FIG. 1

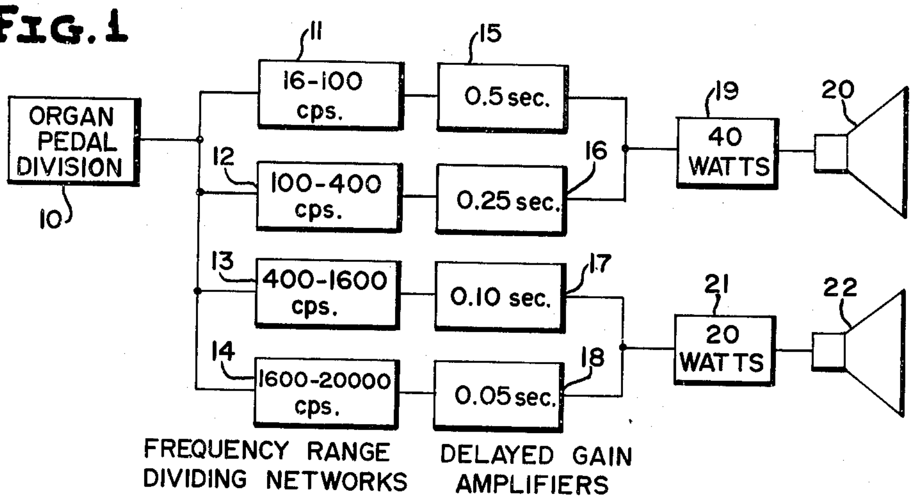

FIG. 2

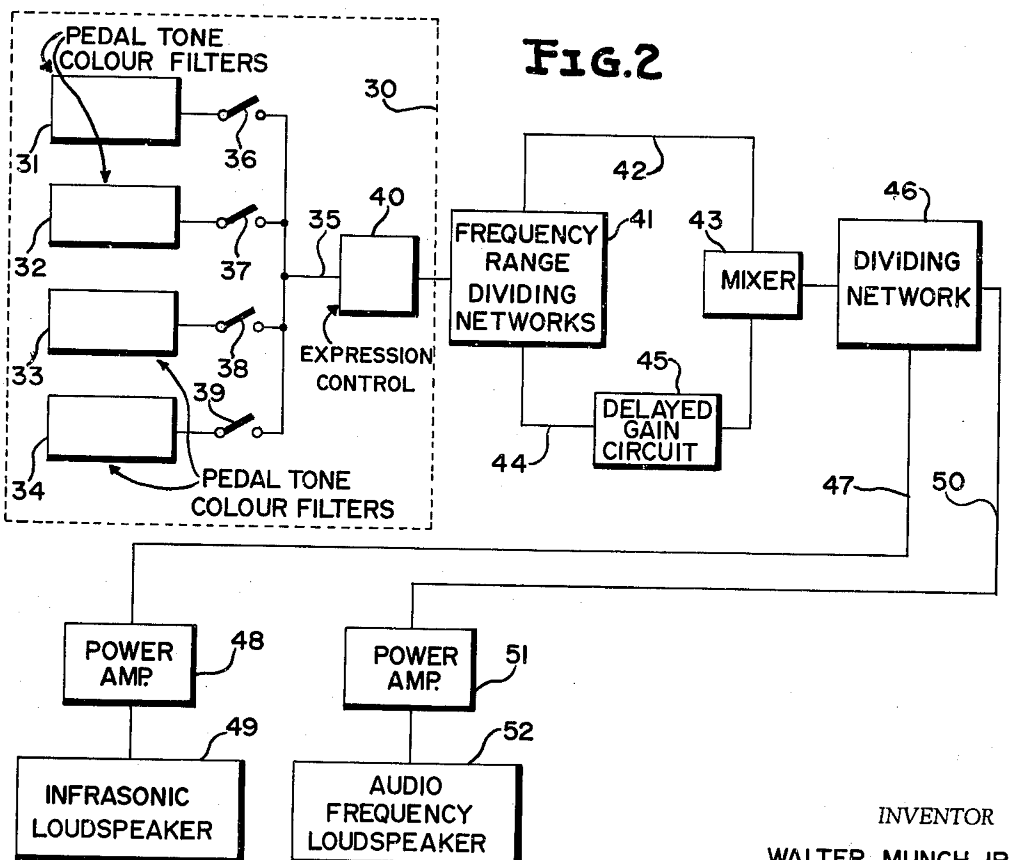

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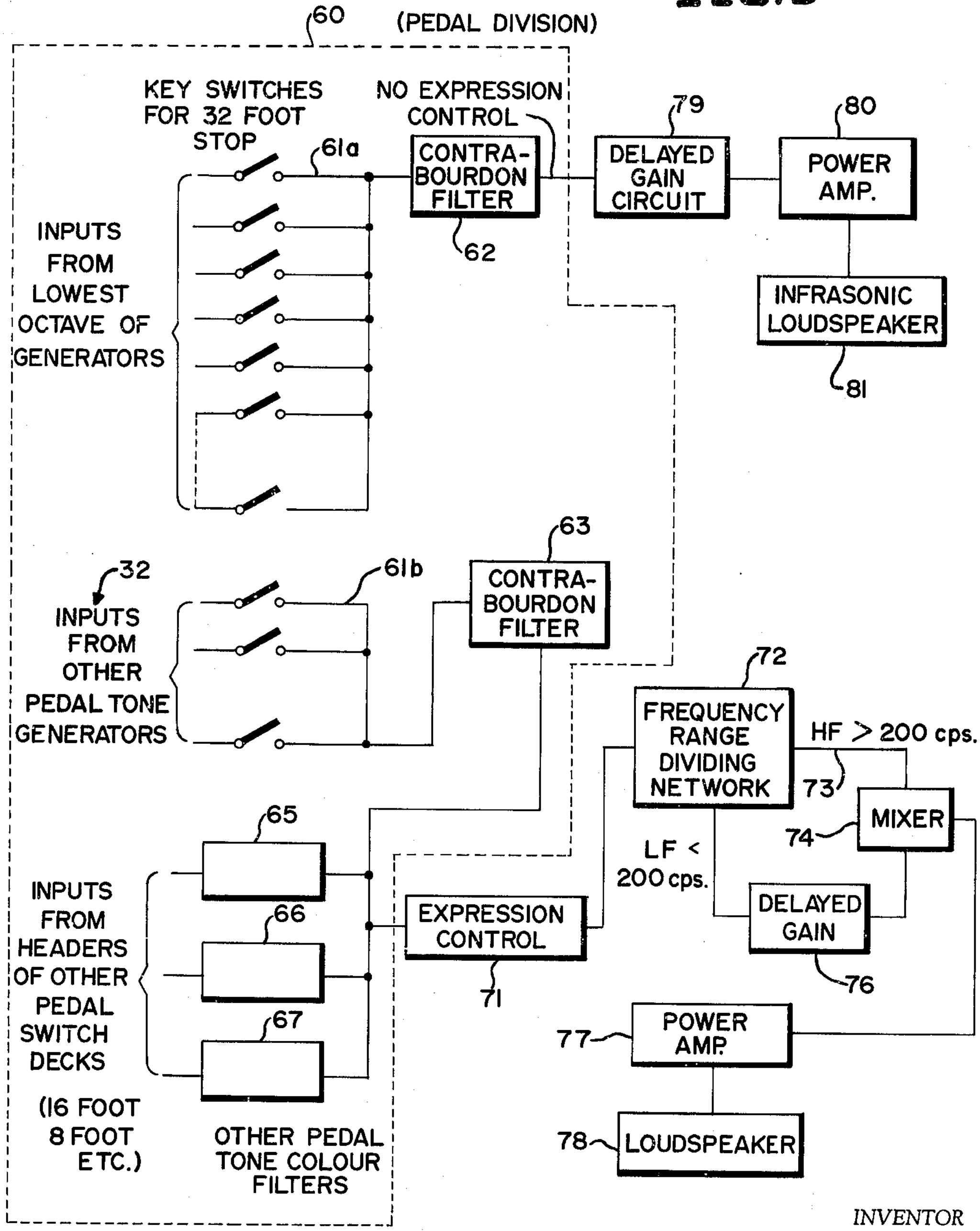
FIG. 3



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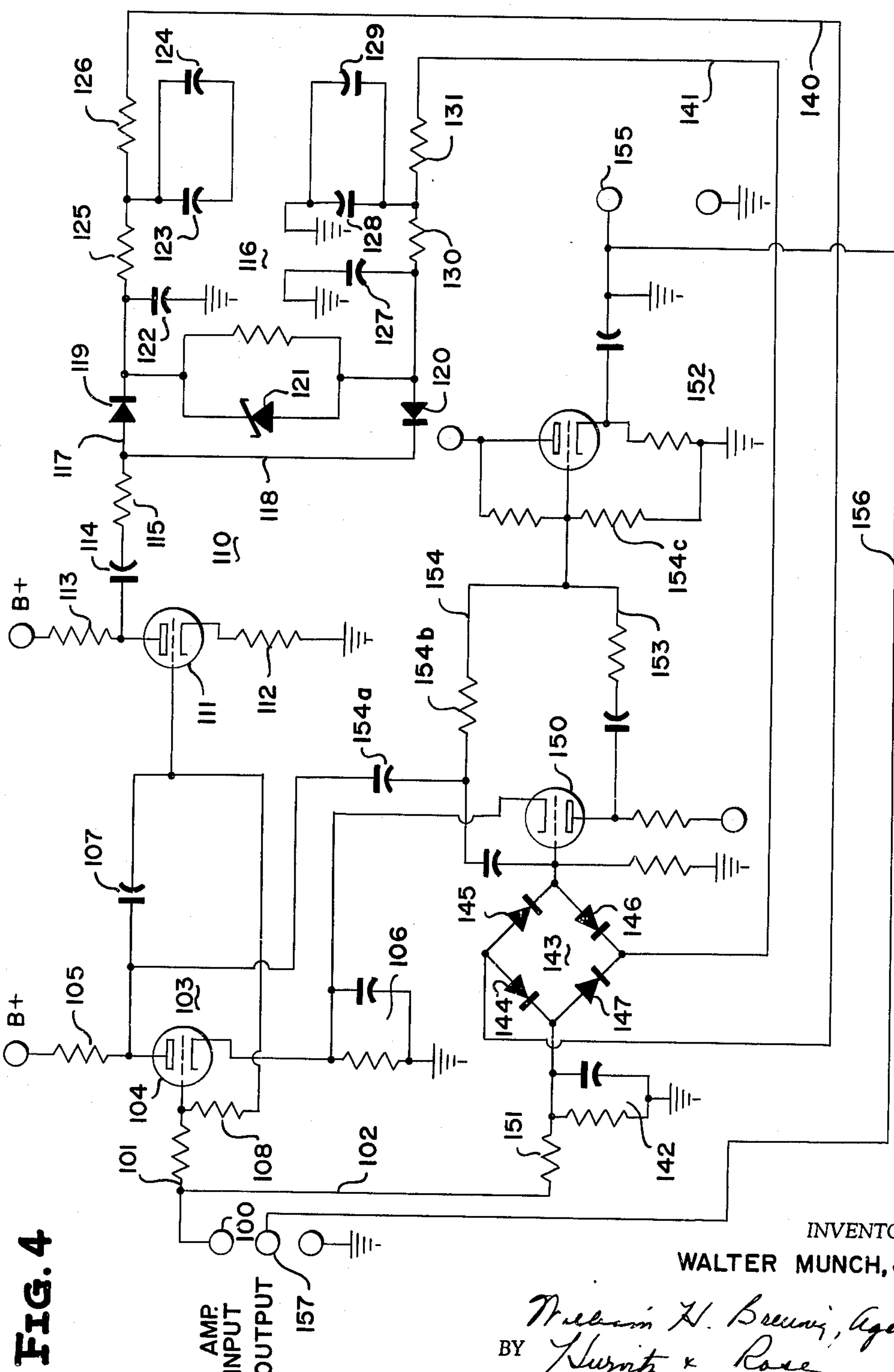

FIG. 4

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FIG. 5

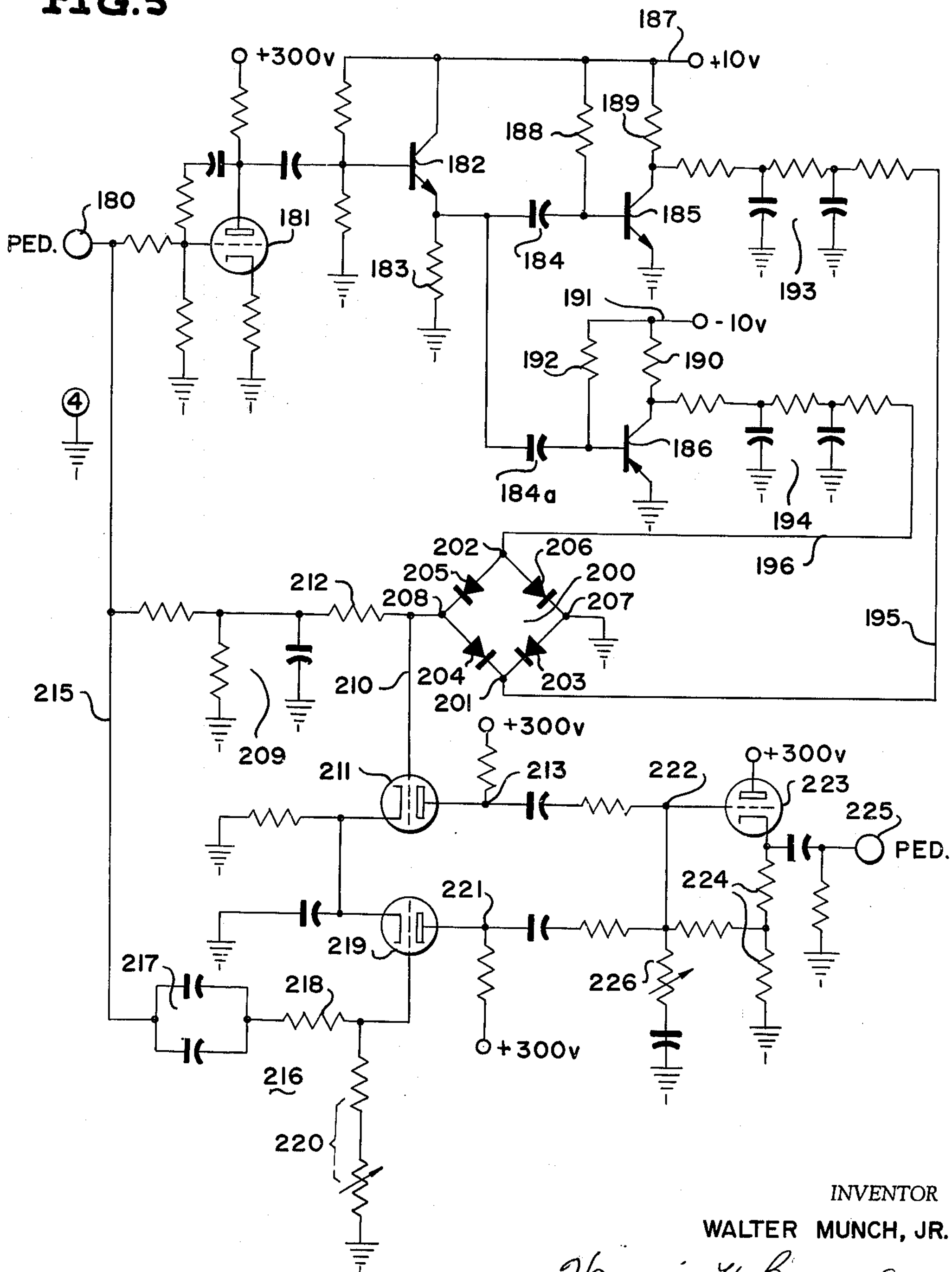

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FIG. 6

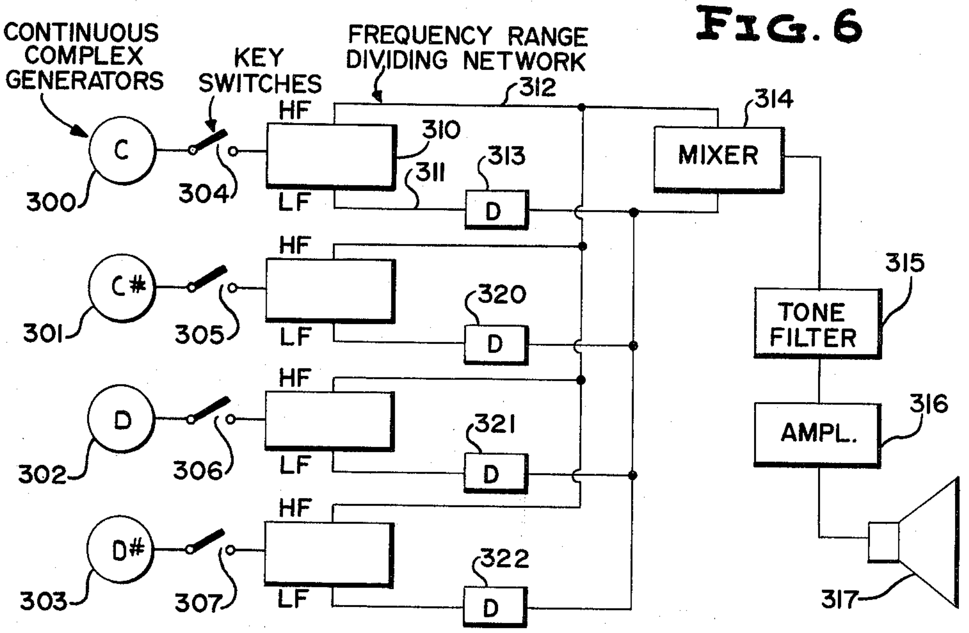
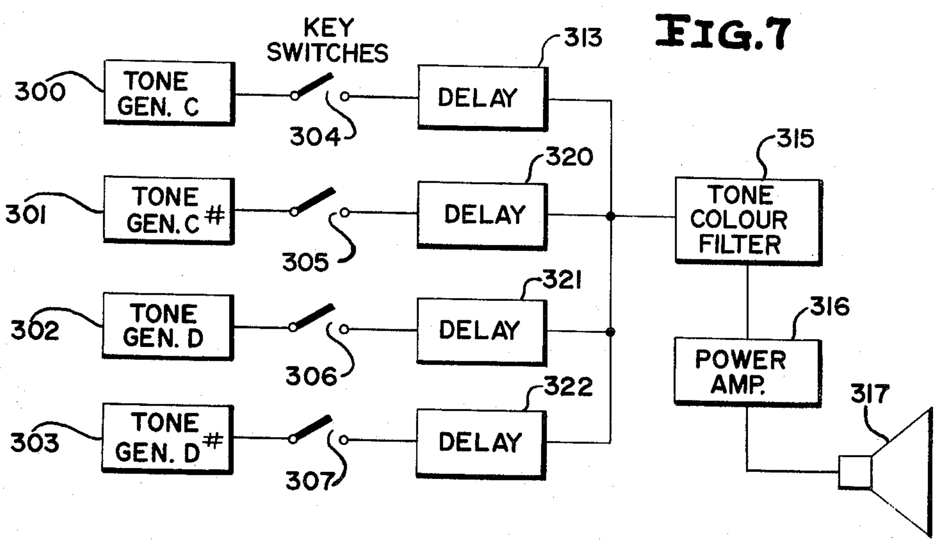


FIG. 7



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3,231,660

GATING CIRCUIT

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8 Claims. (Cl. 84—1.11)

The present invention relates generally to electronic organs, and more particularly to audio systems for electronic organs, having provision for introducing envelope build-up delay in the pedal division output of the electronic organ, on a frequency selective basis, to simulate the tonal build-up pattern of a pipe organ.

In a pipe organ the pipes of very lowest fundamental frequency of the pedal division of the organ, have a much longer build up time than do the pipes of higher fundamental frequency, and as a rough approximation, total build-up time decreases as a direct function of fundamental frequency. However within the complex spectrum of a single pipe tone the partials of lowest frequency build up more slowly than the highest partials, so that the timbre of the tone changes during tonal buildup from a "thinner" to a "rounder or more mellow" tone color. Build up at any one frequency is approximately logarithmic as a function of time. It is considered musically desirable by the classical organist that the acoustic output of the electronic organ simulate that of the pipe organ in every respect. In particular, the pipe organ provides certain transient sound variations which are considered to be characteristic of such organs, and among such variations the shape of the envelope of the overall tone (and of each partial) during tonal buildup obtains a prominent place.

The provision of a suitable build-up delay characteristic, as a function of frequency, may be accomplished by dividing the pedal tones into a plurality of frequency subbands in separate channels, and introducing a different build-up time for each channel. By suitably selecting build-up delay characteristics for the several channels, as well as the frequency limits of the several channels, an appropriate over-all tone-envelope build-up characteristic, for the entire pedal division, can be attained. The separation of separate sub-bands into separate physical channels also facilitates use of amplifiers and radiators which have optimum characteristics for the frequency ranges involved. More particularly, a relatively lower power amplifier is adequate for higher frequencies than for lower frequencies, and a low frequency speaker or other radiator can be most effective if it need not have capacity for radiating high frequencies. The use of separate high and low frequency speakers, supplied with driving current through a frequency dividing or cross-over network, is commonplace in the audio art. But use of this expedient has not heretofore been taken advantage of to facilitate simulation of pipe organ tonal build-up characteristics in electronic organs.

According to one modification of the invention, the tonal output of an electronic organ is divided on a frequency basis into only two channels, division occurring, say, at about 200 c.p.s. Frequencies below the division point are considerably delayed in buildup and those above the division point are not delayed or are delayed only slightly. The frequency division point which provides optimum simulation of pipe organ tone buildup is not necessarily, however, the same frequency which permits optimum amplification and radiation of sound via two loudspeakers, on a frequency division basis. The tones of large organs can extend down to about 16 c.p.s., i.e. into the infrasonic range. A loudspeaker or sound radiator which is capable of effective operation at 16 c.p.s. cannot be expected to operate effectively at very high frequencies, whereas an audio-frequency loudspeaker having capability down to 32 c.p.s. is conventional. Accordingly, we provide a division or cross-over point for sound radiation, as distinct from build-up, at about 30 c.p.s., but introduce delayed build up of tones, above and below the 200 c.p.s. division point which are appropriate to the latter division point. According to this embodiment of the invention the tonal output of an electronic organ is separated into two channels, with frequency division at 200 c.p.s. The low-frequency channel is caused to build up to maximum output slowly, and the high-frequency channel rapidly. The outputs of the channels are combined, and then re-divided, with frequency division occurring at 30 c.p.s. for purpose of radiation through an infrasonic loudspeaker and a normal audio-frequency loudspeaker.

As an alternative, and especially in organs having a 32 foot stop which is primarily fundamental, all sound originating in tone generators below about 30 c.p.s. may be directly applied to a low-frequency channel, having an infrasonic speaker and provision for separate delayed buildup. The remaining tone generator outputs may be connected to a second channel, having an audio-frequency speaker, but also containing provision for division into sub-bands at a 200 c.p.s. division point. The frequency components below about 200 c.p.s. may be subject to delayed build-up before being connected to the audio-frequency amplifier and loudspeaker, while those above are not. The last described embodiment, involving division on the basis of tone generators, has the feature that the fundamentals of the infrasonic tones are delayed together with their associated harmonics, which is not true where division is accomplished solely on a frequency basis. It also has the advantage that very little audio-frequency energy is required from the amplification and radiation equipment designed for the infrasonic range. It has the further advantage of facilitating employment of three different build-up times, one for the infrasonic range, another for the audio range to 200 c.p.s. and the third for the audio range above 200 c.p.s. The latter delay may be zero, if desired.

The 200 c.p.s. division point, below which delayed buildup occurs, is an arbitrary division point. Experience has indicated that frequency division points of over 500 c.p.s. may well be introduced, provided that appropriately shorter delay envelopes are utilized.

Circuitry for developing delayed gain in an infrasonic-frequency keyed channel, without introducing distortion and key thumps, is provided in terms of a balanced diode bridge. Delayed buildup occurs in response to control signals derived from the very tones in which delayed buildup is desired. Immediately on initiation of a tone by depression of a pedal, development of a pair of oppositely poled control voltages is started, one in response to positive excursions or half cycles of the tone and the other in response to negative excursions or half cycles. The tone which is to be delayed in buildup is applied to the input of an amplifier through a balanced diode bridge, which normally, i.e. in the absence of control signal, blocks the tone, and which is rendered gradually conductive in response to action of the separate control voltages upon the opposite halves of the bridge. Because the control voltages are applied to conjugate terminals of the bridge, they oppose and balance out at the amplifier input. The diode bridge thus acts as a variable voltage-responsive series attenuator, in which attenuation for zero control voltage is very high. In addition the diode bridge acts to discharge the integration circuitry on cessation of input signal.

In accordance with still another modification of the present system, the tonal output of the pedal division of an electronic organ is utilized to develop two control voltage waves which rise quasi-logarithmically or logarithmically from zero to a predetermined level, at a rate appropriate to tonal build up in pipe organs, in opposite polarities. These are generated by means of transistorized gating circuits, instead of by means of diodes. The control voltage waves are utilized to vary the attenuation in the low frequency channel of a frequency divider network by varying the shunt impedance presented by a diode bridge, rather than by varying series impedance. The two outputs of the crossover network, i.e., high and low frequency ranges, but with the low frequency range having been subjected to envelope delay, are then recombined to provide the total tone. The modification described in the present paragraph is suitable for utilization in substitution for the system previously described.

While the present brief description of the invention pertains to the pedal division particularly, the utility of the system is not restricted to the pedal division. Very low frequency tone can occur in any division of the electronic organ, and in respect to such tones appropriate envelope shapes to simulate pipe organ tonal build up effects are desirable. However, where the build up occurs in a single circuit for an entire division, it is not desirable to incorporate the required circuitry in other than the pedal division, because of the complexity of music in the other division. It is usual, in the pedal division, to play one note at a time, but not in the other divisions. Also, notes are often played slowly enough, in the pedal division, to afford time for the required build up and decay, whereas in the remaining divisions key manipulation is often extremely rapid.

In order to render the invention applicable generally to the electronic organ, i.e. to all divisions, and to enhance the advantages of the system as applied to the pedal division, it is necessary to provide a separate envelope build-up circuit for each tone generator. In the pipe organ, tonal build up of a complex tone takes place at a different rate for the higher partials than for the fundamental. Accordingly, for each tone generator we provide a frequency divider network which separates the lower harmonics from the higher harmonics, and we delay the lower harmonics, thereafter recombining the tonal components. In more elaborate systems different partials of a simple note might be separated into separate channels, each partial subjected to an appropriate delayed build up, and the partials thereafter recombined to form the complete note. Only economic considerations limit the possibilities in these respects. The advantages of treating each tone generator individually is that the playing of one note does not inhibit the build up of any other note, as is the case in FIGURES 1–3, for example, and, in fact, where each partial of each tone is individually treated in respect to delayed build-up, the pipe organ action is most nearly simulated.

A simplified form of pipe organ simulation can be attained by introducing delayed build up entirely on a tone generator basis, without distinction of partials. Such a system fails to fully simulate the action of a pipe organ, in which delay for separate partials is different, but requires no frequency division or recombining networks, and hence is economically desirable.

It is, accordingly, a broad object of the invention to provide an electronic system for simulating the tonal build up, as a function of time, of the tones of a pipe organ.

It is another object of the invention to provide a system for differentially delaying build up of different frequency sub-bands of the tonal output of an electronic organ.

It is still a further object of the invention to provide a novel balanced keying circuit for alternating current signals, which employs a diode bridge.

It is a further object of the invention to provide circuitry for dividing a relatively wide band of frequencies into two sub-bands, delaying the build up of the lower frequency sub-band, and recombining the sub-bands, without introducing subjectively unpleasant distortion.

It is a further object of the invention to provide a system for delaying build-up of only the infrasonic components of organ music approximately logarithmically and with a total delay time of about 2 seconds.

It is another object of the invention to provide an integrating circuit for generating predetermined approximately logarithmically increasing wave forms of opposite polarities and substantially equal amplitudes with respect to ground, and a predetermined maximum peak-to-peak level.

A further object of the invention resides in the provision of circuitry for integrating opposed half cycles of a signal to generate two equal gradually increasing control voltages of opposed polarities.

It is still a further object of the invention to provide an electronic organ which simulates a pipe organ in its tonal envelope build up characteristics, wherein each tone generator is individually treated in respect to build up delay.

Still a further object of the invention is to provide an electronic organ which simulates a pipe organ in its tonal envelope build up characteristics, wherein individual partials of each tone are individually treated in respect to build up delay.

The above and still further objects, features, and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a block diagram of a simplified tonal envelope build-up system for electronic organ, wherein differential delays are introduced on a frequency basis;

FIGURE 2 is a block diagram of a modification of the system of FIGURE 1;

FIGURE 3 is a block diagram of a modification of the system of FIGURE 2, wherein one of the build-up delays is applied on a fundamental frequency basis, rather than on an absolute frequency basis;

FIGURE 4 is a schematic circuit diagram of a system of division into low and high frequency components, delayed envelope build-up of low-frequency components, and reconstruction of low and high frequency components, which may be employed in various of the systems of FIGURES 1–3;

FIGURE 5 is a schematic circuit diagram of an alternative to the system of FIGURE 4;

FIGURE 6 is a block diagram of a tonal envelope build-up system, wherein tonal build-up occurs separately for each tone generator, and wherein partials of each tone are differently treated; and

FIGURE 7 is a block diagram of a modification of the system of FIGURE 6, wherein build-up delay for each tone generator is total for the tonal output, rather than different for different partials.

Referring now more particularly to the accompanying drawings, the reference numeral **10** represents the pedal division of an electronic organ which generates pedal tones including those in the infrasonic range, where the infrasonic range may be defined as falling below about 30 c.p.s. In general the lowest tone generated by organs is 16 c.p.s.

The output of the electronic organ division **10** is applied in parallel to four band pass filters, identified by the reference numerals **11**, **12**, **13**, and **14**, having pass bands 16 to 100 c.p.s., 100–400 c.p.s., 400 to 1600 c.p.s. and 1600 to 20,000 c.p.s., respectively. Band pass frequencies utilized are in considerable degree arbitrary. The lowest frequency needed in any of the filters is 16 c.p.s. and the highest frequency about 20,000 c.p.s., but intermediate these points more than four filters, or less than four filters, may be utilized and basically the band pass ranges for the separate filters may be selected largely on the basis of economics and ease of electrical design. A desirable delay at 16 c.p.s. is about 2 seconds, i.e. it is desired that the 16 c.p.s. frequency build up logarithmically from zero at the time the appropriate pedal is depressed, to practically full volume, in about two seconds. Buildup time for higher frequency notes is smaller, and where a band pass filter is utilized to pass simultaneously a band of tones, so that these must all be subjected to the same buildup delay, it is usually preferable to select a delay time which is shorter than that suitable for the lowest frequency and perhaps slightly longer than that suitable for the highest frequency. For example, in conjunction with the filters **11**, **12**, **13** and **14**, respectively may be employed delay devices **15**, **16**, **17**, **18** introducing delay times of 0.5 second, 0.25 second, 0.10 second, and 0.05 second, respectively. However, the highest frequency filter may have no delay if desired, and the remaining delay times may be considerably altered, on the basis of subjective tests, without departing from the spirit of the invention. The outputs of the filters **15** and **16** may be combined in a relatively high-power amplifier **19** and radiated through a low-frequency loudspeaker **20**. The outputs of the filters **17** and **18** may similarly be applied to a lower power amplifier **21** and radiated through the relatively high-frequency loudspeaker **22**.

The filters **11** to **14**, then, provide frequency-range dividing networks which might in any event have been desirable in order to permit utilization of appropriate power amplifiers and loudspeaker designs. Generally, the lower frequencies require higher power and a relatively larger loudspeaker, whereas the higher frequencies require lower power and a relatively smaller loudspeaker. It is the usual practice in audio system design to provide appropriate frequency-range dividing networks, amplifiers, and loudspeakers, but in the present case the availability of the networks and their cutoff frequencies may be selected to facilitate insertion of the desired buildup delays.

In the system of FIGURE 2, the pedal division of an electronic organ is represented by the dotted block **30**, and contains therein, in addition to the usual tone generators, keying switches and the like, a series of tone color filters **31**, **32**, **33**, and **34**. All of the tone color filters are connected to a common bus **35**, via appropriate stop switches, the stop switches being identified by the reference numerals **36**, **37**, **38**, and **39**. The organ **30** further includes an expression control **40**, followed by a frequency-range dividing network **41** having a division point at 200 c.p.s. The frequency division point is rather arbitrary, but should occur in the low audio frequencies, say below 600 c.p.s. The high-frequency range proceeds through a channel **42** to a linear mixer **43**, while the low-frequency range proceeds through a channel **44** to a delayed-gain circuit **45**, having a maximum gain of unity, to the same linear mixer **43**. For the frequency division point suggested a delay time of about .3 to .5 second would be appropriate.

The output of the mixer **43** is applied to a further frequency-dividing network **46** having a division point at 30 c.p.s. The range below 30 c.p.s. emerges from the dividing network **46** through a channel **47** and proceeds to power amplifier **48** and infrasonic loudspeaker **49**. The range above 30 c.p.s. proceeds through a separate channel **50** to an appropriate power amplifier **51** and an audio-frequency loudspeaker **52**.

In the case of the system of FIGURE 2 all frequency division takes place on a frequency basis, and, in consequence, high harmonics of a given tone may be subject to no delay, while low harmonics of the tone may be subjected to delay, or delays between low and high harmonics may differ.

While in the system of FIGURE 2 frequency division takes place by means of filters, and therefore occurs on a frequency basis, in the system of FIGURE 3 frequency division takes place by grouping tone generators. The difference in operation as between the systems of FIGURES 2 and 3 is, that in the system of FIGURE 2 higher harmonics of an infrasonic tone may be treated differently in respect to delay build up than are the lower ones, whereas in the system of FIGURE 3 all of the harmonics of any given infrasonic tone are treated identically. In the system of FIGURE 3 the reference numeral **60** denotes the pedal division of an electronic organ having the usual tone generators, key switches, tone color filters and the like. Included in the organ **60** is an octave series of key switches **61***a* corresponding to the lowest octave in the pedal range, a filter **62** for tones in this infrasonic range, of 16–32 c.p.s., another series of key switches **61***b*, its tone color filter **63**, and a series of filters **65**, **66**, **67** representing stop filters for all frequencies above the lowest octave in the pedal range. The output of the filters **63**, **65**, **66**, **67**, i.e. all those pertaining to frequencies above the lowest octave of the pedal range, are gathered on a single bus **70**, subjected to expression control at **71** and then applied to frequency divider network **72** having a division point selected at 200 c.p.s. Frequencies above 200 c.p.s. pass through the channel **73** directly to a linear mixer **74**, whereas frequencies below 200 c.p.s. pass through the channel **75** to the mixer **74**. The channel **75** includes a delayed buildup circuit **76** having a maximum delay time of about .3 to .5 second. The output of the mixer **74** is amplified in a power amplifier **77** and radiated by means of a conventional loudspeaker **78**.

The output of the lowest octave filter **62**, i.e., at 16–32 c.p.s., passes directly, without the interposition of an expression control, to a delayed gain circuit which may have a total delay time of as much as 2 seconds. The output of the delayed-gain circuit **79** is applied to a power amplifier **80** and the output of the latter is radiated by means of an infrasonic loudspeaker **81**.

In FIGURE 4 is a schematically illustrated a suitable circuit for accomplishing frequency division, delayed gain buildup and linear mixing, corresponding generally with the components **41** to **45** of FIGURE 2, or **72** to **76** of FIGURE 3. The delayed gain circuit **79** (FIGURE 3) may also include the circuitry of FIGURE 4, keeping in mind that linear mixing is not requisite in the delayed gain circuit **79** of FIGURE 3.

In the system of FIGURE 4 the entire audio and infrasonic tonal output of the pedal division of an organ, as in FIGURE 2, or the entire pedal output exclusive of the lowest octave filter, as in the system of FIGURE 3, may be applied to an input terminal **100**. The terminal **100** leads to two divided paths **101** and **102** of high impedance relative to the signal source. In the channel **101** is included an amplifier stage **103** including a vacuum tube **104** having an anode load resistance **105**, and a cathode bias circuit **106**. A negative feedback circuit extends from the anode of the vacuum tube **104** through a D.C. blocking condenser **107** and a voltage dividing resistance **108** back to the grid of the vacuum tube **104**. A succeeding amplifier stage **110** includes a vacuum tube **11** having a grid coupled to the anode of the vacuum tube **104** through the condenser **107**. The vacuum tube **111** is provided with a bias and negative feedback cathode resistance **112** and with an anode load **113**. The anode of the vacuum tube **111** is coupled through a D.C. blocking capacitor **114** and a voltage dropping resistance **115**, to a control wave form generating circuit **116** which has the function of developing a control voltage wave which establishes the delayed-gain buildup. The control voltage generator **116** includes two channels, **117** and **118**. Channel **117** includes a diode **119** having its anode presented to the vacuum tube **111**, whereas the channel **118** includes a diode **120** of opposite polarity. Connected between the cathode of the diode **119** and the anode of the diode **120** is a Zener diode **121**, shunted by a leakage resistance path. Because of the opposed polarities of the diodes **119** and **120**, and further because of the D.C. isolating condenser **114**, the diode

119 passes only positive half cycles of any wave form applied thereto, and the diode 120 passes only negative half cycles of any wave form applied thereto. The Zener diode 121 acts to clip the peak-to-peak voltage provided by the diodes 119, 120, since the peak-to-peak value cannot exceed the firing voltage of the Zener diode 121. Sufficient electrical gain is provided ahead of the clipper for the peaks of weakest tone waves to exceed the clipping threshold. Thus the control voltages, and the resulting tone buildup, will be independent of the magnitude of the organ signals, so the buildup effect occurs similarly at the beginning of any tone wave. Of course clipping could be accomplished by other means, e.g. in amplifier stage 110 by overload ahead of rectification.

Connected between the cathode of the diode 119 and ground is a low pass filter comprising shunt capacitors 122, 123, 124 and series resistances 125, 126. Connected between the anode of the diode 120 and ground is a precisely similar low-pass filter comprising shunt capacitances 127, 128 and 129 and series resistances 130, 131. The low-pass filters are connected in a conventional configuration, and serve as integrating networks for the voltage pulses passed by the diodes 119, 120, and clipped by the Zener diode 121. At the output of the filters, i.e. on leads 140, 141 appear, then, gradually increasing voltages, with respect to ground, which increase for each cycle of tone applied to the diodes 119 and 120 respectively, until the peak voltage appearing across the condensers 122 and 127, taken in sum, equals the firing voltage of the Zener diode 121. At this point the charging process is discontinued, because of back biases on diodes 119, 120, except in respect to replenishment of leakage from the storage capacitors of the filters.

The channel 102 leads to one half of a cross-over network 142, which serves to by-pass in channel 102 all frequencies above some predetermined value, and to pass all frequencies below that value, which, taken in the species of the invention illustrated in FIGURES 2 and 3, may be 200 c.p.s. However, values up to 1000 c.p.s. may be utilized, if desired. The sub-band of frequencies passed by the filter 142 proceeds to a balanced diode bridge 143. The latter consists of four diodes, 144, 145, 146, 147. The diode 144 has its cathode connected to the filter 142 and its anode connected to the anode of the diode 145, which in turn has its cathode connected to the input circuit of an amplifier stage 150. The anode of the diode 147 is connected to the filter 142 and to the cathode of the diode 146, the anode of which is connected to the grid of the amplifier stage 150. It follows that the bridge circuit 143 is normally blocked, i.e. blocks passage of currents from resistor 151 to the amplifier stage 150, since each of the series paths through the diodes includes two diodes which are respectively of opposite polarities. The lead 140 proceeds to the junction of the diodes 144, 145 and the lead 141 to the junction of the diodes 146, 147. The voltage applied to the lead 140 is positive with respect to ground and that on the lead 141 negative with respect to ground. Accordingly these voltages, acting as control voltages, unblock the blocking diodes of the bridge 143. The amplification provided by the amplifier stage 103 and 110, in conjunction with the clipping-circuit control-voltage generating circuit 116, are such that when full voltage is developed on leads 140, 141, i.e. at the end of an integration period, even for a weak input signal at the terminal 100, sufficient bias voltage is developed to render the bridge 143 fully conductive in both directions.

The channel 101 and amplifier 103 pass the entire frequency range of tones applied to the terminal 100, whereas the channel 102 passes only the low frequencies. The output of the amplifier 103 is applied through high-pass filter 154, comprising capacitor 154*a* and resistances 154*b*, 154*c* to a linear mixer 152, which also receives the output of low-frequency amplifier 150 through coupling circuit 153. The mixer 152 is a cathode loaded amplifier and supplies the combined output to a terminal 155 as well as to lead 156 which returns to a terminal 157, and reconstitutes the input band, as seen at terminal 100, except for the delayed build-up of the low frequencies.

The channel 154 serves then to eliminate from the input to the linear mixer 152 all the low frequencies which are passed by amplifier 150, with delayed buildup. The signals added by linear mixer 152 then consist of highs only, on depression of a pedal key, and of the original input spectrum as seen at terminal 100, after buildup is complete. On the other hand, the channels 117, 118 must receive the entire spectrum present at terminal 110, to assure that delayed buildup of low frequencies will always occur.

After a pedal switch is closed, and delayed build-up of low frequency tones has been completed, it is necessary that opening of the switch be accompanied by discharge of integrator 116 in preparation for a further cycle of operation. In the circuit of FIGURE 4 a continuously operative discharge path for the integrator 116 exists through a circuit including the diode bridge 143. This discharge circuit is operative even while the integrator 116 is charging, and not alone after completion of a pedal note. However, charge of the integrator overbalances discharge, due to the relative time constants. The existence of the discharge circuit tends to distort somewhat the exponential character of the charging cycle, as does also the switching characteristics of Zener diode 121, and to render the charging characteristic only approximately exponential. Moreover, the charging characteristics are exponential only approximately because multiple energy storage circuits produce a charge and discharge characteristic representative of a higher order differential equation.

In the alternative system of FIGURE 5 the reference numeral 180 denotes an input terminal for the entire output of the pedal division of an electronic organ. This output is amplified in a voltage gain amplifier 181, the output of the amplifier 181 being applied to an impedance matching transistor amplifier 182 connected in the emitter follower configuration. The output of the amplifier 182 is positive, and is developed across an emitter load resistance 183. The amplifier 182 operates without saturating, and its output is supplied through coupling condensers 184 and 184*a* to the base electrodes of a pair of collector-loaded, grounded-emitter transistor amplifiers 185 and 186. The amplifier 185 comprises a PNP type transistor having a resistance load 189 connected between its collector and a positive voltage bus 187. The base of the transistor 185 is connected through a relatively high resistance 188 to the bus 187, and the bias on the transistor is thus arranged to saturate the transistor completely, whereby the collector is essentially at ground potential, in the absence of driving signal applied to the base.

The transistor amplifier 186 includes an NPN transistor having a grounded emitter, and having a collector load in the form of resistance 190 connected between the collector and a negative bus 191. The base of the transistor 186 is connected to the bus 191 through a relatively high resistance 192 which provides a bias sufficient to drive the transistor 186 to saturation, so that its collector is, in the absence of driving signal, essentially at ground potential.

The signal developed across the emitter follower load 183 is an alternating current signal. Its positive excursions drive the transistor 185 out of the saturated condition into cut-off and thereby raise the voltage at the collector of the transistor 185. The negative excursions on the other hand drive the transistor 186 out of the saturated condition, and into cut-off, and thereby lower the voltage of the collector of the transistor 186, or increase its negative voltage with respect to ground. The collector of the transistor 185 is connected to an integrating network in the form of a low pass filter and the collector of the transistor **186** is connected to a similar integrating circuit in the form of a low pass filter. The filter **193** is provided with an output lead **195**, and the filter **194** with an output lead **196**. On the output leads **195**, **196** are developed respectively positive and negative potentials, which are equal, and which have a peak value of half the voltage on the buses **187**, **191**. These voltages are respectively plus 10 volts and minus 10 volts, so that the average approximate values of the control voltages on the leads **195**, **196** are respectively plus 5 and minus 5 volts, when peak clipping is occurring in transistors **185** and **186**. The combined gain of stages **181** and **182** is so arranged that for all organ signals in the practical range of levels, clipping will occur in stages **185** and **186**, so that build up to full gain will occur.

The voltage developed on the output leads **195** and **196** is developed gradually, as the integrating circuits **193** and **194** charge up in response to successive half cycles of driving signal applied to the bases of the transistors **185** and **186**. The delay time of the filters may be taken as equal to twice the time constant of the filters involved, i.e. the time required for the integrators to build up to approximately 90% of their peak value. In the present case this time may be approximately ½ to 1 second.

The bridge circuit **200** is composed of four diodes. The lead **195** is connected to one corner **201** of the bridge and sees the cathodes of diodes **203** and **204**. The lead **196** is connected to the opposed corner **202** of the bridge **200** and sees the anodes of diodes **205** and **206**. Since however the lead **195** is positive and the lead **196** negative, while signals are being processed, and zero at all other times, leads **195** and **196** see a relatively low impedance in the absence of input signal. Of the other two corners of the bridge one corner **207** is grounded, and the remaining corner **208** serves as a variable shunt load connection for a low-pass filter circuit **209**. The low-frequency components passed by the filter circuit **209** are transferred through the diodes **204** and **205**, which present a low impedance, for shunt by-pass to the output of the filter **209**. The terminal **208** is also connected by a lead **210** to the grid circuit of a triode amplifier section **211**. As the voltage of the leads **195** and **196** increases with respect to ground potential, the bias applied to the diodes **205**, **206** and **203**, **204** increases, rendering these diodes progressively less conductive to a signal applied from the filter **209**, so that the bridge **200** acts as a variable attenuator having zero or very small impedance for zero control voltage, progressively increasing impedance for increasing control voltage. As the impedance of the bridge **200** increases, a greater and greater signal appears at the grid of the amplifier **211**, since the bridge **200** acts as one arm of a voltage divider circuit, the other arm of which consists of resistance **212** at the output of the filter circuit **209**. Since the charging rate of the integrator or low pass filter networks **193**, **194** is approximately exponential, the envelope of the signal received by the amplifier **211** is likewise exponential, beginning with zero output and increasing as a function of time, until the impedance of the bridge **200** attains a stabilized value, after the transistors **186**, **185** stabilize. After this time the output of the amplifier **211** as seen at terminal **213** remains proportional only to the amplitude of the input signal as applied at the input terminal **180**.

From the terminal **180** extends a lead **215**, to a high pass filter **216**, comprising series condensers **217** and resistance **218**, which extend to the grid of a triode amplifier section **219**. A variable resistance **220** extends from the grid of the amplifier section **219** to ground, and permits adjustment of the high-frequency channel to that of the low-frequency channel. The output of the amplifier **219** appears at a terminal **221**. Terminals **213** and **221** are connected together to a terminal **222**, which is directly connected to the control grid of a triode amplifier section **223**. The latter is connected in the cathode-follower configuration and its cathode load **224** is coupled to an output terminal **225**.

Connected between the terminal **222** and ground is a variable resistance **226** which enables one, by adjustment of its resistance value, to adjust the overall gain of the system to unity.

Describing now briefly the operation of the system of FIGURE 5, wide-band signals applied to the terminal **180**, and deriving from the pedal division of an electronic organ, are amplified in amplifier **181** and the output of the latter is applied to an impedance transforming transistor stage **182**. The latter stage drives a pair of peak-clipping amplifiers of opposite polarity, one of which clips positive halves of the signal input wave, and the other which clips the negative halves. At the output of the clipping stages **185**, **186**, are connected integrating circuits **193**, **194**, which are designed to provide roughly exponentially rising outputs with respect to ground, one of the outputs rising positively and the other rising negatively. These outputs constitute control waveforms for a diode bridge **200** which operates as a shunt as one arm of a voltage dividing network, having very low impedance for zero control voltage. The low-frequency components of the total signal applied to the terminal **180** are selected by means of filter **209**, which is connected in series with the fixed resistance arm and the variable impedance of the bridge **200**. The junction of the resistance **212** and the bridge **200** is connected to the input of an amplifier stage **211**, which transmits the low-frequency components, after these have been subjected by the bridge to envelope delay, to a linear mixer amplifier **223**. The high-frequency components of the signal present on the input terminal **180** are selected by means of filter **216**, for application in controlled amplitude, and without gain delay, to the input of an amplifier **219**. The output of the amplifier **219** is also applied to the mixer **223**, so that all the original frequency components may be reconstituted at the output terminal **225**, it being recalled that the low-frequency signals, but not the high frequency signals, have been subjected to envelope delay.

The systems of FIGURES 1 to 5, inclusive, do not completely simulate, in respect to tonal envelope build-up, the tonal characteristics of a pipe organ unless single notes are applied in sequence to the delay build-up circuitry. In the case of the pedal division of the organ, this will generally prove to be true, because the pedal division is commonly played by depressing one pedal at a time, at least for the major portion of the total playing time. Insofar as one note is played immediately after the termination of another, the build up circuits will not have time to decay to quiescent condition, and accordingly the second of the notes will not start at zero amplitude, as it should. Where the second note is initiated during the playing of a first tone, the second tone will not be subjected to any amplitude delay. However the systems of FIGURES 1 to 5 are justified on an economic basis, as applied to the pedal division of an organ, because they operate well for the major portion of playing time of the pedal division. Furthermore the lack of gradual buildup in a second tone is hardly audible while a first tone is being sustained. Where it is desirable to simulate more closely the actual operation of a pipe organ, as for example by playing the low-frequency tones in the manual divisions, or even where tones in the pedal division are played very rapidly by a highly skilled organist, one can apply the techniques of FIGURES 1 to 5 individually to each tone generator of the organ which is sufficiently low in frequency to require gain delay. In applying the techniques of the present invention to individual tone generators it is again desirable to treat differently the lower partials and the higher partials, because in a pipe organ the lower partials have longer build-up times than the higher partials of the same tone. In the ultimate each partial of the tone might be treated to introduce the build up time appropriate for that partial by empirical comparison with the output of a pipe organ but, in practice, this may not be economically feasible. Accordingly the practice is followed of dividing each tone into lower and higher harmonics, introducing the delay into the lower harmonics and little or no delay into the higher harmonics, recombining the delayed with the undelayed partials, and utilizing the electrical tone so processed for producing the acoustically radiated tone of the organ.

Turning now more specifically to FIGURE 6 of the accompanying drawings, the reference numerals **300, 301, 302, 303** represent typical tone generators which may or may not pertain exclusively to the pedal section of electronic organ, but which do pertain to low-frequency tones for which simulation of pipe organ tone build-up is pertinent. The generators **300** to **303**, inclusive, may pertain to the musical nomenclatures C, C♯, D, D♯, and by extension all tone generators for one or more octaves may be subjected to the same treatment. In series with the generators **300** to **303**, inclusive, are provided key switches **304, 305, 306, 307**, respectively. Treating the key switch **304** as typical of the remainder of tthe key switches, i.e., connected in cascade with a frequency-range dividing network **310**, it separates the low-frequency components of the tone applied thereto in a channel **311** and the remainder of the frequency spectrum of the generator **200** in a channel **312**. In the channel **311** is included a gain delay network **313**, which may utilize the circuitry of FIGURE 4 or 5 for introducing a controlled delayed build-up of the envelope of the tonal components applied to the gain delay device **313**. The output of the delay device **313** and of the undelayed channel **312** are applied to a linear mixer **314**, which is designed, as in the system of FIGURE 5, to reconstitute the low-frequency and high-frequency components in their original relative intensities. The output of the mixer **314** is then applied to a conventional tone filter **315**, power amplifier **316** and loudspeaker **317**, in cascade. The tone generators **301, 302** and **303** are provided with frequency division, low-frequency tonal envelope build-up delay devices, each of which is individual to a tone generator, and which are individually identified by the reference numerals **320, 321**, and **322**. Further tone generators, corresponding with different musical nomenclatures, or the same nomenclatures in higher octaves, may be provided with similar circuitry. All the delayed and undelayed channels are connected to the same mixer **314**, for combination with the tones generated by the generator **300**.

The system of FIGURE 6 enables different build-up times to be applied to the lower and the upper partials of each tone on an individual basis. Upon depression of any pedal, or closure of any key switch, the upper partials of the corresponding tone are sounded immediately, but the fundamental of the tone or the lower partials build up gradually from zero value to a predetermined maximum value over a period of time appropriate for simulation of pipe organ tones.

In the system of FIGURE 6 considerable expense is involved in providing for each tone generator a frequency division network and controlled delay device. A rough approximation to the results obtainable by the system of FIGURE 6 may be attained much more simply and economically, although at considerable loss in performance characteristics, by omitting the frequency division networks and substituting in each of the tone generator channels merely a simple delay device. Thereby the partials, as well as the fundamental, are delayed correspondingly, a mode of operation which is in fact foreign to the pipe organ.

In the systems of FIGURES 6 and 7, identical components or elements are identified by the same reference numerals. The system of FIGURE 7 requires no further explanation, since it duplicates the system of FIGURE 6, except for omission of frequency range division and recombination.

While I have described and illustrated one specific embodiment of my invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

What I claim is:

1. In a gating wave generator, a source of alternating current signals, a first diode having its anode connected to said source, a second diode having its cathode connected to said source, a Zener diode connected directly between the cathode of said first diode and the anode of said second diode, and a separate integrating device connected between each of said diodes and a point of reference potential common to said devices to generate slowly increasing voltage waves of similar shapes and opposite polarities with respect to said point, said integrating devices having substantially similar time constants long with respect to plural cycles of said signals.

2. The combination according to claim **1** wherein is provided a series capacitor connected between said source of alternating current signals and said diodes.

3. The combination according to claim **2** wherein is provided a linear mixing circuit, a frequency range division circuit dividing a range of wave forms representing music into upper and lower frequency ranges, said first mentioned signals consisting of the lower frequency range, a gating circuit connected in series intermediate said linear mixing circuit and said frequency range division circuit, said gating circuit including a balanced modulator bridge normally blocked to said first mentioned circuits, and means for connecting said integrating low pass filters respectively to balanced points of said balanced modulator bridge to slowly reduce the impedance of said bridge to said first mentioned signals in response to said voltage waves, and means for coupling said upper frequency range into said linear mixer.

4. A gating wave generator for music signals, comprising a source of complex alternating current signal representing said music and having variable amplitude, a first rectifier having its anode connected to said source, a second rectifier having its cathode connected to said source, a bi-directional amplitude clipper connected between the cathode of said first rectifier and the anode of said second rectifier, said clipper having a peak to peak clipping level below the level of the lowermost available peak to peak amplitude of said signal, a separate integrator for each of said rectifiers, said integrators having several time constants separately arranged for integrating oppositely poled half cycles of said signal from a nearly zero peak to peak level on initial application of said signal to a level always clipped by said clipping level of said clipper, the integration occurring over a time equal to plural cycles of said signal.

5. The combination according to claim **4** wherein is connected a gating circuit connected to said source, said gating circuit being balanced with respect to ground and having a signal input terminal connected to said source, and a signal output circuit, said gating circuit further having two gating points balanced with respect to said point of reference potential, said integrators having output terminals connected respectively to said gating points and applying on-gating voltages to said gating points.

6. The combination according to claim **4** wherein is provided a linear mixing circuit, a frequency range division circuit dividing a range of wave forms representing music into upper and lower frequency ranges, said first mentioned signals consisting of the lower frequency range, a gating circuit connected in series intermediate said linear mixing circuit and said frequency range division circuit, said gating circuit including a balanced modulator bridge normally blocked to said first mentioned circuits, and means for connecting said integrating low pass filters respectively to balanced points of said balanced modulator bridge to slowly reduce the impedance of said

bridge to said first mentioned signals in response to said voltage waves, and means for coupling said upper frequency range into said linear mixer.

7. The combination according to claim 4 wherein said amplitude clipper is a Zener diode and a leakage resistance connected in shunt to said Zener diode.

8. In a gating wave generator, a source of alternating current signals, a first diode having its anode connected to said source, a second diode having its cathode connected to said source, a Zener diode connected between the cathode of said first diode and the anode of said second diode, and a separate integrating low pass filter connected in series with each of said diodes to generate slowly increasing voltage waves of similar shapes and opposite polarities, wherein is provided a series capacitor connected between said source of alternating current signals and said diodes, wherein is provided a linear mixing circuit, a frequency range division circuit dividing a range of wave forms representing music into upper and lower frequency ranges, said first mentioned signals consisting of the lower frequency range, a gating circuit connected in series intermediate said linear mixing circuit and said frequency range division circuit, said gating circuit including a four diode balanced bridge normally blocked to said first mentioned circuits, and means for connecting said integrating low pass filters respectively to balanced points of said balanced bridge to slowly reduce the impedance of said bridge to said first mentioned signals in response to said voltage waves, and means for coupling said upper frequency range into said linear mixer.

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