

Jan. 12, 1932.

P. B. FLANDERS ET AL

1,841,101

LOUD SPEAKER

Filed March 6, 1930

FIG. 1

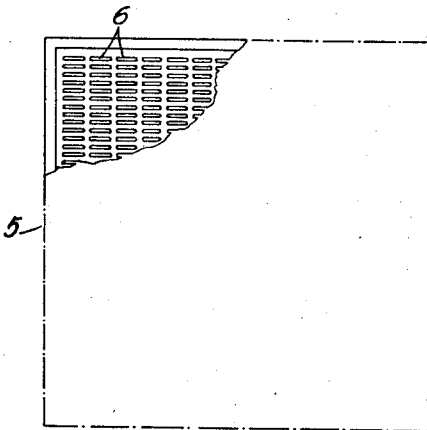
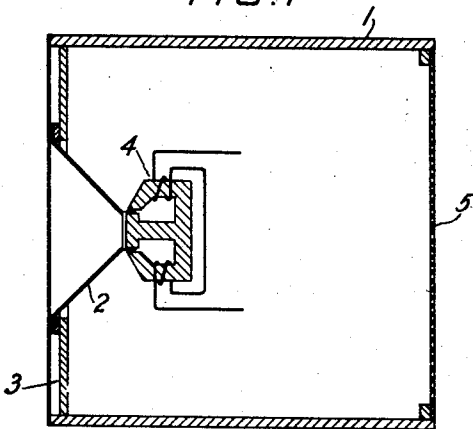


FIG. 3

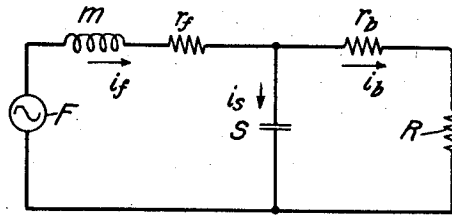
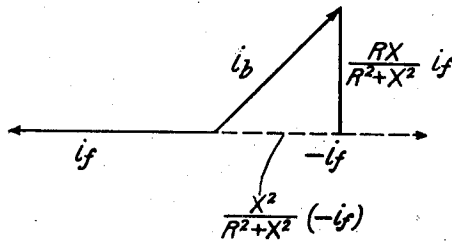


FIG. 2

FIG. 4



P. B. FLANDERS
INVENTORS
H. C. HARRISON
BY *G. M. Campbell*
ATTORNEY

UNITED STATES PATENT OFFICE

PAUL B. FLANDERS, OF EAST ORANGE, NEW JERSEY, AND HENRY C. HARRISON, OF
PORT WASHINGTON, NEW YORK, ASSIGNORS TO BELL TELEPHONE LABORATORIES,
INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

LOUD SPEAKER

Application filed March 6, 1930. Serial No. 433,590.

This invention relates to loud speakers of the direct radiating diaphragm type and more particularly to mountings for inertia controlled speakers having piston diaphragms of the cone or stiff plate type.

These diaphragms as used, for instance, in moving coil loud speakers, are usually of comparatively small dimensions and must be provided with some form of baffle arrangement or its equivalent. If this is not done the response particularly at low frequencies, will be unsatisfactory due to the cancellation effects between the air waves set up by the opposite sides of the diaphragm. These speakers, therefore, were at one time usually mounted in an opening in a large plane surface which acted as a baffle board between the front and rear waves. The diaphragm was supported at its periphery by a mounting member of low elasticity which gave it a low natural period and since the radiation resistance of the air is also low at low frequencies, this construction gave a large low frequency peak in the response curve and was, therefore, not entirely satisfactory even aside from its disadvantage due to its large dimensions.

To obtain the required baffle effect at very low frequencies without resorting to an excessively large structure it is now common practice to mount such cones in a cabinet or box of moderate size open at the rear side. While it is possible in this way to reduce the cancellation effect materially, it is found that this construction has the decided disadvantage of producing other irregularities in the frequency response due to reflection from the walls of the box. Some of these reflected waves return to the diaphragm out of phase with this motion, thereby retarding it, while others are in phase thereby increasing the amplitude of its natural movement and producing the so-called "barrel tone" or resonant effect. It has been proposed to reduce these irregularities by lining the box

or otherwise disposing sound absorbing material within it. In this way resonances in the upper portion of the frequency scale can be largely eliminated but this form of damping is not very effective at lower frequencies due to the relative thinness of the damping layers with respect to the wave lengths of low frequencies.

It might be thought advantageous merely to seal up the open side of the cabinet and thereby prevent the waves radiated from the rear side of the diaphragm from cancelling those set up by the front side, but, if this is done, the air confined within the box acts as an elastic reactance tending to retard the diaphragm and since this effect is inversely proportional to frequency the response is unduly decreased at low frequencies.

The variation of the radiation resistance of the air with frequency has already been mentioned. It is well-known that, while this resistance is comparatively constant for all sound frequencies having wave lengths greater than one-third the diameter of the diaphragm to be used, it falls off very rapidly for frequencies having wave lengths greater than this diameter. For the steady state condition of vibration this is not objectionable. The variation of velocity of vibration with frequency is such that for constant energy input the sound output, (V^2R) is also substantially constant over the range of interest. It will be evident however, that while a low frequency vibration is being built up in the diaphragm, the energy stored in the diaphragm

$$\left(\frac{1}{2}MV^2\right)$$

is relatively large compared with the energy radiated (V^2R) so that the diaphragm must continue to vibrate for an appreciable time after the driving force has ceased in order to dissipate this excess energy. This results in an "overlapping" or reverberation effect simi-

lar to that obtained in an excessively "live" room. Since the impedance of diaphragms of the type under discussion is almost entirely mass reactance, considerable resistance damp-
 5 ing can be introduced to suppress these transients without materially increasing the total impedance of the system, that is, without substantially reducing the response of the diaphragm.

10 It is therefore the object of the present invention to so design the air chamber of such a loud speaker as to obtain a satisfactory baffle effect and at the same time to reduce the transient period to a point where it is no
 15 longer objectionable.

One very advantageous way of attaining these objects in accordance with the invention consists in using a cabinet of only moderate dimensions and enclosing the normally open
 20 side with a material which offers to the air flow an impedance of the nature of a pure acoustic resistance of the proper magnitude. In this way, the cone is damped sufficiently to reduce the transient effect materially and
 25 the air waves which pass through the membrane are so reduced in magnitude and shifted in phase that the result as regards cancellation is the same as if a large plane baffle were used. It is found for instance that very
 30 satisfactory results may be obtained without materially reducing the efficiency of the loud speaker if the magnitude of this added resistance is correlated to the dimensions of the box in such a way that somewhat less than
 35 two thirds of the air displaced by the rear side of the cone passes through the enclosing material.

This general statement of the invention will be more clearly understood from a consideration of the following description of a
 40 specific case in connection with the drawing in which Fig. 1 is a cross-section of a cone type loud speaker mounted in a baffle box with the back resistance added in accordance
 45 with the present invention; Fig. 2 is a detail of the acoustic resistance material employed; Fig. 3 is a representation of the analogs of the mechanical elements of the loud speaker of Fig. 1 in the elements of a corresponding
 50 electrical network; and Fig. 4 is a vector representation of the air velocities set up by the arrangement of Fig. 1.

For purpose of illustration assume an 18" cubical box 1 as shown in Fig. 1 with an 8"
 55 diameter cone diaphragm 2, mounted in the front side 3 of the box and adapted to be driven by the driving unit 4, and an acoustic resistance material 5 covering the rear side. One form of such a resistance consists of a
 60 thin sheet of metal containing narrow slits 6 such as those described in French Patent 665,237 granted to P. B. Flanders May 6, 1929. This system like any other mechanical system may be considered for the sake of con-
 65 venience as a mechanical transmission line

as indicated in Fig. 3 in which F is the driving force in dynes applied to the cone by the unit 4, m is the mass of the cone in grams, r_f is the radiation resistance due to the air on the front side of the cone, S is the stiffness of the air enclosed in the box, r_b is the radiation resistance at the back of the cone and R is the added resistance of the material 5. The velocities imparted to the air at the front and rear sides of the cone are represented by i_f and i_b respectively as indicated. Under these conditions the actual sound emitted is proportional to the vector sum of i_f and i_b . Obviously the ideal condition would be to have i_f alone effective.

From the analogy to an electrical circuit it follows that the impedance in Fig. 3 of S and R in parallel (neglecting r_b which is comparatively small at low frequencies) is

$$\frac{R(-jX)}{R-jX}$$

and also that as regards cancellation effects in front of the cone

$$\frac{i_f}{i_b} = -\frac{R}{Z} = -\frac{R-jX}{-jX} = -(1+j\frac{R}{X})$$

The relation of the ideal to the actual condition is therefore expressed by

$$\frac{i_f}{i_f + i_b} = \frac{\frac{i_f}{i_b}}{1 + \frac{i_f}{i_b}} = \frac{-1-j\frac{R}{X}}{-j\frac{R}{X}} = 1 + \frac{-1}{-j\frac{R}{X}} = (1+j\frac{X}{R})$$

The value of X , the stiffness reactance of the enclosed air, at any frequency such as 60 cycles for which all of the constants of Fig. 3 are computed, is given by

$$X = \frac{S}{\omega}$$

where S is the stiffness of the enclosed air and ω is equal to $2\pi f$.

$$S = \frac{\rho c^2 A_1^2}{V3}$$

where ρ is the normal air density in gms. per cu. cm.

c is the velocity of sound in air in cms. per sec.

A_1 is the area of the cone (324 sq. cms.) and

V is the volume of enclosed air, $18^3 \times 16.4$ cu. cms.

$\rho c^2 = 1.4 \times 10^9$. X is therefore

$$\frac{1.4 \times 10^9 \times 324^2}{18^3 \times 16.4 \times 2\pi f} = 4115 \text{ mechanical ohms.}$$

(A mechanical ohm is defined as the impedance of a system which when acted on by a force of 1 dyne, moves with a velocity of 1 cm. per sec.)

Reducing the above expression

$$1 + j\frac{X}{R}$$

to its absolute value and assuming that a maximum loss of 3 db referred to the ideal condition is permissible.

$$3 = 10 \log_{10} \left(1 + \left(\frac{X}{R} \right)^2 \right)$$

In order to satisfy this equation

$$1 + \left(\frac{X}{R} \right)^2$$

must be approximately equal to 2 and since X has already been found to be 4115 ohms, it follows that R must also be about 4115 ohms total resistance (as referred to area A_1). A_2 , the area of the acoustic material 5 is 2090 sq. cms. so that the resistance required in the added material is

$$\frac{R_1}{A_1} \times \frac{A_2}{A_1} = 82 \text{ ohms per sq. cm.}$$

The normal high frequency air resistance r_p is about 41 ohms per sq. cm. so that this value is only twice normal and therefore will not produce excessive reflection effects at high frequencies. The added impedance due to R and X in parallel will be

$$\frac{4115}{\sqrt{2}} = 2910 \text{ mech. ohms}$$

where as the mass reactance of the diaphragm at the same frequency is $2\pi fm$ or 3000 mech. ohms. Hence the damping necessary for the purposes of the invention will not unduly reduce the diaphragm motion.

Since the added resistance is equal to the air reactance of 4115 ohms at 60 cycles and is large compared with the radiation resistances r_f and r_b which are about 66 ohms at 60 cycles, i_b will be approximately equal to i_a , i. e. substantially $\frac{1}{2}$ the air displaced by the diaphragm will pass through the membrane while the other half will be compressed within the box. While this value may be varied somewhat in any particular case it is found in general that if more than about $\frac{2}{3}$ of the displaced air passes through the membrane the transient effect is not sufficiently eliminated while if much more than $\frac{1}{2}$ the displaced air is confined the response is unduly reduced.

The reason for the reduction in cancellation effect obtained according to the invention will be more clearly understood from the vector diaphragm of Fig. 4 in which i_f and i_b represent the front and rear waves as in Fig. 3. In the absence of the added resistance R, i_b will be in phase with $-i_f$ so that for low frequencies the cancellation effect will be unduly large. However with the resistance

material added the stiffness reactance X, of the enclosed air is effective so that

$$i_b = -\frac{i_f R}{1 + j\frac{R}{X}}$$

This may be written

$$i_b = -i_f \left(\frac{1 - j\frac{R}{X}}{2} \right)$$

$$1 + \frac{R}{X^2}$$

$$= -i_f \left(\frac{X - jR}{R^2 + X^2} \right) X$$

Hence i_b is both reduced in magnitude by the ratio indicated and shifted in phase to give a component in phase with $-i_f$ of only

$$\frac{X^2}{R^2 + X^2} (-i_f)$$

as indicated. In the case chosen for illustrating the invention $R=X$ so that i_b is reduced to an effective value of one half that for the open box condition and the cancellation is correspondingly reduced.

The invention has been described with reference to a specific structure but it will be understood that it is capable of various modifications within the scope of the following claims.

What is claimed is:

1. The method of reducing cancellation effects in the air waves set up by direct radiating diaphragms which consists in confining a portion of the air displaced by one side of the diaphragm and altering the phase of the motion of that portion of the air not confined.

2. The combination with a sound radiating diaphragm, means for driving the diaphragm and means for baffling the air waves set up by the opposite sides of the diaphragm, of means for partially confining and shifting the phase of the waves set up by one of the sides of the diaphragm.

3. The combination with a sound radiating diaphragm, means for driving the diaphragm and means for baffling the air waves set up by the opposite sides of the diaphragm of material in the path of the waves set up by one side of the diaphragm offering an impedance to the waves of substantially pure acoustic resistance.

4. The combination with a sound radiating diaphragm, means for driving the diaphragm and means for baffling the air waves set up by the opposite sides of the diaphragm of an acoustic resistance associated with one side of the diaphragm and adapted to pass of the order of $\frac{1}{2}$ the air displaced on that side of the diaphragm when it is vibrating at low frequencies.

5. The combination with a baffle box and a

loud speaker mounted in the baffle box of a substantially pure acoustic resistance material covering the normally open side of the box.

5 6. The combination with a baffle box and a loud speaker mounted in the baffle box of an acoustic resistance material covering the normally open side of the box the total resistance of the material being of the same order of
10 magnitude as the elastic reactance of the air in the box at 60 cycles.

7. The combination with an inertia type sound radiating diaphragm and means for driving the diaphragm of substantially pure
15 resistance damping means acoustically coupled to the diaphragm.

8. The combination with a sound radiating diaphragm, means for driving the diaphragm and means for baffling the air waves set up by
20 the opposite sides of the diaphragm of a membrane intercepting the waves from one side of the diaphragm and having apertures therein of such minuteness that the effect of the membrane on the waves is in the nature of
25 a substantially pure acoustic resistance.

9. The combination with a sound radiating diaphragm, means for driving the diaphragm and means for baffling the air waves set up by the opposite sides of the diaphragm of a
30 member intercepting the waves from one side of the diaphragm and having an acoustic resistance sufficient to confine not substantially less than one-third nor substantially more than one-half of the air displaced by one side
35 of the diaphragm for important sound frequencies.

In witness whereof, we hereunto subscribe our names this 5th day of March, 1930.

40 PAUL B. FLANDERS.
HENRY C. HARRISON.

45

50

55

60

65