Sept. 10, 1940. D. A. WILBUR 2,214,393

ACOUSTICAL EQUALIZER

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Fig. 1

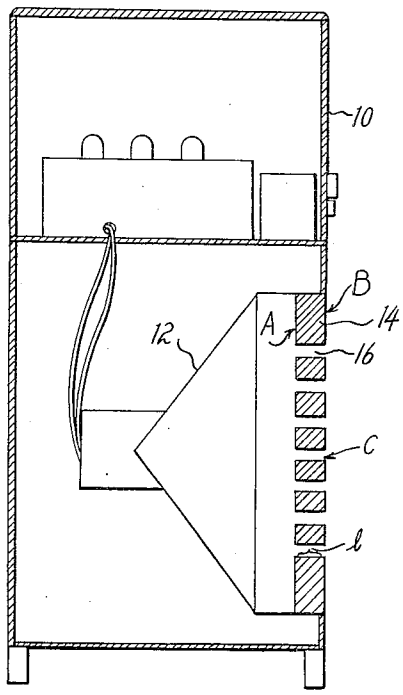


Fig. 2

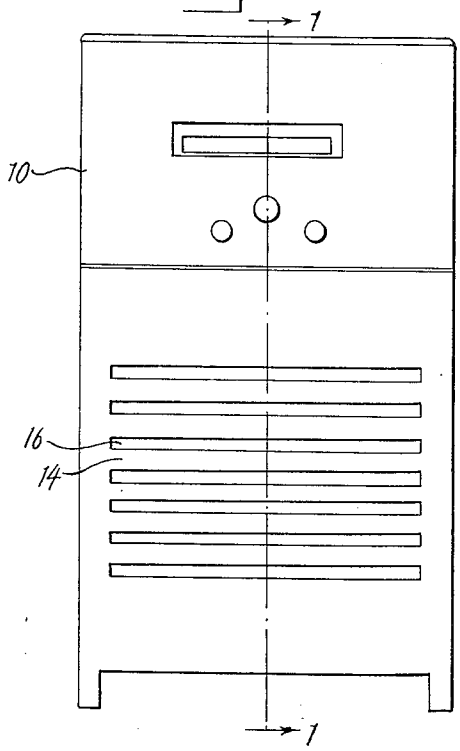
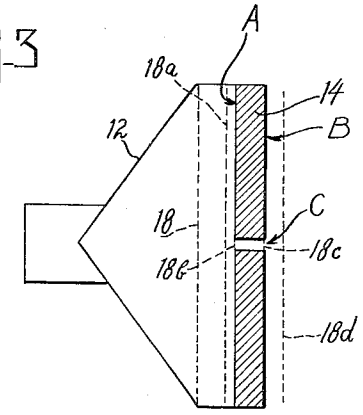


Fig. 3



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Fig 4

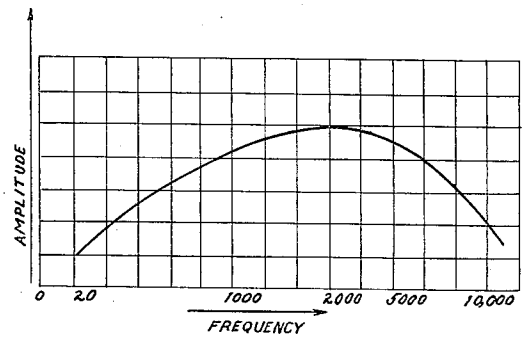


Fig 5

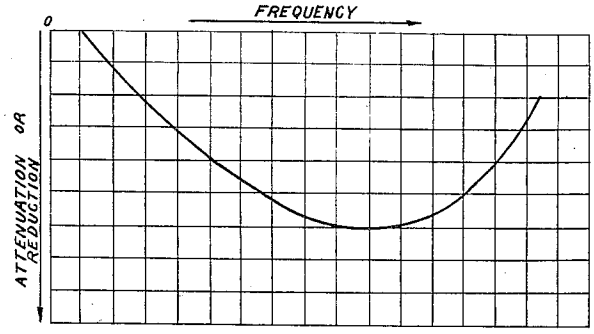


Fig 6

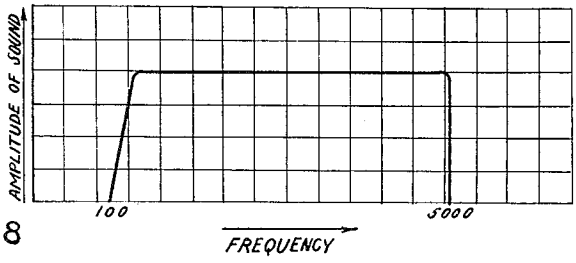


Fig 7

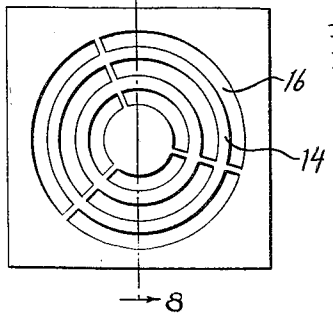
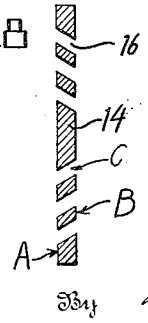


Fig 8



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UNITED STATES PATENT OFFICE

2,214,393

ACOUSTICAL EQUALIZER

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Application September 10, 1938, Serial No. 229,255

3 Claims. (Cl. 181—31)

The present invention relates to electrical acoustic transducers and more particularly to an acoustical equalizer adapted for use in such transducers and the method of producing same.

In the broadcasting of a radio program, the transmitters are operated in such a manner that of the tones to be transmitted those of equal intensity or loudness are transmitted as being of equal intensity or loudness and those having different intensities are transmitted as such and with the original relative relations existing between the intensities of the different tones being maintained in their transmitted wave. As a result, the curve of the over-all frequency response characteristic is linear. However, due to inherent characteristics of the electrical circuit or of the speaker system, or of both, tones of different frequencies which were originally of equal intensity or loudness will be reproduced with intensities which depend upon the frequencies of the tones, thus resulting in distortion and the frequency response characteristic of the set will no longer be linear.

The object of the present invention is the production of an acoustical equalizer which will compensate for the inherent characteristics of the speaker system or of the electrical circuit, or both, whereupon the tones transmitted will be reproduced in their original form. This is accomplished by providing a grille adapted to be positioned in the path of the transmitted tones and partaking of the nature of a filter which will attenuate some of the reproduced frequencies. The grille is adapted to produce a substantially reverse characteristic frequency response curve to that of the set or system in which it is installed, thereby tending to maintain the resultant frequency response curve of the set or system linear. The grille is further adapted to reduce the amplitude throughout a predetermined range while maintaining the amplitude of frequency outside of that range unchanged, thus compensating at the points where maximum distortion occurs.

A still further object is the method of producing a grille or acoustical equalizer having the afore-mentioned characteristics.

Other objects will be in part obvious and in part pointed out more in detail hereinafter.

The invention accordingly consists in the features of construction, combination of elements, and arrangement of parts which will be exemplified in the construction hereafter set forth and the scope of the application of which will be indicated in the appended claims.

In the accompanying drawings:

Figure 1 is a cross sectional view, more or less diagrammatic, taken on the line 1—1 of Fig. 2 of a radio reproducing set embodying the invention herein;

Fig. 2 is a front view of the set of Fig. 1;

Fig. 3 is a diagrammatic view of the type of grille shown in Fig. 1, but having a single opening illustrating the action of an acoustical equalizer made according to the invention herein;

Fig. 4 is the characteristic frequency response curve of the set shown in Fig. 1 without the equalizer;

Fig. 5 is the attenuation curve of the equalizer;

Fig. 6 is the resultant characteristic response curve of the set with the equalizer installed;

Fig. 7 is a view illustrating another type of grille; and

Fig. 8 is a cross sectional view taken on the line 8—8 of Fig. 7.

As is well-known, the speaker of the ordinary receiving or reproducing set converts electrical energy into sound energy by producing a series of sound waves which are sent forward therefrom and out into the open air at the mouth of the speaker. Thus if for any given speaker unit an alternating voltage of constant amplitude and variable frequency from a source of constant internal impedance is applied to the speaker and the sound energy is measured, a characteristic frequency response curve may be obtained. For the purpose of illustration, it will be assumed that the frequency response curve shown in Fig. 4 is the frequency response curve of the reproducing set 10 illustrated in Fig. 1. As is evidenced from Fig. 4, the unit will tend to accentuate the tones being reproduced between one thousand and five thousand cycles beyond the maximum or desired accentuation and thus cause a distortion in the tone reproduced.

In accordance with the present invention, there is provided an acoustical equalizer or grille 14 positioned in the mouth of the speaker 12 and adapted to produce a characteristic curve such as that illustrated in Fig. 5, which curve is substantially the inverse of the curve of the set 10 as shown in Fig. 4. The resultant curve of the unit when provided with the equalizer is substantially that as illustrated in Fig. 6 wherein the equalizer has attenuated the amplitude of the frequencies at one thousand to two thousand cycles and has left relatively unchanged those near one hundred and five thousand cycles, whereupon the tones radiated from the speaker will closely approach the original form in which they were transmitted.

In order to obtain this result, the equalizer 14 is made of a predetermined thickness and provided with a plurality of openings 16. The openings 16 each have an acoustical length l as measured by the thickness of the equalizer from the inner surface A to the outer surface B, which length is determined as a function of the lowest frequency at which maximum attenuation is desired. The openings 16 are shown as transverse slots, but could be of any other shape having a

total cross sectional area C, which area is determined by the amount of attenuation desired.

Due to the positioning of the grille 14 in the mouth of the speaker, the sound waves which leave the speaker 12, instead of radiating directly into the open air, will impinge against the rear surface A of the grille, and thus the equalizer 14 will tend to reflect a part of the waves toward the speaker, whereas another part of the wave will advance through the opening 16 and a portion of the advancing wave will be reflected back into the opening upon impinging the air at the surface B.

By giving to the equalizer opening 16 an acoustical length l, the fraction of the wave reflected from the opening on side B incident on side A will be made to assist or oppose the next successive wave and thereby tend to change the amount finally radiated. This may best be understood by reference to Fig. 3 wherein there is diagrammatically shown a grille similar to grille 14 but having a single opening 16. When the diaphragm of the speaker 12 is energized, it will send forth a wave 18 which will impinge against the rear face A of the grille 14. A portion 18*a* of the wave will be reflected back towards the speaker and a portion 18*b* thereof will enter the opening 16. Upon the portion 18*b* arriving at the outer face B of the cabinet, a portion 18*c* thereof will be reflected back into the opening and a portion 18*d* radiated into the atmosphere. The portion 18*d* finally radiated into the atmosphere may be made to be any fraction of the incident wave 18, depending upon the frequency of the incident wave, the acoustical length l of the opening, and the cross sectional area thereof; this effect being produced by causing the reflected portions 18*a* and 18*c* thereof to effectively aid or oppose the entrance of a corresponding portion 18*b* of the following wave into the opening 16 and its subsequent radiation as a corresponding wave portion 18*d*.

The motion of the air caused by the wave 18*b* as it enters the opening 16 at the inner face A of the grille is the same as at the surface B at the outer face of the grille, except delayed in time by the amount it takes wave 18*b* to go from surface A to surface B. In terms of phase angle, this may be kl, where k is equal to the phase shift per unit length, or, expressed in radians, k is equal to

$$\frac{2\pi}{\lambda}$$

where λ is equal to the wave length of the sound. It will likewise be seen that for low frequencies (long wave lengths) k will be very small, and hence kl and $2kl$ will be very small. Inasmuch as the reflected wave 18*a* and the reflected wave 18*c* combine at the inner surface A, the wave 18*c* tends to neutralize wave 18*a* (as the phase angle of the wave 18*a* has been shifted 180° by reflection, whereas the phase angle of 18*c* remains unchanged except for the small amount $2kl$ which may be neglected) and no energy will be reflected towards the speaker and all the energy will be transmitted from the opening.

However, at high frequencies (short wave lengths) upon reflection when the wave 18*a* is shifted 180° in phase, the wave 18*b* must travel the distance l before arriving at the surface B and the reflected wave 18*c* must travel the distance l before arriving at the surface A. Thus the phase difference between 18 and 18*c* at surface A will, therefore, be equivalent to the phase difference between two points in the wave 18 a distance $2l$ apart. And if

$$l=\frac{\lambda}{2}$$

the wave 18*c* at the surface A will be 180° behind in phase and, therefore, will be in phase with the reflected wave 18*a* and tend to aid it.

For still higher frequencies, the wave 18*c* will get 360° behind in phase and again neutralize the wave 18*a* as in the first case. Thus by properly proportioning the length l, the wave reflected from surface B of the opening 16 can be made to assist or oppose the wave reflected from surface A and thus neutralize or attenuate the transmitted wave. Thus when the wave 18*c* neutralizes the reflected wave 18*a*, no change results in the transmitted wave, whereas when it is made to aid the reflected wave the transmitted wave is attenuated.

Inasmuch as the audio frequency signals are the ones to be compensated in the particular set shown, it is desirable to have maximum attenuation at the frequency of maximum response for the set in question or, as shown, at two thousand cycles. Since the maximum attenuation 18*a* and 18*c* must aid and since 18*a* suffers 180° phase change upon reflection and since wave 18*b* travels a distance l before producing wave 18*c*, which wave subsequently travels a distance l before combining with wave 18*a*, the phase shift due to this distance $2l$ must just compensate for the 180° phase shift of wave 18*a*. It must, therefore, in itself produce a phase shift of 180°—that is, $2kl$ must equal π radians or 180° or

$$2l\cdot\frac{2\pi}{\lambda}=2\pi$$

or

$$\frac{4l}{\lambda}=1$$

and

$$l=\frac{\lambda}{4}$$

As is well known,

$$\lambda=\frac{c}{f}$$

where c is the velocity of sound in air. To attenuate at two thousand cycles in the set illustrated,

$$c=\frac{34,400}{2,000}$$

or 17.2 cm. and, therefore, l=4.3 cm. or 1.69 inches.

Having determined the acoustical length l to be 1.69 inches to obtain maximum attenuation at two thousand cycles, then the amount of attenuation will be determined by the area of the opening 16, inasmuch as the area will control the volume finally emitted from the speaker. If it has been found that the sound or loudness at two thousand cycles is twice as much as desired, then the area should be such as to reduce this loudness fifty percent.

In determining the area C of the opening 16 to obtain the desired amount of attentuation, three factors must be considered. These factors are: the area of the grille or equalizer at the inner surface A; the area of the outer surface B of the equalizer; and the amount of attenuation desired which may be designated as P—that is, the ratio of power transmitted to space to that incident upon the surface A. The surface A, as indicated, is the total area of the

inner surface of the grille, whereas the area B is the effective outside area of the cabinet including the grille, and, as previously stated, P is readily determined by reducing the fraction of volume transmitted the amount desired. With the foregoing factors established, the unknown factor—that is, the cross sectional area C—may be determined as follows:

Assuming—

a_1 to represent the particle displacement at the surface A of the wave incident in the diaphragm of the speaker;

b_1 to represent the particle displacement at the surface A of the wave reflected from surface A;

a_2 to represent the particle displacement of the surface A of the wave entering opening **16** at surface A;

b_2 to represent the particle displacement of the surface A of the wave reflected in opening **16** at the surface B;

a_3 to represent the particle displacement at surface B of the wave which entered opening **16** at surface A;

b_3 to represent the particle displacement of the surface B of the wave reflected in opening **16** at surface B;

a_4 to represent the particle displacement at the surface B of the wave radiated into space from the surface B; and

$$x_1=\frac{C}{A}$$

that is, the ratio of the cross sectional area of the opening **16** to the area of the surface A;

$$x_2=\frac{B}{C}$$

and equal to the ratio of the area B to the cross sectional area of the opening **16**.

Then

$$a_1=A_1e^{jwt}$$
$$b_1=B_1e^{jwt}$$
$$a_2=A_2e^{jwt}$$
$$b_2=B_2e^{jwt}$$
$$a_3=A_2e^{jwt}.e^{-jkl}$$
$$b_3=B_2e^{jwt}.e^{+jkl}$$
$$a_4=A_4e^{jwt}$$

where A_1, B_1, A_2, B_2, and A_4 equal the complex amplitudes of the respective vibrations.

Inasmuch as there must be a continuity of pressure and volume displacement, therefor

$$A_1+B_1=A_2+B_2$$
$$A(A_1-B_1)=C(A_2-B_2)$$
$$A_2e^{-jkl}+B_2e^{-jkl}=A_4$$
$$C(A_2e^{-jkl}-B_2e^{+jkl})=BA_4$$

and thus

$$A_1=\frac{A_4}{2}((x_1x_2+1)\cos kl+j(x_1+x_2)\sin kl)$$

$$B_1=\frac{A_4}{2}((x_1x_2-1)\cos kl+j(x_1-x_2)\sin kl)$$

Now let

P=the ratio of power transmitted to space to that incident upon surface A

p=pressure due to sound wave

v=volume of air displacement through a unit area per second by the wave

Power=area.$p.v$—as is well known

$$P=\frac{Bp_7v_7}{Ap_2v_2}$$

where

p_7=pressure due to sound wave as it enters space **7**

v_7=volume current due to sound wave as it enters space **7**

p_2=pressure due to direct wave impinging upon surface A from volume **2**.

v_2=volume current due to direct wave impinging upon surface A from volume **2**

$p=pcv$

p=density of air

c=velocity of sound in air

Then

$$P=\frac{B1A_4l^2}{A1A_1l^2}=x_1x_2\frac{1A_1l^2}{1A_1l^2}$$

$$P=\frac{x_1x_2}{\frac{1}{4}((x_1x_2+1)^2\cos^2 kl+(x_1x_2)^2\sin^2 kl)}$$

$$P=\frac{\frac{C}{A}\cdot\frac{B}{C}}{\frac{1}{4}\left(\left(\frac{B}{A}+1\right)^2\cos^2 kl+\left(\frac{C}{A}+\frac{B}{C}\right)^2\sin^2 kl\right)}$$

For maximum attenuation $2kl=\pi$

$$kl=\frac{\pi}{2}=90°$$

Therefore

$$\cos kl=0$$
$$\sin kl=1$$

Therefore

$$P_{min}=\frac{4\frac{C}{A}\cdot\frac{B}{C}}{\left(\frac{C}{A}+\frac{B}{C}\right)^2}=\frac{4B}{A\left(\frac{C}{A}+\frac{B}{C}\right)^2}$$

Inasmuch as the frequency response curve of the set prior to the installation of the grille will be dependent upon the outside area B of the cabinet without the grille, the effect of said surface exclusive of the grille will be present whether or not the grille is inserted. Hence, if a frequency response curve of the set is taken without the grille in place and the set is in otherwise finished condition, then for all practical purposes the area B can be considered as the equivalent of the area A.

Inasmuch as P is the ratio of power transmitted to space to that incident upon surface A, there may be substituted for P a value equal to the percentage it is desired to attenuate the frequency of maximum response. With this figure substituted and the other known factors inserted in the above formula, the value of C may readily be determined. If C be considered in terms of percentage of the area of the grille and P the percentage of attenuation desired, the formula resolves itself into

$$C+\frac{1}{C}=2\left(\frac{1}{P}\right)^{\frac{1}{2}}$$

Having determined the value of C, the speaker may be made with the single opening **16**, although to avoid resonance within the speaker cavity the total area may be sub-divided into a plurality of areas such as illustrated in the grille of Fig. 1. It is likewise immaterial what shape these openings assume so long as they have a total cross area C and an acoustical length l. For example, in Fig. 7 there is illustrated a grille having circumferential spaced apart slots **22**, and in order to add to the attractiveness of the set the side walls of the slots are cut at an angle to the horizontal.

As many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the language used in the following claims is intended to cover all of the generic and specific features of the invention herein described and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

I claim as my invention:

1. In an acoustic device a grille having an opening therethrough, said opening having a cross sectional area C and a depth of opening l, said cross sectional area being determined by the formula:

$$P=\frac{\frac{C}{A}\cdot\frac{B}{C}}{\frac{1}{4}\left(\left(\frac{B}{A}+1\right)^2\cos^2 kl+\left(\frac{C}{A}+\frac{B}{C}\right)^2\sin^2 kl\right)}$$

where

A=the inside area of the grille

B=the outside area of the grille

P=the ratio of transmitted and incident sound power

l=the actual length of opening C and is determined by substituting in the formula $2kl=\pi$ the lowest frequency at which maximum attenuation is desired.

2. An acoustical equalizer for the attenuation of sound waves of varying frequency, comprising a grille having a thickness equal to the velocity of said waves divided by approximately four times the frequency of the waves to be maximumly attenuated, and an opening in said grille allowing only a portion of the waves to pass therethrough.

3. An acoustical equalizer for the attenuation of sound waves, comprising a grille having a thickness equal to the velocity of said waves divided by approximately four times the frequency of the waves to be maximumly attenuated and having one or more openings, the total cross sectional area of which is equal to C in the equation:

$$C+\frac{1}{C}=2\left(\frac{1}{P}\right)^{\frac{1}{2}}$$

where C is the total area of the openings in percent of the total area of the grille and P is the percentage attenuation desired.

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