

Jan. 19, 1943.

W. D. PENN

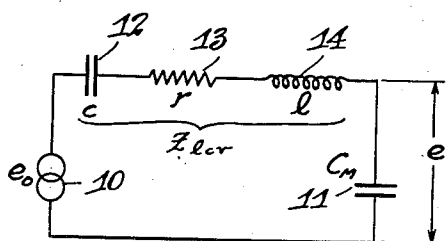
2,308,931

HEARING AID APPARATUS

Filed Oct. 10, 1940

4 Sheets-Sheet 1

Fig. 1.



$$\frac{e}{e_o} = \frac{1}{\sqrt{\left[1 - \left(\frac{f}{f_M}\right)^2 + \frac{C_M}{C}\right]^2 + \left[\frac{r}{X_{C_M}}\right]^2}}$$

$$f_M = \frac{1}{2\pi\sqrt{LC_M}}$$

$$X_{C_M} = \frac{1}{\omega C_M}$$

C_M = Internal capacity of transducer

e_o = Open circuit voltage of signal source as seen from transducer terminals.

Fig. 2.

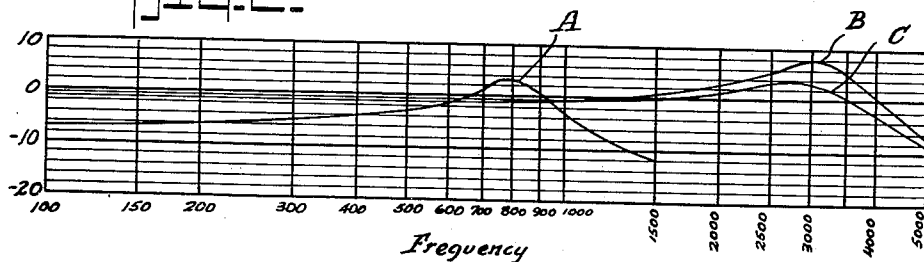
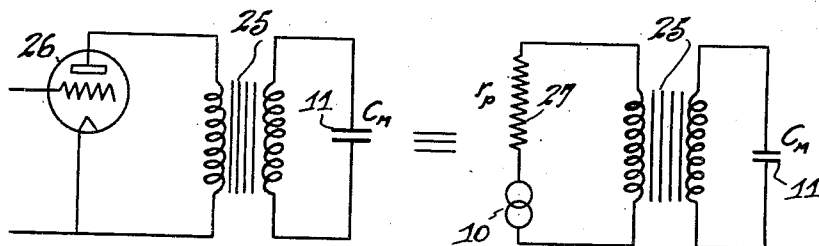


Fig. 14.



Inventor
William D. Penn.

By

Ben J. Chorny
Attorney

Jan. 19, 1943.

W. D. PENN

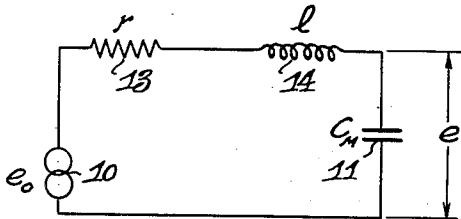
2,308,931

HEARING AID APPARATUS

Filed Oct. 10, 1940

4 Sheets-Sheet 2

Fig. 3.



$$\frac{e}{e_o} = \frac{1}{\sqrt{\left[1 - \left(\frac{f}{f_n}\right)^2\right]^2 + \left[\frac{r}{X_{C_M}}\right]^2}}$$

$$f_n = \frac{1}{2\pi\sqrt{LC_M}}$$

$$X_{C_M} = \frac{1}{\omega C_M}$$

C_M = Internal capacity of transducer

e_o = Open circuit voltage of signal source as seen from transducer terminals.

Fig. 4.

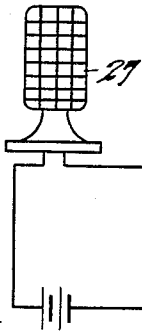
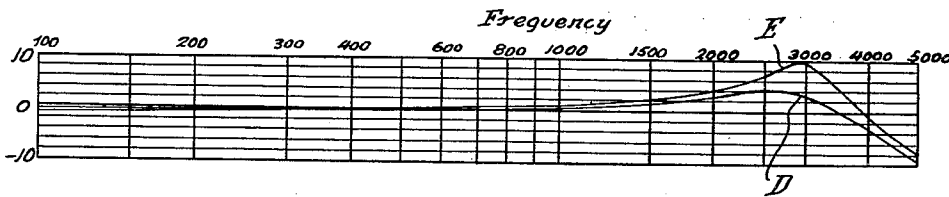


Fig. 15.

Piezo Electric
Crystal
Headphone

Inventor
William D. Penn.

By

Ben J. Chorny
Attorney

Jan. 19, 1943.

W. D. PENN

2,308,931

HEARING AID APPARATUS

Filed Oct. 10, 1940

4 Sheets-Sheet 3

Fig. 5.

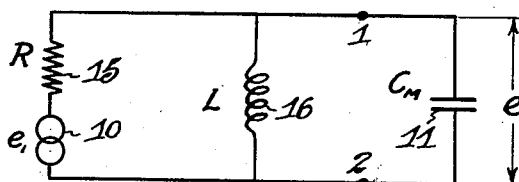


Fig. 6.

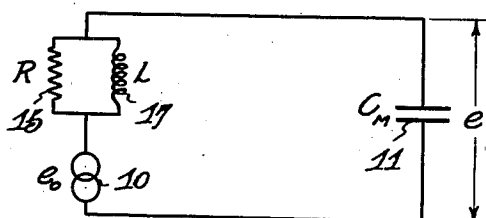


Fig. 7.

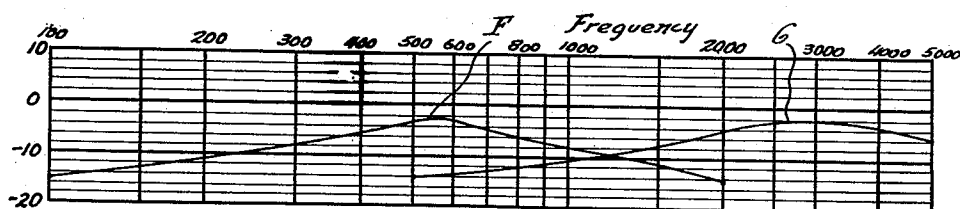
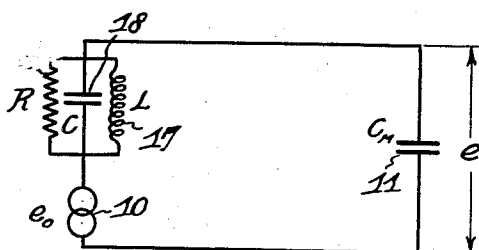


Fig. 8.

Inventor

William D. Penn.

By

Ben. J. Gromey,
his Attorneys

Jan. 19, 1943.

W. D. PENN

2,308,931

HEARING AID APPARATUS

Filed Oct. 10, 1940

4 Sheets-Sheet 4

Fig. 9.

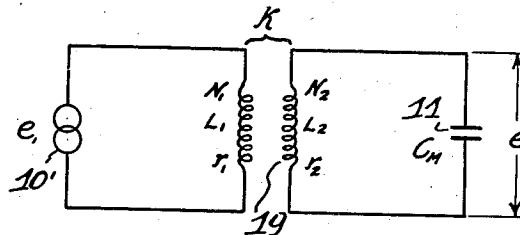
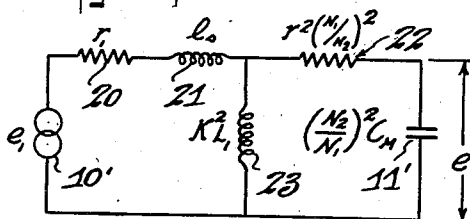


Fig. 10.



Neglecting r_1 and $r_2 (\frac{N_2}{N_1})^2$ because they are small compared to the other impedances and making $K^2 L_1 = L_2$, we obtain

$$e_o = \frac{e_1 j \omega L_1}{j \omega L_2 + j \omega L_1} = \frac{e_1}{1 + \frac{L_2}{L_1}}$$

$$Z_o = \frac{j \omega L_2 j \omega L_1}{j \omega L_2 + j \omega L_1} = \frac{j \omega L_2}{1 + \frac{L_2}{L_1}}$$

Fig. 11.

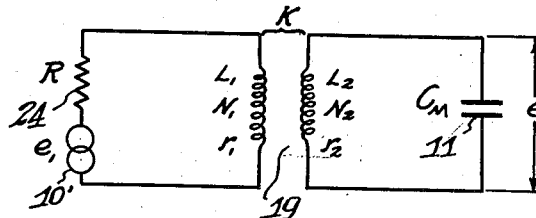
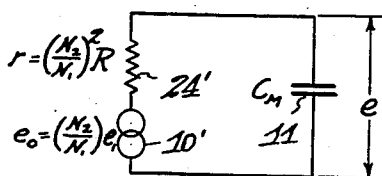


Fig. 12.

$$\frac{e}{e_o} = \frac{1}{\sqrt{1 + \left(\frac{r}{X_{C_M}}\right)^2}} = \frac{1}{\sqrt{1 + \left[\frac{(N_2/N_1)^2 r^2}{X_{C_M}^2}\right]}}$$



C_M = Internal capacity of transducer
 $X_{C_M} = \frac{1}{\omega C_M}$
 $e_o = (\frac{N_2}{N_1}) e_1$ = Open circuit output voltage of signal source as seen from transducer

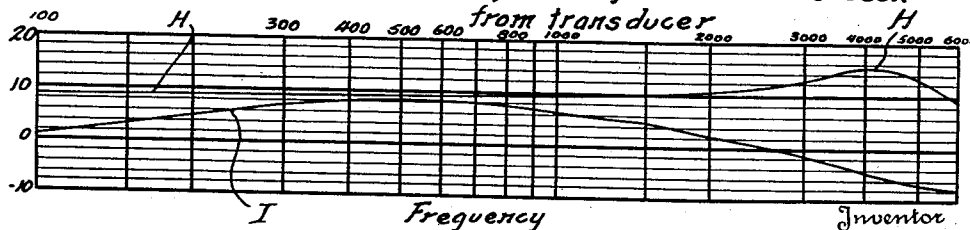


Fig. 13.

William D. Penn.

Ben J. Cherny.

his Attorneys

UNITED STATES PATENT OFFICE

2,308,931

HEARING AID APPARATUS

William D. Penn, Dallas, Tex.

Application October 10, 1940, Serial No. 360,676

6 Claims. (Cl. 179-107)

This invention relates to electrical hearing aid circuits in which the electrical impedance of an electroacoustic transducer is itself employed to produce frequency selectivity in the electrical circuit. One field of practical application for this invention is in amplifying apparatus for the hard of hearing.

This application is a continuation-in-part of my application Serial No. 254,317 filed February 2, 1939, for Hearing aid apparatus.

An object of this invention is to provide an hearing aid circuit arrangement employing an electroacoustic transducer of a type having an internal impedance that is reactive in nature and can be made to have frequency selective characteristics by providing certain relationships between the internal impedance of the transducer and the impedance or admittance to which it is connected.

A further object of this invention is to provide in hearing aid device for selectively accentuating the frequencies to which a particular hard of hearing user is less sensitive than normal, said hearing aid device being provided with a telephone or sound reproducing device of a type having an internal impedance that is reactive in nature so that it can be made to have a frequency selective characteristic by providing certain interacting relationships between the internal impedance of the telephone or reproducing device and the impedance or admittance to which it is connected.

Still another object of this invention is to provide an hearing aid device for selectively accentuating the frequencies to which a particular hard of hearing user is less sensitive than normal, said hearing aid device having a reproducer of the telephone or bone conduction type the internal impedance of which is reactive in nature so that the reproducing device may be made to have frequency selective characteristics by providing certain relationships between the internal impedance thereof and the impedance or admittance to which it is connected.

Other and further objects and features of this invention will be apparent to those skilled in the art to which it relates from the following specification and the claims.

This invention relates to frequency selective electrical circuits in which one of the elements is an electroacoustic transducer of the type having an internal impedance which is predominantly reactive in nature, such as, piezoelectric crystal reproducing devices and condenser type reproducer devices.

One of the greatest advantages of this invention is that it controls the frequency response of the instrument with an absolute minimum of parts. This is of great consequence in commercial application when it is realized that a hearing aid which is to meet popular acceptance must weigh less than 7 oz. and not be much larger than a package of cigarettes or a spectacle case. It is easily seen that there is no extra space for an assortment of chokes, condensers, or other components to be used for frequency control.

This invention will be more readily understood from the following specification and drawings in which, briefly:

Fig. 1 illustrates an arrangement in which the potential source consists of resistance, inductance and capacitance connected in series associated with a capacitive transducer;

Fig. 2 illustrates graphs employed for the purpose of explaining the operation of the apparatus shown in Fig. 1;

Fig. 3 shows a diagram of an arrangement in which the potential source consists of resistance and inductance connected in series associated with a capacitive transducer;

Fig. 4 illustrates graphs employed for the purpose of explaining the operation of the apparatus shown in Fig. 3;

Fig. 5 illustrates an arrangement in which the capacitive transducer is connected across a potential source consisting of inductance connected in parallel therewith and resistance connected in series therewith;

Fig. 6 illustrates a capacitive transducer connected in series with a source of voltage the impedance thereof consisting of parallel connected resistance and inductance;

Fig. 7 is a schematic diagram showing the capacitive transducer connected in series with a source of voltage the impedance thereof consisting of parallel connected inductance, capacitance and resistance;

Fig. 8 illustrates graphs employed for the purpose of explaining the operation of the apparatus shown in Figs. 5, 6 and 7;

Fig. 9 shows schematically, a capacitive transducer transformer-coupled to the source of voltage;

Fig. 10 is a diagram showing the equivalent elements of Fig. 9;

Fig. 11 is a schematic diagram of the capacitive transducer transformer-coupled to the source of voltage consisting of a series resistance;

Fig. 12 is a schematic diagram which is the equivalent of Fig. 11 when the resistance that is

in series with the voltage source is large compared with the values of the other elements;

Fig. 13 shows graphs employed for the purpose of explaining the operation of Figs. 9, 10, 11 and 12;

Fig. 14 is a diagram of equivalent circuit and Fig. 15 is a diagram of a practical embodiment of this invention.

Referring to the drawings in detail, the reference numeral 10 designates a source of potential e_0 of frequency f which may be alternating, pulsating or modulated in accordance with audio frequency signals. This source of potential may be derived from a sound modulated microphone circuit or from an amplifier, and represents the open circuit voltage of the signal source as seen from the terminals of the capacitatively reactive transducer 11 across which is applied under load the output voltage. Associated with the source 10 are capacity 12, resistance 13 and inductance 14 connected in series so that these elements are in effect connected in series between the source and the electroacoustic transducer 11. The transducer 11 functions to convert the alternating, pulsating or modulated electrical potentials into corresponding acoustic signals or frequencies and may be in the form of a device such as a piezo-electric crystal employed either as a telephone receiver or as a bone conduction device or it may be a condenser type reproducing device. In Fig. 3 the source of potential 10 is in effect connected to the transducer 11 through resistance 13 and inductance 14 in series therewith.

Fig. 5 is a form of this invention in which the source 10 is in effect connected in series with a resistance 15 across the inductance 16 and the transducer 11. In Fig. 6 the resistance 15 connected in series with the source 10 is shunted by an inductance 17 and the transducer 11 is connected across this circuit consisting of the source 10 and the resistance-inductance shunt circuit. The arrangement shown in Fig. 7 is similar to that shown in Fig. 6 except that a capacity 18 is provided to the shunt circuit so that this shunt circuit consists of resistance 15, inductance 17 and capacity 18.

In Fig. 9 the source 10 is connected to the transducer 11 through a transformer 19, and this is shown schematically in Fig. 10 where the primary resistance 20 and leakage inductance 21 are connected in series with the source 10 and the element 11' which is equal to the capacity of the capacitatively transducer 11 multiplied by the square of the ratio of the secondary turns to the primary turns of the transformer 19, is connected in series with the resistance 22 which is equal to the resistance of the secondary multiplied by the square of the ratio of the primary turns to the secondary turns. The elements 11' and 22 are connected across the element 23 which is equal to the inductance of the primary of the transformer multiplied by the transformer constant K^2 . The circuit shown in Fig. 9 may be equivalent to a simplified circuit shown in Fig. 12 in cases where a relatively large resistance 24, shown in Fig. 11, is connected in series with the source 10 and in this case the resistance R designated by the reference numeral 24 in Fig. 11 is multiplied by the square of the turns ratio of the secondary to the primary turns as designated by reference numeral 24' in Fig. 12. The source 10, designated by the reference numeral 10' is also multiplied by the secondary to the primary turns ratio. This simplified equivalent circuit holds true only in cases where the value of the resistance R is rather large so

that the effects of the leakage reactances are negligible.

The operation of this invention may be more readily understood from a mathematical consideration of the circuits involved and for that purpose it is assumed that the transducer 11 in the form of a piezo electric crystal or condenser headphone, is fed from a source of impedance $Zlcr$ as in Fig. 1, so that:

$$e = \frac{e_0 Z C_M}{Z l c r + Z C_M}; \frac{e}{e_0} = \frac{1}{1 + \frac{Z l c r}{Z C_M}} \quad (16)$$

For inductance, capacity, and resistance in series as shown in Fig. 1 Equation 16 gives

$$\frac{e}{e_0} = \frac{1}{1 + \frac{r + \left(\omega l - \frac{1}{\omega c}\right)}{1/j\omega C_M}} = \frac{1}{1 - \omega^2 l C_M + \frac{C_M}{c} + j r \omega C_M}$$

$$\omega_M^2 = 1/l C_M$$

let

then the resonant frequency of the circuit comprising these circuit elements,

$$f_M = \frac{1}{2\pi\sqrt{l C_M}}$$

$$\frac{e}{e_0} = \frac{1}{1 - (f/f_M)^2 + \frac{C_M}{c} + j r / X_{C_M}}$$

$$\left| \frac{e}{e_0} \right| = \frac{1}{\sqrt{\left[1 - (f/f_M)^2 + \frac{C_M}{c}\right]^2 + [r/X_{C_M}]^2}} \quad (17)$$

For inductance and resistance in series, as shown in Fig. 3:

$$\left| \frac{e}{e_0} \right| = \frac{1}{\sqrt{[1 - (f/f_M)^2]^2 + [r/X_{C_M}]^2}} \quad (18)$$

when $f = f_M$, that is, the frequency of voltage e_0 of source 10, is equal to the resonant frequency of the circuit,

$$\left| \frac{e}{e_0} \right| = \frac{X_{C_M}}{r} = \frac{\omega l}{r}$$

For inductance and capacitance in series, for example, in cases where r , shown in Fig. 1 is negligible:

$$\left| \frac{e}{e_0} \right| = \frac{1}{1 - (f/f_M)^2 + \frac{C_M}{c}}$$

when

$$f = f_M \sqrt{1 + \frac{C_M}{c}} = \frac{1}{2\pi\sqrt{l C_T}} \quad (19)$$

where

$$C_T = \frac{c C_M}{c + C_M}, \left| \frac{e}{e_0} \right| = \infty$$

For a series inductance, for example, in cases where both r and c shown in Fig. 1 are negligible:

$$\left| \frac{e}{e_0} \right| = \frac{1}{1 - (f/f_M)^2} \quad (20)$$

and

$$\left| \frac{e}{e_0} \right| = \infty$$

when $f = f_M$.

For a series resistance, for example, in cases where c and c are negligible:

$$\left| \frac{e}{e_0} \right| = \frac{1}{\sqrt{1 + (r/X_{C_M})^2}} \quad (21)$$

For the case of the impedance of the source 10 being represented by elements 15, 17 and 18 in parallel as illustrated in Fig. 7, the following is obtained:

$$\frac{e}{e_0} = \frac{1}{1 + \frac{1}{Z_{CM} Y_{LCR}}} \quad (22)$$

When L, C, R are all present Equation 22 gives

$$Y_{LCR} = \frac{1}{R} - j\left(\frac{1}{L\omega} - \omega C\right) \quad (23)$$

$$\frac{e}{e_0} = \frac{1}{1 + \frac{1}{\omega C_M \left[\frac{1}{R} - j\left(\frac{1}{L\omega} - \omega C\right) \right]}} =$$

$$\frac{1}{1 + \left[\frac{C}{C_M} - (f_M/f)^2 \right] - \frac{jX_{CM}}{R}} \quad (24)$$

$$\left| \frac{e}{e_0} \right| = \frac{1}{\sqrt{\left[1 + \frac{\left[\frac{C}{C_M} - (f_M/f)^2 \right]^2}{\left[\frac{C}{C_M} - (f_M/f)^2 \right]^2 + \left[\frac{X_{CM}}{R} \right]^2} \right]^2 + \left[\frac{X_{CM}/R}{\left[\frac{C}{C_M} - (f_M/f)^2 \right]^2 + \left[\frac{X_{CM}}{R} \right]^2} \right]^2}}$$

For inductance and resistance in parallel as shown in Fig. 6:

$$\left| \frac{e}{e_0} \right| = \frac{1}{\sqrt{\left[1 - \frac{(f_M/f)^2}{(f_M/f)^4 + \left(\frac{X_{CM}}{R} \right)^2} \right]^2 + \left[\frac{X_{CM}/R}{(f_M/f)^4 + \left(\frac{X_{CM}}{R} \right)^2} \right]^2}} \quad (25)$$

For inductance and capacitance in parallel, for example when R (Fig. 7) is very high:

$$\left| \frac{e}{e_0} \right| = \frac{1}{1 + \frac{C}{C_M - (f_M/f)^2}} \quad (26)$$

For resistance and capacitance in parallel, for example, when the inductance L (Fig. 7) is negligible:

$$\left| \frac{e}{e_0} \right| = \frac{1}{\sqrt{\left[1 + \frac{C/c_M}{(C/c_M)^2 + \left(\frac{X_{CM}}{R} \right)^2} \right]^2 + \left[\frac{X_{CM}/R}{(C/c_M)^2 + \left(\frac{X_{CM}}{R} \right)^2} \right]^2}} \quad (27)$$

From the various equations given it is possible to select the proper coupling arrangement in order to compensate for a given type of hearing loss curve. Thus, in a hearing aid employing a piezo electric crystal or condenser microphone and/or a piezo electric crystal or condenser earpiece the coupling arrangements for the microphone and earpiece can be so chosen as to provide a frequency selective amplifier of the proper characteristics for the particular type of deafness involved.

For the purpose of illustrating the different frequency responses obtainable a number of graphs are illustrated. In Fig. 2 curves A and C applying to the circuit shown schematically in Fig. 1, show the response obtained when a transducer having a reactive internal impedance is fed from a source having an impedance consisting of a resistance, inductance and capacitance in series.

From curves A and C it is seen that frequencies in different portions of the audio frequency spectrum may be emphasized. Curve A particularly selectively transmits frequencies between 500 and 1000 cycles and shows peaking or emphasis at about 800 cycles. Curve C particularly selectively transmits frequencies between 2500 and 3000 cycles and shows peaking or emphasis at about 2800 cycles.

Curve B, Fig. 2, illustrates the frequency response obtained when the source impedance consists of an inductance in series with a condenser in cases where the resistance is comparatively low particularly selectively transmits frequencies between 2500 and 3500 cycles, and is peaked at about 3000 cycles. It is seen from this curve that the emphasized frequency is increased in relative magnitude to a greater extent than in Curve C.

Curve D, Fig. 4, illustrates the frequency response obtained with a circuit arrangement shown schematically in Fig. 3 when the source impedance consists of resistance and inductance

in series, and particularly selectively transmits frequencies between 2000 and 3500 cycles and is peaked about 2500 cycles. Curve E also applies in this case except that the value of the resistance was small compared to the inductive reactance, and curve E particularly selectively transmits frequencies between 2500 and 3400 cycles, and is fairly sharply peaked at 3000 cycles.

Curve F, Fig. 8, applies to the arrangement shown in Fig. 5. For this case e_0 is found by Thévenin's theorem as follows.

With terminals 1—2 open, the voltage across them is

$$e_0 = \frac{e_1 j\omega L}{R + j\omega L} = \frac{e_1}{1 + \frac{R}{j\omega L}}$$

The impedance looking back from the 1—2 terminals is that of R and L in parallel or

$$Z_0 = \frac{R j\omega L}{R + j\omega L} = \frac{R}{1 + \frac{R}{j\omega L}}$$

The equivalent electrical circuit is that of Fig. 6 of the drawings.

For this case then

$$e_0 = \frac{e_1}{1 + \frac{R}{j\omega L}} \text{ and } Z_0 = \frac{R}{1 + \frac{R}{j\omega L}}$$

and Equation 24 applies. This case would correspond, for instance, to the case of the transducer being fed from a vacuum tube with an internal plate resistance R and having its plate supply fed thru a choke L and the transducer connected across the choke. Curve F particularly emphasizes frequencies between 400 and 650 cycles, and is peaked to emphasize most particularly frequencies between 500 and 600 cycles.

Curve G is similar to curve F and the same equations apply except that the values of L and R are different. Curve G particularly selectively transmits frequencies between 2500 and 3500 cycles, and is peaked to emphasize a frequency of about 3000 cycles.

In Fig. 13, curve H shows the response obtained when the transducer is coupled to a source of sup-

ply by means of a transformer as shown in Fig. 9 of the drawings, and particularly selectively transmits frequencies between 3000 and 5000 cycles, and is peaked to especially emphasize frequencies around 4000 cycles. If the transformer were ideal, that is no leakage inductance and infinitely large primary and secondary inductances the equivalent circuit shown in Fig. 12 of the drawings would apply. Fig. 12, however, also, applies under certain conditions for practical transformers. The conditions corresponding to curve H can be more accurately portrayed by replacing the transformer of Fig. 9 of the drawings by the circuit shown in Fig. 10. By applying Thévenin's theorem an equivalent circuit corresponding to Fig. 1 or Fig. 7 can be obtained and corresponding equations applied.

Curve I is similar to curve H except that R, in series with the source 10 as shown in Fig. 11, is not negligible. Curve I is peaked to particularly selectively transmit frequencies between 300 and 800 cycles. In this instance due to the rather large value of R the effects of leakage reactances are negligible and the circuit of Figs. 11 and 12 of the drawings applies. The curve drops off at the low end due to the fact that the reactance of the primary is not large enough compared to the resistance in series with it.

In this case when the transducer is being actuated by energy from the electrical system and is supplying energy to an acoustical system the voltage e_0 referred to in the drawings, specification and claims, is the open circuit output voltage of the source of signal energy as seen from the transducer terminals. The impedance or admittance in series with this voltage is that obtained when looking back from the transducer terminals and replacing all sources of E. M. F. by impedances equal to their internal impedance.

In other words e_0 and the impedance in series with it are to be determined by applying Thévenin's theorem.

As an example of the case of a transducer fed from a source I have employed a crystal earpiece or headphone coupled to a vacuum tube amplifier 25 by means of a transformer 25 as shown in Figs. 14 and 15.

For this case

$$e_0 = \frac{n_2}{n_1} e_1$$

assuming an ideal transformer, and the impedance in series with e_0 will be

$$\left(\frac{n_2}{n_1}\right)^2 r_p$$

where r_p is the plate resistance of the tube 26. The following equation then applies:

$$\frac{|e|}{|e_0|} = \frac{1}{\sqrt{1 + \left(\frac{r}{X_{CM}}\right)^2}} = \frac{1}{\sqrt{1 + \left[\frac{\left(\frac{n_2}{n_1}\right)^2 r_p}{X_{CM}}\right]^2}}$$

When

$$\left(\frac{n_2}{n_1}\right)^2 r_p = X_{CM}$$

there will be a three decibel loss. By varying the turn ratio

$$\frac{n_2}{n_1}$$

the required frequency characteristic for any given value of r_p can be obtained.

In Fig. 15 I have shown a form of circuit arrangement with which my invention may be em-

ployed conveniently. The piezo electric crystal microphone 27 is coupled through a suitable coupling device such as a transformer 28 to the grid circuit of the tube 26. It will be observed that I have shown both the microphone 10a and the headphone 17a as being of the piezo electric crystal or condenser type; this, however, is not essential since the desired results may be obtained using only a piezo electric crystal microphone or pick-up or using only a piezo electric crystal reproducer or headphone as brought out in the foregoing mathematical analyses. However, both microphone and reproducer may be of the piezo electric crystal type if desired and further improved results may be obtained by employing each of these for frequency selection purposes as well as for their normal functions.

While only one amplifying tube 26 has been illustrated several tubes connected in cascade or otherwise may be employed and these may be of the multiple grid electrode or other high gain type instead of the three electrode tube illustrated.

A plurality of reproducing devices, such as, device 11 may be used simultaneously as for class room work, churches or in similar public or semi-public or private gatherings and in such cases the reproducing devices also may be made to have such characteristics so that when connected to the amplifying device each will emphasize the particular frequencies desired by the particular user. In this latter arrangement the amplifier circuit should, of course, be constructed to be able to feed several reproducing devices and each reproducing device should be coupled to the output of the amplifier through a separate transformer or other coupling device or circuit although this is not necessary if the reproducers are left connected to the amplifier at all times or suitable impedance devices are substituted when they are disconnected.

While I have described certain embodiments of this invention in detail it is of course apparent that modifications therein may be made without departing from the spirit and scope thereof. I do not therefore desire to limit this invention to the exact details shown and described except insofar as they are defined by the claims.

What I claim is as follows:

1. Hearing aid apparatus adapted to transmit audio frequencies selectively, including: a source of signal supply, a transducer having a substantially capacitive internal impedance and being adapted to translate modulated electric currents into acoustic vibrations, means for impressing modulated currents from said source upon said transducer, said source having an open circuit output voltage e_0 and an internal impedance consisting of inductance l , capacitance c and resistance r in series as determined by Thévenin's theorem when viewed from the transducer terminals, the substantially capacitive impedance of said transducer operating in conjunction with the internal impedance of said source so as to electrically select certain audio frequencies independently of any selective effects due to the transducer itself, said series impedance of the source being such that the ratio of the voltage e developed across said transducer to the open circuit output voltage e_0 of said source is given approximately by the equation

$$\frac{|e|}{|e_0|} = \frac{1}{\sqrt{\left[1 - (f/f_M)^2 + \frac{C_M}{c}\right]^2 + \left[\frac{r}{X_{CM}}\right]^2}}$$

Where C_M is the internal capacity of the transducer, X_{CM} is equal to

$$\frac{1}{\omega C_M}$$

f_M is equal to

$$\frac{1}{2\pi\sqrt{LC_M}}$$

and is the resonant frequency of the inductance L and the internal capacity C_M ; said frequency f_M , capacity C and resistance r being such that frequencies between 2500 and 3500 cycles are particularly transmitted selectively.

2. Hearing aid apparatus adapted to transmit audio frequencies selectively, including: a source of signal supply, a transducer having a substantially capacitative internal impedance and being adapted to translate modulated electric currents into acoustic vibrations, means for impressing modulated currents from said source upon said transducer, said source having an open circuit output voltage e_0 and an internal impedance consisting of inductance L and resistance r , in series as determined by Thévenin's theorem when viewed from the transducer terminals, the substantially capacitative impedance of said transducer operating in conjunction with the internal impedance of said source so as to electrically select certain audio frequencies independently of any selective effects due to the transducer itself, said series impedance of the source being such that the ratio of the voltage e developed across said transducer to the open circuit voltage e_0 of said source is given approximately by the equation

$$\left|\frac{e}{e_0}\right| = \frac{1}{\sqrt{[1 - (f/f_M)^2]^2 + \left[\frac{r}{X_{CM}}\right]^2}}$$

Where C_M is the internal capacity of the transducer, X_{CM} is equal to

$$\frac{1}{\omega C_M}$$

f_M is equal to

$$\frac{1}{2\pi\sqrt{LC_M}}$$

and is the resonant frequency of the inductance L and the internal capacity C_M ; said frequency f_M and resistance r being such that the component of substantially 2500 cycles frequency is particularly transmitted selectively.

3. In the translation for hearing aid purposes of a varying electrical current into sound vibrations employing a piezo-electric transducer having a substantially capacitative internal impedance and further employing a signal source which has an internal impedance including a substantial inductive component, said signal source being connected to said transducer, the method of non-uniformly reproducing and selectively emphasizing a certain desired restricted region of the audio spectrum different from the natural frequency of said transducer which consists in selecting the values of the respective components of the internal impedance of said source in such manner with reference to the said capacitative internal impedance of said transducer that the frequency response characteristic curve of the circuit comprising the said capacitative internal impedance of said transducer and the said internal impedance of said source comprising said inductive

component particularly emphasizes a desired restricted frequency region of the audio spectrum.

4. In the translation for hearing aid purposes of a varying electrical current into sound vibrations employing a piezo-electric transducer having a substantially capacitative internal impedance and further employing a signal source which has an internal impedance including a reactive component, said signal source being connected to said transducer and comprising as components, resistance, inductance and capacity in series, the method of non-uniformly reproducing and selectively emphasizing a certain desired restricted region of the audio spectrum different from the natural frequency of said transducer which consists in selecting the values of the respective components of the internal impedance of said source in such manner with reference to said capacitative internal impedance of said transducer that the frequency response characteristic curve of the circuit comprising the said capacitative internal impedance of said transducer and said reactive internal impedance of said source, particularly selectively transmits frequencies between 2500 and 3500 cycles.

5. In the translation for hearing aid purposes of a varying electrical current into sound vibrations employing a piezo-electric transducer having a substantially capacitative internal impedance and further employing a signal source which has an internal impedance having a reactive component, said signal source being connected to said transducer and comprising as components inductance and capacity connected in series, the method of non-uniformly reproducing and selectively emphasizing a certain desired restricted region of the audio spectrum different from the natural frequency of said transducer which consists in selecting the values of the respective components of the internal impedance of said source in such manner with reference to said capacitative internal impedance of said transducer that the frequency response characteristic curve of the circuit comprising the said capacitative internal impedance of said transducer and said reactive internal impedance of said source, particularly selectively transmits components of substantially 3000 cycles.

6. In the translation for hearing aid purposes of a varying electrical current into sound vibrations employing a piezo-electric transducer having a substantially capacitative internal impedance, and a transducer circuit in which the transducer is connected, and further employing a signal source, and a source circuit in which said source is connected and which source circuit is transformer coupled to said transducer circuit, each of said circuits comprising inductance, said source having an internal impedance including a reactive component, the method of non-uniformly reproducing and selectively emphasizing a certain desired restricted region of the audio spectrum different from the natural frequency of said transducer, which consists in selecting the values of the respective components of the internal impedance of said source and of said source circuit in such manner with reference to said capacitative internal impedance of said transducer, that the frequency response characteristic curve of said circuits with reference to a signal impressed by said source and delivered to said transducer is peaked at substantially 4000 cycles.

WILLIAM D. PENN.