Oct. 30, 1956 R. W. CHICK 2,768,551

ELECTRONIC ORGAN WITH TREMOLO

Original Filed Jan. 14, 1947 4 Sheets-Sheet 1

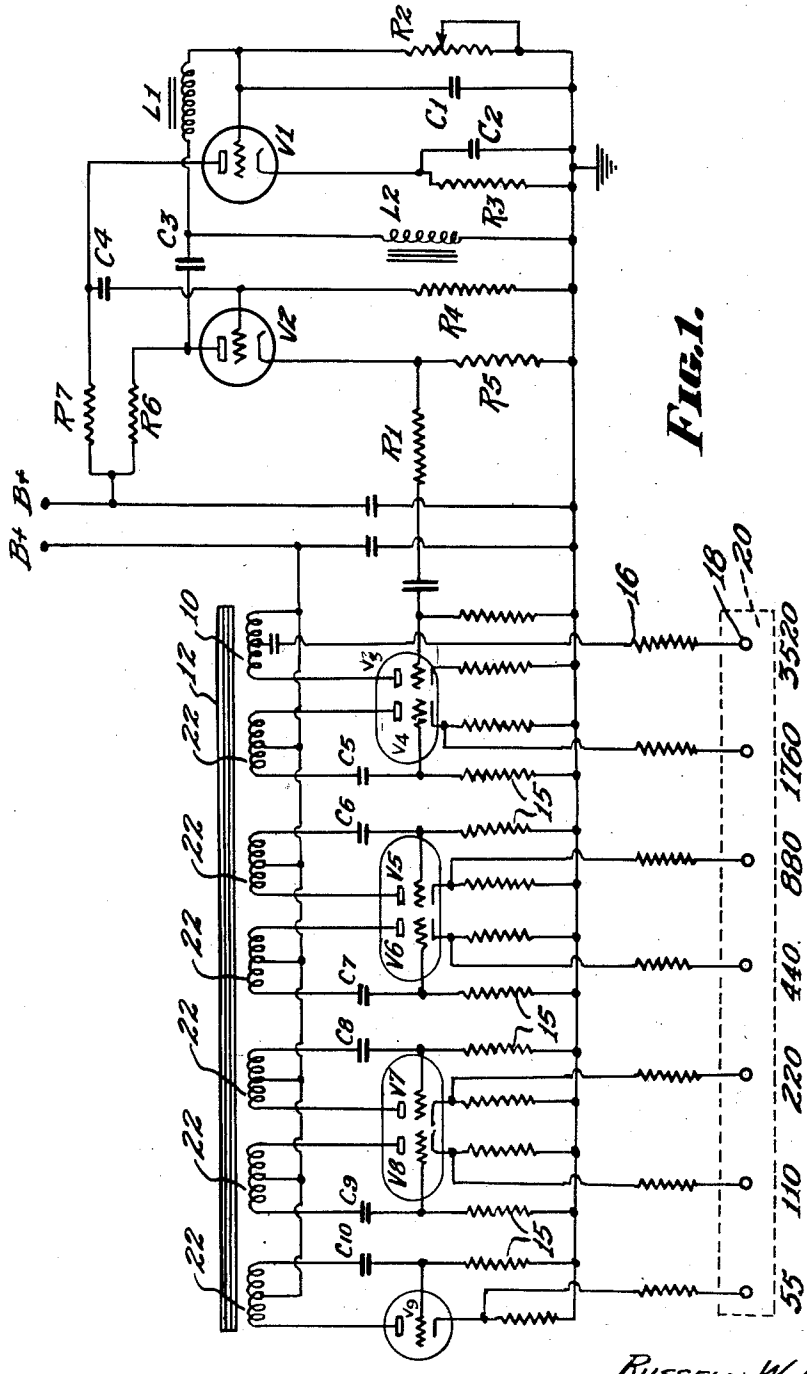


FIG. 1.

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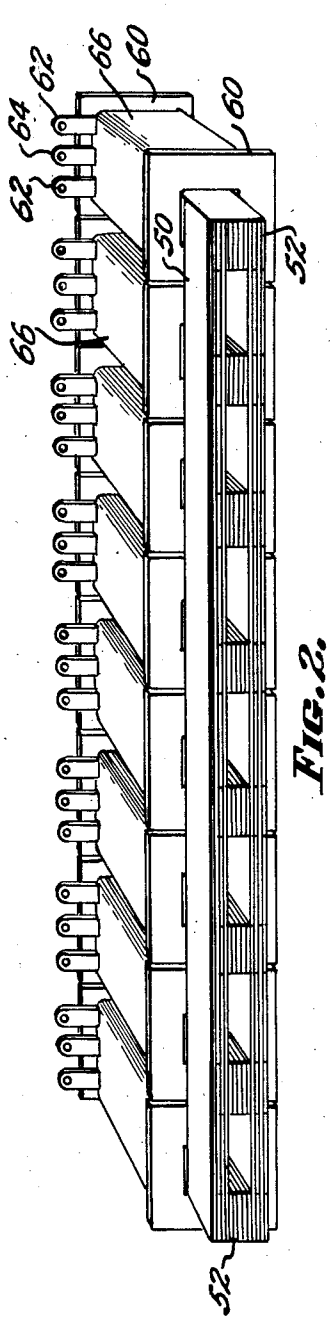


FIG. 2.

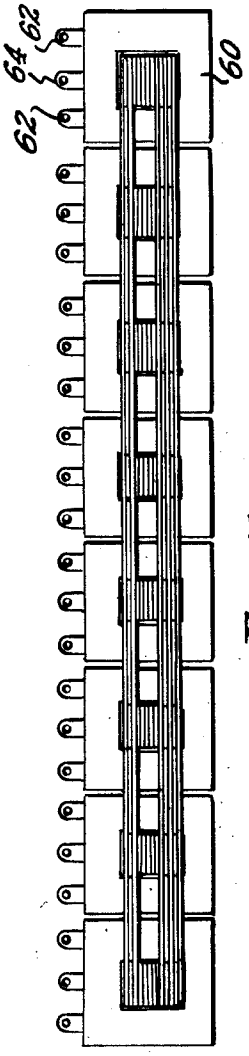


FIG. 3.

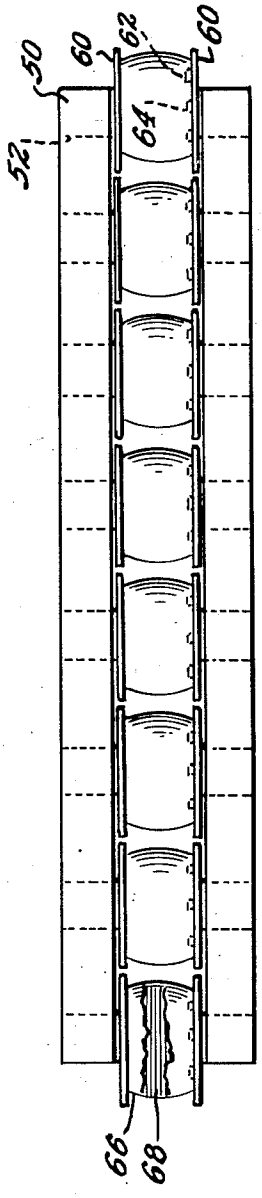


FIG. 4.

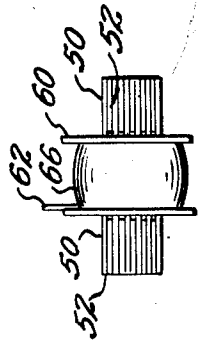


FIG. 5.

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ELECTRONIC ORGAN WITH TREMOLO

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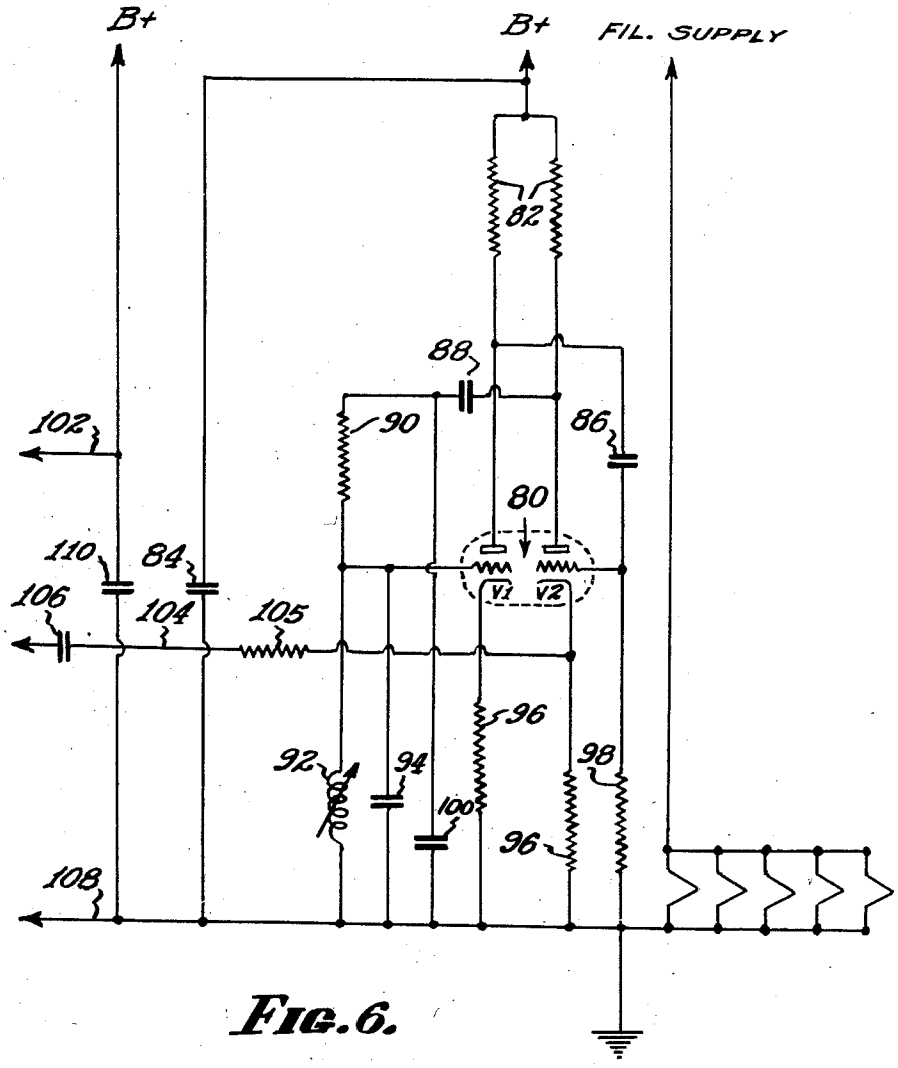


FIG. 6.

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ELECTRONIC ORGAN WITH TREMOLO

Original Filed Jan. 14, 1947 4 Sheets-Sheet 4

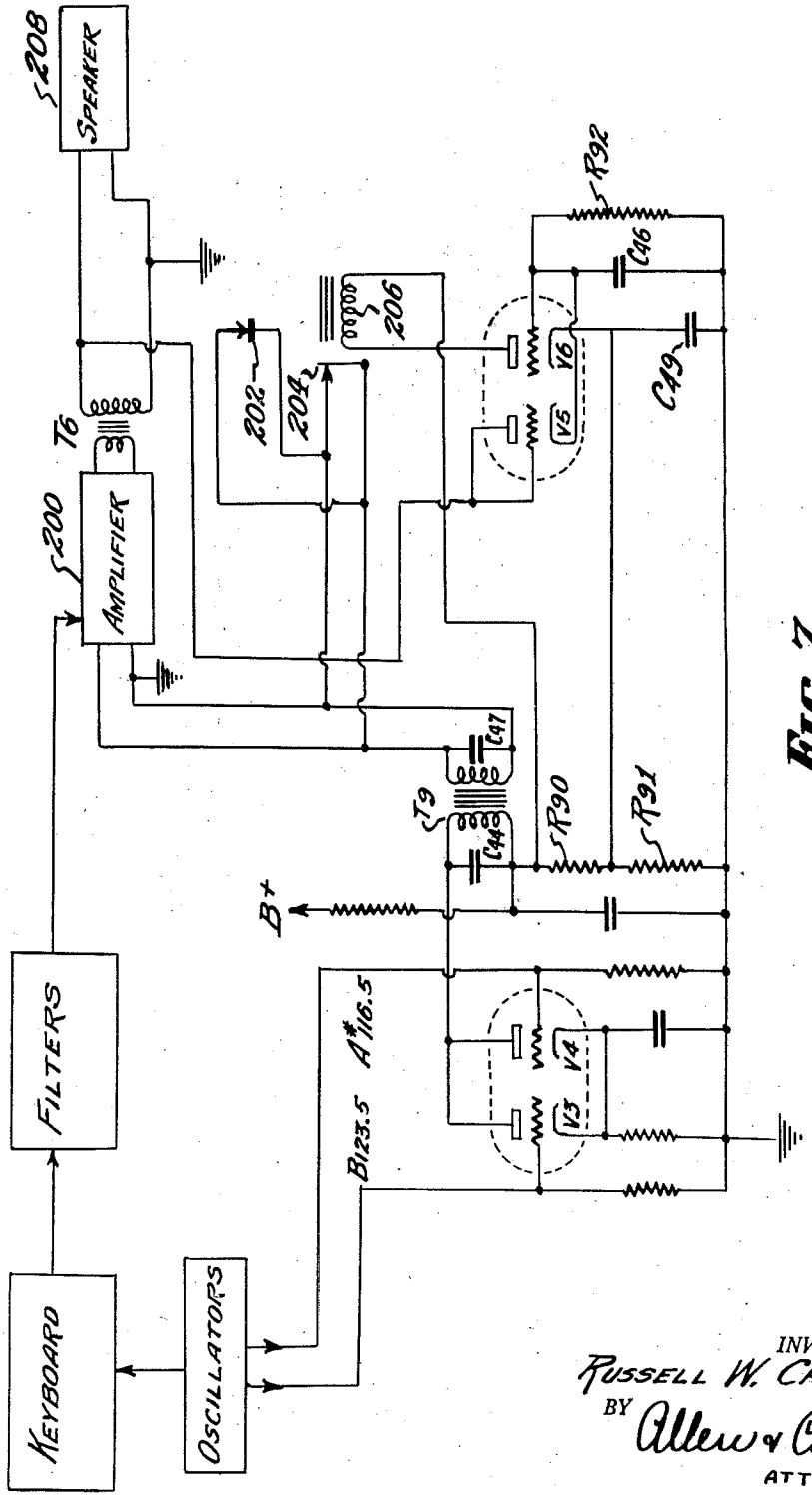


FIG. 7.

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United States Patent Office 2,768,551 Patented Oct. 30, 1956

2,768,551

ELECTRONIC ORGAN WITH TREMOLO

Russell W. Chick, Beverly, Mass., assignor to The Baldwin Piano Company, a corporation of Ohio

Original application January 14, 1947, Serial No. 722,049. Divided and this application January 23, 1952, Serial No. 267,806

4 Claims. (Cl. 84—1.25)

This application is a division of my copending application Serial No. 722,049, filed January 14, 1947, and entitled Electronic Organ, now abandoned.

My invention relates to electronic musical instruments and in particular to oscillator systems adapted to produce musical tones, together with cooperating structure and auxiliary circuits.

The so-called electric organs heretofore produced have relied in general on gear-driven tone wheels or similar electro-mechanical tone generating devices. The most important object of my invention is to produce musical notes entirely by electronic means with the ultimate purpose of producing more satisfactory tones at less cost.

Another object of my invention is to provide means for locking a plurality of oscillators in fixed frequency relationship in which the several oscillators produce different frequencies but in a definite and stable relationship.

A further object of the invention is to prevent factors such as temperature changes and changes in the values of circuit components from causing frequency drifts in the oscillators of an electronic organ.

Another object of the invention is to provide an electronic organ in which a large number of notes may be placed in proper tuned relationship by means of a very small number of adjustments. For example, in an eighty-eight note instrument it is one objective to tune the entire instrument by properly tuning twelve inductances.

One important feature of the invention resides in a master oscillator provided with automatic frequency stabilizing means.

Another feature of the invention resides in the combination of a stable master oscillator and a plurality of slave oscillators loosely coupled and arranged to oscillate at harmonics of the frequency of the master oscillator.

Another important feature of my invention relates to a novel transformer used for coupling the slave oscillators to each other and to the master oscillator.

Still another feature of the invention resides in a novel circuit with an associated automatic control system for producing a tremolo or vibrato effect by modulating the output of the final amplifier at a relatively low frequency.

These and other objects and features of the invention will be more readily understood and appreciated from the following detailed description of a preferred embodiment thereof selected for purposes of illustration and shown in the accompanying drawings in which:

Fig. 1 is a circuit diagram for the master and slave oscillators,

Fig. 2 is a view in perspective of the coupling transformer,

Fig. 3 is a view in side elevation of the transformer,

Fig. 4 is a plan view of the transformer,

Fig. 5 is a view in end elevation of the transformer,

Fig. 6 is a circuit diagram of a second form of stable master oscillator, and

Fig. 7 is a circuit diagram of a tremolo circuit.

General organization

The electronic organ of my invention comprises a number of master oscillators arranged to produce audio-frequency oscillation of great stability, each master oscillator being coupled to a plurality of audio oscillators tuned to subharmonics of the master oscillator frequency and triggered or synchronized by the master so that all the oscillators are locked at predetermined frequencies. The oscillators are designed to produce notes very rich in harmonics. An amplifier and speaker are provided and connected to be driven from the oscillators through a special filter which can be adjusted to remove various percentages of the harmonics or add further harmonics in order to produce final notes of varying timbre in simulation of the instruments of the orchestra. A keyboard having a key for each oscillator is, in effect, a switchboard determining which oscillator, or combination of oscillators, is connected to the amplifier. A special circuit is coupled between two of the oscillators and the amplifier and arranged to modulate the amplifier by the difference of the frequency produced by beating together the output of the two oscillators. The result is a pleasing tremolo or vibrato effect.

With this general explanation in mind the following detailed description of some of the elements of the organ will be better understood.

The master oscillator

The master oscillator is organized about the triodes V1 and V2 as shown in Fig. 1 and comprises essentially a Wien bridge oscillator, generally recognized as a special form of an RC oscillator. Inasmuch as the master oscillator is to fix the frequency of as many as eight tone-producing oscillators, as will later be described, it is imperative that the frequency of the master oscillator be stable. If the frequency drifts, it is not a question of detuning one note; it will affect an entire group. If one note of an instrument is out of tune, the effect is not too serious, but if several notes are out of tune, the result is apparent even to the most unmusical listener.

Those skilled in the art will readily appreciate that the resistor generally connected in series between the grid of V1 and the coupling condenser C3 leading to the plate V2 has been replaced by an inductance L1, in Fig. 1, preferably a high Q, low resistance coil. It will be furthermore appreciated that the frequency of the oscillator may be varied by changing one or more of the circuit elements R2, C1, or C3. The frequency of oscillation, assuming that the amplifier tube V2 has zero phase shift, is given by the equation:

$$f=\frac{1}{2\pi\sqrt{R1R2C1C3}}$$

(assuming that L1 has been replaced by the conventional resistor R1). If all the resistors and all the capacitors are equal, the equation becomes:

$$f=\frac{1}{2\pi RC}$$

Any one of the circuit elements referred to in the equations may change in value as a result of change in the ambient temperature. Furthermore some of the elements may change in value with age. It can be shown by experiment as well as mathematically that a decrease in the value of R2, C1 or C3 will produce a corresponding increase in the frequency of oscillation. Conversely an increase in the value of R2, C1 or C3 will reduce the frequency of oscillation. Furthermore if an impedance be connected in the position of L2 in Fig. 1, the frequency of oscillation will increase as the impedance of L2 is lowered. It has been established that the impedance of a coil increases with increases in frequency. Hence by inserting the inductance L1 between the grid of V1 and the coupling condenser leading to the plate of V2, I insert in the circuit an element tending automatically

to compensate for frequency drift likely to be encountered in the operation of the oscillator. If the frequency tends to increase as the result of a lowered value of R2, C1 or C3, the immediate result will be an increase in the impedance of L1 which in turn lowers the frequency of oscillation.

For additional frequency stabilization I have connected L2 in shunt with L1 and R2, the grid bias resistor for V1. One function of L2 is to vary the shunt impedance across R2 and L1 in the following manner. If the frequency of the circuit should tend to rise, the impedance of L2 also rises and consequently reduces the frequency of the oscillator. By proper selection of the value of L2, the correct amount of compensation may be introduced. Another function of the coil L2 is to control the amount of regenerative feed-back reaching the control grid of the tube V1. As the impedance of the inductance L2 increases with an increase in frequency, the amount of feed-back voltage increases; the increase in feed-back voltage in turn reduces the frequency of oscillation.

Furthermore, should the frequency of oscillation decrease, the impedance of L2 likewise decreases, thus decreasing the shunt impedance across R2 and L1 and resulting in an increase of frequency of the oscillator. Accordingly it will be seen that I have provided means for stabilizing the frequency of the oscillator against factors which would otherwise result in varying the frequency either up or down over a narrow range.

Inasmuch as the frequency is affected by changes in the value of the condenser C1, I prefer to employ a silver-mica condenser or any suitable condenser exhibiting practically zero temperature coefficient. Beneficial results will be obtained if all the circuit components are selected for minimum temperature coefficients.

It is to be understood that while I have invented a stable oscillator for supplying the triggering or synchronizing impulses to the slave oscillators, my invention also relates to the combination of a source of triggering impulses of stable frequency and the slave oscillators coupled by a novel form of transformer for operation at the fundamental frequency of the master and harmonics or sub-harmonics thereof. Consequently the master oscillator may take many forms, including mechanical or electro-mechanical sources of oscillations. The master oscillator shown in Fig. 1 is satisfactory. In Fig. 6 I have shown another form of master oscillator which I have found preferable for reasons of economy and because it is inherently more stable. Furthermore the frequency is not affected by line voltage variations of as much as 150%.

In general organization the master oscillator shown in Fig. 6 is what is generally referred to as a "two-terminal oscillator." That is to say, a second triode is used as a phase inverter in place of the more conventional tickler coil. As shown, the oscillator is formed about a dual triode 80, for example a 6SN7. The plates are supplied from B+ through a pair of plate load resistors 82, a filter condenser 84 being connected across the line to smooth out ripples. The grid of the second triode is connected through a coupling condenser 86 to the plate of the first triode, and the plate of the second triode is connected through a coupling condenser 88 and a resistor 90 to the grid of the first triode. The condenser 88 and resistor 90 supply the necessary feed back voltage to the grid of the first triode to maintain oscillation. In the grid-cathode circuit of the first triode there is connected a tank circuit including a variable inductance coil 92 and a condenser 94. For temperature stabilization the condenser 94 is preferably of the silver-mica type or other construction displaying a negligible temperature coefficient. The cathodes are biased conventionally by means of a pair of resistors 96. A condenser 100 is placed physically adjacent the condenser 88 and is subject to the same temperature effects. It is connected to ground and to the junction of the condenser 88 and the resistor 90. The ratio between charges on the condensers 88 and 100 will remain very nearly constant in spite of temperature changes and their joint function is to maintain the feed-back voltage constant, thus tending to prevent frequency drift.

The capacity of the condenser 94 is purposely made high, i. e. 20,–50,000 mmfd., in order to minimize input tube capacity effects which may be about 3.0 mmfd. Changes in tube capacities are thus minute in comparison with the tank circuit capacity and have no effect on the frequency of the output. The coil 92 should be a high Q coil with minimum D. C. resistance.

The resistor 90 not only provides the feed-back path but also tends to isolate the tuned circuit from variations in tube characteristics and voltage variations, the effects of long use of the tubes, etc. In determining the value of the resistor 90 a number of factors must be recognized, including the mu of the tubes, the plate resistance, and the resistance offered by the tank circuit. The critical value is given by

$$Rc=R1(u-1)-Rp$$

in which Rc is the critical value of the resistor 90; RL is the impedance of the tuned circuit at resonance in shunt with the grid-cathode impedance of V1; u is the amplification factor of the tube, and Rp is the plate resistance. It follows therefore that by employing high resistance of Rc, the feed-back voltage will change very little if at all in response to changes in RL, u, or Rp. Consequently I use a resistor 90 of 500,000 to 1,000,000 ohms.

To recapitulate somewhat, the two-terminal oscillator shown in Fig. 6 is rendered satisfactorily stable by the combination of the condenser 100 connected as shown and disposed adjacent the condenser 88; the high resistance 90; and the silver-mica condenser 94.

The oscillator shown in Fig. 6 is provided with a line 102 leading from B+ to the first winding on the transformer shown in Fig. 1, a line 104 leading from the cathode of the second half of the triode 80 to the grid of the tube V3 of Fig. 1 and including an isolating resistor 105 and a coupling condenser 106. The line 108 is a ground connection. A filter condenser 110 is connected from the B+ supply line 102 to ground as line 108.

The slave system

The output of the stabilized oscillator is taken from the cathode of the amplifier tube V2 and fed to the grid of a triode V3 connected as a buffer and amplifier and including in its plate circuit a coil 10 wound about one end of a long core 12. The output is taken from the coil 10 through a blocking condenser 14 and a series resistor 16 to a binding post 18 mounted in a strip 20. As shown in Fig. 1 the core 12, in addition to the coil 10 has six other windings 22 each of which is included in the grid-plate circuit of a conventional blocking oscillator. The blocking oscillators are organized about triodes V4, V5, V6, V7, V8 and V9 and are all alike except that the circuit constants are varied. For example the frequency of the master oscillator may be fixed at 3520 C. P. S. and the blocking oscillators set at sub-multiples i. e. V4—1760; V5—880; V6—440; V7—220; V8—110 and V9—55. The assembly shown in Fig. 1 will therefore produce seven notes each an octave apart and provide the A's for an organ. I contemplate providing other assemblies to produce the other notes of the chromatic scales. The number of notes is not critical and is entirely a matter of choice; eighty-eight notes is the conventional number.

The master oscillator and all the slaves produce notes rich in harmonics; by means of ancillary circuits (not shown) I may remove various percentages of certain harmonics and thus provide means for simulating accurately the timbre of many instruments of the orchestra.

It is not necessary that each slave per se be precisely

tuned to oscillate at the required frequency. By choosing the circuit components to make each slave oscillator oscillate near the required frequency, I achieve the desired result. The impulses from the master oscillator act as trigger impulses and lock the slave oscillators successively at the required frequencies. This is an important feature of the invention because it permits the slave oscillators to be assembled with relatively inexpensive components and with side tolerances. If the master oscillator is set to produce impulses rich in harmonics about a fundamental of 3520 C. P. S., and the first slave oscillator V4 will naturally oscillate at about 1700 C. P. S., the effect of the master oscillations inductively coupled into the grid-plate circuit of the oscillator V4 will be to change the frequency of the latter at once to 1760 C. P. S., and the master oscillator thus operates to synchronize or lock the slave oscillator at the required frequency.

The coupling between adjacent coils of the transformer is such that the amplitude, say, of the fundamental frequency in L3 is much greater than it is in L4. In L4 the amplitude of the sub-harmonic of the fundamental is much greater. So, in L5 the sub-harmonic of the frequency of the oscillator V5 is much greater in amplitude than that of the first sub-harmonic in V4. In other words the locking is a cascade effect with each oscillator supply triggering impulses to the next one in line.

It is preferable to set the master oscillator at the highest frequency of the series of notes to be produced in the assembly. A change of one cycle per second in the trigger frequency of the master oscillator will be reflected in a change of only 1/64 at the lower end, in the oscillator V9. On the other hand if the master oscillator was set at 55 C. P. S., a change of one cycle per second in the master oscillator would produce a change of 64 cycles in the high note of the assembly. A frequency shift of one cycle out of 3520 C. P. S. is not detectable by the human ear, but a change of 64 cycles is immediately evident, even at 5,000 C. P. S.

The transformer

The success of the system depends in part upon the design of the transformer used to couple the master oscillator to the slaves and the slaves to each other. For one thing the amount of coupling is fairly critical. If the coupling is too close, all of the oscillators will operate at the same frequency. If the coupling is too loose, the desired locking effect is not obtained. I have found that a transformer constructed as shown in Figs. 2–5 may be used to great advantage. The transformer is organized about a special core formed of flat rectangular plates made of silicon steel about .014" thick. I have found that a silicon steel well suited for the purpose is sold under the trademark "Trancor." I provide a number of long plates **50** formed as two spaced stacks in which the plates are separated by short transverse interleaved stacks of silicon steel plates **52**. Consequently the plates **50** are separated from each other by air gaps except at the areas shown where the alternate longer transverse stack plates **52** are interleaved.

In order to avoid too close coupling between successive blocking oscillators, I prefer to leave a wide gap in the centers of the long stacks on each side of the transformer. To obtain this effect I leave out three long plates in the center of the long stacks. The effect is that the three inner plates are discontinuous, thus providing a larger air gap and consequent looseness in the coupling. Various combinations may be employed, and the specific arrangement shown in the drawings is to be considered as exemplary only. The assembly of the plates **50** and **52** is secured by any suitable fastening. About each one of the stacks of the plates **52** there is wound a coil contained between a pair of end plates **60** and provided with soldering lugs **62** attached to the ends of the coil and a soldering lug **64** attached to the center of the coil for a center tap connection. Each coil is covered by a protective layer **66** of treated fabric or paper. The winding of one of the coils is suggested in Fig. 4 at the left end thereof where the covering **66** has been broken away to expose the windings **68**. The several coils are spaced apart equal distances by air gaps between successive covering layers **66**. This construction provides just the right amount of coupling. In a typical assembly, referring again to Fig. 1, the coils L3 and L4 may comprise 8,000 turns of No. 40E wire; the coils L5, L6, L7 and L8 may comprise 10,000 turns of No. 40E; and the coil L9 may comprise 13,000 turns of No. 40E. Condensers C5 and C6 may be .01 mfd.; C7 may be .02 mfd.; C8 may be .03 mfd.; and C9 and C10 may be .1 mfd. The grid bias resistors **15** may then be given the values appropriate to set the slave oscillators at or near the required frequencies, in accordance with established practice.

One of the novel features of my invention resides in a circuit arranged to produce a tremolo or vibrato effect by varying the output volume rapidly. The preferred form of the tremolo circuit is shown in Fig. 7. A pair of triodes V3 and V4 are connected with parallel cathodes and plates and arranged otherwise as conventional amplifiers having some degree of non-linearity so that intermodulation products may be produced for purposes to be explained hereinafter. The control grids are fed from the cathodes of two of the slave oscillators of the type shown in Fig. 1, the slave oscillators being so chosen that a beat frequency of roughly seven cycles per second is obtained on the plates of V3 and V4. For example, the slave oscillator producing A♯ at 116.5 C. P. S. may be used in conjunction with the slave producing B at 123.5. The output from the triodes V3 and V4 will therefore contain a beat frequency of 7 C. P. S. as well as 116.5 C. P. S., 123.5 C. P. S., and 240 C. P. S. as a result of the non-linearity of the amplifier tubes the V3 and V4. Conventional grid bias and cathode bias resistors are shown as well as a cathode bypass condenser.

The primary winding of a transformer T9 is connected in the plate circuit of the parallel triodes V3 and V4 with a condenser C44 shunted across the primary. The secondary of the transformer T9 is shunted across a condenser C47 and connected to the cathode, control, screen, or suppressor grid (not shown) of one of the tubes in an amplifier **200** and to ground. The values of the condensers C44 and C47 are chosen to offer very high impedance to frequencies of the order of 7–60 C. P. S. and very low impedance to higher frequencies. Consequently it is only the beat frequency of 7 C. P. S. which passes through the transformer T9 and is applied to the amplifier **200**.

A manually controlled switch **202** is provided to short-circuit the output of the transformer T9 when no tremolo effect is desired. In parallel with the switch **202** is a relay-controlled switch **204**, the circuit for which will now be discussed.

If the tremolo circuit were continuous in its operation upon the opening of the switch **202**, there would be an objectionable pulsing effect audible to the listener when no keys were depressed and the instrument supposedly silent. Therefore I provide means for short circuiting the tremolo circuit output when no key is depressed; however, it is not desirable to have the tremolo effect shut off for the momentary pauses during the playing of a composition, as for example, during quarter or half rests. Accordingly, I provide time delay means for retaining the tremolo effect for a short time after a note has been played and all keys released.

The time delay relay circuit is organized about a double triode V5 and V6 and a relay **206** controlling the switch **204**. One side of the relay **206** is connected to the primary winding of the transformer T9 which in turn is connected to B+. One half V5 of the double triode is connected as a diode rectifier, the grid and plate being tied together and connected to one side of the output

transformer T6 associated with the amplifier 200 and connected across a speaker 208. The cathode of the triode V5 is connected to the grid of the triode V6. The cathode of the triode V6 is biased from a voltage divider R90 and R91 connected from B+ to ground, the bias being such that the triode V6 is cut off except when the triode V5 is conducting. The grid circuit of the triode V6 includes a resistor R92 shunted across a condenser C46, and the plate is connected to the relay 206. A cathode bypass condenser C49 is also provided.

Normally the switch 204 is closed to short circuit the output of the tremolo circuit and the relay is deenergized. When a key is depressed, the amplifier 200 is driven and the transformer T6 carries current. The diode V5 then delivers positive bias for the grid of the triode V6 which consequently becomes conducting and energizes the relay 206 to open the switch 204 and permit the seven-cycle amplitude modulation of the amplifier 200 from the transformer T9.

When all keys are released, the transformer T6 delivers no A. C. voltage to the tube V5 and the tube V6 is then cut off by cathode bias supply. However, the swing to beyond cut-off is delayed by the charge on the condenser C46 which gradually leaks off across the resistor R92 at a rate determined by the RC constant of C46 and R92. The time is therefore proportional to the values of C46 and R92. When the condenser C46 has been discharged, the tube V6 is cut off and the relay 206 is de-energized; the switch 204 is closed, and the tremolo circuit is cut off.

It should be understood that any convenient beat frequency may be obtained by choosing different slave oscillators to drive the tubes V3 and V4. Also I may provide a switch to select two out of three slave oscillators so that the player may select a fast or slow tremolo. For example, the circuit may be organized to provide a choice between a seven-cycle tremolo or a fourteen-cycle tremolo.

As with nearly all electronic devices it is possible to substitute equivalent circuits or portions of circuits in a device employing a combination of electronically performed functions. I believe the functions performed by the apparatus shown and described form a novel combination; I believe also that the particular master oscillator and tremolo circuits shown are novel per se as well as the physical structure of the transformer shown in the drawings. Some of the appended claims are expressions of my novel combinations of functions; other are specific to the details of the circuits or elements they describe. I could not, without a fantastic multiplication of claims, drawings, and words, describe all the modifications and equivalents known to me. A competent electronic engineer will understand them and be able to produce an instrument embodying my invention.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent of the United States is:

1. In an electronic musical instrument including an amplifier, a pair of sources of different electric audio frequency oscillations, electronic means connected to said sources for beating said oscillations together, a tuned circuit connected to said electronic means for passing only the difference frequency, connections between said amplifier and said tuned circuit, a switch controlling said connections, a relay controlling said switch, a rectifier connected to the output of said amplifier, an amplifier tube having a control grid connected to said rectifier and normally biased beyond cut-off, the plate of the amplifier tube being connected to said relay, the circuit being so arranged that when said amplifier is producing, said rectifier delivers positive bias to said amplifier tube to render it conducting, and a resistor-condenser combination included in the grid-cathode circuit of said amplifier tube to delay the cutting off of said tube and the consequent de-energization of the relay when the rectifier stops supplying positive bias to the control grid of said amplifier tube.

2. An electronic musical instrument comprising a plurality of sources of audio-frequency oscillations, two of said sources differing in frequency by a desired low modulating frequency, a non-linear impedance network having two input circuits and an output circuit, said two input circuits being connected to said two sources, an output system for converting audio-frequency oscillations to sound, a keyboard system connected between said plurality of sources and said output system for selecting and linearly combining oscillations from said sources, modulation means connected between said output circuit of said non-linear network and said output system for modulating at said low modulating frequency the oscillations selected and combined by said keyboard system.

3. The combination claimed in claim 2, including a switching circuit connected to said non-linear impedance network for deactivating its effect on said output system.

4. The combination claimed in claim 3, including a time delay relay circuit in parallel with said switching circuit and connected to said output system, operative upon a cessation of said oscillations to delay the deactivation effect on said output system.

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