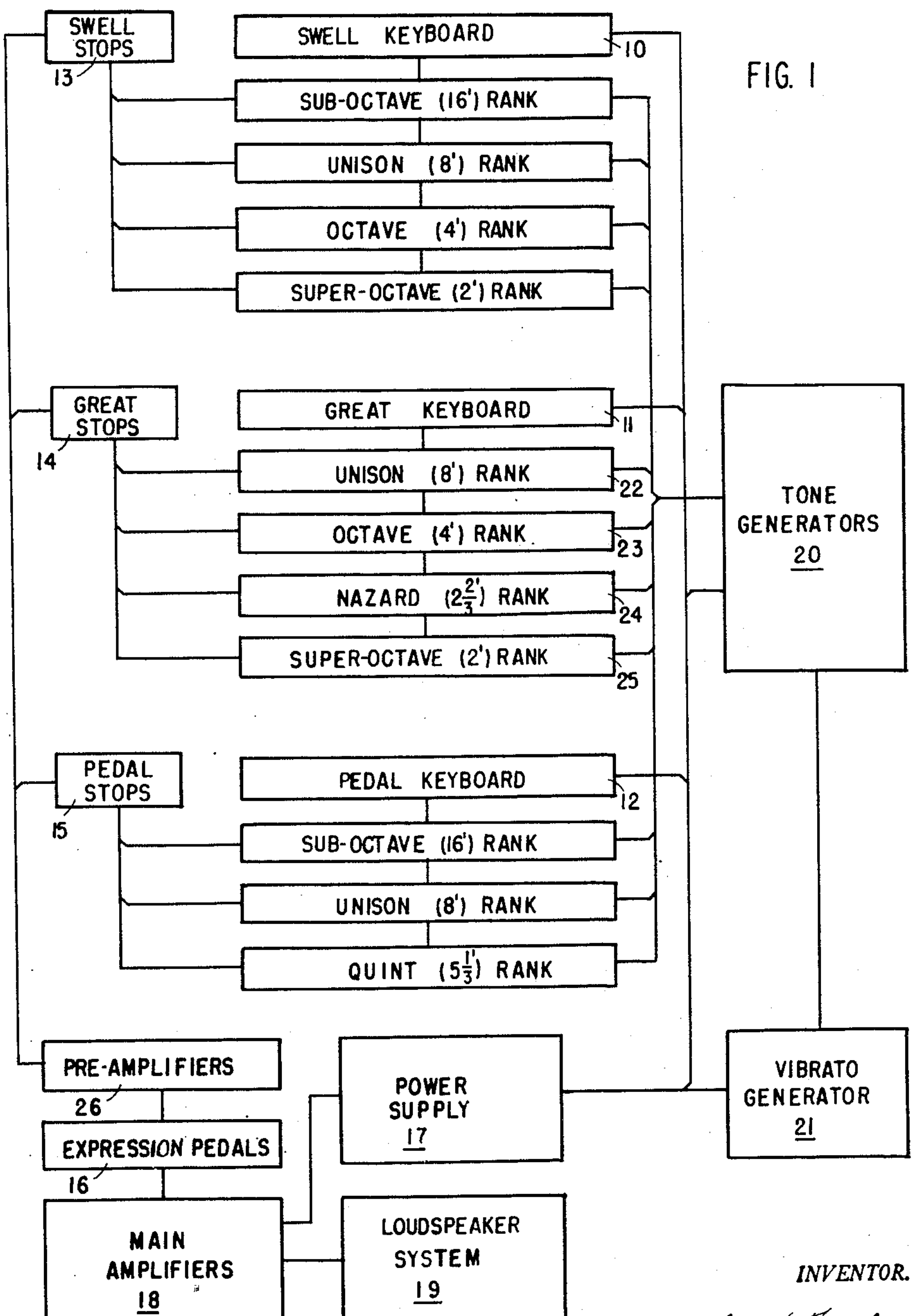
Oct. 29, 1957 A. H. FAULKNER 2,811,069

ELECTRICAL MUSICAL INSTRUMENT

Filed March 3, 1951 3 Sheets-Sheet 1

FIG. 1



INVENTOR.

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FIG. 2

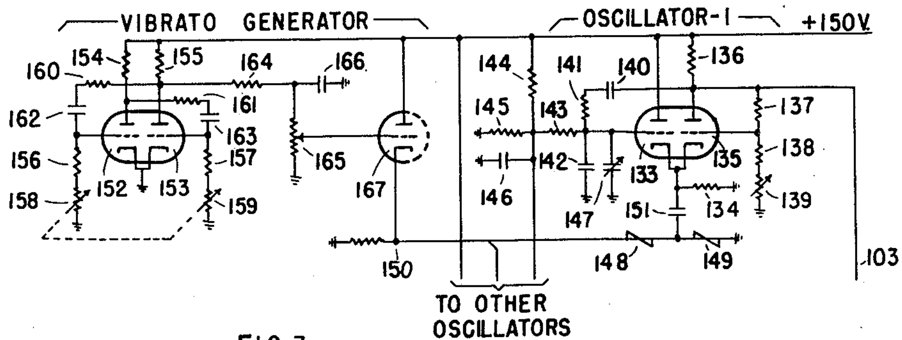


FIG. 3

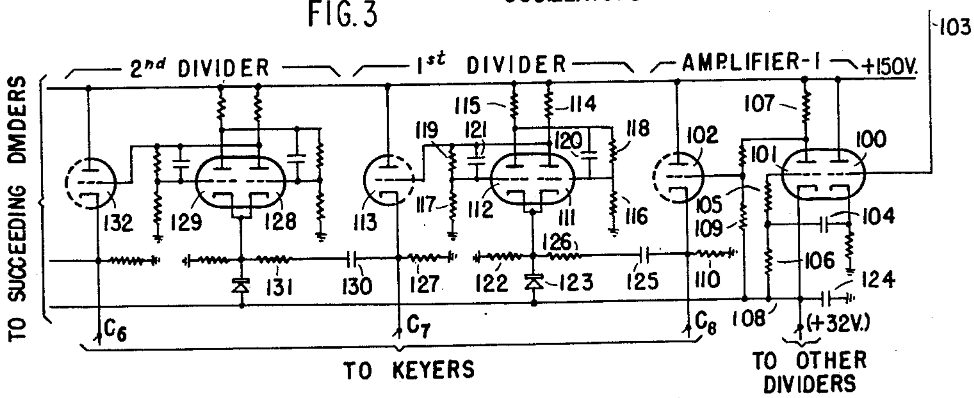


FIG. 4

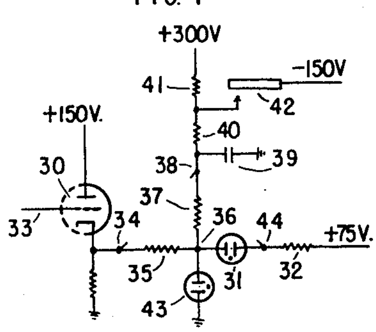


FIG. 5

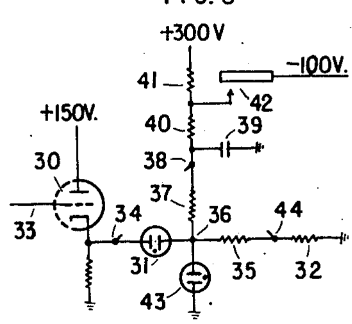
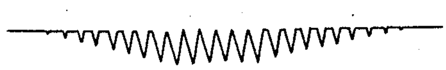


FIG. 6

FIG. 7



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ELECTRICAL MUSICAL INSTRUMENT

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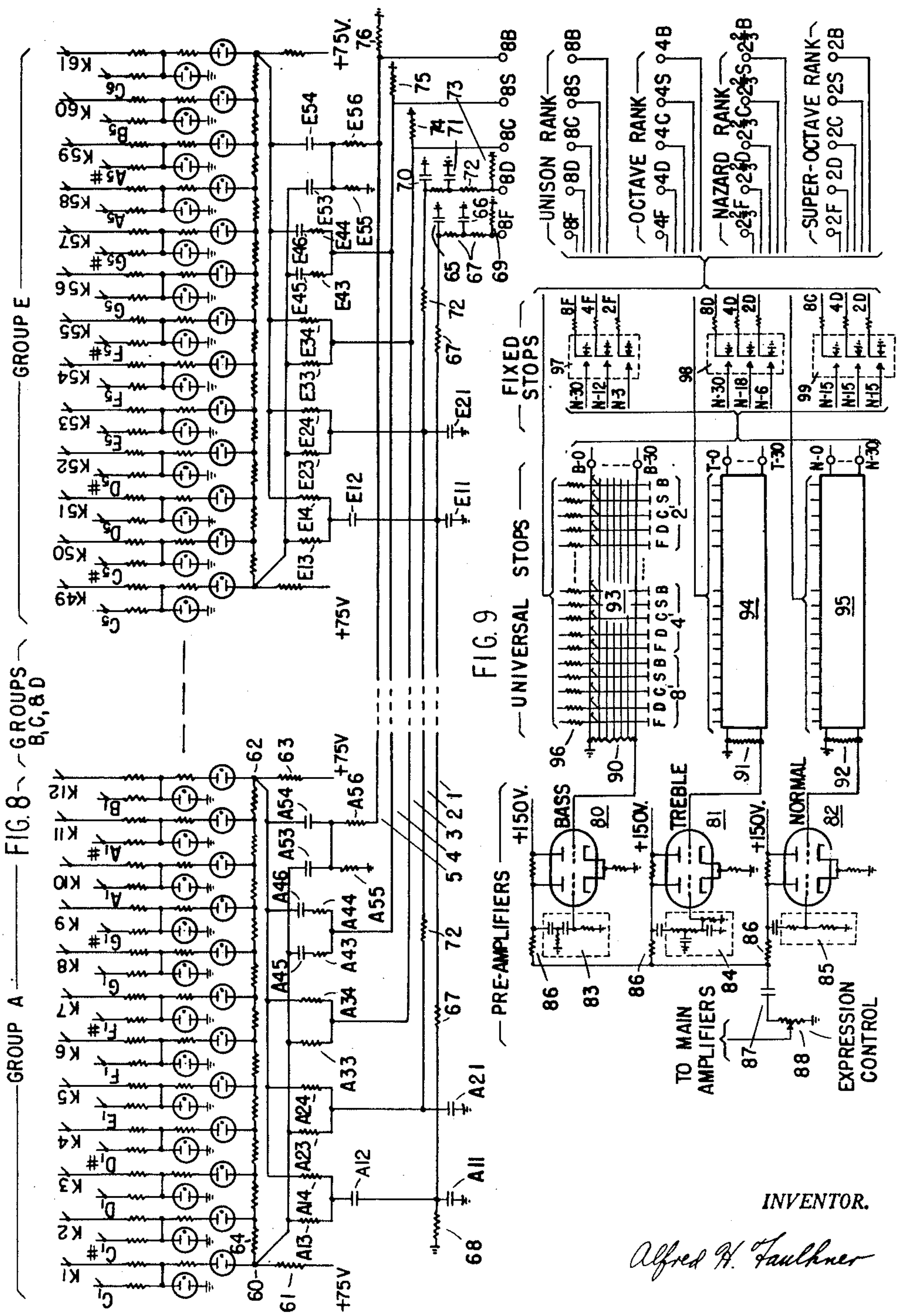

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ELECTRICAL MUSICAL INSTRUMENT

Alfred H. Faulkner, Chicago, Ill.

Application March 3, 1951, Serial No. 213,780

17 Claims. (Cl. 84—1.01)

The present invention pertains in general to instruments for producing musical sounds by electrical means, and more particularly to an instrument of the organ type.

Since the advent of the electronic era numerous attempts have been made to produce an electrical counterpart of the pipe organ, but none have successfully challenged the throne of this king of instruments. The electric organs, including the wind drive reed type, which have achieved commercial success may be divided into two major classifications, namely, the synthetic type in which a composite tone is produced by addition of its sinusoidal components, and the formant type in which a composite tone is produced by filtering out undesired components from a tone source that is overly rich in harmonics. The advantages and shortcomings of these two systems are discussed briefly in the following to facilitate understanding of the advance made by the present invention.

In theory the synthetic system is very attractive since any repetitive complex waveform can be produced by combining the corresponding sinusoidal components in the correct proportions, as is well known. This ideal is not achieved in practice due to the prohibitive cost of the extremely large number of tone generators required. Laboratory experiments have demonstrated that the first twenty harmonics are sufficient to duplicate wooden organ pipes very well, but have also demonstrated that even this large number is insufficient to duplicate the metal pipes. The tonal resources of commercial synthetic type organs are further limited by the practice of borrowing approximate harmonics from higher notes rather than providing independent exact harmonic sources. Sharp dissonances result from use of certain of these pseudo-harmonics, thus greatly restricting their usefulness. The tone qualities obtained by combining these so called harmonics differ radically from those produced by pipe organs as such tone qualities are in reality mere mixture stops made up of flute tones whereas pipe organs provide independent complex tones and mixtures of such complex tones. Finally, the operation of a playing key must complete an independent circuit from each of the corresponding harmonically related tone sources to the registration controls or "stops." Economic considerations dictate the use of mechanical contacts for this purpose, as the relatively high cost of previously known keyers prevents use of a multiplicity per key. The attack and decay of the tone therefore is abrupt and not controllable.

In the formant type of organ, the operation of a playing key need complete only one circuit from the corresponding tone source to the registration controls, as this source contains all of the desired harmonics. Conventional vacuum-tube oscillators are sometimes used as tone sources, the operation of a playing key being effective to slowly change the bias on one electrode of the corresponding oscillator tube to produce a gradual build-up of oscillations. At least one separate oscillator must be provided for each key in this arrangement. As each of these oscillators is operable at only one frequency, each key has a definite pitch (unison) assigned to it. To enable the keys to sound at pitches other than unison, in true organ fashion, it would be necessary to provide a multiplicity of oscillators for each key. Such an arrangement would be very costly and would be difficult to keep in tune. Coupler switches are used to partially over-

come this limitation, but this practice does not permit sounding different pitches simultaneously at different volume levels and also results in many voids or dead notes. Other formant type organs use constantly operating tone sources of the master oscillator and frequency divider chain type. To effect a gradual build up of tone on depression of a playing key, each one is arranged to complete a circuit from the corresponding tone source to the registration controls through a resistor that diminishes in value with further depression of the key. When couplers are used each key must be equipped with a multiplicity of such variable resistors. The number of couplers that can be employed in practice is therefore very limited in this form of organ.

As previously mentioned, the tone sources employed in the formant type of organ are overly rich in harmonics, the desired tone qualities being obtained by filtering out the undesired harmonics. Separate filters, each common to an entire manual of keys, are commonly provided for each desired tone quality. The weakness of this arrangement is that the alteration of tone quality by the filters also upsets the level of the instrument. For example, if the tones produced by the keys in the lower part of a manual are filtered sufficiently to have a flute quality, the tones produced by the upper keys of the manual are barely audible. Similarly, a filter which emphasizes the high harmonics of tones produced by the upper keys, to produce a bright string quality, causes the tones produced by the lower keys to be much too weak in comparison. Consequently, serious comprises are made in order to limit the disturbances in level which accompany changes in tone quality, therefore greatly restricting the range of tone qualities that can be provided.

One of the principal objects of the present invention is to provide an electrical musical instrument having far greater tonal resources, for a given manufacturing cost, than any previously known instrument.

A further object of the invention is to provide an electrical musical instrument having a number of voices in which each voice can readily be arranged to remain constant or to vary in a desired manner in quality and/or level over the compass of the instrument, thereby facilitating imitation of conventional orchestral instruments.

A still further object of the invention is to provide a keyer circuit, for use in electrical musical instruments, of such low cost as to permit thousands to be employed in a single instrument, whereby the tonal resources of such instruments may be vastly extended.

Another object of the invention is to provide an improved tone generator, of the master oscillator and frequency divider chain type, which is exceptionally stable in operation and is capable of furnishing a large number of output circuits with signal voltages at high levels and having waveforms well suited for use in musical instruments.

Still another object of the invention is to provide improved circuit arrangements for producing vibrato effects in musical instruments employing electronic type tone generators.

These and other objects of the invention, together with various modifications and improvements which may be made therein, may best be understood by reference to the following description taken in conjunction with the accompanying drawings which respectively describe and illustrate a particular embodiment of the invention, and wherein:

Fig. 1 is a block diagram of an electrical organ utilizing the invention and illustrates the relationship between the major components which are shown in detail in the remaining figures,

Fig. 2 is a schematic diagram of the vibrato generator and one of the master oscillators,

Fig. 3 is a schematic diagram of a portion of one of the frequency divider chains,

Fig. 4 is a schematic diagram of a preferred form of the new keyer,

Fig. 5 is a schematic diagram of a modified form of the new keyer,

Figs. 6 and 7 are graphs of keyed tones produced by the new keyers,

Fig. 8 is a schematic diagram of a typical rank of keyers together with its associated filter network, and

Fig. 9 is a schematic diagram of the stop controls and associated circuits illustrating the manner in which various tone qualities are obtained.

General description

The operation of a complete organ constructed in accordance with the invention will first be generally described with reference to Fig. 1, after which the operation of the various components will be described in detail with particular reference to the remaining figures. The organ illustrated is a two manual instrument, having a swell keyboard **10** shown at the top of the page, a great keyboard **11** shown some distance below the swell keyboard, and a pedal keyboard **12** shown near the center of the page. The usual swell, great, and pedal groups of stop tablets, or stop knobs, **13**, **14** and **15** respectively, are shown at the left of the corresponding keyboards. The expression pedals **16** are shown near the lower left hand corner of the page. All of these controls are incorporated in a conventional console and fulfill the same purposes as in a pipe organ. Other controls commonly provided on pipe organs, such as the couplers and combination pistons, may also be provided but have not been shown as they are not essential to the invention.

The remaining components, all of which are electronic in nature, may be conveniently located within the organ console. They consist of a conventional power supply **17**, audio amplifier **18**, and loudspeaker system **19**, all shown near the lower left hand corner of the page. At the right center of the page there is shown a set of tone generators **20** consisting of twelve master oscillators, each of which drives a corresponding frequency divider chain. All of the tones produced by the organ are obtained from these frequency dividers. Below the tone generators there is shown the vibrato generator **21**, which is operable to frequency modulate the twelve master oscillators when desired.

Immediately below each of the keyboards, such as **11**, there is shown a number of ranks, or groups, of keyers and filters, such as **22**, **23**, **24** and **25**. To conserve space only a few such ranks have been shown, but it should be understood that in practice at least eight ranks are provided for each keyboard and that any number may be employed in large organs. There are sixty-one keyers in each rank of each manual division and thirty two keyers in each rank of the pedal division; i. e., one keyer per key in each rank. The output circuits of the tone generators, corresponding to the notes in the equal tempered chromatic scale from C_0 (32.7 C. P. S.) to C_8 (8372 C. P. S.), are multipled to the corresponding keyers. The keyers are also connected in multiple to contacts on the corresponding keys of the associated keyboards.

Each of the keyers is in effect an attenuator inserted in a circuit path extending from the corresponding tone source through the associated filter network, stop system, pre-amplifiers **26**, and expression control to the audio amplifier. When none of the keys are depressed the keyers effectively block all such circuit paths, thereby preventing any tone signal from reaching the input of the audio amplifier. The stop system and expression controls are also operable to block the circuit paths to the audio amplifier, but these controls are at least partially open when the organ is being played.

As many keys as desired may be depressed concurrently on all of the keyboards, the total effect being the summation of the individual effects of each depressed key. For the sake of simplicity the effect of depressing only a single key on one keyboard will be described in detail. Assuming that the key corresponding to C_3 (middle C) on the great keyboard **11** is depressed, one keyer in each of the ranks **22**, **23**, **24** and **25** gradually opens and permits the corresponding tone C_3, C_4, G_4, and C_5, respectively, to pass through to the filter networks of these ranks. These pitch designations refer to the frequency of the fundamental components of the tones. For purposes which will later be apparent the tone signals preferably have a square waveform. Thus each tone consists of a fundamental component and a complete series of odd harmonics having amplitudes that decrease in inverse proportion to the order of the harmonic. Each of the filter networks modifies the tones received from the keyers to produce five different tones, having qualities ranging from a flute to a bright string, which appear in separate circuit paths leading to the great stops **14**. With the four ranks shown there is a total of twenty such paths leading to the great stops.

Depending on the setting of the great stops **14**, certain of the twenty tones received from ranks **22** through **25** are allowed to pass in controlled proportions to the pre-amplifiers **26**, and thence through the expression control **16** and audio amplifier **18** to the loudspeaker system **19**, where the tone signals are translated into audible sounds. The pitch of the audible tone, or tones, may be C_3, C_4, G_4 or C_5, or any combination of these depending on which stops are operated. The swell and pedal divisions of the organ operate in like manner to produce audible tones having qualities determined by the settings of the swell stops **13** and the pedal stops **15**. The expression pedals **16** are preferably arranged to permit independent control of the volume of each division, but a single pedal may be made common to several divisions if desired.

From the foregoing general description it should be apparent that a number of problems had to be solved to make such an instrument possible. The most important problem to solve was the provision of a keyer, capable of providing a controllable attack and decay of tone, which could be economically employed in vast numbers. The next most important problem was the provision of economical filter networks capable of deriving a wide range of tone qualities from rich tone sources and at a uniform level over a compass of at least five octaves. Another problem was the provision of stable tone sources having a desired waveform and being capable of feeding tone signals rich in harmonics over an extensive network without objectionable cross-coupling. The means provided by the invention to overcome all of these problems, together with others too numerous to mention, are described in detail in the following.

Keyer operation

As the keyer is regarded as the most important element of the invention, its operation will be described first. In general, the keyer consists of a glow tube connected between a tone source and a load circuit together with circuit arrangements for impressing a variable bias voltage on the glow tube. The tone signal amplitude is purposely made inadequate to fire the glow tube, which consequently is normally deionized and presents a very high impedance to the flow of tone signals from the source to the load. During operation of the keyer the bias voltage is gradually increased until the glow tube breaks down, thereby presenting a very low impedance to the flow of tone signals from the source to the load during a portion of each tone cycle. Through suitable choice of circuit constants a smooth variation in tone signal amplitude with variations in bias voltage is obtained. Distortion of the tone signal by the keyer during attack and decay periods is avoided through use of a tone source having a square, or rectangular, waveform. A square waveform is also preferred for other reasons mentioned hereinafter.

Circuit details of one embodiment of the keyer are shown in Fig. 4, wherein the tone source is represented by a vacuum tube **30**, the keyer tube is designated **31**, and the load is represented by a resistor **32**. Tube **30** (½ type 12AU7) is connected as a cathode follower having its grid **33** driven by a tone generator (not shown) of the desired waveform and amplitude. For purposes of explanation it will be assumed that a square waveform is employed of such amplitude that the potential at the cathode terminal **34** is alternately +25 v. and +125 v. A high valued resistor **35** (5 megohms) connects the cathode to one electrode of the keyer tube **31** (type NE–2 neon lamp) at junction **36**. Another high valued resistor **37** (5 megohms) connects this electrode to a variable bias source which is connected to terminal **38** and comprises a condenser **39** (.2 mf.), resistors **40** (.1 megohm) and **41** (1 megohm), a playing key **42**, and sources for supplying the indicated voltages. A second glow tube **43** (type NE–2 neon lamp) is connected between junction **36** and ground. It is believed that the operation of this tube might confuse the detailed description of the operation of the keyer tube, hence it will initially be assumed that the second tube **43** is not used and that resistor **41** is connected to the +75 v. source rather than the +300 v. source indicated. Under these conditions the potential at terminal **38** is initially constant at +75 v. and the potential at junction **36** is alternating between +50 v. and +100 v., assuming that resistors **35** and **37** are equal. The potential difference between the two electrodes of the keyer tube **31** is then 25 v., which is far below the breakdown value of approximately 75 v. Keyer tube **31** hence remains deionized and presents a practically infinite impedance, at least at low frequencies, to the flow of tone signals from junction **36** to the load terminal **44**.

When playing key **42** is operated the −150 v. source is connected to the junction of resistors **40** and **41**, thereby causing the potential at the bias terminal **38** to vary exponentially from +75 v. towards a final value of nearly −150 v. When the potential at terminal **38** reaches +25 v., the potential at junction **36** is alternating between 0 v. and +50 v. During the intervals when the potential at the junction is 0 v. the keyer tube **31** is just able to glow and draw a minute current through the load resistor **32** (1 megohm), this minute current being interrupted each time that the potential at the junction changes to +50 v. From this point on the amplitude of the load current increases uniformly with increasing bias. Thus when the potential at the bias terminal **38** reaches −75 v., the open circuit potential (i. e., the potential with glow tubes **31** and **43** disconnected) at junction **36** is alternating between −25 v. and +25 v. During the intervals when the open circuit potential at the junction is −25 v. the keyer tube glows and conducts approximately 9 micro-amperes with a drop of 68 v. The potential at the load terminal **44** is then +66 v. and the actual potential at junction **36** is −2 v. Each time that the potential at junction **36** changes to +25 v. the keyer tube is exinguished and the potential at the load terminal **44** returns to +75 v.

The load current continues to increase until the potential at the bias terminal **38** reaches −125 v., at which time the open circuit potential at junction **36** is alternating between −50 v. and 0 v. During the intervals when the open circuit potential at the junction is −50 v. the keyer tube glows and conducts approximately 18 micro-amperes with a drop of 62 v. The potential at the load terminal **44** is then +57 v. and the actual potential at junction **36** is −5 v. Each time that the potential at junction **36** changes to 0 v. the keyer tube is barely able to remain glowing, hence the potential at the load terminal **44** practically returns to +75 v. Further increase in bias merely adds a bias to the load voltage without materially affecting the tone signal.

When playing key **42** is released the potential at the bias terminal **38** returns exponentially to +75 v. at a rate determined principally by the values of condenser **39** and resistors **40** and **41**. The amplitude of the tone signal appearing across the load resistor **32** gradually decreases in the same manner as described for increasing signal, but may take place at either a faster or slower rate than the increase depending on the choice of circuit constants. Fig. 6 is a graph showing the manner in which the load voltage varies with time during a complete keying cycle. The output is pulsating unidirectional current, but the keying component can be eliminated with a simple RC high pass filter to provide an alternating tone signal if desired. It should be apparent from the preceding description that each pulsation is substantially rectangular in shape, hence the harmonic content of the output signal is independent of the signal amplitude. The keyer may be used with other signal waveforms, if desired. For example, Fig. 7 illustrates the manner in which the output signal varies with time during a keying cycle when a triangular wave shape is used. In this case the output signal is distorted at any signal amplitude less than the maximum value. Such distortion is generally undesirable musically, but may not be objectionable in specific instances.

It has previously been noted that when the keyer tube **31** is deionized its impedance is practically infinite at low frequencies. However, due to the unavoidable capacity between the tube electrodes, the impedance drops considerably at high audio frequencies. When a large number of keyers are connected to a common load the total leakage due to inter-electrode capacity is sufficiently great to be very objectionable. The second glow tube **43** is used as a clamp to overcome this objection in the following manner.

In the foregoing description it was assumed that resistor **41** was connected to the +75 v. source, in which case the open circuit potential at junction **36** normally alternated between +50 v. and +100 v. When the second glow tube **43** is employed it is essential that the minimum open circuit potential at the junction be sufficiently high to sustain ionization in the tube. With resistor **41** connected to the 300 v. supply, as shown, the normal open circuit potential at junction **36** alternates between +150 v. and +200 v. Under these conditions tube **43** glows continuously and conducts an average current of approximately 46 micro-amperes at an average drop of approximately 60 v. The instantaneous current through this tube alternates between 36 and 56 micro-amperes, approximately, resulting in an actual potential alternating between +61 v. and +59 v. at junction **36**. The clamp tube **43** thus reduces the tone leakage through the keyer by a factor in the order of twenty-five times, or 28 db. The previous description of the operation of the keyer tube **31** is not materially affected by the addition of the clamp tube **43** since the latter tube ceases to glow before the keyer tube commences to glow in response to operation of the playing key. Similarly, the keyer tube ceases to glow before the clamp tube commences to glow in response to release of the playing key. Some tone leakage occurs during the interval when neither tube is glowing, but this is not serious since the total leakage of several keyers is not objectionable, although the total leakage of a complete rank of sixty-one keyers is objectionable.

At this point it may be well to note that the symbols employed for terminals **34**, **38** and **44** indicate multiple connections at these points. Thus a number of keyers may be connected to the same load terminal, such as **44**. These keyers may each be connected to a different source terminal, such as **34**, each of which may feed a number of keyers. Also the bias terminal **38** may control a number of keyers which may be connected to one or more source terminals and one or more load terminals, Circuit details of a second embodiment of the keyer are shown in Fig. 5. Like reference characters have been used to denote corresponding elements in the two forms of keyer shown. Circuit-wise Fig. 5 is identical to Fig. 4 except for a slight change in supply potentials and an interchange in positions of glow tube 31 and resistor 35. In this case the open circuit potential at junction 36 is normally constant at +150 v. The clamp tube 43 consequently glows continuously and conducts a current of approximately 36 micro-amperes at a voltage drop of approximately 60 v. The incremental resistance of the glow tube is roughly −100,000 ohms in this region, hence the tone leakage due to the inter-electrode capacity of keyer tube 31 is reduced by a factor in the order of twenty five times, or 28 db, compared to the leakage that would occur without the clamp tube. It may be noted that the clamping action is not dependent on the sign of the incremental resistance of the clamp tube, but is dependent solely on the magnitude of this resistance. The potential between the two electrodes of the keyer tube 31 normally alternates from +65 v. to −35 v., neither value being sufficient to cause breakdown.

When the playing key 42 is operated the potential at the bias terminal 38 varies exponentially from +260 v. towards a final value of nearly −100 v. As the potential at the bias terminal decreases the current drawn by tube 43 decreases also, causing the potential at junction 36 to rise slightly. When the current through tube 43 has fallen to zero, the potential at junction 36 is +75 v. and the potential at bias terminal 38 is +137 v. From this point on the potential at junction 36 decreases in direct proportion to the decreasing bias potential until keyer tube 31 commences to glow. This happens when the potential at junction 36 reaches +50 v., at which time the potential at bias terminal 38 is +92 v. Further decrease in bias potential produces a proportional decrease in potential at junction 36 during the intervals when the cathode terminal 34 is at its lower value of +25 v. and keyer tube 31 is consequently deionized, but during the intervals when the cathode terminal 34 is at its higher value of +125 v. the keyer tube 31 glows and raises the potential at junction 36 to +50 v. or more. The amplitude of the pulsations of potential at junction 36, and also at the load terminal 44, increase uniformly until the potential at the bias terminal reaches −92 v., beyond which point the keyer tube 31 glows continuously. At this point the potential at junction 36 alternates from −50 v. to approximately +65 v. The potential at the load terminal alternates proportionately from −8 v. to +11 v.

Upon restoration of the playing key 42 the potential at bias terminal 38 returns exponentially to its original value, causing the above cycle of events to be repeated in reverse order. The manner in which the load, or output, signal varies with time is substantially the same as that shown in Fig. 6 except for slight differences in the keyer component. This embodiment of the keyer may also be used with other tone signal waveforms to produce keyed tones such as that shown in Fig. 7.

Keyer and filter network

One rank of keyers and filters is shown in detail in Fig. 8. The rank shown corresponds to that designated 22 in Fig. 1 and is accordingly arranged for operation at unison pitch. Ranks arranged for operation at other pitch levels, such as ranks 23, 24 and 25 in Fig. 1, differ from that shown only in the values of the filter components and in the connection of the keyers to other tone sources than those indicated. As there are sixty-one keys in the keyboard of each manual division, in accordance with standard organ practice, sixty-one keyers are provided in each rank. The keyers are divided into four groups of twelve keyers, each group covering one octave, and a fifth group of thirteen keyers covering the top octave plus the sixty-first note. To conserve space only the first and last groups of keyers have been shown.

The upper row of terminals, designated K1 to K61, are the bias terminals corresponding to terminal 38 in Fig. 4. These terminals are connected in multiple with the corresponding terminals of other ranks in the same division to variable bias sources individual to each playing key in the manner illustrated in Fig. 4. The second row of terminals, designated C_1 to C_6, are the tone source terminals corresponding to terminal 34 in Fig. 4. These terminals are connected in multiple with other terminals of like pitch designation of other ranks in all divisions to corresponding tone sources, such as those illustrated in Fig. 3, and described hereinafter. It may be well to note here that the tone source terminals of the octave (4′) ranks are designated C_2 to C_7, the nazard (2⅔′) ranks are designated G_2 to G_7, the super-octave (2′) ranke are designated C_3 to C_8, etc. Only the lowermost group of twelve keyers, group A shown at the left of Fig. 8, will be described in detail, as the remaining groups are identical in form to the lower group. The output, or load, terminal 60 of the first keyer is connected to a +75 v. source through resistor 61 (.4 megohm). The output terminal 62 of the twelfth keyer is similarly connected to the +75 v. source through resistor 63 (.4 megohm). Terminals 60 and 62 are coupled through eleven serially connected resistors, such as 64 (.1 megohm), to which the output terminals of the ten intermediate keyers are connected in the manner shown.

Let us assume that the circuit constants of the keyers and the amplitude of the tone signals at the tone source terminals are chosen such that a tone current of 12.5 micro-amperes is obtained from an operated keyer, which may be regarded as an essentially constant current source. Then when the first keyer is operated the total tone current of 12.5 micro-amperes is divided into two parts, 9.9 micro-amperes flowing through resistor 61 and 2.6 micro-amperes flowing through resistors 64 and 63. The tone levels at terminals 60 and 62 are then 4 v. and 1 v. respectively. Similarly, when the second keyer is operated the total tone current divides into 9.2 micro-amperes flowing towards terminal 60 and 3.3 micro-amperes flowing towards terminal 62, resulting in tone levels of 3.7 v. and 1.3 v., respectively, at these terminals. When the following keys are operated successively the tone level at terminal 60 gradually decreases, finally reaching 1 v. when the twelfth keyer is operated, and the tone level at terminal 62 gradually rises, finally reaching 4 v. The other groups B, C, D and E, of keyers are similarly provided with a first output terminal at which the tone level decreases in accordance with the pitch corresponding to an operated keyer, and a second output terminal at which the tone level increases in accordance with the pitch corresponding to an operated keyer.

The filter network is composed of five tone channels, 1 through 5, leading to five output terminals, 8F, 8D, 8C, 8S and 8B. Each tone channel is coupled to the output terminals of each group of keyers by a pair of impedance elements which are preferably so related as to maintain the level and timbre of the tone obtained from terminals 8F through 8B substantially constant over the compass of the ranks of keyers. In the following discussion it is assumed that the tone currents obtained from the keyers have a square waveform, which follows from use of tone generators having a square voltage waveform.

Tone channel 1 is arranged to provide a substantially sinusoidal waveform, corresponding to a flute tone, at output terminal 8F. This result is obtained with a single filter condenser, such as A11, for each group of keyers plus two additional filter condensers 65 and 66, connected between the last group and the output terminal 8F. All of these condensers are connected by resistors 67 to form a cascaded filter which is terminated at each end in resistors 68 and 69. At this point it may be well to note that in practice shielded leads are used to connect the output terminals of the filter network to the stop system. The shunt capacity of each of these leads, which is ordinarily in the order of 100 mmf., is treated as part of the filter network. Each of the filter condensers, such as A11, corresponding to a group of keyers is connected to the output terminals of that group through a blocking condenser, such as A12, and two resistors, such as A13 and A14. It should be apparent that if the output terminals of the twelve keyers in group A were connected directly to the input of the cascaded filter a different tone level would be obtained at the filter output for each operated keyer, since the attenuation of the filter necessarily increases with increasing frequency. The provision of the hwo output terminals **60** and **62**, at which tone levels varying in opposite senses are obtained when the associated keyers are operated successively, permits the varying attenuation of the filter with frequency to be compensated for very simply by a suitable choice of values for resistors A13 and A14. When these resistors are so chosen as to maintain the tone level constant there is a slight variation in timbre of tones within a group, but this difference is so small that it is scarcely noticeable to the ear. The average timbre and tone level of each of the five groups included in a rank can be maintained uniform by choosing suitable values for the components of the cascaded filter. Typical values are given in tabular form hereinafter. It will be noted that the values given for the filter condensers, such as A11, appear to vary in an irregular manner, however it can be demonstrated theoretically and experimentally that the desired results are obtained from this filter configuration.

Tone channel 2 is arranged to produce a substantially symmetrical triangular waveform, corresponding to a diapason tone, at output terminal **8D**. This channel is identical in form to channel 1 and is similarly comprised of a single filter condenser, such as A21, for each group of keyers plus two additional filter condensers, **70** and **71**, connected between the last group and the output terminal 8D. All of these condensers are connected by resistors **72** to form a cascaded filter which is terminated in resistor **73**. Each of the filter condensers, such as A21, corresponding to a group of keyers is connected to the output terminals of that group through two resistors, such as A23 and A24. Blocking condensers are not necessary in this case because the output tone level is sufficiently high to mask the keyer component without any special measures being taken to discriminate against it. As in the preceding case, uniform tone level within each group is obtained by selection of appropriate values for the resistors, such as A23 and A24, coupling that group to the filter, and uniform tone level within the rank is obtained by selection of appropriate values for the components of the cascaded filter. Typical values for these components are given in the aforementioned table.

Tone channel 3 is arranged to produce a substantially square waveform, corresponding to a calliope tone, at output terminal **8C**. No filtering is required in this case because the tone signals at the group output terminals, such as **60** and **62**, already have the desired waveform. The group outputs are isolated from each other by connecting each one through individual high-valued resistors, such as A33 and A34, to a common low valued resistor **74** connected from output terminal 8C to ground. Uniform tone level within each group and within the rank is obtained by making all of the coupling resistors, such as A33, and A34, equal in value, as shown in the table of typical values.

Tone channel 4 is arranged to produce an unsymmetrical triangular waveform, corresponding to a soft string tone, at output terminal **8S**. This channel is similar in form to channel 3, the group outputs being isolated by connecting each one through an individual series combination of a high valued resistor and condenser, such as A43 and A45, to a low value resistor **75** connected between output terminal 8S and ground. The values of the coupling condensers, such as A45, connected to the lower group output terminals, such as **60**, are chosen so as to have a reactance that is numerically considerably greater than the ohmic value of the associated coupling resistors, such as A43, at the fundamental frequency of the lowest note, such as C_1, in the corresponding group. Similarly, the values of the coupling condensers, such as A46, connected to the higher group output terminals, such as **62**, are chosen so as to have a reactance that is numerically considerably greater than the ohmic value of the associated coupling resistors, such as A44, at the fundamental frequency of the highest note, such as B_1, in the corresponding group. Substantially uniform tone level and timbre within each group is obtained with suitably chosen values for the four coupling components, such as A43 to A46. Uniform tone level over the entire rank is obtained by making the impedance of the coupling components in the different groups equal over the range of frequencies covered by the associated groups. The effect of choosing values for the coupling condensers in the above manner is to diminish the lower harmonics of all tones transmitted over channel 4, thus producing a string quality. The high harmonics are also diminished to some extent by reason of the shunting action of channel 5, about to be described, thus softening the string quality obtained from channel 4.

Tone channel 5 is arranged to produce a waveform approaching a spike, corresponding to a bright string tone, at output terminal **8B**. In this case the group output terminals, such as **60** and **62**, are connected through individual high reactance valued condensers, such as A53 and A54, to ground through a network of low-valued resistors, comprising a common resistor **76** and a pair of resistors, such as A55 and A56, individual to a group. The output terminal 8B of this channel is connected to the common resistor **76**. Since the amplitudes of the harmonics of the square waveform available at the group output terminals decrease directly with the harmonic order, or frequency, and the reactance of the coupling condensers, such as A53 and A54, also decreases directly with frequency, the signal voltage developed across the individual resistors, such as A55, and also across the common resistor **76** contains all significant odd harmonics in equal proportion. By suitably proportioning the pair of coupling condensers associated with each group the tone level and timbre can be maintained substantially uniform over the range covered by the group. Uniform tone level over the rank is obtained by suitably proportioning the individual resistors associated with each group. The coupling condensers associated with channel 5 provide a bypass for the high harmonics, thus softening the tone obtained from channel 4, as noted above, and also effectively increasing the filtering action of the other tone channels.

The following table lists representative values for all of the components used in the filter network of a rank intended for use at unison pitch. In ranks intended for use at other pitch levels the values of the condensers should be changed in inverse proportion to the change in frequency. These values should be regarded as approximate only and may have to be modified to compensate for variations in harmonic content of the tone sources.

Tone channel 1:

A11	mmf	5000
B11, C11	mmf	1000
D11, E11	mmf	200
65, 66	mmf	200
A12	mmf	5000
B12	mmf	2000
C12	mmf	1000
D12	mmf	400
E12	mmf	200
A13—E13	megohms	10
A14—E14	do	3
67—69	do	1

Tone channel 2:

A21	mmf	1000
B21, C21	mmf	200
D21, E21	mmf	40
70, 71	mmf	40
A23—E23	megohms	4
A24—E24	do	10
72, 73	do	1

Tone channel 3:

A33—E33	megohms	5
A34—E34	do	5
74	do	.1

Tone channel 4:

A45	mmf	800
B45	mmf	400
C45	mmf	200
D45	mmf	100
E45	mmf	50
A46	mmf	400
B46	mmf	200
C46	mmf	100
D46	mmf	50
E46	mmf	25
A43—E43	megohm	1
A44—E44	do	1
75	ohms	30,000

Tone channel 5:

A53, A54	mmf	400
B53, B54	mmf	200
C53, C54	mmf	100
D53, D54	mmf	50
E53, E54	mmf	25
A55—E55	megohm	.2
A56—E56	do	1
76	do	.1

Stop system

The preceding section described the manner in which a unison rank of keyers and filters provides five tone qualities, herein referred to as flute, diapason, calliope, soft string and bright string tones. These tones are quite useful alone and also when combined in various proportions to obtain intermediate shades of tone color. Far greater variety is possible when these basic tone qualities are also available at other pitch levels. As shown in Fig. 1 and described heretofore, each division of the organ includes a number of ranks, such as **22**, **23**, **24** and **25**, each of which functions in the manner just described to produce the five basic tone qualities at the corresponding pitch levels. The output terminals of these four ranks are shown at the right of Fig. 9, which illustrates the stop system described in the following.

Many organ stops are intended to imitate the tone quality of conventional orchestral instruments, from which such stops derive their names. Since the tone quality of such instruments varies over their compass, the tone quality of the corresponding organ stops must also vary over their compass in order to provide a satisfactory imitation. To further this end, the stop system of the present organ is provided with three separate pre-amplifiers, **80**, **81** and **82**, shown at the left of Fig. 9. Each pre-amplifier utilizes a twin-triode (type 12AT7), the right triode being connected as a cathode follower and the left triode being connected as a cathode drive amplifier. Inverse feed back networks, **83**, **84**, and **85**, are connected between the plates and grids of the left triodes to control the frequency response characteristics of these amplifiers. The constants of network **83** are preferably chosen such that the gain of amplifier **80** decreases at a uniform rate of about three decibels per octave, providing a total variation of fifteen decibels over the five octave compass of an organ manual. Similarly, the constants of network **84** are preferably chosen such that the gain of amplifier **81** increases at a uniform rate of about three decibels per octave, also providing a total variation of fifteen decibels in five octaves. Network **85** is simply a voltage divider and hence it maintains the gain of amplifier **82** uniform over a wide frequency range. The output circuits of these three amplifiers are connected through individual high-valued resistors **86** and a blocking condenser **87** to the expression control rheostat **88**, which determines the signal level supplied to the main amplifier.

When complex tones are transmitted through amplifiers **80** or **81** a slight change in tone quality results from the non-uniform gain of these amplifiers, however this is not objectionable as it can readily be compensated for when necessary by selecting or mixing a slightly purer or richer tone quality from the rank output terminals. When one tone quality is fed to the base amplifier **80** and a second tone quality is fed to the treble amplifier **81**, the first tone quality dominates the lower register and the second tone quality dominates the upper register, a gradual transition from one tone quality to the other occurring in the middle register.

The input grid of amplifier **80** is connected to ground through ten serially connected registors **90**. The terminals of these resistors are connected to the fixed bus bars of a drawbar type of selector **93**, such as that described in detail in Patent 1,956,350 issued to Laurens Hammond, and to eleven terminals B–**0**, B–**3**, B–**6**, etc. to B–**30**. The values of these resistors are preferably chosen so as to cause the signal impressed on the grid to increase in steps of three decibels when a constant current source is connected to terminals B–**0**, B–**3**, etc., successively. The input grids of amplifiers **81** and **82** are similarly connected to resistor groups **91** and **92**, selectors **94** and **95**, and terminals T–**0** through T–**30** and N–**0** through N–**30**.

Each of the selectors **93**, **94** and **95** is provided with a number of slide bars corresponding to the number of rank output terminals, or twenty in the present instance. The slide bars are provided with contacts that are normally in contact with the grounded bus bars but can be selectively connected to any one of the other bus bars by drawing out the slide bar. These contacts are connected through high-valued isolating resistors, such as **96**, to corresponding ones of the rank output terminals **8F** through **2B**. By drawing out the slide bars in various combinations and to various extents an immense variety of tone colors may be obtained, making the selector switches or universal stops very valuable for purposes of experimentation and demonstration. In ordinary playing the universal stop arrangement is somewhat unwieldy, particularly so when a large number of slide bars are provided. Therefore, a registration system employing fixed stops is generally preferred.

A few typical fixed stops are shown at the right of the selectors in Fig. 9. These stops are simply multipole transfer switches and associated isolating resistors. The number of contacts required for a given stop is dependent on the number of basic tone qualities that are needed, the number of different volume levels at which these basic tone qualities must be reproduced, and the manner in which the resultant tone quality must vary, if any, over the compass of the instrument. Two means of controlling the relative intensity of the basic tone qualities used in making a composite tone, or stop, are provided. First, the several sources of basic tones may be connected to different input terminals of the same, or different amplifiers; and, second, different values of isolating resistors may be used between the basic tone sources and a single amplifier input terminal. In many cases both of these methods are employed in combination to conserve contacts on the stop switches, or to avoid undue loading of the tone sources, or to obtain a wider range of intensity levels.

The uppermost stop **97** provides a typical flute tone which is obtained by connecting rank output terminals

8F and 4F and 2F, through suitable isolating resistors, to amplifier input terminals N–30, M–12 and N–3, respectively. The harmonic structure of the resulting tone is as follows:

Harmonic order:	Relative amplitude, db
1	0
2	−12
3	−28
4	−27
5	−36
6	−40

By omitting the connections to rank output terminals **4F** and **2F** the even harmonics can be eliminated, thus providing a typical stopped flute tone.

The middle stop **98** provides a typical open diapason tone which is obtained by connecting rank output terminals **8D**, **4D** and **2D**, through suitable isolating resistors, to amplifier input terminals **N–30**, **N–18** and **N–6**, respectively. The harmonic structure of the resulting tone is as follows:

Harmonic order:	Relative amplitude, db
1	0
2	−12
3	−19
4	−24
5	−28
6	−31
7	−34
9	−38
10	−40

If the connections to rank output terminals **4D** and **2D** are omitted the even harmonics are eliminated, leaving a typical stopped diapason tone structure.

The lowermost stop **99** provides a typical string tone which is obtained by connecting rank output terminals **8C**, **4D** and **2D**, through isolating resistors, to amplifier input terminal **N–15**. The harmonic structure of the resulting tone is as follows:

Harmonic order:	Relative amplitude, db
1	0
2	0
3	−9
4	0
5	−14
6	−19
7	−17
9	−19
10	−28
11	−21
12	−19
13	−22
14	−29
15	−23
17	−25
18	−38
19	−26
20	−28
21	−27
23	−27
25	−28
27	−29
28	−34
29	−30

Tone generator

Now that the operation of the keyers, filter network, and stop system has been described in some detail the requirements of the tone generator can be better appreciated. First, in order that tone qualities corresponding to the stopped organ pipes may be produced, the waveform of the tone sources must be such that the positive and negative half-cycles are identical except for sign, signifying the absence of even harmonics. Second, in order that even harmonics may be borrowed from octavely related sources, such sources must operate in exact octave relationship. Third, the harmonic structure of the tone sources must be stable and accurately reproducible and should preferably be such that a wide range of useful tone colors can be derived from it with a reasonable amount of filtering. Fourth, the tone sources must be able to feed in extensive network of keyers, which must necessarily be spread over a considerable area in close proximity, without objectionable cross-coupling.

The first three requirements point to use of counting chain type of frequency dividers. There are two principal limitations to use of such frequency dividers as generally constructed heretofore. The first limitation is the inoperability of such dividers with load circuits having appreciable shun capacity. The second limitation is the musically undesirable waveform produced by such dividers. This waveform is essentially rectangular, or square, but is studded with spikes resulting from amplification of the driving pulses fed preceding divider stages, the number of spikes increasing directly with the division ratio. Tones produced from such sources have a very harsh quality and are not considered usable in a musical instrument. Both of these limitations are overcome by means of the improved circuit arrangements shown in Fig. 3 and described in detail in the following.

The frequency divider chain shown in Fig. 3 represents that employed to derive all of the "C" notes of the equal tempered scale from a master oscillator operating at the frequency of C_8, which is 8372 C. P. S. The other eleven frequency dividers employed to derive the remaining notes from their corresponding master oscillator are identical to that shown, furthermore all of the divider stages in a chain are identical. Hence a detailed description of the operation of two such stages will suffice for the complete tone generator system. The master oscillators provide a sinusoidal output having an amplitude of approximately fifteen volts. As this waveform is not suitable for driving the counting chains, each one is preceded by a distorting amplifier which provides an output waveform suitable for driving the succeeding counting circuits and also suitable for distribution to the keyers as the top note, or C_8 in the case of the chain illustrated.

In Fig. 3, the distorting amplifier is shown at the right and comprises three triodes, **100** and **101** (type 12AT7) and **102** (½ type 12AU7). Oscillator-**1**, described hereinafter, is connected by lead **103** to the grid of triode **100**, which is connected as a cathode follower and is used as a buffer to minimize loading of the oscillator. The cathode of triode **100** is capacitively coupled to the grid of triode **101** through a blocking condenser **104** (.01 mf.) and a grid current limiting resistor **105** (100,000 ohms). The junction of condenser **104** and resistor **105** is connected through resistor **106** (100,000 ohms) to the cathode of triode **101**, whereby this triode operates at substantially zero bias. The plate of triode **101** is connected to a +150 v. source through resistor **107** (100,000 ohms) and to bus **108** (+32 v.) through resistor **109** (220,000 ohms). Since this triode has a very high mu, it is cut off during substantially all of each negative half-cycle and draws grid current during substantially all of each positive half-cycle. This signal at the plate is consequently a substantially square waveform alternating between values of +50 v. and +113 v. This signal is applied directly to the grid of triode **102**, which is connected as a cathode follower and hence reproduces the square waveform with substantially no alteration at its cathode terminal. The cathode of triode **102** is connected to ground through resistor **110** (100,000 ohms) and to terminal C_8, which is multiplied to all of the corresponding keyers. Since the output impedance of triode **102** is very low, the shunt capacity of the wiring to the keyers has little effect on the waveform and also this wiring is relatively immune to cross-coupling effects which would otherwise result from inter-conductor capacity.

The first divider consists of a pair of triodes, 111 and 112 (type 12AU7), connected in a scale-of-two counting circuit, and an output triode 113 (½ type 12AU7) connected as a cathode follower. The counting circuit is conventional in having resistors 114 and 115 (100,000 ohms), connected between each plate and the plate supply, resistors 116 and 117 (220,000 ohms) connected between each grid and ground, and resistors 118 and 119 (220,000 ohms) bridged by condensers 120 and 121 (100 mmf.) cross connected between the plates and grids. Ordinarily such counting circuits are driven by feeding suitable pulses into the grid or plate circuits. In the present instance cathode drive is employed. To this end the cathodes are connected to ground through a common biasing resistor 122 (33,000 ohms). The circuit constants are such that the cathode potential is normally +32 v. when the plate supply potential is +150 v. The cathodes are also connected through rectifier 123 (type 1N48 germanium diode) to bus 108, which is normally maintained at a potential of +32 v. by reason of its connection to all of the remaining counters through corresponding rectifiers. Bus 108 is by-passed to ground through condenser 124 (5 mf.) to prevent interference between the counting circuits. The counting circuit is driven by pulses obtained from the output of the distorting amplifier by connecting the cathode of triode 102 through condenser 125 (.001 mf.) and resistor 126 (15,000 ohms) to the cathodes of triodes 111 and 112.

The counting circuit has two stable states of equilibrium, in each of which one of the triodes is cut-off and the other draws grid current. When triode 111 is drawing grid current its grid potential is +33 v. and its plate potential is +50 v. The grid potential of triode 112 is consequently +25 v., which is eight volts negative with respect to the cathode, thereby cutting off this triode. With triode 112 cut-off the open circuit potential at its plate is +122 v. and the open circuit potential at the grid of triode 111 is +66 v., but due to the flow of grid current in triode 111 its grid potential is actually +33 v. and the plate potential of triode 112 is actually +113 v. Condenser 120 hence is charged to 80 v. and condenser 121 is charged to 25 v. Assuming that the cathode of triode 102 is at its lower value of +56 v. at this time, condenser 125 is charged to 23 v. When the cathode of triode 102 swings to its higher value of +113 v. the cathodes of triodes 111 and 112 are momentarily driven to approximately +60 v. The plate current of triode 111 drops sharply, causing its plate voltage to rise and drive the grid of triode 112 positive until it draws grid current. The plate potentials of triode 112 consequently falls and drives the grid of triode 111 negative. At this instant the potential at the grid of triode 112 is slightly greater than +60 v., resulting in a potential of +80 v. at its plate and +85 v. at the plate of triode 111. Due to the 80 v. charge stored in condenser 120 the potential at the grid of triode 111 is 0 v. at this time. The charge on condenser 120 rapidly decreases to 25 v. and that on condenser 121 rapidly decreases to 80 v. At the same time condenser 125 charges to 81 v. through resistor 126, permitting the cathodes of triodes 111 and 112 to return to their normal potential of +32 v.

When the cathode of triode 102 swings to its lower value of +56 v., condenser 125 discharges through resistor 126 and rectifier 123 to its initial value of 23 v. If rectifier 123 is omitted the cathodes of triodes 111 and 112 are driven negative at this time, causing the potential at both plates to rise momentarily. With optimum design this negative pulse does not reverse the state of the counting circuit, but the design tolerances are greatly widened when rectifier 123 is used to eliminate the negative pulse in the cathode circuit. The positive pulse in the plate circuit, which is in the form of a spike, is also eliminated by rectifier 123. Such spikes are very objectionable in a musical instrument, particularly in the succeeding divider stages where numerous spikes may appear in a half-cycle.

When the cathode of triode 102 again swings to its higher value triode 112 is cut-off and triode 111 is driven to the grid current point in a manner similar to that described for the first reversal. This cycle of events is repeated for every two cycles of the output signal of the distorting amplifier. The square wave signal thus produced at the plate of triode 111 is impressed directly on the grid of triode 113, which reproduces this signal at terminal C_7, for distribution to the corresponding keyers. The cathode of triode 113 is also connected to ground through resistor 127 (100,000 ohms) and to the cathodes of triodes 128 and 129 through condenser 130 (.001 mf.) and resistor 131 (15,000 ohms). Each time that the cathode of triode 113 swings from its lower value of +56 v. to its higher value of +115 v. the state of the 2nd divider, comprising triodes 128 and 129, is reversed in the same manner as described for the 1st divider. The square wave signal thus produced at the plate of triode 128 is impressed directly on the grid of triode 132, which reproduces this signal at terminal C_6 for distribution to the corresponding keyers. Succeeding divider stages (not shown) operate in like manner to produce the remaining notes C_1 to C_5. Identical component values are used in every stage. The operation of these dividers is exceptionably stable due to the negligible load placed on the counting circuits by the cathode followers and the elimination of the load that is usually placed on the grid or plate circuits by the driving circuits, and due to the complete elimination of undesired pulses by the rectifiers.

Master oscillators

The master oscillator for all of the "C" notes is shown at the right of Fig. 2. It comprises a first triode 133 (½ type 12AT7) connected as a cathode follower and having a cathode load resistor 134 (10,000 ohms), and a second triode 135 (½ type 12AT7) connected as a cathode driven amplifier and having a plate load resistor 136 (50,000 ohms) and voltage dividing resistors 137 (.5 megohm), 138 (.15 megohm) and 139 (.1 megohm), for applying inverse feedback to the amplifier grid. The latter resistor is variable to permit adjustment of the gain of the amplifier stage over a range of approximately 3 to 4.5. A frequency selective network of the Wien bridge type is connected across the amplifier output. This network includes a condenser 140 (126.5 mmf.) and a resistor 141 (150,000 ohms) in the series arm and a condenser 142 (123.5 mmf.) and a resistor 143 (150,000 ohms) in the parallel arm. For biasing purposes the latter resistor is connected to a voltage divider, consisting of resistors 144 and 145, which is common to all of the oscillators. The voltage divider tap is by-passed to ground by a large condenser 146 (10 mf.), whereby this point is effectively grounded at the oscillator frequencies. The junction of the series and parallel arms is connected to the grid of triode 133, whereby positive feedback is obtained at the operating frequency.

In operation, the gain of the amplifier is gradually increased, by reducing the value of resistor 139, until oscillations commence. The gain is then further increased until the amplitude of the output voltage reaches 15 v. (R. M. S.), which is approximately one-half the maximum obtainable without distortion due to clipping. The frequency of oscillation is determined principally by the values of the components in the frequency selective network. To insure satisfactory frequency stability, all of the resistors used in the oscillator are wound with an alloy wire having a low temperature coefficient and the condensers are the silvered mica type. A trimmer condenser 147 (1 to 5 mmf.) is connected in parallel with condenser 142 to permit fine adjustment of the oscillator frequency. The other eleven master oscillators for the remaining notes of the scale are identical to that shown except for the values of the condensers, such as 140 and 142, in the frequency selective networks. The values of these condensers are increased in inverse proportion to the frequency of the corresponding oscillators.

Due to the high order of frequency stability of the master oscillator, it is impractical to obtain a vibrato effect (frequency modulation) by varying the plate supply voltage or the bias voltages. Instead, a phase shift is introduced into the amplifier, which causes the operating frequency to change to such an extent as to produce a complimentary phase shift in the frequency selective network. The phase shift circuit consists of a pair of non-linear resistors 148 and 149, connected in series between the vibrato generator output terminal 150 and ground, and a condenser 151 (.01 mf.) connected between the junction of resistors 148 and 149 and the cathode of triode 133. The non-linear resistors are preferably the silicon carbide type having values such that the effective resistance between the junction and ground is greater than 1,000 megohms when terminal 150 is at ground potential and less than .1 megohm when the potential at terminal 150 is +120 v. When the vibrato effect is not in use terminal 150 is practically at ground potential. The effective resistance of resistors 148 and 149 is then so high that the phase shift network has a negligible effect on the frequency of the master oscillator. When the vibrato effect is in use the potential at terminal 150 varies, in the manner described hereinafter, thereby varying the effective value of the resistors 148 and 149 and consequently introducing a variable reactance component in the cathode circuit of triode 133. A similar phase shift network is provided for each of the other oscillators, the value of the condenser corresponding to 151 being increased in inverse proportion to the oscillator frequency so as to obtain comparable frequency variations.

Vibrato generator

The vibrato generator, shown at the left of the master oscillator in Fig. 2, consists of a square wave generator and a cathode follower power amplifier, which feeds the vibrato circuits of the twelve master oscillators described in the preceding sections. The square wave generator consists of a pair of triodes 152 and 153 (type 12AU7) connected in a conventional multi-vibrator circuit including plate resistors 154 and 155 (50,000 ohms), grid resistors 156 and 157 (100,000 ohms) and 158 and 159 (200,000 ohms) and cross connected resistors 160 and 161 (100,000 ohms) and condensers 162 and 163 (.1 mf.). Since the operation of multi-vibrators is well known the generator need not be described in detail. Suffice it to say that a square wave signal having a peak to peak amplitude of approximately 100 v. is obtained at the plate of triode 153. The frequency of this signal may be varied from 3 C. P. S. to 12 C. P. S. by means of the tandem variable resistors 158 and 159.

The output of the square wave generator is bridged by a low pass filter consisting of resistors 164 (.3 megohm) and 165 (1 megohm) and condenser 166 (.1 mf.). The signal appearing across condenser 166 is a substantially triangular wave having a peak to peak amplitude of approximately 30 v. (at the mid-frequency setting of the frequency controls 158, 159). By adjustment of the potential dividing resistor 165, any desired fraction of this signal, together with a proportionate direct component, can be impressed on the grid of the cathode follower triode 167 (½ type 12AU7), whereby a corresponding signal is produced at output terminal 150. The degree of vibrato is controlled by adjustment of resistor, or potentiometer, 165. When the slider of this resistor is at the ground end the voltage at the output terminal 150 is near zero and is constant in amplitude. Under these conditions the non-linear resistors, such as 148 and 149, associated with the master oscillators behave effectively as open circuits, whereby the vibrato effect is reduced to zero and furthermore the frequency of the master oscillators is rendered immune to change due to drifting of the constants of the vibrato circuits. With increasing degrees of vibrato the average voltage at terminal 150 increases along with the vibrato signal, thus somewhat decreasing the independence of the master oscillator frequencies. However, when considerable vibrato effect is used the requirements on frequency stability may be relaxed because the constantly shifting frequencies prevent formation of the steady beats normally heard when chords are played. On the other hand, when the vibrato effect is not in use the frequency requirements are most stringent since very small changes in frequency affect the beat frequencies very greatly and produce marked changes in the sounds of sustained chords. The circuit arrangements shown enable a high order of frequency stability to be obtained under these conditions due to the provision of inherently stable master oscillators together with phase shifting circuits which are effectively rendered inoperative to change the oscillator frequencies when the vibrato effect is not in use.

While the present invention has been disclosed in connection with a few preferred embodiments, variations and modifications may be resorted to by those skilled in the art without departing from the principles set forth. Therefore, it is the aim of the appended claims to include all such variations and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. In a musical instrument, a rectangular waveform tone generator, a translating device, a non-linear conducting device connected between said tone generator and said translating device, a source of bias potential for said non-linear conducting device, means for causing said bias potential to vary in a continuous manner, said conducting device being operated by said variation of said bias potential to control the amplitude of tone signals transmitted from the tone generator to the translating device, said rectangular waveform preventing frequency distortion of the tone signals despite the non-linear characteristic of said conducting device.

2. In a musical instrument, a plurality of tone signal sources, a translating device, a glow tube connected between each of said sources and said device, said glow tubes being normally deionized and thus ineffective to transmit tone signals to said device, a keyboard, and biasing means controlled by said keyboard for selectively ionizing said glow tubes to effect transmission of tone signals from the corresponding source to said device.

3. In a musical instrument, a tone signal source, a plurality of load circuits, a glow tube connected between each of said load circuits and said source, said glow tubes being normally deionized and thus ineffective to transmit tone signals to said load circuits, a keyboard, and biasing means controlled by said keyboard for selectively ionizing said glow tubes to effect transmission of tone signals from said source to the corresponding load circuit.

4. In a musical instrument, a plurality of tone signal sources, a load circuit, a tone signal path extending between each of said sources and said load circuit, a gaseous tube serially connected in each of said paths, said tubes being normally deionized to block transmission of tone signals over said paths, and a common means for at times impressing a bias on said tubes to initiate glow discharge therein to enable transmission of tone signals from said sources to said load circuit.

5. In a musical instrument, a tone signal source, a plurality of load circuits, a tone signal path extending between each of said load circuits and said source, a gaseous tube serially connected in each of said paths, said tubes being normally deionized to block transmission of tone signals over said paths, and a common means

for at times impressing a bias on said tubes to initiate glow discharges therein to enable transmission of tone signals from said source to said load circuits.

6. In combination, a signal source, a load circuit, a transmission path extending from said source to said load circuit, a first bilateral glow tube connected in series with said path, a second bilateral glow tube connected in shunt with said path, a fixed voltage source connected across said tubes in series to render them selective to polarity of bias signals applied to their common terminals when referred to the midpoint of the fixed voltage source, and a variable voltage source connected to the common terminals of said tubes operative to reverse the bias polarity thereat to effect selective ionization of said tubes and thereby control transmission of signals over said path.

7. In a musical instrument, a plurality of chromatically ordered tone signal sources, a pair of output circuits, circuit arrangements coupling said sources to said output circuits in such manner that the signal levels in the output circuits vary in opposite senses when the sources are rendered operative successively in chromatic order, a waveform modifying filter having an inherent non-uniform frequency transmission characteristic, and circuit arrangements coupling said pair of output circuits to said filter so as to obtain a desired waveform which is independent of the signal frequency.

8. In a musical instrument, a plurality of chromatically ordered groups of tone signal sources, a pair of output circuits for each of said groups, circuit arrangements coupling the sources to the corresponding pair of output circuits in such manner that the signal levels therein vary in opposite senses when the sources are rendered operative successively in chromatic order, a plurality of wave modifying signal channels having inherent non-uniform frequency transmission characteristics, and circuit arrangements coupling said output circuits to each of said signal channels in pairs so as to obtain desired waveforms which are independent of the signal frequency.

9. In a musical instrument, a plurality of chromatically ordered tone signal sources, a keyer connected to each of said sources, a pair of output circuits, circuit arrangements coupling said keyers to said output circuits in such manner that the signal levels therein vary in opposite senses when the keyers are operated successively in chromatic order, a waveform modifying filter having an inherent non-uniform frequency transmission characteristic, and circuit arrangements coupling said pair of output circuits to said filter so as to obtain a desired waveform which is independent of the signal frequency.

10. In a musical instrument, a plurality of groups of keyers, a tone signal source connected to each of said keyers in chromatic order, a pair of output circuits for each group of keyers, circuit arrangements coupling the keyers to the corresponding pair of output circuits in such a manner that the signal levels therein vary in opposite senses when the keyers are operated successively in chromatic order, a plurality of wave modifying signal channels having different inherent non-uniform frequency transmission characteristics, and circuit arrangements coupling said output circuits to each of said signal channels in pairs so as to obtain desired waveforms which are independent of the signal frequency.

11. In a musical instrument, a plurality of tone signal sources having frequencies corresponding to the notes of the musical scale, a filter network having an output and a series of inputs each providing a predetermined degree of attenuation at a corresponding frequency, and circuit means coupling each of said sources to corresponding ones of said inputs, whereby the tone signals obtained from the output of the filter network are uniform in level and timbre over the compass of the instrument.

12. In a musical instrument, a set of tone generators for producing signals at frequencies corresponding to the notes of the musical scale, a plurality of signal channels, an electronic keyer connected between each of said generators and each of said signal channels, a common biasing means for simultaneously operating a plurality of said keyers, a translating device, and registration controls connecting said signal channels to said translating device.

13. In a musical instrument, a set of tone generators for producing signals at frequencies corresponding to the notes of the musical scale, a plurality of signal channels having different transmission characteristics, an electronic keyer connected between each of said generators and each of said signal channels, a common biasing means for simultaneously operating a plurality of said keyers, a translating device, and registration controls connecting said signal channels to said translating device.

14. In a musical instrument, a set of tone generators for producing signals at frequencies corresponding to the notes of the musical scale, a plurality of transmission paths, an electronic keyer connected between each of said generators and each of said paths, a common biasing means for simultaneously operating a plurality of said keyers, a plurality of signal channels having different transmission characteristics, a translating device connected to the outputs of said signal channels, and registration controls connecting said transmission paths to the inputs of said signal channels.

15. An electrical gating circuit for passing electrical input pulses upon occurrence of an electrical gating signal of at least a predetermined voltage, said circuit comprising: a neon tube having first and second electrodes and responsive to a signal of said predetermined voltage applied across said electrodes for conducting current at a substantially constant voltage drop, said constant voltage drop being less than said predetermined voltage; an electrical resistance element conductively coupled to said first electrode; means for applying the gating signal across the combination of said neon tube and said resistance element; means for applying the input pulses to one of said electrodes, the input pulses applied during the occurrence of a gating signal being passed by said neon tube and appearing as output pulses on the other of said electrodes; and an output circuit conductively coupled to said other electrode for passing the pulses appearing thereon and blocking the gating signal.

16. The gating circuit defined in claim 15 wherein said output circuit comprises a differentiating network.

17. An electrical gating circuit comprising: a source of electrical gating signals, each of said gating signals being of at least a predetermined voltage; a gaseous discharge device having first and second electrodes and responsive to a signal of said predetermined voltage applied across said electrodes for passing current at a substantially constant voltage drop; an electrical resistive element having first and second ends; means conductively coupling said first end to said first electrode; means for applying the gating signals from the gating signal source between said second end of said element and said second electrode; a pulse source; and means for applying the pulses from said pulse source to one of the electrodes, the pulses produced by said pulse source during the time intervals said gaseous discharge device is conducting appearing on the other electrode of said gaseous discharge device as output pulses.

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