ELECTRICAL MUSICAL INSTRUMENT

Filed April 2, 1938 4 Sheets-Sheet 1

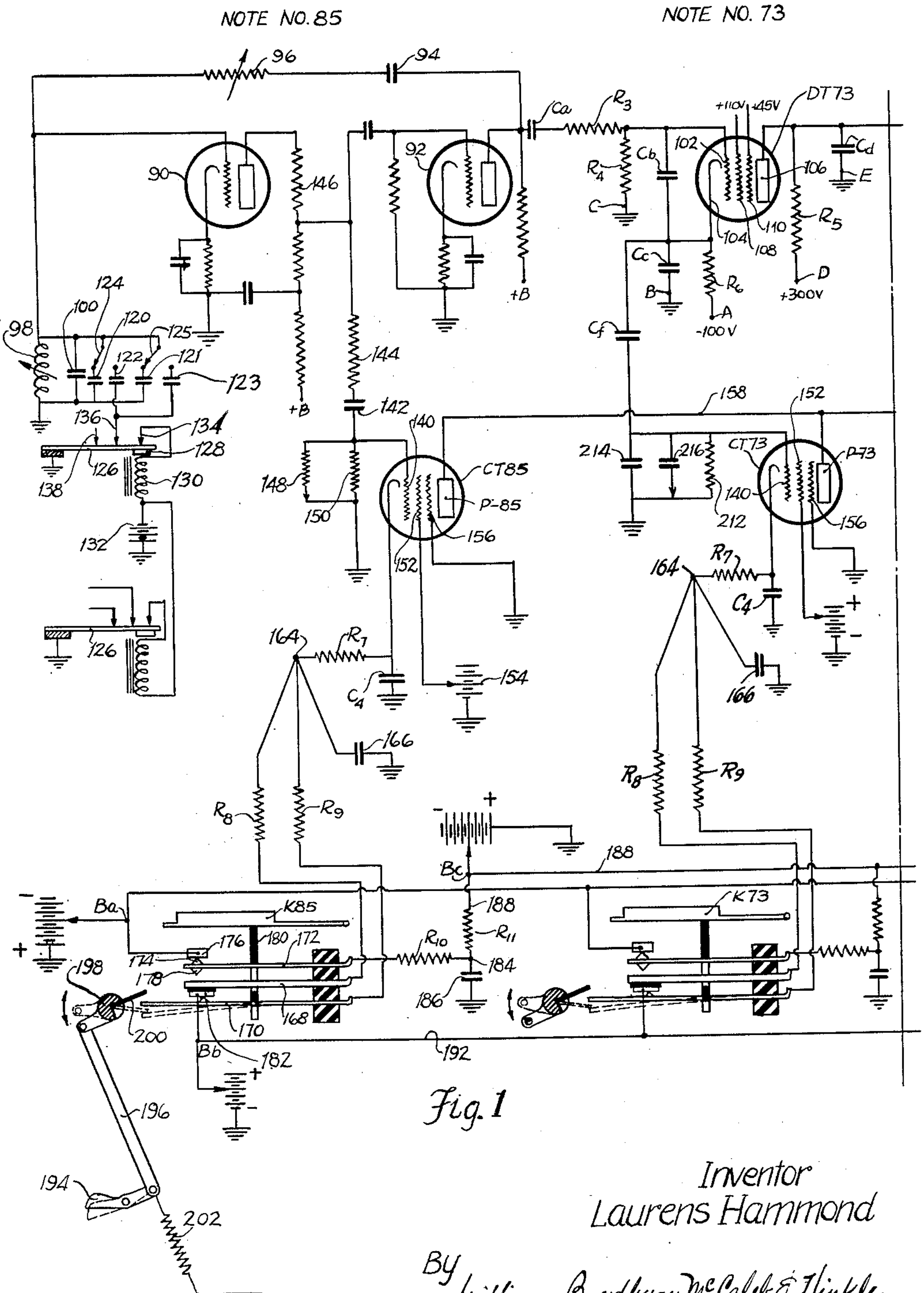

Fig. 1

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Aug. 9, 1938.

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2,126,682

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4 Sheets-Sheet 2

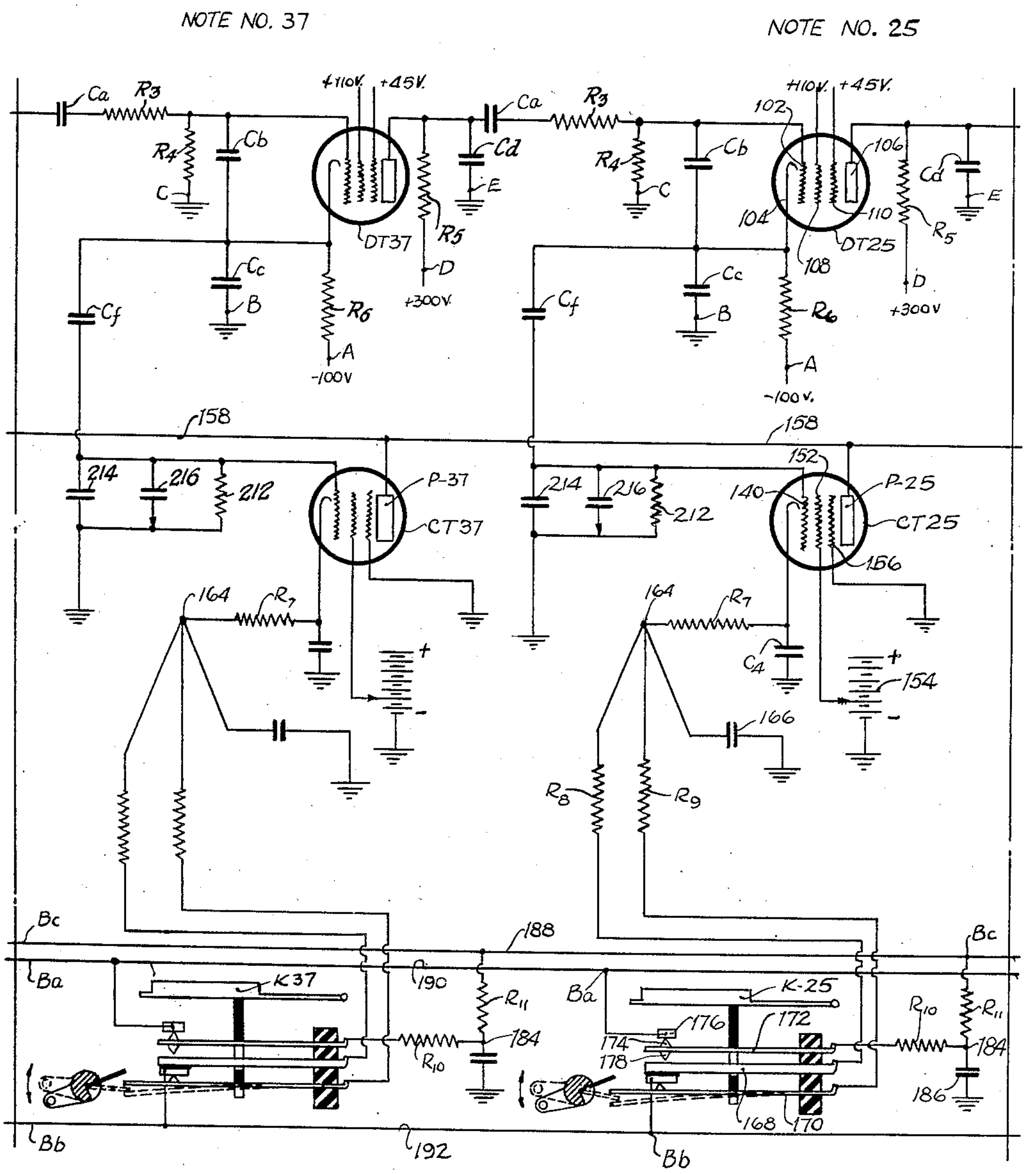

Fig. 1a

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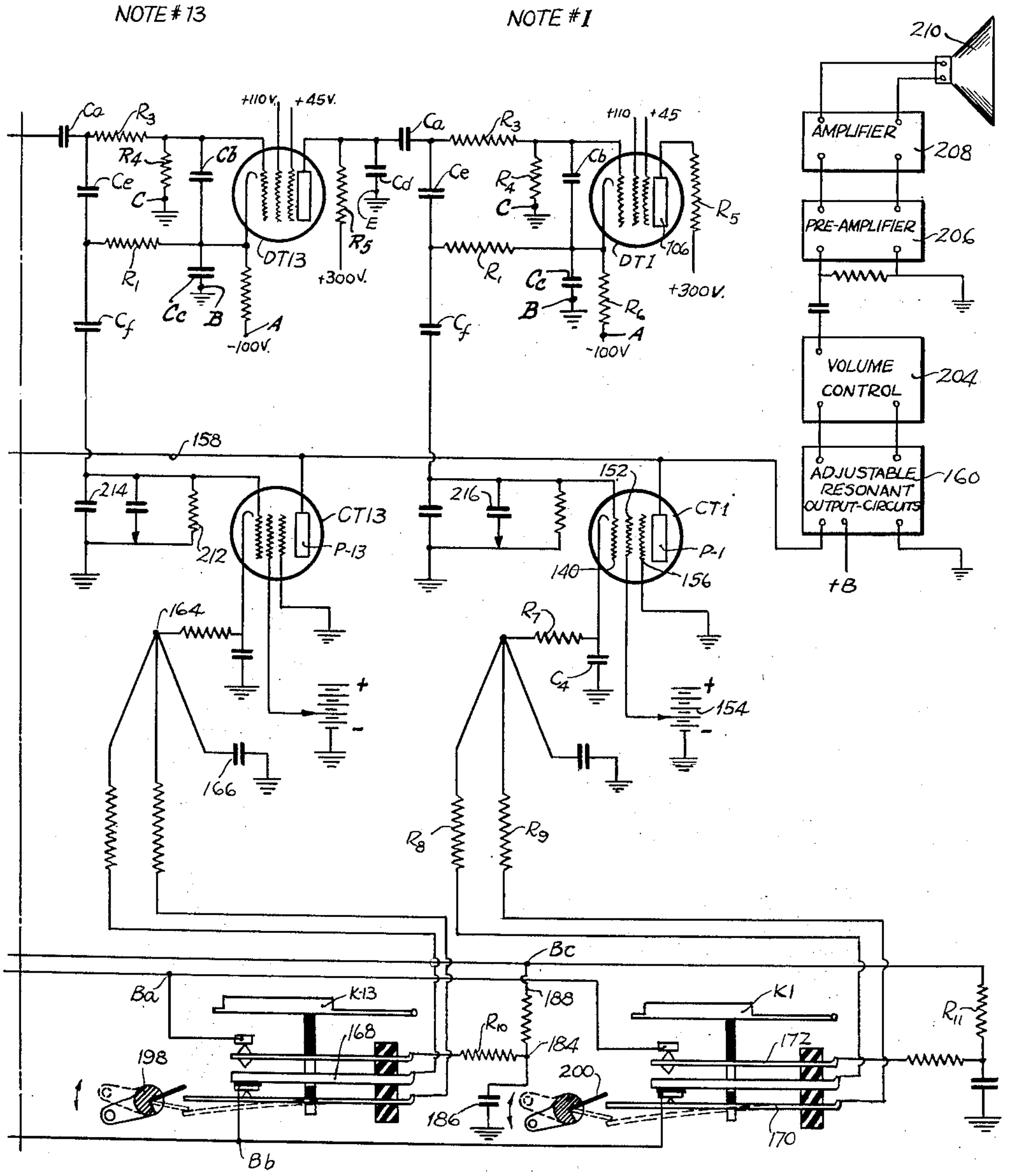

Fig. 1b

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ELECTRICAL MUSICAL INSTRUMENT

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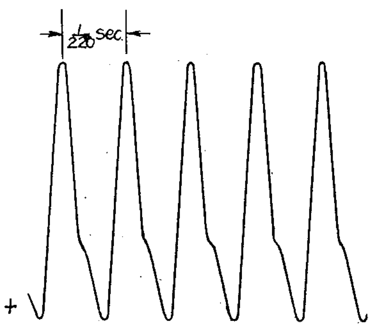

Fig. 2

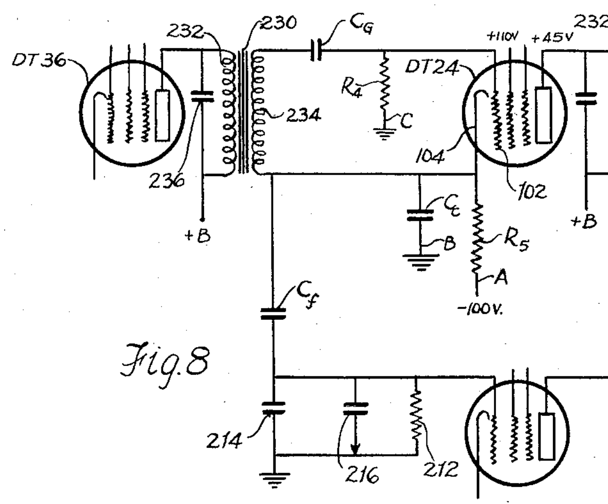

Fig. 8

Fig. 3

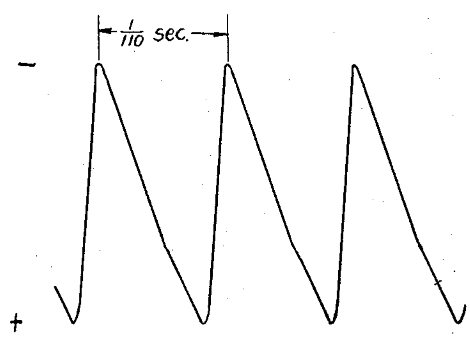

Fig. 6

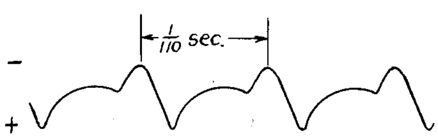

Fig. 4

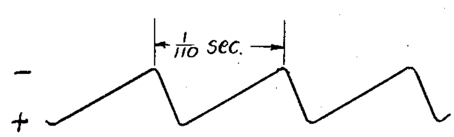

Fig. 7

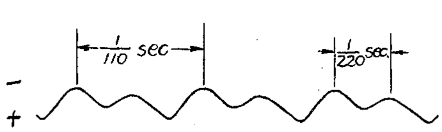

Fig. 5

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UNITED STATES PATENT OFFICE

2,126,682

ELECTRICAL MUSICAL INSTRUMENT

Laurens Hammond, Chicago, Ill.

Application April 2, 1938, Serial No. 199,614

21 Claims. (Cl. 84—1)

My invention relates generally to electrical musical instruments and more particularly to improved instruments of this character which are playable by means of keys.,

It is a primary object of my invention to provide an improved electrical musical instrument playable by keys, and which is capable of producing full rich tones and other novel and interesting musical effects.

A further object is to provide an improved method and means for supplying electrical pulsations of the frequencies of the notes of the musical scale.

A further object is to provide an improved electrical musical instrument in which the means for supplying the electrical pulsations for notes an octave apart are interconnected in cascade so as to maintain exactly their octave intervals.

A further object is to provide an improved electrical musical instrument capable of sounding notes in a plurality of octaves in which the electrical means for supplying corresponding notes of different octaves have their frequency controlled by a master oscillator.

A further object is to provide an improved electrical musical instrument having means for generating electrical pulsations of the frequencies of the musical scale, and having key controlled vacuum tube means for controlling the sounding of a note and the intensity envelope thereof.

A further object is to provide an improved system for supplying electrical impulses of the fundamental frequencies of the musical scale, in which the pulsations are of such wave form as to comprise a long series of higher harmonics.

A further object is to provide an improved electrical musical instrument in which the tone quality may readily be varied.

A further object is to provide an instrument of the character described in which the frequency of the electrical pulsations provided for corresponding notes in successive octaves may be varied periodically so as to produce a vibrato effect.

A further object is to provide an improved electrical musical instrument in which there are means for sustaining a note after the release of the key controlling the sounding of such note.

A further object is to provide an improved electrical musical instrument in which the frequencies of various notes may be varied periodically at different rates so that the notes will have slightly different vibrato rates.

A further object is to provide an improved frequency divider system for supplying electrical impulses of the frequencies of the notes of the musical scale.

A further object is to provide an electrical musical instrument with an improved frequency divider system having a plurality of cascaded stages, in which each stage is non-oscillatory and has its frequency controlled by the stage providing frequencies twice as great as that of the controlled stage.

A further object is to provide an improved frequency divider system for an electrical musical instrument in which the stages are in musical octave relationship, and each stage has its frequency stabilized by the next higher stage.

Other objects will appear from the following description, reference being had to the accompanying drawings in which:

Figs. 1, 1*a* and 1*b* together constitute a wiring diagram of a representative portion of the complete instrument;

Figs. 2 to 7 inclusive are diagrams showing the electrical wave forms present in various parts of the circuit; and

Fig. 8 is a diagram showing a modified form of divider circuit.

General description

To make the detailed description of my invention more readily understandable, I shall briefly describe the general construction of the instrument.

The instrument will have a keyboard which may be of the usual 88 note type found in the standard piano, but may be made with a lesser number of keys, for example, 61 keys, embracing the 5 octaves customary in the manuals of pipe and electric organs. For the sake of simplicity, however, the notes are designated by their piano note numbers, that is, the lowest A of the piano being designated as note No. **1**, and the highest note, C, being designated as note No. **88**.

The electrical impulses for the highest octave notes, (notes Nos. **77** to **88** inclusive), are preferably provided by vacuum tube oscillators, while the electrical pulsations for the remaining notes are provided by successive stages of a cascaded frequency divider system. Thus, for example, the notes Nos. **74**, **61**, **49**, **37**, **25**, **13** and **1**, being the A's, will have their frequencies supplied by successive stages of a cascaded frequency divider circuit, the frequencies of which are determined by an oscillator, generating the frequency of note No. **85**. Similarly, each of the remaining series of corresponding notes will have their frequencies supplied by a separate cascaded frequency divider system in which the frequencies are determined by an oscillator of the highest frequency note of the series.

The instrument may have the usual amplifier and speaker in its output circuit, and the transmission of the electrical impulses from the oscillators and frequency divider circuits to the output circuit is controlled by a vacuum tube for each note. The electrical impulses from the oscillators and the various stages of the frequency divider circuits will be continuously impressed upon these vacuum tubes, hereinafter termed the control tubes, but will not be transmitted to the output circuit except when the potential upon one of the electrodes of the control tube is changed to a value which will cause the control tube to become operative to transmit a signal. This change in value of the potential upon one of the electrodes of the control tube is caused by the depression of one of the keys of the keyboard, and the key switching system for changing the potential on one of the electrodes of the control tube is such that the attack and decay characteristics of the note may be predetermined.

It may be seen that the instrument of my invention comprises generally: (*a*) A frequency generating and divider system; (*b*) A control tube system; (*c*) A key operated switching system; and (*d*) An output circuit. In addition to these features, the instrument may include a vibrato producing apparatus, various tone quality controls, sustaining pedal, volume controls, and incidental controls.

Frequency divider system

The frequency divider system consists essentially of a source of high frequency current for which I prefer to use a vacuum tube oscillator, and a series of vacuum tubes connected together in cascade fashion. Each tube receives a signal from the preceding tube in the cascaded series, except for the tube operating at the highest frequency, which receives a signal from the oscillator. The output of each tube contains a fundamental frequency of one half of the input frequency together with a harmonic series containing the various harmonics of this fundamental. The circuits connected with the cascade of tubes do not contain any inductances in the form in which I prefer to build the apparatus. The tubes themselves do not function as oscillators, and if the input signal be removed, the output signal will disappear and only direct current will flow through the various branches of the tube circuits.

I am aware that other systems have been devised whereby lower frequencies may be obtained from apparatus into which higher frequencies are supplied. Such systems in general are referred to as "frequency divider systems", and one such system has been described by me in my copending application Serial No. 199,612, filed April 2, 1938. All such systems, as far as I am aware, contain oscillators, the frequencies of which are to some extent controlled or "locked" to a sub-multiple of a higher frequency which is supplied to the system. Circuits of this kind have been designed for relaxation oscillators using gas content tubes, or with multi-vibrators or other oscillators in which a feed back from the plate circuit to the grid circuit is employed. All such divider systems may be thought of as independent oscillators which are adapted to oscillate at a frequency in the vicinity of the desired frequency, with provision for locking the frequency to a submultiple of a higher frequency. The divider system of my invention differs in principle from such previous systems in that no oscillators are employed. Each tube operates as a non-linear amplifier. As the principle of operation is new in vacuum tube circuits, as far as I am aware, it is necessary to describe the operation in some detail.

A diagram of an operating circuit is shown in Figs. 1, 1*a* and 1*b*. In these figures, the circuits for notes **85**, **73**, **37**, **25**, **13** and **1** are illustrated. The stages for the intermediate notes **61**, and **49**, being similar to the stage for the note **37** in every respect except for the values of the condensers and resistors used, have been omitted.

The means for generating the electrical impulses for note **85** is illustrated as comprising a pair of triodes **90** and **92** which are herein illustrated as separate tubes, but in actual practice would ordinarily be combined in the form of a twin triode. The plate of tube **92** is connected through a condenser **94** and a variable resistance **96** with the grid of the tube **90** to provide the feed back, while the frequency of oscillation is controlled by a resonant circuit coupled to the grid of tube **90** and comprising a special high efficiency construction variable inductance **98**, and a condenser **100**. The frequency of resonance of the oscillatory circuit including the variable inductance **98** and the condenser **100** may be periodically varied by a vibrato mechanism, shown as associated with this circuit and which will hereinafter be described in detail. The oscillator for the note **85** provides a signal of a frequency of 3520 cycles per second, which is transmitted through a condenser C*a* and a resistor R_3 to a control grid **102** of the divider tube DT**73** for the note **73**.

The divider tubes I prefer to use are pentodes with sharp cutoff characteristics. A tube of the type known as **6J7** is satisfactory. It is possible to operate the circuit with triodes, but I prefer to use pentodes for reasons which will hereinafter appear. Except for the values of the constants used, the series of tubes are interconnected in a manner greatly resembling the conventional resistance-coupled amplifier with self biased tubes, except that two additional condensers will be found in each stage, one C*b*, connecting grid to cathode and the other, C*d*, connecting plate to grounded terminal E.

The cathode **104** of tube DT**73** is connected through a high resistance R_6 with a terminal A connected to source a negative potential indicated as being of −100 volts, and is connected to grounded terminal B through C*c*. The grid of the tube DT**73** is connected to grounded terminal C through a resistor R_4, while the plate **106** of the tube DT**73** is connected to terminal D of the B-supply through a resistor R_5, the B-supply being indicated as of +300 volts. The screen **108** of the tube DT**73** is connected to a positive potential source indicated as being of +110 volts, while the suppressor **110** is connected to a potential of +45 volts.

The signal from the tube DT**73** is derived from voltage fluctuations of the cathode **104** through a condenser C*f* which is connected between the cathode **104** and the grid **140** of a control tube CT**73** which will be described hereinafter. The plate **106** of the tube DT**73** is connected to the grid of the divider tube for the note **61** through a condenser C*a* and resistance R_3 (not shown) in the same manner that the oscillator for note **85** is connected to the divider tube for the note **73**. Similarly, the plate circuit of divider tube for note **61** is connected to the grid circuit of divider tube for note 49, the plate circuit of the latter tube being connected to the grid of the divider tube DT37 (Fig. 1*a*); the plate circuit of the tube DT37 is connected to the grid circuit for the tube DT25 for note 25; and the latter connected in cascaded series to the tubes DT13 and DT1 in the manner shown in Fig. 1*b*. The grid circuit for the tube DT13 is similar to that for the tube DT73 except that an additional condenser *Ce* has one terminal connected between the resistance R_3 and the condenser *Ca*, while its other terminal is connected to the cathode of the tube DT13 through a resistance R_1. The plate circuit of tube DT13 is connected to the grid circuit of tube DT1 in a manner similar to that employed for the tube DT13.

Assuming that the oscillator and the various divider stages are to supply the frequencies necessary for the A's of the musical scale, (A=440), then the oscillator will be designed to oscillate at a frequency of 3520 cycles. In the plate circuit of the first divider tube DT73, the frequency 1760 will develop. Similarly, the plate circuit of the following divider tube DT61 will contain the frequency 880 and so on down through the various stages—the frequencies 440, 220, 110, 55 and 27½ appearing if the instrument contains that many stages.

Unlike an ordinary linear amplifier, the output from each tube will be substantially the same, independent of the amplitude of the input. Thus, the input amplitude may be changed in the ratio of about 2:1 without any appreciable change in amplitude appearing in any succeeding stage. Similarly, the shapes of the output waves from the tubes will be substantially identical and if observed on an oscillograph will be of a characteristic saw-tooth shape except that the steep side of the wave will not approach the vertical. The shapes of the waves appearing in various parts of the circuit are illustrated in Figs. 2 to 7. The reason for the apparently strange operation of this tube may be explained somewhat as follows:

We will consider one particular tube such as tube DT25, Fig. 1*a*, which supplies the fundamental frequency for the operation of note 25, the fundamental of which is 110 cycles per second. This tube receives a signal from the plate circuit of tube DT37 which is supplying the fundamental for note 37, which is one octave higher. The cathode of tube DT25 is connected to ground through the condenser *Cc*, which may have a value of .09 mfd. The cathode 104 is connected to the grid 102 by means of the condenser *Cb* which may have a value of .011 mfd. The grid is connected to ground by means of the grid leak R_4 of 400,000 ohms. The resistor R_6 which connects the cathode to a source of direct current potential of 100 volts more negative than ground, may have a value of 500,000 ohms. The tube is thus self biased and the cathode will float as a direct current potential with respect to ground such that the voltage between cathode and grid will be the cutoff voltage of the tube. For the particular tube used, this will be about 6 volts.

It therefore follows that the direct current through the tube is practically fixed, and is almost entirely independent of the input signal. The average cathode current will therefore be that current which will give rise to a voltage drop of 106 volts across the 500,000 ohm resistor R_6 supplying the cathode, or will have a value of .212 milliamperes, which, it will be noted, is an exceedingly small average plate current for tubes of this type.

The tube may therefore be thought of as operating at a point exceedingly close to cutoff where its operation is totally non-linear. That is to say, an exceedingly small positive excursion of grid voltage with respect to cathode voltage will produce a sudden surge of current of large value, whereas any excursion in the negative direction can have no effect except to cut off the small amount of steady current.

Tube DT37 is functioning to put out a saw-tooth wave which is shown in Fig. 2. This is the input signal for tube DT25 and is fed through the blocking condenser *Ca* and the resistor R_3 of 1,0000,000 ohms to the grid of tube DT25. If tube DT25 were not functioning because the heater was not hot, for instance, then the signal which would develop between the grid of tube DT25 and ground would resemble the wave shown in Fig. 3. The waves of Figs. 2 to 7 inclusive are shown to the same scale, and it is evident that the signal at the grid is of much smaller amplitude and of somewhat different shape than the wave of voltage between plate of tube DT37 and ground. This is of course due to the fact that the signal comes through the series resistor R_3 of 1,000,000 ohms, whereas the impedance from grid to ground of tube DT25 is much lower than this for any of the frequencies involved. It will be noted that the wave of Fig. 3 has positive excursions of equal amplitude occurring 220 times per second and at the most positive part of the wave, which is down, is sharp by comparison with the most negative excursion which is of rounded form.

If now the heater of tube DT25 be energized so that the tube may operate, one may wonder why this tube will not amplify the wave of Fig. 3 and give rise to a wave of the same frequency in the plate circuit. This, however, is not the case, for as soon as the tube begins to operate in a stable manner the wave of Fig. 3 will change in appearance and become the wave illustrated in Fig. 4. Similarly, a wave of voltage will develop between the grid and cathode of tube DT25, which is illustrated in Fig. 5. It will be noted that this wave has a positive excursion 220 times a second, but that every other positive excursion is greater in amplitude, so that the more positive excursions occur 110 times a second. Owing to the non-linear operation of the tube, only the excursions at the rate of 110 times a second are effective in producing sudden impulses of current through tube DT25, and this plate current gives rise to a plate voltage between the plate and ground which is illustrated in Fig. 6. It will be noted that the wave of Fig. 6 is of the same amplitude and of the same general shape as the wave of Fig. 2, except that every transaction is half as fast. The voltage of the wave of Fig. 6 is of course available to repeat the transaction in the next succeeding stage.

A wave of voltage develops between the cathode of tube DT25 and ground, which wave is illustrated in Fig. 7, the fundamental frequency of which is also 110 cycles per second. It is this wave of voltage which is used to supply the signal to the control tube CT25 associated with this divider tube.

A rigorous mathematical treatment of the frequency division property of this circuit is exceedingly complicated because of the non-linear operation of the tube. The operation may be understood in a general way, however, as follows:

The average value of the cathode current is independent of the signal, and the slightest positive excursion of grid voltage with respect to cathode voltage will produce a temporary but short flow of plate current. Assume that such flow of plate current is started: In that case, the potential of the cathode will move rapidly in the positive direction with respect to ground. The condenser Cb connecting the cathode to grid exhibits a low impedance to high frequency and the potential of the grid will be carried in the positive direction along with the potential of the cathode, so that the relative potential between cathode and grid cannot be affected quickly by the positive excursion of the cathode.

The rapid flow of cathode current cannot continue for long, however, (because the condenser Cc becomes discharged) before the tube is cut off. When this occurs, the cathode starts to drift in the negative direction at a rate which is dependent on the flow of direct current through the 500,000 ohm resistor R_6, which flow of current changes the potential across the condenser Cc. The voltage of the grid with respect to ground likewise starts to move in a negative direction, but in this case, the rate is faster because of the value of the grid resistor R_4 of 400,000 ohms relative to the effective capacity of the condensers connecting the grid to ground. Thus, while the potentials of both cathode and grid are drifting in the negative direction, the tube being cut off, the grid is going negative faster than the cathode can go negative.

After a period of time somewhat less than 1/220th of a second later, the grid again receives a positive impulse from tube DT37. This positive excursion has no effect, however, because the grid is at a potential sufficiently negative with respect to the cathode, that the tube is still cut off despite this positive excursion of grid potential. After the elapse of a further period of time of 1/220th of a second, the potential of the cathode, which is still drifting in the negative direction, has so reduced the potential difference between grid and cathode that a positive excursion of grid potential is sufficient to cause another impulse of plate current through the tube. By this process, every other positive impulse on the grid produces an effect, whereas the other impulses do not.

Vibrato means

In the tones of many musical instruments, the effect of vibrato is a very well known and pleasing characteristic. This is especially true of the tones of the violin and similar string instruments. A vibrato effect may be obtained by periodically shifting the frequency of a tone through a small frequency range, the periodicity being preferably in the order of seven per second.

In the instrument disclosed herein, the vibrato effect is obtained solely by changing the tuning of the oscillators for notes Nos. 77 to 88 inclusive, this shift in frequency of these oscillators being reflected through the cascade divider tube circuits so that the frequencies of all of the notes of the instrument will be shifted at the vibrato frequency rate. The vibrato effect is more pleasing to the average listener if it is sensed as a richness and fullness of the tone produced, rather than as a definite pulsation. In order to obtain this desired result, I have provided means whereby the periodicity of the vibrato for different oscillators will be slightly different and whereby the phase relationships of the vibrato frequencies will be constantly changing.

The means for accomplishing this result is shown in Fig. 1 wherein four condensers 120, 121, 122 and 123 are shown as being capable of being connected in parallel with the condenser 100 by means of selectively operable switches 124, 125. The switches 124 and 125 are normally in the positions shown in Fig. 1, thus connecting the condensers 120 and 121 respectively in parallel with the condenser 100. Each of the oscillators Nos. 77 to 88 inclusive will be provided with similar condensers 120 to 123 and switches 124 and 125. The switches 124 and 125 of the various oscillators are preferably mechanically interconnected respectively for simultaneous operation.

In the complete instrument there will be provided six vibratory reeds 126, of which two are illustrated in Fig. 1. Each reed carries a soft iron weight 128, which is adapted to be attracted by an electromagnet 130 which is energized by a battery 132 when the free end of the reed is in its uppermost position completing a circuit with contact 134. Condensers 122 and 123 are connected to a contact 136 which is closed upon the upward swing of the free end of the reed 126, thus connecting these condensers to ground. A contact 138 is provided for connection to condensers corresponding to condensers 122, 123, but associated with a different oscillator such, for example, as the oscillator for note No. 79.

Assuming that the switches 124 and 125 have been shifted to connect with the condensers 122 and 123 respectively, the alternate making and breaking of the circuit between the contact 136 and the vibrating reed 126 will change the tuning of the resonant circuit at the vibrator frequency rate determined by the frequency of vibration of the reed 126, and this change will cause the frequency of the oscillator to shift between a pitch slightly below and a pitch slightly above the normal frequency of oscillation. This is due to the fact that the values of the condensers 122, 123 are so chosen with respect to the values of the condensers 120 and 121 that the resonant frequency is decreased when either or both condensers 122 and 123 are connected in the circuit, as compared with the resonant frequency when either or both condensers 120 and 121 are connected in the circuit. Thus, with condensers 122, 123 in circuit, when the circuit is broken upon the downward swing of the reed 126, the resonant frequency of the mesh will increase slightly above the frequency of resonance when the condensers 120 and 121 are connected in the circuit. The average frequency of the oscillator will therefore be the same irrespective of the positions of the switches 124, 125.

The values of the condensers 120 to 123 are preferably so chosen that upon shifting the switch 124 to the condenser 122, the range of vibrato frequency shift will be relatively slight, whereas when the switch 125 is shifted to the condenser 123, a greater range of vibrator frequency shift will be obtained. When both switches 124 and 125 are operated to connect the condensers 122 and 123 respectively in circuit, the range of vibrato frequency shift will be still greater. In this way it is possible to provide three different degrees of vibrato.

Since the frequency supplied by each of the various divider tubes is determined solely by the frequency of oscillation of the oscillators for the notes Nos. 77 to 88 inclusive, it will be apparent that if these oscillators are properly tuned, the complete instrument will be in tune. Thus, by adjusting the variable inductances 98 of the twelve oscillators, the whole instrument may be tuned. The variable inductances 98 are preferably of special construction which will permit fine adjustment. Since only twelve frequencies need be adjusted, it will be possible for even a relatively inexperienced person to tune the instrument with a reasonable degree of accuracy by making the adjustments of the oscillators in a predetermined sequence.

Control tubes

As previously stated, a control tube is provided for each note of the instrument. The control tube is preferably a pentode having sharp cutoff characteristics, a type such as 6C6 being satisfactory. The control tube CT85 for the oscillator for note No. 85 has its grid 140 connected to the plate of the triode 90 through a condenser 142 and resistors 144 and 146 as shown in Fig. 1. The signal thus impressed upon the grid 140 of tube CT85 may have its amplitude altered by selectively connecting a resistance 148 in parallel with a resistance 150, which is grounded.

The screen grid 152 of the control tube CT85 is preferably connected to a fixed point of direct current potential represented by battery 154, while the suppressor grid 156 is preferably connected to ground. The plate P—85 is connected in parallel with the plates P—73, P—37, etc., through a conductor 158 to the adjustable resonant output circuit 160 (represented as a block in the diagram Fig. 1*b*), to which the positive B supply potential is likewise connected, so that the B supply potential is impressed upon the conductor 158 through a suitable network. It will be understood that groups of the plates of the control tubes may be connected to different adjustable resonant circuits, in the manner, for example, as is more fully disclosed in my copending application Serial No. 199,612, filed April 2, 1938. The cathode 162 of the control tube CT85 is connected to ground through a condenser C_4 and is supplied with plate current through a resistance R_7. It will thus be apparent that the signal output of the tube will depend upon the current flow through the resistance R_7 as slightly modified by the unimportant action of the low value condenser C_4. The input signal impressed upon the grid 140 may be considered as a means for "chopping off" the plate current, and the grid bias is such, that plate current will flow only during the positive peak portion of the input signal wave. Since the input signal is of saw-tooth wave form, the resulting plate current wave from the control tube CT85 will be in the form of a series of steep peaks separated by intervals in which there is no current flow. Such wave may be analyzed into a fundamental and a long series of harmonics in which the harmonics decrease progressively in amplitude, as is more fully described in my aforesaid copending application, Serial No. 199,612.

Key operated switches

The rate at which current will flow through the resistance R_7, and hence the amplitude of the output signal of the control tube CT85, is determined in main part by the potential of the terminal 164. The key operated switches and associated controls are provided for determining the potential impressed upon this terminal 164.

The terminal 164 is connected to ground through a condenser 166. The terminal 164 is likewise connected through a resistance R_9 with a flexible switch arm 170. A flexible switch arm 172 has a contact 174 which, when the key K85 is in its upper position, engages a bus bar 176 common to all, or to a group of keys, and has a contact 178 adapted to make contact with the rigid switch arm 168 when the key is depressed. The flexible resilient switch arm 172 is adapted to be depressed by an actuator 180 of insulating material which is engaged by the manual key K85. The actuator 180 is also adapted to flex the switch arm 170 downwardly upon initial downward movement of the key, thereby to break its contact with a bus bar 182. The actuator 180 is so conformed that the contact between the switch arm 170 and bus bar 182 is broken before the contact 178 makes contact with the rigid switch arm 168.

The flexible switch arm 172 is connected through a resistance R_{10} with a terminal 184, which latter terminal is connected to ground through condenser 186, and to a conductor 188 through a resistance R_{11}. The conductor 188 connects to a terminal B*c*, which is connected to a source of adjustable direct current potential, illustrated as a battery. The bus bar 176 is connected to a conductor 190 which leads to a terminal B*a* connected to an adjustable source of direct current potential illustrated as a battery. Similarly, the bus bar 182 is connected to a conductor 192 which leads to a terminal B*b* which is likewise connected to an adjustable source of direct current potential, illustrated as a battery for the sake of clearness.

A sustaining pedal 194 is diagrammatically illustrated as being connected by a link 196 with a pivotally mounted shaft 198, which carries an insulating strip 200 overlying the ends of switch fingers 170. When the sustaining pedal is depressed, the shaft 198 pivots clockwise, and the insulating strip 200 thereupon engages the free ends of the flexible switch arms 170, and flexes them downwardly to keep open the circuits to the bus bar 182, as shown in dotted lines in Fig. 1*a*. When the sustaining pedal 194 is released, a resilient means illustrated as a spring 202, returns the pedal 194 and shaft 198 to their normal positions, as illustrated as full lines in the drawings. If desired, the shaft 198 may be made in two sections, one for the bass register keys and the other for the treble register keys, and separately and jointly operable pedals provided for the shaft sections.

The output circuits of the control tubes are, as previously stated, connected through a conductor 158 with adjustable resonant output circuits 160 and through a volume control device 204, which may be operated and suitably controlled by an expression pedal, the volume control device being suitably connected through a preamplifier 206, and a power amplifier 208 to a loud speaker 210. A suitable form of volume control device is disclosed in my co-pending application, Serial No. 91,284, filed July 18, 1936.

The signals from the divider tubes DT73, DT37, etc., are, as previously stated, derived from the fluctuating cathode voltage through condensers C*f*. This signal is impressed upon the grid 140 of the associated control tube CT73, CT37, etc., the grid being connected to ground through a resistance 212 which is shunted by condenser 214, and may be shunted by an additional condenser 216 upon closure of a switch, so as to render less sharp the shape of the positive peak of the signal wave. The switch circuits for the control tubes

CT73, CT37, etc., may be identical with those previously described with reference to the control tube CT85, and similar reference characters have therefore been applied to the corresponding elements of these circuits. The values of the various resistors and condensers used in these circuits may, however, be different so as to obtain different amplitudes and rates of attack and decay for the notes of different pitch.

Operation

The operation of the oscillators and the divider tubes associated therewith, has been described above, it being understood that each of the oscillators and the divider tube circuits is adapted to impress a saw-tooth wave form signal upon the grid of its associated control tube. While the potentials of the grids of the control tubes are thus continuously varying in accordance with the signals impressed thereon, the control tubes do not function to transmit these potential fluctuations to their output circuits unless the cathodes of these control tubes are supplied with plate current through their associated resistors R_7.

The adjustable potential source B*b* is normally adjusted, after other adjustments have been made, to a potential just above that at which any one of the control tubes will begin to conduct plate current. That is, the potential difference between the grids and cathodes of the control tubes is made slightly less than that necessary for cutoff. Thus, no current will normally flow through the resistors R_9 to the terminals 164.

To obtain a percussive note similar to that of the standard piano, the potential of the terminal B*a* is adjusted to be at a value in the order of —200 volts with respect to ground, and the potential of the terminal Bc adjusted to ground potential. Under these circumstances, the condenser 186 will be charged to —200 volts, so that upon depression of the key K85, for example, the condenser 186 will be connected through resistor R_{10}, flexible switch arm 172, contact 178, rigid switch arm 168 and resistance R_8 with the terminal 164. Thus, the condenser 166 will be gradually charged, and the potential of the terminal 164 gradually increased negatively, so that the plate current through the control tube will gradually increase, and the resultant note will have a gradual attack. That is, the note will not immediately sound at its maximum intensity, but will build up gradually to its full intensity. After the note has attained its maximum intensity it will commence decaying gradually, due to the fact that the condenser 186 is discharging through the resistance R_{11} as well as through the circuit which includes terminal 164. However, the note will not decay entirely, since the potential of the terminal 184 will rise to ground potential as determined by the potential source Bc which is connected through the resistances R_{11} and R_{10}, the key switch and resistance R_8 to the terminal 164. During the interval that the key is held depressed, the switch arm 170 is held away from contact with the bus bar 182 which is at cutoff potential. As soon, however, as the key is released, switch arm 170 will flex upwardly and connect the terminal 164 to the cutoff potential source B*b* through the resistor R_9. The resistor R_9 will be of such value that the decay of the note will be rapid, but not too abrupt.

If it is desired to sustain the note after the key has been released, the player will depress the sustaining pedal 194 which will swing the insulating strip 200 clockwise and bend all of the flexible switch arms 170 downwardly (as shown in dotted lines in Fig. 1*a*), so that all of the notes which are sounding when the sustaining pedal is depressed, will decay logarithmically to a very low intensity level. Likewise, the depression of any key during the time that the sustaining pedal is depressed, will result in the very gradual decay of the note associated with that key.

When it is desired to have the instrument sound like an organ, the potential of the terminal B*a* may be adjusted to a value such as —100 volts, and the terminal Bc adjusted to the same potential, while the potential B*b* is maintained at safe cutoff potential. Under these circumstances, the notes will commence sounding with a gradual attack, due to the resistances R_{10} and R_8 and the condenser 166, but the potential of the condenser 186 will be maintained at the value of —100 volts through the resistor R_{11}. As a result, the note having attained its maximum intensity as represented by the potential of —100 volts upon the terminal 164, it will continue at this maximum intensity until the key is released, whereupon the note will decay gradually because of the gradual decrease of the potential on the terminal 164, due to the leakage of the charge of the condenser 166, through the resistor R_9, switch arm 170 and conductor 192 to the cutoff potential source B*b*, as well as because of the discharge of the condenser 166 through the plate circuit of the control tube.

When it is desired to produce the effect of a slow attack string instrument, the potential of the terminal B*a* is adjusted to ground potential, the terminal Bc adjusted to a low negative potential such as —200 volts, and the terminal B*b* adjusted to safe cutoff potential. Under these circumstances, the condenser 186 is initially discharged because the terminal 184 is maintained substantially at ground potential through the resistance R_{10}, switch arm 172, contact 174 and bus bar 176, which latter is connected to the conductor 190 leading to the terminal B*a* at ground potential. Upon depression of the key, this circuit connecting the terminal 184 to ground is of course opened, and current may therefore flow through the conductor 188 (at —200 volts), to charge the condenser 186 and to flow through the resistance R_{10}, switch arm 172, contact 178, rigid switch arm 168 and resistor R_8 from the terminal 164. However, due to the fact that the resistance of resistor R_{11} is high, the condensers 186 and 166 will be charged gradually, and the attack of the note will therefore be very slow. However, by holding the key depressed for an appreciable length of time, the potential of the terminal 164 may be gradually lowered to a potential of —200 volts, and the intensity of the note thus raised to a high value. Thus, the player has at his command the ability to accentuate certain notes of the score being played by holding certain keys depressed for longer periods than others. By this method, very entertaining and musically interesting slow attack stringlike effects may be obtained.

It will be readily apparent that by changing the potentials of the terminals B*a*, B*b* and Bc with respect to one another, the intensity envelopes of the notes sounded may be varied considerably to suit the requirements of the musical selection being rendered and to suit the musical taste of the player or audience, as well as to make precompensation for adverse acoustical conditions of the room in which the instrument is being played.

Modified divider circuit

In Fig. 8 is shown a modified form of divider circuit which may be utilized in place of the circuits previously described. The circuit includes many elements which correspond to those previously described, and the corresponding elements of the two circuits are therefore designated with the same reference characters.

Primarily, the modified circuit of the Fig. 8 differs from that previously described in that the stages of the divider system are transformer coupled by means of a transformer **230** having a primary winding **232**, and a secondary winding **234**. The portion of the divider circuit illustrated is that for note No. **24**, and the divider tube for this stage is therefore designated DT**24**. The primary **232** of the transformer **230** is connected to the plate of the tube DT**36** and is shunted by a condenser **236**. In place of the condenser *Cb*, I have provided a condenser *Cg* connected between the grid **102** of the tube DT**24** and the secondary winding **234** of the transformer **230**, the other terminal of said secondary winding being connected to the cathode **104** of the tube DT**24**.

This divider circuit will operate in essentially the same manner as that previously described, since the condenser *Cg* connects the grid and cathode and exhibits a low impedance to high frequency, making it possible for the potential of the grid to be carried in a positive direction along with the potential of the cathode, with the result that the potential difference between cathode and grid cannot be affected quickly by the positive excursions of the cathode. The divider circuit, a stage of which is shown in Fig. 8, will of course have its divider tube for the highest frequency supplied with controlling impulses from an oscillator, and each stage will progressively halve the frequency.

Both of the divider systems disclosed herein have the advantage that the stages thereof are in themselves non-oscillatory and serve to generate a frequency only when supplied with a controlling signal. The system is very stable and the ranges of values of the various circuit elements are sufficiently great to make it feasible to make musical instruments employing these systems by quantity production methods. Since the divider tubes draw but very little plate current, their useful life is extended greatly as compared with their life when subjected to ordinary use. This, of course, is a very important factor since in a complete musical instrument very many of these tubes are used, and it is therefore nearly essential that the tubes have a useful life of many years.

Another great advantage of this frequency dividing system lies in the fact that lower frequencies introduced by a divider being driven from another one are not reflected back into the driver in such a way as to reach the control tube associated with the driver. This is done by supplying the signal to the control tube from the cathode circuit of the divider whereas the connection for driving the next succeeding divider is taken from the plate circuit. The screen and suppressor within the divider both being connected to points of fixed potential in respect to ground together with the characteristics of pentode tubes effectively isolate the plate circuit from the cathode circuit.

The operation of the control tube is such as to transmit only a small part of the wave impressed upon its grid by the divider during periods of the most positive swing of the grid. On this account very minute traces of frequencies lower than the note intended to be transmitted cause highly objectionable exaggeration of these lower frequencies in the output of the control tube. It is for this reason that every possible precaution must be taken to prevent the reflection of lower frequencies from driven dividers from reaching the control tube.

Method of operation

In playing the instrument, the musician has at his command the ability to make a wide variety of adjustments which will result in changes in tone quality and changes in the intensity envelopes of the notes. By means of the adjustable resonant output circuits, certain frequencies may be accentuated and thus give the tones of the instrument individualistic characteristics such as are present in violins, due to the particular characteristics of their resonance chambers. These controls which are available to the player include the following:

(*a*) Control of the intensity envelope of the note by changing the potentials of the terminals B*a*, B*b* and B*c*, and by operation of the sustaining pedal **194**, to produce effects ranging through percussive, organ and string tones.

(*b*) Control of the brightness (harmonic development) of the tone by gang switches connected to the resistances **148** and to the condensers **216**, as well as by adjustment of the potentials of the terminals B*a* and B*c*.

(*c*) Controlling the vibrato by means of gang switches **124**, **125** to have either no vibrato or a vibrato of selected degree of frequency range.

(*d*) Control of the adjustable resonant output circuit.

(*e*) Control of the overall intensity of the music being played, by means of the volume control operated by an expression pedal or the like.

As will be readily apparent to those skilled in the art, numerous changes and modifications may be made in the instrument herein disclosed, without departing from the basic principles of my invention. For example, other forms of oscillators or oscillation generators might be used in place of the oscillators disclosed, for the generation of the frequencies of the highest octave of the instrument. Similarly, different types of tubes with appropriately modified forms of circuits could be employed.

While the specific values of resistances and capacitances of the different circuit elements which appear in the foregoing description have been found to give satisfactory results, it will be appreciated that the values given are merely illustrative and that they may be varied within wide limits, especially if compensatory changes are made in the values of other circuit elements. I therefore do not wish, by the following claims, to limit my invention to the precise details of the instrument disclosed herein, but wish to include within the scope of the invention claimed, all such equivalent methods, constructions, and circuits by which substantially the results of my invention may be obtained in substantially the same way.

The reference characters included in some of the following claims are intended to facilitate an understanding of the meaning of the claims, and are not intended as specifically limiting the claims to the specified part of the exemplary embodiment of the invention disclosed herein.

I claim:

1. In an electrical musical instrument, a frequency dividing system for supplying a plurality of frequencies for octave notes of the instrument, said system including a plurality of stages and each stage comprising an electron discharge device having a cathode, grid and plate, and a plurality of terminals A, B, and C having fixed direct current potentials with respect to one another, a resistor connecting said cathode to the terminal A, a condenser connecting said cathode to the terminal B, a condenser connected between said cathode and said grid to form a connection having a lower impedance for high frequencies, a resistance connecting said grid to terminal C, and means for impressing a signal from a preceding stage between the grid and the cathode, whereby each of said stages will operate to produce a signal of a frequency which is a sub-multiple of the signal supplied from the preceding stage.

2. In an electrical musical instrument, a frequency dividing system for supplying a plurality of frequencies for octave notes of the instrument, said system including a plurality of stages and each stage comprising an electron discharge device having a cathode, grid and plate, and a plurality of terminals A, B, and C having fixed direct current potentials with respect to one another, a resistor connecting said cathode to the terminal A, a condenser connected between said cathode to the terminal B, a condenser connecting said cathode and said grid to form a connection having low impedance to high frequencies, a resistance connecting said grid to terminal C, and means for impressing a signal from a preceding stage between the grid and said terminal B, whereby each of said stages will operate to produce a signal of a frequency which is a submultiple of the signal supplied from the preceding stage.

3. In an electrical musical instrument, a frequency dividing system for supplying a plurality of frequencies for octave notes of the instrument, said system including a stage comprising an electron discharge device having a cathode, grid and plate, and a plurality of terminals A, B, and C, having fixed direct current potentials with respect to one another, a resistor connecting said cathode to the terminal A, a condenser connecting said cathode to the terminal B, a resistance connecting said grid to terminal C, a condenser directly connecting said grid and said cathode, and a high impedance connection for impressing a signal upon said grid, whereby each of said stages will operate to produce a signal of a frequency which is a sub-multiple of the signal supplied from the preceding stage.

4. In an electrical musical instrument, a frequency dividing system for supplying a plurality of frequencies for octave notes of the instrument, said system including a plurality of stages and each stage comprising an electron discharge device having a cathode, grid, and plate; a plurality of terminals, A, B, C, and E, having fixed direct current potentials with respect to one another, a resistor connecting said cathode to said terminal A, a condenser connecting said cathode to said terminal B, a resistance connecting said grid to said terminal C, a condenser connected in circuit between said grid and said cathode, a condenser connected between said plate and said terminal E, and means for impressing a signal from the preceding stage upon said grid, whereby each of said stages will operate to produce a signal of a frequency which is a sub-multiple of the signal supplied from the preceding stage.

5. In an electrical musical instrument, a frequency dividing system for supplying a plurality of frequencies for octave notes of the instrument, said system including a plurality of stages and each stage comprising an electron discharge device having a cathode, grid, and plate; a plurality of terminals A, B, C, and D, all of said terminals having fixed direct current potentials with respect to one another, a resistor connecting said cathode to said terminal A, a condenser connecting said cathode to said terminal B, a condenser connecting said cathode with said grid, a resistance connecting said grid to said terminal C, a resistance connecting the plate of the electron discharge device of the preceding stage to said terminal D, and a condenser connecting said last named plate to said grid, whereby each of said stages will operate to produce a signal of a frequency which is a sub-multiple of the signal supplied from the preceding stage.

6. In an electrical musical instrument, a frequency dividing system for supplying a plurality of frequencies for octave notes of the instrument, said system including a plurality of stages and each stage comprising an electron discharge device having a cathode, grid, and plate, a plurality of terminals A, B, and C having fixed direct current potentials with respect to one another, a resistor connecting said cathode to said terminal A, a condenser connecting said cathode to said terminal B, a resistance connecting said cathode to said terminal B, a resistance connecting said grid to terminal C, a transformer having primary and secondary windings, a condenser connected between said grid and cathode in series with said secondary winding, and means for impressing a signal from a preceding stage upon the primary of said transformer, whereby each of said stages will operate to produce a signal of a frequency which is a sub-multiple of the signal supplied from the preceding stage.

7. In an electrical musical instrument, a frequency dividing system for supplying a plurality of frequencies for octave notes of the instrument, said system including a plurality of cascaded stages and each stage comprising an electron discharge device having a cathode, grid, and plate; a plurality of terminals A, B, and C, having fixed direct current potentials with respect of one another, a resistor connecting said cathode to said terminal A, a condenser connecting said cathode to said terminal B, a resistance connecting said grid to said terminal C, a transformer having primary and secondary windings, a condenser connected between said grid and cathode in series with said secondary; an oscillation generator; means for impressing a signal from said generator upon the primary of the transformer associated with the first of said stages, and means for impressing a signal from the preceding stage upon the primary of the transformer of each following stage.

8. In an electrical musical instrument, the combination of means for generating electrical pulsations of the frequency of the highest note of a series of harmonically related notes of the musical scale, and a plurality of cascaded stages of non-oscillatory frequency dividing means controlled by said generating means, each of said dividing means comprising a multi-electrode electron discharge device having cathode, anode and grid, high impedance means to supply a con-

trol signal from said generating means to said grid, a source of potential negative with respect to ground, a condenser connected between said cathode and ground, a condenser connected between said cathode and said grid, a resistor connecting said grid to ground, and a high resistance connecting said cathode to said source.

9. In an electrical musical instrument having an output circuit including electro-acoustic translating means, the combination of a plurality of control tubes connected to supply signals to said output circuits and each having means for selectively rendering it operative, a generator, a non-oscillatory frequency dividing circuit having a plurality of stages, each stage producing a frequency one half that of the preceding stage, means for transmitting a controlling signal from said generator to the highest frequency stage of said circuit, means for transmitting a controlling signal from each except the last stage of said circuit to the succeeding stage thereof, and means for transmitting a signal from said generator and each of said stages respectively to one of said control tubes.

10. In an electrical musical instrument, an output circuit including electro-acoustic translating means, the combination of a plurality of key operated control tubes for supplying signals to said output circuit, a generator, a non-oscillatory frequency dividing circuit having a plurality of stages, each stage producing a frequency one half that of the preceding stage, means for transmitting a controlling signal from said generator to the highest frequency stage of said circuit for causing the latter to operate at a frequency one half that of the generator, means for transmitting a controlling signal from each except the last stage of said circuit to the succeeding stage thereof, and means for transmitting a signal from said generator and each of said stages respectively to said control tubes.

11. In an electrical musical instrument, the combination of an output circuit including electro-acoustic translating means, a plurality of control tubes connected to supply signals to said output circuit and each having means for selectively rendering it operative, a generator, a non-oscillatory frequency dividing circuit having a plurality of stages, each stage producing a frequency one half that of the preceding stage, means for transmitting a controlling signal from said generator to the highest frequency stage of said circuit, means for transmitting a controlling signal from each except the last stage of said circuit to the succeeding stage, and means for transmitting a signal from each of said stages to one of said control tubes.

12. In an electrical musical instrument, the combination of a first frequency divider comprising a multi-electrode vacuum tube, a second frequency divider for generating a lower frequency, a closed circuit connection from said first divider to said second divider for supplying a signal thereto, a control tube connected to said first divider to receive a signal therefrom, and means for preventing lower frequencies generated by said second divider from being reflected into said control tube, said means comprising separate connections for supplying said second divider and said control tube respectively so that one is driven from the plate circuit of said first divider whereas the other is driven from the cathode circuit of said first divider.

13. In an electrical musical instrument, the combination of a single multi-electrode vacuum tube connected for operation as a frequency divider, a second frequency divider for generating a lower frequency, a closed circuit connection from said first divider to said second divider for supplying a signal thereto, a control tube connected to receive a signal from said first divider, and means for preventing lower frequencies generated by said second divider from being reflected into said control tube, said means comprising separate connections for supplying said second divider and said control tube respectively so that one is driven from the plate circuit whereas the other is driven from the cathode circuit of said first divider, and a fixed potential screen between cathode and plate of said first divider.

14. In an electrical musical instrument, a frequency divider comprising a multi-electrode vacuum tube having a cathode and a grid connected to a constant frequency source to receive a relatively large signal therefrom, a self-biasing network connected to said tube and so chosen as to make the tube operate as an exceedingly non-linear amplifier when driven by so large a signal, a reactive mesh interconnecting said grid and cathode in such manner as to make the grid to cathode impedance of the tube much lower at high frequencies than at low frequencies, a control tube having a grid, and a circuit connecting the cathode of said vacuum tube to the grid of said control tube.

15. In an electrical musical instrument a multi-electrode thermionic device acting as a frequency divider, a control tube adapted to transmit a signal supplied by said divider, said control tube having a cathode, plate, grid and grid circuit; and a signal connection from the cathode circuit of said divider to the grid circuit of said control tube whereby the wave form of the signal transmitted to the control tube may have the shape of its positive peak portion readily controlled by adjustable reactances.

16. In an electrical musical instrument in which various frequencies for different notes are generated by frequency division from higher frequencies to lower frequencies, a frequency divider stage having in combination a multi-electrode electron discharge device of the high vacuum type having a cathode, grid, and plate; a source of direct current, a circuit to supply direct current from said source to said cathode, a high resistance in said circuit connected so that the voltage drop across said resistance due to said direct current appears as a voltage bias between said grid and cathode to bias said grid more negatively with respect to said cathode with increasing cathode current, the value of the resistance being so high, and the cut-off characteristics of the tube being such that the average value of direct current flowing to said cathode is almost entirely independent of grid signal, a pair of conductors for supplying a signal of a frequency to be divided by said stage, a reactive mesh connected between said grid and cathode so chosen that the impedance of said mesh is less great, for current of the lowest frequency contained in said signal, than for current of the lowest frequency generated in said stage, a circuit to impress said signal between said grid and cathode with an amplitude sufficient to cause cathode current cut-off during periods of negative grid excursion and with a combined amplitude and wave form so chosen, with respect to the characteristics of the electron discharge device, as to cause surges of cathode current at a frequency which

is a simple fraction of the lowest frequency contained in said signal.

17. The combination set forth in claim 16, and including a condenser connected across said high resistance.

18. The combination set forth in claim 16, in which said reactive mesh consists of a condenser, and said high resistance is shunted with a second condenser, and said second circuit includes an impedance which is high in comparison with the impedance of said first mentioned condenser at the lowest frequency appearing in said circuit.

19. The combination set forth in claim 16, in which said electron discharge device has an additional screen to prevent coupling between the grid circuit and plate circuit thereof.

20. The combination set forth in claim 16, in which said discharge device has an additional screen to prevent coupling between the grid and plate circuits of said discharge device, and which comprises two output circuits, one of said output circuits including cathode and ground, and the other of said output circuits including said plate and ground, whereby a lower frequency appearing in one circuit is prevented from appearing in the other of said circuits.

21. The combination set forth in claim 16, and including additional means to prevent reaction between the grid circuit and plate circuit of said electron discharge device.

LAURENS HAMMOND.

CERTIFICATE OF CORRECTION.

Patent No. 2,126,682. August 9, 1938.

LAURENS HAMMOND.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 3, second column, line 16, for "1,0000,000" read 1,000,000; page 4, second column, lines 37 and 64, for the word "vibrator" read vibrato; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 1st day of November, A. D. 1938.

Henry Van Arsdale

(Seal) Acting Commissioner of Patents.