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COMPENSATING NETWORK

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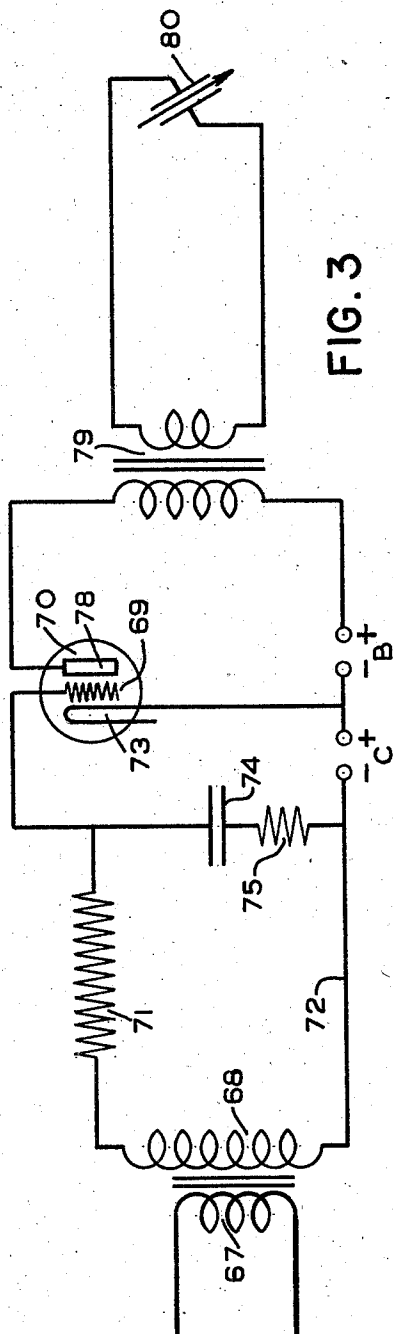


FIG. 3

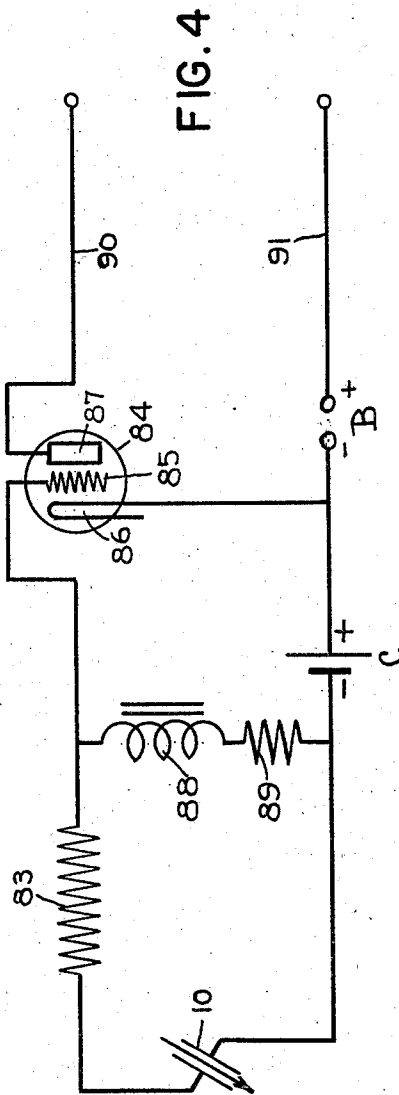


FIG. 4

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COMPENSATING NETWORK

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22 Claims. (Cl. 179—100.4)

The invention relates to a compensating network having a number of applications and designed particularly to correct or compensate electrical oscillations in a circuit in which the transmission of the oscillations is linearly proportional, either directly or inversely, with respect to frequency over some portion of the frequency range, or to control uniform transmission of electrical oscillations in the circuit so that their transmission becomes enhanced or diminished proportionally, either directly or inversely, with respect to frequency over some portion of the frequency range. Such a compensating circuit is particularly applicable in a circuit connected with a generator of a type to be described hereinafter for reproducing or creating a sound groove having a constant velocity characteristic with respect to frequency.

The invention relates further to the combination of the compensating network, discussed above, with an electro-acoustic device having a generator of the type to be described. Such an electro-acoustic device is used for converting a sound groove into electrical oscillations or for transforming electrical oscillations into a sound groove having a constant velocity characteristic. The invention has particular reference to a piezo crystal electro-acoustic device carrying a stylus or cutter for either reproducing or cutting a record sound groove, which groove has a constant velocity characteristic.

The invention in its simplest form contemplates providing a circuit including two generators, one of which is reactive, either capacitive or inductive, and selecting a resistance to be inserted in the circuit, which resistance may or may not be entirely within the other generator. This resistance cooperates with the capacitive reactive generator so that the amplitude of the electrical oscillations in the circuit is uniform or constant with respect to frequency over a predetermined range, which amplitude of the oscillations would otherwise be proportional to frequency over some portion of the frequency range.

The principal object of the invention is to devise a compensating network including a reactive means and a resistance means in series, which network is connected in a circuit carrying electrical oscillations, and the values of the impedance of the reactance means and the impedance of the resistance being such that either a directly proportional or an inversely proportional linear relation or effect is obtained between the frequency and the transmission of the electrical oscillations in the circuit.

Another object is to provide a network having the effect set forth above, but to further control the electrical oscillations transmitted so that the decrease or increase or both the decrease and increase in transmission is limited.

Another object is to devise an electro-acoustic means utilizing a generator of a type to be described which reproduces a sound groove of the constant velocity form with improved fidelity, or will cut or produce a sound groove of constant velocity form.

Another object is to devise a compensating circuit or network for a generator to be described which is to be used either as a generator of mechanical vibrations for a sound groove cutter when electrical oscillations are applied thereto in order that the cutter will generate a constant velocity sound groove, or as a generator of electrical oscillations when used as a pick-up having a stylus tracking in a sound groove, which sound groove has a constant velocity characteristic so that the pick-up will reproduce the sound groove with improved fidelity.

A further object is to devise a circuit or network for a generator which compensates for the variation caused by the generator being of a constant amplitude type and tracking in a constant velocity type of sound groove, and also controls or limits the decrease and increase in the relative transmission of the circuit at frequencies above and below the desired frequency range.

A still further object is to provide a method of modifying or controlling the electrical oscillations in a circuit so that oscillations which have an amplitude which is either directly or inversely proportional to frequency and linear over some portion of the frequency range will have a constant amplitude with respect to frequency over a desired frequency range, and so that the oscillations which have an amplitude which is constant with respect to frequency over some portion of the frequency range will have an amplitude which is either directly or inversely proportional to frequency over a desired frequency range. This object also includes a method of modifying or correcting the electrical oscillations controlling the vibration of or the electrical oscillations created by a generator, the internal reactance of which is effectively capacitive.

Other objects of the invention will be more apparent from the following description taken in connection with the accompanying drawings, illustrating some preferred embodiments of the invention, in which:

Figure 1 is a diagrammatic view of a circuit

having the compensating network of the invention connected therein for modifying the electrical oscillations produced by a generator, such as of the capacitive internal reactance type, when tracking in a constant velocity sound groove on a phonograph record, such as a disk.

Figure 2 is a diagrammatic view of a circuit having the compensating network for reproducing a sound groove of the constant velocity form from a record for reproduction particularly over a radio broadcasting system in which a generator of the constant amplitude type is controlled by the groove.

Figure 3 is a diagrammatic view of a circuit with the compensating network of the invention connected therein for driving a cutter or engraving tool controlled by a generator of the constant amplitude type for producing a sound track upon a sound recording means such that a stylus following the track will vibrate with a constant velocity characteristic or form.

Figure 4 is a diagrammatic view of a modification of the circuit shown in Figure 1 utilizing an inductive reactance and a resistance, instead of a capacitive reactance and resistance as shown in Figure 1, and adapted to produce the same effect.

The invention to be described herein in one of its aspects provides for two different situations which will be enumerated. One situation involves a circuit carrying electrical oscillations of a wide range of frequencies in which the transmission of the circuit or the amplitude of the oscillations over some portion of the range of frequencies being transmitted varies proportionately either directly or inversely with respect to frequency, and inside that portion of the range of frequencies, whether inversely or directly proportional, the transmission may be described as either linearly or substantially linearly varying. The compensating network to be described herein modifies the circuit so that the transmission of the oscillations is modified and the oscillations have an amplitude which is uniform with respect to frequency over that portion of the frequency range in which the proportional relation existed. The second situation involves a circuit carrying oscillations, the amplitude or character of which is substantially uniform with respect to frequency over some portion of the frequency range of the oscillations being transmitted. These electrical oscillations are used to drive or control a device and the effect or result could be improved by modifying the circuit so that the oscillations have an amplitude-frequency relation which is either directly or inversely proportional with respect to frequency over some portion of the frequency range of the oscillations.

It is to be understood that when the amplitude of the oscillations is stated as being proportional, either directly or inversely with respect to frequency, that proportionality may include a constant factor either positive or negative. In other words, if the amplitude-frequency relation is plotted, the linear slope if continued need not pass through the index of the graph, but may cut the X axis at any desired point in the graph.

It will be observed that each situation discussed above in turn involves two sub-divisions for consideration, namely the character of the resultant oscillations are such that the amplitude or transmission frequency relation is either directly or inversely proportional over some portion of the frequency range. The four situations for

which the simple network of the invention is applicable therefore include the correction of a circuit carrying electrical oscillations which vary directly or inversely with respect to frequency over some portion of the frequency range so that the oscillations are substantially uniform with respect to frequency over the corrected range. The network of the invention also includes the modification of a circuit carrying electrical oscillations which are substantially uniform in amplitude over the major portion of the frequency range, which oscillations are used to drive a device which should, in order to obtain a desired response, have the electrical oscillations modified so that the oscillations are directly or inversely proportional to frequency over some portion of the frequency range.

Electrical oscillations having a wide range of frequencies may frequently have certain bands of frequencies excessively pronounced or subdued, and when either condition exists and the oscillations are either directly or inversely proportional to frequency and hence linearly varying, the circuit can be modified by the network to be described herein. Also if a device or generator vibrated or driven by electrical oscillations does not vibrate in the manner desired, certain bands of frequencies of the oscillations controlling or driving the same may be modified in amplitude, either pronounced or subdued. The modified oscillations may be either directly or inversely proportional to frequency in order to have a desired response in the device, and such modified amplitude may be obtained with the compensating network described herein. Such electrical oscillations are frequently found in the radio and sound recording arts, as will appear more fully hereinafter.

Records for phonographs and electrical transcriptions as now manufactured have the sound track formed therein such that a stylus following the groove moves at a velocity which is constant with respect to the frequency of the vibrations recorded thereon over some portion of the frequency range. The sound groove does not have the constant velocity relation throughout its frequency range, but a predetermined portion thereof in the normal frequency working range has this constant velocity characteristic. That portion or frequency range of the groove having the constant velocity characteristic and its relative position in the frequency range, so far as this invention is concerned, may be considered as arbitrarily determined. Commercially these two factors are determined for reasons not necessary to be considered herein.

The constant velocity form of sound groove has an amplitude which increases with decreasing frequency and decreases with increasing frequency. The motion or oscillation of the tracking stylus and the generator vibrated thereby naturally corresponds with the character of the groove. A reproducing apparatus, such as an electro-magnetic pick-up, is capable of translating this constant velocity form of sound track into electrical vibrations which generally only need to be amplified in order to reproduce with good fidelity the sound recorded in the groove.

If now a type of pick-up is used on the constant velocity sound groove which is governed by some other law or characteristic inherent in the form of pick-up used, the reproduction of the constant velocity sound track will not be accurate and after amplifying the oscillations produced by the generator and driving a speaker therewith,

the reproduction is inferior in several respects. For instance, the pick-up may be of a type which is responsive to the amplitude of the oscillations of the stylus tracking in the sound groove and is independent of velocity, that is within limits, and such a reproducer or pick-up, tracking in a groove engraved by a constant velocity type of device, will have a voltage or current output varying inversely with respect to frequency. Such an amplitude responsive pick-up is found in the piezo electric crystal pick-up, in a condenser pick-up, in a stiffness controlled electro-magnetic mechanism, and certain carbon microphone types of pick-ups. The first two are the capacitive internal reactance type of generator, and the third is the inductance internal reactance type.

A piezo electric acoustic device (and also a stiffness controlled electro-magnetic type) is also used as a generator to drive an engraving or cutting tool for producing a sound groove. The sound groove produced from electrical oscillations which are uniform in amplitude over the frequency range, however, would be of a constant amplitude with respect to frequency since this is the inherent characteristic of the oscillations produced by a piezo electric generator. Such a sound groove would be unsatisfactory for use with an electro-magnetic pick-up which has a constant velocity characteristic when used without modification of the electrical oscillations generated. My compensating network is connected into the circuit to the generator so that the electrical oscillations in the circuit are modified or compensated so that the generator vibrates with a constant velocity characteristic and hence produces a sound groove having this same characteristic. Note that the groove produced is of the constant velocity form, although the generator is of a type which would produce a different form of groove if not compensated for with the network of the invention.

A piezo electric crystal generator, used as a generator either for a pick-up or an engraving tool, has several advantages over the electro-magnetic generator now in universal use. The principal advantage is the difference in weight between the two devices, the electro-magnetic generator being considerably heavier as compared with a piezo electric crystal generator. The lighter piezo electric crystal generator provides a mechanism which is more responsive to high frequencies and is also less likely to damage and cause excessive wear of the record.

A piezo electric crystal pick-up, when tracking in a constant velocity sound groove, generates electrical oscillations which vary proportionately in amplitude at different frequencies so that if their amplitude is plotted with respect to frequency, the line of variation plotted will be linear throughout a considerable portion of the frequency range, but which amplitude varies inversely with the frequency. If the electrical oscillations generated by the piezo electric crystal are amplified and operate a speaker, the reproduction of the sound track will be unsatisfactory in various respects and particularly in the lack of high frequencies or over-emphasis of the low frequencies. I have devised, therefore, a group of networks which, when used with a piezo electric crystal pick-up, transpose, correct, or compensate the electrical oscillations generated thereby to give oscillations which are uniform in amplitude with respect to frequency, at least when the stylus is tracking through that por-

tion of the frequency range where the sound groove has the constant velocity characteristic, and transpose or compensate the electrical oscillations controlling an engraving tool so that oscillations which would otherwise vibrate the latter with a constant amplitude characteristic, instead control or vibrate the tool so that it engraves a sound groove having a constant velocity form or characteristic.

A piezo electric crystal device, when used as a pick-up device, is a generator of electrical oscillations, the frequency and amplitude of the oscillations of course being determined by the sound groove. When the piezo electric crystal device is used as a cutting or engraving tool to form a sound groove, it is a generator of mechanical oscillations, the frequency and amplitude of which oscillations are controlled by the electrical oscillations applied thereto. In other words, the piezo electric crystal device is a generator of the capacitive internal reactance type, irrespective of whether it is a generator of electrical or mechanical vibrations or oscillations. Any generator is contemplated which, when its stylus is tracking in a sound groove having a constant velocity or any other characteristic, generates electrical oscillations which are either directly or inversely proportional to frequency over at least some portion of the frequency range and, conversely, any generator is contemplated which requires electrical oscillations which are directly or inversely proportional to frequency over at least some portion of the frequency range in order to produce a desired form or type of mechanical vibrations of the generator, such as, for example, a constant velocity form.

A circuit is shown in Figure 1 which includes a compensating network of the invention connected with a piezo electric crystal mounted stylus which combination is also part of the invention. The circuit is connected with a second generator such as a vacuum tube 11. The piezo electric crystal pick-up consists principally of two crystals mounted or secured at one end and carrying a stylus at the other end for following a sound track in a record. The vacuum tube 11 illustrated is a three element tube having the usual filament 12, plate 13, and grid 14. The tube may be of any suitable form or type and not necessarily a three element tube. One of the crystals of the piezo electro-acoustic device 10 is connected with the grid 14 and the other crystal is connected with the filament of the tube through a means providing a negative bias 15. Piezo electro-acoustic devices, which will be termed capacitive internal reactance generators, are known to the art and therefore further description of these devices is unnecessary. A resistance 16, in the neighborhood of two to ten megohms, is connected across the crystals of the piezo electro-acoustic device.

A second vacuum tube 20 has a filament 21, plate 22, and a grid 23. This tube is shown as a three element tube merely for the sake of illustration and any type of tube is contemplated. The compensating network is located between two generators, such as the tubes 11 and 20, and will now be described. The compensating network or circuit need not be located between two vacuum tubes, but may be located anywhere in the circuit between two generators where it will exercise control over the current passing there-through. The plate 13 of the tube 11 is connected with a source of electric potential through a resistance 24 which is the usual resistance coupling, 75

and any other form of coupling is contemplated. The plate 13 of the tube 11 is connected to the grid 23 of the tube 20 through a blocking condenser 28, as known to the art, which may be about one micro-farad and is in series with a second condenser 29 which is preferably of fifty micro-micro-farads. The second condenser 29 provides the means having a reactance which is a necessary part of the compensating network. The condenser 29 is shunted by a limiting resistance 30 of the order of ten megohms. This resistance limits the decrease in transmission through the circuit for relatively low frequency oscillations caused by the condenser 29. Between the condenser 29 and the grid 23 of the vacuum tube 20 is connected a resistance 31 of the order of one-half megohm. This resistance 31 connects the grid with the filament 21 of the tube 20 through a means providing a negative bias 32 as known to the art.

It is understood that any well known means of providing filament excitation will be added to the circuit, as determined by the types of tubes used.

In the form of circuit shown in Figure 1, the condenser 29, forming part of the compensating network or circuit, is connected in the series circuit linking two relays or vacuum tubes of the amplifying circuit shown, which tubes, so far as the invention herein is concerned, are generators of electrical oscillations. The circuit through the vacuum tubes leads to the output wires 43 and 44. The resistance 31, on the other hand, is in a shunt circuit shunting the generator or tube 20.

Where, as in the circuit illustrated in Figure 1, the resistance 31 also serves as a grid leak for the grid 23 of the tube 20, the value of this resistance is selected to serve its function as a grid leak and the capacitance connected in series therewith is chosen or determined upon the basis of the value of the resistance so that the resistance and the capacitance cooperate to give the proportional transmission frequency effect of the invention.

The plate 22 of the vacuum tube 20 may be connected with the primary winding of a standard transformer 35. The secondary winding of the transformer is connected with a variable resistance 36 of about two thousand ohms. This resistance is shunted by a condenser 37 and inductance 38 which are connected in series and form a series resonant circuit. The condenser 37 is of about five micro-farads capacity, and the inductance has a value of about one henry. This second network has the function of modifying the transmission frequency relation of the circuit at frequencies preferably above or below the frequency range in which the transmission frequency relation is proportional as produced by the first network and as described above, although some overlap between the effects of the two circuits is not harmful.

A compensating circuit 42 may be connected across the transformer secondary circuit formed by the wires 43 and 44. This compensating circuit may consist of an inductance 45 of twenty milli-henries in series with a condenser 46, which compensating circuit corrects for the mechanical resonance of a piezo electro-acoustic device. Mechanical resonance usually takes place between three thousand to six thousand cycles. The condenser 46 is adjusted to tune with inductance 45 to resonate at the mechanical resonance frequency of the device 10. A standard scratch filter 47 may also be connected across the wires 43 and 44 as well as a terminator attenuating

circuit 48 having the common value of five to ten decibels.

The compensating circuit or network, forming the principal part of the invention, comprises principally the resistance 31 and the condenser 29. The resistance 30 is also desirable, although not strictly essential as will appear hereinafter. The other elements of the entire circuit, which has been described, provide means or devices for modifying the transmission of the circuit for frequencies above and below the range where the proportional amplitude frequency characteristic occurs as controlled or determined by the condenser 29 and resistance 31. It is desirable to increase the relative gain of the circuit in the frequency range below four-hundred cycles or thereabout. This increased relative gain may be accomplished by connecting the resistance 30 in shunt across the condenser 29. This resistance is of a value so that it has no effect at the higher frequencies or within the range where the proportional effect occurs, but at the lower frequencies where the reactance of the condenser 29 is high, the resistance functions to stop the decrease of the relative gain or to limit the excessive variation in the circuit at the lower frequencies caused by the reactance means. The resistance, in combination with the characteristics of the piezo crystal, therefore has the effect of increasing the amplitude of the oscillations at the lower or bass frequencies so that they bear a proper ratio with respect to the higher frequencies in the reproduction. This shunt resistance has then the function of limiting the decrease in transmission at the lower frequencies caused, in the circuit shown in Figure 1, by the high impedance of the condenser 29 at these lower frequencies.

Although the limiting resistance 30 is shown as shunting the reactance means or condenser 29, it will appear more fully hereinafter that this resistance will be connected in series with the reactance means in other circuits in order to limit the decrease in transmission caused by the impedance of the reactance means outside of a certain frequency range.

In Figure 2 the network is shown in a circuit using a piezo electrical crystal pick-up connected to a line transformer for connecting the piezo electro-acoustic device to a radio broadcasting system. In this construction the piezo electro-acoustic device 10 is connected to the ends of the primary winding 50 of a transformer. The secondary winding 51 is connected with the mixer 52 of the usual radio broadcasting station. In this construction the piezo electro-acoustic device and the mixer constitute the generators between which the network of the invention is located. The compensating network connected in the circuit between the secondary winding 51 of the transformer and the mixer 52 again comprises fundamentally a reactance means 54 connected in series between two generators. A reactance means or condenser 54, having a capacity in the neighborhood of .1 micro-farad, is connected so that this condenser is in series with the resistance 53 and in series between the generators 10 and 52. The condenser 54 is shunted by a limiting resistance 63 of three thousand ohms which limits the decrease in transmission or the excessive variation in transmission at the lower frequencies below the proportional frequency transmission range in the same manner as the resistance 30 in Figure 1 performs this function.

A series resonant circuit may shunt the re-

istance 63 as well as the condenser 54 and comprises a condenser 55 and an inductance 56 connected in series. The inductance 56 is preferably in the neighborhood of two henries and the condenser 55 has a capacity in the neighborhood of three micro-farads. This circuit causes an increase in transmission at low frequencies below the point at which linear variation begins.

The wires 60 and 61 which connect the secondary winding 51 of the transformer and the compensating network with the mixer 52 may be connected, if desired, through a mechanical resonance peak remover and a scratch filter like those shown in Figure 1. The transformer is preferably designed to work between one-hundred thousand ohms and one-hundred to three-hundred ohms with exceedingly high fidelity.

The invention may also be utilized for compensating the vibrations or oscillations of a cutter controlled from a microphone to make the initial sound groove from which the sound groove of records are made. The circuit, including the network of the invention adapted for controlling a cutting tool, is shown in Figure 3 in which a crystal bimorph or device having a similar characteristic or response is used as a recording cutter by operating an engraving tool which makes the initial sound groove subsequently reproduced as a record. Such a crystal bimorph has an amplitude of vibration for a given voltage which is sensibly independent of the frequency over the frequency range to which it is subjected except near the resonance points. In order, therefore, to vibrate the stylus so that it will produce a sound track having a constant velocity characteristic, it is necessary to provide a coupling unit, driver amplifier, or compensating network in the circuit to the crystal bimorph, having a transmission which varies inversely and proportionally to frequency and hence linearly over some portion of the frequency range. The production of a sound groove which will vibrate a stylus with a constant velocity is necessary in order that the well known and widely used present day electromagnetic pick-up may continue to be used.

Referring now to Figure 3, a transformer 67 is shown which is connected with a device for translating sound vibrations into electrical vibrations or oscillations such as the usual microphone which produces electrical oscillations which are uniform with respect to frequency. The secondary winding 68 of the transformer 67 is connected with the grid or control electrode 69 of a vacuum tube 70. As previously discussed, this vacuum tube is a generator so far as this invention is concerned. A resistance 71 having a value in the neighborhood of one megohm is connected in series with the grid 69 of the tube 70. The other end of the secondary winding 68 is connected by a wire 72 to the filament 73 of the vacuum tube or generator 70. A condenser 74 is connected in shunt with the grid circuit or with the generator 70 between resistance 71 and the grid 69 and to the wire 72 so that the resistance and the condenser are in series with each other. This condenser 74 has a capacity in the neighborhood of .01 micro-farad.

It will be noted that in the form of the invention disclosed in Figure 3, the resistance 71 and condenser 74 are in series with respect to each other, as in Figure 1, but the resistance in Figure 3 differs in its location from that shown in Figure 1 by being in series with the generator 70, whatever its form may be, and the reactance is in shunt with the generator.

The value of the impedance of the resistance is determined, as will appear more fully hereinafter, so that it will give a transmission characteristic for the circuit such that the oscillations will be inversely proportional to frequency over some portion of the frequency range and hence linear in this range. The electrical oscillations controlling the crystal bimorph are, therefore, of a nature which will vibrate the same so as to produce a sound groove of the constant velocity form so that a stylus carried by a pick-up of the constant velocity type will vibrate with its usual vibration to produce uniform transmission with respect to frequency over the major portion of the frequency range.

There is shown in Figure 3, therefore, a compensating network which controls the electrical oscillations in the circuit so that the oscillations decrease proportionally and hence linearly with respect to frequency, or the oscillations are inversely proportional to the frequency of the oscillations over some portion of the frequency range.

A resistance 75 is provided in the shunt circuit having the condenser 74 and in series with the condenser in order to limit the decrease in transmission at higher frequencies which would occur because of the relatively low impedance of the condenser 74 at these frequencies. The impedance of the combined capacitance 74 and the limiting resistance 75 at the frequency of maximum varying transmission may be determined from a formula to be given and discussed hereinafter.

It should also be noted that in Figure 1 the decrease in transmission caused by the condenser 29 is in the lower frequencies, whereas in the circuit shown in Figure 3, the condenser 74 causes a decrease in transmission in the higher frequencies. This change in the position of the reactance means changes the linear relation so that the transmission varies inversely proportional to frequency over the desired range.

The plate 76 of the tube or generator 70 is connected to an amplifying or coupling circuit of any desirable kind, that shown being a transformer 78 which is merely illustrative of any amplifying or coupling device. This coupling circuit is connected to the crystals forming the crystal bimorph 80 which controls the movement of a stylus or cutter which produces the initial constant velocity sound track or groove which can be subsequently reproduced by known methods using the usual constant velocity types of pick-ups, such as the electro-magnetic pick-up.

There is shown in Figure 4 a compensating network which does not utilize a condenser or capacitive reactance, but which controls the electrical oscillations in the circuit in the same manner as the network shown in Figures 1 and 2. In other words, it corrects or compensates for oscillations which are inversely proportional to frequency over some portion of the frequency range to produce uniform transmission with respect to frequency over the desired range. In this construction, the resistance 83 is connected in series with the grid or control electrode 85 of the generator or vacuum tube 84 between the tube and a crystal of a capacitive-effective reactance generator 10. The filament 86 of the vacuum tube is connected with the other element of the pick-up. A negative bias C is employed in a known manner. The vacuum tube or generator 84 is shunted by an inductive reactance 88 and a limiting resistance 89 in series with the reactance. The vacuum tube 84 is connected by

means of the wires 90 and 91 to an output circuit of any desired form or type.

The circuit of Figure 4 will have the same effect as that of the circuit shown in Figure 1.

5 Similarly, the network arrangement of Figure 3 may be reversed by substituting for the resistive impedance 71 an inductive reactance shunted by a resistance, and by replacing the condenser 74 and resistance 75 with a resistance determined in accordance with the formulas to be given. 10 The decrease in transmission at high frequencies is controlled by the limiting resistance shunting the inductive reactance and having a value determined by formulas to be given hereinafter for determining a limiting resistance. 15

In Figure 4, it will be observed that the inductive reactance 88 provides means having a reactance which is in series with the resistance 83 in the series circuit between the generators. 20 The impedance of the inductive reactance 88 controls the electrical oscillations across the resistance 83. When these impedances are determined, the transmission of electrical oscillations in the circuit varies linearly and directly 25 proportional to frequency over some portion of the frequency range. The inverse proportion of relative transmission to frequency is obtainable by placing the inductive reactance 88 in the series circuit and the resistance 83 in the shunt 30 circuit as taught by a comparison of the circuits of Figures 1 and 3. The limiting resistance 89 in series with the inductive reactance 88 limits the decrease in transmission at low frequencies in the circuit, as shown in Figure 4.

35 The four forms of the invention disclosed herein show that the essential features of the invention include a resistance means and a reactive means connected in series and that one of these means is connected in series between 40 two generators, and the other means is connected in shunt with one of the generators. The impedance of the corrective network described alters the relative transmission of the electrical oscillations in the circuit to produce four major effects which, for the lack of a better term, will 45 be defined as a proportional effect or a proportional variation. For example, the transmission of the oscillations in a circuit to be corrected may vary proportionally, either directly 50 or inversely, with respect to frequency over some portion of the frequency range and the desired response may require that the transmission of the oscillations be uniform or constant over this range. The corrective network of the invention corrects 55 for such a situation. Again, a circuit may carry oscillations which are uniform or constant with respect to frequency over a certain range of frequencies and the device or generator operated or controlled by these oscillations may require that 60 the transmission be proportional, either directly or inversely, with respect to frequency over some portion of the frequency range in order to get a desired response therefrom. In such a case, the corrective network of the invention provides such 65 proportional transmission. In some constructions the circuit to be corrected may be predominantly reactive so that the circuit can be corrected merely by the addition of resistance of a suitable value as determined from the formulas hereinafter given, and the reactance already 70 in the circuit cooperates therewith to produce the proportional amplitude frequency effect.

The invention in its preferred form also con- 75 templates connecting a limiting resistance in the

circuit with respect to the reactive means which limits the decrease in transmission of the circuit caused by this means. In other words, the reactive means, whether capacitive or inductive, has an impedance which varies with the frequency of the electrical oscillations and the impedance of the capacitive reactance becomes so high at low frequencies that transmission of the low frequencies becomes negligible when the reactance is in the series circuit, and transmission 5 of the high frequencies becomes negligible when the reactance is in the shunt circuit. Similarly, the impedance of the inductive reactance becomes so high at high frequencies that the transmission through the circuit becomes excessively 10 low in a reverse relation from that described for the capacitive reactance. A limiting resistance is provided, shunting the reactive means or in series therewith, depending upon whether it is an inductive or capacitive reactance and also 15 depending upon whether the reactance is in the series or shunt circuit between the generators. This resistance limits a decrease in transmission at low or high frequencies. Similarly, the impedance of the capacitive reactance in Figure 3 20 becomes so low at high frequencies and the impedance of the inductive reactance of Figure 4 becomes so low at low frequencies that the transmission through the circuit becomes excessively 25 low and the resistances 75 and 89 are provided to limit this decrease in transmission. 30

It will now be pointed out that it is not necessary to have the resistance means and the reactance means connected directly in series and there may be various electrical transmitting devices therebetween, such as a transformer, so long as those devices are not of a blocking type, such as a vacuum tube or a terminator attenuating circuit. 35

I prefer to design my circuit according to the following method, which does not pretend to be of the highest scientific accuracy. However, it is much simpler and shorter than a highly rigorous method would be, and yields results which are entirely satisfactory within the usual practical limits of the art. 40 45

1. Determine generator impedances. These should be predominantly resistive. However, if one generator is predominantly reactive, the other generator should be predominantly resistive, or if it is reactive, then it must be of the same character as the first generator. Where one generator is reactive and the other resistive, the proportion of resistance and reactance should be such that the circuit power factor is as high as possible considering only the two generators. 50 55 Also, in that case a series type of corrective circuit should be used in most applications. For example, in correcting the characteristics of a crystal phonograph pick-up, a series, condenser type of circuit is used which presents a very high impedance to the pick-up at the low frequencies, where the pick-up impedance is great enough to require consideration. This is because the pick-up impedance is capacitive. Thereby the reactive character of the pick-up produces no practical effect and can be ignored thereafter in the calculations. Note also that a transformer may be used to change a generator impedance as presented to the equalizer. 60 65 70

2. Determine response-frequency characteristics of the generator requiring correction. The generator requiring correction need not be one of those between which the corrective network is positioned. In other words, how much lin- 75

early varying transmission in decibels is needed and where is it to be positioned in the frequency spectrum. I am particularly interested in the frequency of maximum linearly varying transmission, and the number of decibels (D.B.) of linear variation required.

3. The value of the limiting resistance may be determined from the following:

Let

10 L_e =range, in D. B., of transmission variation wherein transmission variation and frequency are linearly related.

L_T =range, in D. B., of total transmission variation which will be produced by one of the corrective circuits which produce the linear variation L_e .

Then

$$L_T = .0806 L_e^2 + .791 L_e + 2.78$$

4. Decide on what type of equalizer circuit to use. To a great extent this involves a knowledge of network art. If both generators are resistive in character, pick an equalizer circuit using a condenser in preference to one using an inductance, even though both do the same work. The reason, of course, is that the condenser method is cheaper. In addition, sometimes the inductance found by methods given in succeeding paragraphs is unrealized, for example, due to the distributed capacity being excessive.

Occasionally one of the generators is reactive in character within the working frequency range. Then, as noted in the procedure step 1 above, a circuit configuration is selected (and the other generator impedance where this is possible) which will make the reactive generator's reactance of minimum or no practical effect. If a generator's impedance cannot be directly changed, it may be changed in effect by interposing a transformer. For example, again, in designing a crystal pick-up equalizer, the pick-up reactance may be very great as compared to the other generator, if the latter is a broadcast station mixer. A transformer, however, steps up the mixer's 200 ohms resistance to the desired value to present to the equalizer and the pick-up.

As another example of this procedure, in using a crystal phonograph record cutter, the reactance of the latter may be used as a portion of the equalizer circuit. It is usually ill adapted, however, to cooperate in an efficient way with the amplifier circuit feeding it. Therefore, the crystal reactance may be stepped down to a more desirable value with a transformer, as shown elsewhere in my disclosure.

5. Determine the value of the limiting resistance to be used as follows:

A. Series corrective circuit.

$$R_{limiting} = (Z_1 + Z_2) \left[\left(\log_{10} \frac{L_T}{20} \right) - 1 \right]$$

B. Shunt corrective circuit.

$$R_{limiting} = \frac{Z_1 \times Z_2}{Z_1 + Z_2} \left[\left(\log_{10} \frac{L_T}{20} \right) - 1 \right]$$

Where

Z_1 =impedance of the input generator, and

Z_2 =impedance of the output generator.

Use the formula for the circuit previously chosen.

For most accurate results it is best to use $(L_T + \frac{1}{2})$ in place of L_T in the above formula.

6. Find the frequency of maximum varying transmission. Use formula:

$$K = 1.7 + .0456 L^2 \text{ where } L_e \text{ is in D. B.}$$

Then when transmission of corrective circuit increases with increasing frequency:

$$\text{Frequency of maximum varying transmission} = K \times \text{frequency of maximum linearly varying transmission.}$$

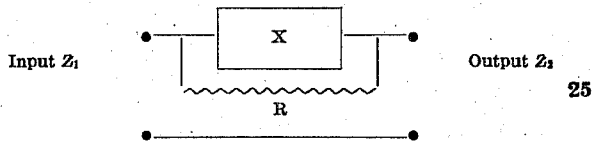
Or, when transmission of corrective circuit decreases as frequency increases:

$$\text{Frequency of maximum varying transmission} = \frac{\text{frequency of maximum linearly varying transmission}}{K}$$

7. Next, calculate Z, the impedance of the combination of the reactance X (of the reactive branch) and its associated limiting resistance R, as connected in either type of circuit, at the frequency of maximum varying transmission.

Choice of condenser or inductance

Series circuit:



The corrective circuit sketched above may be described as having the condenser or inductance X in series with the input and output circuits or in series with the generators. In this corrective circuit the limiting resistance R shunts X. R may be found from formulas previously given.

$$Z = (Z_1 + Z_2) (\sqrt{.05 + \cos^2 \phi} - \cos \phi)$$

Where

Z_1 =impedance of input circuit (assumed resistive)

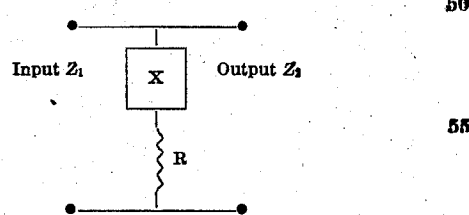
Z_2 =impedance of output circuit (assumed resistive)

Z=impedance of combination of X and R at frequency of maximum varying transmission, and

ϕ =phase angle of Z at above frequency.

Because ϕ cannot be known until Z is calculated, first assume $\cos \phi = .04$ and calculate Z. Then $\cos \phi$ may be calculated from well known electrical principles. Then again calculate Z.

Shunt circuit:



The circuit sketched above may be described as having the condenser or inductance X shunted across input and output circuits or the generators, with the limiting resistance R in series with the inductance. R is determined from previously given formulas.

$$Z = 10R_0 (\sqrt{.05 + \cos^2 \phi} + \cos \phi)$$

Where

$R_0 = Z_1 = Z_2$ that is, input and output are assumed equal, and resistive.

Z=impedance of combination of X and R at frequency of maximum varying transmission

ϕ =phase angle of Z at above frequency.

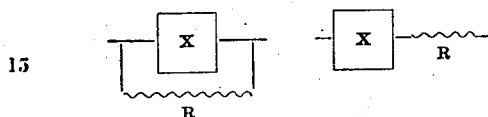
Since ϕ cannot be known exactly until Z is known, exactly the same two-step procedure must

be used as for series equalizer circuit, assuming $\cos \phi = .04$ for the first trial. Then recalculate Z. Formula for Z is on basis of transmission

$$\frac{1}{5} D. B.$$

less than maximum in each case.

8. Calculate X, the reactance of the reactive arm at the frequency of maximum varying transmission previously determined. This is done because either of the following circuits has been previously chosen:



with R, the limiting resistance, known from previous steps, and Z the impedance of the combination also previously determined. This solution is well known and reference may be had to any good book on alternating current theory for the basic formula and idea, such as:

Principles of Alternating Currents, R. R. Lawrence, McGraw Hill Book Co., 1922.

Handbook for Electrical Engineers, Harold Pender, John Wiley & Sons, second edition revised—page 22.

Radio Engineering Handbook, Keith Henney, McGraw Hill Book Co., 1935 edition, section 6.

9. The value of X found directly above; and the frequency of maximum varying transmission, f , found previously, may now be used to calculate the value of L or C to be used in a first trial of the equalizer.

$$L = \frac{X}{2\pi f}$$

$$C = \frac{10^9}{2\pi f X}$$

Where X is in ohms

f is in cycles per second

L is in henries

C is in micro-farads.

10. The value so found is invariably close enough so that it causes no practical difficulty. It is then best to set up such a circuit, as calculated, using commercial adjustable resistances and condensers. Invariably it is found that practical experience dictates slight modifications, chiefly because of unavoidable errors in determining the characteristics in the original test or because slight deviations from linear variation in the device to be corrected exist due to driving mechanism, mechanical impedance, etc. A slight change and retest usually make the best compromise consistent with commercial conditions and the design is then complete.

Various modifications will occur to those skilled in the art in the configuration, composition and disposition of the component elements going to make up the invention as a whole, as well as in the selective combination or application of the respective elements, and no limitation is intended by the phraseology of the foregoing description or illustrations in the accompanying drawings, except as indicated in the appended claims.

What is claimed is:

1. A circuit having or requiring variation in oscillation strength or requiring a correcting variation, each of which variations is linearly proportional with respect to frequency over some portion of the frequency range comprising an input generator, and an output generator, one of

the generators having a reactance which varies proportionally and linearly with respect to frequency over some portion of its frequency range and the other having a resistive character, the resistive generator having a value of resistance so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner in that portion of the frequency range where the aforesaid linearly proportional variation with respect to frequency would normally occur.

2. A circuit having or requiring variation in oscillation strength or requiring correcting variation, each of which variations is linearly proportional with respect to frequency over some portion of the frequency range comprising an input generator, an output generator, one of the generators having a reactance which varies proportionally and linearly with respect to frequency over some portion of its frequency range, and a resistance means connected within the circuit and its value of resistance chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner in that portion of the frequency range where the aforesaid linearly proportional variation with respect to frequency would normally occur.

3. A circuit having or requiring variation in oscillation strength or requiring a correcting variation, each of which variations is linearly proportional with respect to frequency over some portion of the frequency range comprising an input generator, an output generator, a series connection between the generators, a shunt connection, a resistance forming the sole element of one of said connections and its value of resistance chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over some portion of the frequency range, and a reactance means in the other connection which has a reactance which varies linearly with respect to frequency over the desired frequency range and is connected in series with the resistance, the reactance means having a value with respect to the resistance so that transmission of the oscillations in the circuit has a linearly proportional effect with respect to frequency over the aforesaid portion of the frequency range.

4. A corrective network to be connected in a circuit connecting two generators for introducing a linear and proportional correction, or in order for, or convert uniformly transmitted oscillations into, oscillations which vary proportionately with respect to frequency over some portion of the frequency range comprising a series connection adapted to be used between the generators, a shunt connection, a resistance forming the sole element in one of said connections and its value chosen with respect to the impedance of the generators and the total transmission variation so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over the aforesaid portion of the frequency range, and a reactance means, the reactance of which varies linearly and proportionally with respect to frequency over the desired frequency range, the reactance means being connected in the circuit in series with the resistance and in the other connection between the generators, the reactance means having a value of reactance such that the linearly proportional effect of the transmission of the oscillations is at the desired range of frequency of the oscillations.

5. A corrective network to be connected in a

circuit connecting two generators for introducing a linear and proportional correction, or in order to correct for, or convert uniformly transmitted oscillations into oscillations, the transmission of which vary proportionately and linearly with respect to frequency over some portion of the frequency range comprising a resistance forming the sole element connected in series between the generators and its value of resistance chosen with respect to the impedances of the generators and the total transmission variation so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over the aforesaid portion of the frequency range, and a series resonance peak remover connected in shunt between the generators and at any point with respect to the resistance and having a value of transmission loss such as to substantially annul the effect of a resonance peak in one or both of the generators.

6. A corrective network to be connected in a circuit connecting two generators for introducing a linear and proportional correction, or in order to correct for, or convert uniformly transmitted oscillations into oscillations, the transmission of which will vary proportionately and linearly with respect to frequency over some portion of the frequency range comprising a series connection between the generators, a shunt connection, a resistance forming the sole element of one of said connections depending upon the result desired and its value of resistance determined with respect to the impedances of the generators and the total transmission variation so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over the aforesaid portion of the frequency range, and a reactance means connected in the other connection and having a value of reactance such that the linearly proportional effect of the transmission of the oscillations is at the desired range of frequency of the oscillations, and a resistance means connected with respect to the reactance means to limit the decrease in transmission caused thereby.

7. A corrective network to be connected in a circuit connecting two generators for introducing a linear and proportional correction, or in order to correct for, or convert uniformly transmitted oscillations into oscillations, the transmission of which vary proportionately and linearly with respect to frequency over some portion of the frequency range comprising a series connection between the generators, a shunt connection, a resistance forming the sole element of one of said connections and its value of resistance chosen with respect to the resistance of the generators and the total transmission variation so that the corrections to the transmission of the oscillations in the circuit is linearly proportional with respect to frequency over some portion of the frequency range, a reactance means in series with the resistance and in the other connection between the generators, the reactance means having a value of reactance such that the linearly proportional effect of the transmission of the oscillations is at the desired range of frequency of the oscillations, and a second resistance means connected with respect to the reactance means to limit the excessive variation in transmission caused thereby.

8. An electro-acoustic device adapted to cut or reproduce a sound groove comprising a gen-

erator for cutting or reproducing a sound track which generator produces or requires oscillations which vary linearly and proportionally with respect to frequency over some portion of the frequency range, a second generator, and a circuit connecting the two generators which circuit is one of two connections including a series circuit and a series and shunt circuit forming a compensating network, a resistance forming the sole element in one of the connections and the value of which is chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over the aforesaid portion of the frequency range.

9. An electro-acoustic device adapted to cut or reproduce a sound groove comprising a generator for cutting or reproducing a sound track which generator produces or requires oscillations which vary linearly and proportionally with respect to frequency over some portion of the frequency range, a second generator, and a circuit connecting the two generators including a series connection and a shunt connection, a resistance forming the sole element of one of said connections between the generators and the value of which is chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over some portion of the frequency range, and a reactance means connected in series with the resistance and in the other connection between the generators and its value chosen such that the linearly proportional effect of the transmission of the oscillations is over the desired range of frequencies.

10. An electro-acoustic device adapted to cut or reproduce a sound groove comprising a generator for cutting or reproducing a sound track which generator produces or requires oscillations which vary linearly and proportionally with respect to frequency over some portion of the frequency range, a second generator, and a circuit connecting the two generators including a series connection and a shunt connection, a resistance forming the sole element of one of the connections and the value of which is chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over some portion of the frequency range, a reactance means connected in series with the resistance means and in the other connection between the generators and its value chosen such that the linearly proportional effect of the transmission of the oscillations is over the desired range of frequencies, and a resistance connected with respect to the reactance means to limit the excessive variation in transmission caused thereby.

11. An electro-acoustic device adapted to cut or reproduce a sound groove of the constant velocity form comprising a piezo crystal generator for cutting or reproducing a sound track which generator produces or requires oscillations which vary linearly and proportionally with respect to frequency over some portion of the frequency range, a second generator, and a circuit connecting the two generators including a series connections and a shunt connection, a resistance the value of which is chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over the aforesaid portion of the frequency range and forming the sole element in one of the positions of shunt and

series connection with respect to the generators.

12. An electro-acoustic device adapted to cut or reproduce a sound groove of the constant velocity form comprising a piezo crystal generator for cutting or reproducing a sound track which generator produces or requires oscillations which vary linearly and proportionally with respect to frequency over some portion of the frequency range, a second generator, and a circuit connecting the two generators including a series connection and a shunt connection, a resistance forming the sole element of one of said connections and the value of which is chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over the aforesaid portion of the frequency range, and a reactance means connected in the circuit and in the other position in the circuit.

13. An electro-acoustic device adapted to cut or reproduce a sound groove of the constant velocity form comprising a piezo crystal generator for cutting or reproducing a sound track which generator produces or requires oscillations which vary linearly and proportionally with respect to frequency over some portion of the frequency range, a second generator, and a circuit connecting the two generators including a series connection and a shunt connection, a resistance forming the sole element of one of said connections and the value of which is chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over the aforesaid portion of the frequency range, and a reactance means connected in series with the resistance means and in the other connection of the circuit.

14. An electro-acoustic device adapted to cut or reproduce a sound groove of the constant velocity form comprising a piezo crystal generator for cutting or reproducing a sound track which generator produces or requires oscillations which vary linearly and proportionally with respect to frequency over some portion of the frequency range, a second generator, and a circuit connecting the two generators including a series connection and a shunt connection, a resistance the value of which is chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over the aforesaid portion of the frequency range and connected in the series connection with respect to the generators, and a series resonant means connected in the shunt connection in the circuit and in any desired relation with respect to the resistance means.

15. An electro-acoustic device adapted to cut or reproduce a sound groove of the constant velocity form comprising a piezo crystal generator for cutting or reproducing a sound track which generator produces or requires oscillations which vary linearly and proportionally with respect to frequency over some portion of the frequency range, a second generator, and a circuit connecting the two generators including a series connection and a shunt connection, a resistance forming the sole element of one of said connections and the value of which is chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over the aforesaid portion of the frequency range, a reactance means connected in series with the resistance means and in the other connection in the circuit,

and a resistance connected in the connection with the reactance means and in relation thereto to limit the decrease in transmission caused thereby.

16. An electro-acoustic device adapted to cut or reproduce a sound groove of the constant velocity form comprising a piezo crystal generator for cutting or reproducing a sound track which generator produces or requires oscillations which vary linearly and proportionally with respect to frequency over some portion of the frequency range, a second generator, and a circuit connecting the two generators including a series connection and a shunt connection, a resistance forming the sole element of one of said connections and the value of which is chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over the aforesaid portion of the frequency range, and a reactance means connected in series with the resistance means and in the other connection in the circuit.

17. A circuit having or requiring variation in oscillation strength or requiring a linear and proportional correcting variation, each of which variations is proportional with respect to frequency over some portion of the frequency range, comprising an input generator, an output generator, a resistance means connected within the circuit, and a reactance means in series with the resistance means, the value of resistance in the circuit including the generators being determined by one of the formulas

$$(Z_1 + Z_2) \left[\left(\log_{10} \frac{L_T}{20} \right) - 1 \right]$$

and

$$\frac{Z_1 \times Z_2}{Z_1 + Z_2} \left[\frac{1}{\left(\log_{10} \frac{L_T}{20} \right) - 1} \right]$$

so that transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over some portion of the frequency range.

18. A circuit utilizing a series corrective network having or requiring variation in oscillation strength or requiring a linear and proportional correcting variation, each of which variations is proportional with respect to frequency over some portion of the frequency range comprising an input generator, an output generator, a resistance means connected within the circuit, and a reactance means in series with the resistance means, a limiting resistance connected with respect to the reactance means to limit the attenuation caused thereby, the value of limiting resistance in the circuit being determined from the formula

$$(Z_1 + Z_2) \left[\left(\log_{10} \frac{L_T}{20} \right) - 1 \right]$$

so that transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over some portion of the frequency range.

19. A circuit utilizing a shunt corrective network having or requiring variation in oscillation strength or requiring a linear and proportional correcting variation, each of which variations is proportional with respect to frequency over some portion of the frequency range comprising an input generator, an output generator, a resistance means connected within the circuit, and a re-

actance means in series with the resistance means, a limiting resistance connected with respect to the reactance means to limit the attenuation caused thereby, the value of limiting resistance in the circuit being determined from the formula

$$\frac{Z_1 \times Z_2}{Z_1 + Z_2} \left[\frac{1}{\left(\log_{10} \frac{L_f}{20} \right) - 1} \right]$$

so that transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over some portion of the frequency range.

20. An electro-acoustic device adapted to cut or reproduce a sound groove comprising a generator for cutting or reproducing a sound track which generator produces or requires oscillations which vary linearly and proportionally with respect to frequency over some portion of the frequency range, and a compensating network connected with the generator for coaction therewith, the compensating network including one of the two connections namely a series connection and a series and shunt connection, and a resistance means forming one connection and the value of the resistance is chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over the aforesaid portion of the frequency range.

21. An electro-acoustic device adapted to cut or reproduce a sound groove comprising a generator for cutting or reproducing a sound track which generator produces or requires oscillations which vary linearly and proportionally with respect to frequency over some portion of the frequency range, and a compensating network con-

nected with the generator for coaction therewith including a series connection and a shunt connection, a resistance means forming one of said connections and the value of the resistance is chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over some portion of the frequency range, and a reactance means connected in series with the resistance means and in the other connection and its value of reactance chosen such that the linearly proportional effect of the transmission of the oscillations is over the desired range of frequencies.

22. An electro-acoustic device adapted to cut or reproduce a sound groove comprising a generator for cutting or reproducing a sound track which generator produces or requires oscillations which vary linearly and proportionally with respect to frequency over some portion of the frequency range, and a compensating network connected with the generator for coaction therewith including a series connection and a shunt connection, a resistance means forming one of the connections and the value of the resistance is chosen so that the transmission of the oscillations in the circuit is corrected in a linearly varying manner with respect to frequency over some portion of the frequency range, a reactance means connected in series with the resistance means and in the other connection and its value of reactance chosen such that the linearly proportional effect of the transmission of the oscillations is over the desired range of frequencies, and a resistance connected with respect to the reactance means to limit the variation in transmission caused thereby.

CLARENCE J. LE BEL.