be cast or otherwise formed into the desired shape, and thereafter very little optical alignment is necessary in the assembly of the optical parts.

In Fig. 9, parts that are identical to parts shown in Fig. 2 are identified by the same reference numbers; and parts that are somewhat different in form but similar in function to parts shown in Fig. 2 are identified by the same reference numbers with a prime (') added. The three input light chambers are three comb-like transparent solid members 57', 58' and 59', which are preferably made of pure cast methyl methacrylate or an equivalent light-transmitting solid material having a high refractive index. Curved surfaces 63', 64' and 65' at the left-hand ends of members 57', 58' and 59' are silvered to form collimating mirrors that perform the same functions as mirrors 57, 58 and 59 of the embodiment shown in Fig. 2. Oblique surfaces 66' through 71' in the base of members 57', 58' and 59' serve as distribution mirrors to direct light beams along teeth or tongues of members 57', 58' and 59' extending between and parallel to the tone discs 1 and 43 through 53, as shown. Surfaces 66' through 71' are not necessarily silvered, since the angle of incidence of the collimated light to such surfaces, which is substantially forty-five degrees, exceeds the critical angle for a methyl-methacrylate-air boundary, in consequence of which total internal reflection of the light occurs. The inner ends 73' through 78' of the teeth or tongues of members 57', 58' and 59' are V-shaped, as shown, to form surfaces at which the light is again reflected internally, so that the light beam transmitted down each tooth is split into two parts which are directed toward adjacent ones of the tone discs. After the beams

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are split, they pass through the sides of the solid light-transmitting teeth substantially perpendicular thereto.

The output light chamber is a comb-like transparent solid member 90', preferably made of methylmethacrylate, having teeth or tongues which receive the light transmitted by the tone discs. Inner ends 92' through 98' of these teeth have inclined surfaces which reflect the light along the teeth to oblique surfaces 100' through 106' in the base of member 90', which again reflect the light through a condensing system to photoelectric transducer 11. The right-hand end 107' of member 90' is curved to form a condensing lens that performs the same functions as lens 107 of the embodiment illustrated in Fig. 2. The light-transmitting members 57', 58', 59', and 90' are supported by frame members, not shown, and the three input light-transmitting members are separated by opaque dividers.

Instead of filling the entire light chamber with transparent solid material, light pipes made of such material as pure cast methylmethacrylate may be employed. Such pipes may be bent to transmit light around corners and thus eliminate at least some of the mirrors from the optical system.

Figs. 10 and 11 illustrate an alternative optical system using both gas-filled chambers and solid transparent members for transmitting the light. Only five tone discs are shown, but it will be understood that any desired number of such discs may be provided, and that more than five tone discs will generally be provided, duplicate optical parts being inserted between the broken-off sections shown in Fig. 10. Parts identical to these in the embodiments hereinbefore described are identified by the same reference numbers.

In this alternative optical system, the three lamps 5, 6 and 7 of Fig. 1 are replaced by a single lamp 165 of an elongated type, such as a fluorescent or other gaseous conductor which provides an elongated light source having a length greater than the distance between the first and last of the parallel light beams entering the spaces between the tone discs. Elongated light sources of other types may be used, such as incandescent lamps placed behind a diffusing plate. Lamp 165 may be operated at constant brightness, or its brightness can be varied by means linked to the swell pedal for controlling the overall loudness of the composite musical tone produced by the instrument.

As shown in Fig. 10, lamp 165 is contained in the upper portion of an elongated input light chamber 166, having its lower portion divided into three sections by dividers 167 and 167', as is best shown in Fig. 11. Solid transparent rods or light pipes extend from input chamber 166 parallel to the tone discs 1, 43, 44, 45 and 46, between alternate ones of the spaces between the discs, as shown. The three light-transmitting rods 168, 169 and 170 are aligned with the outermost modulation tracks carried by the tone discs. Immediately below these three light-transmitting rods there are three similar rods 171, 172 and 173, the inner ends of which are aligned with the middle modulation tracks carried by the tone discs. Immediately below these rods is a third set of light-transmitting rods 174, 175 and 176 having their inner ends aligned with the innermost modulation tracks carried by the tone discs.

The outer ends of these nine light-transmitting rods are illuminated by lamp 165 through apertures carried by a plurality of adjustable sliding masks 177, 178 and 179, as shown, which are parts of a stop system for controlling the composite timbre of the musical tone produced by the instrument. Each of these masks has a plurality of tapered apertures, as is best shown in Fig. 11, aligned with respective ones of the light-transmitting rods. By moving each mask, the relative amounts of light transmitted to the outermost, middle, and innermost modulation tracks can be adjusted. Instead of tapered apertures, optical wedges or the like may be carried by masks 177,

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178 and 179 for adjusting the relative amounts of light supplied to the three sets of light-transmitting rods.

Each of the light-transmitting rods 168 through 176 has a V-shaped inner end which may be silvered to form a V-shaped beam-splitter mirror or reflecting surface which directs light through the tone discs in a manner similar to the operation of the V-shaped beam-splitter mirrors shown in Fig. 2. After passing through the tone discs, light enters another set of light transmitting rods 180, 181 and 182 which are generally similar to the light-input rods 168 through 176, except that each of the rods 180, 181 and 182 has a depth equal to the overall radial distance occupied by the modulation tracks. Rods 180, 181 and 182 transmit the light to an output light chamber containing mirrors 183, 184 and 185 which direct the light through a collecting lens 186 to the cathode of photoelectric transducer 11.

Since the light directed through the tone disc tracks may not be well collimated, to provide a satisfactorily small effective aperture for the modulation system the keying shutters may be modified in the following manner: Keying shutter part 13, for example, may be identical to the keying shutter 13 described in connection with Fig. 2, but linked thereto and on the other side of tone disc 1 there is a similar keying shutter part 13' having a plurality of optical apertures that are aligned with the apertures of shutter part 13. Shutter part 13' is linked to shutter part 13 by a connection 187 so that these two parts of the keying shutter move together. Of the light that is directed through tone disc 1, the only portion that reaches the output light chamber is that which passes through the apertures of both shutter parts 13 and 13', so that the effective aperture with respect to the modulation tracks carried by disc 1 is the small and well-defined path that is aligned with the apertures of both shutter parts. In a similar way, keying shutter part 79 has associated therewith another shutter part 79' upon the opposite side of tone disc 43, shutter part 80 has a second shutter part 80', shutter part 81 has a second shutter part 81', and shutter part 82 has a second shutter part 82'.

Still another alternative optical system is shown in Fig. 12. In this embodiment, in which parts identical to parts of embodiments hereinbefore described are identified by the same reference numbers, the lamp 5 and the mirror 63 produce a collimated beam of light traveling parallel to the axis of the tone discs, which are identical to the tone discs hereinbefore described and hence are not shown in Fig. 12. Extending into alternate ones of the spaces between the tone discs are a plurality of light-transmitting solid transparent rods 188, 189 and 190, which have V-shaped reflecting surfaces at their inner ends for directing light through the modulation tracks carried by the tone discs. The outer ends of rods 188, 189 and 190 extend for progressively greater distances into the input light chamber 191, so that each rod intercepts substantially the same amount of light from the collimated beam produced by lamp 5 and mirror 63. These outer ends of rods 188, 189 and 190 have oblique reflecting surfaces so that light received from the collimated beam is reflected along the length of the light-transmitting rods parallel to and between the tone discs.

A similar system is used to collect the light that passes through the modulation tracks. Transparent solid rods 192, 193 and 194 have at their inner ends V-shaped (or half V-shaped) reflecting surfaces which direct light from the tone discs along the lengths of rods 192, 193 and 194 parallel to the discs within alternate ones of the spaces between the discs. The output light rods 192 through 194 extend for progressively decreasing distances into the output light chamber 195, and the outer ends of these rods have oblique reflecting surfaces which direct the light down the length of the output light chamber substantially parallel to the axis of the tone discs. A collecting mirror 196 directs this light to the cathode of photoelectric transducer 11.

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 tone discs, and 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. An electrical musical instrument comprising at least one uniformly movable uniplanar member having an optical transmittance sound record thereon, a source of light having a beam substantially normal to the plane of said member, a first reflector spaced from said member, slightly offset from the plane thereof and in line with said beam, a second reflector adjacent said member and in line with said first reflector, a third reflector adjacent said member and on the opposite side thereof from said second reflector, a fourth reflector in line with said third reflector, and a photoelectric transducer in line with said fourth reflector.

2. An electrical musical instrument comprising at least two uniformly rotative parallel discs, each of said discs having an optical transmittance sound record thereon, a source of light having a beam of collimated rays substantially normal to the parallel planes of said discs, a first reflector spaced from a first one of said discs slightly offset from the plane thereof and in line with said beam, a second reflector adjacent to said first disc and in line with said first reflector, a third reflector adjacent to said first disc and on the opposite side thereof from the second reflector, a fourth reflector spaced from said first disc and in line with said third reflector, a fifth reflector spaced from a second one of said discs slightly offset from the plane thereof and in line with said beam, said first and fifth reflectors being in a stepwise arrangement relative to said beam, a sixth reflector adjacent to said second disc and in line with said fifth reflector, a seventh reflector adjacent to said second disc and on the opposite side thereof from said seventh reflector, an eighth reflector spaced from said second disc and in line with said seventh reflector, all of said eight reflectors being positioned in planes at 45° angles to the parallel planes of said rotative discs, a light collector in line with both of said fourth and eighth reflectors, said fourth and eighth reflectors being in stepwise arrangement relative to said light collector, and a photoelectric transducer in line with said light collector.

3. In an electrical musical instrument, the one-note, multi-timbre, tone-generating subcombination comprising a plurality of electric lamps, a photoelectric transducer producing electric signals responsive to modulated light, an optical transmission system defining a plurality of light-beam paths each extending from a different one of said lamps to said transducer, a support having thereon a plurality of modulation tracks each crossing a different one of said paths, each of said modulation tracks having an optical transmittance that varies along its length, the transmittance of said tracks being modulated in accordance with complex musical tones of the same pitch in all of said tracks and different timbres in different tracks, means moving said tracks relative to said paths in a direction lengthwise with respect to the tracks and transverse with respect to the paths for modulating the light in said paths, a note-playing keyboard key, a unitary keying shutter normally blocking and operable by said key to unblock a plurality of said paths simultaneously for producing a composite musical tone, circuit means for supplying electric current to said lamps, and separate adjustment means, one for each

lamp, for adjusting the amount of current to each individual one of said lamps for controlling the timbre of said composite tone.

4. In an electrical musical instrument, the one-note, multi-timbre, tone-generating subcombination comprising a plurality of electric lamps, a photoelectric transducer producing electric signals responsive to modulated light, an optical transmission system defining a plurality of light-beam paths each extending from a different one of said lamps to said transducer, a rotative member carrying a plurality of circular modulation tracks, each of said tracks crossing a different one of said paths, each of said modulation tracks having an optical transmittance that varies along its length, the transmittance of said tracks being modulated in accordance with musical tones of the same pitch in all of said tracks and of different timbres in different tracks, means rotating said member continuously at a constant speed for modulating the light in said paths periodically in accordance with said tones, a unitary keying shutter adjacent to said tracks and normally blocking a plurality of said paths, a keyboard key linked to said shutter and operable to move said shutter and simultaneously unblock a plurality of said paths for producing a composite musical tone, a plurality of current distribution lines, means supplying each of said lines with a different voltage, and switching means for connecting each individual one of said lamps to any selected one of said distribution lines for controlling the relative brightnesses of said lamps.

5. An electrical musical instrument comprising a plurality of members each carrying a plurality of light-modulating sound tracks representing complex musical tones, all tracks carried by the same one of said members being representative of the same note with different timbres represented in different tracks, corresponding tracks on different ones of said members being representative of different notes of similar timbre, a plurality of multi-beam light sources, each of said sources having different beams directed to the corresponding tracks carried by different ones of said members, the beams from different ones of said sources being directed to different tracks on each member, said members and said beams being relatively movable longitudinally of said tracks for modulating the light of said beams in accordance with said musical tones, a photoelectric transducer optically aligned with said tracks for receiving the modulated light transmitted thereby, a plurality of note-playing unitary shutters each adjacent to a different one of said members and normally blocking said light beams directed to that member, each of said shutters being individually operable to unblock simultaneously said light beams directed to that adjacent member for producing a complex musical tone representative of a selected note and a composite timbre, and a plurality of individual adjustment devices, one for each of said light sources, for adjusting the relative brightnesses of said light sources to controllably vary said timbre.

6. An electrical musical instrument comprising a plurality of parallel coaxial spaced-apart rotative discs, each of said discs carrying a track having an optical transmittance that is modulated in accordance with a musical tone, a lamp producing light, means directing said light in a collimated beam parallel to the axis of said discs, a plurality of mirrors positioned in a stepwise staggered array across and along said collimated beam to produce a plurality of spaced-apart parallel beams passing parallel to said discs within alternate ones of the spaces between said discs, a plurality of V-shaped mirrors positioned in said parallel beams within said alternate spaces to split each of such beams into two parts passing in opposite directions through tracks on adjacent ones of said discs, another plurality of V-shaped mirrors positioned within other alternate ones of said spaces for directing the light transmitted by said tracks in other parallel beams passing parallel to and between said discs,

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means including another plurality of mirrors arranged in a stepwise array for collecting the light from said other parallel beams, and a photoelectric transducer receiving the collected light.

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