

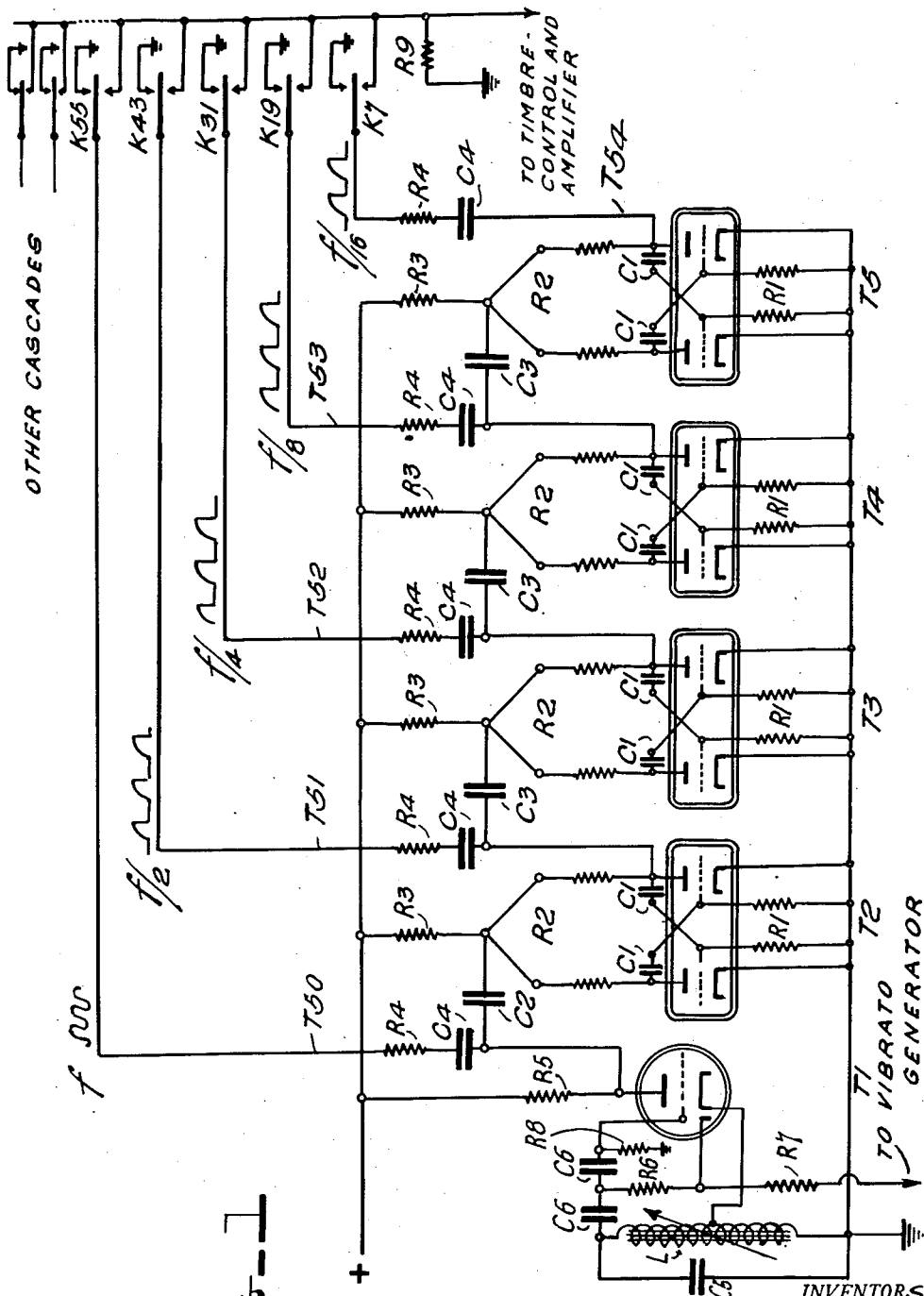
Sept. 18, 1951

M. J. LARSEN ET AL
ELECTRICAL MUSICAL INSTRUMENT

2,568,644

Filed April 6, 1950

8 Sheets-Sheet 1



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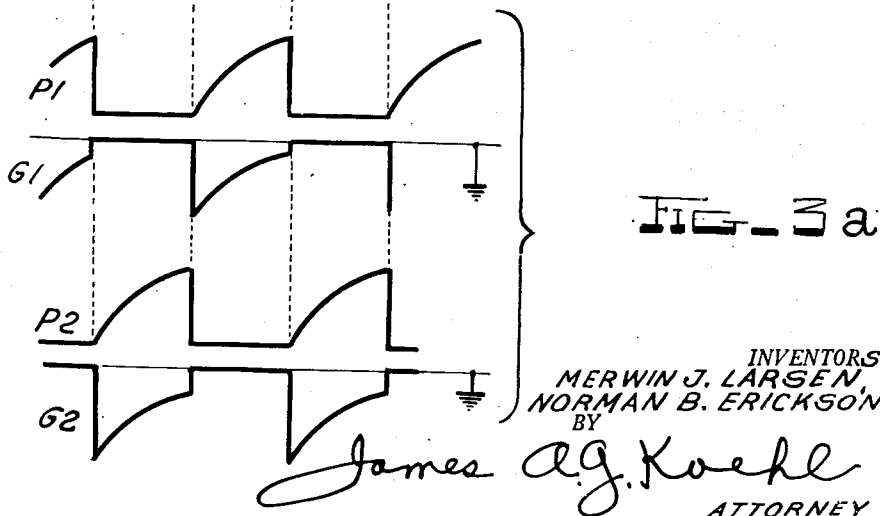
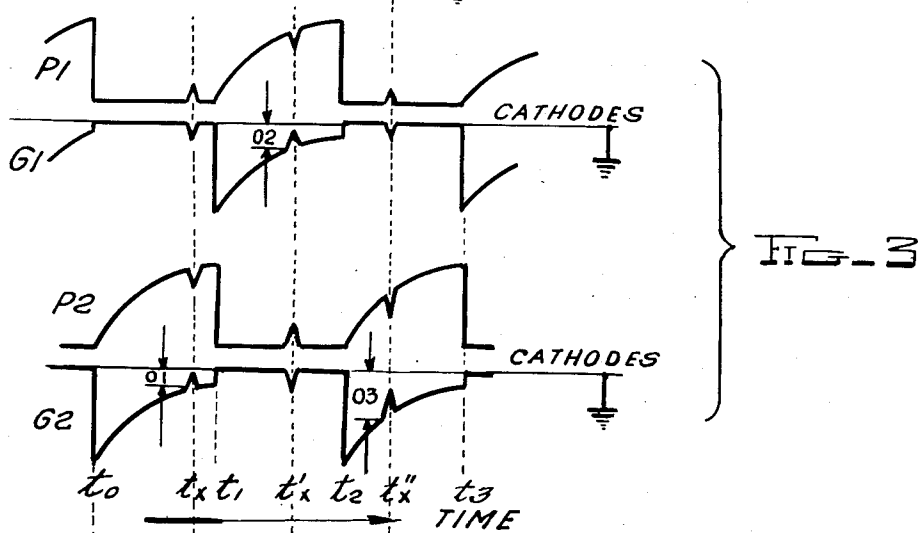
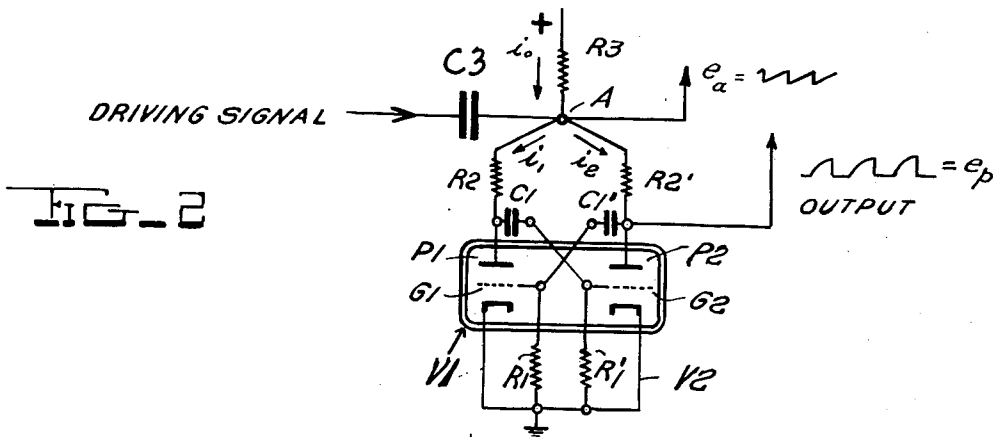
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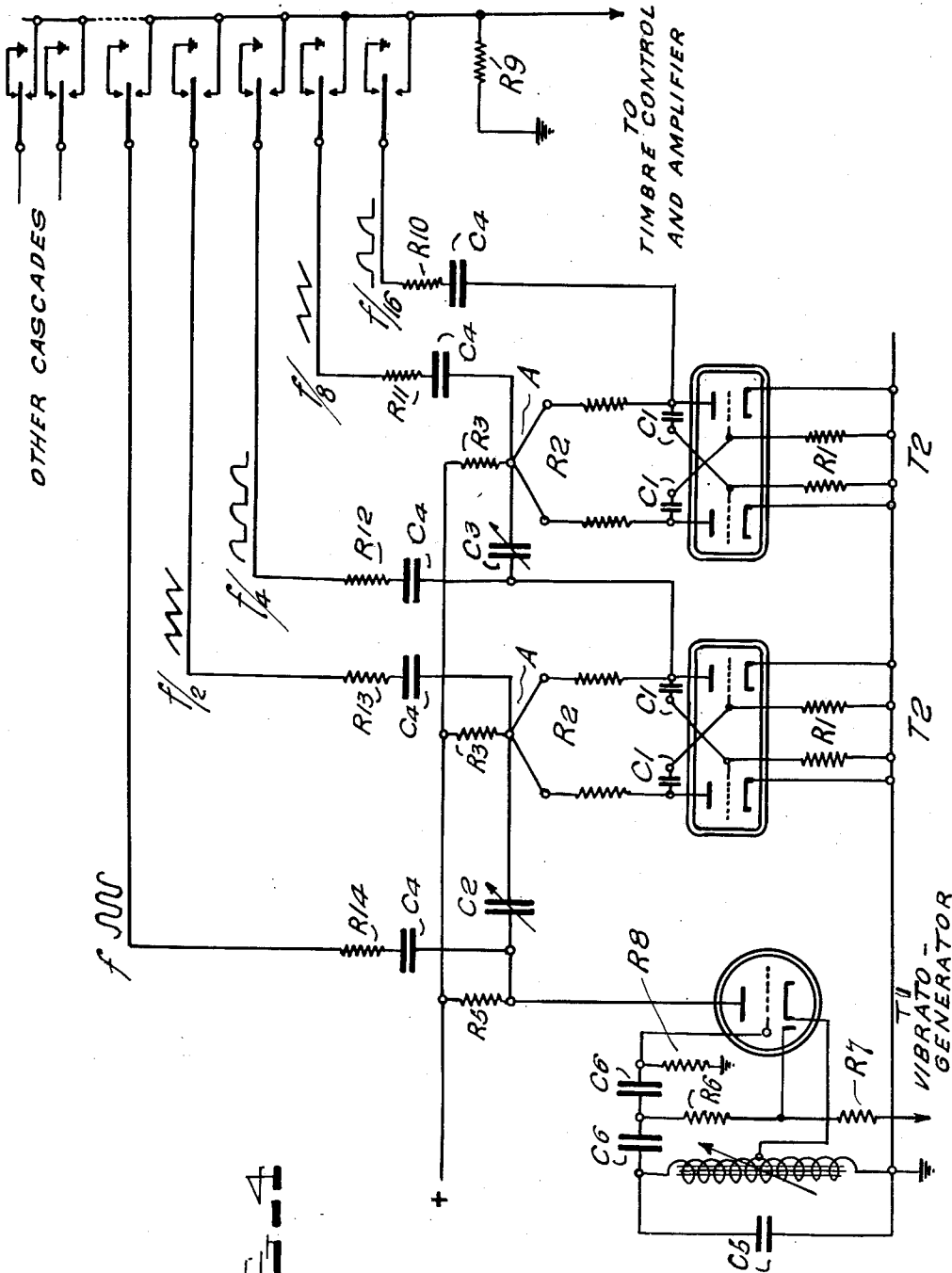


FIG. 4

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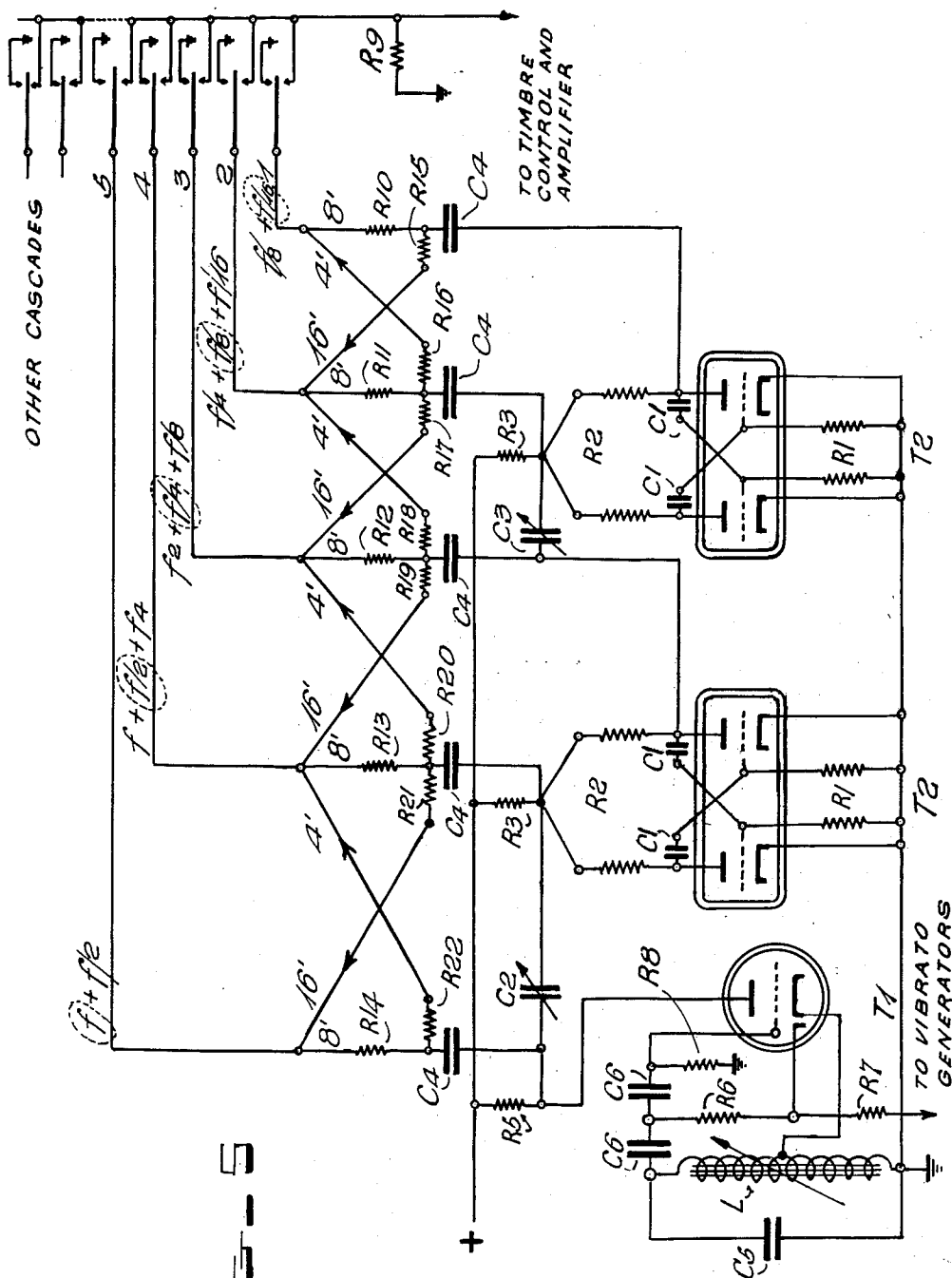


FIG. 5

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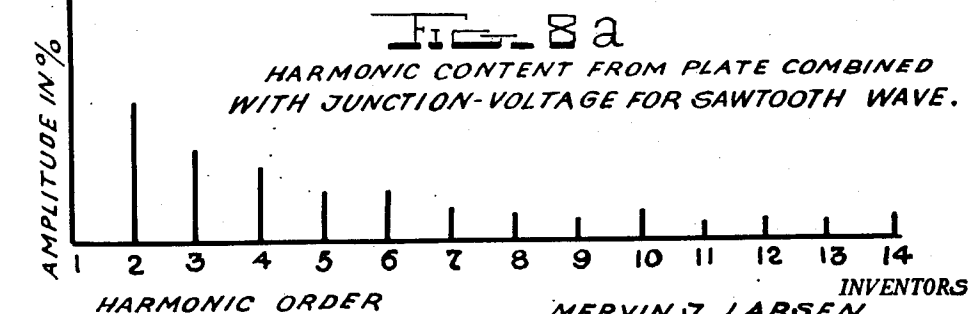
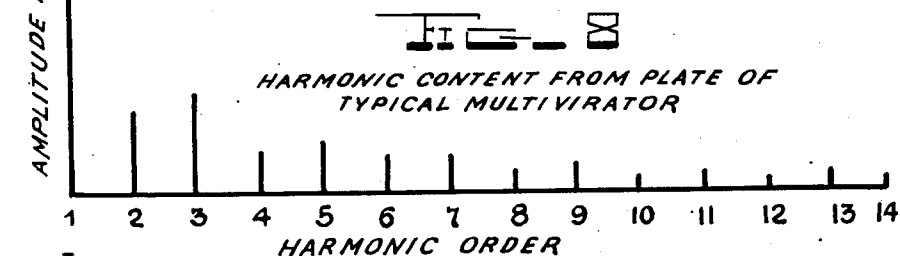
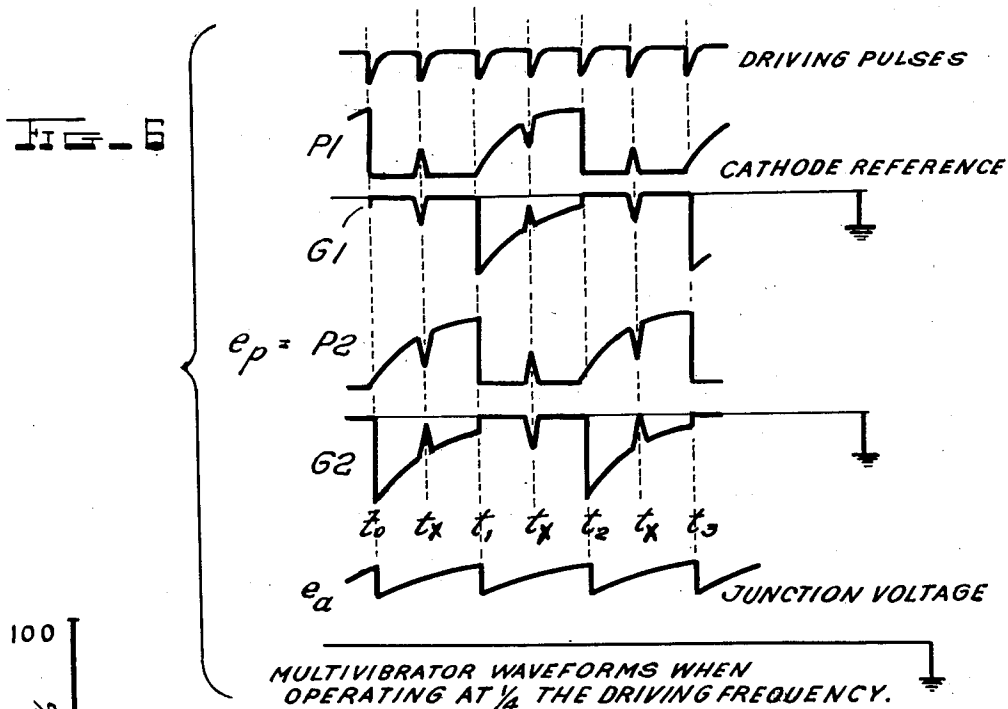
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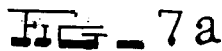
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8 Sheets-Sheet 6



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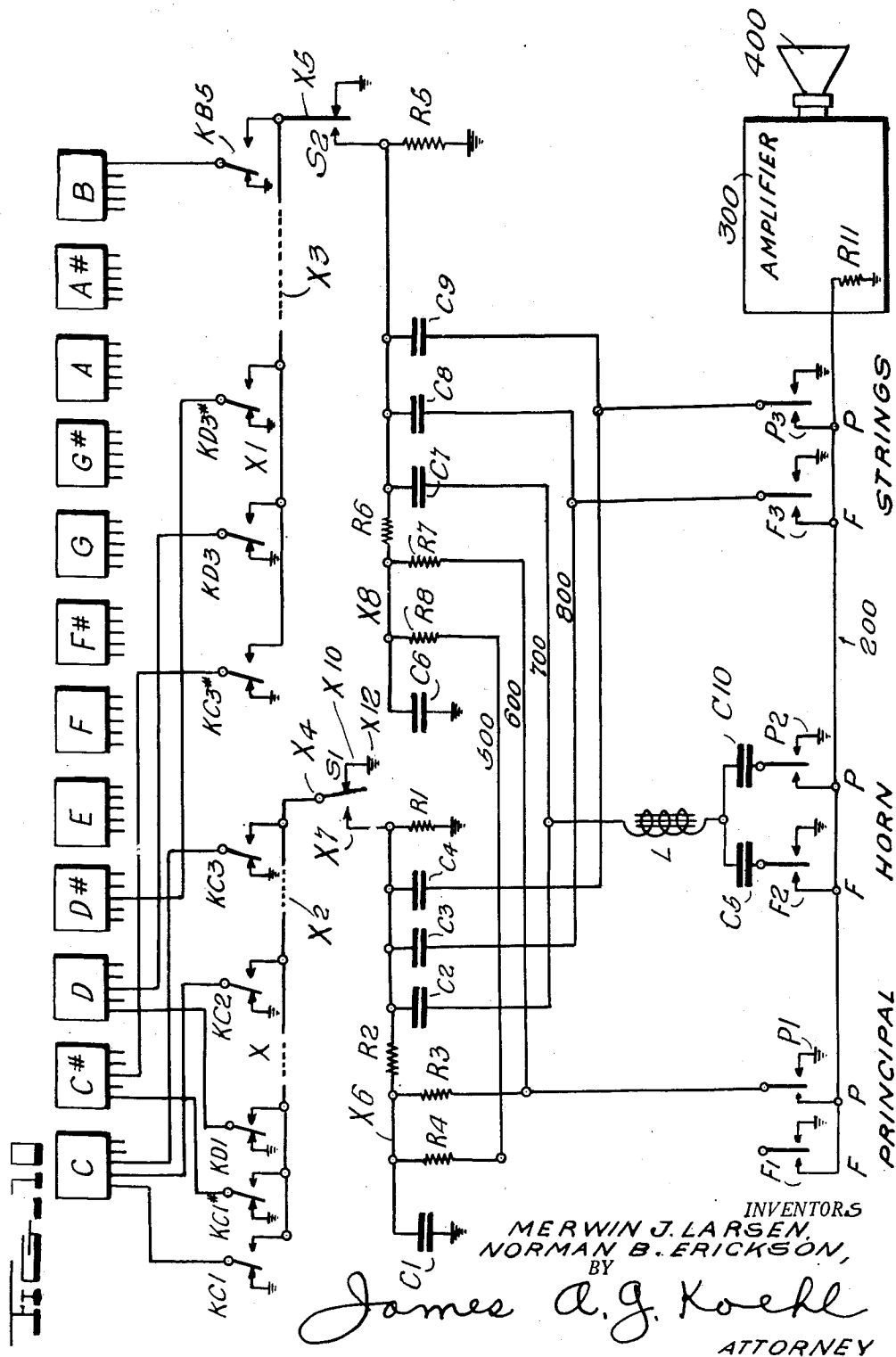
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ELECTRICAL MUSICAL INSTRUMENT

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8 Sheets-Sheet 8



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UNITED STATES PATENT OFFICE

2,568,644

ELECTRICAL MUSICAL INSTRUMENT

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Application April 6, 1950, Serial No. 154,262

19 Claims. (Cl. 84—1.19)

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This invention relates to electrical organs and more particularly to organs of the class in which sustained tones are produced by complex audio frequency electric oscillations in the pitch relation to the vibration frequencies of notes of the even tempered musical scale. An organ of this general class is disclosed in Letters Patent of the United States No. 2,403,090, issued to M. J. Larsen on July 2, 1946, in which patent, multivibrators are the sources from which useful complex electric oscillations are derived, thence treated by a filtering process to provide effective waveforms of oscillations of varying complexity having the pattern characteristics of organ and orchestral tones, which waveforms of oscillations are then amplified and translated into audible sounds for musical expression by means of keying circuits and "stops." The herein disclosed invention is an improvement upon the invention set forth in said patent and particularly with respect to modifications in the divider circuit to secure improved locking with resultant greater assurance of maintaining an invariable pitch relation between the produced tones and to simplify the system as a whole and provide a wide range of frequencies from a minimum number of space discharge tubes such as the multivibrators to be hereinafter described in detail.

Certain of the more essential objects of our invention are:

(1) The provision of dependably functioning sources from which are derived tone signals that are rich in harmonics.

(2) The provision of tone frequency sources capable of withstanding wide changes in line voltage without change in frequency in the produced outputs.

(3) The provision of a tone generating source employing inexpensive components having tolerances that are not too close for practical purposes.

(4) The provision of an electrical musical instrument employing a plurality of divider circuits in which each separate circuit produces electric oscillations at octave separation and consists of a master oscillator tube and a plurality of driven or slave oscillator tubes coupled in cascade by components in a manner that feedback of lower frequencies can be made as negligible as desired.

(5) The provision of a keyboard musical instrument embodying a low-cost and highly dependable tone generating system in which the total number of vacuum tubes employed is appreciably less than the note range of the instrument's keyboard.

(6) The provision of a tone generating system which yields complex waveforms that are uniform throughout the note range of the instrument.

(7) The provision of means for deriving two octavely related tones of dissimilar waveforms from a single multivibrator.

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a single multivibrator two tones having similar waveforms with frequencies that are octavely related.

The manner in which the above and other objects are possible will be more apparent from the following description taken in connection with the accompanying drawings, in which:

Figure 1 is a schematic illustration of a sub-multiple circuit for dividing by a factor of 2;

Figure 2 is a schematic illustration of one of the multivibrator stages;

Figure 3 is a graph of the plate and grid circuit voltages of the triodes of one of the multivibrators as in the case when the driving pulses are too small to cause locking;

Figure 3a is a view similar to Figure 3 indicative of operations in which the plate and grid voltages function to cause effective locking;

Figure 4 is a view similar to Figure 1 showing another example of our invention;

Figure 5 is a view similar to Figure 1 showing a still further embodiment of our invention;

Figure 6 is a view similar to Figures 3 and 3a showing the multivibrator waveforms operating at one-fourth the driving frequency;

Figures 7, 7a and 7b are views respectively indicative of (a) operating conditions effected by variation of component values, (b) operating conditions wherein there is an adjustment of amplitude with natural period of operation equal to the lowest frequency period, and (c) operating conditions the same as in (b) above but with the natural period greater than the lowest frequency period;

Figure 8 is a graph indicating the harmonic content of the output wave from the plate of a typical multivibrator.

Figure 8a is a graph indicating the harmonic content of a saw-tooth wave produced as described herein;

Figure 9 is a view similar to 5 showing a still further example of our invention, and

Figure 10 is a schematic illustration of a composite electrical network embodying our invention.

Our invention essentially comprises coactive, interconnected electrical mechanisms in an electrical network in which keying-circuits connect respective tone generating sources to a work circuit which includes a transducer such as a loudspeaker for translating electric oscillations into audible sounds for musical expression. We have found that space discharge devices designed to yield output waves which are rich in harmonics have many advantages over systems of the prior art including systems wherein simple tone frequencies produced by alternators are selectively synthesized or compounded into various forms of complex waves. One particular advantage of our invention over prior art methods is that the

pitch relation of the produced tones is invariable throughout long periods of time and not affected by atmospheric conditions. This coupled with the advantage which is, that the output waves are rich in harmonics and can be effectively reduced to various less complex waves makes for greater simplicity, compactness of the composite organization of elements than heretofore possible with devices and systems of the prior art.

We particularly stress those features of our invention which insure precision-like operations and coaction between the herein disclosed mechanisms with avoidance of interaction between the elements or intermodulation that would impair operations and render said mechanisms useless in a keyboard musical instrument such as an electric organ.

Two main examples of tone generating sources are shown herein, each consisting of multivibrators coupled in cascade and a control of master oscillator. In one example, frequency division is by a factor of 2. In the other example, division is by a factor of 4 and, by reason of a unique system, but one-half the number of oscillator stages is required for a compass embracing the same number of octaves as the former example.

DIVIDING BY A FACTOR OF 2

At Figure 1 is shown a divider circuit including an electron-coupled L-C master or stabilized oscillator stage T1, followed by four octavely locked "slave" multivibrator stages T2—T5. The plate output circuit T50 of stage T1 and the plate output circuits T51—T54 of the right hand triodes of stages T2—T5 are respectively connected to electric switches K1, K19, K31, K43 and K55. Said switches are connected to an output conductor 100 having a resistance R9. In practice, stage T1 may be a 12AV6 vacuum tube or its equivalent. Multivibrator stages T2—T5 may be vacuum tubes such as either of the types 12AX7 or 12AU7 or equivalent tubes characterized by two half-sections or triodes, each consisting of a cathode, control grid and a plate. The grid circuit of each triode has a resistance R1. The plate circuits of the triodes have resistances R2 connected together at a common junction point P and to resistance R3 from a +B supply source. The plate circuit of stage T1 includes a resistor R5, and as shown, said plate output circuits from stages T1—T5 each has a resistance R4 and a condenser C4. The output circuit of T1 is coupled to the junction point P of stage T2, T3 and T4 are each similarly coupled, each by a condenser C3 to the next succeeding stage.

It follows that from each of the stages T1—T4 a portion of the output wave is impressed on its respective keying circuit and a portion on the junction point P of the next succeeding stage.

A keyboard musical instrument tuned to the even tempered musical scale requires twelve cascaded note producing units as proposed in United States Letters Patent No. 2,410,883. Each separate unit generates octavely separated tones at the vibration frequencies of notes of the same letter of said scale. For example, the "C" note cascade unit may generate complex waveforms having the fundamental frequencies approximating 65 cycles, 130, 260, 520, 1040 cycles respectively. Similarly, the C#, D, D#, E, F, F#, G, G#, A, A# and B, cascade units will each produce octavely separated waveforms at the tone fre-

quencies of all notes of the same letter represented by the oscillator stages of the respective unit. The basic circuit of a typical cascade unit embodying my invention is shown at Figure 1 wherein an electron-coupled L-C master oscillator stage T1 is followed by four octavely locked "slave" multivibrator stages T2, T3, T4, and T5. The plate output of the master oscillator stage T1 is shown as having a slightly distorted sine wave of frequency f , which can be considered as 1040 cycles. The multivibrator outputs drawn from the plates of the successive slave oscillator stages respectively have frequencies $f/2$, $f/4$, $f/8$ and $f/16$. At this point it should be noted that the output waveform of a multivibrator is a combination of a square wave and a saw-tooth wave, i. e. it contains harmonics, diminishing in intensity with increase in the harmonic order, and is more predominant in odd harmonics.

In the circuit shown at Figure 1, the multivibrator plate resistors R3 and R2 are low relative to the grid resistors R1. Hence the driven frequency of each individual multivibrator is approximately proportional to the product $R1C1$, assuming symmetrical construction of the $\frac{1}{2}$ sections of said multivibrators. In practice, the components are selected so that the multivibrator natural frequencies are somewhat lower, such, for example, an octave or more lower than the frequencies at which they are driven. It has been found most expedient in a given cascade to keep the grid resistors the same for all of the stages but to double the tuning capacitors C1 in the grid to plate circuits as the frequency halves.

We have discovered that very superior locking is obtained by driving the sleeve oscillators at the junction points P between the plate resistors R2 and R3 instead of into a single plate or a single grid as disclosed in the aforementioned patent, and as the operability of oscillators for our purpose depends upon maintaining an invariable frequency relation between the coupled oscillators, we stress the novelty of this unique method. Although the ratio between values for R2 and R3 is not critical, excellent results are had when $R2=R3$. The intermultivibrator coupling capacitors C3 are moderately small, as for example, on the order of 150 micromicrofarads as the signal transmitted has a steep wave front. These values can be larger for satisfactory locking operation but if too large, any unbalance in a driven slave oscillator will feed back a signal of sub-octave frequency into the output of the preceding oscillator stage. For the purpose of my invention this must be avoided, hence a moderately small size for the intercoupling capacitors is retained. The coupling capacitor C2 between the master oscillator stage and the first slave oscillator stage is necessarily larger as otherwise sufficient driving voltage would not be supplied due to the fact that the master oscillator stage (an R-L type) has a waveform of less steep wave front. The decoupling resistors R4 are in general several times larger than the plate resistors R2 and R3 so as not to interfere with normal multivibrator operation. Capacitors C4 are blocking capacitors for keeping direct current from the keying circuits X, which circuits connect to a conductor Xa via switches S. Typical waveforms with related frequencies are indicated at the output leads from the coupled oscillator stages. The output impedance shown herein as resistor R9 in conductor Xa must be relatively low so that combined signals from other sources will not "rob" or tend to "steal" the normal

locking signals and give intermittent results. See Figure 10.

The values of the various components necessary in the above referred divider circuit for an F# note cascade are as follows:

F# NOTE CASCADE

Resistors

R1—680,000 ohms	R5—22,000 ohms
R2—100,000 ohms	R6—33,000 ohms
R3—100,000 ohms	R7—1 megohm
R4—470,000 ohms	R8—220,000 ohms

Capacitors

C1—.0012—.0022—.0047—.01 mfd.
C2—.0047 mfd.
C3—150 mmf.
C4—.0022—.0022—.0047—.01—.02 mfd.
C5—.0022 mfd.
C6—.01 mfd.

Inductance

L—.500 henry (variable)

Considering now the typical multivibrator stage shown at Figure 2 and the waveforms shown at Figures 3 and 3a, we will assume that grid G1 of triode V1 at time t_0 rises in potential above cut-off thus lowering plate P1. The lowering of plate P1 of triode V1 forces grid G2 of triode V2 negative via capacitor C1 which connects the plate of V1 to the grid of V2 thus causing plate P2 to rise. These interactions accelerate cause and effect to produce the extremely rapid changes occurring at times t_0 , t_1 , t_2 —etc. as indicated at Figure 3. Immediately after time t_0 plate, P2 starts rising toward the plate supply voltage, thus charging C1 as grid G1 cannot rise appreciably above its cathode. Between t_0 and t_1 , Figure 3, capacitor C1, Figure 2, discharges as grid G2 rises toward its cathode whence at time t_1 the second half of the cycle begins. As mentioned previously the plate resistors R2 and R3 usually are considerably lower than the grid resistors R1 which makes the product (R1) (C1) controlling as to the period of oscillation for the symmetrical arrangement. Should the resistors R2 and R3 be higher and should unsymmetrical operation be considered then the period is approximately proportional to (C1) (R'1+R2+R3) plus (C'1) (R1+R'2+R3) assuming the internal plate resistance of the tube (under conduction) to be much lower than any of the external resistors. This latter case is not considered in the discussion herein.

Consider now the manner of operation while driving the multivibrator by injecting the output of a source into juncture "A" with the intention of locking the multivibrator at some submultiple frequency. An impulse at "A" will affect primarily only the plate of the non-conducting tube because, as mentioned previously, the internal resistance of the conducting plate is considered much lower than that of the external resistors R2 and R3. For clarifying the discussion, voltage pips are indicated in Figure 3 of an amplitude too small to cause "locking." Continuing, it is apparent that between interval t_0 and t_1 , Figure 3 with plate P1 rigid as to potential, then grid G2 is also relatively undisturbed by direct action of any driving pulse because of C1 between P1 and G2. Turning to plate P2 during this same interval, t_0 to t_1 , it is seen that positive rises on P2 are resisted via condenser C1 as G1 cannot rise appreciably above its cathode. The remain-

ing possibility is that a negative impulse on "A" will not be resisted by P2. Hence P2 will lower G1 toward a non-conducting potential (via C1) which causes P1 to rise and urge G2 toward a conduction potential. This rather roundabout phenomenon is illustrated in Figure 3 at times t_x , t'_x , and t''_x .

It is apparent from Figure 3 that transfer would occur at time t_x if the signal at "A" were great enough to cause a grid swing of G2 approximately equal to or greater than the amplitude indicated by 01. Then the "locking," or driven, half period would be equal to interval t_0 to t_x and because of symmetry similarly for the second half. Should, for example, the grid swing be approximately of amplitude 02 as shown on the G1 waveform then the half periods would be equal to the shorter interval t_1 to t'_x . And to the still shorter half periods of t_2 to t''_x if the grid amplitudes were equal to 03. It has been found easy in practice to provide signals of sufficient amplitude, using the circuit of Figure 1, to vary the driving frequency as much as 4 to 1 or more and still maintain locking. This stability is retained with enormous changes in line voltage because driving and driven voltages vary more or less together. In fact, it is common experience to maintain locking throughout when reducing line voltages until the signals disappear from lack of emission in the rectifier supply. In a commercial instrument a complete set of cascades pass routine tests of line voltage having extreme changes from 65 to 130 volts. It is understood from this discussion above that if a cascade is designed to operate with a plus-minus tolerance of one octave (either side) of its design frequency then component tolerances can be broad indeed.

DIVIDING BY A FACTOR OF 4

Figure 4 shows a typical divide-by-four type cascade employing but two slave oscillators and one master oscillator. This embodiment is similar to the divide-by-two cascade embodiment disclosed in Figure 1 except that the slave multivibrators are locked by signals having four times the frequency of the slave oscillators in said embodiment. Certain components in this figure bear the same reference numbers and letters as like components in the embodiment of Figure 5 to be described presently. Also each multivibrator acts as a source for two tones as the fundamental frequency at the junction points "A" of the plate resistors is twice that of either plate when using balanced, symmetrical multivibrators. As the amplitude of the fundamental frequencies $f/2$ and $f/8$ at the junctions A is considerably less than that of $f/4$ and $f/16$ at the plates, suitable adjustment can be made through the dropping resistors R10, R11—R13. For example, R12 may be on the order of 10 times R13.

When dividing by a factor of four the allowances for voltage variation, tube variation, and component tolerances cannot be as generous as when dividing by a factor of two in the first embodiment. It has been found, however, that by choosing an approximate optimum driving signal amplitude these variations can be compensated for very adequately such that this embodiment can be satisfactorily used in a keyboard musical instrument with assurance of an invariable pitch relation of tones. This is accomplished conveniently by using two trimmer coupling capacitors C2 and C3 between the respective stages. For instance, if the component tolerances add up minus there will be a different setting of the

trimmers from the setting for positive tolerance summation. This adjustment is a simple factory expedient and permits the use of components having broader commercial tolerances while at the same time allowing for maximum drift in component values during use of the instrument. By using resistors having values considerably higher than the internal conducting plate resistance of the tubes, then any interchange in tubes has a trivial effect on the operation.

It is observed, as will be demonstrated later, that the harmonic content of the output from the junction points "A" is different from that of the plates. The difference may be great enough to preclude use of this example on a musical instrument. A further difficulty encountered in practice is that some sub-octave signal usually appears at the junction "A" because maintaining a perfect balance is not too practical. However, all of these difference and difficulties are readily surmounted when a musical system is used which intentionally employs fixed sub-octave and octave coupling to enhance the tones as proposed in the co-pending U. S. Patent No. 2,545,665, granted March 20, 1951.

A practical application of this technique is shown in the circuit of Figure 5. Here, of course, the various dropping resistors R10, R11 . . . to R22 are modified to compensate as much as possible for the differences in waveforms in addition to supplying the sub-octave (16 foot) and octave (4 foot) as well as the basic (8 foot) tones. The typical values of the components used in this circuit are, as follows:

"C" NOTE CASCADE

Resistors

R1—510,000 ohms	R13—220,000 ohms
R2—47,000 ohms	R14—100,000 ohms
R3—47,000 ohms	R15—3.9 Megohms
R5—22,000 ohms	R16—470,000 ohms
R6—33,000 ohms	R17—470,000 ohms
R7—1 Megohm	R18—3.9 Megohms
R8—220,000 ohms	R19—3.9 Megohms
R9—4,700 ohms	R20—470,000 ohms
R10—2 Megohms	R21—470,000 ohms
R11—220,000 ohms	R22—220,000 ohms
R12—2 Megohms	

Capacitors

C1—.0027—.01 mfd.
C2—200 to 780 mmf. (variable)
C3—5 to 50 mf. (variable)
C4—.0022—.0047—.0047—.022—.022 mfd.
C5—.039 mfd.
C6—.01 mfd.

Inductance

L—.650 henry (variable)

The operating conditions obtaining while a slave multivibrator is driven at $\frac{1}{2}$ the frequency of its master will be examined more thoroughly as this will bring out both the need for and the value in using trimmer coupling adjustment between the stages.

The waveforms from the circuit, Figure 6 are similar to those of Figure 3 except that there must be a skip pulse between each locking pulse. The skip pulses are indicated as occurring at times t_x . It is evident that if the pulses were too large then locking would occur at t_x and frequency division would be by two instead of by four. If, on the other hand, the pulses were too small, division might drop to six or some other even integer (odd integer division is practically

out for the symmetrical circuit of the type shown). Thus it becomes important to adjust the driving impulse amplitudes for optimum operation by such means as the coupling trimmers of Figures 4 and 5. A more detailed analysis of the relation between driving (or locking) pulse amplitude as related to component tolerance may be made by considering the graphical grid waveform shown in Figure 7.

In Figure 7 the grid discharge curves of Figure 3 are simplified. Periods for the half cycle are indicated. T1 represents the half period of the highest frequency expected when locked while T2 represents that for the lowest frequency to be locked. The skip pulse then will occur at times T1/2 or T2/2 respectively. The locking pulses occur at T1 for the higher frequency and at T2 for the lower frequency. The axis represents the approximate transfer point when the multivibrator is running at its natural frequency. The natural period must always be as long as or longer than the longest locked period if locking is to be expected. Hence the grid wave must follow some path between OAM and OAN. OAM represents the path when capacitor and resistor tolerances fall short while OAN represents the path when these tolerances are plus. When locking for period T1 then the minimum locking voltage is proportional to ordinate 03 while the maximum ordinate is proportional to ordinate 01. Clearly, if 03 were smaller, than the OAN wave would not be tripped. If the signal would be tripped on the minus tolerance wave OAM at time T1 then the locked frequency would be the driving frequency divided by two instead of the desired divided-by-four frequency. A similar argument holds for ordinates 04 and 02. It follows then that to allow for both frequency adjustment and component tolerances as represented by the ratio MN/OM, the signal must be held between a maximum ordinate of 02 and a minimum of 03. In the graph shown this doesn't allow for much variance in the magnitude of the driving signal. If the ratio MN/OM were somewhat greater than that indicated it is possible for the required signal limits to overlap, in which case no one signal amplitude would cover all allowances. This latter situation is overcome readily by permitting adjustment of the driving signal so that the optimum level may be set for each multivibrator.

The value in this is illustrated in Figures 7a and 7b. In Figure 7a OAM represents the grid curve of the natural frequency of a multivibrator, say, which came through the production line with all tolerances piled negative. Allowing for tuning period variation from T1 to T2 it is evident that a value between ordinate 05 and 06 is optimum.

Similarly in Figure 7b where the tolerances pile positive the optimum value is between ordinate 07 and 08. Adjustment of the signal voltage via the trimmer capacitors permits this optimum setting in that it adjusts for the tolerances in the driven tube as well as in the driving source. By making use of this feature dividing-by-four becomes entirely commercial. Without some such adjustment it would necessarily be commercially impractical as very close tolerances would be required and the cost likely would become excessive. This concludes the argument supporting the need and value in using the trimmer capacitors C2 and C3 shown in Figures 4 and 5.

The nature and amplitude of the plate output voltage e_p and the junction output voltage e_a will

be made, as these considerations are helpful in determining the values for the dropping resistor network shown in the circuit of Figure 5. Using the circuit of Figure 2 a symmetrical multivibrator will be assumed wherein $C1=C'1$, $R2=R'2$, and $R1=R'1$. It will be assumed, further, as is true in most cases, that the driving signal has but little effect on the waveform. Both the plate voltage e_p and the juncture voltage e_a are shown to advantage in Figure 6. Because of symmetry, both plate voltages have identical form but one is displaced in time by $T/2$ or $1/2f$ where T represents the total recurrence period of the plate voltage with f its frequency. Thus if one plate is expressed as the alternating portion of a Fourier series it becomes:

$$(1) \quad e_{p1} = \sum_{n=1}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t)$$

and the other plate becomes

$$(2) \quad e_{p2} = \sum_{n=1}^{\infty} [a_n \cos n\omega(t - T/2) + b_n \sin n\omega(t - T/2)]$$

or

$$= \sum_{n=1}^{\infty} [a_n \cos n(\omega t - \pi) + b_n \sin n(\omega t - \pi)]$$

To solve for the juncture voltage e_a the following current and voltage equations are drawn from Figure 2.

$$\begin{aligned} i_0 &= i_1 + i_2 \\ e_{p1} &= i_0 R_3 + i_1 R_2 \\ e_{p2} &= i_0 R_3 + i_2 R_2 \end{aligned}$$

Solving these yields

$$(3) \quad e_a = i_0 R_1 = [e_{p1} + e_{p2}] \left[\frac{R_1}{2R_1 + R_2} \right]$$

Considering the sum $e_{p1} + e_{p2}$ using Equations 1 and 2 the sum is zero for odd harmonics (odd values of integer n) but equal to $2e_{p1}$ for even values of n . Hence

$$[e_{p1} + e_{p2}] = 2 \sum_{n=2,4,6,\dots}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t)$$

or abbreviating

$$(4) \quad [e_{p1} + e_{p2}] = 2e_{p1} \quad n \text{ even}$$

Thus it is necessary only to analyse one plate voltage and note the values of the even harmonics as (3) becomes, using (4)

$$(5) \quad e_a = \left[\frac{2R_1}{2R_1 + R_2} \right] [e_{p1}] \quad n \text{ even}$$

In the circuit shown in Figure 5, $R1=R2$ whence

$$(6) \quad e_a = \frac{2}{3} [e_{p1}] \quad n \text{ even}$$

The harmonic analysis of the plate voltage of a typical multivibrator is shown in Figure 8. From Equation 6 it is evident that the amplitudes of the even harmonics are proportional to the odd and even harmonics making up the junction voltage. It is seen that the junction voltage has a waveform that is substantially saw-toothed, as the amplitudes of this voltage vary approximately inversely proportional to the order of the harmonic. By proper choice of dropping resistors the plate and junction outputs can be combined to yield a substantially saw-toothed wave also from the plate. Such a waveform is shown in Figure 8a which is produced by doubling the percent of the second harmonic content. In this manner a single multivibrator becomes a two-tone source

having similar waveforms with frequencies octavely separated.

By using similar but extended reasoning to that given above it follows that not only can the waveforms be adjusted but also the sub-octave and octave frequencies can be determined through an approximate dropping resistor network.

An alternative generator circuit is shown in Figure 9 in which the outputs taken from a junction point in the grid circuit between resistors $R2$ and $R1$ and also from a plate. The value of resistor $R1$ may be very high as its chief function is to keep the average grid potential from drifting. In this circuit similar analyses hold for the waveform of the grid-juncture output. Equation 6, for example, becomes

$$(7) \quad e_x = \frac{2}{3} [e_g] \quad n \text{ even}$$

where e_x is the junction voltage and e_g either grid voltage. (See Figure 10.)

The chief advantage in taking the double-frequency supply from the grid juncture instead of from the plate juncture is that the grid voltage has a considerably higher content of even harmonics and hence slight unbalance in the circuit components do not inject nearly as much sub-octave frequency component into the output. The values used in practice for a typical cascaded unit, Figure 9, are

Resistors

$R1$ —820,000 ohms	$R12$ —2.2 meg.
$R2$ —330,000 ohms	$R13$ —220,000 ohms
$R3$ —47,000 ohms	$R14$ —470,000 ohms
$R4$ —47,000 ohms	$R15$ —4.7 meg.
$R5$ —47,000 ohms	$R16$ —470,000 ohms
$R6$ —33,000 ohms	$R17$ —470,000 ohms
$R7$ —1 meg.	$R18$ —3.9 meg.
$R8$ —220,000 ohms	$R19$ —3.9 meg.
$R9$ —4,700 ohms	$R20$ —470,000 ohms
$R10$ —2.2 meg.	$R21$ —470,000 ohms
$R11$ —220,000 ohms	$R22$ —820,000 ohms

Capacitors

$C1$ —.0027—.01 mfd.
$C2$ —200 to 800 mmf. (variable)
$C3$ —5 to 30 mmf. (variable)
$C4$ —.0022, .0047, and .022 mfd.
$C5$ —.027 mfd.
$C6$ —.01 mfd.
$C7$ —.01 mfd.

Inductance

$L1$ —.650 henry

At Figure 10 is a diagrammatic view of an organ network in which our improved tone sources are connected for conduction of the output waveforms to a filter system from selected ones of said sources. It is assumed that a keyboard of the organ will have sixty playing-keys, and that for and actuated by each separate key is an electric switch, as first above stated, the arrangement being such that when the key is raised, the switch is in an "off" condition and when lowered, it is in an "on" condition. To avoid complications, only nine of the switches are shown. These are designated $KC1$, $KC2$, $KC3$; $KC\#1$, $KC\#3$; $KD1$, $KD3$; $KD\#3$, and $KB5$. For the purpose herein, the frequency intended to be effective at key $KC1$ will be approximately 65 cycles per second. The frequency effective at key $KB5$, which is key $\#9$ in said keyboard will be approximately 1975—cycles per second. As shown herein said switches are arranged in groups X and $X1$. Common to switches for notes $KC1$ — $KC3$ is a conductor $X2$.

Common to switches KC#3—KB5 is a conductor X3. Conductor X2 is connected by a lead wire X4 to an electric switch S1. Similarly, conductor X3 connects with an electric switch S2 via a lead wire X5. To this point in the description the conductor X2 may be taken to represent the lower register of a split keyboard and conductor X3 the upper register of said keyboard.

A quality or timbre control system is employed for modifying the complex output waves from the aforementioned tone sources, and, as shown, said system comprises a conductor X6, one terminal of which is connected to ground via condenser C1. The opposite terminal of said conductor is connected in circuit to contactor X7 of switch S1, which said contactor connects to ground through a resistor R1. In like manner, a conductor X8 has one of its terminals connected to ground via a condenser C6, the other terminal connecting to contactor X9 of switch S2. Contactor X9 connects to ground via a resistor R5. Contactors X10 and X11 of switches S1 and S2 are each thereof grounded at X12.

The wave filter system is designed to produce output waves which are typical of organ qualities known as the Principal, Horn and Strings. We have made provision for only three tone qualities but this number can be increased by changes in the types of filters employed. Provision, however is made herein for producing each of these tone colors at different predetermined amplitudes as will be described presently. Conductor X6 has a resistor R2. Conductor X8 has a similar resistor R6. Components F1, P1, F2, P2, F3 and P3 are electric switches connected to a common output conductor 200 which connects to an electro-acoustical system which includes power amplifier 300, a loud speaker 400 and a resistance R11 to ground.

Switches F1 and P1 are connected to conductor X6 by resistances R4 and R3. At C2, C3, C4, C7, C8 and C9 are condensers and at R8 and R4 are resistances. Condensers C2, C3 and C4 are connected across conductor X6. Resistances R8, R7 and condensers C7, C8 and C9 are connected across conductor X8, as shown. Resistance R8 is connected by lead 500 to resistance R4 to switch F1. R7 connects in circuit to R3 by lead 700. C8 connects in circuit to C3 by lead 800 and C9 connects in circuit to C4. From lead 700 is a connection 900 to a coil L, which forms part of a circuit mesh that includes condensers C5 and C10 in branch paths to the movable contactors of switches F2 and P2.

In Figure 10 the twelve rectangles designated C, C#, D, D#, E, F, F#, G, G#, A, A# and B respectively represent twelve cascade units, such that there is one such cascade for all notes of the same letter of the chromatic scale, each separate cascade unit having as many output circuits as there are individual oscillators. To avoid complications and confusion, we have shown certain of the outputs from cascade units C, C#, D, D# and B only connected to their coactive keying-circuits. The resistors R1 and R5 are moderately low for two reasons. One is to retain satisfactory multivibrator operation by preventing deleterious reaction between multivibrators when numerous keys are pressed simultaneously. The other is for tonal considerations in holding the "Q" of the Horn resonant circuit moderately low as well as to prevent cross talk between registers by holding to a relatively low impedance level.

The "Principal" tone is produced in the lower

register by means of the R—C low-pass filter comprising R2 and C1. Loud F tone at "stop" switch F1 and soft P tone at switch P1 are determined by the difference in the relative values in the dropping resistors R3 and R4 which connect X6 with switches F1 and P1. The "Principal" tone from the upper register is produced similarly via R6 and C6 in conductor X8. The magnitude of capacitor C6 is considerably smaller than that of C1 in the lower register because of the higher frequencies involved. Were the same size used for both registers there would be no need of separate filter groups, but, in this case, either the lower notes would not have their higher partials filtered sufficiently or else the higher notes would have even their fundamental components attenuated far too severely. Although more groups can be used, two groups provide a reasonable compromise simplicity and tonal amplitude balance.

The "Horn" tone is produced by a series resonance circuit comprising C2, C7, C5, C10, and inductor L. As shown, C5 and C10 connect with respective "stop" switches F2 and P2. A resonance in the vicinity of 600 cycles with a circuit "Q" of approximately 2 has been found to be quite satisfactory in a commercial instrument. Capacitors C2 and C7 which draw from the two registers are alike. C10 is smaller than C5 to provide the required intensity differences. Regardless of the position of any of the switches involved the circuit arrangement is such that C5 and C10 are in parallel, these two acting in series with the parallel combination of C2 and C7. Thus the resonant frequency is unaltered by either registry switch or "P," "F" switch manipulation.

The "String" tones are produced by passing the signal through appropriately chosen capacitors C3, C4 in the lower register and C8, C9 in the upper register and connecting same to respective "Stop" switches F3 and P3. Said capacitors emphasize the magnitudes of the higher frequency components of the various tones.

The switch poles are grounded when in the "off" position so as to prevent any undesired cross-talk between the several stops. The values of the components used in the circuit illustrated at Figure 10, are:

Resistors	Capacitors
R1—4,700 ohms	C1—.047 mfd.
R2—18,000 ohms	C2—.0027 mfd.
R3—220,000 ohms	C3—.0018 mfd.
R4—68,000 ohms	C4—500 mmf.
R5—4,700 ohms	C5—.01 mfd.
R6—18,000 ohms	C6—.01 mfd.
R7—270,000 ohms	C7—.0027 mfd.
R8—100,000 ohms	C8—.0018 mfd.
R11—10,000 ohms	C9—500 mmf.
Inductance	C10—.0027 mfd.
L—24 henry	

The term "unit cascade" employed herein shall be construed to mean any desired number of oscillator stages for any given frequency range.

The term "musical instrument" employed herein shall be construed to mean an instrument employing any well known selectors for the transmission of tone frequencies to an electroacoustical translating system from the aforementioned oscillators. Said selectors may consist of one or more keyboards and a pedal keyboard. We have shown and described a single keyboard which is divided to provide what we have referred to as upper and lower registers, and have

connected same in circuit with a wave filter system and to respective groups of frequency sources so that tonalities can be produced when playing the keys in one register that will be different from tonalities elicited when playing the keys in the other register. By our unique system of wave filters it is also possible to produce the same tonality from both registers and to mix a tone of one quality with a tone of a different quality and with mathematically correct effects and with no "robbing" amongst the different frequencies.

What is said above regarding grouping predetermined tone frequencies for the playing of tones of different timbre from the different registers of a divided or split keyboard applies in like manner to playing different tonalities from separate and distinct keyboards.

The term resistive mesh as used herein shall mean three resistances connected together to provide a common junction point between two resistances and a third resistance, such that the third resistance connects with a plate supply source and two resistances connect to the plate circuits of the triodes of a multivibrator, and whereby a driving pulse wave is injected into the plate circuits via said common junction point.

The means for producing a plurality of harmonically related waveforms from a single multivibrator as disclosed in Figure 9 shall comprise the aforementioned resistive meshes, the values and locations of the various electrical components in the disclosed network, including the variable capacitive couplings between stages and the capacitive devices in the grid circuits of the triodes of said multivibrators.

Particular stress is placed on the herein disclosed means for preventing objectionable or unwanted submultiple feedback from a lower (driven) multivibrator stage to the next adjacent (driving) multivibrator stage. Taking for example, driven stage T3 and driving stage T2 in Figure 1, it is significant that the triode sections of each thereof are alike and that the components are connected in the same positions and are also alike. At the junction point P of the driven stage, the frequency is the same as that of the plate (or grid) of the driving stage. A balanced condition is established, such that the frequency at the junction point P of a driven multivibrator stage is the same as that of the plate (or grid) of a coupled driving multivibrator stage which insures against objectionable or unwanted feedback from the driven to the driving stage. Our use of small capacitors C3 in the couplings between stages further insures against unwanted or objectionable feedback even though the driven multivibrator is considerably unbalanced. The term "balanced" shall be taken to mean that the triodes of the driving and driven stages are alike and that the components are connected in the same positions and are also alike, whereby the operating characteristics become interchangeable.

What we claim as our invention is:

1. A musical instrument of the class employing an electrical network including an output circuit having an electroacoustical translating device; said instrument comprising a control frequency source including a control frequency oscillator producing an output wave of a given frequency; a series of driven multivibrator stages, each having a pair of triodes, a resistive mesh embodying two resistances connected to the respective plate circuits of said triodes and a single resistance connected to said two resistances to provide a com-

mon junction point between the former and the latter, said single resistance connected to $a+B$ supply source, and a resistance to ground in each of the grid circuits of said triodes; a capacitive coupling between the output of said control frequency oscillator and the junction point at the plate resistances of the first multivibrator stage; a capacitive coupling between the output of the first multivibrator stage and the junction point at the plate resistances of said second multivibrator stage; and keying-circuits connecting said control frequency oscillator and said multivibrators for selective transmission to said output circuit of output waves from said oscillator and said multivibrators.

2. A musical instrument according to claim 1, wherein the output circuit of said network has a resistance which is low relative to the impedance of said control frequency oscillator and said multivibrators.

3. A musical instrument according to claim 1, wherein said plate resistances are low relative to said grid resistances.

4. A musical instrument according to claim 1, wherein said plate resistances are low relative to said grid resistances and the output circuit of said network has a resistance which is low relative to the impedance of said control frequency oscillator and said multivibrators.

5. A musical instrument according to claim 1, wherein a capacitive element connects to an intermediate point between the plate and the plate resistance of one triode of a multivibrator stage and the grid of the other triode of the same stage.

6. A musical instrument according to claim 1, wherein and with respect to each multivibrator stage a capacitive element connects to an intermediate point between the plate and the plate resistance of one triode of said stage and the grid of the other triode of the same stage, and wherein all of the aforementioned resistances and said capacitive elements are of such values that each multivibrator stage oscillates at a frequency which is a predetermined submultiple of said given frequency.

7. A musical instrument according to claim 1, wherein and with respect to each multivibrator stage a capacitive element connects to an intermediate point between the plate resistance of one triode of said stage and the grid of the other triode of the same stage, and wherein the values of the last named capacitive elements double progressively in the direction of the lowest frequency multivibrator stage.

8. In an electrical musical instrument employing keying-circuits and an electroacoustical translating system for translating electrical energy into acoustical energy; said instrument comprising a control frequency source consisting of an electron discharge device producing an output wave of a given frequency; a driven frequency source consisting of an electron discharge device having two triodes, the plate circuits of which each has a resistance therein, said plate circuit resistances connected together at a common junction point to a single resistance, said single resistance connected to $a+B$ supply source; a resistance to ground in the grid circuit of each of said triodes; and means coupling the output circuits of the control frequency source and the driven frequency source to respective ones of the aforementioned keying-circuits and a capacitive coupling connecting the control frequency source to the driven frequency source at said junction point.

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9. An electrical musical instrument according to claim 8, wherein the resistances in the grid circuits are equal and high relative to the plate circuit resistances.

10. In a musical instrument employing an electrical network having a plurality of keying-circuits, an output circuit to which said keying-circuits are connected, and an electroacoustical translating system connected to said output circuit for translating electrical energy into acoustical energy; a submultiple generator embodying a control circuit providing a source of alternating current of a given frequency; a multivibrator, the natural oscillation frequency of which is a desired submultiple of said given frequency; means coupling said control circuit to said multivibrator for impressing a portion of the output of said circuit on said multivibrator to control oscillation thereof at said desired submultiple frequency and for impressing another portion of the output on one of said keying-circuits; means for stabilizing oscillation of said multivibrator at said submultiple frequency; and means by which waves at harmonically related frequencies are derived from said multivibrator and respectively impressed on others of said keying-circuits.

11. An electrical musical instrument according to claim 10, wherein the stabilizing means includes a resistance in the plate circuit of each triode of said multivibrator, a resistance connected to a plate supply source and to the first mentioned resistances to provide a common junction point between said resistances, and wherein the coupling means connects with said multivibrator at said junction point.

12. In a musical instrument employing an electrical network having an output circuit provided with an electroacoustical translating system; a submultiple generator having at least two multivibrator stages, each consisting of two triodes, a resistance in the grid circuit of each triode, a resistance in the plate circuit of each triode, and a resistance connected to the plate resistances to provide a common junction point between them; a control frequency oscillator producing an output wave of a given frequency, a capacitive element coupling the output of said control frequency oscillator to the first multivibrator stage at the junction point between the plate resistances thereof, a capacitive element coupling the first multivibrator stage to the second multivibrator stage at the junction point between the plate resistances thereof, and at least one keying-circuit for each multivibrator stage and said control frequency oscillator for transmitting portions of the outputs thereof to the output circuit of said network.

13. An electrical musical instrument according to claim 12, wherein the aforementioned capacitive coupling elements are each thereof adjustable.

14. In a musical instrument employing an electrical network having an output circuit provided with an electroacoustical translating system, said instrument comprising a submultiple generator having a control frequency oscillator and at least a first multivibrator stage and a second multivibrator stage, said multivibrator stages each consisting of twin triodes, a resistance in the plate circuit of each triode, and a single resistance connected to said resistances to provide a common junction point between them; a first keying-circuit connecting the control frequency oscillator to said output circuit, a second keying-circuit connecting the junction

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point at the plate resistances of the first multivibrator stage to said output circuit, a third keying-circuit connecting the plate circuit of one triode of said first multivibrator stage to said output circuit; a fourth keying-circuit connecting the junction point at the plate resistances of the second multivibrator stage to said output circuit, and a fifth keying-circuit connecting the plate circuit of one triode of the second multivibrator stage to said output circuit.

15. An electrical musical instrument having an electroacoustical translating device; said instrument comprising a submultiple generator including a driven frequency device embodying a vacuum tube having two triodes, the grid circuits of which have resistances connected to ground, and plate circuits connected at a common junction point to a third resistance, said third resistance connected to a plate supply source; and a control frequency device operating at a given frequency, said control frequency device capacitatively coupled to said driven frequency device for impressing a driving pulse on the plate circuits thereof via said common junction point; a wave transmitting circuit connecting the control frequency device to said translating device, and at least one wave transmitting circuit connecting the driven frequency device to said translating device.

16. An electrical musical instrument having an electroacoustical translating device; said instrument comprising a submultiple generator including a driven frequency device embodying a vacuum tube having two triodes, the grid circuits of which have resistances connected to ground, and plate circuits connected at a common junction point to a third resistance, said third resistance connected to a plate supply source; and a control frequency device operating at a given frequency, said control frequency device capacitatively coupled to said driven frequency device for impressing a driving pulse on the plate circuits thereof via said common junction point; a wave transmitting circuit connecting the control frequency device to said translating device, and at least two wave transmitting circuits connected to said driven frequency device for transmitting therefrom harmonically related output waves which are submultiples of the output wave of said control frequency device.

17. A musical instrument of the class employing keying-circuits, a divider circuit including a master oscillator having at least a plate, a grid and a cathode, and a plurality of slave oscillators, said master oscillator and said slave oscillators coupled in cascade, each slave oscillator comprising a multivibrator providing a pair of triodes; a plate voltage supply source; an impedance in the plate circuit of each triode of each individual slave oscillator such that for each slave oscillator there is a pair of impedances, another impedance connected to said pair of impedances and providing a common junction point between them; means for impressing a portion of the output from a slave oscillator on the junction point of the plate impedances of the next succeeding slave oscillator and a portion on one of the aforementioned keying-circuits; an impedance connecting the master oscillator to said plate supply source, and means for conducting a portion of the output from said master oscillator to the next succeeding slave oscillator and a portion to another one of the aforementioned keying-circuits.

18. In an electrical musical instrument; a con-

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trol frequency source, a multivibrator of the duo-triode type, means for producing two different wave-forms at harmonically related frequencies from said multivibrator and comprising a resistive mesh including two resistances connected to the plates of the respective triodes of said multivibrator and a single resistance connected to said two resistances and providing a common junction point between the latter and the former, a capacitive coupling connecting said control frequency source to said common junction point, a resistive mesh including two resistances connected to the respective grids of said triodes and a single resistance connected to said grid resistances to provide a common junction point between the latter and the former, a keying-circuit connected to plate of one of said triodes, and a keying-circuit connected to said second named junction point, the first named single resistance connected to a plate supply source and the second named single resistance connected to ground.

19. In a musical instrument employing an electroacoustical translating system, said instrument comprising, a submultiple generator including a control frequency source operating at a given frequency and a series of multivibrators capacitively coupled in cascade, each of said multivibrators consisting of a vacuum tube of the type employing duo-triodes; each multi-

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vibrator including a resistive mesh consisting of two resistances connected to the plates of the respective triodes thereof and a third resistance connected to said two resistances and providing a common junction point between the former and the latter, a keying-circuit for and connecting the junction point of the resistive mesh of each multivibrator to said translating system, a keying-circuit for and connecting one plate of the triode of each multivibrator to said translating system, each of said multivibrators having electrical components which are coactive with the resistive mesh of said multivibrator and with the capacitive couplings of said generator so that the output frequency at said one plate is one half that of the output frequency at the junction point between the two resistances and the third resistance of said resistive mesh.

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