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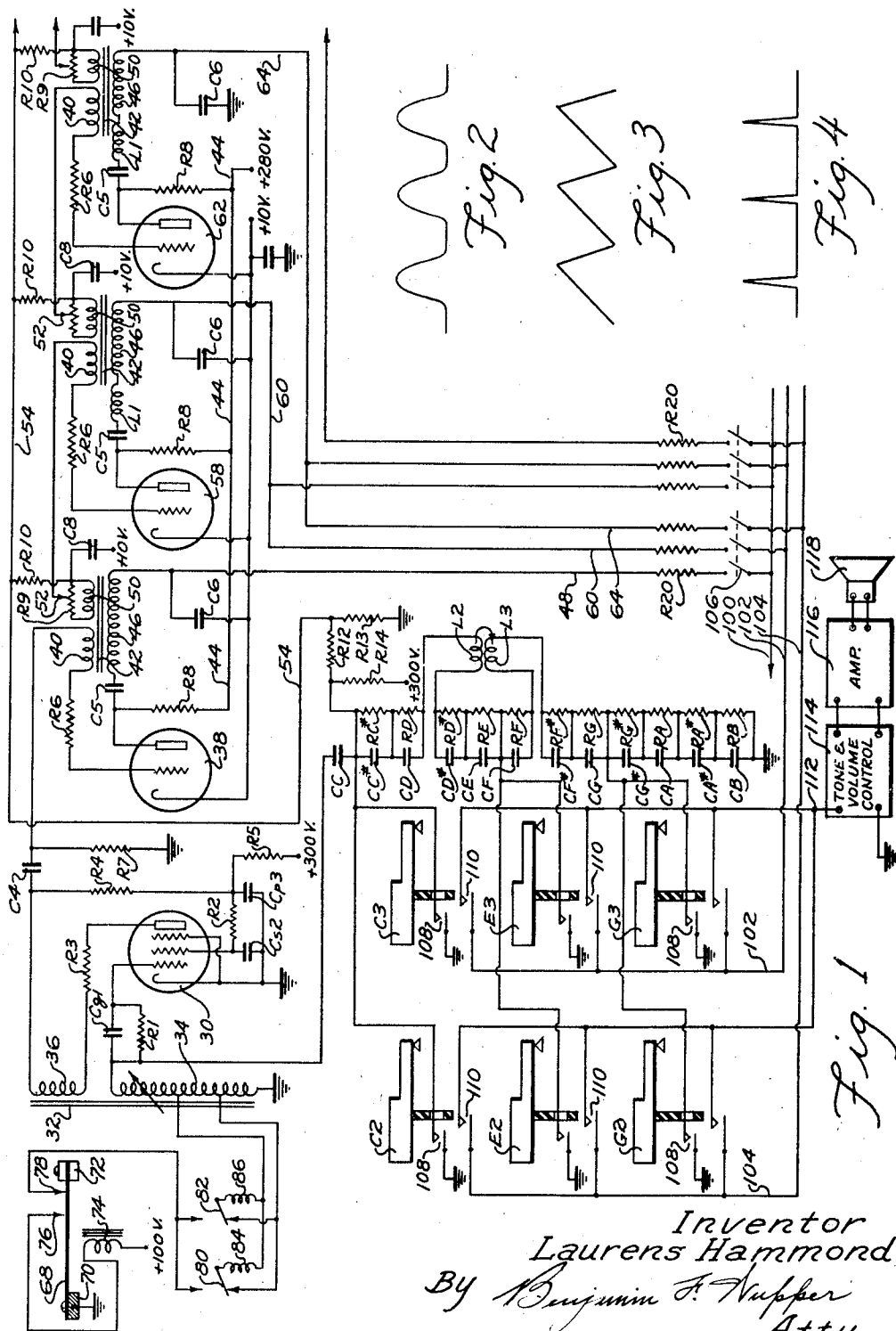
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2,301,869

FREQUENCY GENERATING SYSTEM

Filed April 3, 1940

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

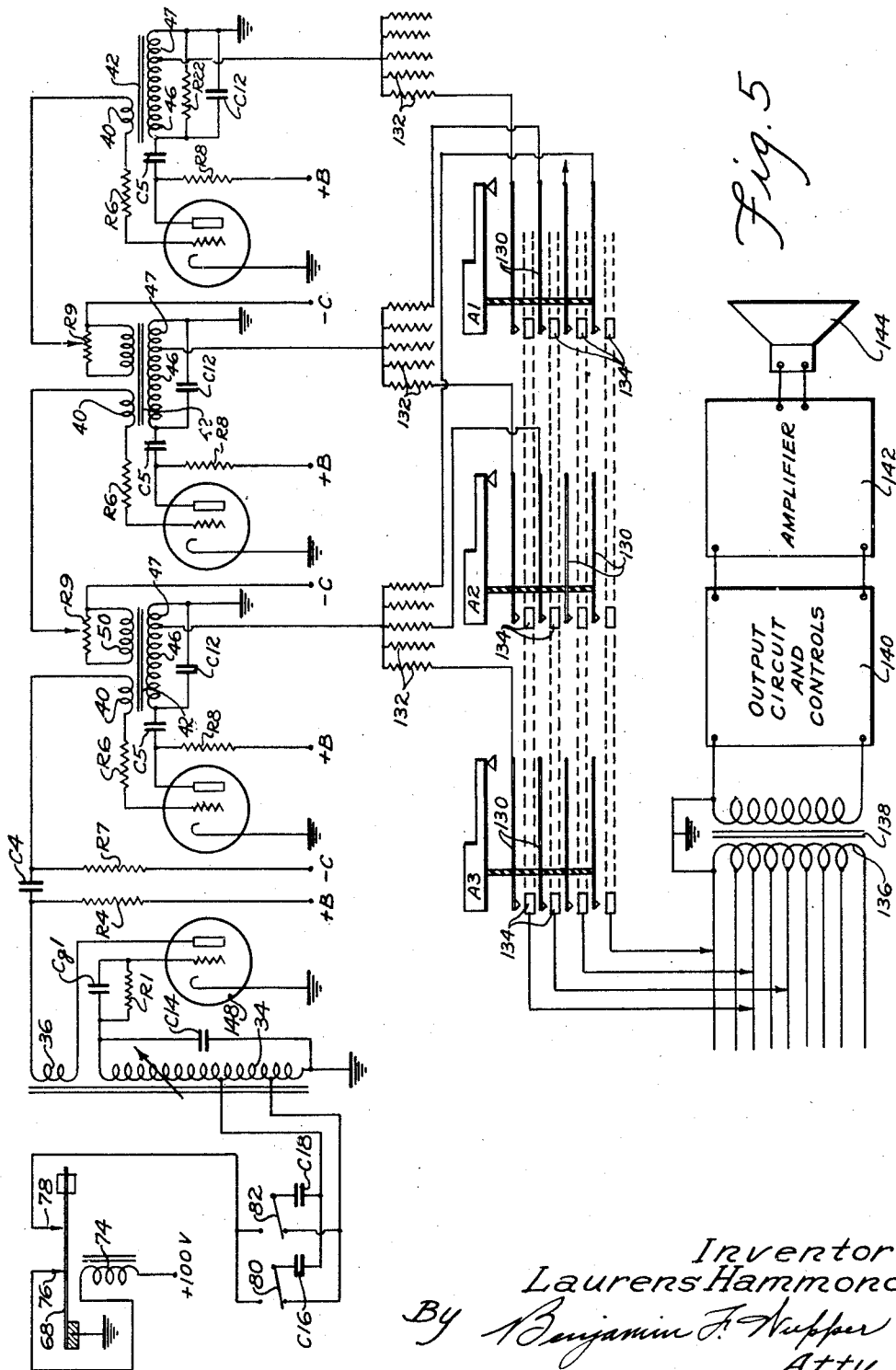


Fig. 5

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UNITED STATES PATENT OFFICE

2,301,869

FREQUENCY GENERATING SYSTEM

Laurens Hammond, Chicago, Ill.

Application April 3, 1940, Serial No. 327,572

2 Claims. (Cl. 250—36)

My invention relates generally to electrical musical instruments and more particularly to improved frequency generating systems for such instruments.

It is an object of my invention to provide an improved frequency generating system for electrical musical instruments, which is simple in construction, and which is capable of supplying signals accurately maintained at the desired musical frequencies, despite wide variations in operating conditions.

A further object is to provide an improved vacuum tube oscillator circuit.

A further object is to provide an improved frequency dividing system.

A further object is to provide an improved oscillator for supplying musical frequencies, in which the output signal is of rich harmonic development suitable for producing pleasing musical tones.

A further object is to provide an improved form of relaxation oscillator in which the timing resistor and condenser form part of the plate circuit of the tube.

A further object is to provide a frequency dividing system in which the various frequency stages are coupled by means of transformers, and in which the signal from each stage is derived across a low impedance condenser in the plate circuit of the stage.

A further object is to provide an improved frequency generating system for electric organs and other polyphonic electrical musical instruments.

A further object is to provide a circuit in which the potential difference between windings of oscillators is kept low to prevent electrolysis under adverse humidity conditions.

A further object is to provide means for eliminating undesirable high frequencies in the output of oscillators with small chokes.

A further object is to provide a frequency dividing system which will accurately follow appreciable percentage variations in the frequency of the control signal.

A further object is to provide an improved relaxation oscillator which can readily be stabilized to oscillate reliably at the frequency of a control signal impressed thereon, or at a frequency which is a sub-multiple of such control frequency.

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

Figure 1 is a schematic wiring diagram of the instrument;

Figures 2, 3 and 4 are curves illustrating the

forms of waves appearing in different parts of the circuit; and

Figure 5 is a schematic wiring diagram of a modified form of the invention.

For the purposes of illustrating the invention, it is disclosed in the drawings and described herein as forming part of an electrical musical instrument of the melody type wherein it is intended that not more than one tone (or a plurality of tones under the control of one key), be sounded at any one time. An instrument of this type is disclosed in greater detail in the co-pending application of Laurens Hammond and John M. Hanert, Serial No. 293,444, filed September 5, 1939.

The instrument is provided with three octaves of keys, herein termed the low, middle, and high octaves. Keys C2, E2 and G2 are illustrated as representative of three keys of the low octave, while keys C3, E3 and G3 are illustrated as representative of the keys of the middle octave. The range of the keyboard may, of course, be increased to any extent desired.

The frequency generating system of the instrument comprises a controlling oscillator tube 30 which may be a pentode of the 6J7G type illustrated, the input and output circuits of which are coupled by means of an oscillation transformer 32 having a primary 34 and a secondary 36. The frequency of oscillation is determined principally by the inductive reactance of the oscillation transformer 32 and the capacitive reactance of condensers CC to CB for the respective notes of the octave. The condensers are connected in series, and depending upon the number of these condensers which are thus connected in the resonant circuit, tune the oscillator 30 to one of the semi-tone notes of an octave. The frequencies thus generated correspond to the semi-tones of the highest octave of frequencies available in the instrument, which may be approximately 2093 to 3951 C. P. S.

Bias to the tube 30 is supplied by means of a grid leak R1 which is in parallel with a condenser Cg1. Screen bias to the tube 30 is supplied through voltage dropping resistor R2 and filter condenser Cs2. The plate load on the tube 30 comprises resistor R3 in series with winding 36 of the oscillation transformer 32, and resistance R4 which is connected to filter condenser Cp3 and filter resistance R5, the latter being connected to terminal 300V of the power supply system. The power supply system is not disclosed herein but may be of any suitable construction having a reasonably regulated output, and which

may supply the various potentials required, being considered as having terminals at ground potential +10 volts, +280 volts and +300 volts, the terminals being designated by their voltages. All voltages are preferably derived from the same source, so that fluctuations in line voltage will not cause disproportionate changes in plate voltage and grid bias voltage.

The output of the oscillator 30 is coupled to the grid circuit of a controlled oscillator 38 through a condenser C4. The oscillator tube 38 may be a triode of the 6J5G type, the grid circuit of which includes a resistance R6, a secondary winding 49 of an oscillation transformer 42, and grid resistor R7 which is connected to ground. The resistance R3 not only serves the purpose of limiting the grid current, but also greatly attenuates the very high frequencies, above the audible range. The cathode of tube 38 is connected by a conductor 39 to a terminal +10V of the power supply system. Since the grid is connected to ground through resistor R7, there is 10 volts negative bias on the grid of the tube 38.

Current is supplied to the plate of tube 38 through a timing resistor R8 and a conductor 44, the latter being connected to a terminal +280V of the power supply system. The rate of relaxation of the oscillator 38 is controlled in part by the relative values of the timing resistor R8, and the capacitance of a timing condenser C5. The condenser C5 is in series with a condenser C6 and the primary winding 48 of oscillation transformer 42. Other factors which control the frequency of oscillation are the characteristics of the tube, the grid bias voltage, plate voltage, the amplitude of the controlling signal, and the characteristics of the transformer 42.

An output signal is derived from the oscillator 38 through a conductor 42 which is connected to a point intermediate the condenser C6 and the secondary winding 48. The output of the oscillator 12 appearing across the condenser C6 will be generally of saw-tooth shape, thus comprising a fundamental frequency with a long series of harmonic partials, or other tones of progressively decreasing amplitude. The value of condenser C6 is large relative to that of C5 with the result that the shunt key circuits across C5 do not have an appreciable effect upon the rate of relaxation of the oscillator 12.

The constants of the oscillating circuits for the oscillator tube 38 and the potentials supplied to these circuits, are such that relaxations occur at the same frequency as the master oscillator 30. In other words, the signal derived from the oscillator 30 and impressed upon the grid of oscillator tube 38 through the coupling condenser C4, serves to trip the relaxation oscillator 12 for each positive excursion of the impulse received by the latter.

The transformer 42 has a tertiary winding 50 which is shunted by a resistance R9 of a value in the order of 100 ohms. The secondary winding 48 may have approximately one half, while the tertiary winding 50 may have approximately one eighth as many turns as the primary winding 48. The resistor R9 shunted across the tertiary winding 50 is reflected into the plate circuit of the tube 38 as a load impedance.

The next stage in the frequency dividing circuit may comprise an oscillator tube 58 having grid and plate circuits similar to those described with reference to the oscillator tube 38. It will be noted, however, that the oscillator tube 58 is coupled to the oscillator 38 through an adjustable

tap 52 on the resistance R9, the adjustment of the tap 52 being made during the course of assembly of the instrument in such manner that the oscillator 58 will relax at one half the frequency derived from the plate circuit of oscillator 38 and impressed upon the grid circuit of oscillator tube 58. The grid biasing potential for the oscillator 58 is supplied from a conductor 54 through a filter resistor R10.

A filter condenser C8 has one terminal connected to a fixed potential terminal 10V of the power supply, and its other terminal connected to the tertiary winding 50 of the transformer 42. The potential on the conductor 54 is varied, depending upon the key depressed, as will appear more fully hereinafter, so that the oscillator 58 will relax at one-half the rate of the oscillators 30 and 38 regardless of the frequency to which the master oscillator 30 is tuned.

The oscillator 58 is preferably provided with an inductance L1 connected between the condenser C5 and the primary winding of its output transformer 42, so as to attenuate musically undesirable high frequencies in the generally saw-tooth wave shape occurring across its condenser C5. In all other respects, the circuits for the oscillator tube 58 are identical with those previously described, except for slight differences in values of some of the elements, and similar reference characters have therefore been applied to the elements of the oscillator 58 which correspond to the elements of the oscillator 38. The output of oscillator 58 is supplied through a conductor 60, corresponding to the conductor 48 of oscillator 38.

A third stage oscillator comprising a tube 62 is identical with the oscillator 58, except for small differences in the values of some of the circuit elements, this oscillator supplying a signal of one-half the frequency of the oscillator 58 through a conductor 64.

The oscillator including the triode 62 may be connected to a fourth similar relaxation oscillator, and the fourth connected to a fifth, etc., to provide all of the frequencies desired. The oscillator of the last stage need not have a tertiary winding 50 on its oscillation transformer, so that in its place a resistor shunting its primary winding 48 may be provided for the necessary plate load.

As previously stated, the bias potentials upon the grids of oscillator tubes 58, 62, and such other oscillator tubes as may be connected in cascaded series, are determined by the potential of conductor 54. The potential upon the conductor 54, in order to make certain that the relaxation oscillators will safely follow changes in the frequency of the relaxation oscillator 38 and controlling oscillator 30, must be varied as the frequency of the oscillators 30 and 38 is changed. The conductor 54 is connected to a point intermediate resistors R12 and R13, which together with a resistance R14, form parts of a voltage divider connected between the terminal +300V of the power supply and ground. The voltage appearing intermediate resistances R12 and R14 will be determined by the particular key which is depressed, as will be described hereinafter.

Tuning of the controlling oscillator 30 is accomplished by connecting the terminals of condensers CC to CB to ground, and such connection likewise determines which of a series of resistors RC# to RB are effective in the voltage dividing mesh provided by these resistors, as well as the resistors R12, R13 and R14. All of the resistors in this voltage dividing mesh are so chosen that

resistors RC# to RB inclusive do not constitute appreciable loads (to alternating current of the frequency generated by the controlling oscillator 30), upon tuning condensers CC# to CB. In this way, the frequency of the controlling oscillator 30 is determined substantially by the reactive elements of the tuning system, and not appreciably by the resistances RC# to RB, R12, R13 or R14, and thus good frequency stability for the oscillator 30 is assured because of the high Q (sharpness of resonance of this tuning circuit).

It will be noted that inductances L2 and L3 forming a mutual inductance M between them, are inserted between tuning condensers CD and CD#, and CF and CF# respectively. These inductances are very small compared to the inductance of oscillation transformer 32, and thus have inappreciable effects upon the tuning of the oscillator 30. Their function is to suppress the spark incident to tuning the oscillator 30 upon completion of the tuning circuits.

It will be noted that when the number of condensers CC to CB effective in the tuning circuit is changed, the circuits by which such changes are made are subjected to the residual DC voltage on such of these condensers as are shunted out of the tuning circuit, such residual voltage resulting from the fact that the voltage divider resistances RC# to RB are connected in shunt with these condensers. The inductances L2 and L3, either singly or both mutually, depending upon which group of condensers is shunted, thus serve as a means to limit the discharge of the condensers to a rate which will not cause excessive sparking at the switches when these tuning circuits are completed.

The frequency of oscillator 30 and hence the frequencies of all of the control oscillators 38, 58, 62, etc., may, whenever desired, be periodically shifted through a small range in the order of 3%, at a vibrato periodicity of approximately 7 C. P. S. to provide a vibrato effect in the tones ultimately produced.

The vibrato mechanism comprises a vibratory magnetic metal reed 68 secured to a suitable rigid grounded support 70, having a weight 72 adjustably secured thereto, so as to permit variations in the vibrato periodicity. The reed is maintained in vibration by an electromagnet 74, one end of the winding of which is connected to a terminal +100V of the power supply system, the other end of the winding of electromagnets 74 being connected to a contact 76 which makes contact with the reed during the upper portion of its vibratory oscillation. Since the reed is grounded at the support 70, current flows through the coil of the electromagnet 74 and attracts the reed 68, whereupon its contact with the contact 76 is broken.

A second contact 78 is provided for engagement with the reed 68 and is thus periodically grounded through the reed at the rate of vibration of the reed. This contact 78 is connected to single-pole, double-throw switches 80 and 82, by which the contact 78 may be made to interrupt the circuit through a coil 84 of relatively high inductance, or through a coil 86 of lesser inductance. The coils 84 and 86 are connected in parallel with approximately 13% of the turns of the primary winding 34 of transformer 32 at a tap 88.

When either of the switches 80 or 82 is in its off position (in the positions in which they are shown in Fig. 1), the inductance 84 or 86 associated therewith is connected to a tap 90 on the primary 34, so as to cause the oscillator 30 to

oscillate at a frequency which is the mean of the frequencies at which it oscillates when the inductance 84 (or 86) is periodically connected between the tap 88 and ground by the contact 78. The number of turns between ground and tap 88 is 29.1% of the number of turns between ground and tap 90. The switches 80 and 82 are manually operable and may be used singly or together, to provide three different degrees of vibrato. The taps 88 and 90 are at such points upon the primary 34 that the mean frequency of oscillator 30 will be the same, irrespective of the position of switches 80 and 82. The reed 68 may be manually started in vibration or may be provided with some means to start it automatically whenever the instrument is placed in operation.

The signals from the relaxation oscillators 38, 58, 62, etc., are supplied to conductors 100, 102 and 104 through resistors R20, upon closure of switches 106. The switches 106 are preferably triple gang switches, and the circuits are so arranged that upon closure of one group of these switches, signals from successive relaxation oscillators are impressed upon the conductors 100, 102 and 104. If desired, more than one group of switches 106 may be closed at the same time so that signals from several relaxation oscillators may be impressed upon each of the conductors 100, 102, or 104.

Each of the keys, such as C2, is adapted successively to close a switch 108 and switch 110, the switch 108 being effective to connect a terminal between two of the condensers CC to CB to ground, while the switch 110 is arranged to connect one of the conductors 100, 102, 104 to the input terminal 112 of a tone and volume controlling apparatus 114, from which the signal is supplied to an amplifier 116 and transmitted to a loud speaker 118.

Since the switch 108 is closed during the initial portion of the down-stroke of the key, while the switch 110 is closed after the key has been moved through a substantial portion of its stroke, the oscillators will have had time to shift to the new frequency determined by the tuning circuit before the switch 110 is closed, with the result that transient frequencies incidental to the changes in the frequencies of the oscillators will not be transmitted to the amplifier and speaker. The particular circuits utilized to accomplish this result and other desirable effects are more fully disclosed in the aforesaid application Serial No. 293,444, the keying circuits illustrated herein being merely a simplified form which would ordinarily be modified so as to eliminate the possibility of transient noises when a second key is depressed, before the first key is released.

Upon closure of any one of the switches 108, for example, the switch operated by the key E2, the series of condensers CC to CE are the only condensers effective in the tuning circuit of the controlling oscillator 30, the remaining tuning condensers being shunted. The closure of the switch 108 associated with the key E2 also connects the resistor RE to ground, thus lowering the biasing potential on the conductor 54. The lowering of the biasing potential upon the relaxation oscillators 38, 58, 62, etc. facilitates their shifting to the frequencies of the notes E of their respective octaves under the control of the controlling signal derived from the preceding oscillator.

The voltages appearing across the resistors R7 will have a wave shape similar to the wave shown in Fig. 2, while the voltage appearing across the

resistances R8 will be of saw-tooth shape as illustrated in Fig. 3. The voltage appearing across the primary windings 46 of the oscillation transformers will be sharply peaked waves of the type illustrated in Fig. 4, which represent a tone which is of high harmonic development.

The elements of the relaxation oscillator circuits are, according to well known principles, of such values as to obtain the operation above described. Of course the values of the different parts may be varied considerably, especially if compensatory changes are made in the values of other elements of the circuit. The following tabulation of the values of the elements of the relaxation oscillators is therefore intended to be merely illustrative of satisfactory values, and not intended as limiting the invention in any way to these particular values.

The circuit elements for the relaxation oscillator including the tube 38, which oscillates at a frequency of from 2093 to 3951 C. P. S., may be as follows:

R6	ohms	20,000
R7	do	30,000
R8	do	100,000
R9	do	100
R10	do	10,000
C5	mfd	.001
C6	mfd	.1

The resistors constituting the voltage divider providing for the biasing voltages on the grids of the relaxation oscillators may be as follows:

	Ohms
R12	60,000
R13	8,000
R14	200,000

Resistors RC# to RB: 3400, 3500, 3800, 4100, 4700, 5200, 5900, 6500, 7200, 8300 and 9800 respectively. The inductances L2 and L3 may be in the order of .7 mh.

The relaxation oscillators 38, 58, 62, etc., operate according to the general principles of oscillators of this type, but due to a number of refinements are more stable, can be more easily controlled as to frequency, and produce a more desirable signal than prior art relaxation oscillators of which I am aware. The theory underlying the operation of the relaxation oscillators disclosed herein does not lend itself readily to mathematical exposition, but may be briefly described as functioning in the following manner:

The operation of the oscillator will be described with reference to the oscillating circuit of the tube 38. It will be noted that in this tube, the grid is normally biased 10 volts negative with respect to the cathode, which is sufficient to cut off the tube for low plate potentials. The current flow through resistor R8 results in charging the condenser C5 and raising the potential of the plate of the tube 38 as the latter condenser becomes charged. During the period of charging the condenser C5, the potential induced in the secondary winding 40 of the oscillation transformer 42 is in a direction to reduce the potential, or increase the grid bias on the tube 38. However, eventually the plate potential is raised (due to the approaching completion of the charging of the condenser C5), and, at an instant determined by a positive pulsation transmitted from the controlling oscillator 30 through the condenser C4, secondary winding 40, and resistor R6 to the grid of the tube 38, the plate current commences flowing, thus discharging condenser C5.

As the condenser C5 thus discharges through

the tube, the induced potential across the secondary winding 40 is in a direction to swing the grid of the tube 38 more positive with respect to the cathode, thus increasing the rate at which the condenser C5 may discharge through the tube. Due to this accelerating action, the condenser C5 discharges very rapidly, and after a short time the plate potential is therefore reduced to a value at which the tube is cut off. The cut off of the tube is accelerated by virtue of the fact that as the rate of discharge of the condenser decreases, the potential on the grid swings negatively due to the current flow in the secondary winding 40. As a result, the voltage across the primary winding 46 of the transformer 42 has a sharply peaked wave shape of the type shown in Fig. 4.

The voltage wave induced in the tertiary winding 50 is therefore also a sharply peaked wave, and thus assures reliable control of the next stage of the cascaded oscillators including the tube 58. During the part of the cycle that the condenser C5 associated with oscillator tube 58 is being charged through the resistor R8, the grid of the tube 58 will of course receive a positive impulse from the oscillator 38, but at such time the condenser C5 of the oscillator tube 58 will be only partially charged, and the bias potential upon the grid of the tube 58 will be sufficiently negative to prevent the flow of plate current at this low plate voltage.

If desired, the grid bias on the relaxation oscillator tubes 38, 58, 62, etc., may be made sufficiently high that oscillation will not take place unless a controlling signal, decreasing the bias, is impressed upon the grids of the tubes. I prefer, however, to have the normal grid bias of such value that the relaxation oscillator will oscillate at a frequency close to its desired frequency, even though no controlling signal is impressed upon its grid, to use a controlling signal to trip the oscillator, and to utilize each, or each alternate impulse, of the controlling frequency as a means for stabilizing the oscillator at exactly the desired frequency.

The inductances or small chokes L1 greatly attenuate the very high frequencies which render the tones too bright for most desirable musical effects.

From a consideration of the operation of the frequency generating system it will be apparent that the potential differences between the windings of the oscillation transformers is low, so that these transformers will function reliably under very adverse humidity conditions.

The modified form of the invention shown in Fig. 5 may be utilized as a frequency generating system for an electrical organ, or may be utilized to supplement the frequency generating system of an electric organ of the type shown in my prior Patent No. 1,956,350 granted April 24, 1934. For this purpose twelve cascaded series of oscillators will be necessary to provide all of the note frequencies.

In the apparatus disclosed in said patent, each of the electrical generators has a field winding having an impedance of approximately 4 ohms. In adapting the generating system of the present invention for use in conjunction with the generating system of such organ, it is therefore desirable that each of the oscillators shall have an effective impedance of 4 ohms. This is accomplished by tapping the primary windings 46 of the oscillation transformers 42 at a point such that a section 47 of this winding between the tap

and ground has an impedance of approximately 4 ohms at the signal frequency.

The signal across the portion 47 of the primary winding 46 is supplied to key switches 130 through relatively high value resistances 132. The resistances 132 may have an impedance in the order of 15 to 20 ohms, and thus prevent so-called "robbing" as fully disclosed in my aforesaid patent.

The switches 130 are operated by keys of which the three keys A1, A2, and A3 illustrated are representative of the keys of one or more manuals, and the pedal clavier of an organ, these keys being adapted upon depression to flex the switch contact arms 130 into contact with bus bars 134. The bus bars 134 are adapted to be selectively connected to various taps on a low impedance primary winding 136 of an output transformer 138, the secondary of which is connected through various output circuits and controls, represented by the block 140, and amplifier 142, to a loud speaker 144. The bus bars 144 may be connected to the taps of the primary 136 in any suitable manner as by means of selectively adjustable draw bars, or preset key-operated switches, as disclosed in the aforesaid patent.

Inasmuch as the signals across the primary windings 46 of the oscillation transformers 42 are very bright, it will usually be desirable to shunt the primary windings by condensers C12. In addition, the primary winding 46 of the oscillation transformer associated with the lowest frequency oscillator of a cascaded series is preferably shunted by a resistor R22, to take the place of the load provided by the tertiary winding 50 shunted by resistance R9 of the other oscillators.

The master oscillator of the generating system shown in Fig. 5 differs slightly from the master oscillator previously described, comprising a triode 148 having a primary winding 34 in its grid shunted by a fixed condenser C14.

The means for producing the vibrato is similar to that shown in Fig. 1, except that condensers C16 and C18 are utilized in place of the inductances 84 and 86.

Since the bias on the oscillator tubes may be fixed, it is unnecessary to provide the filtering condensers C8, but instead, the ends of the tertiary windings 50 and resistors R9 may be connected directly to a source of biasing potential. Inductances L1 need not be used in the circuit of Figure 5 since a satisfactory signal may be derived from the oscillators without their use. In other respects, the frequency generating system of Figure 5 may be identical with that of Figure 1, and reference characters identical with those of Figure 1 have therefore been applied to the corresponding elements of the circuits.

In the frequency generating systems described, it will be noted the grids of the oscillator tubes do not require any power input because of the current limiting resistors R6 in the grid circuits. The impedance of the plate circuit is of value comparable with that of the internal resistance of the tube. The oscillators are cascaded in such manner that there is no perceptible reflection of the lower frequencies into the signal provided by the oscillators, and, it will be noted, this result is obtained without the necessity of using buffer

tubes between the stages, or of using pentodes for the oscillator tubes. The winding 50 and its resistance R9 present a low impedance circuit at the signal frequencies, and because the high impedance grid circuit of the tube of the succeeding stage is connected to this low impedance circuit, the possibility of reflection, or reverse coupling, from the lower to the higher frequency oscillator is avoided.

The amplitude of the tripping signal may be readily adjusted by varying the position of the sliding contactor 52 on the resistance element R9, the latter acting as an energy dissipating impedance in the A. C. plate circuit of the oscillator. Since the oscillator tubes are of the high vacuum type, as distinguished from gas-filled tubes, their operating characteristics will remain substantially constant for long periods of use.

While I have shown and described particular embodiments of my invention, it will be apparent to those skilled in the art that numerous variations and alterations may be made without departing from the underlying principles of the invention. I therefore desire to include within the scope of my invention as defined in the following claims, all such modifications and variations whereby substantially the results of my invention may be obtained by the use of substantially the same or equivalent means.

I claim:

1. An audio frequency oscillation generator of the relaxation type, comprising an electron discharge device having a cathode, control grid, and plate, an oscillation transformer having a primary winding and a secondary winding, means connecting said secondary winding between said grid and cathode, a timing condenser having one terminal connected to said plate, a source of plate current having one terminal connected to said cathode, a timing resistor connected between the other terminal of said source and said plate, a condenser having a capacitance high with respect to that of said timing condenser and having one terminal thereof connected to said cathode, means connecting said primary winding between the other terminal of said high capacitance condenser and the other terminal of said timing condenser, and a signal utilizing circuit coupled across said high capacity condenser.

2. An oscillation generator comprising an electron discharge device having a cathode, control grid, and plate, an oscillation transformer having a primary winding and a secondary winding, means connecting said secondary winding between said grid and cathode, a source of plate current having one terminal connected to said cathode, a resistance-capacitance network including a timing condenser, one element of said resistance-capacitance network being connected between the other terminal of said source and said plate, a high capacitance condenser having one terminal thereof connected to said cathode, means connecting said primary winding between the other terminal of said high capacitance condenser and said plate, said last mentioned means including another element of said resistance-capacitance network, and a signal utilizing circuit connected across said high capacitance condenser.

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