July 27, 1937. C. T. JACOBS 2,088,205

TONE MODIFYING CIRCUIT

Original Filed April 18, 1933

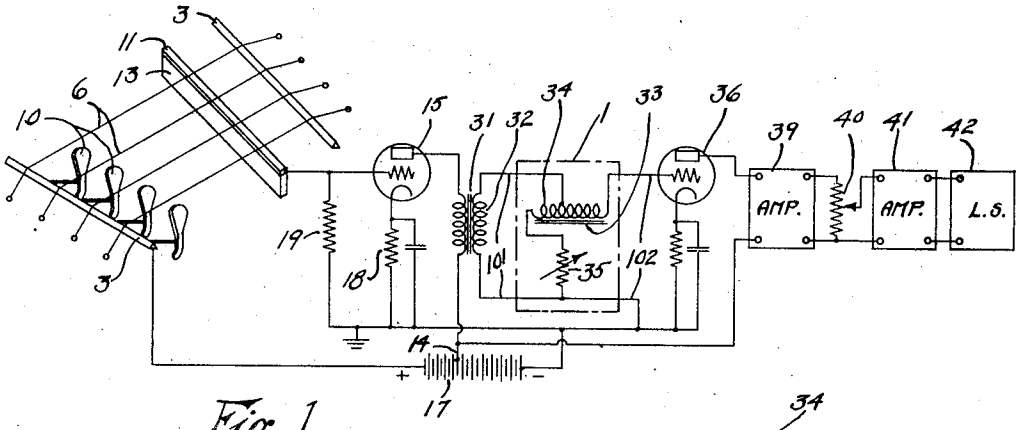


Fig. 1

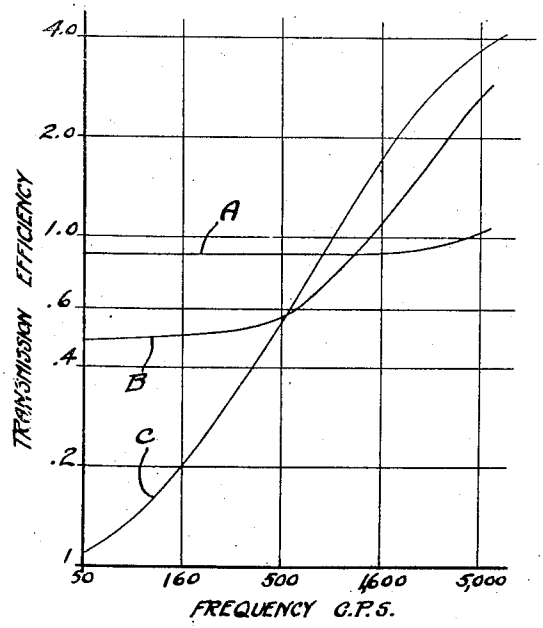


Fig. 2

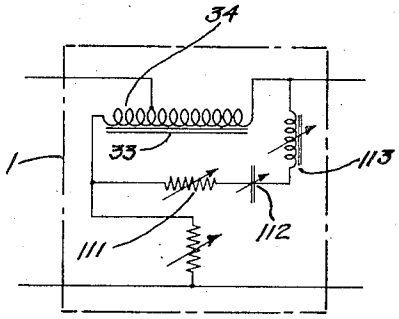


Fig. 3

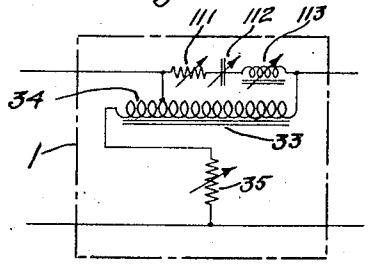


Fig. 4

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TONE MODIFYING CIRCUIT

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Application April 18, 1933, Serial No. 666,673
Renewed May 3, 1937

17 Claims. (Cl. 179—1)

This invention relates to systems for the transmission and translation into sound of electric oscillations and more particularly to the control of the tone quality of the output sound. While the invention may have its widest application in instruments employing electric oscillations for the original production or creation of music, it is also adapted for more general employment, such as in electro-acoustic systems for the reproduction of sound. This application is a continuation in part of my co-pending application, Serial Number 607,677, filed April 27, 1932.

It is an object of my invention to provide improved means and methods for controllably increasing the brilliance of the output sound in systems of the class described.

It is a further object of my invention to provide improved means and methods for controllably modifying the amplitude ratios between different frequency components of the output sound.

It is another object to provide means and methods whereby certain components of the output sound may be controllably emphasized, and extended in duration.

It is a still further object of my invention to provide means and methods operable simultaneously to vary the inter-component ratios and the extension of duration of certain components, both above mentioned.

Other and allied objects will more fully appear from the following description and the accompanying drawing, in which latter

Figure 1 is a schematic diagram of a simple embodiment of my invention as applied to an instrument for the original production of music through the medium of electric oscillations;

Figure 2 comprises a group of curves illustrating the effects produced by the embodiment of Figure 1; and

Figures 3 and 4 are schematic diagrams of slightly more elaborate embodiments of my invention.

Reference being had to Figure 1, my invention will be seen applied to a musical instrument of the type wherein the vibrations of tuned strings are translated into electric oscillations and these in turn into sound. Such strings are shown as 6, and hammers 10 are illustratively shown as vibrating means therefor. The strings may be of electrically conductive material, and they may conveniently be electrically connected together, as by the use of metallic chevalets 3 supporting the strings.

For translating the vibrations of the strings into electric oscillations I show an electrically conductive strip 11 of small cross-section, which may be adjacent and below each string preferably at a constant, small fractional part of its length from the rear end thereof. This strip may be cemented to the top edge of a supporting strip 13 of insulating material, which may be retained in fixed position in any convenient manner. The conductive strip 11 is spaced away from the strings in general just sufficiently to avoid contact therewith under conditions of maximum vibration of the latter.

Conductive strip 11 may be electrically connected to the grid of a thermionic vacuum tube 15, whose cathode may be energized in any well-known manner, and whose anode current may be supplied as from a tap 14 on high voltage battery or other current source 17. The cathode of tube 15 may be established at a potential higher than that of the negative terminal of battery or source 17 by the flow of anode current through condensively by-passed resistor 18; and the grid of tube 15 may be biased to the potential of such negative terminal by high resistance 19. The strings may be established at a D. C. potential positive with respect to that of conductive strip 11, as by connection of one of the chevalets 3 (with which the strings make contact) to the positive terminal of battery or source 17. In the output circuit of tube 15 may be provided further apparatus hereinafter described.

It will be appreciated that between each string 6 and the conductive strip 11 a small electrostatic capacity exists, and that these capacities in parallel with each other form a total capacity between such strings and conductive strip. This capacity is charged from battery or source 17 through resistance 19, and this charge cannot change rapidly because of the high value of the latter resistance. If now any string 6 be vibrated in a vertical plane, as by striking by its hammer 10, the capacity between it and the conductive strip 11 will be varied oscillatorily in accordance with the frequency and waveform of the point of the string opposite the conductive strip. The total capacity between the strings and the conductive strip 11 will be likewise varied, though in reduced degree; and by virtue of the relatively constant charge in this capacity the voltage across it will likewise vary. The oscillatory variations in this voltage will be seen to be applied to the grid of tube 15 and therefore to appear as variations in its anode current. Thus in the input and output circuits of tube 15 appear electric oscillations translated from the vibrations of

the points of the strings opposite the conductive strip.

In the anode circuit of tube 15 may be provided any convenient means for coupling the output of this tube to succeeding apparatus, and as an example of such a coupling means I have shown a transformer 31, through the primary of which will flow the current oscillations in the output circuit of tube 15. The oscillations thereby induced in the secondary 32 of the transformer may be applied to the tone regulating circuit enclosed in the dotted line 1, and hereinafter most particularly described. From this circuit they may be applied to the cascade of apparatus shown as thermionic vacuum tube 36, amplifier 39, potentiometer or volume control 40, further amplifier 41 and loudspeaker 42, by which it will be understood that they are amplified, controlled in respect of amplitude, and translated into sound, all in a manner substantially uniform at different frequencies.

In my co-pending application Serial Number 564,305, filed September 22, 1931, I showed certain tone control circuits operable to vary the transmission efficiency of portions of the electrical system differentially with frequency, and indicated a plurality of uses thereof in the control of harmonic structure of output tones of musical instruments such as the one herein described. The actual circuits therein shown accomplished the differential variation by differently attenuating components of different frequencies—i. e., their transmission efficiency never exceeded unity. I have found that other tone regulating circuits may operate with higher absolute efficiencies; and further that they may approximate over at least a limited band of frequencies the effect of controllably rotating the transmission-frequency characteristic about a mean point or region, from a horizontal position to a position tilted in the usually desired direction—i. e., upward at the higher frequencies and downward at the lower. Such tone regulating circuits I have found particularly effective in the duplication, by an instrument of the type herein shown, of the piano and similar instruments, the output tones of which are notably deficient in strong low frequencies and conversely rich in high frequency components.

Such a preferred tone regulating circuit is the one mentioned above and shown in Figure 1 as comprising auto-transformer 33, with primary 34, and variable resistance 35 in series with the primary end of the auto-transformer. Input leads 101 may connect to the primary 34 and resistance 35 in series, and output leads 102 may connect across the entire auto-transformer and resistance 35 in series. The action of the circuit may be understood by considering that the voltage input divides into drop across primary 34 and drop across resistance 35. The former is stepped up by the auto-transformer before transmission by leads 102, while the latter is transmitted by these leads without step-up. With a high value of resistance 35 the drop across 34 is negligible; the transmission efficiency is therefore practically unity at all frequencies. As the value of resistance 35 is decreased, however, the drop across 34—the portion which will be stepped up—increases, more rapidly the higher the frequency. At the same time the input impedance of the circuit is being reduced, particularly at the lower frequencies, and thus progressively greater attenuation of components of these frequencies takes place.

This composite effect may be most generically expressed by showing the transmission efficiency of the circuit in terms of frequency ($\omega/2\pi$), the resistance value (R) to which the variable 35 may be adjusted, the impedance (R_0) out of which the circuit works, the inductance value (L) of the primary 34 of the auto-transformer 33, and the turns ratio (T) between the entire auto-transformer and the primary. In these terms the transmission efficiency is given by

$$\sqrt{\frac{R^2+\omega^2L^2T^2}{(R+R_0^2)+\omega^2L^2}}$$

This assumes a high or infinite input impedance of tube 36, which assumption is justified at audio frequencies. The value of R_0 for the apparatus shown in Figure 1 is essentially the plate impedance of tube 15 multiplied by the square of the step-up ratio of the transformer 31.

While an almost limitless number of combinations of values of the components may produce a like number of frequency-transmission characteristics, I may illustrate a typical choice of component values and show the resulting transmission efficiencies at different frequencies for each of several values of R. Thus I have employed the circuit with R_0 effectively about 50,000 ohms, L approximately 2 henries, T equal to 5, and R variable from 5,000 ohms or lower to 500,000 ohms. The following approximate transmission efficiencies are thus obtained.

	R: 500,000 ohms	R: 50,000 ohms	R: 5,000 ohms
At 16 cycles	.92	.5	.1
At 50 cycles	.92	.5	.11
At 160 cycles	.92	.51	.21
At 500 cycles	.92	.59	.58
At 1,600 cycles	.93	1.1	1.72
At 5,000 cycles	1.07	2.7	3.8

This data is graphically shown as Figure 2, wherein curve A shows transmission efficiency at different frequencies with a value of R of 500,000 ohms, curve B the same but with a value of R of 50,000 ohms, and curve C the same but with a value of R of 5,000 ohms.

From the above it will be seen that with a high value of R the transmission-frequency characteristic is essentially uniform or flat; that with intermediate values of R the efficiency is lower at frequencies below approximately 1000 cycles and higher at frequencies thereabove; and that with low values of R such change of efficiency with frequency is increased or made steeper. Still greater steepness of the change with frequency may be effected at intermediate and low values of R by the increase of T, within limits, and vice versa. Furthermore the respective efficiencies for various values of R may be made to occur at respectively lower or higher frequencies by increasing or decreasing the value of L, since this and the term ω appear in the formula above only as multiples of each other. These and other changes of component values from those I have shown will be suggested, for the production of particular characteristics, by the formula itself. In any event, however, it will be found that variation of the value of R from a high or infinite value to a low value will produce progressively greater accentuation of high, and progressively greater attenuation of low, frequency components. The tone regulating circuit shown may be employed if desired with a fixed resistance 35, having re-

sistance R of such a value that a particular effect on tone quality will be obtained; I have always preferred, however, to make the resistance 35 variable.

It will be observed that in the choice of the above recited typical values I have chosen L so that the value of ωL at low frequencies is small compared to R_0; and that I have made R variable, from a value small compared to that of R_0 and to that of ωL at high frequencies, to a value large compared to both said last mentioned values.

The auto-transformer 33 has been illustrated in Figure 1 without shunt capacity, and this condition has been assumed in the formulae given above. As a practical matter, however, any auto-transformer which may be employed will have some distributed capacity. This capacity will resonate with the leakage reactance of the auto-transformer to some particular frequency. If the values of distributed capacity and leakage reactance be properly chosen, as is well understood from conventional transformer design, this resonant frequency may be optionally established above the useful limit of audibility or at any desired value below such limit. The effect of a resonant frequency below such limit is to provide additional accentuation of oscillation, and hence sound, components at and near such frequency, and to provide a slight increase in duration of such components as they may occur in the oscillations being transmitted through the system. The degree of such accentuation and duration increase is of course largely influenced by the resistance of the auto-transformer winding, as is well understood.

I have found, however, that it is also convenient to control the degree of these effects by regulating the input to the auto-transformer proper. In the circuit which I have shown and described such input regulation is obviously effected by adjustment of the resistance 35—e. g., when this is of high resistance it limits the current through and voltage drop across the primary 34 to a negligible value. It will thus be seen that when resistance 35 is of high value and therefore provides transmission of the oscillations by the tone control system with negligible alteration of inter-component ratios, it at the same time suppresses modification of the oscillations in respect of the abovementioned extra accentuation and duration increase in the certain frequency band. Conversely, when resistance 35 is of low value and therefore provides a large increase in the amplitude ratios of high to low frequency components, it at the same time permits the resonant conditions of the auto-transformer circuit to work an appreciable extra accentuation and duration increase in the particular frequency band.

This correlation of effects I have found very useful musically. When the energy of the oscillations and output sound is predominately located in lower frequency components or more or less evenly distributed over the whole frequency range, the effect of extra duration of certain components is probably undesirable. When, however, the energy of the oscillations and output sound is deliberately made to predominate in higher frequencies, an extra accentuation in this frequency region is helpful and a slight duration increase in this region is striking.

While the resonant effects above discussed are capable of production as a result of the inherent characteristics of the auto-transformer, any or all of the circuit parameters of capacity, resistance and leakage reactance may be externally provided. In this case they may be made variable, so that the frequency region at which the resonant effects occur, and the degree of these effects for any particular value of resistance 35, may be independently adjusted. I have therefore shown in Figure 3, which is basically the identical tone regulating circuit shown in Figure 1, the additional elements comprising variable resistance 111, variable small capacity 112; and variable inductance 113. The circuit comprising these elements may if desired be shunted across a portion only of the auto-transformer, as I have shown in Figure 4.

While I have shown and described my invention in terms of particular embodiments, it will be understood that these are exemplary rather than comprehensive, and that the scope of my invention is intended to be expressed by the following claims.

I claim:—

1. In a system including a source of plural-frequency sound-representing electric oscillations and means responsive to said oscillations: an oscillation-transmitting circuit interposed between said sourse and said responsive means; and adjustable means included in said circuit for modifying the transmission-frequency characteristic of said circuit in a manner substantially corresponding to rotation thereof about an intermediate frequency region thereon.

2. In a system including a source of plural-frequency sound-representing electric oscillations and means responsive to said oscillations: an oscillation-transmitting circuit interposed between said source and said responsive means; and adjustable means included in said circuit for modifying the transmission-frequency characteristic of said circuit in a manner substantially corresponding to rotation thereof about a substantially constantly maintained intermediate frequency point thereon.

3. In a system including a source of plural-frequency sound representing electric oscillations and means responsive to said oscillations: a circuit having normally a substantially flat transmission-frequency characteristic interposed between said source and said responsive means; and adjustable means included in said circuit for modifying said characteristic in a manner substantially corresponding to rotation thereof upwardly at high frequencies and downwardly at low frequencies about a substantially constantly maintained intermediate frequency point thereon.

4. The combination according to claim 3, further including means controlled by said adjustable means for increasing the duration of high frequency oscillation components simultaneously with said modification of the transmission-frequency characteristic.

5. In a system including a source of plural-frequency sound-representing electric oscillations and means responsive to said oscillations: an oscillation-transmitting circuit interposed between said source and said responsive means; means included in said circuit for attenuating lower frequency components of said oscillations in a degree increasing with lowering frequency; means included in said circuit for amplifying higher frequency components of said oscillations in a degree increasing with increasing frequency; and a single means for simultaneously adjusting said attenuation and said amplification, to increase or to decrease both simultaneously while

maintaining substantially constant the amplitude of intermediate frequency components.

6. In a system including a source of plural-frequency sound-representing electric oscillations and means responsive to said oscillations: a circuit having normally a substantially flat transmission-frequency characteristic interposed between said source and said responsive means; and means included in said circuit for modifying said characteristic, comprising means for attenuating lower frequency components of said oscillations in a degree increasing with lowering frequency, means for amplifying higher frequency components of said oscillations in a degree increasing with increasing frequency, and a single means for simultaneously adjusting said attenuation and said amplification, to increase or to decrease both simultaneously while maintaining substantially constant the transmission of intermediate frequency oscillation components.

7. The combination according to claim 6, further including means controlled by said adjusting means for increasing the duration of high frequency oscillation components simultaneously with increase of said attenuation and of said amplification.

8. In a system including a source of plural frequency sound-representing electric oscillations and means characterized by a high input impedance for receiving said oscillations and translating the same into sound: a tone modifying device interposed between said source and said means and comprising a resistance and an inductance in series with said resistance, said resistance and a portion only of said inductance being connected across said source, and said means being connected across said resistance and the entire said inductance.

9. In a system including a source of plural frequency sound-representing electric oscillations and means characterized by a high input impedance for receiving said oscillations and translating the same into sound: a tone control device interposed between said source and said means and comprising a resistance and an inductance in series with said resistance, said resistance and a portion only of said inductance being connected across said source, said means being connected across said resistance and the entire said inductance, and said resistance being variable whereby to produce substantial variation of the transmission-frequency characteristic of said device within the range of audible frequencies.

10. In a system including a source of plural frequency sound-representing electric oscillations and means characterized by a high input impedance for receiving said oscillations and translating the same into sound: a tone modifying device interposed between said source and said means and comprising a step-up transformer having primary and secondary windings and further comprising a single resistance in series with both of said windings, said resistance and said primary winding being connected across said sources, and said means being connected across said resistance and said secondary winding.

11. In a system including a source of plural frequency sound-representing electric oscillations and means characterized by a high input impedance for receiving said oscillations and translating the same into sound: a tone control device interposed between said source and said means and comprising a step-up transformer having primary and secondary windings and further comprising a single resistance in series with both of said windings, said resistance and said primary winding being connected across said source, said means being connected across said resistance and said secondary winding, and said resistance being variable whereby to produce substantial variation of the transmission-frequency characteristic of said device within the range of audible frequencies.

12. The combination with an oscillation transmitting circuit, a voltage-responsive device connected across the output of said circuit, and an oscillation source for applying plural frequency sound representing electric oscillations across the input of said circuit, of means included in said circuit for stepping up in voltage a fractional part of each different frequency component of said applied oscillations, such fractional part of each component being greater the higher the frequency of that component; means included in said circuit for transmitting without step-up the remaining fractional part of each such different frequency component; and means for simultaneously varying all of said fractional parts and the input impedance of said circuit at lower audible frequencies, to increase said fractional parts while decreasing said impedance and vice versa.

13. In a system including a source of plural frequency sound-representing electric oscillations and means characterized by a high input impedance for receiving said oscillations and translating the same into sound: a tone modifying device interposed between said source and said device and comprising a resistance, an inductance in series with said resistance, and capacity associated with said inductance to form a closed resonant circuit, said resistance and a portion of said inductance being connected across said source, and said means being connected across said resistance and a larger portion of said inductance.

14. In a system including a source of plural frequency sound-representing electric oscillations and means characterized by a high input impedance for receiving said oscillations and translating the same into sound: a tone control device comprising a resistance, an inductance in series with said resistance, and capacity associated with said inductance to form a closed resonant circuit, said resistance and a portion of said inductance being connected across said source, said means being connected across said resistance and a larger portion of said inductance, and said resistance being variable whereby to produce substantial variation both of the transmission-frequency characteristic of said circuit within the audible frequency range and of the amplitude of oscillations impressed on said resonant circuit.

15. In a system including a source of plural frequency sound-representing electric oscillations and means characterized by a high input impedance for receiving said oscillations and translating the same into sound: a tone modifying device interposed between said source and said means and comprising a step-up transformer having primary and secondary windings, further comprising a single resistance in series with both of said windings, and further comprising capacity associated with said secondary winding to form a closed resonant circuit, said resistance and said primary winding being connected across said source, and said means being

connected across said resistance and said secondary winding.

16. In a system including a source of plural frequency sound-representing electric oscillations and means characterized by a high input impedance for receiving said oscillations and translating the same into sound: a tone control device interposed between said source and said means and comprising a step up transformer having primary and secondary windings, further comprising a single resistance in series with both said windings, and further comprising capacity associated with said secondary winding to form a closed resonant circuit, said resistance and said primary winding being connected across said source, said means being connected across said resistance and said secondary winding, and said resistance being variable whereby to produce substantial variation both of the transmission-frequency characteristic of said circuit within the audible frequency range and of the amplitude of oscillations impressed on said resonant circuit.

17. In a system including a source of plural frequency sound-representing electric oscillations, said source having output impedance R_0, and means characterized by a high input impedance for receiving said oscillations and translating the same into sound: a tone control device interposed between said source and said means and comprising a transformer having a primary of inductance L and a secondary having a turn ratio T to the primary and further comprising a resistance R in series with both said primary and said secondary, the efficiency of transmission of said oscillations by said device from said source to said means being given substantially by the expression:

$$\frac{\sqrt{R^2+\omega^2L^2T^2}}{\sqrt{(R+R_0)^2+\omega^2L^2}}$$

the value of T being greater than unity, the value of R_0 being large compared to that of ωL at low frequencies, and the value of R being variable from a relatively low value to a value large compared both to that of R_0 and to that of ωL at high frequencies.

CHARLES T. JACOBS.