Jan. 19, 1943.　　W. D. PENN　　2,308,930

HEARING AID APPARATUS

Filed Feb. 2, 1939　　2 Sheets-Sheet 1

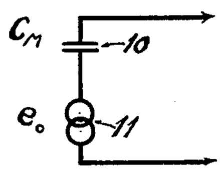

Fig. 1

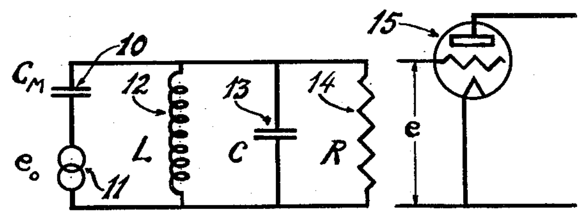

Fig. 2

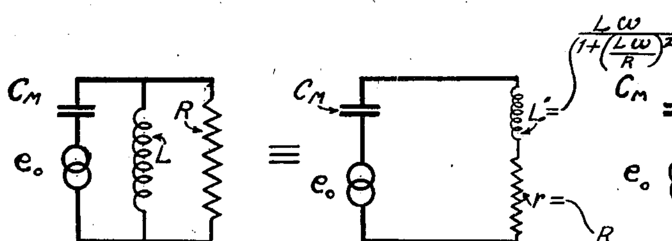

Fig. 3

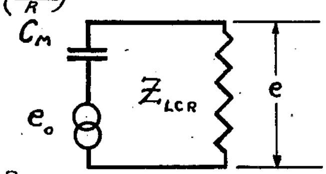

Fig. 4

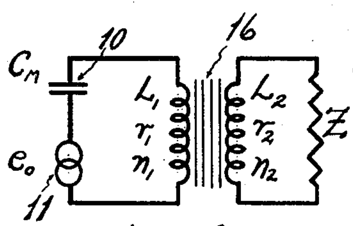

Fig. 5

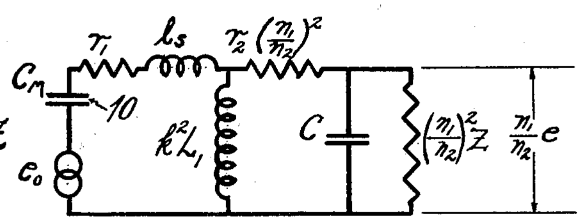

Fig. 6

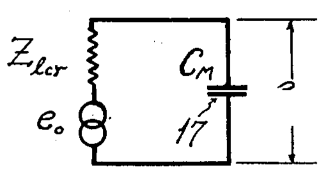

Fig. 7

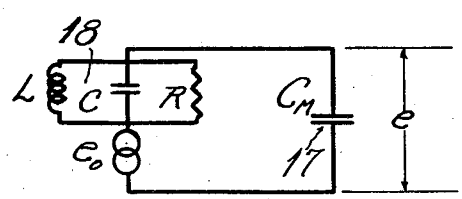

Fig. 8

Inventor

William D. Penn.

By

Ben J. Chromy
Attorney

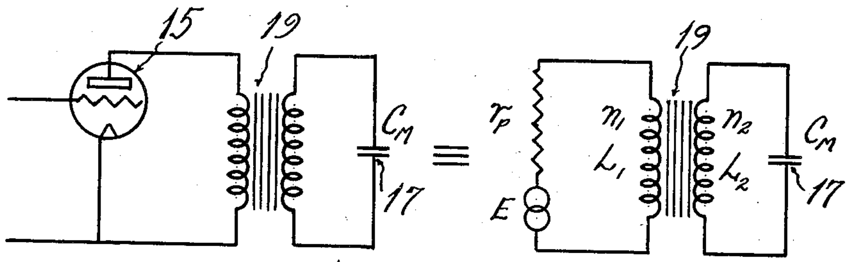

Fig. 9

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

$$e_o = \left(\frac{n_2}{n_1}\right) E$$

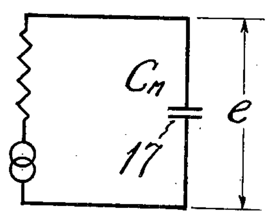

Fig. 10

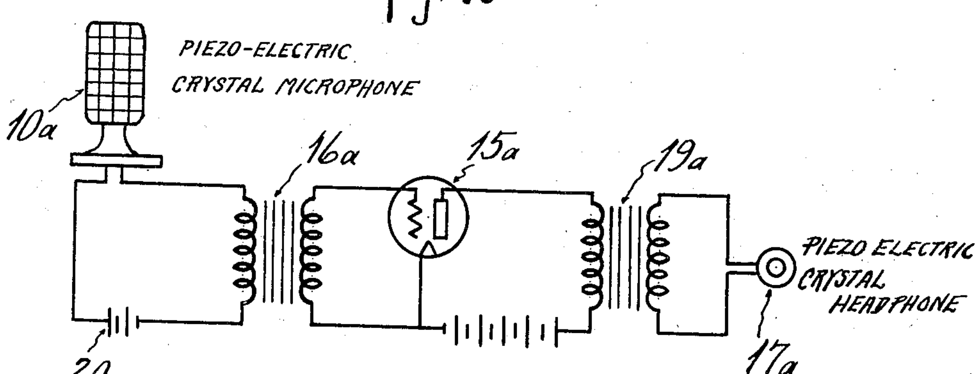

Fig. 11

Inventor

William D. Penn

By Ben J. Chromy

Attorney

Patented Jan. 19, 1943 2,308,930

UNITED STATES PATENT OFFICE

2,308,930

HEARING AID APPARATUS

William D. Penn, Dallas, Tex.

Application February 2, 1939, Serial No. 254,317

3 Claims. (Cl. 179—107)

This invention relates to a method and apparatus for aiding hearing. More particularly this invention relates to an apparatus and method for selectively accentuating the frequencies to which a particular hard of hearing user is less sensitive than normal.

An object of this invention is to provide a hearing aid device, having no more elements than the conventional hearing aid devices, said hearing aid device being adapted to selectively transmit certain frequencies within the audible range to a greater extent than other frequencies.

Another object of this invention is to provide a hearing aid device with transducers 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 a 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 microphone or sound record pick-up 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 relationships between the internal impedance of the microphone or the pick-up device and the impedance or admittance to which it is connected.

Still another object of this invention is to provide a 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 imdepance 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 a frequency selective coupling system for transducers of the type having an internal impedance which is predominantly reactive in nature, such as, piezo-electric microphones, piezo-electric pick-ups, condenser microphones, condenser pick-ups, piezo-electric 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 weight 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.

Referring to the drawings briefly, Fig. 1 illustrates schematically, a transducer having a capacitative impedance; Fig. 2 illustrates a general case of a transducer having a capacitative impedance being associated with a load circuit having inductance, capacitance and resistance; Fig. 3 shows two electrically equivalent circuits for the purpose of facilitating the explanation of this invention; Fig. 4 illustrates schematically a form of this invention in which a series circuit is connected across the terminals of the transducer; Fig. 5 illustrates a form of this invention in which the load impedance is connected to the transducer by means of a transformer; Fig. 6 represents a circuit electrically equivalent to the circuit of Fig. 5; Fig. 7 is an embodiment of this invention in which the transducer having a capacitative reactance forms the load; Fig. 8 illustrates a form of this invention similar to that shown in Fig. 7 except that in this case the impedance of the source is represented by elements connected in parallel; Fig. 9 illustrates a form of this invention showing a transducer that is transformer coupled to a source and vacuum tube amplifier, and Fig. 10 illustrates a circuit embodying this invention, said circuit being electrically equivalent to that of Fig. 9 and Fig. 11 shows a complete circuit wherein the capacitative reactance of my piezo-electric transducer forms an essential part of the impedance unit which determines the frequency selection characteristics of the system.

Referring to Fig. 1 of the drawings in detail, reference numeral 10 designates a capacitative reactance and 11 refers to a source of current supply of the pulsating type which may be an alternating current, an undulating direct current and the like of frequency f, having frequency characteristics corresponding to those of sound and the like. The elements 10 and 11 together refer to a transducer, such as, a microphone or pick-up having a capacitative reactance.

The transducer, for the case of a capacitative impedance, may be represented as shown in Fig. 1. C_M is the internal capacity of the device and C_0 is the open circuit voltage of frequency f. In practice the capacity C_M will have associated with it a certain amount of resistance since the power factor of such devices is usually of the order of ten percent as compared to zero for a perfect condenser. Hence, for purposes of illustrative computation the internal impedance is considered a pure reactance. The computations can be suitably altered to fit any given power factor if greater accuracy is deemed necessary. When the transducer is actuated by energy from an acoustical system and is delivering energy to an electrical system e_0 is the open circuit output voltage of the transducer.

For the general case of a transducer acting as a source of signal voltage it is assumed that all three elements, that is, inductance L, capacitance C and resistance R, designated by reference numerals **12**, **13** and **14** are connected across the output terminals of the transducer **10—11** as shown in Fig. 2. These elements **12**, **13** and **14** also include any inductance, capacitance, or resistance due to the input circuit of the associated load circuit which may or may not be a vacuum tube **15**. While in the equations and results to follow the elements L, C, R, are assumed to be all in shunt across the transducer terminals, the present invention is not to be construed as limited to this arrangement since any elements in series with the shunt elements can by suitable transformations be replaced by an equivalent shunt impedance. The two circuits *a* and *b* of Fig. 3 are therefore equivalent. The shunt circuit of R and L is electrically equivalent to the series circuit of r and L' where

$$r=\frac{R(L\omega)^2}{R^2+(L\omega)^2}=\frac{R}{1+(R/L\omega)^2}$$

$$L^1=\frac{R^2(L\omega)}{R^2+(L\omega)^2}=\frac{L\omega}{1+\left(\frac{L\omega}{R}\right)^2}$$

It should be noted in the results to follow that the internal reactance of the transducer plays a very important part as one of the actual circuit elements of the frequency discriminating network.

For the circuit and notation of Fig. 2 I obtain:

$$Z_{C_M}=\frac{-J}{\omega C_M}$$

$$Y_{LCR}=g-Jb=\frac{1}{R}-J\left(\frac{1}{L\omega}=\omega C\right)=\frac{1}{Z_{LCR}}$$

$$i_0=\frac{e_0}{Z_{C_M}+Z_{LCR}}$$

$$e=i_0Z_{LCR}=\frac{e_0Z_{LCR}}{Z_{C_M}+Z_{LCR}}=\frac{e_0}{1+Z_{C_M}Y_{LCR}}$$

$$\frac{e}{e_0}=\frac{1}{1+Z_{C_M}Y_{LCR}} \qquad (1)$$

$$=\frac{1}{1+\frac{C}{C_M}-\frac{1}{\omega^2LC_M}-\frac{J}{\omega C_MR}}$$

for L, C, R in shunt. The absolute value of

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

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{\left(1+\frac{C}{C_M}-\frac{1}{\omega^2LC_M}\right)^2+\left(\frac{1}{\omega C_MR}\right)^2}} \qquad (2)$$

Let

$$\omega_M^2=\frac{1}{LC_M}$$

then the resonant frequency of the circuit comprising these circuit elements

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

and

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{\left[1+\frac{C}{C_M}-(f_M/f)^2\right]^2+\left[\frac{X_{C_M}}{R}\right]^2}} \qquad (3)$$

Let

$$\omega_0^2=\frac{1}{LC}$$

then

$$f_0=\frac{1}{2\pi\sqrt{LC}}$$

and

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{\left[1+\frac{(f/f_0)^2-1}{(f/f_M)^2}\right]^2+\left[\frac{X_{C_M}}{R}\right]^2}} \qquad (4)$$

Equation 1 is a general equation and for any value of Y_{LCR} the ratio

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

may be determined.

From these equations the action of the circuit is known. For the cases in which all three elements L, C, R are not present the above equations are easily modified.

Thus when R only is present Equation 2 reduces to

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{1+\left(\frac{1}{\omega C_MR}\right)^2}} \qquad (5)$$

When inductance and resistance are present

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{[1-(f_M/f)^2]^2+\left[\frac{X_{C_M}}{R}\right]^2}} \qquad (6)$$

When inductance only is present

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{[1-(f_M/f)^2]^2}}=\frac{1}{1-(f_M/f)^2} \qquad (7)$$

When capacity and resistance are present

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{\left(1+\frac{C}{C_M}\right)^2+\left(\frac{X_{C_M}}{R}\right)^2}} \qquad (8)$$

When capacity only is present

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{\left(1+\frac{C}{C_M}\right)^2}}=\frac{1}{1+\frac{C}{C_M}} \qquad (9)$$

For this case there is no frequency discrimination, only a reduction in the value of

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

From Equation 5 for the case of the capacitative transducer working into a resistance load

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{1+\left(\frac{Xc_M}{R}\right)^2}} \quad (10$$

When

$$R \rightarrow \infty, \left|\frac{e}{e_0}\right|=1$$

and using this as a reference the corresponding loss in decibels for some value R is

$$N=-20 \log_{10} \sqrt{1+(Xc_M/R)^2} \quad (11)$$

thus at the frequency for which $Xc_M=R$ the loss is three decibels.

For a specified value of C_M the frequency response at the low end of the audible range will depend upon the value of R. In order to attenuate low frequencies the value of R is made small compared to the reactance of C_M. Thus if $C_M=.0015$ ufd and $R=.1$ Meg. then

$$\frac{Xc_M}{R}=10.6$$

and

$$\left(\frac{Xc_M}{R}\right)^2=112$$

at one hundred cycles. Hence

$$N=-20 \log_{10}\sqrt{113}=-20.5 \text{ db.}$$

At a frequency of two thousand cycles there will be practically no loss—the loss gradually decreasing as the frequency is increased. This gives a characteristic suitable for use with hearing aids in which it is desired to attenuate the low frequencies in order to compensate for certain types of partial deafness in which the hearing loss is small at the lower frequencies and increases at the higher end of the spectrum. For a given value of C_M it is possible by choosing the proper value of R to obtain a frequency response curve which complements the hearing loss curve of a partially deaf person. Curves can be plotted showing the loss at any frequency corresponding to a particular value of R for a fixed value of C_M.

Equation 6 corresponds to the case of inductance and resistance connected across the output terminals of the transducer. In this equation

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

and is the resonant frequency of the inductance and internal reactance of the transducer.

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{[1-(f_M/f)^2]^2+\left(\frac{Xc_M}{R}\right)^2}} \quad (6)$$

The frequency f_M may be given any required value by choosing the proper value of L. When

$$f_M/f=1; \left|\frac{e}{e_0}\right|$$

is a maximum and is equal to $R/Xc_M=R\omega L$. Thus at the frequency $f=f_M$ there is a step-up limited only by R and ωL. If $R/L\omega=1$ at the frequency f_M there is no step-up and

$$\left|\frac{e}{e_0}\right|=1$$

thereby eliminating the resonant peak. As the frequency is decreased below the resonant frequency $(f_M/f)^2$ becomes larger likewise $(Xc_M/R)^2$ becomes larger causing

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

to decrease as the frequency is lowered. Above the resonant frequency

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

gradually approaches unity. A sharper cutoff at the low frequency end of the spectrum can be obtained when using L and R in parallel than when using R only.

Each of the various combinations of circuit elements will manifest their own particular behavior as given by their corresponding equations and the desired characteristic can be obtained by selection from the various equations.

Fig. 4 shows the case for a series circuit of impedance Z_{lcr} connected across the terminals of the transducer. The following equations holds for this case

$$Z_{lcr}=r+Jx$$

$$Zc_M=-J/\omega C_M$$

$$e=i_0Z_{lcr}=\frac{e_0Z_{lcr}}{Zc_M+Z_{lcr}}$$

$$\frac{e}{e_0}=\frac{1}{1+Zc_M/Z_{lcr}} \quad (11)$$

Equation 11 is the general equation for the case of a series impedance.

For the case of l, c, r in series

$$Z_{lcr}=r+j\left(\omega l-\frac{1}{\omega c}\right)$$

and

$$\frac{e}{e_0}=\frac{1}{1-\dfrac{j}{r\omega C_M+j\omega^2lC_M-\dfrac{jC_M}{c}}}$$

$$=\frac{1}{1-\left[\dfrac{\omega^2lC_M-\dfrac{C_M}{c}}{\left(\omega^2lC_M-\dfrac{C_M}{c}\right)^2+(r\omega C_M)^2}+\dfrac{j\omega rC_M}{\left(\omega^2lC_M-\dfrac{C_M}{c}\right)^2+(r\omega C_M)^2}\right]}$$

Let $f_M=\tfrac{1}{2}\pi\sqrt{lC_M}$

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{\left\{1-\dfrac{(f/f_M)^2-\dfrac{C_M}{c}}{\left[(f/f_M)^2-\dfrac{C_M}{c}\right]^2+\left[\dfrac{r}{Xc_M}\right]^2}\right\}^2+\left\{\dfrac{r/Xc_M}{\left[(f/f_M)^2-\dfrac{C_M}{c}\right]^2+[r/Xc_M]^2}\right\}^2}} \quad (12)$$

For the cases in which all three elements are not present the general equation can be modified. Thus for resistance and inductance only

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{\left[1-\frac{(f/f_M)^2}{(f/f_M)^2+(r/Xc_M)^2}\right]^2+\left[\frac{r/Xc_M}{(f/f_M)^2+(r/Xc_M)^2}\right]^2}} \quad (13)$$

For resistance and capacity in series I obtain the following:

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{\left[1+\frac{C_M/c}{\left(\frac{C_M}{c}\right)^2+\left(\frac{r}{Xc_M}\right)^2}\right]^2+\left[\frac{r/Xc_M}{\left(\frac{C_M}{c}\right)^2+(r/Xc_M)^2}\right]^2}} \quad (14)$$

For inductance and capacity in series

$$\left|\frac{e}{e_0}\right|=\frac{1}{1-\frac{1}{(f/f_M)^2-\frac{C_M}{C}}}=\frac{1}{1-\frac{1}{2\pi l C_M(f^2-f_0^2)}}$$

$$=\frac{1}{1-\frac{1}{(f/f_M)^2-(f_0/f_M)^2}},\quad f_M=\frac{1}{2\pi\sqrt{lC_M}},\quad f_0=\frac{1}{2\pi\sqrt{lC}} \quad (15)$$

When

$$\frac{1}{(f/f_M)^2-\frac{C_M}{c}}=1,\ f=f_M\sqrt{1+\frac{C_M}{c}}=\frac{1}{2\pi\sqrt{lC_r}}$$

where

$$Cr=\frac{cC_M}{c+C_M}$$

and

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

is a maximum.

When

$$f=f_0\left|\frac{e}{e_0}\right|=0$$

The transducer also may be connected to a load by means of a transformer 16, as shown in Fig. 5, in which case the windings of the transformer including their distributed capacity and leakage inductance may be used as circuit elements in controlling the frequency response in accordance with the general Equations 1 and 11. Any impedance connected to the secondary will be equivalent to an impedance on the primary side as modified by the turns ratio of the transformer. Fig. 5 shows the circuit and Fig. 6 is the electrically equivalent circuit.

The elements of these circuits are as follows:

r_1 =Resistance of primary winding.
r_2 =Resistance of secondary winding.
l_s =$L_1(1-k^2)$=leakage inductance referred to primary.
L_1 =Primary inductance.
k =Co-efficient of coupling.
Z =Secondary load impedance.
n_1 =Primary turns.
n_2 =Secondary turns.
C =Total capacity referred to primary.
C_M=Internal capacity of transducer.
e_0 =Open circuit voltage of transducer.

The present invention is not to be construed as limited to the case of the transducer working as a generator into a load circuit. The transducer may be the load and may be fed from a source such that the voltage developed across the transducer is a function of frequencies. 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 EMF 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 Thevenin's theorem. Thus, suppose a device such as a piezo electrical crystal headphone 17 is fed from a source of impedance Z_{lcr} as in Fig. 7.

$$e=\frac{e_0 Zc_M}{Z_{lcr}+Zc_M};\quad \frac{e}{e_0}=\frac{1}{1+\frac{Z_{lcr}}{Zc_M}} \quad (16)$$

For inductance, capacity, and resistance in series Equation 16 gives

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

let

$$\omega_M^2=1/lC_M$$

then

$$f_M=\tfrac{1}{2}\pi\sqrt{lC_M}$$

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

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

For inductance and resistance in series

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

when $f=f_M$

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

For inductance and capacitance in series

$$\left|\frac{e}{e_0}\right|=\frac{1}{1-(f/f_M)^2+\frac{C_M}{c}} \quad (19)$$

when

$$f=f_M\sqrt{1+\frac{C_M}{c}}=\tfrac{1}{2}\pi\sqrt{lC_I}$$

where

$$C_I=\frac{cC_M}{c+C_M}$$

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

For a series inductance

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

and

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

when $f=f_M$

For a series capacitance

$$\left|\frac{e}{e_0}\right|=\frac{1}{1+\frac{C_M}{c}} \quad (21)$$

and there is no frequency discrimination.

For a series resistance

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{1+(r/Xc_M)^2}} \quad (22)$$

For the case of the impedance of the source being represented by elements in parallel as illustrated by circuit 18 in Fig. 8, the following is obtained.

$$\frac{e}{e_0}=\frac{1}{1+\frac{1}{Zc_M Y_{LCR}}} \quad (23)$$

For L, C, R all present Equation 23 gives

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

$$\frac{e}{e_0}=\frac{1}{1+\frac{1}{\frac{-1}{\omega C_M}\left[\frac{1}{R}-J\left(\frac{1}{L\omega}-\omega C\right)\right]}}=\frac{1}{1+\frac{1}{\left[\frac{C}{C_M}-\left(\frac{f_M}{f}\right)^2\right]-\frac{JXc_M}{R}}}$$

$$\left|\frac{e}{e_0}\right|=\frac{1}{\sqrt{\left\{1+\frac{\left[\frac{C}{C_M}-(f_M/f)^2\right]}{\left[\frac{C}{C_M}-(f_M/f)^2\right]^2+\left[\frac{Xc_M}{R}\right]^2}\right\}^2+\left\{\frac{Xc_M/R}{\left[\frac{C}{C_M}-(f_M/f)^2\right]^2+\left[\frac{Xc_M}{R}\right]^2}\right\}^2}} \quad (24)$$

For inductance and resistance in parallel

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

For inductance and capacitance in parallel

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

For resistance and capacitance in parallel

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

For capacitance only

$$\left|\frac{e}{e_0}\right|=\frac{1}{1+\frac{C_M}{c}} \quad (28)$$

and there is no frequency discrimination.

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 microphone and a piezo-electric crystal earpiece, the coupling arrangements for the microphone and earpiece can be so chosen as to provide a frequency selective system of the proper characteristics for the particular type of deafness involved. This is accomplished with a minimum of extra equipment because the internal impedance of the transducer, that is, the piezo-electric crystal microphone and/or the piezo-electric crystal earpiece, is used as one of the circuit elements controlling the frequency response. The terms microphone and earpiece or headphone are used here in a broad sense in that microphone is intended to include both the sound pick-up type and the phonograph record pick-up. Earpiece or headphone is intended to include both the telephone type and the bone conduction type.

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 15 by means of a transformer 19 as shown in Fig. 9.

For this case

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

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

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

giving the equivalent circuit shown below in Fig. 10. Hence Equation 22 applies and

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

When

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

there will be a three decibel loss. By varying the turn ratio n_2/n_1 the required frequency characteristic for any given value of r_p can be obtained.

In Fig. 11 I have shown a form of circuit arrangement with which my invention may be employed conveniently. The piezo-electric crystal microphone 10a includes the capacitative reactance 10 of Figs. 1, 2, 5 and 6 and the reactance of this crystal microphone or other pickup device bears certain relations to the inductance, capacity and resistance of the other elements of the circuit, including the transformer 16a, amplifier tube 15a, transformer 19a and reproducer 17a, whereby the foregoing mathematical relations are satisfied and the circuit is made to produce the desired frequency selection. It will be observed that I have shown both the microphone 10a and the headphone 17a as being of the piezo-electric crystal 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 head-phone 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 **15a** 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 **17a** 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. In the translation for hearing aid purposes of sound vibrations into a varying electrical current employing a piezo-electric crystal transducer having a substantially capacitative internal impedance and further employing a load circuit which has an impedance including a substantial inductive component, said load circuit being conductively connected to said transducer, the method of non-uniformly translating 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 impedance of said load circuit in such manner with reference to the said capacitative, internal impedance of said transducer to which it is conductively connected that the frequency response characteristic curve of the conductivity connected circuit comprising the said capacitative internal impedance of said transducer and the said impedance of said load circuit comprising said inductive component, emphasizes a desired restricted frequency region of the audio spectrum.

2. In a piezo-electric pick-up system, a piezo-electric pick-up transducer element having a substantially capacitative internal impedance, a load circuit conductively connected to said transducer element and including a substantial lumped inductive component, the values of the respective components of the impedance of said load circuit being so selected with reference to the said capacitative internal impedance of said transducer element that the frequency response characteristic curve of the conductively connected circuit comprising the said capacitative internal impedance of said transducer element and the said impedance of said load circuit, emphasizes a desired restricted frequency region of the audio spectrum.

3. In a piezo-electric pick-up system, a piezo-electric pick-up transducer element having a substantially capacitative internal impedance, a load circuit conductively connected to said transducer element and including as components capacitance and lumped inductance connected in parallel, the values of the respective components of the impedance of said load circuit being so selected with reference to the said capacitative internal impedance of said transducer element that the frequency response characteristic curve of the conductively connected circuit comprising the said capacitative internal impedance of said transducer element and the said impedance of said load circuit, emphasizes a desired restricted frequency region of the audio spectrum.

WILLIAM D. PENN.