Dec. 17, 1940. G. W. FYLER 2,225,337

TONE CONTROL

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Fig. 1.

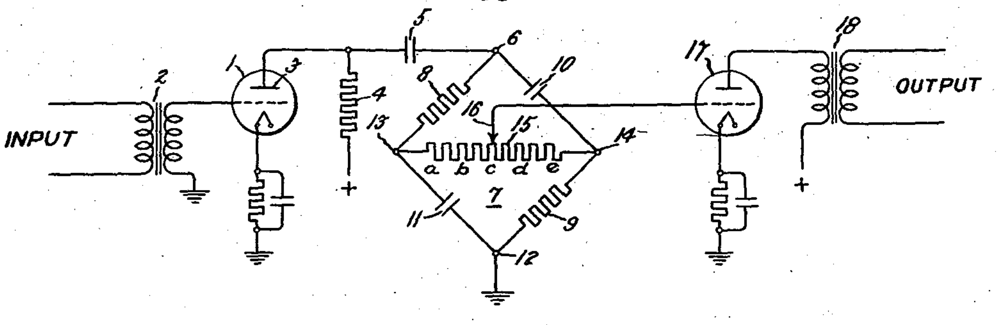

Fig. 2.

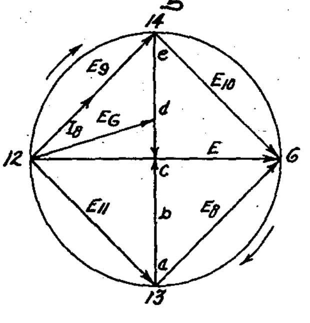

Fig. 3.

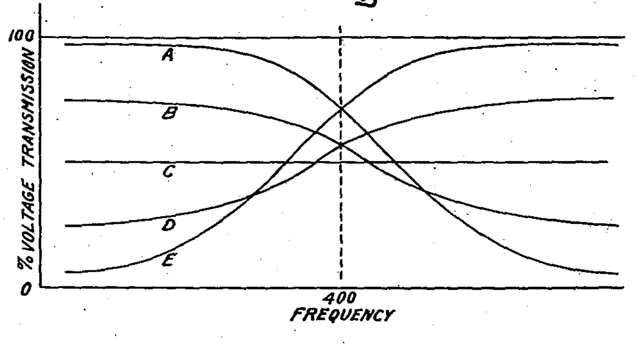

Fig. 4.

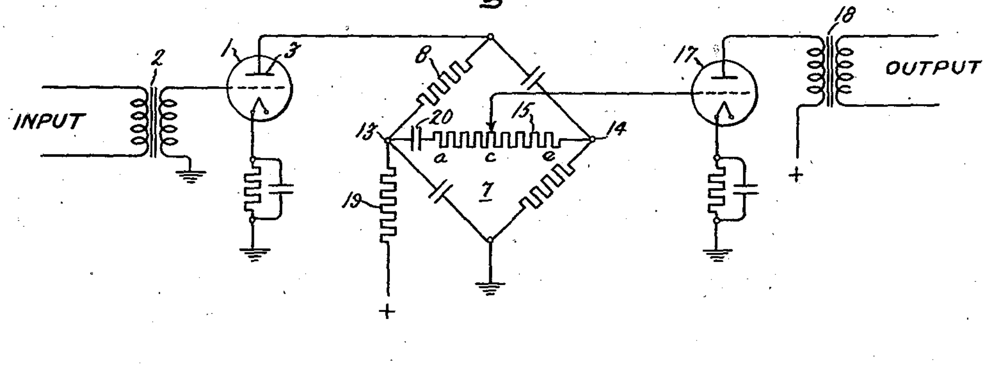

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Fig.5.

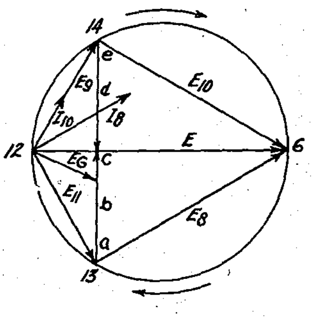


Fig.6.

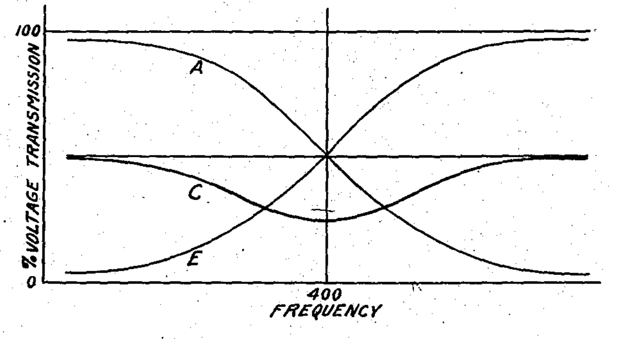


Fig.7.

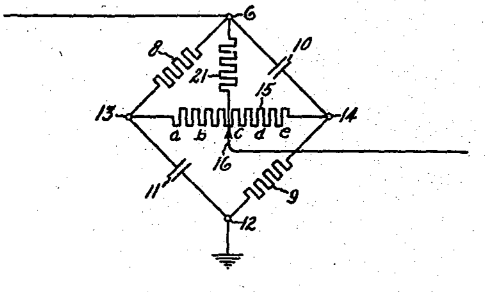


Fig.8.

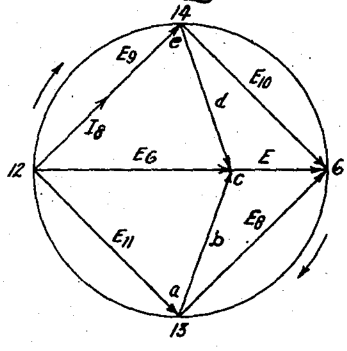
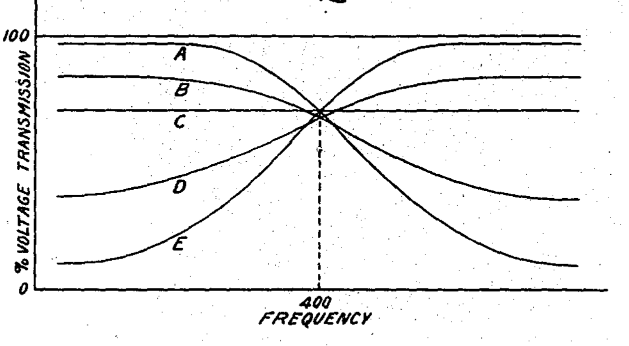


Fig.9.



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UNITED STATES PATENT OFFICE

2,225,337

TONE CONTROL

George W. Fyler, Stratford, Conn., assignor to General Electric Company, a corporation of New York

Application January 12, 1939, Serial No. 250,517

7 Claims. (Cl. 178—44)

My invention relates to that type of tone control in which the relation between the high and low frequencies is adjusted throughout the entire frequency band to be controlled by adjustment of a single adjustable element. It is adapted particularly for use in connection with the audio amplifiers of radio receivers where it is highly useful for tone control purposes. One of its objects is to effect certain improvements in such tone controls whereby improved relations between the intensities of the high and low frequency currents transmitted are obtained over the various adjustments of the adjustable element while, at the same time, the apparent audio output level is not materially affected by adjustment of said element.

It is a still further object of my invention to provide such an attenuation means which comprises a circuit having relatively few and simple parts and which may be constructed and incorporated in a signal transmission system at a low cost.

The novel features which are considered characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation together with additional objects and advantages thereof may best be understood from the following description taken in connection with the accompanying drawings in which Fig. 1 illustrates a circuit embodying my invention; Fig. 2 is a diagram showing the vector relations of the electrical quantities therein; Fig. 3 illustrates certain operating characteristics of my invention; Fig. 4 illustrates a modification of my invention; Fig. 5 is a diagram similar to Fig. 2; Fig. 6 illustrates certain operating characteristics of the embodiment of Fig. 4; Fig. 7 shows another modification of my invention; Fig. 8 is a diagram similar to Fig. 2; and Fig. 9 illustrates certain operating characteristics of the embodiment of Fig. 7.

Referring to Fig. 1, an electron discharge amplifier device 1 is illustrated as coupled to a suitable source of audio frequency currents, which is represented by a suitable input transformer 2. This transformer may, for example, be suitably connected to the output of a radio receiver. Instead of the transformer 2, any suitable type of coupling to a source of audio frequency signals may be used. The anode 3 of the electron discharge device 1 is connected to a suitable source of positive potential through a resistor 4 and is also connected by a coupling condenser 5 to a point 6 in a bridge circuit designated generally by 7. This bridge circuit comprises resistors 8 and 9 in opposite arms of the bridge 7 and condensers 10 and 11 in the remaining opposite arms of the bridge 7. Point 12, which is opposite the above-mentioned point 6 on the bridge 7, is grounded to provide a suitable current return path to the cathode of the electron discharge device 1. The remaining points 13 and 14 of the bridge 7 are connected by a high resistance potentiometer 15. A movable contact 16 is provided for this potentiometer 15 and is connected to the grid of the electron discharge device 17, which in turn delivers amplified current to a suitable transformer 18 from which output signals may be taken. The cathode of the electron discharge device 17 is suitably grounded through a bypassed cathode resistor. The grid of the device 17 assumes a potential determined by the bias voltage on the cathode resistor and by voltage developed between point 12 of the bridge 7 and the movable contact 16.

The resistors 8 and 9 may be of approximately equal value and the capacities of condensers 10 and 11 may also be of approximately equal value. The reactance of condensers 10 and 11 at some intermediate frequency in the band of frequencies to be transmitted should be equal to the resistance values of the resistors 8 and 9. In a particular case, in which the invention was employed in a radio receiver, it was assumed that a frequency of 400 cycles is approximately at the weighted midpoint of the normal frequency characteristic. Resistors 8 and 9 were made 40,000 ohms, while the value of condensers 10 and 11 was made 0.01 microfarad. The value of resistor 15 may be about 2 megohms. It should be noted that the value of resistor 4 should be somewhat less than the values of the resistors 8 and 9, particularly if the anode-cathode impedance of device 1 is high. This relation of values is desirable in order to maintain the response at point 6 fairly constant. The values of the component parts are given purely by way of example and are intended to be merely illustrative. Other values, which may be calculated by well known methods, should be employed where selective attenuation is desired in other frequency ranges or for other mid-frequencies.

In operation it may be seen that with movable contact 16 in the left-hand position, marked *a* in Fig. 1, the grid and the cathode of electron discharge device 17 are connected together through condenser 11, which provides a low reactance to high frequencies and a high reactance to low frequencies. Since condenser 11 is substantially a short circuit for high frequencies, it maintains the grid of device 17 substantially at the potential of point 12 of bridge 7 or, in other words, near cathode potential for high frequencies. Condenser 11 has a high reactance for low frequencies and the major portion of the low frequency voltage appears across it and directly influences the grid of device 17. Thus in this position the high frequency voltage is transmitted in slight amount and the low frequency voltage is transmitted in large amount.

If the movable contact 16 be placed in the right-hand position, marked *e* in Fig. 1, the grid of electron discharge device 17 will be connected by condenser 10 to point 6 of the bridge 7 which is substantially at the alternating voltage of plate 3 of electron discharge device 1. Condenser 10 will maintain the grid of electron discharge device 17 substantially at the potential of point 6 of the bridge 7 for high frequencies, since condenser 10 is substantially a short circuit for high frequencies and the major portion of the high frequency voltage will appear across resistor 9. Condenser 10 has a high reactance for low frequencies and the major portion of the low frequency voltage will appear across it and thus will not affect the grid of device 17. Thus in this position of movable contact 16 the high frequency voltage is transmitted in large amount and the low frequency voltage is transmitted in small amount.

When the movable contact 16 is in position *c* at the center of potentiometer 15, the high frequency current principally follows the path from point 6 through condenser 10, potentiometer 15, and condenser 11 to point 12 so that approximately one-half the total available high frequency voltage supplied from point 6 appears on the grid of electron discharge device 17. The low frequency current from point 6 principally follows the path through resistor 8, potentiometer 15, and resistor 9 to point 12. The low frequency voltage supplied to the grid of device 17 thus also is about one-half the total available low frequency voltage between points 6 and 12. Thus in this position of movable contact 16 the high frequency and the low frequency voltages are transmitted in equal amounts and the response is uniform over the frequency range.

In positions *b* and *d* of movable contact 16 effects are obtained similar to the effects obtained at positions *a* and *e* respectively, but in smaller proportion.

Fig. 2 is a diagram showing the vector relations of the voltages and currents appearing in the bridge of Fig. 1 at the frequency of 400 cycles. While the analysis represented by this diagram is not rigorous it is sufficient for practical purposes. It is assumed that no current flows through potentiometer 15, and thus that the current through the resistor 8 is equal to the current through the condenser 11 and that the current through condenser 10 is equal to the current through resistor 9. This is not strictly true, since for extremely low frequencies a small current flows through the high resistance potentiometer 15. However, since potentiometer 15 is much larger than resistors 8 and 9, the assumption leads to sufficiently accurate results in the normal frequency range. Point 12 of this bridge may be considered as the origin. The vector marked I_8 represents the current through either resistor 8 or condenser 10, and the vector marked E represents the voltage between points 12 and 6 of the bridge. It will be understood that I_8 may represent the current through either side of the bridge, since the impedance is equal through either path from point 12 to point 6. Vector E_9 represents the voltage across resistor 9 and extends from the origin to point 14. Vector E_9 is in phase with vector I_8 since it represents the voltage drop across a pure resistance. Vector E_{10} lags vector I_8 by 90 degrees since it represents the voltage drop across a condenser. This vector extends from point 14 to point 6. Vector E extends betwen point 12 and point 6.

Considering the other arm of the bridge, vector E_{11} lags vector I_8 by 90 degrees and extends from point 12 to point 13. Vector E_8 is in phase with vector I_8 and extends from point 13 to point 6. The diameter of the circle extending from point 13 to point 14 represents the two voltages across potentiometer 15. It will be noted that the response of the bridge may be determined from this vector diagram by rotating this diameter so that the voltage vectors meeting at its ends are accordingly varied. If the diameter be rotated clockwise, as indicated by the arrows, the diagram represents higher frequencies than 400 cycles. As point 13 approaches point 12 the frequency approaches infinity. Conversely, if the diameter be rotated counterclockwise, the diagram represents frequencies lower than 400 cycles.

The vector E_g extends from point 12 to a point on the diameter betwen points 13 and 14 and represents the voltage applied to the grid of device 17. Points along the diameter 13—14 are represented in the same way as in Fig. 1 by corresponding small letters. It will be seen that with the potentiometer contact at position *c* the voltage vector E_g will remain fixed for any angular position of the diameter 13—14, that is, for any frequency. For position *a* of the contact the vector E_g will be coincident with the vector E_{11} and hence will be small for high frequencies and large for low frequencies. If the contact be placed at position *e*, the converse will be true, since the vector E_g will be coincident with the vector E_9. It will be seen that at any intermediate position *b* or *d*, effects are obtained similar to the effects obtained at positions *a* and *e* respectively, but in smaller proportion.

It has been assumed above that the locus of the points 13 and 14 in the vector diagram, as frequency varies, is the circle between points 12 and 6. The validity of this assumption may be determined easily if it be remembered that under the specified conditions, with potentiometer resistance 15 much larger than resistors 8 and 9, the vectors E_9 and E_{10} must lie at right angles to each other because they represent voltages across a resistor and a condenser respectively, and they must form the two legs of a triangle whose hypotenuse is the vector E. The locus of the corner 14 of the triangle formed by these vectors is then, of course, a semi-circle.

Fig. 3 illustrates certain operating characteristics of the receiver shown in Fig. 1. The voltage transmitted through the bridge, assuming a constant voltage is applied thereto, is plotted as ordinate and frequency is plotted as abscissa. Curve A represents the amount of voltage transmitted at various frequencies when movable contact 16 of Fig. 1 is in position *a*. The voltage transmitted at low frequencies is large and that at high frequencies is a small portion of that applied to the bridge. Curve B illustrates the response at position *b* of contact 16. The low frequency voltage transmitted is less than that for curve A and the high frequency voltage transmitted is greater than that for curve A. Curve C illustrates the response when movable contact 16 of Fig. 1 is in the mid-position *c*. The voltage transmission at this position is the same for any frequency. Curves D and E correspond respectively to positions *d* and *e* of contact 16 in Fig. 1. It will be seen that they are the inverse of curves B and A respectively.

It will be noted that the voltage at the mid-frequency, which in the particular case described was 400 cycles, is not transmitted with equal attenuation for any position of the movable contact 16. It may be seen clearly that this follows from the vector diagram of Fig. 2 in which the diameter 13—14, as shown, is in correct position for 400 cycles. If the contact be moved from position *a* through position *c* to position *e* the voltage will first decrease to a minimum at position *c* and then increase to a value at position *e* equal to its original value at position *a*. It will be noted in Fig. 3 that the curves *a* and *c* cross at about 71 per cent voltage transmission, as may be deduced from the vector diagram of Fig. 2.

In Fig. 4 is shown a modification of the circuit of Fig. 1 wherein resistor 8, which forms one arm of the bridge 7, is placed in series with resistor 19 to connect the plate 3 of electron discharge device 1 to a suitable source of positive potential. A blocking condenser 20 is placed in series with potentiometer 15 between point 13 of the bridge and the potentiometer 15 in order to prevent the plate voltage of the electron discharge device 1 from interfering with the grid bias of electron discharge device 17. Resistor 19 must be made large compared with resistor 8 to permit the voltage response at position *a* to follow the desired curve. Other than these changes the bridge is the same as that shown in Fig. 1 and its operation is practically identical.

It may be desired to obtain a transmission characteristic different from that shown in Fig. 3. As was noted in connection with that figure, the voltage transmission at 400 cycles varies considerably when the potentiometer contact is moved from one extreme to the other. At the extreme positions of the contact the voltage transmission is about 71 per cent at 400 cycles. It may be desired to reduce this to a smaller value, for example, 50 per cent. This may be accomplished conveniently by changing the values of the condensers 10 and 11 in the bridge circuit as shown in Fig. 1. To achieve values of 50 per cent voltage transmission for 400 cycles at contact positions *a* and *e* the capacity of condenser 10 should be reduced in the ratio of $1/\sqrt{3}$ or to about 58 per cent of the value required to make the reactance of condenser 10 equal to the value of resistors 8 and 9 at 400 cycles. The value of the condenser 11 must accordingly be increased by $\sqrt{3}$ times the value indicated as used in Fig. 1, or to about 173 per cent of its original value. The value of resistors 8 and 9 is thus the geometric mean between the values of condensers 10 and 11. In making a change of this nature the product $R_8R_9C_{10}C_{11}$ should be constant, where R_8 and R_9 are the values of resistors 8 and 9 and where C_{10} and C_{11} are the values of condensers 10 and 11 respectively. It is obvious therefore that instead of changing the values of condensers 10 and 11, the values of resistors 8 and 9 may be changed according to the above relation, or the values of both condensers and resistors may be changed. It is also possible to use other types of impedance to obtain the same results. Other relations between the values of the impedances may be used to obtain any desired operating characteristic.

Fig. 5 is a vector diagram illustrating the voltages and currents appearing in the type of bridge shown in Fig. 1, modified by having condenser 10 reduced and condenser 11 increased in capacity in reciprocal relation. In this diagram the notation is the same as has been used before in Fig. 2. The vectors shown are those existing at the mid-frequency, 400 cycles. That the desired result is obtained may be seen from an analysis of this diagram. In the contact positions *a* and *e*, vector E_8 is coincident with vector E_{11} and E_9 respectively. It may be seen by geometrical analysis that vectors E_{11} and E_9 are one-half of vector E. It will be remembered that the current I_{10} flows through resistor 9 and condenser 10. Since the capacity of condenser 10 is now $1/\sqrt{3}$ of its former value, its reactance is $\sqrt{3}$ times as large as that of resistor 9. Hence voltage E_{10} is $\sqrt{3}$ times the value of voltage E_9. The only configuration which will satisfy this condition is a right triangle having a 60 degree angle between vectors E_9 and E. It is thus obvious that E_9 is one-half as large as E. Similar reasoning will prove that the phase angle between vector E_{11} and E is also 60 degrees, and that E_{11} is one-half as large as E.

Fig. 6 illustrates the operating characteristics of the circuit of Fig. 1 as modified by making condensers 10 and 11 unequal. As in Fig. 3, the voltage transmitted through the bridge is plotted as ordinate and frequency is plotted as abscissa. Curve A represents the amount of voltage transmitted at various frequencies when the potentiometer contact is in position *a*, and likewise curves C and E represent the same functions for positions *c* and *e*. It will be noted, as indicated by curve C, that the voltage transmission for position *c* on potentiometer 15 is not now the same for any frequency, but that there is a smaller voltage transmission at mid-frequency than at the low and high frequency ends of the transmission band. It may be highly desirable to obtain such a transmission characteristic in certain types of apparatus when it be considered that the aural response is a maximum at some mid-frequency in the audio range and drops off considerably at the low and high frequency ends of this range. This peculiar characteristic may also be used to aid in the faithful reproduction of audio frequency signals which are transmitted through apparatus having a greater voltage transmission at some mid-frequency than at the low and high frequency ends of the audio band.

In Fig. 7 an additional modification of the bridge circuit of Fig. 1 is illustrated. In this bridge the impedances of the four arms at 400 cycles are equal as was the case in Fig. 1. The only change lies in the addition of a resistance 21 between the mid-point or electrical center of potentiometer 15 and point 6 of the bridge. It will be found that the addition of this resistance 21 changes the curves as shown in Fig. 3 principally by raising curve C from 50 per cent throughout its length to some value greater than 50 per cent. It may be desired to raise this curve C to 71 per cent throughout its length, and at the same time to make curves B and D cross near 70 per cent. This may be done by choosing a suitable ratio between the value of resistance 21 and potentiometer 15. A suitable value in such a case for resistance 21 is about 707,000 ohms, if the value of potentiometer 15 be made about 2 megohms.

This may be seen to be true by the following calculations. Let R be the resistance of either half of potentiometer 15 and let S be the value of resistance 21. At extreme frequencies near zero or infinity the impedance values of condensers 10 and 11 will be either so high or so low as to be negligible. At either extreme frequency practically the entire voltage between points 12 and 6 will exist across a network including potentiometer 15 and resistor 21, because resistors 8 and 9 are relatively small and can be neglected. Therefore, for either extreme frequency, one may calculate the conditions for this network in which resistors R and S in parallel are connected in series to a resistor R. Since we wish the voltage across the series R part of the net to be 71 per cent of the applied voltage across the net, we may determine the desired ratio of the resistors R and S by the following formula:

$$\frac{R}{R+\frac{RS}{R+S}}=0.707$$

S will be found equal to 0.707R.

Fig. 8 is a vector diagram illustrating the vector relations of the currents and voltages appearing in the modification shown in Fig. 7. The notation used in this diagram is the same as that used above. Calculations indicate that the vector E_g tends to remain constant for any position of the potentiometer contact 16, and that for position *c* the vector E_g is constant at any frequency.

Fig. 9 illustrates the operating characteristic of the modification shown in Fig. 7. The voltage transmitted through the bridge is plotted as ordinate and frequency is plotted as abscissa. It may be noted that these curves are very similar to the curves of Fig. 3 except that the response at 400 cycles is very nearly the same for any position of the potentiometer contact. As before curve C shows that the voltage transmitted is constant at any frequency when the potentiometer contact is in mid-position c.

This modification of my invention is especially desirable because substantially uniform response at the mid-frequency is obtained thereby, which is quite suitable for the usual application of this control in radio receivers. Inspection of the curves of Fig. 9 will show that they are not symmetrical about the curve C. Obviously, this asymmetry may be adjusted in any desired way by approximate selection of values for the bridge arms. The asymmetry may be reversed about curve C by connecting resistor 21 to point 12 instead of point 6. The asymmetry shown in Fig. 9 may be very desirable in certain applications of this control where, for example, it is designed to reduce the low frequency response more than the increase in high frequency response or conversely.

It should be understood that the attenuation means of the present example is not necessarily limited to any particular range of frequencies, although it is preferably applicable to audio frequencies and in circuit with an audio frequency amplifier substantially as shown. The attenuation means herein shown may be applied across any audio frequency or other signal transmission circuit.

It will be obvious from the description taken in connection with the accompanying figure that an attentuation means is provided which is easily designed to deliver a substantially constant apparent sound level, and in which the relation between the various frequency components may be varied widely. Since the devices of the particular types described comprise only resistors and capacitors, they may be constructed very cheaply. The arrangement is of great simplicity, since the movable contact 16 is the only control provided.

While I have shown a particular embodiment of my invention, it will, of course, be understood that I do not wish to be limited thereto, since different modifications may be made both in the circuit arrangement and instrumentalities employed, and I contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a tone control circuit for signal receiving systems comprising an electron discharge amplifier having cathode and plate electrodes, and an output circuit including a resistor and a source of operating potential connected to the plate and cathode of said electron discharge amplifier, said resistor forming one arm of a bridge in which the opposite arm includes a resistor and the two remaining arms each include a condenser, a third condenser having one terminal connected to that corner of said bridge between said resistor and said source and having the other terminal connected to a potentiometer, the other terminal of said potentiometer being connected to the opposite corner of said bridge, a contact movable along said potentiometer, and an output circuit connected to said movable contact and to the remaining corner of said bridge.

2. The combination of a signal transmission circuit and a tone control network connected thereto, said network comprising a bridge circuit, an input circuit having a pair of terminals connected to two opposite corners of said bridge, the opposite arms of said bridge being identical impedances and the adjacent arms being unlike impedances, a variable voltage divider connected between the two remaining opposite corners of said bridge, an output circuit connected to the division point of said variable voltage divider and to one of said terminals, and an impedance connected between the electrical center of said variable voltage divider and the other of said input terminals, thereby to increase the voltage of an intermediate frequency supplied to said output circuit at intermediate positions of said division point.

3. The combination of a signal transmission circuit and a tone control network connected thereto, said network comprising a bridge circuit, an input circuit connected to two opposite corners of said bridge, the opposite arms of said bridge being impedances of like character, and the adjacent arms being impedances of unlike character, two of said like impedances being unequal in magnitude and the other two said like impedances being equal in magnitude and of such value as to be a geometric mean between said first two like impedances, a variable voltage divider connected between the two remaining opposite corners of said bridge, and an output circuit connected to the division point of said variable voltage divider and to one of said input terminals.

4. In an attenuation network, a bridge having an input circuit connected to two opposite corners thereof, two opposite arms of the bridge having equal resistances, and the two remaining arms comprising condensers, a potentiometer having an adjustable tap and being connected between the two remaining opposite corners of said bridge, an output circuit connected between said

tap and one side of said input circuit, and means to cause energy supplied from said input circuit through said bridge to said output circuit to have relatively large attenuation for middle frequencies at all positions of said tap, said means comprising said condensers, one of said condensers having reactance greater than said resistance and the other less than said resistance by such amounts as to produce said relatively large attenuation at said middle frequency.

5. In an attenuation circuit, a source of currents having frequencies extending over a broad range, a potentiometer having an adjustable tap, means connected between said source and the ends of said potentiometer to produce across said potentiometer a voltage having a constant magnitude and a different phase angle relation for every frequency of said source, means connected between said source and the center of said potentiometer tending to maintain the center of said potentiometer at a voltage with respect to one terminal of said source of constant phase relation to all the frequencies of said source and of constant magnitude substantially greater than half that of said source, and a load circuit connected from one side of said source to said tap, whereby adjustment of said tap along said potentiometer is effective to cause substantially constant attenuation from said source to said load circuit at a certain frequency and varying amounts of attenuation at frequencies above and below said certain frequency.

6. In combination, a bridge having a pair of diagonally opposite corners connected to a source of currents having frequencies extending over a broad range, and a potentiometer connected between a second pair of opposite corners, a load circuit connected between one side of said source and a variable point on said potentiometer, said bridge having two capacitive arms lying opposite each other and two resistive arms lying opposite each other and in alternate relation with said capacitive arms, said arms having unequal impedances at a middle frequency in said range, the product of the values of said capacitive arms and said resistive arms being equal to the product of the values of such arms whose impedances are equal at said middle frequency, whereby said arms are so proportioned that when said variable point is at one end of said potentiometer high frequency currents are supplied to said load circuit with great attenuation, when it is at the opposite end of said potentiometer low frequency currents are supplied with great attenuation, and when it is at an intermediate point of said potentiometer middle frequency currents are supplied with different attenuation than either currents of higher or lower frequency.

7. In combination, a bridge having a pair of diagonally opposite corners connected to a source of currents having frequencies extending over a broad range, and a potentiometer connected between a second pair of opposite corners, a load circuit connected between one side of said source and a variable point on said potentiometer, opposite arms of said bridge being capacitive and the alternate arms being resistive, said arms being so proportioned that when said variable point is moved along said potentiometer the attenuation of middle frequency currents is varied, and means to maintain substantially constant the attenuation of said middle frequency currents at all positions of said point.

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