March 31, 1936. R. H. RANGER 2,035,836

SYNTHESIS OF MUSICAL TONES

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FIG. 1

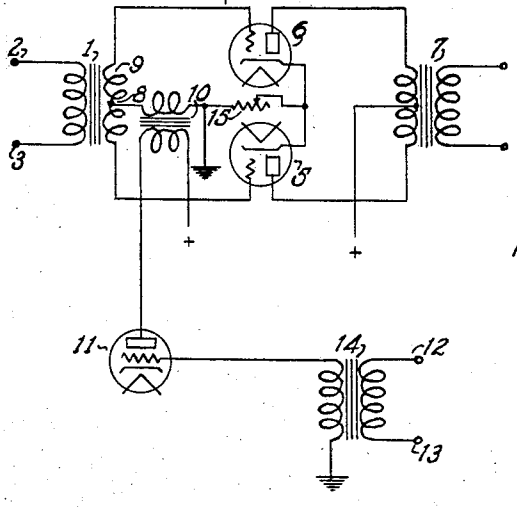


FIG. 2

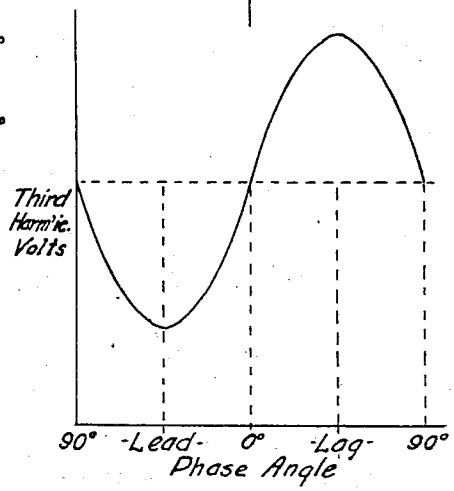


FIG. 3

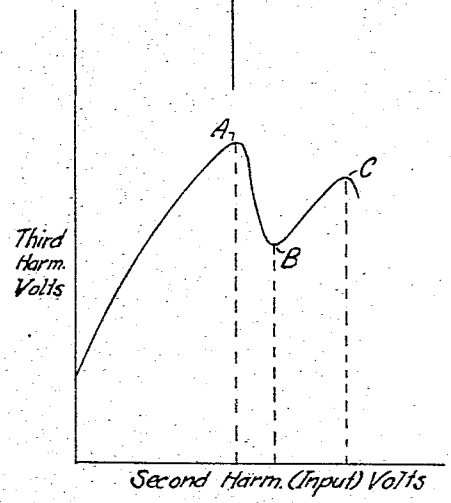


FIG. 4

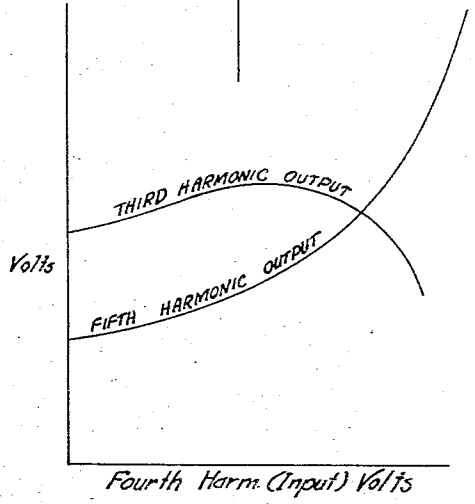
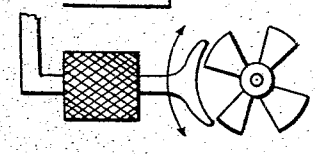


FIG. 8.



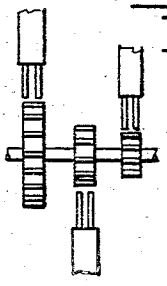


FIG. 9.

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FIG. 5

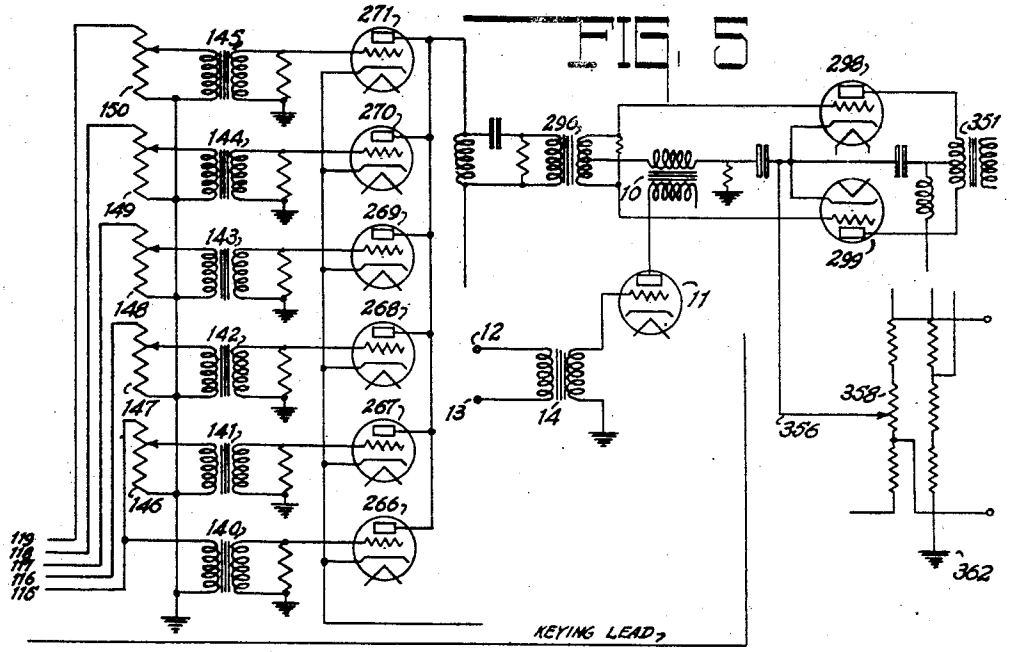
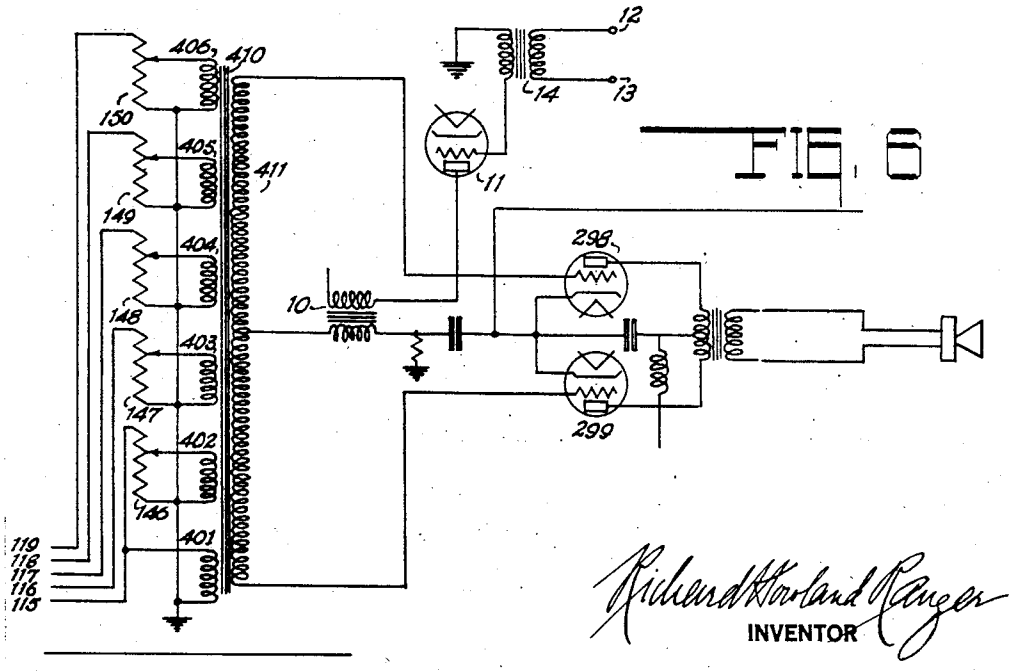


FIG. 6

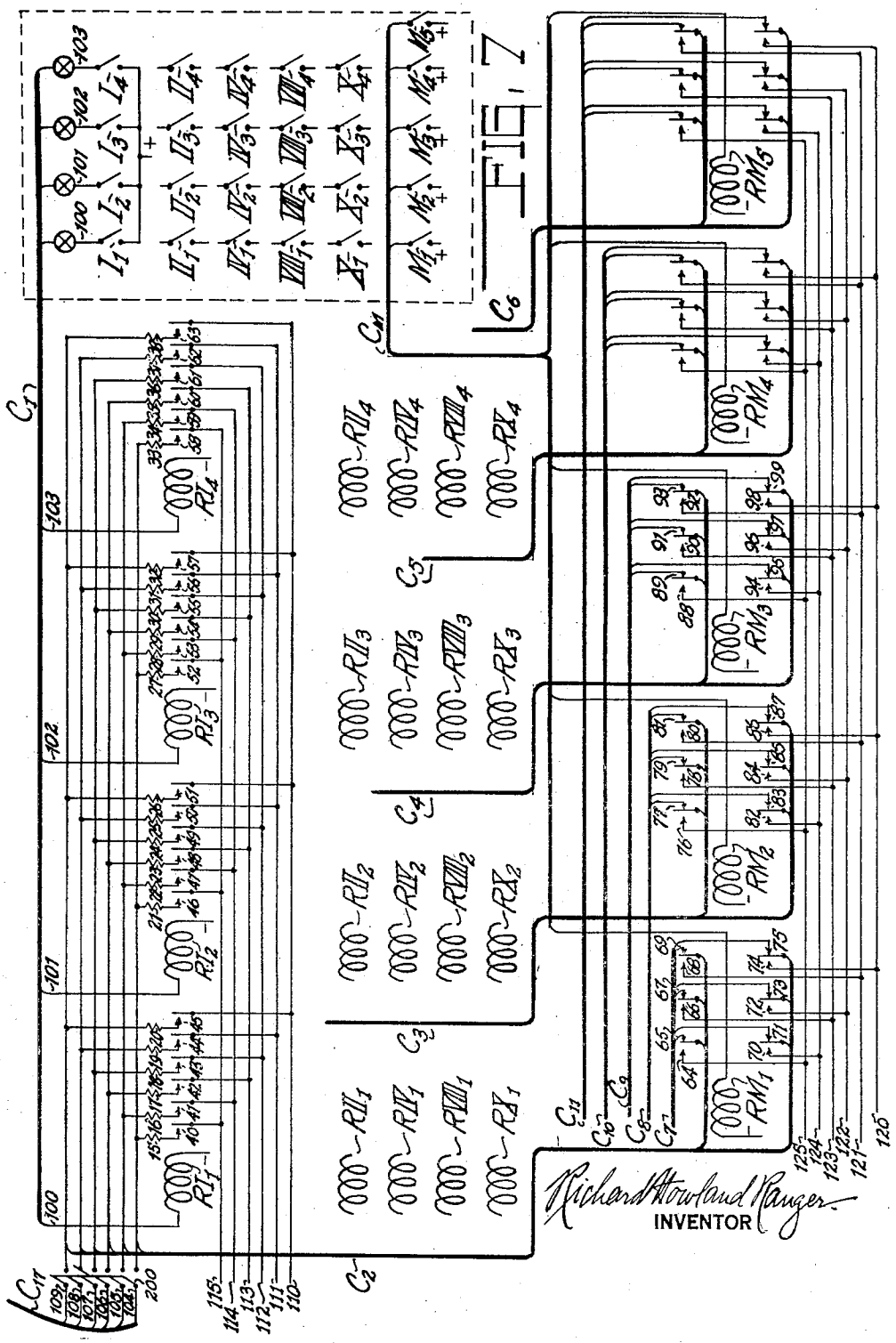


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SYNTHESIS OF MUSICAL TONES

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Patented Mar. 31, 1936

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2,035,836

SYNTHESIS OF MUSICAL TONES

Richard Howland Ranger, Newark, N. J.

Application October 22, 1931, Serial No. 570,377

42 Claims. (Cl. 84—1)

This invention relates in general to electrical systems of producing musical tones, and in particular to means included in such systems for varying the tone-color or timbre of the tones produced.

The timbre of a musical tone is a measure of its purity or complexity as a wave of sustained vibrations: in other words, the particular character or quality which identifies a tone is a result of the number, degree, and amplitude of the various harmonic vibrations, commonly called overtones or partials, present in the tone in addition to its fundamental or pitch-setting vibrations. It is these overtones, for instance, which enable a hearer to distinguish at once between a tone produced by a violin and one produced by a cornet, even should both these tones be of the same pitch and amplitude. The differences in timbre between various instruments, skillfully combined and blended by composer and conductor, are responsible for the pleasing variety of tone contained on a good orchestral selection.

Perfectly pure musical tones; that is, those which contain no overtones and may thus be represented graphically by a sine curve, may be said to have timbre only in a negative sense, much as perfectly pure distilled water may be said to have a negative flavor. Pure tones are occasionally valuable for musical purposes, because of their great clarity, but they have not the richness of complex tones.

It is obvious from the foregoing that an instrument capable of producing tones whose timbre could be varied at the will of the performer should have a much wider application in the musical art than an instrument producing tones only of a single fixed timbre. In my co-pending application for Letters Patent, Serial No. 417,466, filed Dec. 30, 1929 now Patent No. 1,901,985, granted March 21, 1933, I have described a musical system wherein the tones are electrically generated and are essentially sinusoidal or pure in quality. It is the object of this invention to describe a means for combining the pure tones of such a system into complex tones of any timbre desired.

The most obvious way of attaining this object is of course to analyze the desired complex tones according to the methods of Fourier into their component simple tones, and then merely to introduce these component tones simultaneously and in the proper proportions into the amplifying circuit. In order that this direct method may be used, however, it is necessary to have available sources of tone corresponding to each note of the scale, and to each of the principal harmonics of each of these notes. If the well- or equally-tempered scale is used as the basis of the system, as must be the case if occidental music is to be performed, this means that over 300 separate sources of tone must be provided for a 70 note scale, assuming that each complex tone contains 5 harmonics in addition to its fundamental tone. The octaves of the fundamental tone may be used to provide the second and fourth harmonics, but the third, fifth, and sixth must be separately generated.

Should it be possible, on the other hand, to produce complex tones containing the odd harmonics of the fundamental in any desired proportion, without the necessity of generating these harmonic tones separately, the entire musical system would of course be much less expensive, less complicated, and easier to operate and maintain. Accordingly, it is in this manner that complex musical tones are produced by the present invention.

To illustrate the underlying principles of the invention, and its application to the musical system described in the above noted patent, I have included the following drawings:

Fig. 1 a schematic wiring diagram of the electrical circuit of my invention; Figs. 2, 3, and 4, graphical representations of the changes in harmonic output of the circuit of Fig. 1 resulting from change in the input conditions; Fig. 5, which depicts a method of applying the system of this invention to an amplifier circuit similar to the one shown in Fig. 3 of the above-mentioned patent; Fig. 6, showing an altered form of the same amplifier circuit better adapted to be combined with the circuit of the present invention; and Fig. 7, a circuit diagram of the console stop and relay system for controlling the timbre of a complete electrical organ by employing the system of my invention. Figs. 8 and 9 show a side view and a plane view respectively of the tone generating means.

Transformer 1 of Fig. 1 represents the input transformer of either the first or an intermediate stage of an electrical music system amplifier. Across terminals 2 and 3 of this transformer is fed the fundamental tone of the complex musical note which is to be reproduced by the loud-speaker of the system. From the secondary winding of transformer 1 the tone is fed into the grids of the thermionic amplifier tubes 5 and 6, connected in the well-known push-pull fashion as shown, and from the plates of these tubes are amplified tone passes to the primary winding of transformer 7 and thence to the next ampli-

fier stage. Connected in series with the return lead from the center tap 8 of the secondary winding 9 of transformer 1 to the common cathode lead of tubes 5 and 6 is the secondary of an interstage transformer 10, into which is fed the output of amplifier tube 11. The input to tube 11 is fed in across terminals 12 and 13, passing through transformer 14. The grid bias of tubes 5 and 6 is regulated by means of resistor 15.

It is a well-known fact that in a circuit of the type shown in Fig. 1, if the grids of the push-pull amplifier tubes be biased at about normal value and then subjected to a signal voltage greatly in excess of the rated value of the tubes, an appreciable electronic current will flow between the grid and the cathode during a major portion of each cycle of the input wave; that is, during that portion of each cycle when the instantaneous sum of the grid bias voltage and the applied signal voltage is positive with respect to the cathode of the tubes. This electronic grid current causes an internal impedance drop in the transformer secondary winding and introduces distortion into the amplifying action of the tubes, so causing numerous harmonics of the input tone to appear in the output tone. Since the circuit is of the push-pull type, the even harmonics will very nearly cancel out: their amplitudes will in any case be negligible compared to that of the lower odd harmonics. Furthermore, by regulation of the effective grid potential (by varying either the input voltage or the grid bias) any desired one of the odd harmonics may be made to predominate in the output tone.

A more extended explanation of the action of thermionic amplifiers when caused to distort in the manner explained above may be found on pp. 960–962 of "Principles of Radio Communication", by J. H. Morecroft (second edition, John Wiley & Sons, New York), and in the Bell Laboratories Record of April, 1927.

By introducing regulated distortion into the amplifier circuit shown in Fig. 1, I have been able to produce complex tones at the output terminals of transformer 7 containing any desired amount of third harmonic component up to 15% of the total, and any desired amount of fifth harmonic up to 8% of the total, while feeding in a pure fundamental tone across terminals 2 and 3. Thus by feeding in also the requisite even harmonic components I am able to produce a great range of full complex tones in the loud speakers of my musical system without the necessity of generating any of the odd components.

This distortion method of tone composition is, however, rather limited in practice, since many complex tones which are musically very desirable require a greater percentage of third, fifth, and sixth harmonics than can be obtained by this means without introducing undesirably large second and fourth harmonic components. Accordingly, I introduce a modulating or heterodyne effect into the amplifying circuit by feeding in the second and/or the fourth harmonic of the fundamental tone across terminals 12 and 13 of transformer 14. These even harmonics, so fed in, combine with the fundamental tone to produce odd harmonic components representing the sums of and the differences between their frequencies and that of the fundamental, these odd harmonics appearing in the output tone passing through transformer 7, while the heterodyning even harmonics are balanced out between the push-pull tubes 5 and 6.

Assume now that the distorting push-pull amplifier circuit of Fig. 1 has been adjusted so that a predominant third harmonic component appears in the output tone, and that the second harmonic of the fundamental is fed in across terminals 12 and 13. There will then be two third harmonic waves present in the amplifier circuit; one due to the distortion and the other to the modulating second harmonic, and the total third harmonic will obviously be the sum of the two, its magnitude depending upon the phase relationship between them.

The curve of Fig. 2 represents the total third harmonic potential available at the secondary winding of transformer 7, and is plotted for various phase angles between the fundamental tone and the modulating second harmonic. This curve, which I have determined experimentally, shows the third harmonic to be a maximum when the modulating tone lags the fundamental by 45 degrees or ¼ cycle of the fundamental frequency. Conversely, the third harmonic approaches a minimum when the phase angle is 45 degrees lead.

It is possible also to vary the third harmonic content of the output wave by varying the intensity of the modulating wave, as shown by the curve of Fig. 3. In determining this curve the phase relation of modulating tone to fundamental was set at 45 degrees lag. As shown by Fig. 3, the third harmonic component at first rises as the strength of the modulating tone is increased, until a peak is reached at point A. Further increase of the modulating voltage then causes a decrease in the third harmonic component of the output tone, probably due to a secondary heterodyne effect in the amplifying circuit, until a minimum is reached at B, whereafter the curve rises again to a second maximum at C.

Operating the circuit of Fig. 1 under the most favorable overload conditions for producing the third harmonic in the output, and introducing the proper value of second harmonic modulation through transformer 14 to give the condition shown at maximum point A of Fig. 3, I am able to vary the third harmonic content of the output tone between limits 5 and 50% of the total by shifting the phase of the modulating tone. Either distortion or modulation, of course, will of itself be sufficient to introduce the third harmonic component, but the method here described is capable of producing much larger third harmonics than could ever be produced by distortion alone, and requires only a small fraction of the modulating tone voltage necessary to produce a corresponding effect by pure heterodyning. In addition to this, regulation of the phase of the modulating tone provides an ideal method of control.

If a fourth harmonic modulating tone is introduced at terminals 12 and 13, it also will heterodyne in the amplifying circuit, producing a fifth harmonic tone as well as another third harmonic. When both a second and a fourth harmonic modulation are used, and the two modulating waves are exactly in phase, the third harmonic heterodyne product of the fourth harmonic modulation is 180 degrees out of phase with that of the resultant of the other third harmonic waves present in the circuit, so that, as shown in Fig. 4, increase of the fourth harmonic modulation will result in an increased fifth harmonic component in the output wave and a proportional decrease in the third harmonic component. All quantities except the fourth harmonic modulation are assumed constant in the curve of Fig.

4. Under these conditions I am able to regulate the fifth harmonic content of the output wave at will.

The modulation of the fundamental wave described above need not be limited to the use of even harmonic modulating tones. Odd harmonic or even enharmonic or dissonant tones may be introduced in this manner and caused to heterodyne with the fundamental. I have attempted enharmonic modulation and have found it to give striking effects—the resulting tones, while not truly musical, are most effective when used sparingly in contrast with the more ordinary tones. A special effect making use of enharmonic modulation will be described below.

Fig. 5 shows a portion of the electrical music system amplifier circuit shown in Fig. 3 of Patent No. 1,901,985, altered to accommodate the system of tone synthesis of the present invention. Transformer **296**, bridging the first and second stages of the amplifier, here fulfills the same purpose as transformer 1 of Fig. 1. The secondary winding of transformer **10** is connected in series with the secondary center-tap lead of transformer **296**, and tube **11** and transformer **14** are connected in exactly as in Fig. 1, tubes **298** and **299** corresponding to tubes **6** and **5** of Fig. 1, and transformer **351** to transformer 7 of Fig. 1. The fundamental tone and the even harmonics of the complex note to be synthesized feed into the amplifier through leads, **115**, **116**, **117**, **118**, and **119**, adjustable resistors **146**, **147**, **148**, **149**, and **150**, transformers **140**, **141**, **142**, **143**, **144**, and **145**, and tubes **266**, **267**, **268**, **269**, **270**, and **271**, appearing in the secondary circuit of transformer **296** at sufficient voltage to cause distortion in the push-pull amplifier tubes **298** and **299**. At the same time modulating second and/or fourth harmonic tones are fed in as explained above through transformer **14**, tube **11**, and transformer **10**, these modulating tones being appropriately adjusted as to phase and amplitude. Thus the full complex note appears in the secondary circuit of transformer **351**, and is then further amplified and reproduced. The grid bias of push-pull tubes **298** and **299** is set by means of adjustable resistor **358**, connected to the cathodes of the tubes through lead **356**, and to ground at **362**.

The method of setting the phase of the modulating tones depends of course on the way in which such tones are generated, for instance, if they are produced by alternators or tone-generators of the type described in the patent, the phase may be shifted by an arcuate adjustment of the pickup magnet about the alternator rotor. Should forks be used, on the other hand, a lateral adjustment of the pickup along the tine of the fork will change the phase.

In the circuit of Fig. 6 the fundamental and even harmonic tones, coming in through leads **115**, **116**, **117**, **118**, and **119** do not pass to individual parallelled input tubes as in the circuit of Fig. 5, but are connected instead to the primary windings **401**, **402**, **403**, **404**, **405**, and **406** of a special input transformer **410**. Each of the primary windings of transformer **410** is matched to the tone input line, while its secondary winding **411** matches the grids of push-pull tubes **298** and **299**. Since the secondary winding **411** feeds directly to the grids of a push-pull amplifier stage, the modulation input circuit (transformer **10**, tube **11**, and transformer **14**) may be connected in series with the secondary mid-tap lead **412** as shown. From the push-pull stage on, the amplifier circuit is exactly the same as that of Fig. 5. Another stage of amplification may be added if necessary, but I have not found it so.

In addition to the reduction in the relative amplitude of the modulating fourth and second harmonic tones, and the consequent greater range of modulation made possible by the circuit of Fig. 6, the latter has the further advantages of materially reducing the number of vacuum tubes needed for the system, thus making it cheaper and easier to maintain, and of precluding the possibility of cross-modulation between the fundamental tone and the various even harmonics fed in through leads **115**, **116**, **117**, **118**, and **119**. In the circuit of Fig. 5 all these tones, passing through their individual input tubes, are connected in parallel to the primary winding of transformer **296**, and may thus modulate each other. In the circuit of Fig. 6 the tones are separately induced in secondary winding **411**, and are consequently less likely to modulate each other.

Were each of the component tones of a desired complex note available at the amplifier input, the amplifier circuit of Fig. 3 of Patent No. 1,901,985 would undoubtedly be the most desirable, due to its great flexibility. Using the tone synthesizing method of the present invention, however, the circuit of Fig. 6 of this application is far superior to that of Fig. 5.

Fig. 7 shows a complete system of timbre control for an electrical organ such as the one described in the above noted patent. With the control system here shown, the performer has at his command a virtually unlimited range of tone quality. The switches contained within the dotted square to the upper right of Fig. 7 represent stops, tilting tablets, or other convenient means of control located at the organ console, and wires **110**, **111**, **112**, **113**, **114** and **115** are each assumed to carry the fundamental or ground tone of one of six different notes resulting from the performer's depression of six keys of the organ manual. It will be recalled that in an electric organ of the type disclosed in the patent each note played selects an idle amplifier and reproducer, which is then reserved for the exclusive use of that note as long as the corresponding key is depressed. Thus wires **110**, **111**, **112**, **113**, **114**, and **115** would each ordinarily pass to one of say six amplifier and reproducer assemblies. Instead of this, each wire passes to one of the contacts on each of the four relays RI_1, RI_2, RI_3, RI_4, controlled respectively by stop switches I_1, I_2, I_3, and I_4. For example, wire **115** is connected to contact **40** of relay RI_1, contact **46** of relay RI_2, contact **52** of relay RI_3, and contact **58** of relay RI_4; wire **114** is connected to contact **41** of relay RI_1, contact **47** of relay RI_2, contact **53** of relay RI_3, and contact **59** of relay RI_4, and so on. From the relay contacts, the tones pass through the amplitude regulating resistors associated therewith, and then through cable C_2 to the contacts of relay RM_1. When relay RM_1, is in its open position, the six tones pass through contacts **65**, **67**, **69**, **71**, **73** and **75** to cable C_7, and thence through a selector system to their six separate amplifier and reproducer units. When relay RM_1 is closed, however, the six tones pass through contacts **64**, **66**, **68**, **70**, **72**, and **74** to wires **125**, **123**, **121**, **124**, **122**, and **120**, and each of these wires feeds its tone in modulator fashion into one of the six amplifiers available. In other words, assuming the type amplifier shown in Fig. 6 to be used, a fundamental tone selecting this amplifer would, with relay RM_1 open, pass through lead **115**,

resistor 146, and primary windings 401, and 402. With relay RM_1 closed it would pass through transformer 14, tube 11, and transformer 13.

Relays RI_1, RI_2, RI_3, and RI_4 control the percentage of fundamental tone present in the final reproduced note by means of the amplitude regulating resistors already mentioned. Relay RI_1, for instance, has its associated resistors 15, 16, 17, 18, 19, and 20 so adjusted that, with a given amplitude of tone coming in on leads 110, 111, 112, 113, 114, and 115, it will pass tones ½ as strong as those passed by either RI_2, or RI_3, and ⅕ as strong as those passed by RI_4. Thus by closing switches I_1, I_2, I_3, and I_4, in various combinations, ten different amplitude steps of the fundamental tones are available between zero and an arbitrary maximum determined by the strength of the input tones to the timbre control system. Closing switches I_1, I_2, and I_4, simultaneously, for instance, would permit fundamental tones 80% of the maximum value to be passed on to the contacts of relay RM_1, since relays RI_1, RI_2, and RI_4, would close, positive potential reaching them through leads 100, 101 and 103.

A bank of relays similar to RI_1, RI_2, and RI_3, and RI_4 is provided for the control of each order of partial of the notes to be reproduced by the organ. Relays RII_1, RII_2, RII_3, and RII_4, operated by positive potential supplied from switches II_1, II_2, II_3, and II_4, through a cable similar to C_1, regulate the amplitude of the second partials (or first harmonics) of the fundamental or first partial tones controlled by relays RI_1, RI_2, RI_3, and RI_4, in an exactly similar fashion to the latter relays, passing the second partial tones on through cable C_3 to relay RM_2. In the same way relays RIV_1, RIV_2, RIV_3, and RIV_4, control the amplitude of the fourth partial tones and relays $RVIII_1$, $RVIII_2$, $RVIII_3$, and $RVIII_4$, the amplitude of the eighth partial tones of any notes reproduced by the organ, relays RM_3, and RM_4, serving to mix these partial tones in the amplifiers either directly or in modulating fashion. Relays RX_1, RX_2, RX_3, and RX_4, may be used to pass at any desired amplitude any additional tone or tones, whether harmonic or enharmonic, necessary to produce special effects in timbre. These tones then pass through cable C_8, and the contacts of relay RM_5, to the amplifiers. Connections are indicated only for the control relays for the fundamental tones in Fig. 7, due to space limitations.

Should it be desired to feed the first partial tones of a complex note to the amplifier both directly and as a modulating tone, this may be effected by the simultaneous closure of switch 200 and switch M_1. The tone will then feed normally to the amplifier through cable C_{17}, which is appropriately connected to a selector system, at the same time that relay RM_1 is feeding it as a modulating tone. Switches similar to 200 are provided for each relay bank, and like the single-pole stop switches are operable from the console.

One of the most striking synthetic timbre effects obtainable with an electrical organ, and one which illustrates well the use of the timbre control system of Fig. 7, is the bell. When a bell or any other percussion type musical instrument is struck sharply by a hammer or clapper, the note it produces at first is extremely impure. The force of the blow tends to change the characteristics of the bell so that it vibrates at some frequency slightly higher than its normal rate. Numerous minor vibrations are also set up, small areas of the bell surface acting as individual sounding bodies. These parasitic vibrations are highly damped, however, and soon subside, leaving only the normal tone of the bell audible, together with a few weak harmonic tones.

I achieve the bell effect by feeding into relays RX_1, RX_2, RX_3, and RX_4 two enharmonic and one harmonic component for the final complex tone; namely, the tones a musical second and a musical third above, and the tone two octaves below the fundamental tone feeding into relays RI_1, RI_2, RI_3, and RI_4. I thus have available in physical terms, a complex tone wave made up of vibrations at three frequencies;

$$\sqrt[6]{2.0}, \sqrt[3]{2.0}$$

and 0.25 times the frequency of the fundamental tone respectively. I now close switches I_1, I_2, I_4, II_3, IV_1, X_1, X_2, X_3, X_4, M_2, and M_5, thus operating the corresponding relays RI_1, RI_2, RI_4, RII_3, RIV_1, RX_1, RX_2, RX_3, RX_4, RM_2, and RM_5. Through relays RI_1, RI_2, and RI_4, fundamental tone is supplied normally to the amplifiers at 80% of its maximum value, to mix with 10% of the maximum fourth partial supplied through relay RIV_1. Relay RII_3, supplies 20% of the maximum second partial tone, and this, together with the full value enharmonic tones coming through relays RX_1, RX_2, RX_3 and RX_4, is fed as a modulating wave to the amplifiers, by virtue of the closure of relays RM_2 and RM_5. The resultant note thus contains a strong fundamental tone, weak third and fifth partial components produced by the modulating second partial, a weak fourth partial, and a mass of strong enharmonic partials based chiefly on fundamental tones of higher frequency than the true fundamental tone of the note. At the same time I reproduce the fundamental and the third, fourth and fifth components on a separate amplifier system, preferably controllable from a second key-board or manual. By some appropriate means I then cause the plate supply of the amplifier passing the full tone including the enharmonic components to die away logarithmically, causing the full complex tone to die away likewise, leaving only the comparatively pure note controlled by the second manual. In this way the bell-tone is closely imitated. A conveniently applicable means of achieving such a decaying plate supply for an amplifier is fully disclosed by me in Letters Patent No. 1,901,968, granted March 21, 1933. I have, in fact, applied the general principles disclosed in said patent to the principles of the present invention to make possible effects such as the bell. In combination with the synthesizing method of the present invention in the manner described above many pleasing musical effects may be attained. The component proportions of the partial tones in the bell effect described above need not be strictly adhered to, of course—an infinite variety of bell-qualities may be produced by changing the proportions slightly, just as slight changes in the manner of casting an actual bell will change its tone quality.

Many entirely new musical effects may be achieved by varying the details of design of my invention slightly. For instance, the invention might be so combined with the condenser-supplied amplifier plate circuit mentioned above that the enharmonic tones persist while the harmonic constituents of a note die away. Or, instead of introducing the enharmonic tones at full strength and allowing them to die away, they may be su

plied through an amplifier whose plate supply is obtained from a charging condenser, thus causing the enharmonic tones to increase logarithmically in amplitude after the manual key is depressed. A most unusual effect is obtainable by subjecting tube 11 to the action of a tremolo device such as the one described in Patent No. 1,901,985. In this way a tremolo is superimposed upon the modulating harmonic tones, and the final complex tone has what may be called a "timbre-tremolo", its quality changing regularly at the tremolo rate.

Having now described my invention, and feeling myself entitled not only to the specific embodiments thereof discussed above, but also to such variations in design which might be judged as falling fairly within the spirit and scope of my invention, what I claim is the following:

1. The method of producing synthetic musical notes which comprises supplying to a modulating electrical circuit in modulating relation oscillations comprising as a component oscillations of the frequency of the fundamental of the note to be produced and modulating oscillations comprising as a component oscillations of a different audio frequency.

2. In an electrical music system, a plurality of tone generators for generating frequencies corresponding respectively to consecutive notes on a musical scale throughout a plurality of octaves, a plurality of amplifying systems for amplifying the tones generated in accordance with a predetermined note selection, a sound-reproducer coordinated with each of the said amplifying systems, and circuits for connecting each of said amplifying systems with those tone generators supplying the fundamental tone and the even numbered partials of a note of a musical scale to be produced, including a divided input circuit having a common portion and means for connecting one tone generator to the common portion of said divided input circuit.

3. In an electrical music system, a plurality of tone generators for generating frequencies corresponding respectively to consecutive notes on a musical scale throughout a plurality of octaves, a plurality of amplifying systems for amplifying the tones generated in accordance with a predetermined note selection, a sound-reproducer coordinated with each of the said amplifying systems, and circuits for connecting each of said amplifying systems with those tone generators supplying the fundamental tone and the even numbered partials of a note of the musical scale to be produced, including a divided input circuit having a common portion and a circuit for additionally supplying one of said tones to the common portion of the divided input circuit, provision being made for causing said amplifying systems to draw grid current.

4. In an electrical music system, a plurality of tone generators for generating frequencies corresponding respectively to consecutive notes on a musical scale throughout a plurality of octaves, a plurality of amplifying systems for amplifying the tones generated in accordance with a predetermined note selection, a sound reproducer coordinated with each of the said amplifying systems, circuits for connecting each of said amplifying systems with those tone generators supplying the fundamental tone and the even numbered partials of a note of a musical scale to be produced including a divided input circuit having a common portion and connections for additionally connecting one of said tone generators to the common portion of the divided input circuit, said divided circuit having the common portion connected to each of two control electrodes of parallel electrical discharge devices forming a part of said circuit, provision being made for causing the amplifying systems to draw grid current from said divided circuit.

5. In an electrical music system, a plurality of tone generators for generating frequencies corresponding respectively to consecutive notes on a musical scale throughout a plurality of octaves, a plurality of amplifying systems for amplifying the tones generated in accordance with a predetermined note selection, a sound reproducer coordinated with each of the said amplifying systems, circuits for connecting each of said amplifying systems with those tone generators supplying the fundamental tone and the even numbered partials of a note of a musical scale to be produced including a multi-primary transformer and a divided input circuit having a common portion and circuits for additionally connecting one of said tone generators to the common portion of the divided input circuit, said common portion having an individual portion connected to each of the control electrodes of a pair of electrical discharge devices forming a part of the input circuit of said amplifying systems, provision being made for causing said amplifying system to draw grid current.

6. In an electrical music system as described in claim 3, means for separately controlling the intensity of each of the fundamental and partial frequencies supplied to said amplifiers in accordance with the tone quality desired.

7. In an electrical music system as described in claim 3, means for varying the relative phase of the tones supplied through the common branch of the divided input circuit in accordance with the tone quality desired.

8. The method of simulating by electrically generated tones the timbre of a percussion type musical instrument which comprises the admixture with a fundamental tone and its related partial tones of a plurality of enharmonic tones of frequencies higher than that of the said fundamental tone, the simultaneous reproduction of the resulting composite tone with a second composite tone containing only the said fundamental and the said related partial tones, and the maintenance of the said second composite tone at its original amplitude while the amplitude of the first composite tone is reduced logarithmically until it is no longer audible.

9. In an electrical music system as described in claim 3, means for varying the amplitude of the tones supplied through the common branch of the divided input circuit between predetermined limits at a predetermined rate.

10. The method of producing synthetic timbre effects in an electrical music system which comprises the admixture of two compound tones, the first compound tone consisting of a fundamental audio frequency tone and various partials thereof, and the second compound tone consisting of the said fundamental tone, the said partial tones, and a plurality of enharmonic tones of frequencies higher than that of the said fundamental tone, the simultaneous reproduction of the said first compound tone with the said second compound tone, and the increase or decrease in amplitude of either or both of said two compound tones at separately predetermined rates during said reproduction.

11. The method of producing synthetic musi-

cal notes defined in claim 1, wherein the modulating oscillations are of a frequency corresponding to a partial of a note to be produced.

12. The method of producing synthetic musical notes defined in claim 1, wherein the modulating oscillations are compounded of oscillations of a plurality of frequencies each corresponding to a partial of the note to be produced.

13. The method of producing synthetic musical notes defined in claim 1, wherein the modulating oscillations are composite oscillations comprising as components oscillations of frequencies corresponding to the second and fourth partials of the note to be produced.

14. The method of producing synthetic musical notes which comprises supplying to the individual portions of a frequency translating circuit, including a pair of electrical discharge devices each having an anode, a cathode and a control electrode, a divided input circuit therefor having an individual portion connected to each of said control electrodes respectively and a common portion connected to said cathodes and a divided output circuit having an individual portion connected to each of said anodes and a common portion connected to said cathodes, oscillations of the frequency of the fundamental tone of the note to be produced and regulating the effective grid potential to introduce distortion in the current produced in the output circuit thereby producing harmonic components.

15. The method of producing synthetic musical notes which comprises supplying to the individual portions of a frequency translating circuit, including a pair of electrical discharge devices each having an anode, a cathode and a control electrode, a divided input circuit therefor having an individual portion connected to each of said control electrodes respectively and a common portion connected to said cathodes and a divided output circuit having an individual portion connected to each of said anodes and a common portion connected to said cathodes, oscillations of the frequency of the fundamental tone of the note to be produced, regulating the effective grid potential to introduce distortion in the current produced in the output circuit thereby producing harmonic components and supplying to the common portion of the input circuit oscillations of a frequency corresponding to that of a partial of the note to be produced.

16. The method of producing synthetic musical notes which comprises supplying to the individual portions of a frequency translating circuit, including a pair of electric discharge devices each having an anode, a cathode and a control electrode, a divided input circuit therefor having an individual portion connected to each of said control electrodes respectively and a common portion connected to said cathodes, a divided output circuit having an individual portion connected to each of said anodes and a common portion connected to said cathodes, oscillations of the frequency of the fundamental tone of the note to be produced and supplying to the common portion of said input circuit oscillations of audio frequency.

17. The method of producing synthetic musical notes as defined in claim 16, wherein the oscillations supplied to the common portion of the input circuit are of a frequency corresponding to that of a partial of the note to be produced.

18. The method of producing synthetic musical notes as defined in claim 16, wherein the oscillations supplied to the common portion of the input circuit are compounded of oscillations of a plurality of frequencies each corresponding to the frequency of a partial of the note to be produced.

19. The method of producing synthetic musical notes as defined in claim 16, wherein the oscillations supplied to the common portion of the input circuit are composite oscillations comprising as components oscillations of frequencies corresponding to those of the second and fourth partials of the note to be produced.

20. The method of producing synthetic musical notes which comprises supplying to the individual portions of a frequency translating circuit, including a pair of electric discharge devices each having an anode, a cathode and a control electrode, a divided input circuit therefor having an individual portion connected to each of said control electrodes respectively and a common portion connected to said cathodes and a divided output circuit having an individual portion connected to each of said anodes and a common portion connected to said cathodes, oscillations comprising as components oscillations of the frequency of the fundamental and of a partial of the note to be produced, supplying to the common portion of said input circuit oscillations of the frequency of an even partial and adjusting the phase of the last mentioned oscillations to produce the desired intensity of the partials in the output.

21. The method of producing synthetic complex notes which comprises supplying to a modulating electrical circuit oscillations having a frequency corresponding to the fundamental of a note to be produced distorting said oscillations to introduce a harmonic component and supplying also to said circuit modulating oscillations having a frequency corresponding to a partial of the note.

22. The method of producing synthetic complex notes which comprises supplying to a modulating electrical circuit oscillations having a frequency corresponding to the fundamental of a note to be produced distorting said oscillations to introduce an odd partial component and supplying also to said circuit modulating oscillations having a frequency corresponding to an even partial of the note.

23. The method of producing synthetic complex notes which comprises supplying to a modulating electrical circuit oscillations having a frequency corresponding to the fundamental of a note to be produced distorting said oscillations to introduce an odd partial component and supplying also to said circuit modulating oscillations having a frequency corresponding to an even partial of the note, and thereby to produce by modulation an odd partial of the same frequency as the odd partial introduced by distortion and shifting the relative phase of the even partial to vary the resultant total intensity of the above-mentioned odd partial.

24. An electrical musical system comprising a modulating electrical circuit, means for supplying to one portion of said circuit current having a component of the frequency of a partial of a note to be produced and means for supplying to another portion of the circuit in modulating relation current having a component of audio frequency.

25. An electrical musical system comprising a modulating electrical circuit, means for supplying to one portion of said circuit current having a component of the frequency of the fundamental of a note to be produced and a component of the

frequency of a partial of the note and means for supplying to another portion of the circuit in modulating relation current the principal component of which is of the frequency of a partial of the note and means for regulating the relative phase of the modulating current.

26. An electrical musical system comprising a modulating electrical circuit, means for supplying to said circuit in modulating relation current of a frequency corresponding to that of the fundamental of a note to be produced and current of a frequency corresponding to that of a partial of said tone.

27. An electrical musical system comprising a modulating electrical circuit, means for supplying to said circuit in modulating relation current of a frequency corresponding to that of the fundamental of a note to be produced and current of a frequency corresponding to that of the second partial of the note and means for distorting the first mentioned current to cause a component corresponding to an odd partial of the note to be introduced.

28. An electrical musical system comprising a modulating electrical circuit, means for supplying to said circuit in modulating relation current of a frequency corresponding to that of the fundamental of a note to be produced and current of a frequency corresponding to that of the second partial of the note, means for distorting the first mentioned current to cause a component corresponding to an odd partial of the note to be introduced and means for adjusting the phase of one current relative to the other.

29. An electrical musical system comprising a frequency translating circuit including a pair of electric discharge devices each having an anode, a cathode and a control electrode, a divided input circuit therefor having an individual portion connected to each of said control electrodes respectively and a common portion connected to said cathodes, means for supplying an oscillating electrical current of audio frequency to said individual portions, means for supplying an oscillating electrical current of audio frequency to said common portion, and a divided output circuit having an individual portion connected to each of said anodes and a common portion connected to said cathodes.

30. An electrical musical system comprising a push pull modulating electrical circuit including a divided input circuit with a principal transformer connected to the side portions and a second transformer connected to the centre portion, means for supplying audio frequency electrical current to the principal transformer and means for supplying audio frequency electrical current to the second transformer.

31. An electrical musical system comprising a push pull modulating electrical circuit including a divided input circuit with a principal transformer connected to the side portions and a second transformer connected to the centre portion, means for supplying audio frequency electrical current to the principal transformer, means for supplying audio frequency electrical current to the second transformer and means for adjusting the relative phase of the current in one transformer.

32. An electrical musical system comprising a frequency translating circuit including a pair of electric discharge devices each having an anode, a cathode and a control electrode, a divided input circuit therefor having an individual portion connected to each of said control electrodes respectively and a common portion connected to said cathodes, means for supplying audio frequency current to said individual portions, means for regulating the effective potential of the control electrodes to modify the character of the current, and means for supplying audio frequency current to the common portion of the circuit.

33. An electrical musical system comprising a frequency translating circuit including a pair of electric discharge devices each having an anode, a cathode and a control electrode, a divided input circuit therefor having an individual portion connected to each of said control electrodes respectively and a common portion connected to said cathodes, a divided output circuit having an individual portion connected to each of said anodes and a common portion connected to said cathodes, means for supplying current of a frequency of the fundamental of a note to be produced to said individual portions of the input circuit, means for regulating the effective potential of the control electrodes to modify the wave character of the current in the output circuit to produce an additional harmonic wave therein, and means for supplying a current of a frequency corresponding to that of a partial of the note to be produced to the common portion of said input circuit.

34. An electrical musical system comprising a frequency translating circuit including a pair of electric discharge devices each having an anode, a cathode and a control electrode, a divided input circuit therefor having an individual portion connected to each of said control electrodes respectively and a common portion connected to said cathodes, a divided output circuit having an individual portion connected to each of said anodes and a common portion connected to said cathodes, means for supplying current of a frequency of the fundamental of a note to be produced to said individual portions of the input circuit, means for regulating the effective potential of the control electrodes to modify the character of the current in the output circuit to produce therein additional oscillations corresponding to the frequency of an odd partial of the note, means for supplying a current of a frequency corresponding to that of an even partial of the note to the common portion of said input circuit and means for regulating the relative phase of said last mentioned current.

35. An electrical musical system comprising a frequency translating circuit including a pair of electric discharge devices each having an anode, a cathode and a control electrode, a divided input circuit therefor having an individual portion connected to each of said control electrodes respectively and a common portion connected to said cathodes, a divided output circuit having an individual portion connected to each of said anodes and a common portion connected to said cathodes, means for supplying current of audio frequency to the individual portions of the input circuit, means for supplying a second current of audio frequency to the common portion of the input circuit said latter means including an amplifier with a plate circuit having therein a relatively large condenser arranged to cause relatively high plate circuit current when the note is initiated followed by fading.

36. The method of producing synthetic complex notes which comprises supplying to an electrical circuit current having a component of a frequency corresponding to the fundamental of a note to be produced, supplying simultaneously to said

circuit current having a component of a frequency of an enharmonic of the note and gradually reducing the amplitude of the enharmonic waves while maintaining the amplitude of the first mentioned waves.

37. The method of producing synthetic complex notes which comprises supplying to a modulating electrical circuit composite oscillations having components of audio frequencies corresponding to the fundamental and selected partials, supplying also to said circuit modulating oscillations having components of frequencies corresponding to selected enharmonics and maintaining the amplitude of the first mentioned oscillations while gradually reducing the amplitude of the modulating oscillations.

38. The method of producing synthetic musical notes which comprises supplying to an electrical circuit in modulating relation two oscillatory electrical currents of audio frequency.

39. The method of producing synthetic musical notes which comprises supplying to an electrical circuit oscillations of the frequency of a partial of a note to be produced and supplying to said circuit in modulating relation other oscillations of the frequency of a partial of the same note.

40. Apparatus for producing a musical note comprising means for producing oscillations of audio frequency, a second means for producing oscillations of audio frequency, means for causing the second oscillations to modulate the intensity of the first oscillations and means for shifting the phase of the modulation.

41. The method of producing a complex musical note which comprises passing oscillations of the frequency of one partial of the note through an amplifier tube and varying the momentarily effective output of the tube at a rate corresponding to the frequency of another partial of the note.

42. In the operation of an electrical musical system comprising a push-pull modulating electrical circuit having a divided input circuit with a principal transformer connected to the side portions and a second transformer connected to the center portion, the method of producing synthetic complex notes which comprises supplying to the principal transformer audio frequency electrical current and supplying to the second transformer audio frequency electrical current.

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