

June 4, 1929.

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AUDIO FREQUENCY AMPLIFIER CIRCUIT

Filed Jan. 17, 1927

2 Sheets-Sheet 1

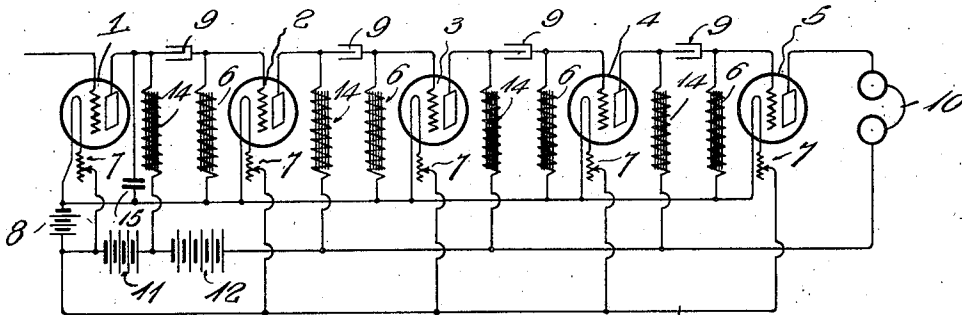


Fig. 1

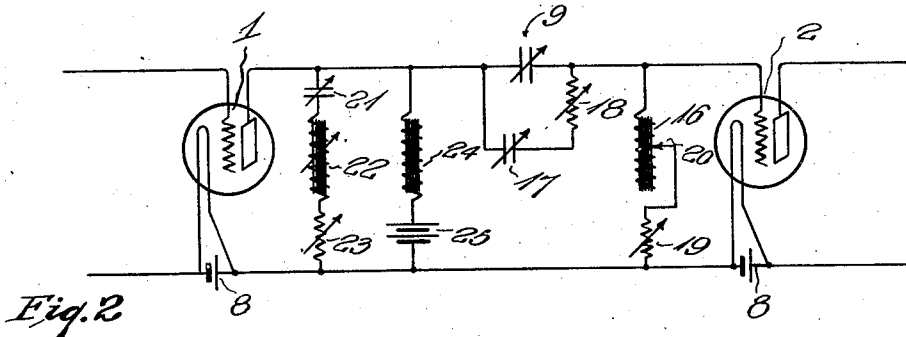


Fig. 2

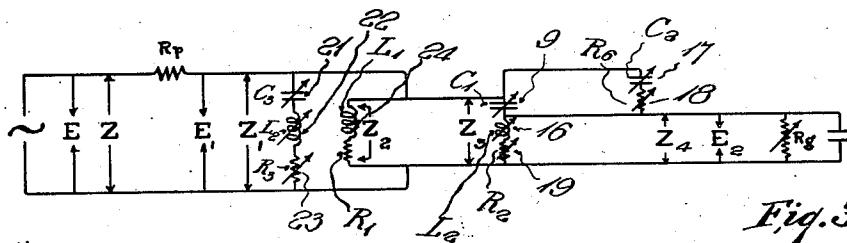


Fig. 3

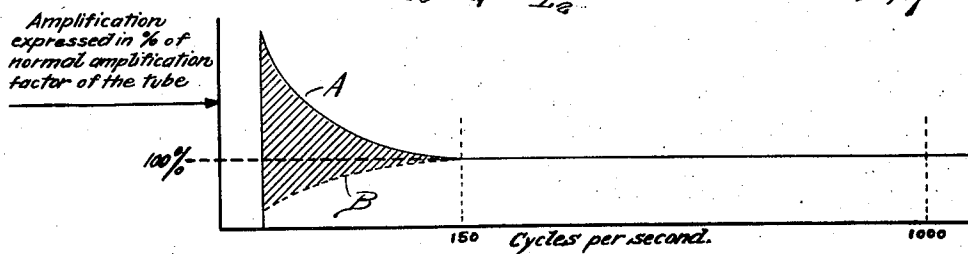


Fig. 4

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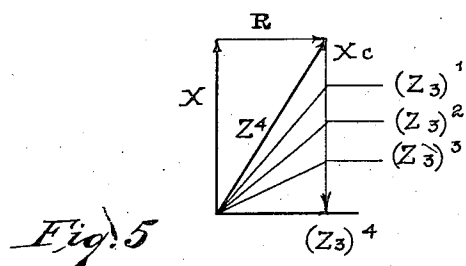
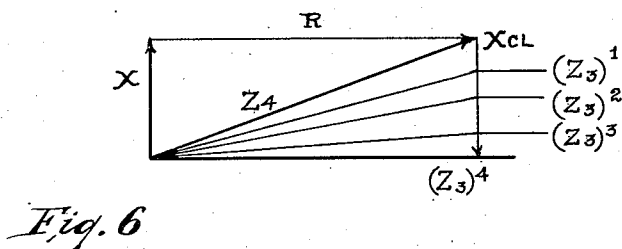
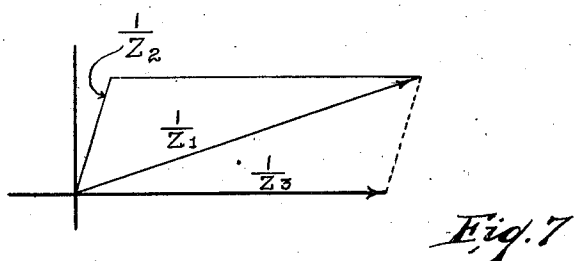
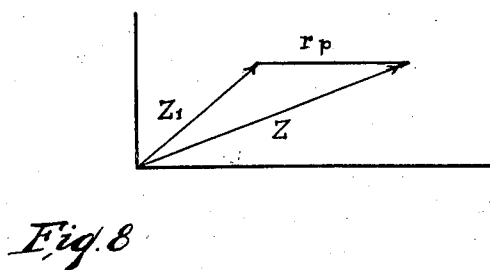
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AUDIO FREQUENCY AMPLIFIER CIRCUIT

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2 Sheets-Sheet 2



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# UNITED STATES PATENT OFFICE.

EDWARD E. HILER, OF BLOOMFIELD, NEW JERSEY.

## AUDIO FREQUENCY AMPLIFIER CIRCUIT.

Application filed January 17, 1927. Serial No. 161,556.

My invention relates broadly to electron tube amplification systems and more particularly to an audio frequency amplifier circuit which is particularly adapted for amplification of the lower range of musical frequencies.

One of the objects of my invention is to provide a system of amplification for audio frequency currents in which the defects normally present in the output circuit of the amplification system, such as the inherent deficiencies in loud speakers or electromagnetic sound reproducers, may be compensated and overcome.

Another object of my invention is to provide an arrangement of double impedant circuit for an electron tube amplification system by which it is possible to effect greater amplification per stage of amplification than the amplification factor of one of the electron tubes constituting the amplification system.

Still another object of my invention is to provide a circuit arrangement for an audio frequency amplification system wherein the output circuit of one electron tube is conductively connected with the input circuit of a succeeding electron tube by a coupling circuit which operates to exaggerate the amplitude of the lower audio frequencies and uniformly transfer audio frequencies over a predetermined band of frequencies above the lower range of musical frequencies.

A still further object of my invention is to provide a circuit arrangement for coupling a pair of electron tubes constituting a stage of audio frequency amplification in which the relation between positive and negative impedances is adjusted in such manner that the product of the total external impedance of the amplification stage and the impedance of the positive impedance in the input circuit of the amplification stage is greater than the product of the total external and internal impedances and the vectorial sum of the negative and positive impedances in the input side of the amplification stage.

Other and further objects of my invention reside in the proportioning of the values of the elements in the coupling system of an audio frequency amplifier by which a substantially uniform amplification characteristic is obtained throughout a predetermined audio frequency range above a selected limit while the lower frequencies below the selected limit are substantially increased in amplitude for compensating for the deficiencies normally encountered in the electromagnetic sound

reproducer connected to the output circuit of the amplification system.

My invention will be more fully understood from the specification hereinafter following by reference to the accompanying drawings in which:

Figure 1 is a diagrammatic circuit arrangement showing the connections of the audio frequency amplifier system of my invention; Fig. 2 illustrates a modified arrangement of coupling circuit for each stage of amplification constructed in accordance with the principles of my invention; Fig. 3 is a theoretical diagram showing the relation of the elements constituting an amplification stage in the amplification system of my invention; Fig. 4 is a chart illustrating the advantages which are obtained by the amplification circuit arrangement of my invention; and Figs. 5 to 8 are vector diagrams for more clearly describing the principle of operation of the circuits of my invention.

My invention finds application in audio frequency amplifier circuits employed in electrical phonographs, radio broadcast receivers and in telephone operation, where there is normally a decrease in volume of reproduction on low frequencies due to defects inherent in electromagnetic sound reproducer construction. The frequencies which are difficult to reproduce extend approximately between 16 and 150 cycles. This is the frequency range which is depended upon to give realism, fullness and resonance to the quality of the sound. The ideal condition is to deliver electrical vibrations to the loud speaker in such form that the loud speaker reproduces all of the audio frequencies with the same relative intensities as exist in the sound at its point of origin. The circuit arrangement of my present invention accomplishes this object by the employment of a double impedance circuit wherein a relationship is established with respect to the impedances of the electron tubes constituting a stage of amplification wherein the product of the total external impedance of the coupling circuit and the impedance of the positive impedance in the input circuit is greater than the product of the total external and internal impedances and the vectorial sum of the negative and positive impedances in series in the input side of the circuit.

Advantage is taken of the fact that when a capacity, an inductance and a resistance are connected in series the impedance  $Z$  of the

circuit is less than the impedance  $Z'$  of the inductance and resistance by themselves. Therefore the voltage across  $Z'$  is greater than the voltage across  $Z$ , and  $Z'$  divided by  $Z$  is greater than "one". Unless the current lags nearly or close to  $90^\circ$  behind the voltage in the inductance and resistance, the ratio of  $Z'$  to  $Z$  will never be very much greater than "one". If, however, a choke coil is designed which has very little effective resistance the condition is satisfied and it will be many times greater than "one" at certain frequencies. The maximum is reached at the resonant frequency, that is, where the inductive reactance is equal to the capacity reactance. By making the resonant frequency 16 cycles or thereabouts the maximum voltage across  $Z'$  is at the resonant frequency and this voltage gradually drops as the frequency increases until a frequency is reached where it is only appreciably greater than the voltage across  $Z$ .

By the circuit arrangement of my invention the lower frequency notes are exaggerated while the notes above the lower frequency range are uniformly amplified giving efficient reproduction in a loud speaker system which has its lower frequency range corrected by the exaggerated impressed frequencies so that substantially uniform amplification over the entire frequency range results.

Referring to Fig. 1 of the drawing in more detail, reference character 1 designates an electron tube detector coupled with succeeding electron tubes 2, 3, 4 and 5 constituting separate stages of audio frequency amplification. The detector tube 1 may be connected to the output of a radio frequency amplification system or to a tuned circuit, which in turn connects with a high frequency signal receiving circuit. When my invention is applied to the audio frequency amplification circuit of an electrical phonograph or to a telephonesystem then the detector tube 1 is unnecessary. Each of the electron tubes is provided with grid, filament and plate electrodes, with input and output circuits interconnecting the electrodes. The filament electrodes of each of the tubes may be heated from battery 8 under control of a rheostat 7. The plate electrode of the electron tube 1 is connected to the grid electrode of electron tube 2 through a coupling condenser 9. In a similar manner the plate electrode of electron tube 2 connects through coupling condenser 9 with the grid electrode of electron tube 3. The remaining tubes are similarly coupled and a loud speaker or telephone 10 connects to the output circuit of the final stage of audio frequency amplification constituted by electron tube 5. A choke coil 14 connects the plate electrode of detector tube 1 with a source of plate potential represented at 11. A bypass condenser 15 is connected across the output circuit of detector tube 1 for eliminating undesirable high frequency currents from the

audio frequency amplifier. Each of the output circuits of electron tubes 2, 3, 4 and 5 are energized from a battery system including batteries 11 and 12. In each instance a choke coil 14 is included in the output circuit of amplifier tubes 2, 3 and 4. Between the grid electrodes of each of the tubes 2, 3, 4 and 5 and the negative side of battery 8 I provide a choke coil 6. The effective resistance of these choke coils is very low in comparison with their inductive reactance at all audio frequencies. That is, the phase angle of the coils approaches as near as possible to  $90^\circ$ . These choke coils serve to maintain the proper bias potential on the grids of the several tubes by carrying off the charges which collect on the grids from the filament emission. Fig. 1 shows a diagrammatic circuit arrangement for the connections of a multi-stage audio frequency amplifier, in which the system of my invention may be used in one or more stages.

Fig. 2 shows the circuit connections of a single stage in which the system of my invention is made adjustable or variable in order to select the resonant frequency, and to further predetermine the amount of amplification over the selected lower audio frequency range. The choke coils 6 in Fig. 1 or 16 in Fig. 2 serve as tuned instrumentalities when capacity 9 has a value such that its capacity reactance is equal to the inductive reactance of 6 or 16 at a predetermined frequency.

In Fig. 2, however, the auxiliary condenser 17 and resistance 18 serve to vary at will the predetermined frequency and resistance 19 serves to vary the phase angle of inductance 16. Reference character 20 designates a tap for increasing or decreasing the ratio of inductance to capacity which ratio is a factor in determining the height of the peak of the characteristic curve of the coupling system.

A clearer understanding and mathematical analysis of the action of the amplifier circuit can be obtained by referring to Fig. 3 (which is a circuit analysis of Fig. 2) and solving the same by means of vector diagrams illustrated in Figs. 5, 6, 7 and 8. It can be readily shown in analyzing the diagram in Fig. 3 that

$$\frac{E_2}{E} = \frac{Z_1}{Z} \times \frac{Z_4}{Z_3}$$

$Z$  is equal to the vectorial sum of  $Z_1$  and  $R_1$  (see Fig. 8) and, as both are positive,  $Z$  is always greater than  $Z_1$ , so that  $E$  is always greater than  $E_1$ . The lower the frequency the greater  $E$  is than  $E_1$ . However,  $E_1$  can be made to approach  $E$  as a limit so that throughout the audio frequency range  $E_1$  will be only very little less than  $E$ .

In arm 9, 16,  $(C_1, L_2, R_2)$  of Fig. 3, however, the impedance  $Z_3$  is usually less than the impedance  $Z_4$  and therefore the

voltage  $E_1$  is usually less than the voltage  $E_2$  due to the fact that when adding vectorially the impedances of  $C_1$ ,  $L_2$ , and  $R_2$ ,  $C_1$  is negative. Adjustable resistance  $R_2$  may be varied to reduce the phase angle from  $89^\circ$  to  $45^\circ$  or less.  $R_2$  can represent either a variable resistance inserted in series with a high phase angle coil or it can represent the effective resistance of  $L_2$  caused by hysteresis losses and eddy current losses in the iron of  $L_2$ , and in the latter case an effect as shown in Fig. 6 is obtained where  $Z_4$  is not much greater than  $Z_3$ . Fig. 5 shows the effect of high phase angle where  $Z_4$  is considerably greater than  $Z_3$ .

In both Figs. 5 and 6 the various lines representing  $Z_3$  shown as  $(Z_3)^1$ ,  $(Z_3)^2$ ,  $(Z_3)^3$ ,  $(Z_3)^4$  picture the effect of varying frequency,  $(Z_3)^4$  being the peak of the resonant point or frequency of resonance.

In Fig. 7 the method of arriving at the resultant impedance  $Z_1$  by reciprocals and parallelograms is shown. In Fig. 8 the method of vectorially adding  $r_p$  to  $Z_1$  to obtain  $Z$  is shown.

When grid convection current is present there is another factor  $r_g$  of Fig. 3, being the effective resistance from grid to filament of tube 2 in Fig. 2, and a similar parallelogram can be drawn to represent this addition to arm  $C_1$ ,  $L_2$ ,  $R_2$ . Since the low frequencies require more energy or have greater amplitude than the middle audio frequencies,  $r_g$  becomes a lower value and effects the phase angle of  $L_2$  more quickly on the low frequencies, thus automatically reducing the peak in the low frequencies before the grid can swing so far positive or negative that it passes beyond the straight portions of the curve.

The advantages of the novel circuit and value combinations above described, can best be understood from Fig. 4 representing the frequency characteristic curves obtainable in the audion amplifier itself (curve A), and the frequency characteristic curve of the transmitted wave (curve B).

A normally poor reproduction of the low frequencies below 150 cycles is the chief cause of poor quality loud speaker operation. The proper combination of these two frequency characteristic curves produces a result which represents an integration of the amplitude of various frequencies (with constant power) in the air at the studio or point of origin, with the amplitudes of various frequencies in the air at the receiving station. However, due to the threshold curves of audibility of the human ear together with the curves of feeling of sounds, the resulting curves might be made to take a form which would give a more pleasing effect to suit the tastes of the hearer than actually in the studio proper. This is due to improper placing of instruments or balancing of instruments for instance in an orchestra or imperfect modula-

tion of voice in the nose or throat cavities of a singer. Or, for instance, it is well known that the effect in music that appeals unconsciously to the emotions is the vibrant low tones and also the high frequency harmonics of high pitched notes. This is due to the fact that the threshold of feeling curve rises at both ends of the audio frequency range.

For this reason it is desirable in some cases of transmission or loud speaker design or type of music to vary not only the low end of the scale but also the high end and for this reason I have shown in Fig. 2 an optional arm  $C_3$ ,  $L_2$ , and  $R_3$  comprising a variable condenser 21, a variable inductance 22 and a variable resistance 23, giving a variable adjustment to the amplitude of the high frequencies at the same time that there is a peak in the low frequency. The lower range of frequencies below 150 cycles are actually exaggerated or boosted in amplitude.

The parts of the amplification circuit are so proportioned that the arrangement of inductance and capacity elements is such as to effect greater amplification per stage of amplification than the amplification factor of an individual tube included in the stage of amplification. The proportion of values of the inductance and capacity elements is such that the ratio of  $Z_1$  and  $Z_4$  each approach unity as a limit in this proportion:

$Z_1$  = total ohms external impedance of said circuit;

$Z$  = total ohms external and internal impedances of said tubes and circuits;

$Z_3$  = vectorial sum in ohms of the negative and positive impedances in series in the input side of said circuit;

$Z_4$  = impedance in ohms of positive impedance in the input side of said circuit.

The system by which efficient amplification is secured may be explained by stating that the lower range of frequencies is actually exaggerated while the upper range of frequencies is uniformly amplified. The relation between the negative and positive impedances in the input side of the circuit is adjusted in such manner that the product of  $Z_1$  and  $Z_4$  is greater than the product of  $Z$  and  $Z_3$ . The relative proportion of the inductance and capacity elements is such that the inductances have values from 20 to 1000 henries, whereas the coupling condenser has a value of from .0005 to .05 microfarads where the direct current resistance is from 500 to 10,000 ohms and the effective alternating current resistance as low as possible, particularly in the inductance 6 or 16.

While I have stated certain values for the coupling elements, I desire that it be understood that my invention is broader than the inclusion of elements of the stated propor-

tions in an amplification circuit, and that all combinations of circuits which accomplish the method of amplification herein set forth are intended to be included within the scope of my invention as set forth in the appended claims.

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

1. An audio frequency amplification system constituted by a plurality of electron tubes each having input and output circuits, means coupling the output circuit of one electron tube with the input circuit of a succeeding electron tube, comprising a circuit resonant to a selected audio frequency below a predetermined frequency including inductance and capacity elements cooperatively related for the transfer of audio frequency currents wherein the ratio  $\frac{Z_1}{Z}$  and  $\frac{Z_4}{Z_3}$

each approach unity as a limit wherein:

$Z_1$ =total ohms external impedance of said circuit;

$Z$ =total ohms external and internal impedances of said tubes and circuits;

$Z_3$ =vectorial sum in ohms of the negative and positive impedances in series in the input side of said circuit;

$Z_4$ =impedance in ohms of positive impedance in the input side of said circuit.

2. A method of accentuating a selected band of audio frequencies included in a relatively wide band of frequencies transmitted through an electron tube audio amplifying circuit, consisting in predetermining the relation between negative and positive reactances in the input side of said circuit in such manner that the product of  $Z_1$  and  $Z_4$  is greater than the product of  $Z$  and  $Z_3$  wherein:

$Z_1$ =total ohms external impedance of said circuit;

$Z$ =total ohms external and internal impedances of said tubes and circuits;

$Z_3$ =vectorial sum in ohms of the negative and positive impedances in series in the input side of said circuit;

$Z_4$ =impedance in ohms of positive impedance in the input side of said circuit;

to thereby increase the voltage of said selected band of audio frequencies relative to the voltage of the wide band of frequencies on the grid of an amplifying tube in said circuit.

3. An audio frequency amplification system constituted by a plurality of electron tubes each having input and output circuits, means coupling the output circuit of one electron tube with the input circuit of a succeeding electron tube comprising a circuit having inductive reactance substantially equal to capacitive reactance over a predetermined frequency range to a predetermined limit and a circuit connected with said aforementioned circuit for effecting uniform transfer of signaling energy at frequencies above said predetermined limit to the input circuit of the next adjacent tube.

4. An audio frequency amplification system constituted by a plurality of electron tubes each having input and output circuits, means coupling the output circuit of one electron tube with the input circuit of a succeeding electron tube comprising a circuit including conductively connected inductance and capacity elements cooperatively related for exaggerating the amplitude of particular frequencies and rendering the amplification uniform over another range of frequencies.

In testimony that I claim the invention set forth above I have hereunto set my hand this 15th day of January, 1927.

EDWARD E. HILER.