

July 26, 1960

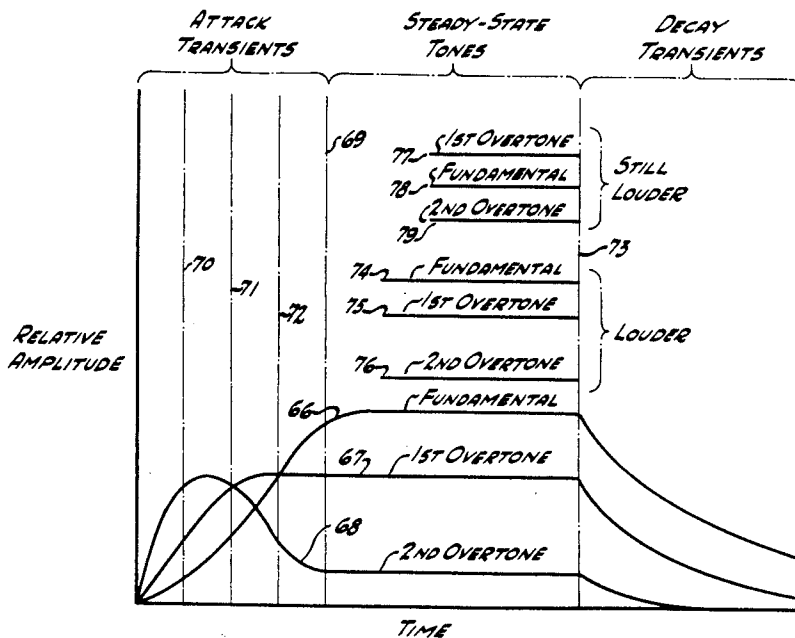
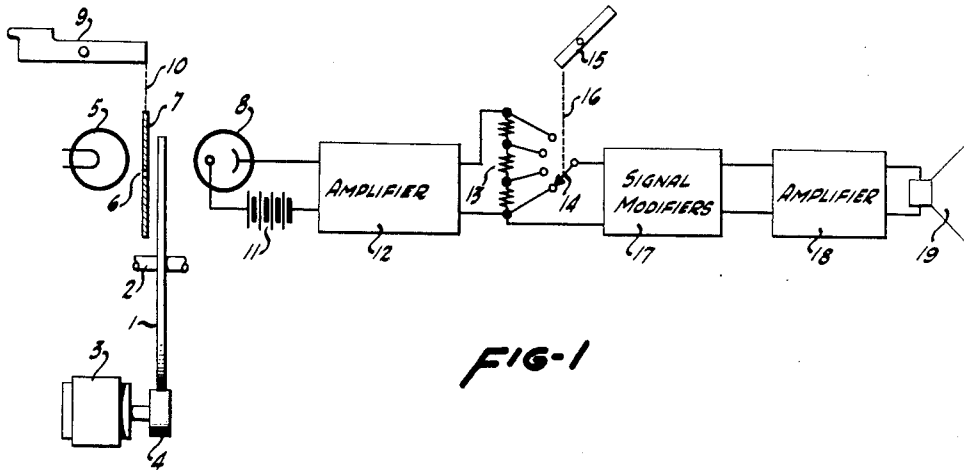
M. CLARK, JR

2,946,252

PROGRESSIVELY KEYED ELECTRICAL MUSICAL INSTRUMENT

Filed Oct. 31, 1955

6 Sheets-Sheet 1



INVENTOR.
MELVILLE CLARK, JR.
BY *Lippincott and Smith*
ATTORNEYS

July 26, 1960

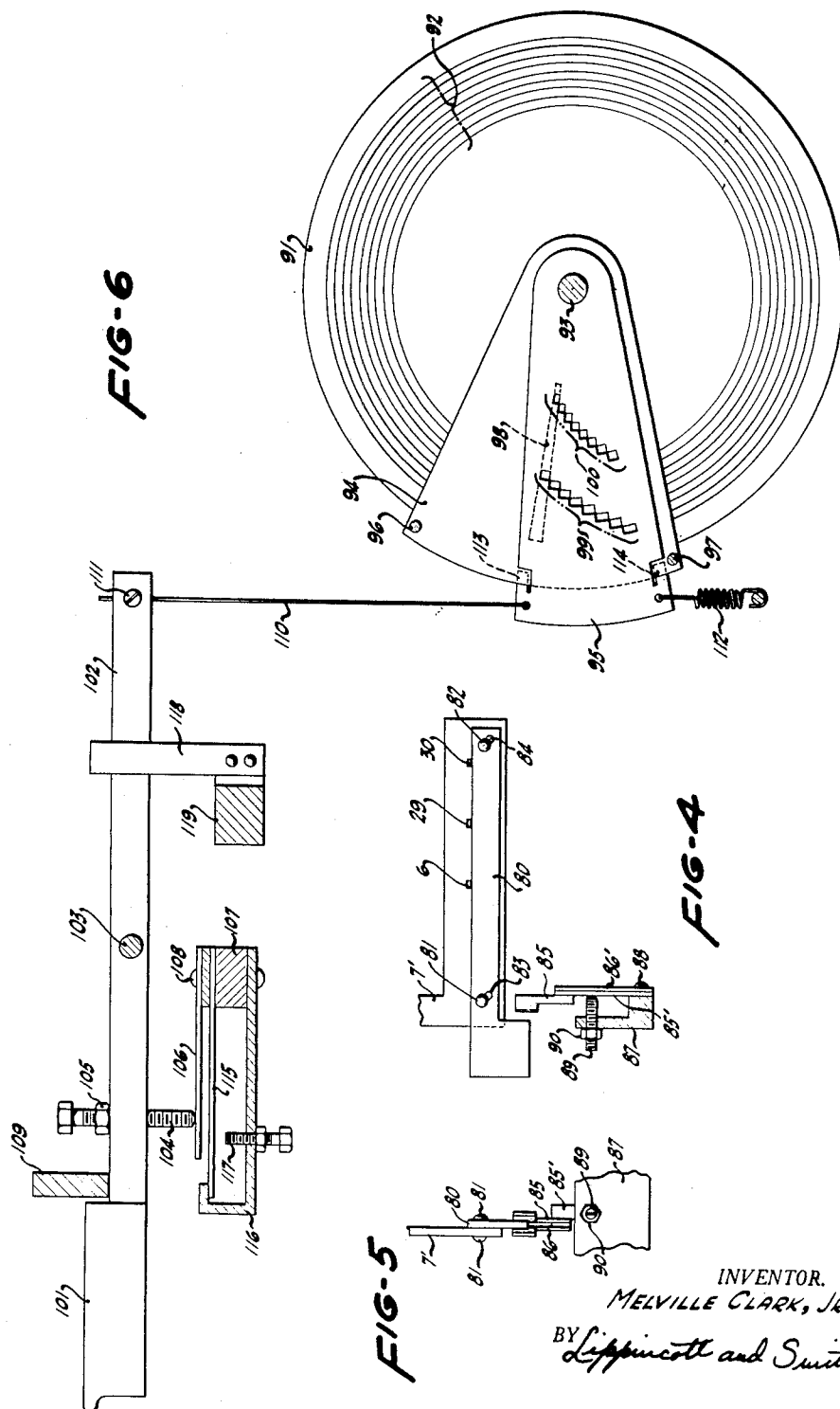
M. CLARK, JR

2,946,252

PROGRESSIVELY KEYED ELECTRICAL MUSICAL INSTRUMENT

Filed Oct. 31, 1955

6 Sheets-Sheet 3



INVENTOR.
MELVILLE CLARK, JR.
BY *Lippincott and Smith*

ATTORNEYS

July 26, 1960

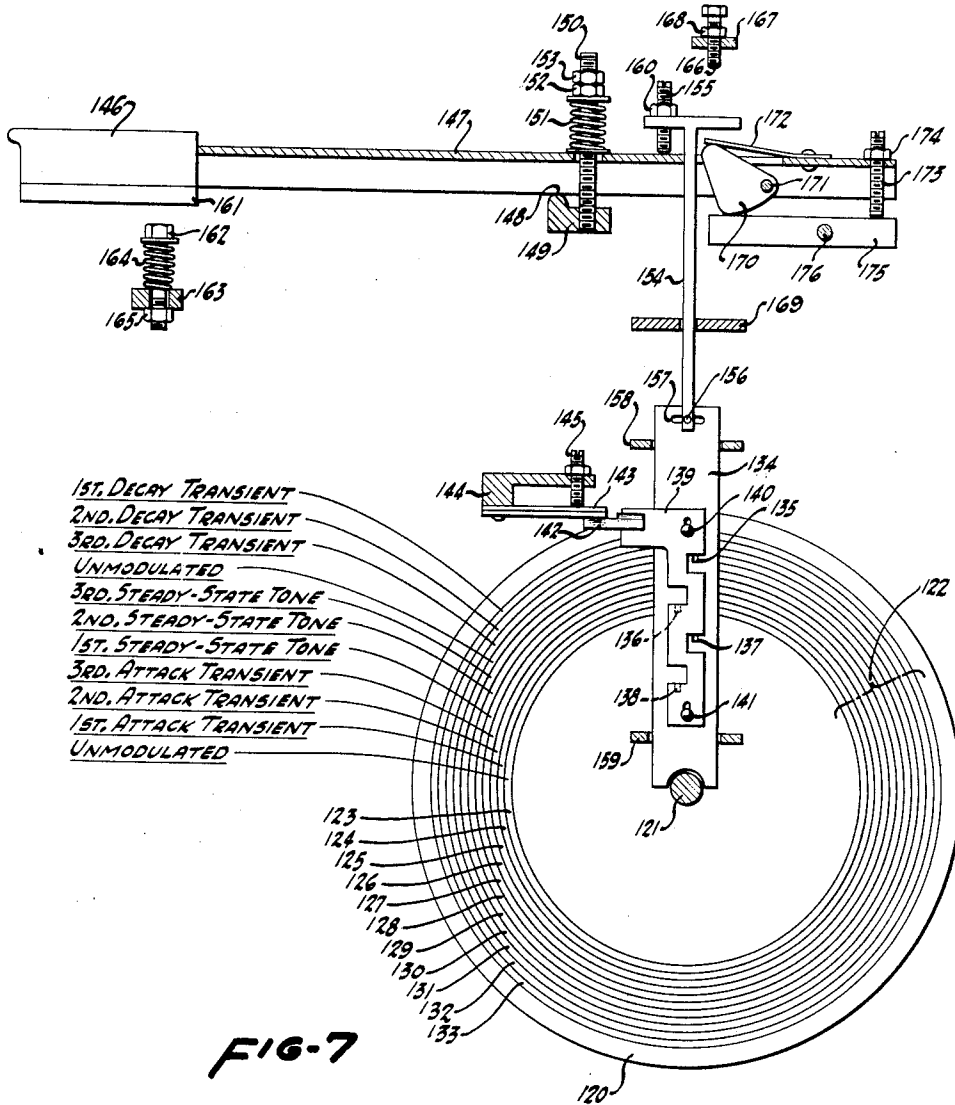
M. CLARK, JR

2,946,252

PROGRESSIVELY KEYED ELECTRICAL MUSICAL INSTRUMENT

Filed Oct. 31, 1955

6 Sheets-Sheet 4



INVENTOR.
MELVILLE CLARK, JR.
BY *Lippincott and Smith*
ATTORNEYS

July 26, 1960

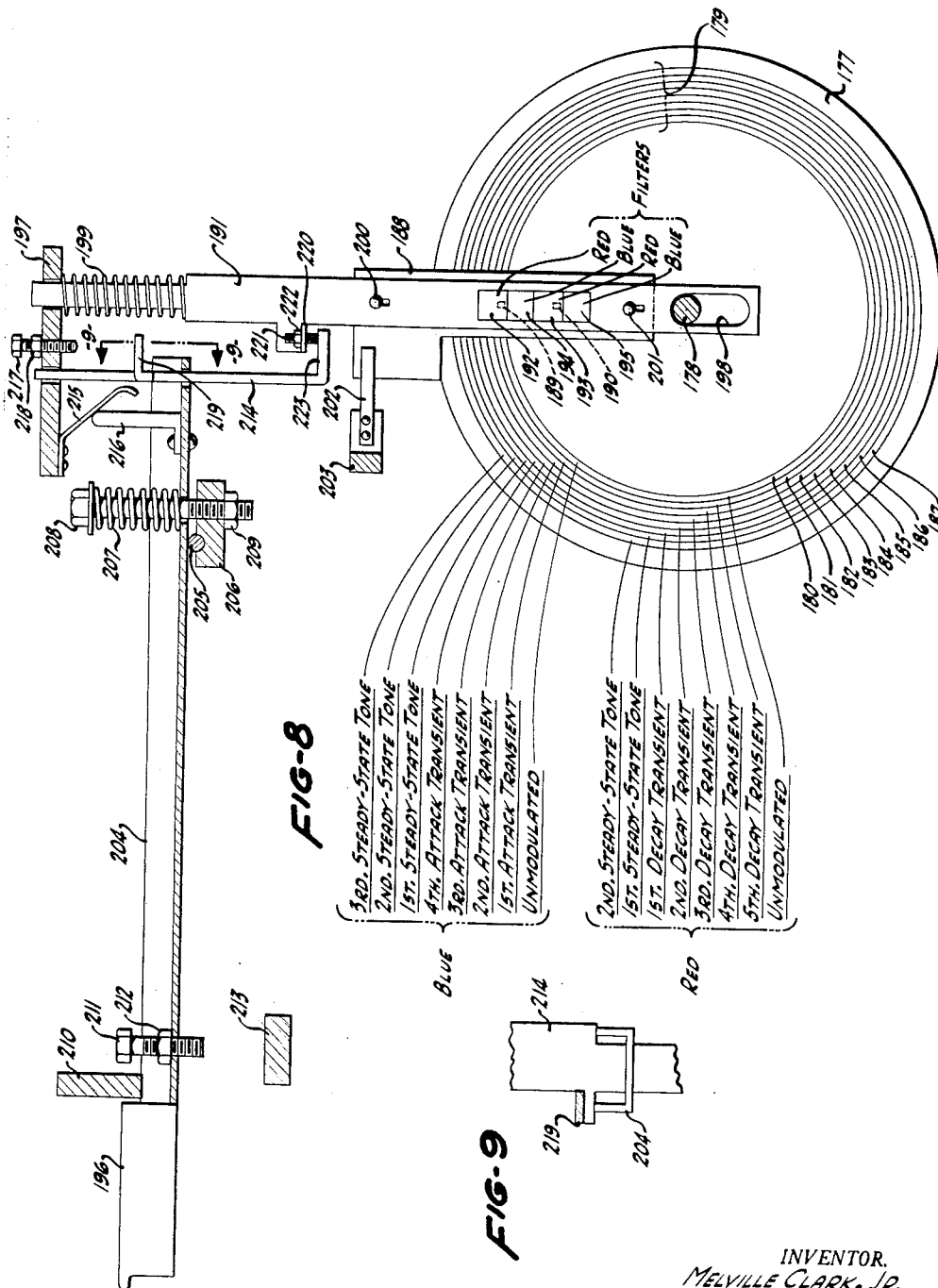
M. CLARK, JR

2,946,252

PROGRESSIVELY KEYED ELECTRICAL MUSICAL INSTRUMENT

Filed Oct. 31, 1955

6 Sheets-Sheet 5



INVENTOR.
MELVILLE CLARK, JR.
BY *Lippincott and Smith*

ATTORNEYS

July 26, 1960

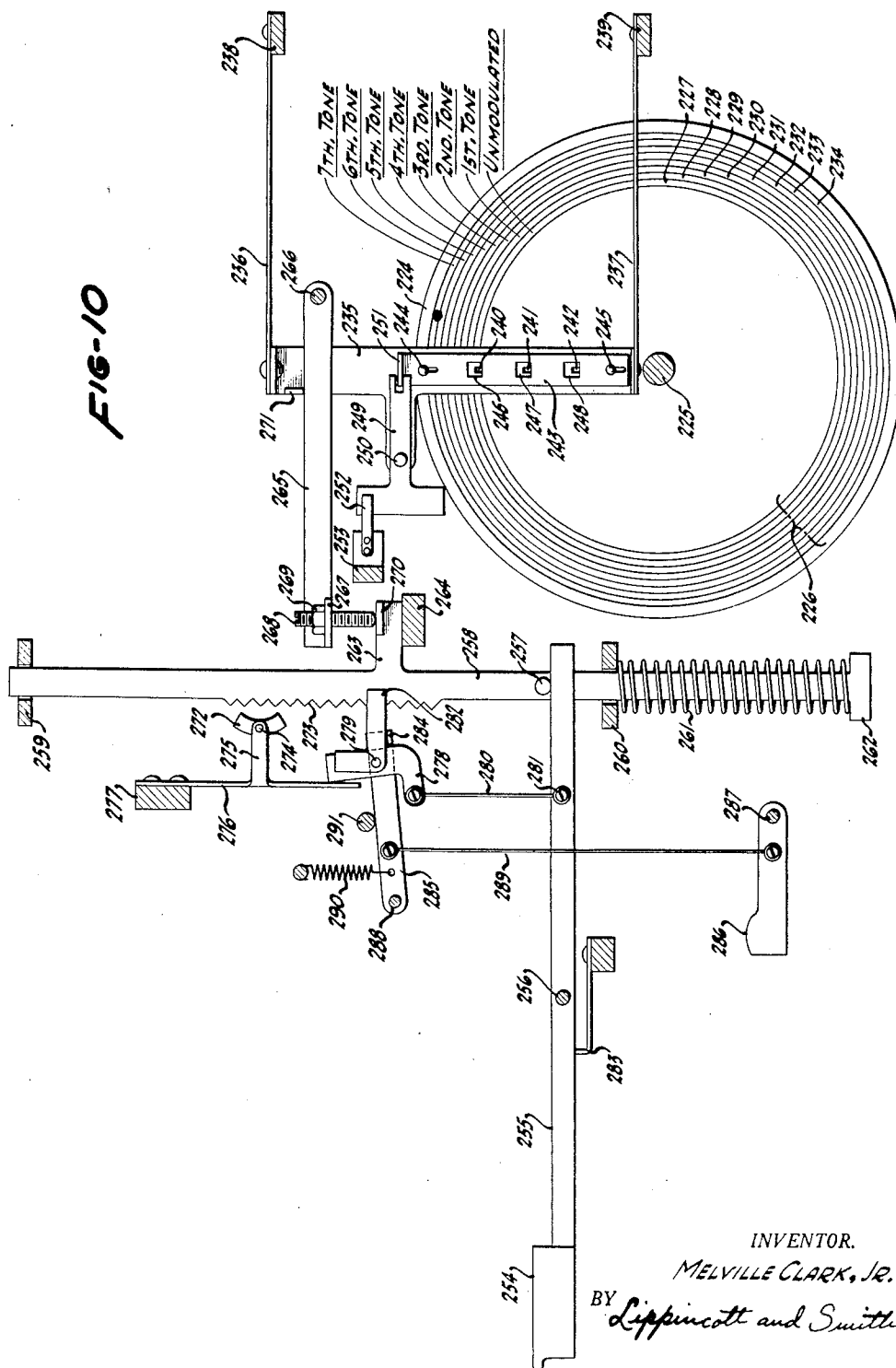
M. CLARK, JR

2,946,252

PROGRESSIVELY KEYPED ELECTRICAL MUSICAL INSTRUMENT

Filed Oct. 31, 1955

6 Sheets-Sheet 6



INVENTOR.

MELVILLE CLARK, JR.

BY *Lippincott and Smith*

ATTORNEYS

1

2,946,252

PROGRESSIVELY KEYED ELECTRICAL MUSICAL INSTRUMENT

Melville Clark, Jr., Boston, Mass. (Dept. of Chemical Engineering Massachusetts Institute of Technology, Cambridge 39, Mass.)

Filed Oct. 31, 1955, Ser. No. 543,949

4 Claims. (Cl. 84—1.01)

This invention relates to electrical musical instruments; and in particular to electrical musical instruments for producing transient as well as steady-state portions of musical tones, to key-operated electrical musical instruments in which the loudness and quality of the tone can be controlled by the key, and to electrical musical instruments for producing tones having prolonged decay transients simulating tones produced by percussion instruments.

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

Another object is to provide an improved electrical musical instrument for simulating faithfully the transient as well as the steady-state portions of tones produced by conventional musical instruments.

Another object is to provide an electrical musical instrument in which the quality of timbre of a tone varies as a function of loudness, for simulating the variations in timbre as a function of loudness that are found in many non-electrical musical instruments.

Another object is to provide a keyboard-operated electrical musical instrument in which the loudness of each tone is controlled by the manner of striking the key, so that a plurality of tones played simultaneously or in rapid succession may be given different degrees of emphasis.

Another object is to provide an electrical musical instrument in which the loudness of a sustained tone may be varied during the duration of the tone.

Still another object of the invention is to provide an improved electrical instrument for simulating the tones of percussion instruments having prolonged decay transients.

Other objects and advantages will appear as the description proceeds.

Briefly stated, in accordance with one aspect of this invention, an electrical musical instrument has a plurality of side-by-side light-transmitting tracks, forming a multisection composite track, with means for producing a different portion of a musical tone as a light beam crosses each of said tracks. A key-operated keying shutter is provided to direct a beam of light to a plurality of these tracks sequentially, so that the instrument is progressively keyed by a single operation of a playing key to produce in succession different portions of a musical tone.

In accordance with another aspect of this invention, a plurality of side-by-side tracks are modulated to simulate transient portions of a musical tone, so that transient as well as steady-state portions of tones produced by musical instruments can be simulated more faithfully than has been possible heretofore.

In accordance with another aspect of this invention, a plurality of side-by-side tracks are modulated to simulate steady-state tones of different loudness, and the key-

2

ing mechanism is so arranged that the manner of striking a key determines which of these tracks is ultimately uncovered by a keying shutter, so that different notes can be played simultaneously or in succession with different intensities or loudness values to provide emphasis and musical nuances.

In accordance with another aspect of this invention, different ones of the tracks providing steady-state tones are modulated with different timbres or tone colors, so that variations in timber with loudness can be provided which simulate the variations in timbre as a function of loudness that are found in many musical instruments.

In accordance with another aspect of this invention, the distance that a keying shutter travels from its rest position varies with the speed with which a playing key is depressed, so that dynamic keying is provided which is similar in many respects to that provided by the piano.

In accordance with another aspect of this invention, the keying shutter may be moved an additional distance in either direction by altering the degree of depression of the playing key, so that variations in the loudness of prolonged tones can be obtained during the duration of the tone.

In accordance with still another aspect of this invention, means are provided for delaying or slowing the return motion of the keying shutter to produce prolonged decay transients for simulating the tones of percussion 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 in which principles of the present invention are useful;

Fig. 2 is a schematic view illustrating a tone disc and keying mechanism, embodying principles of this invention, which may be used in the musical instrument shown in Fig. 1;

Fig. 3 is a diagram illustrating a spectrum analysis of a musical tone;

Fig. 4 is a fragmentary side view illustrating a modification of the keying shutter shown in Fig. 2;

Fig. 5 is an end view of the same keying shutter modification;

Fig. 6 is a schematic view illustrating a tone disc and alternative keying system;

Fig. 7 is a schematic view of another alternative tone disc and keying mechanism;

Fig. 8 is a schematic view of another alternative tone disc and keying mechanism;

Fig. 9 is a detail taken along the line 9—9 of Fig. 8; and

Fig. 10 is a schematic view of still another alternative tone disc and keying mechanism.

Reference is now made to Fig. 1 of the drawings, which illustrates an electrical musical instrument of a type particularly well suited to the practice of the present invention. A tone disc 1 is supported by a shaft 2 and is continuously rotated at constant speed by suitable means such as a motor 3 and driving wheel 4. A light source, such as electric lamp 5, provides a beam of light through an optical aperture 6 of a keying shutter 7 which is adjacent to and movable radially with respect to tone disc 1. Light transmitted by aperture 6 and tone disc 1 reaches a photoelectric transducer 8 which may be a phototube or a photomultiplier tube.

Tone disc 1 carries a light-transmitting composite modulation track consisting of a plurality of contiguous side-by-side concentric circular sections or tracks, of which the inner section is unmodulated and preferably

is opaque. The other sections of the composite track have optical transmittances that vary or are modulated along their lengths in accordance with musical tones.

In the rest position of shutter 7, aperture 6 is aligned with the unmodulated track carried by disc 1 so that the light, if any, which is transmitted to photoelectric transducer 8 under such conditions is unmodulated. Shutter 7 is linked to a key 9, as is indicated by the broken line 10 in Fig. 1, so that when key 9 is depressed aperture 6 is moved into alinement with a modulated section of the track carried by tone disc 1. As tone disc 1 rotates, the beam of light through aperture 6 moves relative to the tone disc along the length of a modulated track, so that the light beam is modulated by the variations in optical transmittance along the length of the track. Modulated light then reaches photoelectric transducer 8, which provides an electric signal corresponding to a musical tone represented by the modulation of the track. Key 9 may be one key of a piano or organ type manual keyboard, or it may be a pedal of an organ-type pedal clavier. Although only one tone disc, keying shutter and key is illustrated, it will be understood that a plurality of tone discs, shutters and keys will be provided in practice, there generally being one tone disc and associated parts for each different pitch to be produced by the instrument.

Electric power is supplied to phototube 8 by suitable means such as battery 11. The electric signal produced by phototube 8 is amplified by an amplifier 12, which may be a conventional vacuum tube amplifier, and is supplied to a volume control which may consist of a resistance-type voltage divider 13 having an adjustable tap 14 linked to an organ-type swell pedal 15, as is indicated in the drawing by broken line 16. Swell pedal 15 may be operated to control the over-all loudness of musical tones produced by the instrument in a manner analogous to the operation of an organ swell pedal.

Signal modifiers 17 may be provided, if desired, for adding various musical effects, such as reverberation, vibrato and tremolo 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. In certain embodiments of this invention hereinafter described, the use of a reverberation device is particularly advantageous, and other signal modifiers may be used if desired. In other embodiments of this invention, the reverberation device may be omitted as well as the other signal modifiers. After further amplification by an amplifier 18, the electric signal is supplied to one or more loud-speakers 19 which convert the electric signal into sound waves.

Preferred forms of the optical transmission system between lamp 5 and transducer 8, the stop or timbre-controlling system of the musical instrument, drive mechanisms for rotating the tone discs, and other portions of the musical instrument illustrated in Fig. 1, are more fully described in my copending patent application entitled "Multi-tone Electrical Musical Instrument," Serial No. 543,865, filed October 31, 1955. The present invention is chiefly concerned with the multisection composite modulation tracks carried by tone disc 1 and with the keying mechanism. However, it should be understood that principles of this invention in its broader aspects are not limited to musical instruments of the rotative tone-disc type, but are equally applicable to moving-beam instruments having stationary modulation tracks, such as the musical instruments described in my copending patent application entitled "Moving Beam Photoelectrical Musical Instrument," Serial No. 543,948, filed October 31, 1955, and to other musical instruments not necessarily limited to photoelectric tone generation types.

Reference is now made to Fig. 2 of the drawings, which

illustrates a tone disc and keying mechanism embodying principles of the present invention. Parts shown in Fig. 1 and Fig. 2 are identified by the same reference numerals in both figures. Tone disc 1 carries a composite or multisection light-transmitting modulation track 20 consisting of a plurality of side-by-side concentric circular sections or tracks identified in the drawing by reference numerals 21 through 28 inclusive. The innermost track 21 is unmodulated, while the remaining tracks have optical transmittances that vary along their lengths in accordance with different portions or components of a musical tone. The overall width of composite track 20 may be about one centimeter.

The keying shutter 7 carries an optical aperture 6 which in the rest position of the shutter is aligned with the unmodulated track 21. If desired, shutter 7 may carry other optical apertures 29 and 30 associated with other composite or multisection modulation tracks carried by disc 1 in the manner described in my copending application "Multi-tone Electrical Musical Instrument" hereinbefore identified. In other words, tone disc 1 may carry a plurality of composite tracks for simulating different musical instruments or other complex timbres, and each such composite track preferably is subdivided into a plurality of sections or tracks in a manner similar to the subdivision of track 20. For simplicity, only one of the composite tracks is herein illustrated and described. To provide a more convenient terminology, each of the track sections 21 through 28 is hereinafter referred to as a track, it being understood that such tracks are in fact side-by-side sections of the composite track 20.

A first plurality of the modulated tracks, tracks 22 through 25 for example, represent successive transient portions of a musical tone. An second plurality of the modulated tracks, tracks 26 through 28 for example, represents steady-state portions of the same musical tone having different loudness values. In the unkeyed or rest position of shutter 7, aperture 6 is aligned with the unmodulated track 21, and no modulated light is transmitted to the photoelectric transducer.

When key 9 is depressed, shutter 7 is moved outward in a radial direction with respect to tone disc 1, so that aperture 6 is brought sequentially into alinement with successive ones of the modulated tracks and the beam of light provided through aperture 6 successively crosses the transient tracks 22 through 25 to produce in sequence successive transient portions of the desired musical tone. The ultimate or outermost position reached by aperture 6 depends upon the manner of striking key 9, as is hereinafter more fully explained, and is in alinement with a selected one of the steady state tracks 26, 27 and 28. Consequently, notes of different loudness can be played by varying the force applied to depress key 9.

In the embodiment illustrated in Fig. 2, key 9 is attached to a key channel 31, which may be a channel-shaped metal bar pivotally supported upon a stationary axle 32. A compression spring 33 supported by a bolt 34 presses down upon the right-hand portion of channel 31, and biases key 9 to a rest position in which the key channel abuts on a stationary member 35 of the instrument frame. If desired, the lower end of member 35 may be covered by a strip of felt 36 to reduce key noise. Bolt 34 passes through an opening in the bottom in channel 31, as shown, and helps to hold the key and key channel in position. Bolt 34 is screwed into a stationary frame member 37, and is locked into position by a lock-nut 38 or other locking means. The compression of spring 33, and hence the restoring force supplied to key 9, can be adjusted by screwing bolt 34 a greater or lesser distance into frame member 37.

Shutter 7 comprises a generally Z-shaped metal member pivotally supported by a stationary axle 39. The upper left-hand end of this Z-shaped member is bent outward to form an ear 40 which carries a set screw 41 abutting on the right-hand end of key channel 31. Set

5

screw 41 is adjusted to bring aperture 6 into alinement with unmodulated track 21 when key 9 is in its rest position, and set screw 41 is then locked in position by a lock nut 42 or other locking means.

The lower portion of shutter 7 has a tab 43 extending through a slot in a stationary guide bar 44 which assists in holding the lower portion of the shutter in its desired position adjacent to tone disc 1. If desired, other guide members may be provided to assist in keeping shutter 7 in proper alinement. A small spring 45 biases the lower portion of shutter 7 radially inward with respect to tone disc 1, and thus keeps set screw 41 in abutting relation to key channel 31.

When key 9 is depressed, the right-hand end of key channel 31 and the upper left-hand end of shutter 7 are moved upward, and the lower portion of shutter 7 is moved radially outward with respect to tone disc 1, so that aperture 6 crosses a plurality of the tracks 21 through 28 sequentially. When key 9 is released and is returned to its rest position by spring 33, spring 45 moves the lower end of shutter 7 radially inward with respect to tone disc 1 and returns aperture 6 to its rest position adjacent to unmodulated track 21. During this return motion aperture 6 recrosses the same modulation tracks in reverse sequence.

The left-hand portion of key channel 31 carries an adjustable bolt or set screw 46 which is locked in position by suitable means such as locking nut 47. A plurality of leaf springs 48 and 49 are attached to a stationary frame member 50 by suitable means such as rivet 51. The left-hand ends of springs 48 and 49 abut on stationary rods or rests 52 and 53 and are thereby maintained in a prestressed condition.

Set screw 46 is adjusted to abut spring 48 and establish a first key-bottoming position when key 9 has been depressed an amount sufficient to move aperture 6 into alinement with the innermost steady-state track 26. Consequently, additional force is necessary to depress key 9 by a greater amount against the restraining force of spring 48 and to bring aperture 6 into alinement with tracks 27 and 28 which are modulated to produce louder steady-state tones. As key 9 is depressed beyond its first bottoming position, spring 48 contacts spring 49 and still greater force is required for farther depression of the key. When key 9 has been depressed a sufficient distance to bring aperture 6 into alinement with the outermost modulation track 28, a plate 54 attached to the bottom of the key abuts on a rest, which may be a bolt 55 screwed an adjustable distance into a stationary frame member 56 and locked into position by suitable means such as locking nut 57. The position of bolt 55 establishes the ultimate or lowest bottoming position of the key at which the loudest tone is produced by the musical instrument.

When key 9 is depressed lightly, the key travels downward to the first bottoming position where screw 46 comes into contact with spring 48, and aperture 6 is moved into alinement with the first steady-state track 26 to produce a relatively soft musical tone. If additional force is applied to key 9, it travels downward an additional distance against the additional bias supplied by springs 48 and 49, and aperture 6 is moved outward a greater distance to produce louder musical tones. The loudest tone is produced when key 9 is depressed to its lowest bottoming position where plate 54 abuts on bolt 55, whereupon aperture 6 is brought into alinement with the outermost track 28.

With this keying mechanism, accents and musical nuances can be provided by depressing different keys of the keyboard with different amounts of force, so that a plurality of musical notes can be played simultaneously or in rapid succession with one or more of the notes played more loudly than the others. Furthermore, the loudness of a sustained tone can be varied at will by the musician during the duration of the tone merely by ap-

6

plying more or less force to the depressed key. Consequently, a variety of musical effects are possible with the electrical musical instrument herein described that are beyond the capabilities of any single conventional musical instrument.

To prevent oscillation of key 9 when it is held in a depressed position, frictional damping means preferably are provided. Such damping means may consist of a brake 58 in frictional engagement with an arcuate plate 59 carried by key channel 31. Brake 58 is held in firm contact with plate 59 by a spring 60 enclosed in a stationary cylinder 61 supported by a bracket 62 attached to a stationary frame member 63 by suitable means such as rivet 64. Brake 58 is attached to a guide rod 65 which extends through the center of spring 60 and through an opening at the back end of cylinder 61, as shown.

The modulation tracks 22 through 28 are preferably contiguous, or touching, side-by-side variable-density tracks each somewhat similar and analogous to the variable-density tracks often used in sound-on-film recording. The steady-state tracks 26 through 28 may be made from actual recordings of sustained tones played by musical instruments or groups of instruments, and in some embodiments they may be identical except that the amplitude of modulation is increasingly greater in successive tracks, increasing from the innermost steady-state track 26 to the outermost track 28 for producing musical tones of different loudness values.

The loudness range covered by the steady-state tracks may be about fifteen decibels. In other words, when three steady-state tracks are used, each successive steady-state track may differ in loudness from the preceding track by an amount in the order of five decibels. This provides an adequate loudness range for accenting one musical note over another, and for providing other musical nuances. A greater loudness range controlled by the manner of depressing the key would make the instrument rather more difficult to play. For playing soft and loud passages, preferably covering a range of about seventy decibels from triple piano (ppp) to triple forte (fff), the volume control linked to the swell pedal or the stop system is employed.

In some embodiments of this invention, the transient tracks 22 through 25 may be identical to the steady-state tracks 26 through 28 except for the modulation amplitude, and they may be made from the same original recording. Generally, the modulation amplitude of the transient tracks is less than that of the steady-state tracks, and it progressively increases from one transient track to the next succeeding track beginning with the innermost transient track 22. When key 9 is depressed, aperture 6 first moves into alinement with the innermost transient track 22, and a very soft musical tone is produced. As the depression of key 9 continues, aperture 6 crosses successive ones of the modulation tracks and thus produces a tone of progressively increasing loudness, simulating the transient build-up of loudness found in the tones of many orchestral and other musical instruments. A steady-state tone is sustained as long as key 9 is held in a depressed position, and when the key is released aperture 6 recrosses successive ones of the modulation tracks in the opposite direction, so that a tone is produced which gradually decays in amplitude to produce transient decay characteristics.

When key 9 is depressed with considerable force, aperture 6 crosses the transient tracks quickly and ultimately reaches a position in alinement with one of the outer most steady-state tracks 27 or 28, so that a rapid build-up to a relatively loud tone is provided. On the other hand, when key 9 is depressed gently, aperture 6 crosses the transient tracks more slowly and reaches an ultimate position in alinement with steady-state track 26, so that a relatively slow build-up to a soft musical tone is pro-

vided. In this way the attack transient characteristics of many musical instruments are closely simulated.

It is well known that the musical tones produced by some musical instruments have relatively long transient portions, while the tones produced by other instruments have very short transient portions. For simulating these differences between different instruments, the number of transient sections provided in different composite tracks for simulating different instruments can be varied. To simulate an instrument producing tones with relative long transient portions in which the amplitude slowly builds up to a steady-state value, all of the transient sections 22 through 25 are employed, it being understood that space may be provided for even more transient sections if so desired.

To simulate an instrument producing tones having short transient portions in which the amplitude quickly builds up to the steady-state value, some or all of the transient sections are omitted. For this purpose, the innermost transient sections, 22 and 23 for example, may be unmodulated so that the transient portion of the tone does not begin until aperture 6 comes into alinement with section 24. Alternatively, sections 22 and 23 may be modulated in accordance with the short transient portion of the desired tone, and tracks 24 and 25 may be made identical to the steady-state track 26, so that in this case also the steady-state amplitude is reached in a relatively short time.

Preferably the light beam transmitted by aperture 6 is of sufficient size to just cover the width of one modulation track. With this arrangement there is no discontinuity in loudness of the musical tone as aperture 6 crosses successive ones of the modulation tracks. In its rest position, aperture 6 is in alinement with unmodulated track 21, and no modulated light is transmitted through the tone disc. As the shutter begins to move outward, an increasingly larger portion of shutter 6 comes into alinement with the first transient track 22, and the tone amplitude gradually increases to the intensity provided when the entire area of aperture 6 is alined with track 22. As shutter 7 continues to move outward, an increasing portion of aperture 6 comes into alinement with track 23, while a decreasing portion of the aperture is alined with track 22. Consequently, a smooth transition occurs between the amplitudes represented by tracks 22 and 23.

In the same way, the amplitude of the tone produced by the instrument increases steadily and continuously as shutter 7 moves outward across the other modulation tracks. Furthermore, it is immaterial if aperture 6 reaches an ultimate position straddling two of the steady-state tracks—midway between tracks 27 and 28, for example. In this case, the ultimate loudness or intensity of the tone produced will be intermediate between the loudness values represented by the modulation amplitudes of tracks 27 and 28.

Alternatively, instead of dividing track 20 into discrete sections each modulated with different modulation amplitudes, the amplitude of modulation may vary continuously from the innermost to the outermost portions of the composite track. Within the broader principles of this invention, such an arrangement is fully equivalent to a plurality of side-by-side tracks.

As hereinbefore explained, all of the tracks 22 through 28 may be modulated with tones having the same timbre or harmonic content, differing from one another only with respect to modulation amplitude. For a more faithful simulation of tones produced by conventional musical instruments, provisions may be made for varying the timbre or harmonic content as well as the amplitude of the tone during the transient period.

Refer now to Fig. 3, which is a diagram illustrating a harmonic or spectrum analysis of a hypothetical musical tone consisting of a fundamental and two overtones. Actual musical tones comprising a larger number of over-

tones may be analyzed in a similar manner. The amplitude of the fundamental component as a function of time is represented in Fig. 3 by curve 66, while the amplitudes of first and second overtones are represented by curves 67 and 68, respectively.

During the steady-state portion of the tone, the amplitudes of the three partials or frequency components remain substantially constant. During the attack period, however, the amplitudes of the three partials vary with time, not only absolutely but also relative to one another. Assume that four transient tracks are to be used for simulating the built-up or attack transient of this musical tone. The attack transient portion of the diagram, which in general is that portion to the left of vertical broken line 69, is divided into four parts by vertical broken lines 70, 71 and 72.

Consider for example, the first transient interval between the solid vertical line, which represents zero time, and the first vertical broken line 70. From the diagram, an average amplitude for each of the three partials during this first transient interval can be determined, which represents a timbre to be simulated by the first transient modulation track 22. In a similar way, the average amplitude of the three partials during the interval between lines 70 and 71 represents the timbre to be simulated by the second transient modulation track 23.

By the time vertical broken line 69 is reached, the amplitudes of all three partials are sufficiently close to their ultimate maximum values that portions of the tone represented immediately to the right of vertical line 69 may be considered steady-state tones, and may be simulated adequately by a steady-state portion of a recording of a sustained tone played by the instrument that is to be simulated.

At the time represented by the vertical broken line 73, the playing key or equivalent device is released and the steady-state portion of the tone is terminated. However, in musical instruments the tone does not suddenly cease, but decays gradually as is indicated by the decay transient portions of curves 66, 67, and 68 to the right of vertical line 73. The decay transients are usually of much longer duration than the attack transients.

In the manufacture of modulation tracks for simulating orchestral and other musical instruments, several alternative procedures may be followed. A master recording may be made of a tone played upon the instrument that is to be simulated. A spectrum analysis of this tone can be made to produce a diagram similar to that shown in Fig. 3. From this diagram, the average amplitude of each partial during each of the attack transient periods and during the steady-state period can be determined, and each such portion of the actual tone can be simulated by a tone produced by harmonic synthesis—that is, by generating a pure tone of proper frequency and amplitude to simulate each of the partials and by mixing these pure tones to simulate the desired complex tone. The five simulated tones thus produced, one for each transient portion and one for the steady-state portion of the actual tone, can be recorded and reproduced on tone disc 1 to form the modulation tracks 22 through 26.

According to an alternative method for making the modulation tracks, a spectrum analysis is unnecessary since the tones may be reproduced directly from a master recording of the tone to be simulated. Such a recording is made upon film, magnetic tape or the like, and the master recording is cut into sections corresponding to a plurality of transient portions and a steady-state portion of the tone. Each section is then reproduced repetitively to provide a sustained tone simulating a desired portion of the original tone, and these sustained tones are recorded upon respective ones of the modulation tracks.

If desired, all of the steady-state sections of the composite track may be identical in harmonic content, but different in amplitude. When this is the case, all of the steady-state sections can be made from the steady-state

portion of the same master recording, with variations in amplification during rerecording upon the tone disc. In many musical instruments, however, the timbre or harmonic content of the tone varies as a function of the loudness with which the tone is played. This variation can be simulated by making the three steady state modulation tracks 26, 27 and 28 (Fig. 2) have different harmonic contents.

For example, in Fig. 3 the curves 74, 75 and 76 represent a louder tone than curves 66, 67 and 68, while curves 77, 78, and 79 represent a still louder tone. In general, as the tone becomes louder the amplitude of each partial increases, but not at the same rate, so that the timbre of the tone, or the relative amplitudes of the partials, varies as a function of loudness.

In electrical musical instruments embodying this invention, as shown in Fig. 2 for example, the variations in timbre with loudness of musical instruments can be simulated by modulating the three steady state tracks 26, 27 and 28 with different timbres or harmonic contents. This can be accomplished, for example, by making three recordings of the same tone played at different loudness values upon the instrument that is to be simulated. Steady-state portions of these three recordings can then be reproduced to make the three steady-state modulation tracks 26, 27 and 28.

With the keying mechanism illustrated in Fig. 2, aperture 6 recrosses the transient tracks 25, 24, 23 and 22 when key 9 is released, and transient portions of the musical tone are repeated in reverse sequence. This arrangement is adequate for simulating tones having similar attack and decay transients—for example, musical tones in which the partials increase exponentially during the attack period and decay exponentially during the decay period. Generally the duration of the decay transients is much longer than that of the attack transients, but this condition can be satisfied by providing a relatively slow return motion of the keying shutter. In other musical tones, such as a tone having the frequency spectrum illustrated in Fig. 3, the decay transients are distinctively different from the attack transients and cannot be faithfully simulated solely by the tone disc and keying mechanism shown in Fig. 2.

In general, decay transients most commonly encountered in musical tones are exponential in form, as is illustrated in Fig. 3 by the portions of curves 66, 67 and 68 to the right of vertical broken line 73. Such decay transients can be produced by a reverberation device included in signal modifier 17 of the circuit shown in Fig. 1, and if the attack transients are relatively short and of small amplitude compared to the steady-state tones, the entire tone can be simulated faithfully with the keying mechanism shown in Fig. 2 if the electrical circuit includes an appropriately adjusted reverberation device.

However, when some of the partials have transient portions of relatively large amplitude, as is illustrated by curve 68 of Fig. 3, for example, it is desirable to prevent the repetition of the attack transients while aperture 6 is recrossing the transient tracks 25, 24, 23 and 22. This can be accomplished by means of a mask which covers aperture 6 during the return motion of shutter 7.

Reference is now made to Figs. 4 and 5, which are fragmentary views showing a modified shutter 7' which may replace the shutter 7 of Fig. 2, and which is generally similar to shutter 7 except for the modifications herein explained.

An opaque mask 80 may be a flat metal strip carried by shutter 7' and supported thereon by a plurality of pins or rivets 81 and 82 secured to shutter 7' and extending through diagonal slots 83 and 84 in the mask 80. This arrangement holds mask 80 in a position parallel to shutter 7', but movable relative thereto both lengthwise and transversely simultaneously in a diagonal direction. When mask 80 is moved downward to the right relative to

shutter 7', the optical apertures 6, 29 and 30 of shutter 7' are uncovered. When mask 80 is moved upward to the left relative to shutter 7', the optical apertures 6, 29 and 30 are covered so that no light is transmitted thereby.

Fig. 4 illustrates a position of the shutter and mask when shutter 7' has been moved the maximum distance to the left by maximum depression of key 9, so that aperture 6 is in alignment with the outermost modulation track 28. When key 9 is released, shutter 7' moves toward the right as hereinbefore explained, and aperture 6 crosses the steady-state tracks 27 and 26. As long as aperture 6 is in alignment with any of the steady-state tracks, mask 80 preferably remains in its downward position so that variations in loudness of the musical tone can be produced at will by applying greater or less pressure to key 9.

As soon as aperture 6 crosses the innermost steady-state track 26 during its return motion and starts to come into alignment with transient track 25, a downwardly extending tab at the left-hand end of mask 80 contacts and passes between in frictional engagement with a pair of stationary leaf springs 85 and 86. The frictional engagement of springs 85 and 86 with mask 80 impedes the motion of mask 80 toward the right, and as a result pins 81 and 82 acting in slots 83 and 84 move mask 80 upward to the left relative to shutter 7', so that optical apertures 6, 29 and 30 are covered during the return motion of the shutter across the transient modulation tracks.

Conversely, when key 9 is depressed the mask 7' begins to move toward the left, the frictional engagement of springs 85 and 86 with mask 80 impedes the motion toward the left of the mask 80, whereupon pins 81 and 82 acting in slots 83 and 84 move mask 80 downward to the right relative to the shutter 7' and uncover apertures 6, 29 and 30 during the forward motion of shutter 7' away from its rest position. Mask 80 remains down after the tab has passed out of frictional engagement with springs 85 and 86. Consequently, transient tones are produced by motion of aperture 6 across transient tracks 22 through 25 in one direction, but not in the return direction, while steady-state tones are produced when aperture 6 is in alignment with steady-state tracks 26 through 28 regardless of the direction of the shutter motion.

The upper left-hand edges of springs 85 and 86 have outwardly bent ears, as is best shown in Fig. 5, to facilitate entry of the tab of mask 80 between the springs during the return motion of shutter 7'. Lower portions of springs 85 and 86 are bent over, as shown at 85' and 86', and are attached to a stationary frame member 87 by suitable means such as rivet 88. A set screw 89 extends through a threaded hole in member 87 and abuts on the bent-over portions of the springs, as is best shown in Fig. 4, for adjusting the position in which the tab of mask 80 first contacts springs 85 and 86 during the return motion of shutter 7'. After set screw 89 has been adjusted, it is locked in place by suitable means such as a lock nut 90.

The shutter and mask mechanism shown in Figs. 4 and 5 can be modified by supporting mask 80 by stationary pins and mounting springs 85 and 86 to move with shutter 7'.

Reference is now made to Fig. 6, which illustrates an alternative keying mechanism. Tone disc 91 is generally similar to the tone disc 1 hereinbefore described, and it carries a composite modulation track 92 which may be identical to the composite track 20 carried by tone disc 1. Disc 91 is rotated at constant speed about a shaft 93 by suitable means, not shown. Adjacent to tone disc 91 there is a stationary mask 94 and a keying shutter 95 which is rotative through a small angle about shaft 93.

Stationary mask 94, which may be held in position by any suitable means such as supporting rods 96 and 97 forming part of the instrument frame, is generally opaque but has a slit-like optical aperture 98 extending radially

with respect to tone disc 91. Shutter 95 likewise is generally opaque, but carries a diagonal composite aperture 99 consisting of a plurality of generally rectangular apertures arranged in a stepwise diagonal array, as shown. One of the small rectangular apertures in the composite aperture 99 is alined with each of the sections of composite track 92 carried by the tone disc. In the rest position of shutter 95, the aperture alined with the unmodulated section of track 92 is in alinement with the mask aperture 98, so that light is transmitted only to the unmodulated track section. If desired this rectangular aperture may be omitted. When the playing key is depressed, shutter 95 moves in a clockwise direction so that successive ones of the small rectangular apertures within composite aperture 99 successively come into alinement with slit-like aperture 98 and light is transmitted sequentially to successive ones of the modulated tracks.

With this keying mechanism, the entire width of each track section is illuminated simultaneously, and consequently track sections of the variable-area type may be used in place of variable-density tracks, if desired, without excessive distortion due to clipping, which with the keying arrangement shown in Fig. 2, if variable area tracks were used, could occur at times when the aperture 6 occupied positions between adjacent tracks.

If variable-density tracks are carried by tone disc 91, the composite aperture 99 may be replaced by a diagonal slit, as is illustrated in my copending patent application entitled "Multi-tone Electrical Musical Instrument" hereinbefore identified.

If tone disc 91 carries more than one composite track, additional composite apertures, such as aperture 100, may be provided for keying the additional tracks carried by the tone disc. Since aperture 100 occupies the same angular space as aperture 99, its transverse dimension is somewhat smaller. Accordingly, to equalize the areas of the two apertures and provide equal amounts of light through inner and outer composite light-transmitting tracks, the inner light-transmitting tracks are made somewhat wider than the outer tracks. Alternatively, the inner composite tracks may have larger modulation amplitudes than the outer composite tracks.

Playing key 101 is attached to a key channel 102 pivotally supported on a stationary axle 103. A bolt 104 extends through key channel 102 and is held in place by a lock nut 105. The lower end of bolt 104 abuts a leaf spring 106 attached to a stationary frame member 107 by suitable means such as a rivet 108. Spring 106 biases key 101 to a rest position in which channel 102 abuts on a stationary frame member 109. A flexible wire link 110 connects keying shutter 95 to the right-hand end of channel 102, so that shutter 95 is rotated in a clockwise direction around shaft 93 when key 101 is depressed. Wire 110 is attached to channel 102 by means of a set screw 111, which may be loosened to adjust the rest position of shutter 95. A spring 112 tends to rotate shutter 95 in a counterclockwise direction and thus keeps wire 110 taut. Tabs 113 and 114, bent down from shutter 95, pass under mask 94 and help to keep shutter 95 in proper alinement with the mask.

When key 101 has been depressed sufficiently to produce the first or softest steady-state tone, spring 106 abuts on a prestressed spring 115 which is attached to stationary frame member 107 and which is kept in a prestressed condition by abutment against a stationary channel 116, as shown in Fig. 6. When key 101 is depressed a sufficient amount to produce the loudest steady-state tone, spring 115 abuts on a bolt 117 which prevents further depression of the key. Oscillation of the key is damped by a friction brake consisting of a leaf spring 118 attached to a stationary frame member 119 and frictionally engaging a side of key channel 102. A similar damping spring may frictionally engage the opposite side of channel 102.

Refer now to Fig. 7, which illustrates another alternative tone disc and keying mechanism. Tone disc 120 rotates at a constant speed about a shaft 121. Disc 120 carries a composite light-transmitting track 122 for producing attack-transient, steady-state and decay-transient portions of a musical tone. For this purpose composite track 122 consists of a plurality of side-by-side concentric circular tracks identified in the drawing by reference numerals 123 through 133 inclusive.

The innermost track 123 is unmodulated. The next three tracks, 124 through 126, are modulated in accordance with successive attack-transient portions of the musical tone that is to be simulated. The next three tracks, 127 through 129, are modulated in accordance with steady-state tones of different loudness. The next track 130 is unmodulated. The three outermost tracks, 131 through 133, are modulated in accordance with successive decay-transient portions of the tone that is to be simulated.

A keying shutter 134 carries a pair of optical apertures 135 and 136. In the rest position of shutter 134, as illustrated in Fig. 7, aperture 135 is alined with unmodulated track 130 and aperture 136 is alined with unmodulated track 123. Additional apertures, such as 137 and 138, may be provided for keying additional composite tracks carried by the same tone disc. A mask 139 is supported on shutter 134 by suitable means such as rivets 140 and 141 fastened to shutter 134 and extended through vertical slots in mask 139 so that mask 139 can move vertically relative to shutter 134 by a small amount. When mask 139 moves upward relative to shutter 134, to the position shown in Fig. 7, aperture 136 is covered by the mask while aperture 135 is uncovered. Conversely, when mask 139 moves downward relative to shutter 134 the aperture 135 is covered while the aperture 136 is uncovered. Apertures 137 and 138 are covered and uncovered by the mask in a similar manner.

A tab extending to the left from the upper portion of mask 139 is in frictional engagement with a pair of springs 142 and 143 which are similar to the springs 85 and 86 described in connection with Figs. 4 and 5. Springs 142 and 143 are attached to a stationary frame member 144 and their position may be adjusted by a set screw 145. When the playing key 146 is depressed, shutter 134 moves upward, in a direction radially outward with respect to disc 120, and apertures 135 and 136 cross successive ones of the modulation tracks carried by disc 120. As shutter 134 starts to move upward, the motion of mask 139 is restrained by springs 142 and 143, so that mask 139 moves downward slightly relative to shutter 134 and covers apertures 135 and 137 while uncovering apertures 136 and 138.

Aperture 136 crosses the attack transient tracks 124, 125 and 126 in succession, and thereby produces attack-transient portions of the musical tone. When aperture 136 comes into alinement with steady-state track 127, the tab of mask 139 moves out of engagement with springs 142 and 143, and the mask remains in a downward position relative to shutter 134 as long as steady state-tones are being produced. Depending upon the manner of depressing key 146, as hereinafter explained, aperture 136 may be brought into alinement with any of the steady-state tracks 127, 128 and 129 for producing tones of different loudness.

When key 146 is released and shutter 134 moves downward, mask 139 comes into frictional engagement with springs 142 and 143 just as aperture 136 begins to come into alinement with the outermost attack transient track 126. The springs restrain the downward motion of mask 139 and move mask 139 upward with respect to shutter 134, covering aperture 136 and uncovering aperture 135. At this time aperture 135 is in alinement with the outermost decay transient track 133, and decay-transient portions of the musical tone are produced as

13

aperture 135 successively crosses tracks 133, 132 and 131 during the return motion of shutter 134.

After shutter 134 has returned to its rest position, both of the apertures 135 and 136 are aligned with unmodulated tracks, so that no musical tone is produced regardless of the position of mask 139. With this arrangement tones having different attack and decay characteristics of complex types may be faithfully simulated.

Key 146 is attached to a key channel 147 pivotally supported at 148 by a stationary frame member 149. A bolt 150 extending loosely through an opening in the key channel supports a compression spring 151 which biases key 146 to a rest position. The compression of spring 151 can be adjusted by a nut 152 which is locked into position by suitable means such as a lock nut 153.

A metering bar 154 has an upper portion carrying a set screw 155 which abuts on the top of key channel 147, as shown. When key 146 is depressed, channel 147 imparts to metering bar 154 a velocity proportional to the speed with which key 146 is depressed. By virtue of its momentum, metering bar 154 continues to move upward away from its abutting relation to channel 147, and is thus thrown upward a distance depending upon the speed with which key 146 is depressed.

The lower end of metering bar 154 is linked to shutter 134—for example, by a pin 156 passing through a horizontal slot 157 in the upper portion of the shutter. Shutter 134 is held in alinement by guide bars 158 and 159 containing slots or the like receiving the keying shutter. Set screw 155 is adjusted so that apertures 135 and 136 are in alinement with unmodulated tracks carried by disc 120 when key 146 is in its rest position. Set screw 155 is then locked in place by suitable means such as lock nut 160.

A first bottoming position for key 146 is established by a plate 161 attached to the bottom of the key and a bolt 162 extending loosely through a stationary frame member 163. Bolt 162 is urged upward by a spring 164 until a nut 165 on the bottom of the bolt abuts on the bottom of member 163. Preferably nut 165 is so adjusted that plate 161 abuts on the top of bolt 162 when key 146 is slowly depressed a sufficient amount to bring aperture 136 into alinement with the innermost steady-state track 127 without moving screw 155 out of abutting relation to channel 147. This establishes the minimum distance that shutter 134 is moved upward when key 146 is depressed gently for playing a soft tone.

When key 146 is depressed quickly to the first bottoming position, metering bar 154 is thrown upward a greater distance, thereby moving set screw 155 out of abutting relation to channel 147 and bringing aperture 136 into alinement with one of the louder steady-state modulation tracks such as track 128 or 129. In this way, notes of different loudness can be played by depressing key 146 more or less rapidly. Overtravel of the metering bar and shutter is prevented by a stop bolt 166 adjustably mounted on a stationary frame member 167 and held into position by a lock nut 168. Bolt 166 is adjusted to stop the motion of metering bar 154 as soon as aperture 136 comes into alinement with the outermost steady-state track 129. The metering bar is held in alinement by a slot in a stationary guide bar 169 and by a slot in the key channel 147.

Key channel 147 carries a latch 170 which is pivotally attached to the key channel at 171 and is urged into frictional engagement with metering bar 154 by a leaf spring 172. When key 146 is depressed, spring 172 brings the upper left-hand edge of latch 170 into frictional engagement with metering bar 154 and provides frictional damping to limit the upward travel of the metering bar relative to the key channel. When motion of the metering bar 154 stops at the top of its trajectory, the metering bar is held in its upper position by the frictional engagement of latch 170 as long as key 146 re-

14

mains depressed, so that prolonged musical tones may be produced.

By depressing key 146 an additional amount against the force of spring 164, the right-hand end of key channel 147 is raised an additional amount, and latch 170 forces metering bar 154 and shutter 134 up an additional amount to increase the loudness of the tone. Conversely, the loudness of the tone may be decreased by slightly reducing the pressure applied to key 146 and allowing it to return a short distance toward its rest position.

When key 146 is released, it quickly returns to its rest position under the influence of spring 151, whereupon a set screw 173 carried by the right-hand end of key channel 147, and locked in position by a lock nut 174, abuts on the right-hand end of a lever 175 pivoted at 176 upon a stationary frame member. The left-hand end of lever 175 is thus moved upward into abutment with the lower left-hand edge of latch 170, which thereupon raises latch 170, against the bias of spring 172, out of frictional engagement with metering bar 154. Metering bar 154 then drops quickly to its rest position in which set screw 155 abuts on key channel 147, and in which the apertures 135 and 136 are aligned with unmodulated sections of the light-transmitting track 122.

Reference is now made to Figs. 8 and 9, which illustrate another alternative tone disc and keying mechanism. Tone disc 177 is rotated at constant speed about a shaft 178 by suitable driving means, not shown. Disc 177 carries a composite light-transmitting track 179 consisting of a plurality of side-by-side concentric circular sections or tracks identified in the drawing by the reference numerals 180 through 187 inclusive. Tracks 180 through 187 are multicolored tracks which may be made from color photographic films or emulsions similar to those used in making photographic color slides or transparencies for the projection of color pictures. This permits each track to be modulated differently with respect to a plurality of colors—blue and red, for example.

The multicolored tracks may comprise two layers of film or emulsion, one of which is transparent to red light and which has an optical transmittance to blue light that varies along the length of the track in accordance with one portion of a musical tone. Another layer is substantially transparent to blue light and has an optical transmittance to red light that varies along the length of the track in accordance with another portion of the musical tone.

In the embodiment illustrated in Fig. 8, the blue-modulating layer comprises a first section or track 180 which is unmodulated, a plurality of tracks 181 through 184 which are modulated in accordance with attack-transient portions of a musical tone, and tracks 185 through 187 which are modulated in accordance with steady-state portions of the musical tone. In the red-modulating layer, tracks 186 and 187 are modulated in accordance with steady-state portions of the musical tone, tracks 181 through 185 are modulated in accordance with decay transient portions of the musical tone, and track 180 is unmodulated. Preferably, in the blue-modulating layer tracks 185, 186, and 187 are modulated in accordance with soft, intermediate and loud values respectively of the steady-state tone; and in the red-modulating layer tracks 186 and 187 are modulated with soft and intermediate loudness values respectively of the steady-state tone.

In other words, track 180 is unmodulated with respect to both red and blue light. Track 181 transmits blue light which is modulated in accordance with the first attack-transient portion of the tone, and transmits red light which is modulated in accordance with the fifth decay-transient portion of the tone. Track 182 transmits blue light which is modulated in accordance with the second attack-transient portion of the musical tone, and transmits red light which is modulated in accordance with

the fourth decay-transient portion of the tone. Track 183 transmits blue light which is modulated in accordance with the third attack-transient portion of the tone, and transmits red light which is modulated in accordance with the third decay-transient portion of the tone. Track 184 transmits blue light which is modulated in accordance with the fourth attack-transient portion of the tone, and transmits red light which is modulated in accordance with the second decay-transient portion of the tone. Track 185 transmits blue light which is modulated in accordance with the first or softest steady-state portion of the tone, and transmits red light which is modulated in accordance with the first decay-transient portion of the tone. Track 186 transmits blue light which is modulated in accordance with the second or intermediate-loudness steady-state portion of the tone, and transmits red light which is modulated in accordance with the first or softest steady-state portion of the tone. Track 187 transmits blue light which is modulated in accordance with the third or loudest steady-state portion of the tone, and transmits red light which is modulated in accordance with the second or intermediate-loudness steady-state portion of the tone.

A keying shutter 188 carries an optical aperture 189 which, in the rest position of the keying shutter, is aligned with the unmodulated track 180. Shutter 188 may also carry other optical apertures, such as aperture 190, for keying other composite tracks that may be carried by tone disc 177 concentric with the composite track 179.

A mask 191 carries a plurality of red color filters 192 and 193 which are substantially transparent to red light and substantially opaque to blue light, and also carries a plurality of blue color filters 194 and 195 which are substantially transparent to blue light and substantially opaque to red light. The color filters 192 through 195 may be made from a strip of photographic color film, attached to mask 191 by any suitable means, in which alternate lengthwise sections of the film have been exposed to light of different colors and then developed to form a composite color filter of the type herein illustrated and described.

Mask 191, which is linked to a key 196 by keying mechanism hereinafter described, is movable radially outward relative to tone disc 177 from a rest position illustrated in Fig. 8. The upper end of mask 191 extends through a slot in a stationary frame member 197, and the lower end of mask 191 has a lengthwise slot 198 which receives shaft 178 or a guide or bearing member attached thereto. In this way the mask 191 is kept in radial alignment with tone disc 177 and in alignment with the optical system of the musical instrument. A spring 199 abuts on frame member 197 and also abuts on a shoulder of mask 191, as shown, so that spring 199 biases mask 191 toward its rest position.

Keying shutter 188 is supported upon the mask 191 by suitable means such as a pair of rivets 200 and 201 which are attached to the keying shutter and which extend through small lengthwise slots or oversize holes in mask 191 so that the keying shutter can move lengthwise relative to mask 191 a sufficient amount to bring optical apertures 189 and 190 into alignment either with red or with blue color filters carried by the mask. A tab at the upper left-hand portion of shutter 188 is in frictional engagement with a spring 202 attached to a stationary frame member 203. Preferably, the length of this tab is such that it is in frictional engagement with spring 202 at all times.

When key 196 is depressed, mask 191 is moved upward, or radially outward, with respect to tone disc 177. However, upward motion of shutter 188 is restrained by its frictional engagement with spring 202 until the blue filter 194 comes into alignment with optical aperture 189. The keying shutter is then carried upward with the mask and successively crosses tracks 181, 182, 183, and 184. These tracks transmit blue light which is modu-

lated in accordance with attack-transient portions of the musical tone, and this blue light is transmitted through filter 194 to a photoelectric transducer which generates an electric signal representing the desired tone. Any red light transmitted by the tracks at this time is blocked by the blue color filter 194. After crossing the transient tracks, aperture 189 comes into alignment with one of the blue-modulated steady-state tracks 185, 186, and 187 to produce steady-state portions of the tone. Assume, for example, that the ultimate or outermost position of aperture 189 is in alignment with the outermost track 187. This produces the loudest steady-state tone that the musical instrument is capable of generating.

When key 196 is released, mask 191 starts to move downward, but downward movement of shutter 188 is initially restrained by its frictional engagement with spring 202 until the red filter 192 comes into alignment with aperture 189. Now the red-modulated light transmitted by the modulation tracks passes through filter 192 to the photoelectric transducer, and the blue-modulated light is blocked by the red color filter. Since the red-modulated light transmitted by track 187 represents the intermediate loudness value of the steady-state tone, the tone produced by the instrument begins to decay in amplitude almost immediately upon the release of key 196. As mask 191 continues its downward motion toward its rest position, keying shutter 188 is carried downward with the mask and aperture 189 successively crosses tracks 186, 185, 184, 183, 182 and 181. The red-modulated light transmitted by the tracks passes through color filter 192 to the photoelectric transducer and produces the decay-transient portions of the musical tone. When mask 191 has reached its rest position illustrated in Fig. 8, aperture 189 is again in alignment with the unmodulated track 180.

Key 196 is attached to a key channel 204 which is pivoted about a fulcrum 205 supported by a stationary frame member 206. A spring 207 is supported by a bolt 208 which extends through an opening in the key channel and through a threaded hole in stationary frame member 206. Bolt 208 may be adjusted to vary the compression of spring 207, and is then locked in position by suitable means such as a lock nut 209. Spring 207 presses downward upon the right-hand portion of key channel 204 and biases key 196 to a rest position in which the key channel abuts on a stationary frame member 210. The bottoming position of key 196 is controlled by an adjustable bolt 211 carried by key channel 204 and locked in position by suitable means such as a lock nut 212. When key 196 is fully depressed, the lower end of bolt 211 abuts on a stationary frame member or rest 213.

A metering bar 214 extends through a slot in frame member 197 and a slot in the right-hand end of key channel 204, as shown. A shoulder of metering bar 214 abuts on the top of key channel 204, as is best shown in Fig. 9, so that metering bar 214 is moved upward when key 196 is depressed. Upward motion of the metering bar is damped by a leaf spring 215, attached to a stationary frame member 197, which is moved into frictional engagement with metering bar 214 when key 196 is depressed by an arm 216 attached to key channel 204. When key 196 is depressed quickly a velocity is imparted to metering bar 214 such that the metering bar continues to move by virtue of its momentum and the shoulder of the metering bar moves upward out of abutting relation to key channel 204. Consequently, when key 196 is depressed quickly, metering bar 214 is thrown upward a distance depending upon the speed with which key 196 is depressed, and the metering bar is held in its uppermost position by the frictional engagement of spring 215 as long as key 196 remains depressed.

When key 196 is released, spring 215, which is biased into engagement with arm 216, moves out of frictional engagement with metering bar 214 and allows the metering bar to return to its rest position.

Upward motion of the metering bar is limited by an adjustable stop bolt 217 which extends through stationary member 197 and is locked in position by suitable means such as lock nut 218. Metering bar 214 carries an outwardly bent ear 219 which abuts on the bottom of bolt 217 when the metering bar reaches its uppermost position and thus limits the upward motion of the metering bar to prevent aperture 189 from travelling upward beyond the outermost track 187. Also, upward motion of the metering bar is damped by the frictional engagement of spring 215.

Mask 191 has an outwardly bent ear 220 which carries an adjustable set screw 221 locked in position by suitable means such as a lock nut 222. The lower end of set screw 221 abuts on an ear 223 at the lower end of metering bar 214, so that mask 191 is moved upward along with metering bar 214 when key 196 is depressed. Spring 199 urges mask 191 downward to keep set screw 221 in abutting relation to ear 223. Set screw 221 is adjusted so that optical aperture 189 is aligned with unmodulated track 180 when metering bar 214 is in its rest position. Bolt 211 is adjusted so that aperture 189 is in alignment with the innermost blue-modulated steady-state track 185 when key 196 is slowly depressed by the maximum amount and the shoulder of metering bar 214 remains in abutting relation to key channel 204. Bolt 217 is adjusted so that aperture 189 is in alignment with the outermost track 187 when key 196 is depressed quickly to throw metering bar 214 upward by the maximum amount.

Reference is now made to Fig. 10 which illustrates still another alternative tone disc and keying mechanism. This embodiment is particularly useful in simulating percussive tones which have negligible attack transients but have prolonged decayed transients. Tone disk 224 is continuously rotated at constant speed about a shaft 225 by suitable driving means, not shown. Tone disk 224 carries a composite light-transmitting track 226 composed of a plurality of side-by-side concentric tracks identified in the drawing by reference numerals 227 through 234 inclusive. Track 227 is unmodulated, while successive ones of the tracks 228 through 234 are modulated with seven tones of progressively increasing loudness.

A keying shutter 235 is supported by a pair of leaf springs 236 and 237 attached to stationary frame members 238 and 239 so that shutter 235 can move radially outward with respect to tone disc 224 from the rest position shown in Fig. 10. Shutter 235 carries an optical aperture 240 which in the rest position of the shutter is aligned with unmodulated track 227. Keying shutter 235 may carry other optical apertures such as 241 and 242, for keying other composite light-transmitting tracks carried by tone disc 224 concentric with composite track 226.

A mask 243 is supported by suitable means such as rivets 244 and 245 attached to shutter 235 and extending through lengthwise slots or oversize holes in mask 243, so that mask 243 can move a small distance lengthwise relative to shutter 235. Mask 243 carries a plurality of apertures 246, 247 and 248 so arranged that apertures 240, 241 and 242 are uncovered when mask 243 is moved downward relative to shutter 235, and are covered when mask 243 is moved upward relative to shutter 235.

A lever 249 is pivotally mounted upon shutter 235 by means of a rivet 250. The bifurcated right-hand end of lever 249 engages an ear 251 bent outward from the upper end of mask 243. The left-hand end of lever 249 is in frictional engagement with a spring 252 attached to a stationary frame member 253. When shutter 235 begins to move upward, or outward radially with respect to tone disc 224, upward motion of the left-hand end of lever 249 is restrained by the frictional engagement of spring 252 so that lever 249 turns about its pivot at 250 and moves mask 243 quickly upward to cover the apertures 240, 241 and 242. Preferably, the right-hand portion of lever 249 is considerably longer than the left-hand

portion of the lever to provide sufficient mechanical amplification so that apertures 240, 241 and 242 are quickly covered by a small initial motion of shutter 235.

When a playing key 254 is depressed, shutter 235 is moved rapidly upward, by mechanism hereinafter described, a distance depending upon the speed with which the key is depressed. During this upward motion, apertures 240, 241 and 242 are covered by mask 243, so that no attack transient tones are generated. As soon as shutter 235 begins to return toward its rest position in response to the biasing force provided by springs 236 and 237, the frictional engagement of spring 252 with lever 249 rotates lever 249 about its pivot at 250 and quickly moves mask 243 downward with respect to shutter 235 and uncovers apertures 240, 241 and 242. During this quick downward motion of the mask, very short attack transient tones are produced while the apertures are being uncovered. As soon as the aperture 240 has been fully uncovered, a musical tone is produced having an initial loudness determined by the extent of the previous upward motion of shutter 235. As shutter 235 continues to move toward its rest position, aperture 240 crosses successive ones of the modulation tracks to provide a musical tone that progressively decays in amplitude.

Key 254 is attached to a key channel 255 which is pivotally supported by a stationary axle 256. As key 254 is depressed, the right-hand end of key channel 255 raises a pin or cross-bar 257 carried by a metering bar 258 and imparts to the metering bar a velocity which lifts pin 257 out of contact with the key channel. Consequently, when key 254 is depressed metering bar 258 is driven upward a distance depending upon the speed with which the key is depressed.

The metering bar 258 extends through slots in two stationary frame members 259 and 260 which hold the metering bar in vertical alignment. A spring 261 abuts on frame member 260 and also abuts on a shoulder 262 at the lower end of metering bar 258, as shown, so that spring 261 urges the metering bar downward to its rest position, shown in Fig. 10, in which a tab 263 of the metering bar abuts on a stationary frame member 264.

A lever 265 is pivotally supported by a stationary shaft 266 and has an ear 267 which carries an adjustable set screw 268 which may be locked in position by a lock nut 269. The lower end of screw 268 abuts on an ear 270 bent over from tab 263 of the metering bar, so that when the metering bar moves upward lever 265 is rotated in a clockwise direction about its pivot at 266. An ear 271 bent forward from the keying shutter 235 abuts on the top of lever 265, so that keying shutter 235 is moved upward as lever 265 is rotated in the clockwise direction.

Composite light-transmitting track 226 is preferably about one centimeter in total width, so that the maximum upward motion of keying shutter 235 is approximately one centimeter. The maximum upward motion in the metering bar 258 preferably is considerably greater than one centimeter, but the motion of the metering bar that is transmitted to the shutter is reduced by lever 265 so that these two upward motions may have any desired ratio. Set screw 268 is so adjusted that aperture 240 of the keying shutter is in alignment with unmodulated track 227 when metering bar 258 is in its rest position.

To produce tones having prolonged decay transients, means are provided for delaying or slowing down the return motion of metering bar 258. Dash pots, magnetic dampers, or the like may be used for this purpose, but preferably a simple escapement mechanism is employed which is illustrated in Fig. 10. This escapement comprises a pallet 272 and a rack 273 carried by or integral with the metering bar 258. Pallet 272 is mounted for oscillatory motion about a rivet 274 attached to a tab 275 which preferably is a bent-forward portion of a leaf spring 276 attached to a stationary frame member 277.

A bell crank 278 is pivoted on a rivet or shaft 279 and is connected by a flexible cord or wire 280 to the

right-hand portion of key channel 255, as shown. Wire 280 preferably is connected to the key channel by a set screw 281 so that the length of the wire link can be adjusted. When key 254 is in its rest position, wire 280 rotates bell crank 278 into abutment with the lower end of spring 276 and thus withdraws pallet 272 from engagement with rack 273. When key 254 is depressed, bell crank 278 is permitted to rotate in a clockwise direction about its pivot at 279 and spring 276 tends to move toward the right and bring the pallet into engagement with the rack. However, as metering bar 258 moves upward, a bell crank 282 having its right-hand end in frictional engagement with metering bar 258 is rotated in a counterclockwise direction about shaft 279 so that the upper end of bell crank 282 abuts on the lower end of spring 276 and holds pallet 272 out of engagement with rack 273 to permit rapid upward motion of the metering bar.

As soon as metering bar 258 begins to move downward, bell crank 282 is rotated in the clockwise direction by its frictional engagement with the metering bar, and spring 276 moves pallet 272 into engagement with rack 273. The downward force applied to the rack by gravity and by spring 261 causes pallet 272 to oscillate about its pivot at 274, so that metering bar 258 moves downwardly slowly at a rate set by the pallet-and-rack escapement. The return motion of shutter 235 is correspondingly slow, and prolonged decay transients are produced as optical aperture 240 slowly crosses successive ones of the modulation tracks carried by tone disc 224.

When key 254 is released, the key and key channel are returned to their rest positions by a spring 283 and wire 280 rotates bell crank 278 in a counterclockwise direction, bringing the upper end of bell crank 278 into abutment with the lower end of spring 276 and withdrawing pallet 272 from engagement with rack 273. Under the influence of gravity and spring 261, metering bar 258 and keying shutter 235 quickly return to their rest positions to terminate the decay transient. Excessive clockwise rotation of bell crank 282 is prevented by a stop 284 which may be an ear of a lever 285 which supports shaft 279.

At times it may be desirable that the decay transients be sustained after key 254 is released. For this purpose, a sustaining lever or pedal 286 is provided, which is pivoted about a stationary shaft 287. Lever 285 is pivoted on a stationary shaft 288, and is linked to the sustaining pedal 286 by suitable means such as wire 289 so that lever 285 is rotated in a clockwise direction when pedal 286 is depressed. The right-hand end of lever 285 supports the shaft 279 which serves as a pivot for bell cranks 278 and 282. When the sustaining pedal is depressed, shaft 279 is moved downward a sufficient amount to release the tension of wire 280, so that pallet 272 is not withdrawn from engagement with rack 273 when key 254 returns to its rest position. A spring 290 rotates lever 285 counterclockwise to a stationary stop 291, as is shown in Fig. 10, when the sustaining pedal 286 is released.

Since the upward motion of shutter 224 is rapid while its downward motion is relatively slow, mask 243 may be omitted, if desired, in which case short attack transients will be produced as shutter 235 moves upward rapidly, and prolonged decay transients will be produced as shutter moves downward slowly.

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 a keyboard electrical musical instrument of the type having a plurality of keyboard keys, one for play-

ing each note of the musical scale, the one-note tone-generating subcombination comprising one of said keys, a support, said support having thereon a plurality of side-by-side reproducible tone representations, one of said tone representations being that of the designated note, the others being of the same note with progressively different characteristics, a tone selector member operatively associated with said tone representations, said tone representations and said tone selector being uniformly longitudinally movable with respect to each other, and said tone representations and said tone selector being selectively transversely movable with respect to each other, and said one key being operatively connected to said tone selector so as to move said tone selector transversely across said tone representations in uninterrupted succession, whereby when said tone selector is moved across said tone representations to the designated note, a transient effect will be produced.

2. In a keyboard electrical musical instrument of the type having a plurality of keyboard keys, one for playing each note of the musical scale, the one-note tone-generating subcombination comprising one of said keys, a support, said support having thereon a plurality of side-by-side variable-density sound tracks, each of said sound tracks being a representation of a reproducible tone, one of said tracks being a representation of a note and the others being representations of the same note with progressively different waveforms, a source of light uniformly movable relative to and longitudinally along said sound tracks, a note-playing shutter disposed between said source and said support, said shutter being generally opaque and having an aperture therein selectively movable transversely across said tracks permitting said source to illuminate said tracks one after another in uninterrupted succession, said one key being operatively connected to said shutter for so moving said aperture, whereby in the playing of a single note the light is modulated with successive tone representations of the same note having progressively varying waveforms, and a photoelectric transducer receiving the so-modulated light.

3. A one-note tone-generating subcombination as in claim 2, additionally comprising a mask mounted upon said movable shutter and selectively movable with respect to said shutter between a position covering said aperture and a position uncovering said aperture, and a stationary member in frictional engagement with said mask opposing movement of the mask in unison with the shutter, whereby movement of the shutter in one direction moves the mask relative to the shutter into the aperture-covering position and movement of the shutter in the other direction moves the mask relative to the shutter into the aperture-uncovering position.

4. In a keyboard electrical musical instrument of the type having a plurality of keyboard keys, one for playing each note of the musical scale, the one-note tone-generating subcombination comprising one of said keys, a continuously and uniformly rotative disc, said disc having thereon a plurality of concentric circular variable-density sound tracks, each of said sound tracks being a representation of a reproducible complex tone composed of fundamental and overtone components, one of said tracks being a representation of a note and the others being representations of the same note with progressively different proportions of said fundamental and overtone components, a source of a stationary light beam normal to said track, a note-playing shutter disposed across said beam between said source and said disc and adjacent to said tracks, said shutter being selectively reciprocally movable in a direction radial with respect to said disc, said shutter being generally opaque and having therein an aperture selectively movable therewith radially of said disc and into alinement with said tracks one after another in uninterrupted succession, said one key being operatively connected to said shutter to so move said shutter radially of said disc, whereby in the playing of a single note

21

the light of said beam is modulated with successive tone representations of the same note having progressively varying proportions of the fundamental and overtone components, and a photoelectric transducer receiving the so-modulated light.

5

References Cited in the file of this patent

UNITED STATES PATENTS

1,218,324	Severy -----	Mar. 6, 1917	10
1,778,374	Spielmann -----	Oct. 14, 1930	
1,980,292	Potter -----	Nov. 13, 1934	

1,991,522
1,998,461
2,164,809
2,314,496
2,484,914
2,540,285
2,586,664
2,588,680

22

Ranger -----	Feb. 19, 1935
Kucher -----	Apr. 23, 1935
Fisher -----	July 4, 1939
Hammond -----	Mar. 23, 1943
Spielmann -----	Oct. 18, 1949
Phillips -----	Feb. 6, 1951
Knoblauch -----	Feb. 19, 1952
Williams -----	Mar 11, 1952

FOREIGN PATENTS

Great Britain -----	Oct. 3, 1932
Italy -----	May 28, 1946

381,210
413,804