Jan. 6, 1931. C. R. HANNA 1,788,103

LOUD SPEAKER

Filed June 22, 1927

Fig. 1.

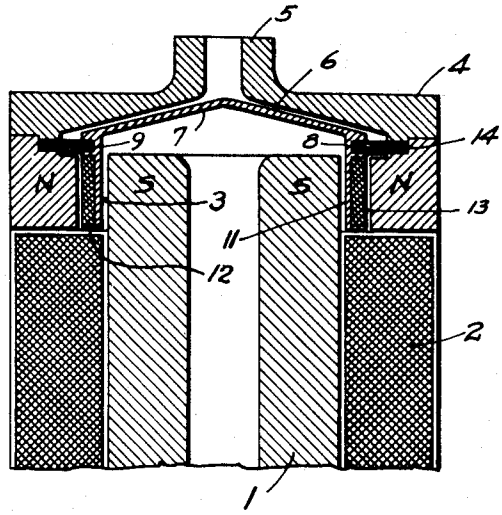


Fig. 2.

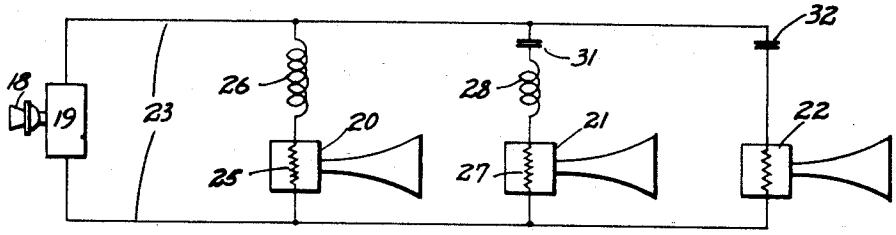
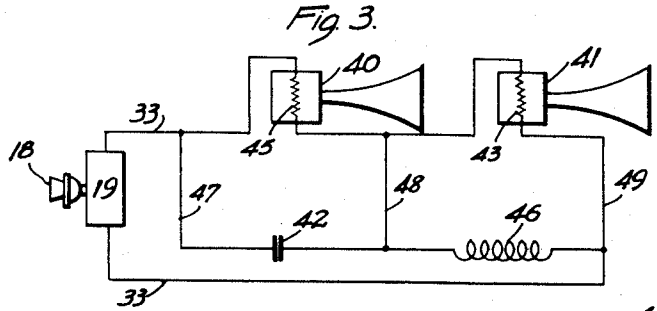


Fig. 3.



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UNITED STATES PATENT OFFICE

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LOUD-SPEAKER

Application filed June 22, 1927. Serial No. 200,546.

This invention relates to sound-reproducing devices and particularly to such devices intended for handling large amounts of power.

Sounds of low pitch are frequently sounds of large power. They are frequently produced by instruments in which the vibrating parts have large amplitude. For this reason, sounds from drums, from low-pitch organ pipes from tubes or bass horns and from similar sources have heretofore been unsatisfactorily represented by sound-reproducing devices of the moving-diaphragm type because a diaphragm cannot make an adequate excursion without striking some stationary part.

In the patent to Joseph Slepian and myself, No. 1,623,561, granted April 5, 1927, for an improvement in acoustic horn, rules for the design of loud speakers which will result in equalizing the response over a large range of frequency are given.

A horn designed according to the disclosure of the above-named patent and adapted for the radiation of very low notes is of great length. For the range of pitches usually covered, which does not extend much below 250 cycles per second, the directions to make the diaphragm-chamber of a height only a few times the amplitude of the maximum movement of the diaphragm were equivalent to requiring the chamber to be as small as it could conveniently be made.

When the formula for the volume of the diaphragm chamber given in said patent is applied to a loud speaker intended for sounds of low pitch and great power, either the upper frequency limit must be taken far below what has heretofore been the practice or there will not be good clearance for the diaphragm movement.

An instrument comprising a vibrating diaphragm and a horn usually requires a greater excursion of the diaphragm at low notes for the same power in the radiated sound. If the horn be of the exponential form, the radiated sound is the same for the same velocity of the diaphragm at all frequencies, from the cut-off frequency of the horn up to chamber causes the radiated sound to fall off perceptibly.

With instruments of this form, therefore, at low frequency, the amplitude will be large because, during the whole of a long half-period, the velocity is in one direction. At high frequency, the period is short and the amplitude, therefore, must be small. With other forms of horns, the excessive amplitude at low frequencies is even greater than this.

As pointed out in the above-mentioned patent, the consequence of making the diaphragm chamber larger than the formula there given indicates is a failure to efficiently reproduce sound of high frequency.

Moreover, a loud speaker designed with a small diaphragm chamber and intended to accommodate only small excursions of the diaphragm, ordinarily is adapted only for small power and, if large power is impressed on the input of such a loud speaker, the instrument will be damaged thereby.

If the production of sufficient power at low notes, with instruments as heretofore designed, be attempted, a too great amplitude will be produced and, even if the diaphragm does not actually strike against the walls of the diaphragm chamber, its movement will exceed that at which correct quality is obtained.

Heretofore, when it has been necessary to produce sound enough to fill a ball room or a large auditorium, it has been usual either to group a number of loud speakers together or to connect a number of separately-driven similar diaphragms to one horn by separate channels. The number of diaphragms for the latter method must be impractically large in order to afford sufficient power at low notes without excessive amplitude of diaphragm movement.

If, following the first of said two methods a plurality of instruments are operated together, the disadvantage just explained is still present. Moreover, for the low notes, the cut-off point of each horn must be low and that necessitates bulky horns. The plurality of large horns requires a larger space than is or-

It is an object of my invention to so modify the loud speaker described in the above-mentioned patent that it shall be particularly adapted to the reproduction of low notes. In order to accomplish this object, it is proposed herein to construct a loud speaker which will not be effective for notes above some 200 to 500 cycles per second.

It is a further object of my invention to devise an effective system for the reproduction of sound in which the loud speaker just mentioned shall be supplemented by a loud speaker that will satisfactorily reproduce the high notes.

It is a further object of my invention to so combine the loud speakers that the loud speaker adapted for the higher notes shall be protected from the heavy currents of low frequency which are necessary for the proper reproduction of the low notes.

It is a further object of my invention to provide a combination of loud speakers in a circuit, in which the several parts of the circuit shall be so designed that each loud speaker therein will be protected from all frequencies lower than those for which it is intended.

It is a further object of my invention to prevent any loud speaker in such a combination from diverting current of a frequency to which it is not responsive away from the loud speaker which is responsive thereto.

It is a further object of my invention to provide such a circuit in which the impedance shall be independent of the frequency.

Other objects of this invention and details of the construction will be apparent to those skilled in the art from the following specification and the accompanying drawing, in which

Figure 1 is a sectional view of a portion of a loud speaker particularly adapted for low notes,

Fig. 2 is a diagram of circuits and apparatus representing a system in which a plurality of loud speakers are used, and

Fig. 3 is a diagram illustrating a modification of the circuits which may be used.

In Fig. 1, the magnet 1 may be a permanent magnet or may be supplied with a winding 2 to constitute an electromagnet. Preferably, the magnet 1 is to produce a very powerful flux through an annular gap, as is indicated by the letters N and S on the two sides of the gap 3.

Upon the magnetic structure, a cap 4 is secured which has an opening 5 intended to be connected to the small end of a horn. The horn, as explained in the above-mentioned patent, should have the area of its cross-section increase with the distance from the throat 5, according to an exponential law. Below the orifice 5, the cap 4 provides a diaphragm chamber 6.

The diaphragm 7 has the shape of a cone. At the edge of the cone, the diaphragm is integral with a cylindrical skirt 8, including a heavy portion provided with a groove 9 and a thin portion 11 which is in the air gap. At the bottom of the portion 11, a flange 12 may be provided to cooperate with the heavy part 8 to form an annular channel, in which is located a coil 13.

The groove 9 receives the inner edge of a collar or annular member 14 of heavy rubber or other flexible material. The outer edge of the collar 14 is clamped between the cap 4 and the upper part of the magnet. The cap may be caused to compress the collar by any desired means.

In my invention, I associate with the throat 5 in Fig. 1, a horn having so small a rate of flare that the cut-off frequency is lower than 60 cycles per second. Such a horn is very bulky and it is, therefore, highly desirable that the results be obtained with only one such horn.

In order to radiate the power corresponding to a big organ, a band of some fifty pieces, or a chorus of several hundred voices, the sound delivered by the loud speaker should have a power of several watts. I have found, for example, that it is necessary to radiate 2½ watts in the form of sound in order to satisfactorily reproduce such sounds.

In order to exert as much power as this, it is necessary that the orifice 5 be small. Practical considerations of convenience in mounting render it inadvisable to make the diameter of the diaphragm 7 more than about four inches. Also, the practical limit of movement for the diaphragm, when mounted by the flexible strip 14, as shown, is about $\frac{1}{32}$ of an inch. From these considerations, I find that the diameter of the throat 5 should be about ½ inch.

From these dimensions, the volume of air which must flow into or out of the throat for each movement of the diaphragm is easily computed. At low frequencies the movement of the diaphragm is large and the volumetric displacement produced by said movement is a large fraction of the volume of the diaphragm chamber. Consequently, the pressure change in the chamber is large enough to effectually drive the air through the throat of the horn. The volumetric flow through the throat will, therefore, at low frequencies be substantially equal to the volumetric displacement by the diaphragm.

At high frequencies, the amplitude of the diaphragm movement is small and the volumetric displacement is a small fraction of the volume of the diaphragm chamber. The pressure in the chamber, therefore, changes by only a small amount and, consequently, will be more or less ineffective in driving the air through the throat. The volumetric flow through the throat thus becomes less than the volumetric displacement by the dia-

phragm at high frequencies and this causes the instrument to give out less response at higher frequency and at very high frequencies to give practically no response.

If the clearance between the diaphragm 7 and the walls of the diaphragm chamber 6 be only slightly greater than the $\frac{1}{32}$ of an inch mentioned, the movement of the diaphragm causes a large percentage change in the volume of the diaphragm chamber. If there is large clearance between the diaphragm and the walls of the diaphragm chamber, even at maximum displacement of the diaphragm, the movement of the diaphragm makes a smaller percentage change in the volume. Greater compression of the air will occur, therefore, when the clearance is smaller.

When the compression is more than very slight, the reaction against the diaphragm 7 by the compressed air follows a non-linear law, with the consequence that the radiated sound, instead of faithfully representing the movements of the diaphragm, will have certain extraneous frequencies. I have found that this difficulty may be avoided for frequencies below about 500 cycles per second by making the clearance between the diaphragm 7 and the walls of the chamber 6 about $\frac{1}{16}$ of an inch, that is to say, about twice the maximum amplitude of the movement of the diaphragm.

A structure, as described above, will have such damping characteristics that the greatest excursion of the diaphragm will be less than one half of the clearance afforded by the diaphragm chamber when the radiated power in watts is as great as one two-thousandth of the square of the frequency in cycles per second.

Because the damping is large, the mass of the vibrating system may be great without disadvantage. A large mass means ineffectiveness at high frequencies, but, because the clearance of the diaphragm chamber has been so chosen that high frequencies will not be reproduced effectively in the instrument, the choice of a large mass will sacrifice hardly anything which has not already been sacrificed. I have found it advantageous to make the combined mass of the diaphragm 6 and the coil 13 about ½ pound. Moreover, by making the diaphragm and skirt of aluminum, the proportion of the mass of the moving system which is in the coil is increased.

This weight is sufficient to enable me to make the coil of a conductor so long that the desired force may be developed by the interaction between said coil and the magnetic flux, and, at the same time, to make the conductor of ample cross-section, whereby the resistance of the device is readily brought within the limits indicated below.

The circumstance that the coil is attached to the diaphragm at its circumference, enables the coil to be made with a small radial thickness. The air gap may, therefore, be short. That the portion 11 of the skirt beside the coil 13 is thin not only is another reason why the gap may be short but has also the advantage that eddy currents are minimized.

In Fig. 2, three loud speakers 20, 21 and 22 are shown in parallel. The line 23, across which each of these loud speakers is connected, is supplied with signal-conveying current. This is indicated by the microphone 18 and amplifier 19. The loud speaker 20 is designed, as explained in connection with Fig. 1, for the production of low notes and will not readily produce notes above 250 or, at most 500 cycles per second. The cut-off frequency of the horn forming part of the loud speaker 20 is as low as the lowest frequency of the signal-conveying current. It may very well be below 30 cycles per second. In order to respond with proportionate power to this low frequency, the loud speaker 20 must possess inherent limitations which prevent it from effectively radiating frequencies above, at most, 500 cycles per second.

The loud speaker 21 is of an intermediate character. The horn associated with it should have a cut-off frequency well below the frequency at which the instrument 20 ceases to be effective. For example, the instrument 21 should be capable of effectively reproducing frequencies lower than 250 cycles per second. Because designed for sufficient power at those low frequencies, the instrument 21 must fail to give full power at very high frequencies.

The loud speaker 22 should be designed to reach frequencies of 5,000 or more cycles per second. The cut-off frequency of the horn forming part of the instrument 22 should be below the upper limit of the frequencies at which the instrument 21 is effective. The smaller horns used with the instruments 21 and 22 in Fig. 2 may be added to the large horn used with the instrument 20 without adding seriously to the bulkiness of the arrangement.

In the branch circuit including the instrument 20, a resistor 25 and an inductor 26 are shown. It is permissible to so design the instrument that the desired resistance and inductance are obtained without the addition of external inductance.

The branch circuit including the instrument 21 is provided with a resistor 27 and an inductor 28 which, likewise, may be provided by the electrical properties of the instrument itself. This branch of the circuit also includes a condenser 31 which is not a part of the instrument itself, but must be added to the branch circuit. The condenser 31 is of a suitable size to make the branch circuit including it of comparatively small

impedance to the medium frequencies, but the branch circuit is not tuned in the sense of having a well defined maximum of response at a particular frequency.

The resistor 27 is of sufficient magnitude to insure that the branch circuit will be nearly untuned. Very low frequencies, however, will not pass through this circuit because, for them, the condenser 31 acts as a blocking condenser.

In the branch circuit including the instrument 22, no inductance is represented. The instrument possesses a winding, and, therefore, will have some inductance, but by expedients well known in the art, and particularly by providing conductive plating upon the surfaces of the gap, as explained in connection with my Patent No. 1,691,243, dated Nov. 13, 1928, the inductance of this instrument may be made very small. A condenser 32 is placed in the branch of the circuit including the instrument 22 and acts as a means by which the higher frequencies are received through this circuit more readily than the lower frequencies.

The resistances R of the instruments 20 and 22 in Fig. 2 are preferably equal, and equal to

$$\sqrt{\frac{L}{3C}},$$

where L is the inductance of the inductor 26 and C is the capacity of the condenser 32. Also, the resistance 27 of the instrument 21 is made twice this magnitude. If then, the inductance of the inductor 28 is made

$$\frac{1}{2}L$$

and the capacity of the condenser 31 is made 2C, the impedance of the circuit 23 will be independent of the frequency.

If it is preferred to use two parallel branches in the circuit instead of three, the resistance of the two instruments should be made equal to each other and equal to

$$\sqrt{\frac{L}{C}}.$$

If this is done, the impedance of the two-branch circuit will be equal at all frequencies within the audio frequency range of reception

It is also possible to apply the advantages of this invention to a circuit in which the instruments are arranged not in parallel but in series. Such a circuit is illustrated in Fig. 3, in which the line 33 is supplied with signal-conveying current in any desired way. As in Fig. 2, this is indicated by means of a microphone 18 and an amplifier 19.

The instrument 40 is, in design, like the instrument 20 in Fig. 2. Its resistance is represented by the resistor 45, and, over its intended range of frequencies, its inductive reactance may be neglected.

The instrument 41 is designed like the instrument 22 in Fig. 2, and the resistor 43 represents the resistance of this instrument. The condenser 42, unlike the condenser 32 in Fig. 2, is in parallel with an instrument and the instrument is the low-frequency one.

A connection 47 and a connection 48 establish a closed circuit including the instrument 40 and the condenser 42. The connection 48 and a connection 49 establish a closed circuit including the instrument 41 and the inductor 46. The combination of the two closed circuits constitutes a connection across the line 33. The return conductor may be a part of the line itself, as illustrated, or it may be the usual ground connection.

It is possible, by making

$$R=\sqrt{\frac{L}{C}}$$

as before, to produce a circuit including two instruments which will have a constant impedance at varying frequencies and will, consequently, have the advantage which the circuit disclosed in Fig. 2 possesses. The overlapping of the frequency ranges provided for in the design of instruments 40 and 41 gives the advantages already explained in connection with Fig. 2, when Fig. 2 is supplied with only two instruments, as already discussed.

In the operation of the device, current which is modulated in accordance with sound is impressed upon the line 23. The microphone 18 and the apparatus represented by the rectangle at the right of the microphone are intended to indicate any kind of apparatus for producing such modulated current.

The low frequencies in the current in line 23 of Fig. 2 pass readily through the instrument 20. The high frequencies will not pass through the branch of the circuit including the instrument 20 because of the large inductance in this branch.

High frequencies pass more readily through the branch including the instrument 22 than lower frequencies because of the presence of the condenser 32. This condenser also serves to prevent this branch from acting as a shunt through which low-frequency currents may be diverted from the instrument 20. In the same way, the inductance in the branch circuit including the instrument 20 prevents this branch from shunting high-frequency energy from the instrument 22.

In the same way, but to a smaller degree, the branch including the instrument 21 conducts intermediate frequencies and is prevented from short circuiting either the low frequencies or the high frequencies.

The instrument 20 in the inductive branch responds to the very lowest frequencies and produces sound therefrom. At frequencies

above about 200 cycles per second, the response of the instrument 20 begins to fall off. The falling off is not abrupt, but gradual, and a considerable portion of the energy at frequencies up to 500 cycles is translated into sound by the instrument 20.

The intermediate instrument 21, or the high-frequency instrument, if there are but two, as a cut-off frequency so far below 500 cycles that it effectively supplements the instrument 20, at those frequencies for which the response from the instrument 20 is small. The higher frequencies to which the instrument 21 will respond extend well beyond the point of cut-off for the instrument 22.

The upper limit of frequencies to which the instrument 22 will respond is as high as the highest frequencies to which the system is intended to respond. In practice, it is usually sufficient if this limit is about 5,000 cycles. If only two instruments are used, the upper one must cover the range from well below 500 cycles to above said limit.

In this way, a faithful reproduction, both of the extremely low pitches and of the high pitches, is obtained without overloading any of the instruments. Moreover, since the combination of several instruments in parallel presents a constant impedance to the line 23, the load upon said line is independent of the frequency.

In the circuit illustrated in Fig. 3, low-frequency currents pass through the instrument 40 which is designed to produce sound effectively therefrom. High frequency currents are not substantially impeded by the instrument 40 because the condenser 42 acts as a short-circuit about the instrument 40 for them. Moreover, the inductance of the instrument 40, although presenting a negligible impedance to frequencies within the range of that instrument, offers considerable impedance to frequencies well above its intended range.

Similarly, the inductance 46 affords a short circuit about the instrument 41 for the low frequencies to which it is not responsive and a path of little impedance for the currents to which the instrument 40 responds. Thus, the current in each instrument to which that instrument is responsive follows mainly a path outside the other instrument.

In both Fig. 2 and Fig. 3, it is a consequence of the constant impedance of the circuit that, for those frequencies to which more than one instrument responds, the current so divides between the responsive instruments that no over emphasis of such frequencies results.

Many variations of this invention and many applications of it beside those specially stated herein will be apparent to those skilled in the art. I, therefore, do not wish the specific description to be construed as a limitation but I intend to be limited only by the prior art and by the claims.

I claim as my invention:

1. A loud speaker comprising a diaphragm chamber, a diaphragm constituting one wall thereof, means for moving the diaphragm and means for acoustically damping said diaphragm and radiating sound, the magnitude of said damping being so great that the greatest excursion of the diaphragm is less than one half the clearance afforded by the diaphragm chamber when the radiated power in watts is as great as one two-thousandth of the square of the frequency in cycles per second.

2. A loud speaker comprising a diaphragm chamber, a diaphragm constituting one wall thereof, means for moving the diaphragm and means including a horn communicating with said diaphragm chamber through an orifice for acoustically damping said diaphragm and radiating sound, the volume of said diaphragm being so great in comparison to the area of said orifice that the power of the radiated sound in watts at any frequency is greater than one two-thousandth of the square of said frequency when the excursion of said diaphragm is one-half the clearance afforded by the diaphragm chamber.

3. A high-power loud speaker comprising a diaphragm, means for acoustically damping said diaphragm and radiating the resulting sound, means for driving the diaphragm against said damping and a diaphragm chamber affording clearance between its walls and said diaphragm, the acoustic damping being sufficient to cause the power radiated as sound to exceed a half a watt when the driving means moves the diaphragm through one-half of said clearance at the lowest frequency for which the speaker is intended and the clearance being great enough to prevent efficient radiation above 1,000 cycles per second.

4. In a sound-producing instrument, a diaphragm, means for vibrating said diaphragm, a diaphragm chamber provided with an orifice through which air moves upon movement of the diaphragm and acoustic damping means associated with said orifice, the ratio of the area of the diaphragm to the area of said orifice being great enough to so limit the movement of the diaphragm at frequencies above 500 cycles that, at a given power, the volumetric displacement by diaphragm will be so small a fraction of the volume of the diaphragm chamber that the volumetric flow through said orifice will be substantially less than said volumetric displacement and said ratio being small enough to permit so great a movement of the diaphragm at frequencies below 250 cycles per second that, at the same power, the volumetric displacement of the diaphragm will be a sufficiently large fraction of the volume of the diaphragm chamber to cause the volumetric flow through said orifice to be substantially equal to said volumetric displacement.

5. In a loud speaker, a conical diaphragm, a coil support integral therewith, a magnetic circuit having an air gap in which said coil support is located and a coil on said coil support, the mass of said coil exceeding the mass of said diaphragm.

6. In a loud speaker, a conical diaphragm, a coil support integral therewith, a magnetic circuit having an air gap in which said coil support is located, a coil on said support, and an annular flexible member seated in an annular channel formed in said diaphragm for guiding and supporting said diaphragm against permanent displacement.

In testimony whereof, I have hereunto subscribed my name this 13th day of June, 1927.

CLINTON R. HANNA.