Aug. 29, 1939. R. J. ROCKWELL 2,171,048

CIRCUITS FOR MORE NEARLY PERFECT SOUND REPRODUCTION

Filed Aug. 28, 1936 2 Sheets-Sheet 1

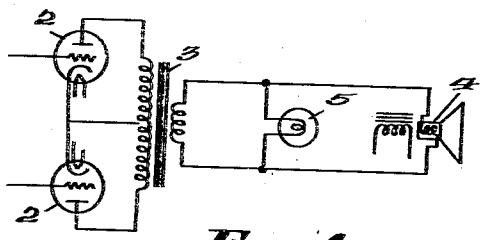


FIG. 1

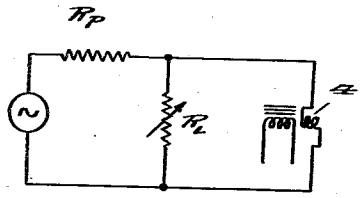


FIG. 2.

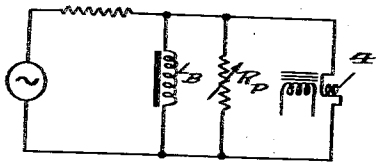


FIG. 3.

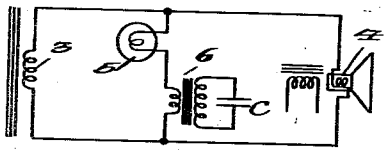


FIG. 4.

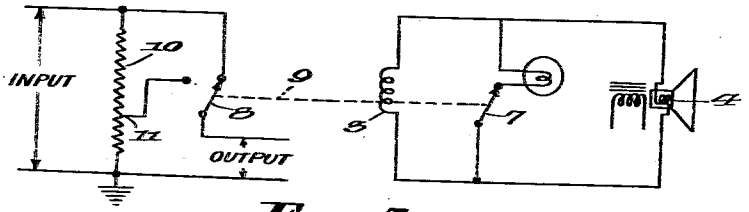


FIG. 5.

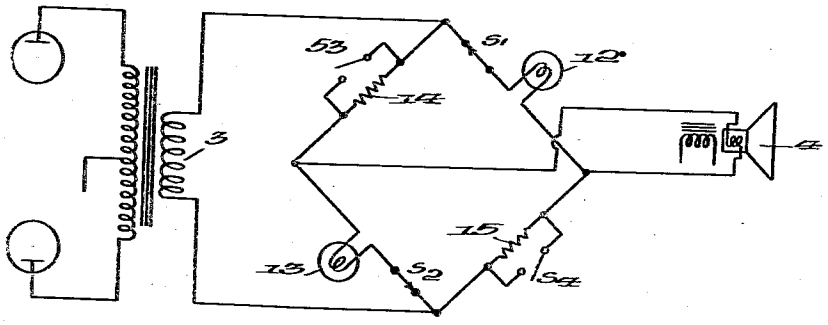


FIG. 6.

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CIRCUITS FOR MORE NEARLY PERFECT SOUND REPRODUCTION

Filed Aug. 28, 1936 2 Sheets-Sheet 2

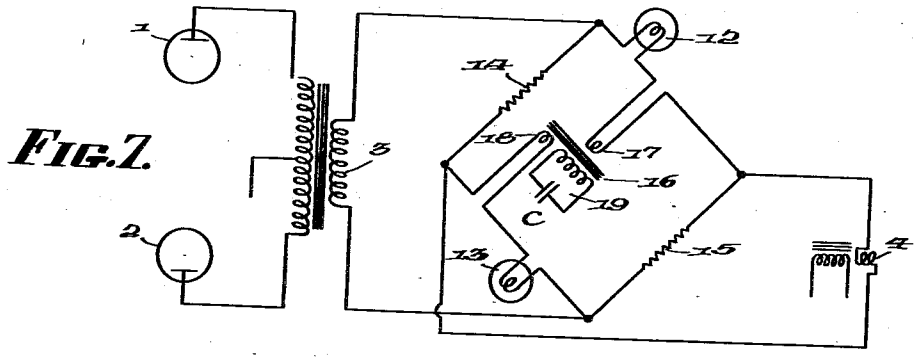


FIG. 7.

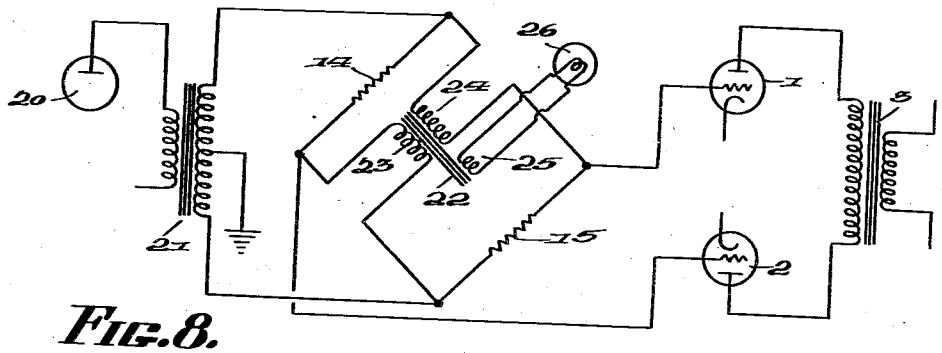


FIG. 8.

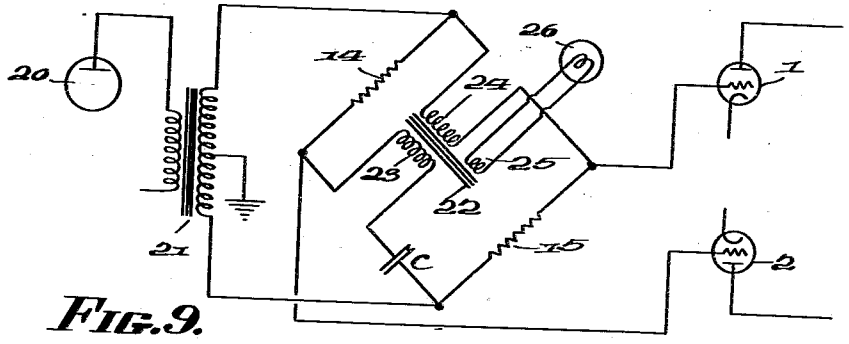


FIG. 9.

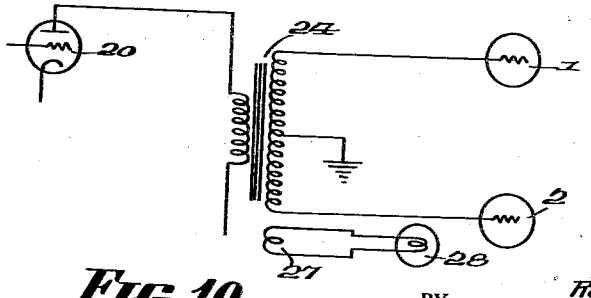


FIG. 10.

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UNITED STATES PATENT OFFICE

2,171,048

CIRCUITS FOR MORE NEARLY PERFECT SOUND REPRODUCTION

Ronald J. Rockwell, Cincinnati, Ohio, assignor to The Crosley Corporation, Cincinnati, Ohio, a corporation of Ohio

Application August 28, 1936, Serial No. 98,428

18 Claims. (Cl. 178—44)

My invention relates broadly to means for reproducing sound electrically with more nearly natural volume range and especially with more nearly natural proportioning of the various frequencies involved, irrespective of overall volume. I shall of course describe my invention in connection with reproduction in a radio receiving set for the purpose of illustration.

The problems involved are not simple. The term "volume range" refers to the ratio of the maximum to the minimum acoustical power in the reproduced sound. The ratio is expressed in decibels (db.). The human ear ordinarily accustoms itself to a range extending from a somewhat variable minimum up to about 120 decibels. Ordinary conversation covers a range of only about 30 decibels, but a symphony orchestra frequently covers the entire range from the lowest audible sounds to 120 decibels or even into a volume which becomes painful to the ear. The natural volume range of different types of sounds thus differs radically. But it is not always possible to record or transmit sounds in their natural volume range. In radio broadcast transmission the lowest volume that can be handled, is as in the various recording arts, limited by the volume level of noise inherent in the transmission medium. The maximum volume level that can be handled is limited by the modulation capabilities of the transmitter and frequently by the receiver also. Ordinarily, radio broadcasting must be limited to a range of 35 to 40 decibels. In radio broadcasting the volume range has artificially to be compressed into a range of this character. It has been done primarily in two ways, either by manual monitoring in which the control operator boosts the soft volume passages and reduces the high volume passages, or (as is preferable in musical renditions) the score is rewritten to decrease the volume range, and is rendered with a compressed range. Automatic means for the purpose have also been devised as set forth in my copending application Ser. No. 98,429, filed August 28, 1936.

Thus it will be seen that there is a fundamental problem of providing some means for expanding the volume of the reproduced sound in order to make it seem natural.

Second there is the problem of providing means for rendering the volume expander effective and ineffective at will, since some sorts of reproduced sounds, having originally no greater volume range than the range of the transmitter, do not need to have the volume of their reproduction expanded. Yet manual elimination of the effect of the volume expander means should preferably not be such as to cause the sound to assume a disturbingly different volume level.

Third, the volume level has a great effect upon the apparent need for volume expansion and in particular greatly affects the apparent proportion of different frequencies in a reproduction. Thus in motion picture theatres voices are listened to at a much higher volume level than that of ordinary conversation. Music is also heard at high volume level. Since the apparatus is capable of reproducing the low frequencies, these appear augmented, and the sound will be boomy or bassy unless some means is provided to discriminate against the low frequencies. On the other hand the radio receiver in the home is nearly always turned down to a volume level considerably lower than the natural volume level of the sounds at the point of origin. The reproduction therefore tends to appear thin and lacking in bass. If an orchestra is rendering a selection at a certain level of volume, the reproduction of the sound at a substantially lower level may cause the lower notes to drop below the threshold of audibility. This is one cause of the phenomenon. Another cause is to be found in the fact that at a low volume level there is appreciably less "masking effect" of the lower frequencies on the higher frequencies. Thus the problem stated generally above reduces itself practically to the need for automatic bass compensation means.

The general objects of my invention relate to the provision of solutions for the problems which I have outlined above, and I accomplish these objects by that certain construction and arrangement of parts of which I shall now describe certain exemplary embodiments. Reference is made to the drawings in which:

Figure 1 is illustrative of a simple ballast lamp circuit.

Fig. 2 is a circuit diagram illustrative of the principle of operation of the circuit of Fig. 1.

Fig. 3 is a diagrammatic representation of the principle of operation of a ballast lamp circuit having a certain type of bass compensation.

Fig. 4 is a diagrammatic representation of another type of bass compensation.

Fig. 5 is a diagrammatic showing of a certain type of switching means.

Figs. 6, 7, 8, 9, and 10 are respectively circuit diagrams of various commercial types of expander circuits used by me and will hereinafter be more particularly described in detail.

A ballast lamp type of expander is based on

the variation of the resistance of a lamp filament at various temperatures. If a tungsten filament, for example, is arranged in a circuit designed to drain or by-pass a part of the power of a radio set before that power gets to the loud speaker, an effect of volume expansion will be observed, because at higher voltages the temperature of the filament will increase and so will its resistance, so that the filament circuit by-passes less of the power. This is illustrated in a rudimentary way in Fig. 1, where 1 and 2 are output tubes arranged for push-pull amplification, 3 is a transformer, 4 is the voice coil of a speaker and 5 is a ballast lamp. It will be understood that in place of a tungsten filament any resistor whose resistance increases with increase of current or voltage may be employed.

In Fig. 2 there is shown the equivalent circuit of this device, where R_P represents the plate impedance, R_L the ballast resistance, and 4 the voice coil impedance. From this figure it can be seen that volume range expansion is derived from two effects that take place: first, the power output of the final vacuum tubes varies as the parallel impedance of 4 and R_L vary, second, the division of power between 4 and R_L varies as R_L varies. The expansion derived from either effect alone is rather small. However, considerable expansion is obtained when the relative magnitudes of R_L, 4 and the plate resistance of the tubes are properly proportioned.

Some degree of automatic bass compensation may be achieved rather simply in the circuit of Fig. 2. In Fig. 3 the effect of the reactance of the output transformer primary, shunting a load, is taken into account and is represented at L_B. Now if the signal applied to the grids of the output tubes has a frequency characteristic which shows a rising low frequency response (bass augmented) and if the inductance of the primary of the output transformer is lower than that which would ordinarily be used for a load equal to that reflected by a parallel combination of the voice coil and the ballast lamp when hot, then the loss caused by this relatively low inductance will about equal the bass augmentation already present in the signal as applied to the grids at high levels, and an over-all characteristic which is flat will be obtained. At lower levels when the load on the output tube is less because of the decrease in resistance of the ballast lamp, there will be less loss of bass due to the shunting effect of the primary inductance and hence the over-all characteristic will have a certain degree of bass augmentation. The lower this level becomes the more nearly we will approach the bass augmentation that is present in the signal on the grids of the output tubes. There is an objection to this method in that it introduced some harmonic distortion in the lower frequencies.

Another means of obtaining automatic bass compensation is that of placing a capacity reactance in series with a ballast lamp, but obviously the size of the condenser used in a circuit of such low impedance as that incorporating a voice coil would be so great as to be prohibitive. But it is theoretically possible to employ such an arrangement as shown in Fig. 4 whereby the reactance of a small condenser is reflected to the correct impedance so as to have the effect of a large condenser in series with the ballast lamp. Here in Fig. 4 a capacity C is connected to one winding of a transformer 6, the other winding of which is connected in the circuit of the ballast lamp 5. The reactance transformer must have very low resistance in order not to lessen the expansion range in a system of this type.

The figures and discussion above are illustrative of fundamental principles involved in the circuits of my invention. Two other preliminary considerations are worthy of mention. In a volume expander installation in a radio receiving set, some means has to be provided for switching the expander circuit on and off, since volume expansion will not be desired on all broadcast reception. Since the ballast lamp circuit operates as a drain on the power of the set, a switching means, which merely throws it out of the circuit is likely to produce marked and unpleasant changes in the general volume level. This can be overcome by using a double throw switch, which, when it cuts out the ballast lamp circuit, cuts in a fixed resistor, the value of which is slightly greater than the resistance of the ballast lamp when cold. Thus at relatively low volume levels, there will be no perceptible change in volume when the expander circuit is cut on or off. At higher general volume levels, for reasons which will be obvious, cutting the expander into the circuit will cause an increase in volume level, but this is not undesirable.

Because this method wastes power, however, whether the expander is on or off, a more desirable arrangement is one in which a change of the voltage gain of the radio set is accomplished by a voltage divider in the audio or radio frequency systems of the radio set, operated by a switch coupled to the switch which throws the ballast lamp into or out of the voice coil circuit. Such a voltage divider may be a tapped resistance, shunting to ground the plate circuit of a tube in the set. A double throw switch in the circuit may be arranged to contact respectively the end of said resistance or the tap therein and such switch may be in tandem with the ballast lamp switch, so that when the ballast lamp is out of the circuit, the voltage divider switch contacts the tap. In this arrangement a loss in the sensitivity of the set is the only disadvantage when the expander is switched to the off position. The full power output of the set may be utilized in the loud speaker.

This is illustrated in Fig. 5 where there is a switch 7 for the ballast lamp circuit and another switch 8 mechanically coupled to the first switch, as indicated at 9. The switch 8 is a double throw switch in which, as illustrated, the blade is connected to an output lead, one of the contacts is connected to an input lead and the other of the switch contacts is connected as at 11 to a tap on the resistance 10.

Another preliminary consideration is the matter of the time constant of the expander circuit. The time constant may be defined as the time necessary for the ballast resistance to reach a new steady value after a given new steady voltage has been applied to it, considering the series impedance in the rest of the circuit. It has been found that if the attainment of a new resistance value is very rapid or is instantaneous, appreciable distortion of the lower frequencies is apparent because of the change over the cycle, and also unnatural accentuation of the syllabic groups. In the use of a ballast lamp, the thing which mainly controls the time constant is the rate of heating or cooling of the filament. Therefore, I endeavor to control the time constant in the design of the lamp, by adopting any

or all of the following design characteristics: The use of an inert gas surrounding the filament of the ballast lamp; the use of a short, thick filament in place of a long thin one; the use of heavy lead supports for the filament or the use of several heavy metallic members in contact with the filament at interspaced points along its length; the use of a metallic shield surrounding the filament; coating the filament with a non-conductive substance which is a heat insulator, for example, a ceramic material, all of which tend to retard the rate of heating or cooling.

In Fig. 6 I have shown a more complex circuit which uses two ballast lamps 12 and 13 arranged in the opposite arms of a bridge circuit, the voice coil 4 being one diagonal of the bridge. This circuit allows almost any range of volume expansion desired. The output of the transformer 3 is applied across the other diagonal of the bridge, and the arms of the bridge opposite those arms which contain the ballast lamps are preferably provided with balancing resistors 14 and 15. The bridge is balanced at a very low signal level when the lamp resistance is at a minimum. Under conditions of balance, of course, there will be no voltage in the voice coil circuit even though a slight voltage may exist at the transformer secondary. At a higher level than the level at which the bridge was balanced, the resistance of the ballast lamps 12 and 13 changes so as to throw the bridge off the balance with respect to the voice coil diagonal circuit. With lamps of the type which I have been using, the resistance increases about ten times over the cold resistance at full signal strength. This produces a decided unbalance in the bridge and gives a high degree of volume expansion.

In providing means for switching the expander circuit on and off, I may provide two switches S_1 and S_2 in the ballast lamp arms, operating these switches in tandem (preferably mechanically coupled). This causes an increase in volume when the expander is switched off and when this is done it is advisable to incorporate a third switch which will reduce the audio or radio frequency gain of the set at some point ahead of the expander circuit, as described hereinabove in connection with Fig. 5. There may also be switches S_3 and S_4 to short out the resistors 14 and 15 when the ballast lamps are switched out. All switches are preferably controlled by the same switch knob.

The switching may also be accomplished, as will be obvious, by a switching means which effectively replaces the ballast lamps with fixed resistors.

Automatic bass compensation may be obtained in this type of bridge circuit by inserting a condenser in series with each ballast lamp in its own bridge arm. In this way the capacity reactance at low frequencies becomes rather large compared to the variable resistors of the bridge when operating at low volume level, and the bridge is off balance for bass tones thereby accentuating them. At the same time, for frequencies above 200 cycles the reactance of the condensers becomes negligible as compared with the ballast lamp resistance, and volume range expansion is obtained for frequencies in the high and middle ranges. At high volume levels the variable resistance becomes comparable to or higher than the capacity reactance of the condensers and the bass augmentation is practically negligible. This is a desirable characteristic. Inasmuch, however, as the voice coil circuit is of low impedance the condensers which have to be employed would be of the order of several hundred microfarads as heretofore explained in connection with Fig. 4. This would be impracticable within the limits of design of the average class radio receiver; but it is possible to transform the reactance of a small condenser so as to match the bridge impedance. This may, of course, be done by the use of two separate transformers each with its own condenser on the secondary windings and each transformer being located in one of the bridge arms containing a ballast lamp. It may, however, be accomplished by the use of one transformer and in Fig. 7 I have shown a transformer 16 having low impedance windings 17 and 18 connected respectively into the two ballast lamp arms of the bridge and a single high impedance winding 19 to which the condenser C is coupled, as shown. This is a preferable construction; but I may point out that I have found that a considerable automatic bass compensation action may be observed when capacity is placed in only one of the bridge arms, a condenser being located in series in one only of the arms of the bridge containing a ballast lamp. To cut down the size of the condenser under these circumstances the condenser reactance may be transformed by the use of a transformer having a single primary and a single secondary.

Hereinabove I have been speaking of low impedance expander circuits employing ballast lamps of very low wattage, say one-half watt at full excitation for a reasonable life. The use of a small lamp, i. e., a lamp of low wattage, is very desirable in order to lessen the power capacity requirements in an output circuit. In Fig. 8, however, I have indicated a type of circuit of high impedance. Such a circuit might be any of the amplifier circuits in the radio set ahead of the final output circuit. For purpose of illustration the transformer 3 and the push-pull tubes 1 and 2 are now located after the expander circuit. The grids of these tubes are driven from a preceding stage as represented by a tube 20 through the usual center tap transformer 21. A bridge circuit comprising the resistances 14 and 15 in opposite arms is set up and the leads from the secondary of the transformer 21 are connected across one diagonal of the bridge, while the leads to the grids of the tubes 1 and 2 are connected across the other diagonal. In a circuit of this type, characterized by high impedance, it would be impracticable to use a lamp of very low resistance and yet, as has been indicated, it would not be desirable to use lamps having inherently high resistance due to their inherently poor time constant characteristics. Under these circumstances I have found it possible to transform the lamp impedance to an impedance which will match the impedance of the bridge circuit. This may be done by means of a transformer 22, as shown in Fig. 8, having high impedance windings 23 and 24 connected respectively into the arms other than arms which contain the resistors 14 and 15. A low impedance winding 25 of the transformer is connected to a single ballast lamp 26. By this device I reflect the impedance of a single low impedance lamp having a proper time constant into both arms of the bridge with the effect of two lamps, one in each arm, and each having high impedance, while retaining the favorable time constant of a low impedance lamp.

Automatic bass compensation is obtained in this circuit by the insertion of one or more con-

densers in series in the ballast lamp arms of the bridge, as indicated in Fig. 9. Inasmuch as the bridge is of high impedance in this embodiment, the value of the capacity required for bass augmentation is in a reasonable range as to size. Therefore, ordinarily it will not be necessary to transform the reactance of the condensers, since the use of a condenser of the required capacity is not out of the question for the usual commercial radio set.

I have found that it is preferable to use only one condenser in one arm of the bridge as shown in Fig. 9. It will be noticed that the condenser is in series with one of the primaries of the transformer 22. Therefore, its capacity is reflected in both arms of the bridge so that the use of one condenser accomplishes the same result as the use of condensers in each arm.

The impedance at which the bridge will work is determined by the lamp wattage and the grid to grid voltage necessary for driving the output tubes for maximum power. The transformer between the driver tube and the bridge is advantageous to transform the bridge impedance to the proper value to match the driver tube. However, a center tap choke might be used if the mismatch between the tube and bridge is neglected. The advantage of this type of expander lies in the fact that there is no waste of the power generated by the output tubes. Full power output of the receiver is obtained either with or without operation of the expander. This type of expander is switched on or off by using a single pole double throw switch which operates to replace the ballast lamp with a dummy resistor, whose value is equal to that of the cold resistance of the ballast lamp.

Still another type of expander circuit is illustrated in Fig. 10. This circuit may be used either in an output tube circuit or in a driver tube circuit but in the latter use it finds its greatest advantage. In Fig. 10 a driver tube is again indicated at 20 which, through the transformer 24, feeds the grids of the tubes 1 and 2. A third winding is incorporated in the driver transformer 21 and is indicated at 27. This winding will ordinarily have an impedance such as will match the ballast lamp 28 to which it is connected. The action of this circuit is very similar to that obtained in the circuit of Fig. 1. Automatic bass compensation may be obtained in this circuit by the use of a transformer 24 the primary inductance of which is less than that usually found necessary for the good transmission of low notes, and the automatic bass compensation is produced essentially as described in connection with Fig. 3 above. The action of the circuit of Fig. 10 is to impose a variable loading on the driver tube 20, so that some distortion may be encountered.

Throughout the descriptions thus far I have been contemplating the use of a tungsten filament lamp as a ballast lamp the resistance of which increases when it is heated. A carbon filament lamp has the opposite characteristics; namely, its resistance decreases when the filament is heated. It will, therefore, be clear that carbon filament lamps may be employed in connection with tungsten filament lamps to get even a greater range of volume expansion. In those types of circuits such as the circuit of Fig. 1 where the ballast lamp shunts the power output, the carbon filament lamp can be located in any part of the circuit other than the ballast lamp shunt circuit. In the bridge type of device the carbon filament lamps may be located in the arms of the bridge other than those arms which contain the tungsten filament lamp, e. g., in place of the resistors 14 and 15.

It will be understood that modifications can be made in my invention without departing from the spirit thereof and the particular circuit embodiments herein disclosed are exemplary only of those which may be employed by me.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent, is:

1. In a volume expander an input-output circuit and a resistance means shunting said circuit and having the characteristic of increasing its resistance upon increase of the impressed voltage and means for automatic compensation at low frequencies comprising a capacity in said shunting means, said capacity having effectively a large capacity value.

2. In a volume expander an input-output circuit and a resistance means shunting said circuit and having the characteristic of increasing its resistance upon increase of the impressed voltage and means for reflecting a large capacity effect into said shunting means.

3. In a volume expander an input-output circuit of low impedance and a shunting circuit therefor, said shunting circuit containing a resistance variable with the impressed voltage and a low impedance winding, a high impedance winding coupled to said first mentioned winding and a capacity connected across said high impedance winding.

4. In a volume expander a bridge circuit at least one arm of which contains a resistance variable with the impressed voltage and a low impedance winding, a high impedance winding coupled to said first mentioned winding and a capacity connected across said high impedance winding.

5. In a volume expander a bridge circuit at least one arm of which contains a resistance variable with the impressed voltage and a low impedance winding, the opposite arm of said bridge containing another low impedance winding, said windings being inductively coupled, a high impedance winding coupled to said first mentioned windings and a capacity across said last mentioned winding.

6. In a volume expander for use in a high impedance circuit a bridge, a high impedance winding in at least one arm of said bridge, a low impedance winding inductively coupled thereto, and a low resistance lamp connected across said last mentioned winding.

7. In a volume expander for use in a high impedance circuit, a bridge, high impedance windings in a pair of opposite arms of said bridge, said windings being inductively coupled together, a low impedance winding inductively coupled to said last mentioned windings, and a low resistance lamp connected across said low impedance winding.

8. In a volume expander for use in a high impedance circuit, a bridge, high impedance windings in a pair of opposite arms of said bridge, said windings being inductively coupled together, a low impedance winding inductively coupled to said last mentioned windings, and a low resistance lamp connected across said low impedance winding and a condensor in series in at least one of the two arms having said high impedance windings.

9. In a volume expander an input-output circuit and a resistance means shunting said circuit

and having the characteristics of increasing its resistance upon increase of the impressed voltage and switching means comprising a switch to break the circuit in said shunting means, and to establish another circuit said other circuit containing a fixed invariable resistance of comparable cold value.

10. In a volume expander an input-output circuit and a resistance means shunting said circuit and having the characteristics of increasing its resistance upon increase of the impressed voltage and tandem switching means for simultaneously breaking the circuit in said shunting means and reducing the amplification gain in an associated amplifier circuit.

11. In a volume expander forming part of an amplifying means, a transformer having a primary fed from a preceding stage of amplification and a secondary feeding an output load, and a third winding of low impedance inductively coupled to said first mentioned windings and shunted by a low impedance tungsten filament lamp.

12. In a volume expander for use in a high impedance circuit, a bridge, a high impedance winding in one arm of said bridge, a low impedance winding inductively coupled thereto, a low resistance lamp connected across said last mentioned winding, and means for automatic compensation at low frequencies comprising a capacity in said bridge circuit.

13. In a volume expander for use in a high impedance circuit, high impedance windings in a pair of opposite arms of said bridge, said windings being inductively coupled together, a low impedance winding inductively coupled to said last mentioned windings, a low resistance lamp connected across said low impedance winding, and means for automatic compensation at low frequencies comprising a capacity in said bridge circuit.

14. Apparatus as claimed in claim 1, in which said resistance means is an incandescent lamp having a filament, the time constant of which is long enough to prevent distortion during substantially the longest audio cycle to be reproduced.

15. Apparatus as claimed in claim 2, in which said resistance means is an incandescent lamp having a filament, the time constant of which is long enough to prevent distortion during substantially the longest audio cycle to be reproduced.

16. Apparatus as claimed in claim 3, in which said resistance means is an incandescent lamp having a filament, the time constant of which is long enough to prevent distortion during substantially the longest audio cycle to be reproduced.

17. Apparatus as claimed in claim 4, in which said resistance means is an incandescent lamp having a filament, the time constant of which is long enough to prevent distortion during substantially the longest audio cycle to be reproduced.

18. Apparatus as claimed in claim 5, in which said resistance means is an incandescent lamp having a filament, the time constant of which is long enough to prevent distortion during substantially the longest audio cycle to be reproduced.

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