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Beigel

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[54] **SOUND EFFECTS GENERATOR**

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[73] Assignee: **Musitronics Corporation**, Rosemont, N.J.

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[51] **Int. Cl.²** **G10H 1/02**; H03H 7/10

[58] **Field of Search** ..... 84/1.01, 1.09–1.12, 84/1.19, 1.21, 1.22, 1.24, 1.27, DIG. 9, DIG.19, 1.25; 179/1 D; 307/271; 328/127, 149, 167, 175, 209; 330/52, 75, 98–100, 103, 109; 333/70 R, 70 CR

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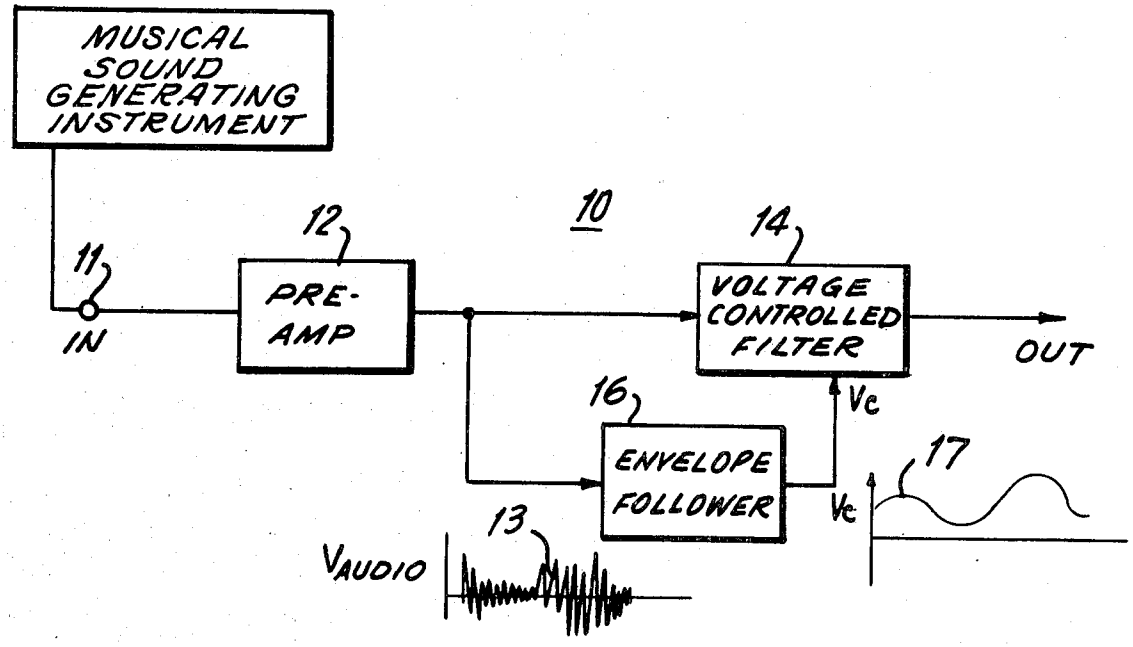
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Primary Examiner—L. T. Hix
Assistant Examiner—Stanley J. Witkowski
Attorney, Agent, or Firm—Curtis, Morris & Safford

[57] **ABSTRACT**

A sound effects generator for modifying a sound generating signal is comprised of a voltage-controlled filter having a variable peak response frequency for transmitting at a maximum amplitude those frequency components included in the sound generating signal that correspond to the instantaneous filter peak response frequency. The peak response frequency is determinable by a control voltage applied to the voltage-controlled filter; such a control voltage being proportional to the envelope of the sound generating signal as extracted by a control voltage generator. The filter peak response frequency is thus varied in accordance with the varying envelope of the sound generating signal.

24 Claims, 6 Drawing Figures



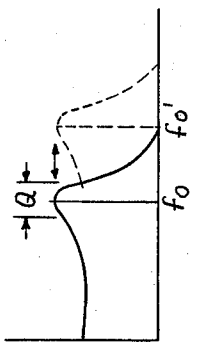


FIG. 2A

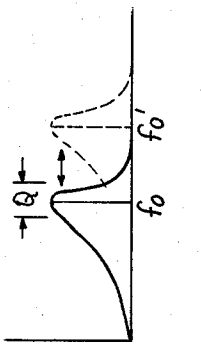


FIG. 2B

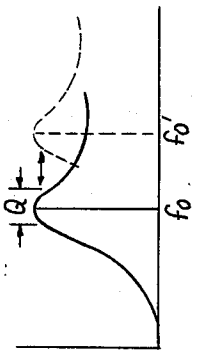


FIG. 2C

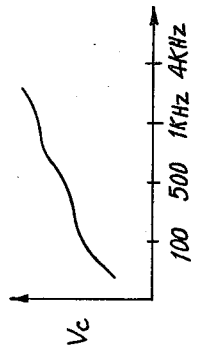


FIG. 3

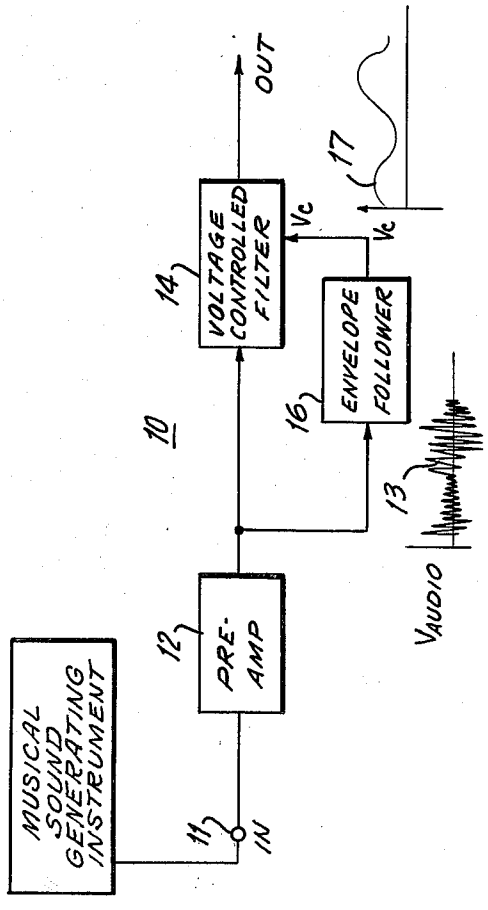


FIG. 1

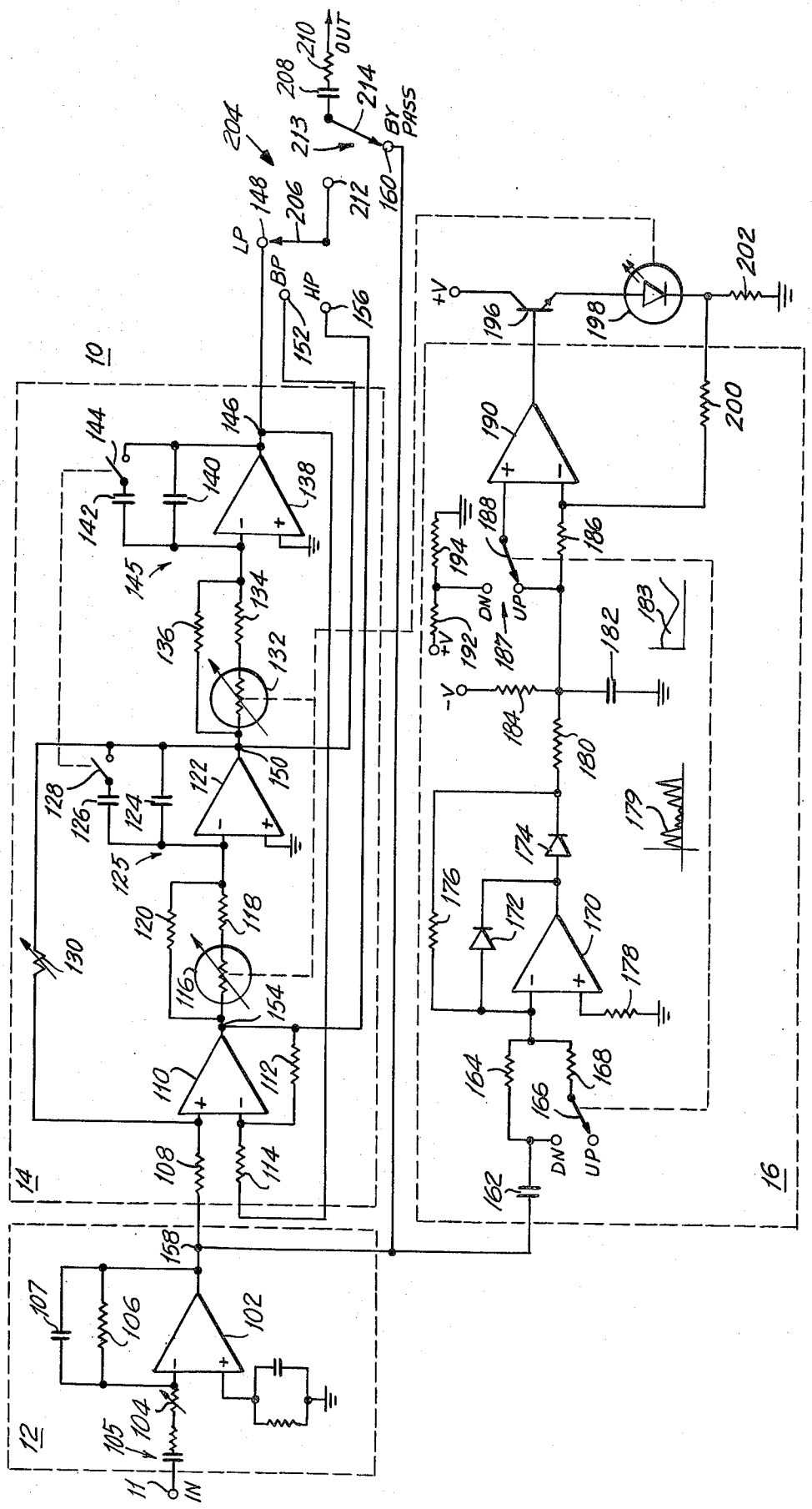

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FIG. 4

SOUND EFFECTS GENERATOR

BACKGROUND OF THE INVENTION

This invention relates to apparatus for varying a sound generating signal and, in particular, to a sound effects generator for automatically modifying a sound generating signal produced by a musical sound generating instrument in accordance with a preselected control signal.

In the field of sound generation, and in particular the field of musical tone generation and synthesis, it is frequently desirable to produce various types of electronic musical effects in accordance with the playing of a musical instrument. The contemporary practice of electronically generating musical tones by tone synthesizing generaters or other types of devices employed with suitable electronic transducers is frequently accompanied by modifying such electronic signals to produce a variety of audio responses or sound effects.

Numerous types of sound generation and effects are readily obtained by the use of conventional electronic music synthesizers. However, such synthesizers are generally expensive and usually require the unique skill of a trained operator. Consequently, the advantageous use of such synthesizers, although justifiable for large-scale public preformances, has not been wide spread for private or rather limited entertainment. The prior art has, therefore, sought an inexpensive device that is relatively simple to operate which can produce sound effects similar to those obtainable from electronic music synthesizers and that is operable with conventional musical instruments.

An exemplary tone signal modifier that has been employed to produce desirable sound effects comprises an electronic filter capable of generating a vowel-like effect upon a tone signal that is transmitted therethrough. This filter may be either a high-pass filter, a band-pass filter or a low-pass filter having a peak frequency response that is variable over a given frequency range. The peak response frequency of this filter is, of course, that frequency at which an input signal is transmitted therethrough with maximum gain or amplitude. That is, those frequency components included in the frequency spectrum of an input signal that correspond to the peak response frequency of the filter will be subjected to a minimum amount of attenuation by the operation of the filter. The aforenoted vowel-like effect is produced by varying the peak response frequency or the cut-off frequency of the filter during a filtering operation. Such variation in the frequency characteristic of the filter functions as a simple electronic analog of the complex acoustic "filtering" of speech tones produced by the human vocal cords. Unfortunately, such variations in the filter characteristics have heretofore been obtainable only by a manual operation executed by, for example, a sound technician or the instrumentalist himself. In the latter respect, although the musician may selectively obtain the sound effects he particularly desires, such operation requires significant concentration which necessarily interferes with his musical performance.

Therefore, it is an object of the present invention to provide an improved sound effects generator that automatically produces sound effects without the requirement of manual control or operation.

It is another object of the present invention to provide a sound effects generator that operates in synchronism with a produced sound generating signal.

It is a further object of the present invention to provide a sound effects generator that may be advantageously employed with musical tone generators to modify the sound generating signals produced by such musical tone generators.

Yet another object of the present invention is to provide a voltage-controlled filter for varying a sound generating signal to produce desirable sound effects.

A still further object of the present invention is to provide apparatus for varying a sound generating signal in accordance with the changes in the signal itself.

Another object of the invention is to provide a sound effects generator that is automatically controlled by a sound generating signal upon which the generator operates.

Various other objects and advantages of the present invention will become apparent from the detailed description set forth below and the novel features will be particularly pointed out in the appended claims.

SUMMARY OF THE INVENTION

In accordance with the present invention apparatus is provided for varying a sound generating signal, including a voltage-controlled filter that has a variable peak response frequency for passing, at a maximum amplitude, those frequencies included in the sound generating signal that correspond to the peak response frequency, the peak response frequency being variable over a given range of frequencies and being determinable by a control voltage applied to the filter; and a control voltage generator that is operable upon the sound generating signal to derive therefrom a sound generating signal envelope, such envelope being used as the control voltage to determine the peak response frequency of the filter.

BRIEF DESCRIPTION OF THE DRAWINGS

The forthcoming detailed description of the present invention will be readily understood in conjunction with the accompanying drawings in which:

FIG. 1 is a block diagram, with typical wave forms, of a preferred embodiment of the present invention;

FIGS. 2A–2C are graphical representations of the filter characteristics of the voltage-controlled filter of the present invention;

FIG. 3 is a graphical representation of one relationship between the peak response frequency and the applied control voltage of the voltage-controlled filter of the present invention; and

FIG. 4 is a schematic circuit diagram of a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF ONE OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, and in particular to FIG. 1, there is illustrated a block diagram of a preferred embodiment of the present invention comprising a sound effects generator **10**. The sound effects generator is adapted to modify a sound generating signal applied to an input terminal **11** by, for example, a musical sound generating instrument **9**, such that the resulting output signal is capable of deriving a synthesized or vowel-like tone. The sound effects generator **10** here comprises a preamplifier **12**, a voltage-controlled filter

14 and an envelope follower 16. The preamplifier 12 is, preferably, a variable gain amplifier adapted to amplify a produced sound generating signal to predetermined levels. The preamplifier is connected to input terminal 11 and includes an output that is coupled, in common relationship, to the voltage-controlled filter 14 and the envelope follower 16. In the preferred environment of the present invention, the preamplifier 12 is operable upon signals that are derived from musical instruments or are produced by conventional musical sound synthesizers. Hence, the audio signal coupled to the input terminal 11 may be produced by any conventional musical sound generator including electronic transducers or the like.

The voltage-controlled filter 14 is, preferably, a low sensitivity active filter of the type described in the paper "Synthesizing Active Filters" by S. K. Mitra, IEEE Spectrum, January 1969, pages 47–63. In particular, the filter 14, which is shown and described in greater detail hereinbelow, exhibits a peak response frequency that is variable over a given frequency range in accordance with the magnitude of a control voltage applied thereto. As noted hereinabove, a peak response frequency is a predetermined frequency, or narrow band of frequencies, at which an input signal is transmitted with maximum amplitude (or, stated otherwise, with minimum attenuation). Hence, if an input signal applied to the voltage-controlled filter 14 admits of a frequency spectrum, those frequency components corresponding to the peak response frequency will be transmitted by the filter at a maximum amplitude with respect to the remaining frequency components. The filter 14 may comprise a low-pass filter, a band-pass filter or a high-pass filter. In accordance with a preferred embodiment of the present invention, the filter exhibits high-, band-and low-pass filtering characteristics, one of which may be individually selected by an operator of the sound effects generator.

The particular peak response frequency of the filter 14 is determined by the magnitude of a control voltage V_C applied thereto. Hence, if the control voltage is a time varying signal then the peak response frequency will correspondingly vary with respect to time. As will be apparent from the forthcoming description thereof, the peak response frequency of the filter 14 is capable of being rapidly varied so as to synchronously follow all expected variations in the control signal V_C applied to the filter. In one preferred embodiment thereof, the peak response frequency varies directly with changes in the control voltage. That is, as the control voltage increases, the peak response frequency will likewise increase; and as the control voltage decreases, the peak response frequency similarly decreases. In an alternative embodiment, the peak response frequency of the filter 14 varies inversely with changes in the control voltage.

The envelope follower 16 is adapted to produce the control voltage V_C determinative of the peak response frequency of the filter 14. This control voltage is capable of varying in synchronism with variations in the sound generating signal applied to the preamplifier 12 to thereby permit the corresponding synchronous variations in the peak response frequency of the filter. Since the actual wave form of the electronic audio signal is expected to include relatively high frequency variations having peak amplitudes that define an envelope therefor, it is appreciated that the envelope follower 16 comprises a conventional filtering circuit capable of extracting the audio signal envelope. Preferably the envelope follower is comprised of a conventional rectifier and low-pass filter to thus extract either a positive or negative audio signal envelope. In the preferred embodiment of the present invention, a positive audio envelope is extracted and supplied as a control voltage to the filter 14.

In operation, let it be assumed that the voltage-controlled filter 14 comprises a low pass filter having a frequency response characteristic graphically represented in FIG. 2A. The ordinate of this graphical representation depicts the amplitude of the output signal transmitted by the filter and the abscissa of the graphical representation depicts the frequency components of the transmitted signal. As may be observed the filter 14 admits of a peak response frequency f_o whereat the output signal transmitted thereby exhibits maximum amplitude. That is, if the sound generating or audio signal applied to the filter 14 includes a component at the frequency f_o, that component will be transmitted by the filter at relatively maximum amplitude. As further depicted in FIG. 2A, the desirable or limited bandwidth, or Q is established about the peak response frequency f_o. This Q serves to accentuate preselected frequency components included in the audio signal.

The sound generating audio signal applied to the input terminal 11 by the suitable musical instrument, transducer, sound synthesizer or the like, is amplified by the preamplifier. The amplified audio signal V_{audio}, having the typical wave form 13, is applied to the filter 14 and, concurrently therewith, to the envelope follower 16. As is apparent, the higher frequency components of the audio signal waveform vary in amplitude to define a time varying envelope that changes at a slower rate. The envelope follower 16 serves to extract the slower time varying envelope and to supply such extracted envelope to the filter 14 as a control voltage V_C therefor. The extracted envelope admits of a waveform 17. Although the audio signal 13 is seen to include a positive and negative envelope, the envelope follower 16 preferably extracts only a single polarity envelope. In the preferred embodiment described herein, the positively poled envelope is extracted by the envelope follower and applied as a control voltage to the voltage-controlled filter 14. Hence, the control voltage applied to the filter varies in synchronism with the variations in the effective volume of the audio signal aupplied to the input terminal 11.

Again referring to FIG. 2A, it is apparent that the peaks response frequency f_o may vary throughout a given range of frequencies in accordance with the amplitude of the control voltage V_C. That is, the instantaneous peak response frequency is determined by the instananeous amplitude of the control voltage. In the illustrated embodiment, the peak response frequency is variable throughout a range from a lower frequency f_o to a higher frequency f'_o. Hence, as the control voltage V_C increases in amplitude, the peak response frequency of the filter 14 increases from its lower value f_o to its higher value f'_o. As the peak response frequency varies, it may be appreciated that the graphical representation of the filtering characteristics of the filter 14 is expanded, or "stretched", to the right in FIG. 2A. Conversely, as the amplitude of the control voltage V_C decreases, the peak response frequency of the filter 14 correspondingly decreases from a maximum frequency

value f'_o to its lower frequency value f_o. It is appreciated that, since the envelope follower **16** preferably extracts only the positively poled envelope of the audio signal, the control voltage V_C remains at a positive value.

In the foregoing description, the peak response frequency of the filter **14** is assumed to vary directly as the changes in the control voltage V_C. Hence, the relationship between the control voltage and the peak response frequency of the filter is graphically represented in FIG. **3.** However, it is contemplated that an inverse relationship may be established between the control voltage and the peak response frequency. That is, as the control voltage increases in amplitude, the peak response frequency f_o may decrease and, conversely, as the amplitude of the control voltage decreases, the peak response frequency increases. This relationship may be readily obtained merely by inverting the control voltage produced by the envelope follower **16,** as by applying the control voltage to a conventional inverting operational amplifier, and then adding the inverted control voltage V_C to a predetermined reference voltage; the summed voltages being applied to the filter **14.** In this modification, it may be appreciated that the voltage thus applied to the filter varies inversely with the control voltage V_C extracted by the envelope follower **16** to thus vary the peak response frequency f_o in a similar manner. In a still further alternative embodiment, the control voltage V_C extracted by the envelope follower **16** may be subtracted from a predetermined reference voltage in a conventional subtracting, or differencing network. The resultant output signal produced by such subtracting or differencing network may then be applied to the filter **14** to thus determine the frequency value of the peak response frequency thereof. In yet another alternative embodiment, the envelope follower **16** may be adapted to extract the negatively poled envelope of the audio signal and to then sum this extracted negative envelope with a predetermined reference voltage. The resulting sum, if used as a control voltage for the filter **14,** would thus vary the peak response frequency thereof in the desired inverse manner.

If the voltage-controlled filter **14** is assumed to comprise a band-pass filter, it is appreciated that the filtering characteristics thereof may appear as graphically represented in FIG. **2B.** Of course, as a band-pass filter, the voltage-controlled filter **14** is capable of passing only a predetermined band of frequencies included in the audio signal. However, such frequency pass band may be appropriately selected to encompass the desired frequencies expected in the audio signal. Nevertheless, such band-pass filter admits of a peak response frequency f_o and additionally exhibits a predetermined bandwidth or Q about such peak response frequency to thus accentuate the filtered audio signal at certain selected frequencies while attenuating such filtered signal at other frequencies. As in the aforedescribed embodiment, the instantaneous value of the peak response frequency f_o is determined by the instantaneous amplitude of the control voltage V_C applied to the filter **14** by the envelope follower **16.** If it is desired to vary the peak response frequency directly as the control voltage changes, then it is appreciated that as the control voltage increases the peak response frequency increases from a lower frequency value f_o to a higher frequency value f'_o. Conversely, as the control voltage amplitude decreases, the peak response frequency likewise decreases from the higher frequency value f'_o to the lower frequency value of f_o. Of course, such variation in the peak response frequency is effected in synchronism with the envelope extracted from the audio signal by the envelope follower **16.** As in the example described above, the peak response frequency of the band-pass filter may be varied inversely with the changes in the control voltage V_C if desired.

If it is now assumed that the filter **14** comprises a high-pass voltage-controlled filter, it is appreciated that the filtering characteristics thereof may be represented as depicted graphically in FIG. **2C.** As there depicted, the filter exhibits a peak response frequency f_o and, additionally, a limited bandwidth or Q about the peak response frequency. As in the previously described embodiment, the peak response frequency may be varied between a lower frequency value f_o and a higher frequency f_o' in accordance with variations in the amplitude of the control voltage V_C applied to the filter **14.**

It should be appreciated that the selection of low-pass, band-pass or high-pass characteristics of the filter **14** is dependent upon the sound effects that are desired. That is, if the lower frequency tones are to be accentuated to produce a desired vowel-like effect, the low-pass filtering characteristics would be selected. Similarly, if the higher frequency tones of the audio signal are to be accentuated, the high-pass filtering characteristics would be selected. And if the intermediate frequency tones of the audio signal are to be accentuated the band-pass filtering characteristics would be selected. Nevertheless, in each of the pass-bands that are provided, and as will be described in greater detail hereinbelow, the absolute range over which the peak response frequency f_o may be varied can be altered as desired. That is, the absolute frequency range f'_o–f_o may admit of a low range or a high range to produce the vowel-like effect on a corresponding range of frequencies included in the audio signal. Preferably, however, the ratio f'_o/f_o is constant for all frequency sweep ranges and for all filtering characteristics.

Referring now to FIG. **4,** there is illustrated a schematic diagram of one preferred embodiment corresponding to the block diagram depicted in FIG. **1.** The preamplifier **12** is seen to comprise a conventional operational amplifier **102** adapted for variable gain amplification. Accordingly, the input terminal **11** is coupled to the operational amplifier by a conventional a.c. coupling circuit **105** connected in series with a variable input resistor **104.** The resistor **104** may, typically, comprise any conventional variable resistance element, such as a potentiometer, a rheostat, or the like. A feedback resistor **106** is provided between the output terminal of the operational amplifier **102** and the input terminal thereof. As is appreciated, the gain of the preamplifier **12** is a function of the ratio of the resistors **106** and **104.** As resistor **104** is variable, the gain of the preamplifier is correspondingly variable. If desired, a conventional high frequency "stop" may be provided as, for example, the capacitive element **107** illustrated in parallel relationship with the feedback resistor **106.** The operational amplifier **102** is conventional, as is well known to those of ordinary skill in the art, and may include an inverting input terminal supplied with an audio signal and a non-inverting input terminal coupled to a suitable reference potential, such as ground, by a conventional biasing network. Alternatively, the opera-

tional amplifier may include a single inverting or non-inverting input terminal as desired.

The output terminal **158** of the preamplifier **12** is coupled to the voltage-controlled filter **14** and to the envelope follower **16.** Additionally, the output terminal **158,** which is thus seen to comprise the input terminal of the voltage-controlled filter **14,** is coupled to a bypass switch **213** for a purpose soon to be described.

The voltage-controlled filter **14,** which is a low sensitivity active filter, is adapted to provide a second order transfer function and, in this regard, is conventional as noted hereinabove and as described in the IEEE Spectrum publication. Accordingly, an input operational amplifier **110** is provided with a variable gain function and is connected in series relationship with first and second integrator circuits. Each integrator circuit is comprised of an operational amplifier disposed in conventional integrator circuit configuration and including input resistance and feedback capacitance.

The input operational amplifier **110** includes a non-inverting input terminal coupled to the preamplifier **12** via an input resistor **108.** The inverting input terminal of the operational amplifier **110** is coupled, by resistor **114,** to the output terminal **146** of the filter **14.** Additionally, a feedback resistor **112** is provided between the output of the operational amplifier **110** and the inverting input terminal thereof. A variable feedback resistor **130** is provided between the output terminal **150** of the first integrator circuit **125** and the non-inverting input terminal of the operational amplifier **110.** The variable resistor **130** may be similar to the aforedescribed variable resistor **104** and, therefore, may comprise a conventional potentiometer, a rheostat, or the like. It may be appreciated that the bandwidth or Q of the filter **14** is a function of the ratio between resistors **130** and **108.** Additionally, since the gains of the low sensitivity active filter is proportional to the Q thereof, it may be appreciated that such gain is variable in accordance with the value of the resistor **130.**

The output of the operational amplifier **110** is coupled to the input terminal **154** of the first series connected integrator circuit **125.** Additionally, the input terminal **154** is coupled to a switch **204** for a purpose soon to be described. The first integrator circuit is comprised of an operational amplifier **122** having a non-inverting input terminal coupled to ground and a feedback capacitor **124** intercoupled between the output terminal **150** thereof and the inverting input terminal thereof. The input resistance coupled to the inverting input terminal of the operational amplifier **122** is comprised of resistor **120** connected in parallel relationship with the series combination of resistors **116** and **118.** The resistor **116** is a variable resistor that, preferably, admits of a resistance value determined by a control voltage, soon to be described. Thus, the resistor **116** may be considered to be a voltage dependent resistor, various embodiments of which are well known to those of ordinary skill in the art. As is appreciated, the time constant of the first integrator circuit is a function of the feedback capacitor and the input resistance. Furthermore, since the peak response frequency of the filter **14** is related to the charging time constant of the first integrator circuit, it is appreciated that a variation in the resistance value of resistor **116** effects a corresponding variation in the frequency value of the peak response frequency. Hence, the instantaneous value of the resistor **116** is at least determinative of the instantaneous peak response frequency of the filter **14.**

A supplemental capacitor **126** is selectively connected in parallel with capacitor **124** by the series connected switch **128.** It is recognized that the total feedback capacitance is increased when the switch **128** is closed. As the range over which the peak response frequency of the filter **14** may be varied is dependent upon the total feedback capacitance of each integrator circuit, it is appreciated that switch **128,** together with switch **144** to be described, is adapted to establish the appropriate frequency varying range.

The output terminal **150** of the first integrator circuit is connected to a second integrator circuit **145** and, additionally, to the switch **204** for a purpose soon to be described. The second integrator circuit includes an operational amplifier **138** disposed in substantially identical configuration as the operational amplifier **122** of the first integrator circuit. Accordingly, a non-inverting input terminal of the operational amplifier **138** is connected to ground and the output terminal thereof is interconnected with the inverting input terminal by a capacitor **140.** The input resistance to the inverting input terminal of the operational amplifier **138** is comprised of the resistor **136** connected in parallel relationship with the series combination of resistors **132** and **134.** Resistor **132** is substantially identical to the aforedescribed resistor **116** and, as may be appreciated, a variation in the resistance value thereof is effective to correspondingly alter the charging time constant of the second integrator circuit. Thus, a change in the resistance value of the resistor **132** is capable of resulting in a corresponding change in the frequency value of the peak response frequency of the filter **14.** As will soon be described, the variable resistors **116** and **132** cooperate to substantially simultaneously vary the charging time constants of the respective integrator circuits to thereby effect a corresponding variation in the peak response frequency of the low sensitivity active filter **14.**

A supplemental capacitor **142** is adapted to be connected in parallel relationship with the feedback capacitor **140** by the selective operation of switch **144.** As indicated by the broken line depicted in FIG. **4,** the switches **128** and **144** are adapted for ganged operation to thereby simultaneously increase or decrease, in accordance with the selective operation thereof, the total feedback capacitance of their respective integrator circuits.

The output terminal **146** of the second integrator circuit is interconnected, by resistor **114,** to the input of the operational amplifier **110** and, additionally, is coupled to the switch **204** for a purpose soon to be described.

The aforedescribed resistors **116** and **132** are adapted to function as voltage dependent resistors. That is, the resistance value exhibited by each resistor **116, 132** is seen to be a function of a control voltage. Hence, these resistors are electronically variable. It is here noted that the particular construction of the resistors **116** and **132** is dependent upon various considerations. The resistors should not detract from the preferably high signal-to-noise ratio to be exhibited by the filter **14.** Additionally, the resistance values of the resistors should be variable at a sufficiently high rate such that the peak response frequency of the filter may vary in synchronism with the extracted envelope of the sup-

plied audio signals. That is, the expected rate of change of the audio signal envelope should not exceed the peak response frequency variation capability. Furthermore, each resistor **116** and **132** should vary in a substantially identical manner so that the filtering characteristics of the filter **14** are substantially preserved over the frequency range within which the peak response frequency thereof is to vary. Also, the resistor **116** and **132** should preferably be inexpensive to thus facilitate a commercially feasible and marketable sound effects generator. In accordance with these considerations, various types of voltage dependent resistances are available. For example, dual matched field effect transistors (FET's) wherein the resistance value is dependent upon the control voltage applied thereto might be employed. However such FET's might be accompanied by leakage of control voltage transients into the audio signal path resulting in distortion of the filtered signals. Additionally, audio signals that exceed a modest level could be distorted, thus necessitating low level signal processing and an attendant poor signal-to-noise ratio. Furthermore, the cost of such dual matched FET's is significant.

Alternatively the resistors **116** and **132** may comprise conventional resistance elements disposed for high frequency FET-chopping. Such technique is known to vary the effective resistance value but has heretofore required considerable expense in implementation.

Therefore, in accordance with the preferred embodiment of the present invention, the resistors **116** and **132** desirably comprise photo-resistance elements such as conventional photocells, photo-resistors or other photo-electric devices having a resistance value that is dependent upon the intensity of radiant energy incident thereon. As a typical example, the resistors **116** and **132** may each comprise conventional photo-resistors in communication with a source of radiant energy such that the resistance value of each photo-resistor is determined by the intensity of the radiant energy transmitted thereto. Such photo-resistors are commercially available and satisfy the considerations noted hereinabove. It may be appreciated that the intensity of radiant energy emitted by a suitable source thereof may conventionally be a function of the magnitude of a control voltage applied thereto. Although such source of radiant energy may comprise an incandescent lamp, it is known that the intensity of the radiant energy transmitted by an incandescent lamp cannot be rapidly altered. Thus, if an incandescent lamp is employed, it is possible that the resistance values of the respective photo-resistors might not be varied at the rate of change of the audio signal envelope. Therefore, it is preferred to employ a conventional light emitting diode (LED) as the source of radiant energy. A single LED **198** may be provided to transmit radiant energy of substantially equal intensity to each of the photo-resistors **116** and **132.** Preferably, these elements are provided in a suitable housing to prevent interference from ambient light.

The intensity of the radiant energy emitted by the LED **198** is determined by the control voltage applied thereto by the envelope follower **16.** Preferably, the envelope follower comprises an operational amplifier rectifying circuit and a low-pass filter. As illustrated, the operational amplifier-rectifier is comprised of a conventional operational amplifier **170** disposed in precise rectifier configuration and admitting of an amplification factor. A non-inverting input terminal of the operational amplifier **170** is coupled to ground by resistor **178.** The inverting input terminal of the operational amplifier is coupled to the output terminal **158** of the preamplifier **12** by a conventional a.c. coupling capacitor **162** and a series connected resistor **164.** A supplemental resistor **168** is adapted to be connected in parallel with the resistor **164** by switch **166** for a purpose soon to be described. Additionally, a rectifying diode **172** is provided to interconnect the output of the operational amplifier with the inverting input terminal thereof and is poled so as to be reverse biased in response to negative input signals. A further rectifying diode **174** is provided at the output of the operational amplifier **170** and is poled so as to be positively biased when positive signals are produced by the operational amplifier-rectifier. A feedback resistor **176** interconnects the rectifying diode **174** and the inverting input terminal of the operational amplifier **170.** A series circuit comprised of resistor **180** and capacitor **182** is coupled between the output of the rectifying diode **174** and ground. The junction defined by the resistor **180** and the capacitor **182** is coupled to a suitable source of energizing potential −V by a resistor **184.** As will soon be described, the operational amplifier **170,** disposed in the illustrated rectifying configuration, is adapted to provide the capacitor **182** with positive rectified signals. Hence, the capacitor **182** is capable of rapidly charging to the maximum value of the rectified signals. However, when the output of the rectifying circuit is a minimum, as when a positive component of the audio signal is applied to the operational amplifier **170,** the charge potential provided at the capacitor **182** slowly discharges through the resistor **184.** Accordingly, the resistor **184** is selected so as to provide a relatively high time constant for the filtering capacitor **182.** A positive envelope of the audio signal is thus provided at the capacitor **182.**

As noted hereinabove with respect to FIG. **1,** it might be desirable in some instances to vary the peak response frequency of the low sensitivity active filter **14** directly as the envelope of the audio signal changes. In other instances it might be preferable to establish an inverse relationship between the variations in the peak response frequency and changes in the audio signal envelope. To this effect, a selective circuit including operational amplifier **190** is provided. The operational amplifier is provided with an inverting input terminal coupled to the capacitor **182** by a resistor **186.** Additionally, a non-inverting input terminal is selectively coupled to the capacitor **182** by a switch **187.** The switch includes a movable contact **188** adapted to engage a first stationary contact designated UP and a secondary stationary contact designated DN. The DN contact is coupled to a source of reference potential. In the illustrated embodiment, the source of reference potential is derived from a voltage divider circuit comprised of series connected resistors **192** and **194** that are disposed between ground potential and a suitable source of energizing potential +V. Of course, any other conventional source of reference potential may be provided to supply the DN contact accordingly. It may be appreciated that, in the illustrated configuration, the operational amplifier **190** is adapted to selectively operate as a subtracting or a difference circuit. Hence, the operational amplifier may, alternatively, be replaced by a conven-

tional subtracting circuit such as a resistance network, a differential amplifier, or the like.

The output signal provided by the operational amplifier **190** is adapted to operate as the aforedescribed control voltage V_C. However, as is well known, conventional LED's are current sensitive devices. Accordingly, the operational amplifier **190** is further adapted to function as a voltage-to-current converter and is provided with an appropriate feedback circuit comprised of the LED **198** and resistors **200** and **202.** Additionally, current gain is obtained by the emitter-follower transistor **196** disposed in the feedback circuit of the operational amplifier. The junction defined by the LED **198** and the resistor **202** is interconnected with the inverting input terminal of the operational amplifier **190** by the resistor **200.**

It may be appreciated that, depending upon the particular terminal included within the low sensitivity active filter **14** that is selected to provide an output filtered signal, the filter may accentuate high-pass, band-pass or low-pass frequency components in the manner previously described with respect to FIG. **1.** Accordingly, switch **204** is provided to select those particular filtering characteristics that are desired to produce the preferred sound effects. The switch **204** is comprised of a plurality of stationary contacts **148, 152** and **156** coupled, respectively, to the output terminal **146** of the second integrator circuit **145** the output terminal **150** of the first integrator circuit **125** and the input terminal **154** of the first integrator circuit. Additionally, a movable contact **206** is provided to selectively engage one of the stationary contacts of the switch. The movable contact **206** is coupled to the stationary contact **212** of switch **213** and hence via movable contact **214** to an output terminal by a conventional a.c. coupling circuit comprised of the series combination of capacitor **208** and resistor **210.** Although not shown herein, it should be recognized that the output terminal of the illustrated sound effects generator may be connected to a suitable output jack to which further operating apparatus such as amplifier systems, may be connected.

The operation of the schematically illustrated sound effects generator **10** is substantially similar to that described hereinabove with respect to FIG. **1** and, therefore, need only be briefly described. The audio signal supplied to the input terminal **11** of the preamplifier **12,** as by any conventional audio signal generating device, such as a musical synthesizer, an electronic transducer, a musical instrument, or the like, is amplified to a desired level in accordance with the preselected gain of the preamplifier **12** as determined by the resistance value of variable resistor **104.** Although the presence of the preamplifier **12** may be considered to be optional, the function thereof is preferable to permit the filter **14** and the envelope follower **16** to operate upon audio signals admitting of sufficient average amplitude. The preamplifier **12** thus amplifies the audio signal to the appropriate signal level suitable to the dynamic range of the filter **14** and the envelope follower **16.**

The amplified audio signal is simultaneously applied to the filter **14** and to the envelope follower **16.** By suitably selecting the appropriate resistance value of the resistor **130,** the operator thereof establishes a desirable Q and gain of the active filter. These parameters may, of course, be varied in accordance with the preference of the operator and the desired sound effects obtained. As is appreciated, an increase in the Q of the low sensitivity active filter results in more pronounced filtering action such that at higher values of Q, individual frequency components of the audio signal may be emphasized.

As the amplified audio signal is transmitted through the filter **14,** the envelope thereof is extracted by the envelope follower **16** to thus vary the intensity of the radiant energy transmitted to the photo-resistors **116** and **132** by the LED **198.** Accordingly, the peak response frequency of the filter **14** is correspondingly varied, the frequency range of variation being determined by the feedback capacitors of the first and second integrator circuits. In this latter regard, it is apparent that switches **128** and **144,** which are adapted for simultaneous operation, may be closed to thus increase the feedback capacitance of each integrator circuit and to thus decrease the range of frequencies over which the peak response frequency of the filter **14** may be varied. For example, with switches **128** and **144** closed, the peak response frequency of the filter may be swept over a relatively low range. Alternatively, when the switches **128** and **144** are opened the range of frequencies over which the peak response frequency may be swept will be increased. It is recalled that, notwithstanding the frequency sweep range, the ratio of the lower frequency limit to the higher frequency limit will remain substantially constant. Hence, the octaves over which the peak response frequency is swept is constant.

Let it be assumed that the peak response frequency of the filter **14** is to be varied directly as the audio signal envelope changes. Accordingly, switches **166** and **188,** which are adapted for simultaneous operation, are disposed at their respective UP contacts. Thus, the effective input resistance to the operational amplifier **170** is comprised of resistor **164.** It is appreciated that resistor **168** is here electrically isolated. The audio signal, having a typical wave form as depicted by wave form **13** in FIG. **1,** is supplied to the operational amplifier **170** by the a.c. coupling capacitor **162.** The capacitor **162** isolates the operational amplifier **170** from any initial d.c. offset voltage that might otherwise be applied thereto. If the instantaneous amplitude of the audio signal coupled to the operational amplifier **170** admits of negative polarity, the inverting input terminal of the operational amplifier provides a positive amplified output signal. Such positive output signal reverse biases the diode **172** and forward biases the diode **174.** Hence, the operational amplifier **170** operates as a conventional inverting amplifier for audio signals admitting of negative polarity. As is recognized, the gain of such inverting amplifier is determined by the ratio between the feedback resistance **176** and the input resistance **164.**

If, now, the audio signal supplied to the operational amplifier **170** by the preamplifier **12** admits of positive polarity, the output signal produced by the operational amplifier in response thereto is negative. Such negative polarity serves to forward bias the diode **172.** Consequently, the gain of the operational amplifier circuit is determined by the ratio between the forward bias resistance of diode **172** and the resistance **164.** Since the forward bias resistance of the diode may, for practical purposes, be so negligible as to be substantially equal to zero, it is appreciated that a substantially zero output signal is produced by the operational amplifier **170** when positive audio signals are applied thereto. Thus, it is seen that the operational amplifier-rectifier func-

tions as a half-wave rectifier having an amplification factor determined by the ratio between the resistances **176** and **164.** Audio signals admitting of negative polarity are inverted and amplified by the operational amplifier-rectifier, whereas audio signals admitting of positive polarity are not transmitted therethrough. The audio signal is thus positively half-wave rectified.

The low-pass filter comprised of resistors **180** and **184** and filtering capacitor **182** transforms the relatively rapidly varying signal supplied thereto by the operational amplifier **170** so as to produce an output signal that is proportional to the maximum amplitude obtained by each rectified peak voltage. More particularly, when the output signal produced by the operational amplifier **170** is positive, the capacitor **182** rapidly charges through the resistor **180** to the maximum or peak amplitude obtained by the rectified signal. It is recognized that the charging time constant of the capacitor **182** is a function of the resistance **180** and the capacitance of the capacitor. Hence, the resistance **180** may be selected to be relatively small to thus define a rapid charging time.

Now, when the output signal produced by the operational amplifier **170** is substantially equal to zero, as may be observed by the rectified waveform **179,** the maximum voltage stored by capacitor **182** tends to discharge through the resistor **184.** However, if resistor **184** is selected to have a relatively high resistance value to thereby define a relatively high discharge time, it is appreciated that the stored voltage slowly discharges from the capacitor **182.** Consequently, when the next rectified peak, as indicated by the wave form **179,** is coupled to the capacitor **182,** the capacitor rapidly charges to the newly presented rectified amplitude. Thus, the rapid charge and slow discharge of the capacitor functions to extract the envelope wave form **183** from the rectified audio signal. Therefore, it is appreciated that the combination of the operational amplifier-rectifier **170** and the low pass filter coupled thereto serves an an envelope follower to extract, for example, the positive envelope of the audio signal. Of course, should it be desired, the negative envelope of the audio signal may be readily extracted by modifying, in minor respects, the illustrated circuit.

In the presently described embodiment, it is desired to vary the peak response frequency of the filter **14** directly as the extracted audio signal envelope changes. That is, as the audio signal envelope increases in magnitude, it is preferred to increase the peak response frequency of the filter. With reference to FIGS. **2A–2C,** an increase in the audio signal envelope results in a sweep of the peak response frequency f_o to the right and a decrease in the audio signal envelope correspondingly results in a sweep of the peak response frequency f_o to the left.

Since the variable resistors **116** and **132** are preferably photo-resistors that are responsive to radiant energy incident thereon, and since the source of radiant energy is preferably a light emitting diode, it is appreciated that the voltage representing the extracted audio signal envelope must be converted to a corresponding current to appropriately drive or vary the radiant energy intensity emitted by the LED. Accordingly, the operational amplifier **190,** in cooperation with the feedback resistors **200** and **202,** functions as a voltage-to-current converter. When the movable contact **188** of switch **187** is disposed at its UP contact, an increase in the amplitude of the audio signal envelope results in a corresponding increase in the current supplied to the LED **198** by the voltage-to-current converter. Conversely, a decrease in the amplitude of the extracted audio signal envelope results in a decrease in the current supplied to the LED. Thus, when the movable contact **188** is positioned at its UP contact, the illustrated voltage-to-current converter operates in the direct proportional relationship.

Therefore, as the audio signal amplified by the preamplifier **12** is filtered by the low sensitivity active filter **14,** the resistance values of the photo-resistors **116** and **132** vary in response to the changes in the radiant energy emitted by the LED **198.** That is, as the extracted audio signal envelope increases in magnitude, the intensity of the radiant energy transmitted to the photo-resistors **116** and **132** likewise increases to thereby increase the charging time constant of the respective integrator circuits. The result, of course, is to vary, in an increasing manner, the peak response frequency f_o of the filter **14.** As the peak response frequency varies, the corresponding frequency components included in the audio signal are accentuated. In this instance successively higher frequency components of the audio signal will be accentuated to thus produce the vowel-like effect, aforedescribed.

Now, when the extracted audio signal envelope decreases in magnitude, the radiant energy transmitted to the photo-resistors **116** and **132** by the LED **198** likewise decreases. Hence, the resistance value of the corresponding photo-resistors decreases to thus decrease the charging time constant of the respective integrator circuits. Consequently, the peak response frequency f_o of the filter **14** is varied in a decreasing manner to now accentuate successively decreasing frequency components of the audio signal. As the filtering characteristics of the filter **14** are varied in syncronism with the changes in the audio signal envelope, the desired sound effects are obtained.

If it is desired to vary the peak response frequency of the filter **14** inversely as the extracted audio signal envelope changes, the switch **187** need merely be operated such that the movable contact **188** thereof is disposed at its DN contact. Simultaneous with the operation of the switch **187,** the movable contact **166** is positioned at its DN contact. In this configuration, the effective input resistance of the operational amplifier **170** is now comprised of parallel connected resistors **164** and **168** to correspondingly increase the gain of the operational amplifier-rectifier. Also, the operational amplifier **190** now operates as a difference or subtracting circuit. That is, the current produced by the illustrated voltage-to-current converter is now proportional to the difference between the voltages applied to the operational amplifier **190.** Hence, the extracted audio signal envelope is subtracted from the reference voltage applied to the DC contact of the switch **187,** resulting in an energizing current supplied to the LED **198** that now varies in a manner that is inversely proportional to the changes in the extracted audio signal envelope. Thus, as the audio signal envelope increases, the difference between the reference voltage supplied to the DN contact of the switch **187** and the audio signal envelope decreases to thus decrease the current supplied by the voltage-to-current converter. Conversely, as the audio signal envelope decreases, the difference between the reference voltage and the audio signal envelope now

increases to correspondingly increase the energizing current supplied to the LED **198.**

It is, therefore, seen that when the switch **187** is operated to position the movable contact **188** at its DN contact, the intensity of the radiant energy transmitted to the photo-resistors **116** and **132** varies inversely with the changes in the extracted audio signal envelope. Hence, the peak response frequency f_o of the filter **14** is caused to vary inversely with changes in the audio signal envelope to produce the corresponding sound effects.

As the filtering characteristics of the filter **14** are varied in accordance with the extracted audio signal envelope, an operator of the illustrated apparatus may select specific frequency components of the audio signal which he desires to accentuate to produce the corresponding sound effects. Thus, switch **204,** which is coupled to the output terminal of the illustrated apparatus, may be selectively operated in accordance with the operator's preferences. For example, if an operator prefers to derive the sound effects resulting from the emphasis of the higher frequency components of the audio signal, the movable contact **206** of switch **204** is positioned at the HP contact **156** and the movable contact of switch **213** is positioned at stationary contact **212.** In this configuration, the input terminal **154** of the first integrator circuit is coupled by the switches **204** and **213** to the sound effects generator output terminal. Should it be desired to emphasize the intermediate frequencies of the audio signal, the movable contact **206** is positioned at the BP contact **152.** As thus disposed, the output terminal **150** if the first integrator circuit is connected by switches **204** and **213** to the sound effects generator output terminal. And should it be desired to emphasize the low frequencies of the audio signal, the switch **206** is positioned at the LP contact **148** to thus connect the output terminal **146** of the second integrator circuit to the sound effects generator output terminal.

Thus, when the moveable contact **206** is positioned at a selected one of the respective contacts **148, 152,** and **156,** it may be appreciated that the emphasized audio signal supplied to the sound effects generator output terminal appears as if operated upon by an effective low-pass, band-pass, and high-pass filter, respectively, exhibiting the frequency response characteristics graphically depicted in FIGS. 2A–2C, respectively. Additionally, an operator of the illustrated apparatus may selectively shift the absolute frequency range over which the peak response frequency f_o may vary merely by selectively operating the ganged switches **128** and **144.**

If the aforedescribed sound effects are not desired, the movable contact **214** of switch **213** may be positioned at the by-pass contact **160** to thus interrupt the output channel from the filter **14** to the output terminal and avoid the result of the operation of the filter upon the audio signal. In this configuration, the audio signal amplified by the preamplifier **12** and provided at the output terminal **158** is directly coupled by the switch **213** through the coupling circuit to the sound effects generator output terminal. In an alternative embodiment switches **204** and **213** are combined in a single switching device.

Although the present invention has been described in detail with respect to a preferred embodiment of a sound effects generator, it should be readily apparent to one of ordinary skill in the art that the disclosed apparatus may be advantageously used for any application wherein a voltage-controlled filtering effect is desired. Moreover, the foregoing has described a sound effect generator operable on audio signals produced by musical instruments, or the like. It is readily apparent, however, that the present invention may be utilized with virtually any sound or any tone generating device wherein the variable filtering effect is desired. Furthermore, the control voltage described herein to vary the peak response frequency of the voltage-controlled filter need not be limited solely to the described embodiment wherein an audio signal envelope is extracted to derive such control voltage. Alternatively, any suitable source of control voltage such as a time varying voltage wave form generator or the like, may be used. Additionally, the specific circuit components described hereinabove may be replaced by other fully equivalent devices. For example, a conventional highly precise rectifier may be substituted for the disclosed operational amplifier-rectifier. Also, various alternative amplifying devices adapted to perform substantially the same function as the operational amplifiers used in the present invention may be substituted therefor. Likewise, the low-pass filter connected to the operational amplifier-rectifier may be replaced by other equivalent filtering means capable of functioning as the described envelope follower circuit, and other conventional voltage-to-current converters or drive circuits may be used. Furthermore, various resistance configurations may be employed where desired to control the various gains of the exemplary circuits.

Therefore, while the invention has been particularly shown and described with reference to a specific preferred embodiment thereof, it will be obvious to those skilled in the art that the foregoing and various other changes and modifications in form and details may be made without departing from the spirit and scope of the invention. It is intended that the appended claims be interpreted as including all such changes and modifications.

What is claimed is:

1. Apparatus for varying a sound generating signal comprising:

voltage controlled filter means having a variable peak response frequency for transmitting at a maximum amplitude those frequencies included in said sound generating signal that correspond to said filter peak response frequency, said peak response frequency being determinable by a control voltage applied to said filter means;

envelope follower means comprised of rectifying means for transmitting sound generating signals of a single predetermined polarity and low pass filter means coupled to said rectifying means for generating a control voltage proportional to the amplitude of the envelope of said sound generating signal and for supplying said control voltage to said voltage controlled filter means;

and means for supplying said sound generating signal to said voltage controlled filter means and to said envelope follower means.

2. Apparatus in accordance with claim **1** wherein the peak response frequency of said voltage controlled filter means varies directly with changes in the magnitude of the control voltage generated by said voltage generating means.

3. Apparatus in accordance with claim 1 wherein the peak response frequency of said voltage controlled filter means varies inversely with changes in the magnitude of the control voltage generated by said control voltage generating means.

4. Apparatus in accordance with claim 1 wherein said filter means comprises a low-pass filter.

5. Apparatus in accordance with claim 1 wherein said voltage controlled filter means comprises a band-pass filter.

6. Apparatus in accordance with claim 1 wherein said voltage controlled filter means comprises a high-pass filter.

7. Apparatus in accordance with claim 1 wherein said voltage controlled filter means selectively exhibits low-pass, band-pass and high-pass filtering characteristics and includes switch means for selecting one of said filtering characteristics.

8. Apparatus in accordance with claim 1 wherein said voltage controlled filter means comprises a low sensitivity active filter including variable resistance means having a resistance value that is a function of said control voltage, said resistance value being determinative of said peak response frequency.

9. Apparatus in accordance with claim 8 wherein said variable resistance means comprises radiant energy sensitive means having a resistance value proportional to the intensity of radiant energy incident thereon, and further including a source of radiant energy supplied with said control voltage for emitting radiant energy having an intensity determined by said control voltage.

10. Apparatus in accordance with claim 9 wherein said low sensitivity active filter includes integrator circuit means having a charging time constant determined by the resistance value of said radiant energy sensitive means.

11. Apparatus in accordance with claim 10 wherein said integrator circuit means comprises first and second series connected integrator circuits, and wherein said radiant energy sensitive means comprises first and second photoresistors, said first and second photoresistors being included as input resistors of said first and second integrator circuits, respectively.

12. Apparatus in accordance with claim 11 wherein each of said integrator circuits includes switchable means operative to vary the range of frequencies over which the peak response frequency of said low sensitivity active filter is variable.

13. Apparatus in accordance with claim 12 wherein said switchable means comprises a capacitor and a switch for selectively switching said capacitor into the feedback circuit of said integrator circuit to thereby increase the value of the feedback capacitance of said integrator circuit.

14. Apparatus in accordance with claim 11 wherein said source of radiant energy comprises a light-emitting diode for transmitting radiant energy to said first and second phototesistors.

15. Apparatus in accordance with claim 1 wherein said rectifying means comprises an operational amplifier rectifying circuit.

16. Apparatus in accordance with claim 15 wherein said envelope follower means further includes selecting means coupled to said low-pass filter means for selectively producing said control signal directly proportional to the envelope of the signals transmitted by said operational amplifier rectifying circuit or inversely proportional to the envelope of the signals transmitted by said operational amplifier rectifying circuit.

17. Apparatus in accordance with claim 16 wherein said selecting means comprises a difference circuit coupled to said low-pass filter means; a source of reference voltage; and a switch for selectively coupling said source of reference voltage to said difference circuit whereby said signal proportional to the envelope of the signals transmitted by said operational amplifier rectifying circuit is subtracted from said reference voltage when said switch couples said source of reference voltage to said difference circuit to thereby produce said control voltage.

18. A sound effects generator for modifying a sound generating signal produced by a musical sound generating instrument, comprising:

a preamplifier having variable gain for amplifying said produced sound generating signal to predetermined levels;

a low sensitivity-active filter coupled to the output of said preamplifier and exhibiting a peak response frequency that is variable over a given range of frequencies, said low sensitivity active filter including integrator circuit means comprising photoresistance means having a resistance value proportional to the intensity of radiant energy incident thereon, said resistance value determining the charging time constant of said integrator circuit means to thus be determinative of said peak response frequency;

means for selecting a predetermined band of frequencies in said sound generating signal to be modified;

a source of radiant energy for transmitting radiant energy to said photoresistance means, said source being responsive to a control signal applied thereto for emitting radiant energy having an intensity proportional to the magnitude of said control signal;

control signal generating means for supplying said control signal to said source of radiant energy;

and output means for receiving said modified sound generating signal.

19. A sound effects generator in accordance with claim 18 wherein said photoresistance means comprises first and second photoresistors and wherein said integrator circuit means comprises a first integrator circuit including said first photoresistor and a second integrator circuit including said second photoresistor, said first and second integrator circuits being connected in series relationship and each of said integrator circuits having a charging time constant determined by the resistance value of its associated photoresistor.

20. A sound effects generator in accordance with claim 19 wherein said means for selecting a predetermined band of frequencies to be modified comprises a switch having a movable contact adapted to selectively engage each of a plurality of stationary contacts including a first stationary contact coupled to the input of said first integrator circuit, a second stationary contact coupled to the output of said first integrator circuit and a third stationary contact coupled to the output of said second integrator circuit, whereby the high frequency components of said sound generating signal are modified and supplied to said output means when said movable contact engages said first stationary contact, the low frequency components of said sound generating signal are modified and supplied to said output means when said movable contact engages said third station-

ary contact and the intermediate frequency components of said generating signal are modified and supplied to said output means when said movable contact engages said second stationary contact.

21. A sound effects generator is accordance with claim **20** wherein said source of radiant energy comprises a light-emitting diode.

22. A sound effects generator in accordance with claim **21** wherein said control signal generating means comprises envelope follower means coupled to the output of said preamplifier for extracting the envelope of said sound generating signal and for supplying a signal proportional to said extracted envelope to said light-emitting diode.

23. A sound effects generator in accordance with claim **22** further comprising a difference circuit coupled to said envelope follower means; a source of reference voltage; and a switch for selectively coupling said source of reference voltage to said difference circuit; whereby the intensity of the radiant energy emitted by said light-emitting diode increases as said sound generating signal envelope increases and decreases as said sound generating signal envelope decreases when said source of reference voltage is not coupled to said difference circuit, and the intensity of the radiant energy emitted by said light-emitting diode decreases as said sound generating signal envelope increases and increases as said sound generating signal envelope decreases when said source of reference voltage is coupled to said difference circuit.

24. A sound effects generator in accordance with claim **23** wherein said low sensitivity active filter further includes means for selectively varying the range of frequencies over which said peak response frequency is variable.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 3,911,776

DATED : October 14, 1975

INVENTOR(S) : Michael L. Beigel

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 17, line 7, before "filter means" insert -- voltage controlled --;

Signed and Sealed this

sixteenth Day of *March 1976*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks

UNITED STATES PATENT AND TRADEMARK OFFICE

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