July 4, 1939. R. C. FISHER 2,164,809

PHOTOELECTRIC MUSICAL INSTRUMENT

Original Filed July 20, 1932 3 Sheets-Sheet 1

Fig. 13.

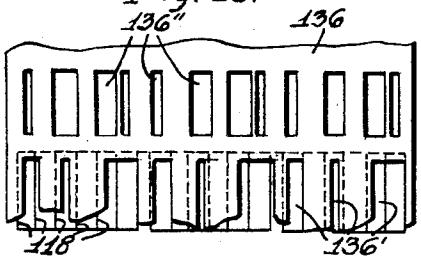


Fig. 14.



Fig. 1.



Fig. 2.

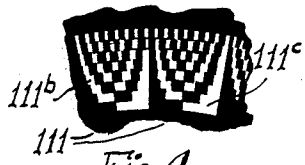


Fig. 4.

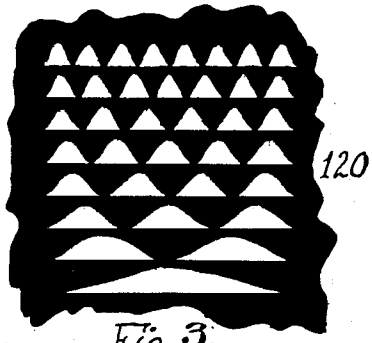
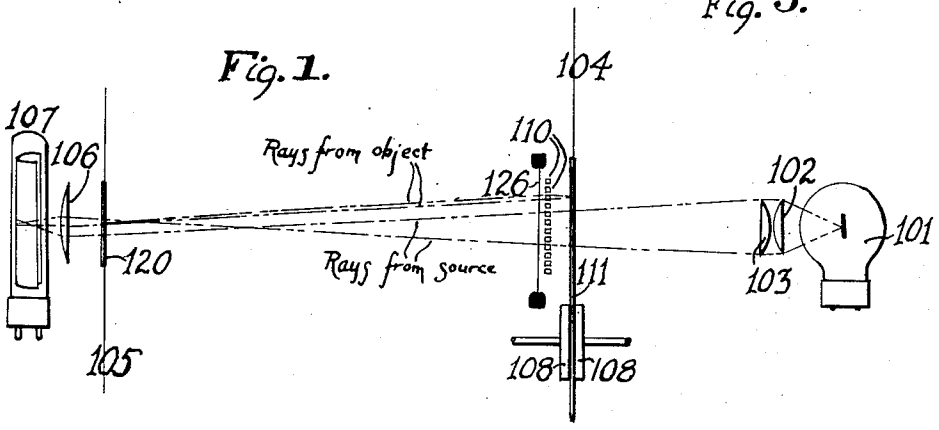


Fig. 3.



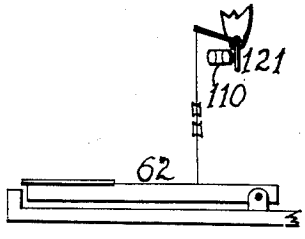


Fig. 5.

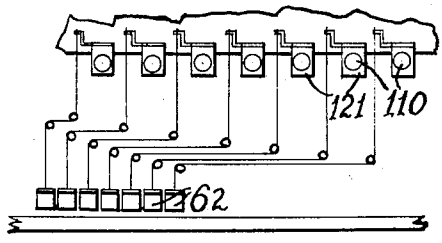


Fig. 5a.

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PHOTOELECTRIC MUSICAL INSTRUMENT

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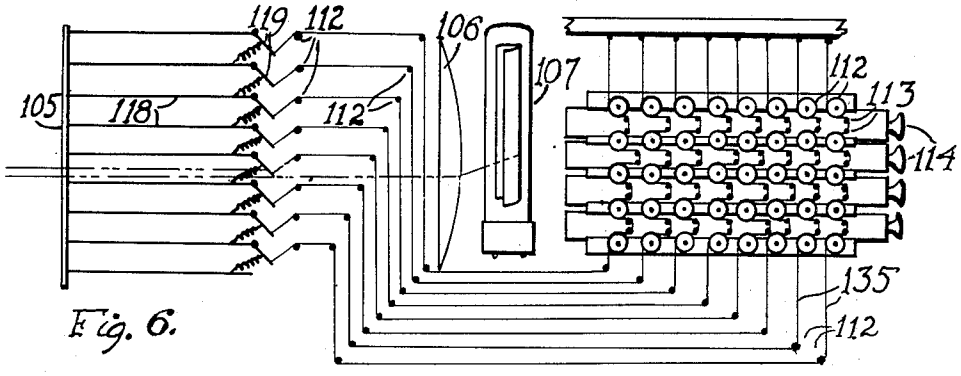


Fig. 6.

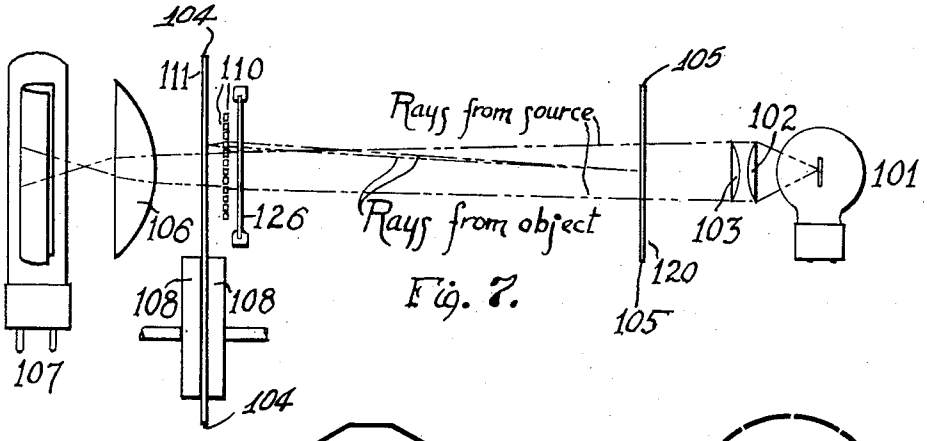


Fig. 7.

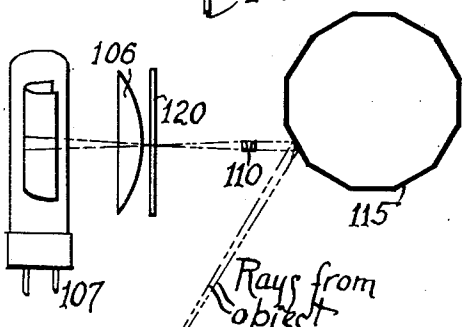


Fig. 8.

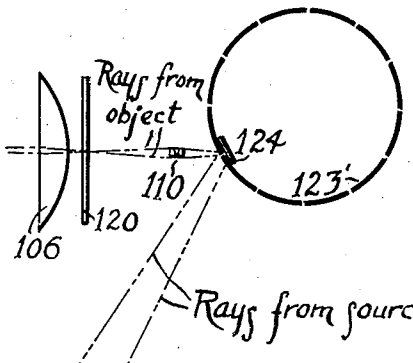
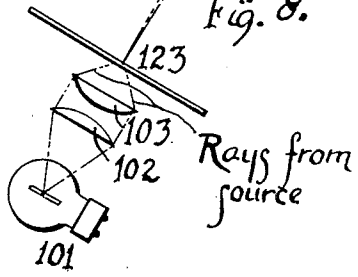
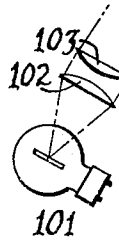


Fig. 9.





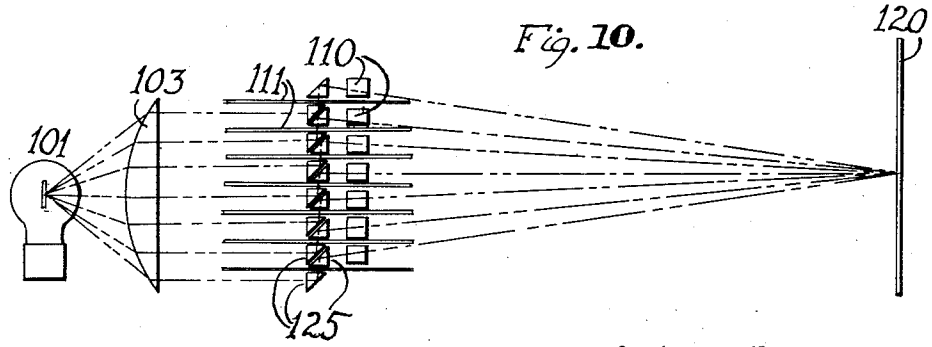
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July 4, 1939. R. C. FISHER 2,164,809

PHOTOELECTRIC MUSICAL INSTRUMENT

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Fig. 10.



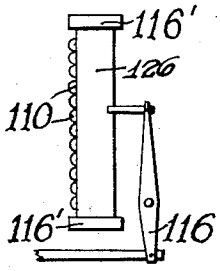


Fig. 11.

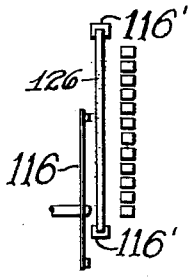
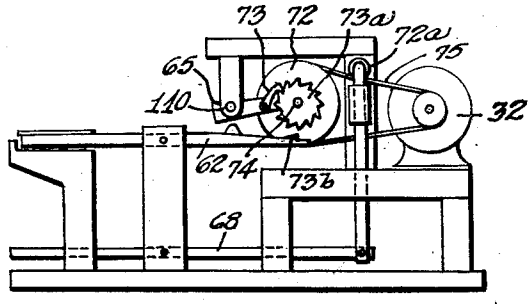


Fig. 11a.

Fig. 15.



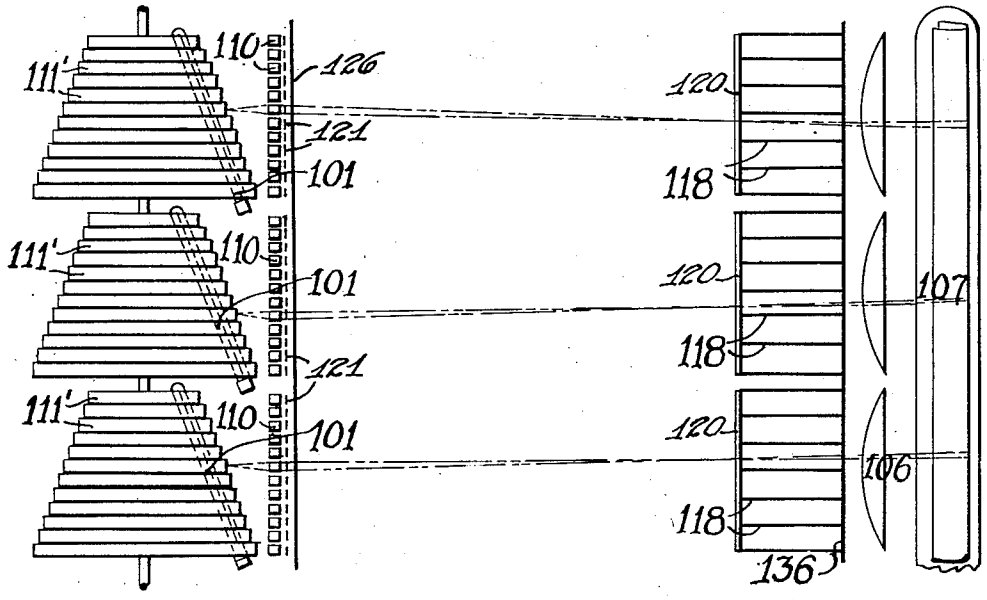


Fig. 12.

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Patented July 4, 1939 2,164,809

UNITED STATES PATENT OFFICE

2,164,809

PHOTOELECTRIC MUSICAL INSTRUMENT

Raymond C. Fisher, Tacoma, Wash.

Original application July 20, 1932, Serial No. 623,639, now Patent No. 2,055,719, dated September 29, 1936. Divided and this application August 19, 1936, Serial No. 97,239

31 Claims. (Cl. 84—1)

The present invention relates to improvements in a photoelectric musical instrument, and more particularly to certain optical and mechanical arrangements adapted to produce, by photoelectric action, electric currents translatable into musical tones.

The present application is a division of my application, Serial Number 623,639, filed July 20, 1932, for an Electrical musical instrument, and now become Patent Number 2,055,719 issued Sept. 29, 1936.

The objects of this invention are several. The first of these is to provide a musical instrument capable of producing, in certain of its forms, tones of a timbre closely resembling that of the piano, organ, and/or common orchestral instruments. It is capable of imitating not only sustained tones but also for example the rather sudden onset and gradual dying away of a piano tone. At the same time and in the same instrument, it can moreover, create new tonal effects such as cannot be produced by any mechanical or pneumatic means. Its possibilities for the development of the music of the future are thus very great. It has been the history of music that musical composition and technique have progressed largely according to, and in response to, the invention of instruments for the performance of music.

A second object is to provide an instrument incapable of getting "out of tune." So long as the speed of the driving motor in the present instrument is held constant (and motors of sufficiently constant speed have already been invented by others), the pitches of all tones are correct within limits satisfactory to the most critical ear.

A third object is to make possible the building of an instrument which is simple, compact, low in first cost, low in maintenance expense, and light in weight, particularly as compared with the pipe organ. To this end, I may employ a construction which permits one source of radiant energy, and one light-sensitive cell, and one set of partial shutters, to serve several pitches of tone. Partly responsible for these advantages are my use of objective lenses, superposed images, and separate and distinct "tracks" for the partials of a given tone, as will appear later.

A fourth object is the attainment of a musical instrument wherein a wide variety of complex tone qualities can be readily synthesized. Certain of the above constructional features make this possible.

It is possible to connect many keyboards with one such instrument thus enabling a number of musicians to simultaneously play on the same instrument. Since the volume of sound associated with any one keyboard can be varied through very wide limits, it is possible, for example, for one musician, at one keyboard, to take the place of all the flutists and of all of their flutes, in a large symphony orchestra. In addition, and simultaneously, other musicians at other keyboards would be taking the place of other groups of instruments in the orchestra.

A further object is the production, for laboratory and other uses, of alternating electric currents and voltages of accurately controllable frequency and wave form. It is well known to researchers in the electrical field that this has hitherto been a task of considerable importance, but one difficult or impossible to achieve, according to the degree of accuracy of waveform demanded.

It is well known (see Webster's Unabridged Dictionary, under the word "tone", in sense 2*a*), that sustained musical tones are characterized by their pitch, timbre, and intensity, and that their timbre is determined by the proportions of so-called partials which they contain. Hence a sustained musical tone of any desired timbre or quality can be synthesized by simultaneously producing several component sound waves of the proper relative pitches and intensities. In the present instrument periodic variations of electric current or voltage are produced and are caused to operate a sound translating device, usually a loudspeaking receiver and often more than one.

It is by no means necessary that the loudspeaker which is operated be connected by wires with the part of the apparatus which originates the alternating currents and voltages. The latter could for example be used to modulate a radio telephone transmitter in which case the loudspeaker might be a part of a radio receiver. Nevertheless, the primary purpose of the invention is the production, or origination, of musical tones; that is, of tones characterized by definite pitch and timbre.

In brief, my invention consists in means for originating alternating or otherwise varying electric currents and electromotive forces of a greater or less degree of complexity, which are subsequently amplified and caused to operate a sound translating device, loudspeaker, or telephone receiver which terms, as I use them throughout this application, include the electrodynamic loudspeaker, the magnetic speaker or receiver, the piezoelectric loudspeaker, and, in fact, all devices for translating electric currents or voltages into sound waves. However, the invention of this divisional application does not embrace amplification or sound translation. In addition, the invention includes means for controlling the volumes the pitches, and the timbres of the various components comprising the sound.

I am well aware that United States Letters Patent for photoelectric means designed for ac-

complishing generally similar ends have already been granted to others. I believe, however, that my invention has the advantages of a degree of simplicity, compactness, and inexpensiveness of construction not possessed by other photoelectric musical instruments whose musical possibilities are comparable.

With the above and other objects and advantages in view, this invention has particular relation to certain novel features of construction, operation, arrangement of parts, and methods of use, examples of which will be given in this specification and illustrated in the accompanying drawings, wherein:

Figure 1 illustrates a form of the invention in which a beam of radiant energy is modulated by a rotating disc;

Figure 2 shows in detail a portion of the apparatus of Figure 1, known as an aperture screen;

Figure 3 shows in detail another portion of the apparatus of Figure 1, known as a wave screen;

Figure 4 shows a portion of another form of aperture screen;

Figure 5 shows in side elevation the key action for use with a photoelectric form of alternating current producer;

Figure 5*a* is a front elevation of the same;

Figure 6 shows the stop mechanism for use with a photoelectric form of alternating current producer;

Figure 7 shows an alternative optical system, which may be used instead of that in Figure 1;

Figure 8 shows a form of optical train which includes rotating mirrors;

Figure 9 shows a form of optical train which includes a slotted cylinder;

Figure 10 shows an optical system suitable for producing a gamut of several octaves;

Figures 11 and 11*a* show a shutter type of volume control;

Figure 12 shows an optical system for three octaves, which includes rotating transparent cylinders and an aperture belt for the control of timbre;

Figure 13 shows a detail of the aperture belt of Figure 12;

Figure 14 shows an alternative form of timbre shutter; and

Figure 15 shows a mechanism for obtaining a gradual decay of tone after a key has been operated.

Like numerals designate the same parts throughout the specification.

The purpose of all the above forms of the invention is the production and control of varying electric currents having suitable waveforms for musical or other purposes. Since the musical apparatus illustrates the essentiai features whatever the application, I shall describe first the optical system for the production of one octave of musical tones.

For purposes of description, I shall assume that we wish to produce twelve different tones, forming the even-tempered chromatic scale above scientific middle C, which is characterized by a frequency of 256 cycles per second. It is understood, however, that any series of tones can be thus produced, within very wide limits; in fact, pitches of tone, if such they may be called, which are inaudible to the human ear. Moreover, the tones of an instrument need not be those of the even-tempered scale, but may belong to any recognized scale, or may have any other inter-relationship.

Referring to Figure 1, I illustrate an optical train wherein **101** is a source of radiant energy, preferably an incandescent electric lamp, with concentrated filament. Numerals **102** and **103** represent suitable condensing lenses, whose purpose it is to concentrate light in a certain area at the plane **104**. They do not, of course, form any images. To the left of plane **104** I show a series of small objective lenses **110**, so placed that they will focus on screen **120** at the plane **105** the images of any objects which may be in the plane **104**. The light of the images at **105** is condensed by means of a condensing lens, **106**, upon the sensitive surface of a selenium cell, photo-electric cell, photo-voltaic cell, or other photosensitive device, which is shown at **107**. For brevity I shall refer hereinafter to a cell, or a photosensitive cell, or a photosensitive device, and it is to be understood that I mean to include any type of cell or device in which the electric current is a function of the radiation flux falling upon some portion of it. In this and succeeding drawings, the paths of light beams are illustrated by means of lines made up of a dash followed by two dots.

In the plane **104** is a screen in the form of a flat disc, **111**, of glass or other transparent material, attached by means of flanges **108** to the rotating shaft **109**, and caused to rotate at a uniform rate in the plane of the glass by virtue of such attachment to the shaft. Certain elongated, approximately rectangular areas of the glass disc are rendered opaque and certain others transparent, as for example by photographing on the sensitized surface thereof a many-times-repeated pattern, like that of Figure 2. The transparent areas I term apertures. Actually, these areas, when used on a disc, are bounded by radii and arcs of circles in their preferred form. On other forms of screen, such as a cylindrical one, they may be true rectangular areas, bent to conform to the cylindrical surface. For all such approximately rectangular areas, I here use the word, "rectangle". The exact shape to use will be obvious from the fact of their function as scanning instrumentalities. Alternatively, the disc may be of metal, with elongated slits, which, like the transparent areas, I also call apertures, punched through it. This rectangular pattern, or motif as I prefer to term it when it is repeated around a circular track, is in the present instance repeated in a series of circles concentric with the shaft, one circle for each tone which one wishes to produce. These circles I term tracks or, more specifically, pitch tracks, and their purpose is, as will appear, to modulate the radiant energy passing through them, and thus to generate tones. Thus the innermost track, or circle of motifs, may generate middle C together with its harmonics and, in the form of the invention here described there are 108 repetitions of the motif, arranged entirely around the circle; that is, there are 108 short radial lines, uniformly spaced and narrow as compared with the angular distance between them. Just outside this track is a slightly larger one for the generation of the tone C-sharp. It will have 114 complete repetitions of the motif, and a small fraction of another. This small fraction results because the ratio of frequencies characterizing C-sharp and C in the even-tempered scale is not precisely 114/108, but an incommensurate number, $\sqrt[12]{2}$, which cannot be exactly expressed by the ratio of any two numbers. This point has been already mentioned more at length in its connection with the tone belts of Figures 10 and 10*a* of the parent applica-

tion. The motifs in the circles for C and for C-sharp are, as nearly as possible, of the same dimensions and spacing, but there are more of them in the latter circle, or pitch track, in accordance with its greater diameter. Outside the latter circle are still other circles of motifs for the production of D, D-sharp, E, F, F-sharp, and so on up the musical scale to and including the B above middle C.

Near each of the twelve tracks is mounted a lens, 110, Figure 1. Each lens focuses on plane, 105, an enlarged, inverted, real, moving image of its corresponding pitch track, or rather of a portion thereof; i. e., an image larger than the object at 105. Thus there are twelve images at 105. These scanning images do not appear side by side, but, due to the positioning of the lenses, are superimposed upon one another, and all twelve images occupy the same area at plane, 105. As the disc screen rotates, the motifs rotate with it, and their images travel along on plane, 105, in a direction perpendicular to the plane of the paper in the drawings. These lenses do not rotate, but remain stationary relative to 107.

At plane 105 is a sheet of glass or the like which acts as a second energy-modulating screen. It is in part transparent and in part opaque, due to having photographed on its sensitized surface sinusoidal curves like those shown in Figure 3. This I also term a screen or plate and designate by the numeral 120 in Figures 1 and 3. It is seen that screen 120, like 111, bears one pitch track which consists of eight distinct and separate partial tracks lying side by side. The lowermost of these has a single sinewave and is for generating a fundamental, or first partial tone; the second has two sinewaves, and generates the second partial and so on. Each is for modulation at a different frequency, but the frequencies are all integral multiples of a common fundamental frequency.

In Figure 4 is shown the same glass disc 111 with a different motif from that of Figure 2, or rather a portion of the disc. There are twelve concentric pitch tracks of such motifs, as on the disc shown in Figure 2.

It will be noted that the motif of Figure 4 is twice-repeated on the fragment shown, and that it is composed of eight rows (which, like those of 120, I term partial tracks) of transparent and opaque portions 111b, 111c; the first, or outer, partial track has one transparent and one opaque portion, the second has two of each, the third has three of each, and so on up to the eighth, which has eight transparent and eight opaque portions. Thus, to each partial track on stationary screen 120, there is a corresponding partial track in each of the concentric moving circular pitch tracks of 111. Even when the motif like Figure 2 is used, there may still be said to be eight partial tracks or the equivalent of this, since the image of each transparent rectangle extends over all eight of the partial tracks on 120, and each eighth of the rectangle corresponds to each of the partial tracks of the latter. The width of the image of each aperture of a motif of the form of Figure 2 is preferably a half of the shortest wavelength appearing on the wave track, and in any case not greater than this. In the motif of Figure 4, each aperture should have a width, in the tangential direction, such that its image on the wave screen is a half wavelength on that particular partial track whereon its image falls.

Either form of motif, that of Figure 2 or Figure 4, may be used. However, the latter has the advantage over the former that it has, or may have, eight times the transparent area of that of Figure 2, and so will admit eight times more light to the photoelectric cell, as will appear in the following. My invention comprises both forms of motifs, and others as well.

For simplicity, we shall first consider the manner in which the motif of Figure 2 is employed to produce musical tones. Lenses 110, situated intermediate the screens 111 and 120 in Figure 1, focus a moving image of the motif of 111 on the corresponding area of pattern 120. This image constitutes a beam of light which travels across pattern 120 as pattern 111 rotates and which therefore scans the sinewaves of pattern 120 at plane 105. When this beam is so directed that it falls on a portion of the sinewave plate 120 which is chiefly opaque, only a little light reaches the photosensitive cell; when, on the other hand, the glass in its path is largely transparent, a considerable amount of light strikes the cell. At the instant when one of these light beams recedes at the edge of the sinewave plate, the beam from the next succeeding motif of the same circle approaches the sine curves at the opposite edge of the plate, and there is a cyclic variation in the light which reaches the cell. It can be shown by mathematical reasoning that this variation of light follows definite laws of variation with time, and may be expressed as the sum of eight sinusoids, one for each of the eight sinewaves at 105.

When a tone is played, each of the partial tracks on 111, in cooperation with its corresponding partial track on 120, modulates in a simple harmonic manner (i. e., sinusoidally) its own component of the radiation flux transmitted by it and subsequently striking the photosensitive device. The components combine or coalesce, and produce at 107 a synthetic periodic electric current of complex waveform.

It is a characteristic of a suitable cell that the eleectric current which flows through it is proportional at every instant to the radiation flux striking it, and thus the current also varies sinusoidally, and thus represents a complex musical tone, with a fundamental and seven harmonics. A similar design may be used for tones having a far larger number of harmonics, if so desired.

As for the type of motif shown in Figure 4, it is apparent that, if properly constructed, it will also cause a current which is the sum of eight sinusoidally varying currents. The mode of operation is easily inferred from the explanation of the operation of the motif of Figure 2. Proper construction implies that, for example, the tangential dimension of the motif be such that its image as projected on plane 105 be just the width of the active portion of that plate; that is, of that portion in which the sinewaves appear. The image of the row with one opaque and one transparent portion must coincide with the wave at the bottom of Figure 3, that with two of each must coincide with the second lowest sinewave, which exhibits two full wavelengths, and so on. Each beam of light is, as nearly as possible, one-half wave'ength in width, as referred to the particular sinewave on which it falls. It will be seen that such a motif will be eight times as efficient as the simpler one of Figure 2. If there were sixteen partials, we should have sixteen times the efficiency in the motif corresponding to Figure 4.

There may be also light reaching the cell through tracks other than that for middle C. It is obviously necessary to exercise some control over which tones shall be played, and one of the simplest means of accomplishing this is to interpose, near the circles on the discs, or preferably near their respective lenses 110, a series of shutters 121, one for each lens, as shown in Figures 5 and 5a, and 12. These will always, except when in motion, be fully open or fully closed and not, like the timbre shutters to be described below, capable of being fixed in a partly opened position. They may be under the control of a series of manually operable selectors 62, arranged like the conventional organ keyboard, so that the performer may select his tones at will. Thus they control the fundamental frequency of the tone emitted by the instrument. It will be noted that two or more tones may be played simultaneously without interference, by simply pressing several keys at a time. This is in contrast to some other forms of device for the electrical production of musical tones, notably some of those utilizing vacuum tube oscillators, wherein the number of tones which may be simultaneously sounded is limited even when the number which can be successively sounded is large.

It has been stated in the parent application that the order in which the various partials of a tone come into action at the onset of the tone determines whether that onset is an "explosive" or a smooth one. Hence the exact shaping and speed of the shutters under the control of the keyboard are able to influence the musical effect to a marked degree, and their edges may be so shaped as to permit certain harmonics to first come into action; that is, to uncover the tracks on the rotating disc or cylinder associated with certain harmonics before those associated with others. To best accomplish this, the shutter is usually to be placed quite close to the rotating member with its tracks.

The principle of the device has been explained with reference to a rotating screen in the form of a disc, having on it transparent areas which are substantially rectangular, and whose images successively scan a stationary screen in the form of a flat plate which has sinewaves to mark the boundaries between its transparent and opaque areas. It is evident that the device could just as well be constructed with sinewaves on the first screen, and rectangular areas on the second screen, an image of the one being focused on the other by a lens interposed in the light train intermediate the two screens. Such an arrangement of parts is illustrated in Fig. 7, as explained hereinbelow. The relative motion of waves and rectangles is the matter of chief importance. If a somewhat broad definition of the term "scan" or "scanning" be adopted, it may be said that the sinewaves in Fig. 1, or their images in Fig. 7 are, successively scanned by the rectangular areas of pattern 111. Such a broad definition I employ here. Also, the sinewaves, whether moving or stationary, need not represent the boundaries between totally opaque and nearly perfectly transparent areas. In the device as above described, the width of transparent area varies from place to place along the plate, according to a sinusoidal law. It is also feasible to make the variable quantity the transparency of the plate from place to place, in which case the light reaching the cell will, or may be made to, vary in the same manner as described in preceding paragraphs. This plate of variable density to light might conveniently be formed by means of a light-sensitive emulsion, exposed, developed, and fixed in the manner common in photographic work. All such closely similar processes I comprehend in the term "scan," "modulate," or the like. It is only essential that there be two screens, or a screen and an image, in relative motion.

To distinguish, I use the term, aperture screen, for one like Figure 2 or Figure 4, or one having a single slit, whether the same be moving or stationary; that is, any where the transparent areas are approximately rectangles; I use the term, wavescreen, for one having a pattern similar to Figure 3.

It is entirely feasible to give to the transparent areas on the rotating and stationary screens shapes which are neither rectangular, nor bounded by a sinusoid or sinusoids. There are an infinite number of different shapes of transparent area for either screen which do not fall into either of the above categories, yet which will, if combined with a suitable pattern on the other screen, give a law of light variation through the pair of tracks in question which is sinusoidal. Or the degree of transparency of fixed and rotating screens may vary from point to point in an infinite number of ways, yet the light variation through the tracks will be sinusoidal. Since it is impossible to describe all of these, I have illustrated and described in the foregoing the type of construction which I regard as preferable because of the simplicity of its design.

There are still other types of construction of the optical system for originating a complex waveform, which I wish to include specifically in this application. One of these is shown in Figure 7, wherein like numbers represent the same components as in Figure 1. It will be noted that these components are the same as in Figure 1, but that their arrangement is different. The sinewave screen is now between the rotating disc and the source of light, and the objective lenses are, as before, between the stationary screen 120 and the disc screen 111. The lenses in this case project a reduced stationary image of each partial track of 120 onto its associated moving partial track on 111. That is, the image of 120 is smaller than 120 itself. Just as before, the stationary sinewave screen may be of conveniently large size for practical design of timbre shutters, yet the rotating discs need not be excessively large. The principle of operation may be easily inferred by comparison of the two figures, 1 and 7. Either the pattern of Fig. 2 or that of Fig. 4 may be used at plane 104. It is evident that each pitch track of 111 can be considered as made up of a plurality of partial tracks, the apertures of several partial tracks coalescing to form a single pitch track aperture.

A comparison with the principles set forth in the discussion in my parent application will make evident the fact that the eight sinusoids on the sinewave plate may be used in various combinations to produce musical sounds of any of a wide variety of timbres, or tonal qualities. It is evidently desirable to have some mechanically movable and manually adjustable means for controlling the relative magnitudes, or amplitudes, of the several components of radiation intensity, and hence of emitted tone. The light passing thru each of the sinewaves must be forced to follow a definite "channel," so that its particular shutter will cut off only the light from that "wave" and none of the light from any of the

other seven. I accordingly show in Figure 6, just to the right of 105, a series of horizontal lines 118, which represent opaque fins, whose purpose it is to "channelize" the light from 105 until it reaches the timbre shutters 119. The light at these shutters is not in focus, and the shutters are preferably at some distance from the focal plane 105. Otherwise, when a given shutter is partially closed, to cut down the intensity of its corresponding harmonic component, it would be difficult to avoid cutting out the light from some portions of the corresponding sinewave more markedly than that from others. The result would be a distorted waveform in the sound emitted.

A set of four manually operable waveform or timbre selectors 114 which, in this case, perform a function analogous to organ stops, serves to open and close the shutters 119 through the intermediary of flexible wires or cords 135, which are guided by pulleys 112. Obviously, the wires and pulleys might be replaced with any other mechanism mechanically linking the stops and timbre-regulating shutters. All of the pulleys 112 are attached to a suitable supporting framework, 115. Attached to each stop are eight small pulleys 113, shown by black dots. When a stop is pulled, it pulls loops in each of the wires or cords, as shown, and the further the stop is pulled, the longer the loop. These pulleys 113 may be so placed on the stops that they do not touch the wires until the stop has been pulled a little distance. This serves to determine how much shutter opening shall be imparted by the pulling of a given stop. As illustrated, the stops are in their half-operated positions, so all pulleys 113 are in contact with their wires. If the stops were returned to normal, that is, pushed to the left, certain pulleys 113 would then come out of contact with their wires, as just stated. Some shutters, perhaps, we may not wish to open at all in response to a manipulation of certain of the stops. It is also seen that the motion imparted to any of the shutters by the simultaneous operation of several stops is approximately the sum of the motions imparted by each of the stops operated separately, or that it can be made so by proper design. Thus, the shutters should be made long enough so that each travels through only a few degrees of arc from closed to wide open position. In such a case, the magnitude of each current component is approximately equal, when several stops are operated, to the sum of the magnitudes which are imparted to it by the same stops operated individually. A mechanism, operated by a plurality of selectors through direct mechanical linkage as in the present case, and of which this additive relationship is true, I term an additive mechanism. The selectors in this instance cooperate to determine the waveform of modulation of light flux; that is, they control the current not only through a mechanical linkage, but through the intermediary of a beam of radiant energy.

I have throughout the last few paragraphs referred to eight timbre shutters and eight partials. It is evident that more or less than eight might be used without altering the principle of the device. I have found that sixteen partials will provide about all of the different types of tone quality one could desire.

It seems that the very simplest possible type of timbre or waveform shutter is that about to be described. However, in case it is used, the aperture screen must be the stationary one.

It is obvious that the sound output associated with a given harmonic will be decreased if we broaden each of the opaque areas on the portion of the motif which produces that harmonic, and meanwhile correspondingly narrow the adjacent transparent portions, keeping the combined width of the opaque area and its neighboring transparent one, constantly equal to one wavelength. A given harmonic will be entirely missing when there is no transparent area at all in its track on the motif. The above conditions being fulfilled, such a shutter action will not give rise to distortion.

It would be somewhat difficult to actually vary the width of the transparent areas of a motif; that is, the widths of the apertures. However, a preferred method of effectively accomplishing the same result is shown in Figure 14. I place in front of the aperture track 111'' a partial shutter, 119', which has uniformly spaced opaque and transparent areas precisely like those of the track. That is, all transparent areas on both parts are uniform in width, likewise all opaque areas. If such a shutter now be slid along such a track, there will be positions wherein its transparent areas are superimposed on those of the track, and positions wherein its transparent areas are superimposed on the opaque areas of the track. In the former case, a maximum amount of light will get through the shutter and screen, and in the latter case no light will get through, at least insofar as the particular harmonic track in question is concerned. Between these positions, the light beams will be narrower than they would be without the shutter, but they will be spaced a wavelength apart. Such a shutter is provided for each of the several partials present on the screen, and can probably be made most easily, like the screen, by a photographic process. A suitable simple mechanism similar to that of Figure 6 will serve to connect the shutter to the stops of the instrument, and to slide it in a direction perpendicular to the direction of the bands and also perpendicular to the beam of light or other radiant energy transmitted by it.

In Figure 8, I show a form of my invention wherein an aperture screen 123 is provided with a slit or other aperture, illuminated by the source of light 101. On a cylindrical surface adapted for rotation are mounted a plurality of plane mirrors, or other reflectors, 115, and these form the moving part of the system, analogous to the disc of Figure 1. Suitable lenses are provided, as shown, so that the mirrors cause successive images of the slit to sweep across a sinewave plate or screen 120, and so to scan the same. The result is a modulation of the radiant energy in accordance with a complex periodic waveform, as in foregoing figures. The two "screens" in this case are 123 and 120.

It is apparent that a stationary slit and a plurality of rotating plane mirrors is equivalent optically to a cylinder in which there are a plurality of transparent slits, or apertures, and, immediately adjacent to it, a plane mirror which is stationary. This form of the invention is drawn in Figure 9. Numeral 123' represents the slotted cylinder and 124 the stationary plane mirror. Here, the aperture and wave screens are shown respectively at 123' and 120, and 110 is a means for focusing an image of the former onto the latter.

In Figures 8 and 9, the lens 110 is, as in foregoing figures, interposed in the light train intermediate the two screens because the radiant en-

ergy encounters the lens intermediate the screens, as it travels from source to photosensitive device.

It is usually desirable to build an instrument so that it is capable of covering a gamut of several octaves. Assuming twelve tones or one octave on each disc, a group of seven discs will provide nearly all of the tones of which the piano is capable. Each disc rotates at twice the speed of that which produces the tones of the octave next below. The seven discs might, for example, rotate at speeds of 20, 40, 80, 160, 320, 640, and 1280 revolutions per minute, respectively.

In Figure 10, I illustrate one of the several arrangements of seven discs 111, which will render possible the use of but one light source, one sine-wave plate, and one photosensitive cell for the entire gamut of tones. These discs may be driven at their appropriate speeds through a system of accurately cut gears, driven by a shaft which runs parallel to the several shafts of the discs. This is a mechanism already familiar in this art. Suitable gearing arrangements are shown in Figure 35 of Patent No. 1,213,803 to Cahill, the gear-tooth numbers in the present instance being chosen to suit the speeds desired. Or, see Figure 1 of Patent No. 1,848,222 to Potter. Numeral 125 represents reflectors, preferably mirrors or totally-reflecting prisms, whose function it is to direct the light through the discs and then redirect it toward the cell. The prisms appear in end view in the figure.

Two prisms are associated with each disc. One, below its corresponding disc, is interposed in the optical train intermediate the source and disc or moving screen; the other, above its disc, is inteposed in the optical train intermediate the two discs, 111 and 120.

It should be pointed out here that there is great economy in a design which makes possible the use of a single light source and a single photosensitive cell for a plurality of tones. These are among the few perishable parts in such an instrument, and it is advantageous to reduce the number of them necessary. My invention also contains in the form just described only one timbre shutter for each partial one wishes to produce, by whose means the tone qualities of all of the tones of the instrument may be simultaneously controlled. This reduces to a minimum the amount of mechanism necessary. I have found, moreover, that a simple meniscus lens is adequate for each tone, as an objective lens. I do not wish, however, to limit my invention to the use of but one source of light, one set of timbre shutters, or one cell for all the pitches on a given instrument or keyboard, for it may be advantageous in certain special cases to use more than one of each, and to appropriately alter the other portions of the assembly to correspond. Thus, all the tones of an octave might use one source, cell, or set of shutters; all those of a second octave might use another, etc.

A preferred form of volume control makes use of a shutter 126, placed just to the right of the bank of lenses 110, as seen in Figure 1. The details of this shutter are illustrated in Figures 11 and 11*a*. Numeral 116 designates a lever serving to slide the shutter 126 in its guides 116'. The lenses 110 are shown about half covered by the shutter.

Little has been said about an amplifier, or of methods for connecting this to the photosensitive device. It is, of course, commonly necessary to use an amplifier, on account of the feeble amount of energy emitted by such a device. The method of connecting the two may be any one appropriate to the particular kind of device used. Such circuits are well known in the art; the manufacturers of such cells usually illustrate circuits for this purpose, and the requirements in the matter of coupling means are quite similar in the present invention to those in common use in sound-on-film reproduction. Usually a loudspeaker or the like serves to convert the output energy of the amplifier into sound. I have not illustrated the amplifier and loudspeaker circuits, since my invention consists only in their combination with certain forms of optical train.

In certain instances it may be desirable to control the rate and nature of attack or of dying away of a tone after a key has been struck, just as has been described under the treatment of the electrostatic input circuit in the parent application. Moreover, just as in the latter, it may be desirable to put the tonal volume under the control of the keyboard; in other words, to make the tone sound louder if the key is struck harder, as in the piano. In Figure 15, I illustrate a type of key and action which accomplishes this. This device utilizes a rotating shaft 74, a pulley 72, and a ratchet 73*a*, all rotated by electric motor 32 at a speed dependent upon the tightness of the belt 75 between them. The tightness of this belt is under the control of foot pedal 68. When the pedal is not pressed, the idler pulley 72*a* keeps the belt taut, and pulley 72 rotates with its maximum speed. When the key lever 62 rises, it strikes shutter 65 and causes it to rise to a height dependent upon the force of the blow which it imparts to it, and to admit an amount of light which is greater the greater this height. In addition, it raises tooth 73*b* into contact with ratchet wheel 73*a*. This wheel has formerly been rotating with shaft 74, due to the friction between them. However, when 73*b* comes into engagement with 73*a*, the rotation of the latter is temporarily arrested, and remains so as long as the key is depressed, even though the shaft may go on rotating.

When shutter 65 has risen to the top of its arc of motion, the pawl 73 which it carries engages ratchet wheel 73*a*, and it remains in that position until the key is again released; ratchet wheel 73*a* then resumes its rotation, and shutter 65 falls as fast as the rapid rotation of the shaft will permit.

If the shaft with which ratchet 73*a* rotates is made to rotate slowly or to stop altogether, by reason of pedal 68 being depressed, the tone will be prolonged after key lever 62 has been released. The length of time the tone is prolonged depends upon the rate of rotation of the shaft, which can be controlled through wide limits by depressing pedal 68 to varying distances. When the pedal 68 is released, the shaft and ratchet resume their rapid rotation almost immediately, thus permitting 65 to fall.

It is evident that pedal 68 performs for the present invention just what the loud pedal does for the piano. It serves to maintain or prolong the tone after the key has been released, for a shorter or longer interval. In the present case, the pedal can prolong the tone indefinitely, whereas in the piano, the tone can persist only during the intervals when the strings are able to continue their vibration. However, it is unnecessary to prolong the tone indefinitely if one chooses not to, for 65 may be made to return at any desired rate to its position of rest, according to how far pedal 68 is depressed.

It will be readily seen that certain of the parts of Fig. 13 need not be duplicated for every note of a keyboard.

It is to be understood that equivalent mechanisms may be substituted for parts shown in Figure 15. Such substitutes are included within the spirit of my invention. In broad language, Figure 15 shows a shutter whose motion is controlled by an electric motor for gradually varying the effect of a source of radiant energy upon a photosensitive device when a selector is manipulated. With the motor running in such a direction as to close the shutter, the key selector opens the shutter and admits radiant energy, while the motor and its mechanism shut off this energy gradually whereupon the tone gradually decays in loudness. Or, if 72 is caused to stop its rotation, the ratchet wheel will arrest the shutter and hence prolong the admission of energy, and the tone, indefinitely.

In Figure 12, I show a form of photoelectric instrument having its rotating modulating tracks disposed on cylinders instead of discs. I show three rotating cylinders 111', one for each of three octaves. Numeral 101 again designates suitable light sources, inside the cylinders. These are long and narrow in this instance. Each group of cylinders rotates at a different speed generally. In particular, if the groups are all alike and we wish to produce three successive octaves of tones, the speed ratios of the three will be 1:2:4. The means for rotating them may consist of a synchronous or other constant speed motor, together with appropriate gearing which, because they are already familiar in the electrical musical instrument art, are not illustrated. See, for example, Figure 35 of Patent No. 1,213,803, to Cahill, the gear-tooth numbers in the present instance being chosen to suit the speeds desired. In this case all of the motifs on all of the cylinders could be alike, and in order to generate twelve different tones from each group, the cylinders of a group must have different diameters, so that we can give to each of the twelve cylinders a different peripheral velocity. All of the objective lenses 110 in a bank will not be alike, for they are at different distances from the objects whose images they are supposed to project, namely the motifs on the cylinders. Figure 12 shows three wave screens 120, and three condensing lenses 106, one for each of the three groups of cylinders; these might, in certain cases where the conformation of the device permitted, be combined into one plate and one lens.

A volume shutter 126, and a set of pitch shutters 121 are disposed near the objective lenses 110. These elements 121 are for the purpose of starting and stopping the tones under the control of the keys 62, as shown in detail in Figs. 5 and 5*a*. These parts 121 and 126 are represented schematically, to indicate their locations, since they were shown in detail in other figures. Stationary screens 120, and channelizing fins 118, already disclosed in Figure 6, also appear in Figure 12.

The timbre may be conveniently controlled by means of slots or perforations 136' in an opaque timbre-controlling belt 136, Figure 13, which lie adjacent to the fins 118. Such a belt I term a timbre-controlling aperture belt. This belt may be substituted for timbre shutters, as 119, in Figure 6. In Figure 12, I again show these parts, in this case in combination with the optical system.

There is one aperture in 136 for each of the several partial waves on 120, except where two slots are so wide that they merge into one. The light is channelized, as in Figure 6, by means of the fins 118. Thus the width of a slot determines the amount of light reaching the cell from the sinewave corresponding to that particular slot, just as the shutter opening determines it in Figure 6.

In order to change the timbre to some other preselected one, 136 in Figure 13 may be shifted downward until apertures 136'' lie in front of 118. Since the widths of the apertures 136'' are different from 136', it follows that the proportions of the various partials will now be altered. Obviously, only timbres which were preselected in the design of the aperture belt can subsequently be played, and the number of different timbres is limited to the number of groups of apertures on 136. The mechanism for operating 136, it has been considered unnecessary to illustrate, since it would be so similar to the rolls of a player piano. A slight difference would be, however, that 136 would be shifted only occasionally from the position for one timbre to that for another, remaining stationary meanwhile, whereas the player piano mechanism would be kept in continuous uniform motion for automatic playing. I do not claim this mechanism. It is not an additive one like that of Figure 6, since the effects of the several stops in the latter figure add up at the shutter; in the mechanism for operating 136, on the other hand, one would not use a plurality of stops.

Belt 136 may be either an endless one or not, as desired. Instead of the opaque belt with holes punched out, one could use a belt on which transparent rectangles were photographed, just as the apertures on 111 were photographed. Such a photographed belt I also include in the term, aperture belt. Like 111, it would be made of a transparent material, for example, celluloid. Although I prefer a flexible belt to a rigid mask having similar apertures, it is to be understood that sheet metal or glass might be substituted for the flexible celluloid. Such rigid forms I include in the term, mask or aperture mask.

It is to be noted that the apertures in 136 occur in a plurality of tracks, each of which associated with a different partial of the complex tone or waveform produced. It is also to be noted that the keyboard selects the fundamental pitch only, the waveform or timbre being determined by the sizes of the apertures in the mask, 136.

One means of introducing vibrato effects, that is, periodic variations in pitch at a slow rate, into the tones emitted by the photosensitve type of musical instrument herein described is to incorporate into the rotating part of the apparatus a means, such as that shown at 36, 37, 37*a*, 37*b*, 37*c*, and 38 in Figures 10 and 10*a* of the parent application, since such means are applicable to any of a large number of different types of electrical musical instrument in which a moving mechanical system is used in conjunction with electrical means for producing sound. The method of applying such a form of vibrato mechanism to the present photoelectric instrument is obvious to one familiar with driving means for electrical musical instruments, who has first studied these figures and their accompanying description.

Where the claims include a source of radiant energy, or a photosensitive device, I do not confine myself to a single source or device, since it is obvious that separate sources or devices may be used for the several tracks. The term "photosen-

sitive device" embraces both devices of the self-generating type, which need no external battery or source of direct E. M. F. in series, and also those whose internal resistance varies in response to variations in radiant energy and which consequently require an external direct E. M. F.

The term "radiant energy" in the claims is intended to comprehend all forms, whether within, above, or below, the range of visibility. Likewise with radiation flux.

Where I refer to relative motion in the claims, I mean to include oscillation, translation, rotation, or reciprocation or a combination of these, unless otherwise limited, also, the physical form of the screens is not confined to flat or cylindrical ones.

Many of the details of my invention are applicable to other forms of the parts with which they are associated. Thus the location in the optical train of shutters in Figure 12 may be used in combination with the discs of Figure 10.

This invention is not limited, except where the language of the claims demands, to the production of periodic modulation and currents; nor is it limited to the production, in separate and distinct tracks, of a plurality of sinusoidal alternations in radiant energy, with subsequent synthesis of these in a photosensitive device. For it is evident that the variation of energy may follow a certain law as a function of time for a limited period and then, before this variation has begun to repeat itself, the moving part of the apparatus may be stopped or the electric current may be interrupted. Or the light may be interrupted or extinguished. A variation of radiant energy, in the optical instrument, which is non-periodic and not the result of synthesis is attainable, for example, through the use of a moving motif like Figure 2, in conjunction with a stationary plate on which appear, not a plurality of sinusoids like Figure 3, but opaque portions bounded by any desired irregular sort of curve. The image of the motif, as it sweeps over such a plate, will cause a corresponding irregular or complicated sort of variation of radiant energy, provided the tangential width of the image is less than substantially half of the shortest wavelength on the stationary plate which it is desired to copy in electrical form. This principle was enunciated in the parent application in connection with Figure 11*b*. Except in limited instances, however, I prefer the periodic and synthetic means for voltage generation, as earlier described.

In the claims, where I refer to "an electrical apparatus for producing a varying electric current translatable into a musical tone" or words to the same effect, it is not to be inferred that musical tone is the ultimate purpose of the apparatus referred to. Thus the ultimate purpose may, for example, be the production of currents for the testing of amplifiers. I use the word "musical" in two senses; (*a*) useful in making music, and (*b*) characterized by a sustained and definite pitch. The first is the dictionary definition while the second is that of the physics textbook.

Because of the comparative familiarity of the phrase, in various places through this specification I have, somewhat loosely perhaps, spoken of modulation of radiant energy. To be very exact, what I possibly should have said was "modulation of radiation flux", the flux being the time rate of radiation or flow of radiant energy, and having the dimensional formula L^2MT^{-3}. It is to be understood that by either phrase I mean the same thing. The more exact one, or wording closely similar, I employ in the claims.

Where I refer to "selectors" in the claims, I mean to include manual keys, pedal keys, stops for timbre control, and other instrumentalities, except as otherwise limited by the terms of the claims.

The drawings and description illustrate and describe by way of illustration only what I now consider to be preferred forms of the device for the photoelectric production of musical tones or of alternating or otherwise varying currents or electromotive forces, while the broad principle of the invention will be defined by the appended claims.

What I claim as my invention and desire to secure by Letters Patent is:

1. An electrical apparatus for producing a varying electric current translatable into a musical tone; said apparatus including an optical train comprising; (1) a source of radiant energy, (2) a photosensitive device receiving radiant flux from said source, (3) means for modulating said flux at a plurality of audio frequencies, comprising two screens, each bearing a plurality of modulating tracks and interposed in said train intermediate said source and device, and (4) interposed in said train intermediate said screens, means stationary relative to said device for focusing on one of said screens an image of at least a portion of each of the modulating tracks on the other screen.

2. The combination set forth in claim 1, further characterized by the fact that each of said tracks is adapted, in cooperation with a corresponding track on the other screen, to modulate sinusoidally and at a different frequency that portion of the radiation flux from said source which said track transmits, the several frequencies being multiples of a common fundamental frequency, and the effects of the several modulations combining to produce in said photosensitive device electric current variations having said fundamental frequency and a complex waveform.

3. The combination set forth in claim 1, in combination with a plurality of manually adjustable means interposed in said optical train for controlling the magnitude of each of the partial components of said tone.

4. The combination set forth in claim 1, said screens being adapted for mechanical motion relative to each other whereby scanning is effected.

5. An electrical apparatus for producing a periodically varying electric current translatable into a complex musical tone, comprising a source of radiant energy, a photosensitive device receiving energy from said source, a plurality of manually actuated means for selecting the fundamental pitch of said tone independently of its waveform, and, interposed in the path of said energy intermediate said source and device and independent of said means, a mask having a plurality of tracks of transparent apertures of fixed size and shape, each of said tracks being associated with a different partial of said tone and serving to regulate the amplitude of said partial.

6. The combination set forth in claim 1, in combination with a stationary reflector interposed in said train intermediate said screens, the means for focusing including at least one lens.

7. The combination set forth in claim 1, in combination with a moving reflector interposed

in said optical train, whereby scanning is effected.

8. The combination set forth in claim 1, wherein one of said screens rotates and carries a plurality of pitch tracks, one for the production of each of a plurality of fundamental frequencies, wherein the other of said screens is stationary, and wherein said means for focusing include a plurality of lenses, each associated with one of said pitch tracks, and adapted to focus upon the stationary screen an enlarged moving image of its associated track, in combination with a plurality of timbre regulating means adjacent to the stationary screen.

9. The combination set forth in claim 1, wherein one of said screens rotates and carries a plurality of pitch tracks, one for the production of each of a plurality of fundamental frequencies, wherein the other of said screens is stationary, and wherein said means for focusing include a plurality of lenses, each associated with one of said pitch tracks, and adapted to focus upon its associated track on the rotating screen a reduced stationary image of said stationary screen, all in combination with a plurality of timbre regulating means adjacent to said stationary screen.

10. In an electrical apparatus for producing varying electric currents, an optical train comprising: (1) a source of radiant energy, (2) a photosensitive device, (3) two radiant-flux-modulating screen interposed in said train intermediate said source and device, and (4) interposed in said train intermediate said screens, a plurality of means for focusing on one of said screens superimposed images of different portions of the other.

11. The combination set forth in claim 10, in combination with a plurality of timbre regulating means adjacent to one of said screens.

12. In an electrical apparatus for producing varying electrical currents, an optical train comprising: (1) a source of radiant energy, (2) a photosensitive device, (3) a radiant-flux-modulating screen interposed in said train intermediate said source and device, and (4) interposed in said train intermediate said source and screen, a plurality of means for focusing on said screen superimposed scanning images.

13. The combination set forth in claim 12, in combination with a plurality of timbre regulating means adjacent to said screen.

14. An apparatus for optically synthesizing complex periodic electric currents, said apparatus comprising a plurality of stops and an optical train: said train including (1) a source of radiant energy, (2) a photosensitive device receiving radiant energy from said source, (3) a plurality of distinct and separate modulating partial tracks interposed in said train intermediate said source and said device, each of said tracks adapted to modulate, at a different frequency and in a simple harmonic manner, that portion of the radiation flux from said source which it transmits, the frequencies being integral multiples of a common fundamental frequency, and all of the several components combining to produce in said device a complex, periodically varying electric current, and (4) a plurality of means actuated by said stops for controlling the amplitude of the variation of each of said components.

15. An apparatus for producing a varying electric current comprising: (1) a plurality of manually operable selectors for the purpose of controlling said current, (2) a mechanically movable element for controlling the magnitude of a component of said current, and (3) an additive mechanism mechanically linking said element and said selectors.

16. An apparatus according to claim 15, wherein said selectors cooperate to determine the waveform of said current.

17. In an electrical apparatus for producing varying electric currents translatable into sound; an electric motor, a selector, and an optical train; said train including a source of radiant energy, a photosensitive device, and, interposed in said train intermediate said source and device and actuated by said selector, means whose motion is controlled by said motor for gradually varying the effect of said source upon said device after said selector has been operated.

18. In an electrical apparatus for photoelectrically producing varying electric current translatable into sound; (1) an electric motor, (2) a mechanism operated thereby, (3) a selector, and (4) an optical train; said train including (*a*) a source of radiant energy, (*b*) a photosenstive device, and (*c*) interposed in said train intermediate said source and device, and actuated by said selector, means for admitting to said device and shutting off from the same device energy from said source; said energy being admitted under control of said selector, and shut off gradually under control of said motor and mechanism, whereby a gradual decay of tone is attained.

19. In an electrical apparatus for producing varying electric currents translatable into musical tones, an optical train comprising; (1) a source of radiant energy, (2) a photosensitive device receiving energy from said source, (3) a wave screen interposed in said train intermediate said source and device and having distinct and separate wave tracks, each for modulating, at a different frequency and in a simple harmonic manner, the radiation flux transmitted by it, the several frequencies being multiples of a common fundamental frequency, (4) an aperture screen also interposed in said train and bearing apertures cooperating with said tracks to modulate said flux, the effects of the several modulations combining to produce in said device electric current variations having said fundamental frequency and a complex waveform.

20. In an apparatus for photoelectrically producing musical tones, the combination of (1) a plurality of stationary aperture tracks, each associated with one of a plurality of tonal partials, and (2) a plurality of timbre shutters, each for controlling at will the amplitude of one of said partials, and each corresponding to one of said tracks; said tracks each bearing a series of opaque bands, all of the same width, alternating with a series of transparent bands, likewise all of the same width; said shutters also each bearing a series of opaque bands, all of the same width, alternating with a series of transparent bands, likewise all of the same width; said shutters and tracks being adapted for relative motion perpendicular to the direction of said bands on said shutters and perpendicular to the direction of the radiation flux transmitted by said shutters.

21. In an electrical apparatus for the production of a varying electric current translatable into a musical tone and having (1) a source of radiant energy, (2) a screen bearing a plurality of modulating tracks and adapted to modulate the radiant flux from said source, and (3) a photosensitive device receiving the energy modu-

lated by said screen; the combination therewith of (a) a second screen positioned in the stream of radiant flux emanating from said first screen and also bearing a plurality of modulating tracks and adapted to cooperate with said first screen to modulate the flux emanating from said source at a plurality of audio frequencies and (b) means stationary relative to said device for focusing an image of at least a portion of each of the modulating tracks of the first screen at the second screen, said means being interposed in the stream of radiant flux intermediate the two screens.

22. In an electrical apparatus for the production of a varying electric current translatable into a musical tone and having (1) a source of radiant energy, (2) two screens separated by a substantial distance from each other for cooperatively modulating at an audio frequency a portion of the radiant flux emanating from said source, and each bearing a plurality of modulating tracks, and (3) a photosensitive device receiving the energy modulated by said screens; the combination therewith of means stationary relative to said device for focusing on one of said screens an image of at least a portion of each of the modulating tracks on the other screen, said means being interposed in the stream of radiant flux intermediate the two screens.

23. In an electrical apparatus for producing a periodically varying electric current translatable into a complex musical tone and having (1) a source of radiant energy, (2) a plurality of manually actuated means for selecting the fundamental pitch of said tone independently of its waveform, and (3) a photosensitive device receiving energy from said source; the combination therewith of a mask comprising a plurality of tracks of transparent apertures of fixed size and shape interposed in the path of said energy intermediate said source and device and functioning independently of said means, each of said tracks being associated with a different partial of said tone and serving to regulate the amplitude of said partial.

24. The apparatus set forth in claim 23, said apertures being arranged in a plurality of groups, each group being associated with a particular desired quality of tone, and serving to regulate the amplitudes of the partials characteristic of that quality.

25. In an electrical apparatus for producing varying electric currents and having (1) a source of radiant energy, (2) two modulating screens for modulating a portion of the radiant flux emanating from said source, and (3) a photosensitive device receiving flux modulated by said screens; the combination therewith of a plurality of focusing means interposed in the light train with said screens and intermediate the two, said means focusing on one of said screens superimposed images of different portions of the other screen.

26. In an electrical apparatus for producing varying electric currents and having (1) a source of radiant energy, (2) a screen for modulating at least a portion of the radiant flux emanating from said source, and (3) a photosensitive device receiving flux modulated by said screen; the combination therewith of a plurality of means for focusing superimposed scanning images on said screen.

27. In an apparatus for optically synthesizing complex musical tones and comprising (1) a source of radiant energy, (2) a screen for modulating at least a portion of the radiant flux emanating from said source, (3) a photosensitive device receiving flux modulated by said screen, and (4) a plurality of stops; the combination therewith of (a) a plurality of distinct and separate partial modulating tracks borne by said screen, said tracks being adapted to modulate, each at a different partial frequency, and each in a simple harmonic manner, that portion of the radiation flux from said source which it transmits, the several frequencies being integral multiples of a common fundamental frequency, and all of the several partials combining to produce in said device a complex, periodically varying electric current, and (b) a plurality of means actuated by said stops for controlling the relative amplitudes of each of said partials, whereby a controlled quality of tone is attained.

28. In an apparatus for producing a varying electric current and comprising (1) a plurality of manually operable selectors for the purpose of controlling said current, and (2) mechanically movable valves for controlling the magnitudes of components of said current; the combination therewith of an additive mechanism mechanically linking said valves and said selectors.

29. In an electrical apparatus for producing varying electric currents translatable into sound, and comprising (1) a source of radiant energy, (2) a photosensitive device, (3) a selector, and (4) means actuated by said selector for gradually varying the effect of said source upon said device after said selector has been operated; the combination therewith of an electric motor mechanically linked to said means in a manner adapted to effect such variation at a desired rate of speed.

30. In an electrical apparatus for photoelectrically producing varying electric current translatable into sound and having (1) a source of radiant energy, (2) a photosensitive device, (3) a selector, and (4) means actuated by said selector for admitting to said device and shutting off from the same device radiant energy emanating from said source; the combination therewith of an electric motor and a mechanism operated thereby, said mechanism being adapted to gradually shut off the energy reaching said device, whereby a gradual decay of tone is attained.

31. In an electrical apparatus for producing varying electric currents translatable into musical tones and comprising (1) a source of radiant energy, (2) two radiant-flux-modulating screens, and (3) a photosensitive device receiving flux emanating from said source and modulated by said screens; the combination therewith of (a) a wave pattern borne by one of said screens and having several distinct and separate wave tracks, each associated with a separate tonal partial, and (b) an aperture pattern borne by the other of said screens and having apertures cooperating with said several wave tracks, to modulate said flux, the combined effect of said wave tracks and apertures on the radiation flux transmitted therethrough providing a series of partial frequencies, of simple harmonic form and of multiples of the common fundamental frequency, and the effects of the several partials combining to produce in said device electric current variations having said fundamental frequency and a complex waveform, whereby the desired quality of tone is attained.

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