

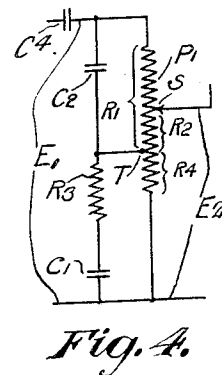
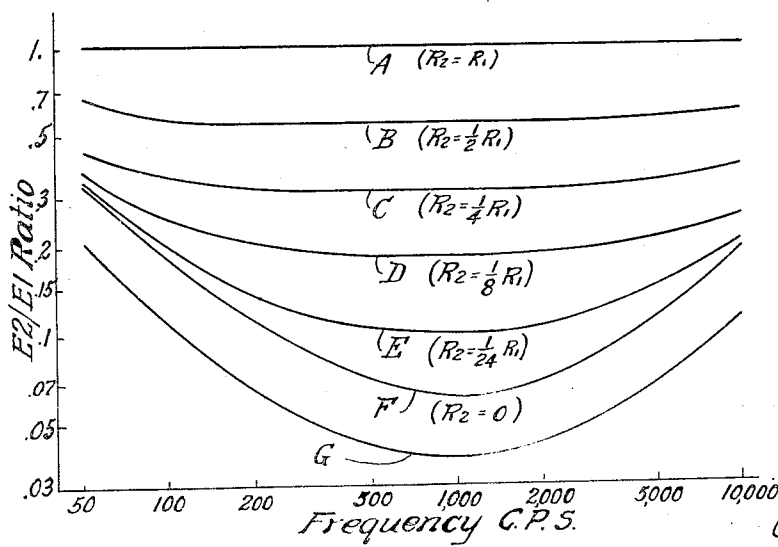
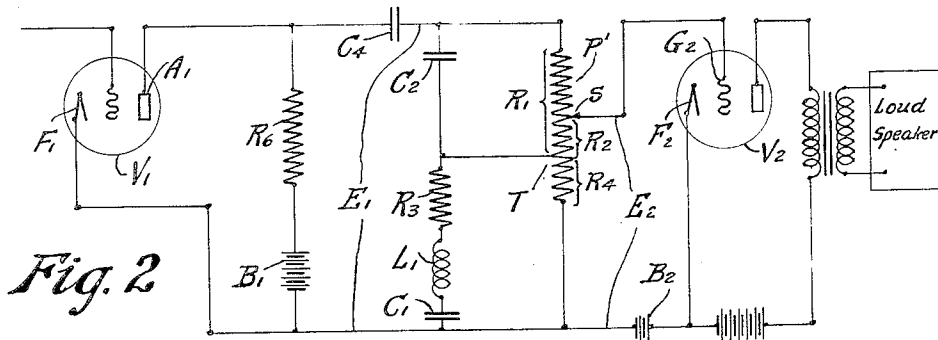
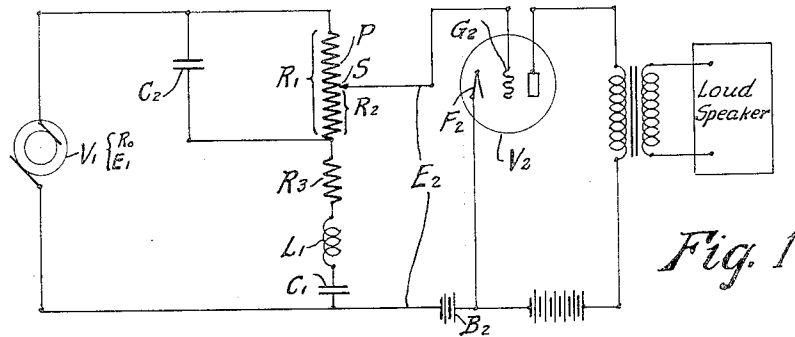
Dec. 5, 1933.

C. T. JACOBS

1,938,256

VOLUME CONTROL CIRCUITS

Original Filed Aug. 9, 1930



INVENTOR.

Charles T. Jacobs

UNITED STATES PATENT OFFICE

1,938,256

VOLUME-CONTROL CIRCUITS

Charles T. Jacobs, New Providence Township,
Union County, N. J.Refiled for abandoned application Serial No.
474,272, August 9, 1930. This application April
22, 1932. Serial No. 606,891

16 Claims. (Cl. 178—44)

This invention relates to electrical systems for sound production or reproduction, and more particularly to methods and apparatus for controlling the volume of sound output of such systems. This application is a substitute for my prior application, Serial Number 474,272, filed August 9th, 1930.

It is well known that the ear is differentially sensitive to sounds of various frequencies—i. e., that it less readily perceives changes in the amplitude of sound at certain frequencies than at others. It is most sensitive to sound amplitude changes in the extreme (very high and very low) audible registers, and least sensitive to changes at intermediate frequencies. If in systems of the class described the general amplitude, or level, of the sound output be changed by any operation which uniformly affects all the different frequency components, it will seem to the ear that the amplitudes of components of extreme frequencies have been changed to a greater degree than those of intermediate frequency. It is a broad object of my invention to provide means for so changing the sound output level of a system of the class described that the ear will perceive the amplitude changes at different frequencies as essentially similar. It is an allied object to provide, in association with means operative to control the sound output level, means for counteracting or compensating for the differential sensitivity of the ear abovementioned.

The most common method of changing the output sound level of this type of system is by the use of a potentiometer, across the entire resistance of which are applied electric oscillations conforming in their various characteristics to the eventual sound, the voltage thereby developed between the inferior extremity of the potentiometer and a contact selectively positionable along its resistance being taken off and translated into sound. I am aware that at least two circuit arrangements have been proposed in connection with such potentiometers for fulfilling the broad object of my invention. In one of these, as shown in U. S. Patent 1,785,048 to Reynolds, a variable frequency-discriminating circuit electrically independent of the potentiometer is employed, its control being mechanically linked to that of the potentiometer to operate in unison therewith; in the other, as shown in U. S. Patent 1,788,035 to Stevenson, one or more parallel L—C circuits are provided as a shunt between the superior extremity and the variable contact of the potentiometer. I have found, however, that the desired results may be obtained by other arrangements having great advantages in respect of effectiveness, simplicity, economy, and freedom from various undesirable effects, including susceptibility to external stray fields, etc. Accordingly it is a specific object of

my invention to provide improved circuits useful with potentiometer volume controls for fulfilling the broader objects of my invention.

It is a further broad object to provide means for simultaneously varying both the tone quality and volume level of the sound output of a system of the class described, to effect predetermined relationships of quality to volume level. Other and allied objects will more fully appear from the following description and the appended claims.

In such description reference is had to the accompanying drawing, of which

Figure 1 is a diagrammatic view illustrating my invention in one form;

Figure 2 is a like view illustrating my invention in a modified and in general preferred form;

Figure 3 comprises a set or family of curves showing certain effects of the use of my invention under certain typical conditions; and

Figure 4 is a diagrammatic view illustrating my invention in the form shown in Figure 2, but with the omission of one of the elements shown in that figure.

For purposes of most useful and appropriate illustration, but not intending any limitation thereby, I have shown and described my invention applied to a system which is presumed to produce a satisfactory tone quality when the control is set for the production of the maximum volume level. A problem is thus presented of reducing the volume level without appreciable disturbance of the amplitude ratios, as perceived by the ear, between all the different frequency components of the output. The solution of this problem requires that, as general volume level is reduced, a greater reduction of oscillation amplitude take place at intermediate than at extreme frequencies.

An embodiment of my invention whereby this effect is produced is shown in Figure 1, in which P is a potentiometer having total resistance R_1 , variable contact or slider S, and variable portion R_2 of resistance between slider S and the inferior extremity of the potentiometer. The contact or slider S has been shown as continuously movable over the resistance R_1 , the word continuously of course being used in the sense of denoting substantially unrestricted interpolation of contact positionings rather than in any sense of sustained motion over a period of time. V_1 is an electric circuit element, shown schematically as a generator having output impedance R_0 . It will be understood, of course, that V_1 is intended to represent a plural frequency oscillation source; by way of example, it may be a magnetic phonograph pick-up having output impedance R_0 . The potentiometer P, shunted by the capacity C_2 , is connected in the output circuit of element V_1 , in series with resistance R_3 and reactance comprising inductance

L_1 and capacity C_1 . The a. c. voltage appearing across C_1 , L_1 , R_3 and the variable R_2 in series is applied to the input of a succeeding circuit element V_2 , shown for example as an electric vacuum tube having an input circuit comprising grid G_2 , cathode F_2 and such input biasing potential source B_2 as may be required. To the output of V_2 may be connected such succeeding circuits as may be desired, which may terminate in an electro-acoustic translating device. Such circuits and translating device are shown in Figure 1 as a transformer and loudspeaker, respectively. Of the reactances, which with the potentiometer and R_3 comprise the control system proper, C_1 of course increases the impedance of the lower portion of the system at lower frequencies; L_1 increases it at the higher frequencies; and C_2 decreases the impedance of the upper portion of the system at the higher frequencies.

The operation of this embodiment of my invention may be best understood quantitatively as well as qualitatively by recourse to the simple algebra of complex quantities. E_1 may denote the no-load a. c. voltage output of V_1 at any given frequency $\omega/2\pi$, and E_2 the voltage thereby produced at the input of V_2 with any given setting of slider S . The ratio of E_2 to E_1 will then express the degree of amplitude control exerted on electric oscillations of such frequency by the control system with such slider setting; it may otherwise be termed the transmission efficiency of the control system for such frequency and adjustment. Provided the input impedance of V_2 be very high, as is the usual case with an amplifying vacuum tube at audible frequencies, this transmission efficiency may readily be shown to be:—

$$\frac{E_2}{E_1} = \frac{R_2 + R_3 + N}{R_1 + R_3 + N_1} \quad (1)$$

when

$$N = R_1(1 - \omega^2 L_1 C_1) C_2 / C_1 + j\{\omega[L_1 + R_1 R_3 C_2] - 1/\omega C_1\}$$

and

$$N_1 = R_1(1 - \omega^2 L_1 C_1) C_2 / C_1 + R_0 + j\{\omega[L_1 + R_1(R_3 + R_0)C_2] - 1/\omega C_1\}$$

wherein j has its usual operative significance of $\sqrt{-1}$.

As will hereinafter appear, L_1 and C_2 need not both be used, the two being essentially alternative to each other. The real component of N , and the similar first term of the real component of N_1 , are obviously zero if C_2 be omitted (i. e., open-circuited, and therefore of a zero capacity value), and it is readily seen that the equation (1) under these conditions becomes:—

$$\frac{E_2}{E_1} = \frac{R_2 + R_3 + j(\omega L_1 - 1/\omega C_1)}{R_1 + R_3 + R_0 + j(\omega L_1 - 1/\omega C_1)} \quad (1a)$$

This will be found to be inherently an expression for the ratio of the output impedance of the system—i. e., the impedance across which the voltage E_2 is taken off—to the sum of the input impedance—i. e., the impedance across which the input voltage is applied—and the impedance (R_0) out of which the system works.

Returning to the generic expression (1), it has just been noted that the first term of both N and N_1 was actually zero if C_2 was omitted. On the other hand if C_2 be employed but L_1 omitted, the two mentioned terms may still be neglected, for the following reason: Both capacities C_2 and C_1 cooperate with R_1 , C_2 being effective as a significant shunt reactance at quite high frequencies

and C_1 as a significant series reactance at quite low frequencies. Because of the contrast of frequencies at which these respective capacities are to be effective C_2 is normally very small compared with C_1 , and the ratio C_2/C_1 therefore a very minor fraction, justifying the neglect of the terms in question. This remains true if not only L_1 but also C_1 be omitted (i. e., C_1 theoretically short-circuited), since C_1 is then effectively of an infinite capacity value and the value of the terms in question then actually zero.

For the preferred cases, therefore, in which only one of the elements L_1 and C_2 is employed, expression (1) becomes:

$$\frac{E_2}{E_1} = \frac{R_2 + R_3 + j\{\omega[L_1 + R_1 R_3 C_2] - 1/\omega C_1\}}{R_1 + R_3 + R_0 + j\{\omega[L_1 + R_1(R_3 + R_0)C_2] - 1/\omega C_1\}} \quad (2)$$

Still further simplification is justified if R_0 be small compared to R_1 and R_3 ; and for purposes of further description of the circuit this will be assumed. The justifiability of this simplification in any given case, however, must be determined for the particular value of R_0 being dealt with. Neglecting it, (2) becomes:—

$$\frac{E_2}{E_1} = \frac{R_2 + R_3 + j\{\omega[L_1 + R_1 R_3 C_2] - 1/\omega C_1\}}{R_1 + R_3 + j\{\omega[L_1 + R_1 R_3 C_2] - 1/\omega C_1\}} \quad (3)$$

in which the imaginary components of numerator and denominator are seen to be identical, and the real components to differ only in the presence of the variable R_2 in the numerator instead of the fixed R_1 which appears in the denominator.

Any of the above expressions for transmission efficiency will be seen to be in the form of the quotient of two complex quantities. In accordance with the accepted view that phase relations between different frequency components of sound are not of significance to the ear, these phase relations may be disregarded. The quotient of the effective values of numerator and denominator may therefore be taken as the significant value of any of the expressions. Such effective value of a term is, of course, the square root of the sum of the squares of its real component and of its imaginary component.

Reference being had to expression (3), it will be seen that if L_1 be removed by short-circuiting (i. e., assume a zero value), C_2 be removed by open-circuiting (i. e., assume a zero value), and C_1 be removed by short-circuiting (i. e., assume an infinite value), the circuit is without reactance, the imaginary components of numerator and denominator each become equal to zero, and the transmission efficiency becomes independent of frequency. This will be true whatever value the variable R_2 be caused to assume by adjustment of the position of slider S . If any of the reactances be restored to circuit, the imaginary components will cease to be zero and will assume a different value for each different frequency. Still, if R_2 is made equal to R_1 by positioning of slider S at the superior extremity of the potentiometer, the numerator and denominator are equal, and the transmission efficiency remains independent of frequency, in that it is unity for all frequencies. But with any of the reactances in circuit, downward adjustment of the slider, reducing the value of R_2 from that of R_1 , will cause the transmission efficiency to decrease differently for different frequencies—i. e., to change less, the higher the absolute values of the imaginary components; since with varying R_2 the value of the numerator of any of the foregoing

expressions obviously changes by a smaller percentage at any frequency, the higher the absolute value of its imaginary component at that frequency.

Thus by making the absolute values of the imaginary components high at the extreme, and low at intermediate, frequencies, the transmission efficiency change occurring upon movement of the slider may be reduced at the extreme frequencies, thereby compensating for the higher sensitivity of the ear to sound amplitude changes at these frequencies. Since the imaginary components take the form of an expression for the reactance of a tuned, or resonant, series circuit, it is very easy so to arrange the values of the reactances that each imaginary component assumes high negative values at low frequencies, a zero value at an intermediate frequency, and high positive values at high frequencies. When L_1 is employed, such a resonant circuit is formed by it and the capacity C_1 . Instead of actually employing such a resonant circuit, however, I may produce its effects by a physically non-resonant circuit arrangement wherein the inductance is absent and its function performed by the capacity C_2 . This results from the fact that the latter capacity, modified by certain of the resistance values, appears in the imaginary components in a position and algebraic sign similar to those of L_1 . This similarity of effect, and the opportunity which it affords to replace an inductance by a capacity, I regard as an important and useful detail of my invention; the capacity is less costly and entirely free of susceptibility to stray magnetic fields; and the physically non-resonant circuit is incapable of producing the objectionable "hang-over" effects sometimes characteristic of physical resonance.

It is to be noted that if the reduced change in transmission efficiency with variation of general volume level be desired at only one end of the audible register instead of at both, this may readily be arranged by appropriately omitting certain of the reactances. Thus if the reduced change be desired only at the high frequencies, the condenser C_1 may be omitted and either L_1 and/or C_2 retained; the imaginary components will then have a positive sign at all frequencies, but will be of appreciable value only at the higher frequencies. Again, if the reduced change in transmission efficiency be desired only at the low frequencies, both L_1 and C_2 may be omitted and C_1 alone retained; the imaginary components will then have a negative sign at all frequencies, but will be of appreciable value only at the lower frequencies. In removing or omitting any of the reactances it is important to observe the method appropriate thereto: i. e., short-circuiting for L_1 and C_1 and open-circuiting for C_2 , the appropriate treatment in the formulæ having been indicated above.

In review of the circuit of Figure 1, it will be seen that I have provided the desired differential effect of the potentiometer volume control on different frequencies, not by parallel resonant circuits shunted from the superior extremity of the potentiometer to the movable contact, but by a series resonant circuit in series with the inferior extremity. I have further provided an alternative, physically non-resonant arrangement for producing identical effects; and also non-resonant arrangements for reducing the action of the control at either end, instead of both ends, of the audible register. One deficiency of the general

circuit arrangement of Figure 1 exists, however, and this will hereinafter be seen to be cured in Figure 2. This deficiency comprises the inability to reduce the output volume level to absolute zero, or below a certain minimum established by the voltage drop in R_3 , L_1 and C_1 .

In Figure 2 V_1 is shown, by way of alternative illustration, as a vacuum tube having a cathode F_1 , an anode A_1 , and a grid to which electric oscillations of sound frequencies may be applied. In the output circuit thereof is shown a conventional coupling resistor R_6 , and a source B_1 of d. c. anode potential, such potential being blocked from the succeeding circuit by conventional blocking condenser C_4 . For purposes of further analysis the a. c. output voltage of the circuit $V_1-R_6-C_4$ —i. e., of the tube and its necessary associated apparatus—may be represented by E_1 . The potentiometer P of Figure 1 is replaced in Figure 2 by potentiometer P' , which has thereon a fixed tap T dividing the total resistance thereof into two sections, R_1 and R_4 . A movable contact or slider S may operate over the entire resistance of potentiometer P' . That portion of the resistance R_1 which may lie below slider S , when the latter is above tap T , is designated as R_2 . The condenser C_2 is shunted across R_1 , as in Figure 1; and the resistances R_3 and reactances L_1 and C_1 , again in series, are shunted across R_4 . The value of R_4 should be appreciably higher than the impedance, at any frequency to be transmitted, of the series circuit $R_3-L_1-C_1$ shunting it. If this condition be fulfilled, then as long as slider S is not moved below tap T , the basic action of the potentiometer P' and the associated resistance and reactance is sensibly unaltered from that of the circuit of Figure 1, and the formulæ given above for that circuit may be applied to the circuit of Figure 2 with negligible error. Thus as slider S is moved downward from the superior extremity of the potentiometer, general output volume level will be reduced and at the same time amplitude ratios between different frequency components will be progressively altered, as in the case of Figure 1. This progressive altering action will continue with downward motion of the slider until the latter has reached the position of tap T . From this point on, continued downward motion will further reduce (eventually to zero) the output sound level, but will not further change the amplitude ratios between different frequency components, these ratios remaining fixed at the values they respectively had when the slider was at the position of tap T —i. e., when R_2 equalled zero.

While the effects of various choices of component values is most generically expressed in the formulæ above, I have tabulated below a list of representative values of components which I have employed to advantage in the circuit of Figure 2; and I have shown as Figure 3 a group or family of curves showing the transmission-frequency characteristics of the circuit with such component values at various settings of the slider S . It is to be understood that these values and curves are not presented as examples of the best possible compensation for the differential sensitivity of the average ear—rather do they illustrate the action of my invention, and its adaptability to the production of effects of the nature required for the counteraction of ear characteristics. In these representative values, no L_1 is employed, C_2 being relied on for the perform-

ance of the function performable by L_1 and/or C_2 —

R_1 : 350,000 ohms C_1 : .024 microfarads
 R_2 : 20,000 ohms C_2 : .00015 microfarads
 R_4 : 200,000 ohms

These curves of Figure 3 are plotted to logarithmic scales, transmission efficiencies being plotted vertically and frequency horizontally. They are computed without regard to the value of R_4 , the neglect of which is justifiable because of its high value compared to the impedance, at any frequency between 50 and 20,000 cycles, of the series circuit shunting it. Slider S is taken as being so set in the computation of curve A that R_2 equals R_1 ; in the computation of curve B, that R_2 equals $R_1/2$; of curve C, $R_1/4$; of curve D, $R_1/8$; of curve E, $R_1/24$; in the computation of curve F, that R_2 is of zero value; and in the computation of curve G, slider S is taken as being so set that .6 of the resistance of R_4 lies below it and .4 above it. It will be noted that curve G is identical with curve F, being merely lowered in the logarithmic scale; and it may be shown that the curve for any setting of slider S on resistance R_4 —i. e., below tap T—is identical with curve F, being determined only in position by the exact setting of S. All curves for settings above tap T and thus falling intermediate curves A and F, however, are of respectively different form as well as position, as is illustrated by B, C D and E.

It may readily be seen from the curves that the imaginary components of numerator and denominator of (3) became zero at approximately 1,000 cycles, the relative values of the reactances having been chosen to that end. But an infinite number of sets of reactance values would produce such zero value at such frequency. It is therefore appropriate to say that the absolute values of the reactances (in relation to the resistances and particularly to R_1) affect the steepness of the rise of each of the lower curves on either side of its low point. Lower C_1 and higher C_2 capacity values (and higher values of inductance L_1 if employed) tend to produce steeper slopes in the curves, and vice versa. These reactance values (relative to resistance) affect the steepness of the curves essentially because they determine the curves themselves at and toward the extremities; and it is to be noted that extreme reactance values will not only steepen the slopes of the curves, but will also flatten off the extremities. A second factor affecting the steepness of the slopes is the resistance R_3 , which (in relation to R_1) essentially fixes the central portions of the lower curves. These central portions become lower, and the slopes thus steeper, the smaller the value of R_3 , and vice versa. Of course, the value of R_3 also modifies the action of the capacity C_2 , in that C_2 appears in the imaginary components multiplied by R_3 . In order, therefore, that the effect of changing R_3 be confined to a change merely of the form of a curve, the value of C_2 should be varied approximately inversely to the variation of R_3 .

If the right-hand (high frequency) rise, or slope, of each of the lower curves shown in Figure 3 be replaced by a horizontal line at the level of the central portion of the curve, and the left-hand slope be made to curve somewhat more gradually into such horizontal line, the resulting curves will be characteristic of the system with C_2 (and L_1) omitted. Conversely, if similar changes be made, but reversed between right- and

left-hand, the resulting curves will be characteristic of the system with C_1 omitted. In either of these cases the value of R_3 (in relation to R_1) will affect not only the steepness of the remaining slope, but also the level of the entire horizontal portion of the curve, rather than merely of the central portion as formerly; and the reactance values (in relation to resistance) will determine the other extremity of, and generally the position in the frequency spectrum of the slope of, each curve.

The element L_1 having been omitted in the example of component values given above and in the curves compiled therefrom, I have included as Figure 4 of the drawing the essential portion of Figure 2 but with the element L_1 omitted in manner as above discussed.

It is desirable that the resistance element of potentiometer P', comprising resistances R_1 and R_4 , be specially tapered if relatively uniform change, either logarithmic or arithmetic, of average output volume level be desired for equal distances of motion of slider S. Such taper may be readily determined by trial with the particular values of the components chosen for use in any given case.

If the circuit of Figure 2 be employed with C_2 as the sole reactance, not only will L_1 and C_1 be omitted (theoretically short-circuited), but the resistance R_3 may also be omitted (theoretically open-circuited), so that no circuit or element shunts R_4 ; but in this case the actual value of R_4 should be used in the formulae as a value of R_3 therein. In this case R_4 , in addition to performing its usual function of permitting reduction of volume level to zero, is also performing the normal function of R_3 , and should assume a value indicated as desirable for the latter.

It will be appreciated not only that wide departures may be made from the component values set forth above as typical, but also that various modifications may be made from the precise circuits and arrangements described. Again, while I have most completely described my invention in connection with the problem of maintaining apparent output tone quality approximately constant at various volume levels, it will be understood that it is equally useful for the production of a wide variety of tone quality changes coincident to volume level change. Such and other modifications and uses will not necessarily constitute departures from the spirit or scope of my invention, as hereinabove set forth and in the appended claims defined.

It will of course be understood that the transmission efficiency of the systems herein disclosed at any frequency and with any adjustment is the reciprocal of the attenuation effected by the system at such frequency and with such adjustment; and that the transmission-frequency characteristic with any adjustment is the inverse of the attenuation-frequency characteristic with such adjustment. Except as specially qualified, however, the term attenuation is used herein in the broader context of general or average reduction of amplitude or volume level at all frequencies, independent of the degree of non-uniformity at the several frequencies.

I claim:—

1. The combination with a source of plural frequency sound-representing electric oscillations, of an adjustable attenuating system therefor comprising a resistive voltage-dividing circuit; means for applying said oscillations thereacross; reactive means fixedly bridged across a

80

85

90

95

100

105

110

115

120

125

130

135

140

145

150

portion of said circuit; output connections from said circuit; and means for controlling the attenuation effected by and the transmission-frequency characteristic of said system in predetermined mutual relationship, said means consisting in a single contact selectively movable over said circuit to a plurality of positions within and to a plurality of positions without said bridged portion thereof, said contact forming one of said output connections.

2. The combination with a source of plural frequency sound-representing electric oscillations, of an adjustable attenuating system therefor comprising a resistive voltage-dividing means; an input circuit connected thereacross for applying said oscillations thereto; a contact substantially continuously movable over said voltage-dividing means; an output circuit connected from said contact to an extremity of said voltage-dividing means; and a reactive system permanently bridged to said input circuit from a point on said voltage-dividing means intermediate the extremities of the motion range of said contact; whereby adjustment of said contact simultaneously controls the attenuation effected by and the transmission-frequency characteristic of said system in predetermined mutual relationship.

3. The combination with a source of plural frequency sound-representing electric oscillations, of an adjustable attenuating system therefor comprising a resistive element and an input circuit connected thereacross for applying said oscillations thereto; a contact associated with said element and an output circuit connected from said contact to an extremity of said element, said contact being substantially continuously movable over said element to vary said attenuation at all frequencies; a fixed tap on said element intermediate the extremities of the motion range of said contact; and fixed reactive means, bridged from said fixed tap to said input circuit, for progressively augmenting said attenuation at intermediate frequencies as said attenuation at all frequencies is increased over a finite range.

4. The combination with a source of plural frequency sound-representing electric oscillations, of an adjustable attenuating system therefor comprising a potentiometer including a resistive element, a fixed tap thereon, and a contact movable thereover to any of a plurality of positions on each side of said tap; a circuit, including reactance, connected between said tap and an extremity of said resistive element; means for applying said oscillations across said resistive element; and means for transmitting oscillations appearing between an extremity of said resistive element and said movable contact; whereby adjustment of said contact simultaneously controls the attenuation effected by and the transmission-frequency characteristic of said system in predetermined mutual relationship.

5. The combination with a source of plural frequency sound-representing electric oscillations, of an adjustable attenuating system therefor comprising a potentiometer formed by a resistive element and a contact substantially continuously movable thereover; a circuit, including reactance, having a first extremity connected to a point on said resistive element intermediate the extremities of the motion range of said contact and a second extremity connected to an extremity of said element; means for applying said oscillations across said resistive element; and means for transmitting oscillations appearing between said extremity of said element and said movable con-

tact; whereby adjustment of said contact simultaneously controls the attenuation effected by and the transmission-frequency characteristic of said system in predetermined mutual relationship.

6. The combination with a source of plural frequency sound-representing electric oscillations, of an adjustable attenuating system therefor comprising a potentiometer including a resistive element, a fixed tap thereon, and a contact movable thereover to any of a plurality of positions on each side of said tap; a series circuit, including at least one reactance and resistance, connected between said tap and an extremity of said resistive element; means for applying said oscillations across said resistive element; and means for transmitting oscillations appearing between said extremity of said element and said movable contact; whereby adjustment of said contact simultaneously controls the attenuation effected by and the transmission-frequency characteristic of said system in predetermined mutual relationship.

7. The combination with a source of plural frequency sound-representing electric oscillations, of an adjustable attenuating system therefor comprising a resistive element; a circuit, including reactance, having a first extremity connected to an extremity of said element; means for applying said oscillations across said element and said circuit in series; a further resistive element connected across said circuit; a single contact consecutively movable over said elements to any of a plurality of positions on each; and means for transmitting oscillations appearing between said movable contact and the second extremity of said circuit; whereby adjustment of said contact simultaneously controls the attenuation effected by and the transmission-frequency characteristic of said system in predetermined mutual relationship.

8. In a potentiometer system for the adjustable attenuation of plural frequency sound-representing electric oscillations, the combination of means included in a portion of said system for increasing the impedance of such portion progressively as frequency approaches a limit of audibility; a further portion of said system connected in series with said first mentioned portion; means for applying said oscillations across said serially connected portions; means for transmitting oscillations from said serially connected portions; and a single continuously adjustable means operable selectively to reduce said transmission from said further portion, or to eliminate the same and reduce the transmission from said first mentioned portion; whereby adjustment of said last mentioned means simultaneously controls the attenuation effected by and the transmission-frequency characteristic of said system in predetermined mutual relationship.

9. In a potentiometer system for the adjustable attenuation of plural frequency sound-representing electric oscillations, the combination of means included in a portion of said system for increasing the impedance of such portion progressively as frequency approaches a limit of audibility; a further portion of said system connected in series with said first mentioned portion, said further portion having a substantially constant impedance with varying frequency; means for applying said oscillations across said serially connected portions; means for transmitting oscillations from said serially connected portions; and a single voltage-reducing means successively adjustable within said further and said first mentioned portions to reduce said transmission from said

further portion or to eliminate the same and reduce the transmission from said first mentioned portion; whereby adjustment of said last mentioned means simultaneously controls the attenuation effected by and the transmission-frequency characteristic of said system in predetermined mutual relationship.

10. The combination with a source of plural frequency sound-representing electric oscillations, of an adjustable attenuating system therefor comprising a potentiometer including a resistive element, a contact substantially continuously movable thereover, and a tap thereon intermediate the extremities of the range of motion of said contact; means for applying said oscillations across said resistive element; means for transmitting oscillations appearing between said contact and an extremity of said element; and a series circuit resonant to an intermediate frequency connected between said tap and said extremity of said element; whereby adjustment of said contact over the portion of said element between the other extremity thereof and said tap effects a greater change of attenuation at intermediate than at extreme frequencies.
11. In a potentiometer system for the adjustable attenuation of plural frequency sound-representing electric oscillations, the combination of means included in a portion of said system for increasing the impedance of such portion progressively with increasing frequency difference from a mean frequency; a further portion of said system connected in series with said first mentioned portion, said further portion having a substantially constant impedance with varying frequency; means for applying said oscillations across said serially connected portions; means for transmitting oscillations from said serially connected portions; and a single voltage-reducing means successively adjustable within said further and said first mentioned portions to reduce said transmission from said further portion or to eliminate the same and reduce the transmission from said first mentioned portion; whereby adjustment of said last mentioned means within said further portion effects a smaller change of attenuation at extreme than at intermediate frequencies.
12. The combination with a source of plural frequency sound-representing electric oscillations, of an adjustable attenuating system therefor comprising a potentiometer formed by a resistive element and a contact substantially continuously movable thereover; a capacity connected between a first extremity of said resistive element and a point thereon intermediate the extremities of the range of motion of said contact; means for applying said oscillations across said resistive element; and means for transmitting oscillations appearing between the second extremity of said resistive element and said movable contact; whereby adjustment of said contact over the portion of said element shunted by said capacity effects a smaller change of attenuation at high frequencies than at other frequencies.
13. The combination with a source of plural frequency sound-representing electric oscillations having output impedance R_0 , of an adjustable attenuating system for said oscillations,

said system having fixed resistive parameters R_1 and R_3 serially connected, an adjustable resistive parameter R_2 forming part of R_1 , a relatively large capacitive parameter C_1 in series with R_3 , and a relatively small capacitive parameter C_2 shunting R_1 , the transmission efficiency of said system in said combination being given substantially by the following expression:

$$\frac{R_2 + R_3 + j\{\omega R_1 R_3 C_2 - 1/\omega C_1\}}{R_1 + R_3 + R_0 + j\{\omega R_1 (R_3 + R_0) C_2 - 1/\omega C_1\}}$$

and the values of said fixed parameters being so chosen that the imaginary component of the numerator in the foregoing expression assumes a zero value at an intermediate frequency; whereby adjustment of the value of R_2 effects a smaller change of oscillation attenuation at extreme than at intermediate frequencies.

14. The combination with a source of plural frequency sound-representing electric oscillations, of an adjustable attenuating system therefor comprising a potentiometer including a resistive element, a fixed tap thereon, and a contact movable thereover to any of a plurality of positions on each side of said tap; a series circuit, comprising a capacity and a resistance, connected between said tap and a first extremity of said resistive element; a smaller capacity connected between said tap and the second extremity of said resistive element; means for applying said oscillations across said element; and means for transmitting oscillations appearing between said first extremity of said element and said movable contact; whereby adjustment of said contact over a portion of said resistive element effects a smaller change of attenuation at extreme than at intermediate frequencies.

15. In the amplitude control of plural audio frequency electric oscillations by a potentiometer system whose transmission efficiency at any frequency is substantially the ratio of its output impedance to the sum of its input impedance and the impedance out of which the system works, the method of volume control of sound translated from said oscillations to provide volume changes of apparently similar degree at different frequencies, which consists in varying the output impedance of said system by greater percentages at intermediate than at extreme frequencies, while maintaining essentially unchanged the input impedance of said system at each discrete frequency.

16. In the amplitude control of plural audio frequency electric oscillations by a potentiometer system whose transmission efficiency at any frequency in the lower audio band is substantially the ratio of its output impedance to the sum of its input impedance and the impedance out of which the system works, the method of volume control of sound translated from said oscillations to provide volume changes of apparently similar degree at various frequencies within said band, which consists in varying the output impedance of said system within said band by percentages which are progressively smaller the lower the frequency, while maintaining essentially unchanged the input impedance of said system at each discrete frequency.

CHARLES T. JACOBS.