May 9, 1933.

L. G. BOSTWICK

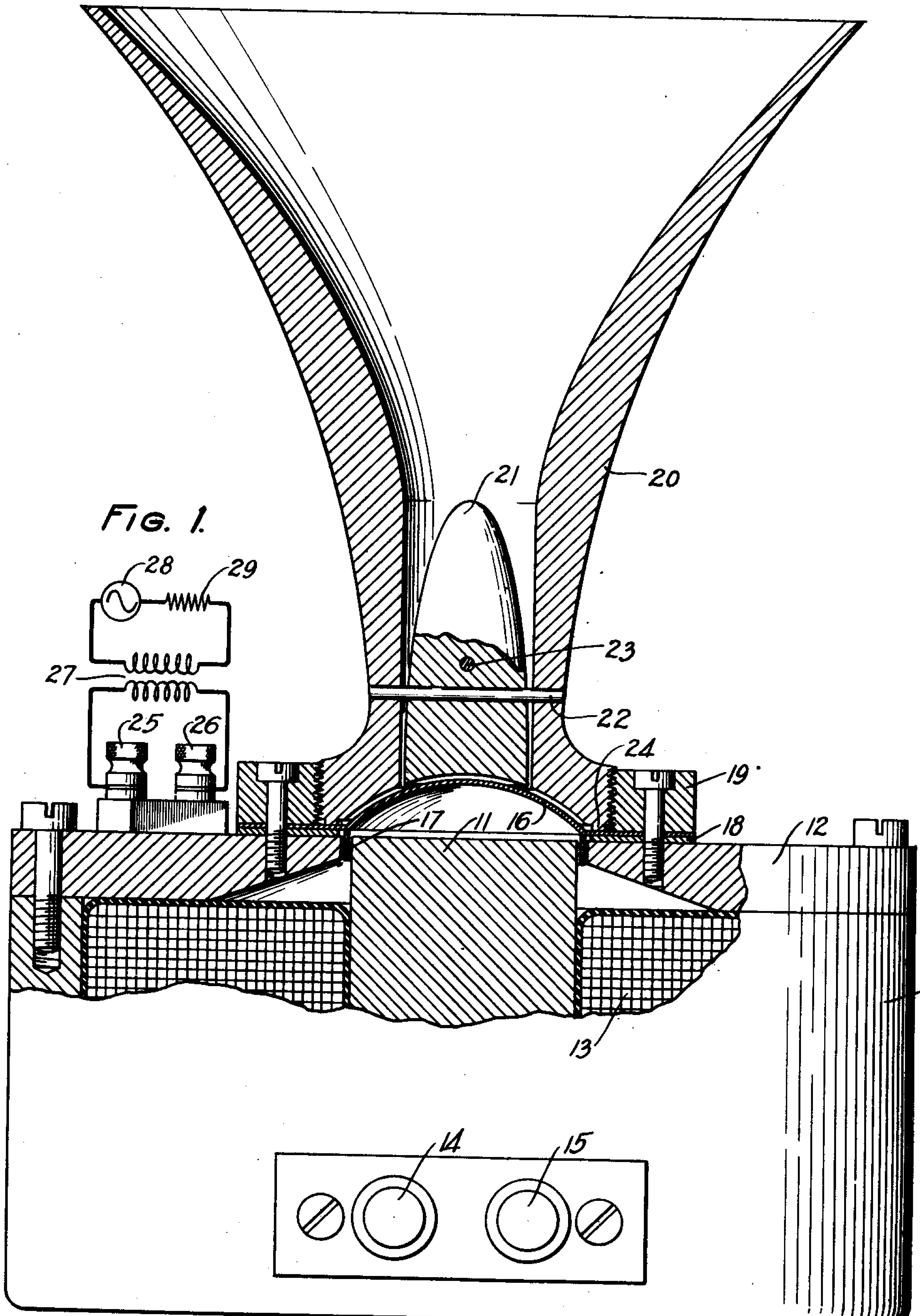
1,907,723

SOUND REPRODUCING DEVICE

Filed Sept. 28, 1929

3 Sheets-Sheet 1

FIG. 1.



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SOUND REPRODUCING DEVICE

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FIG. 6.

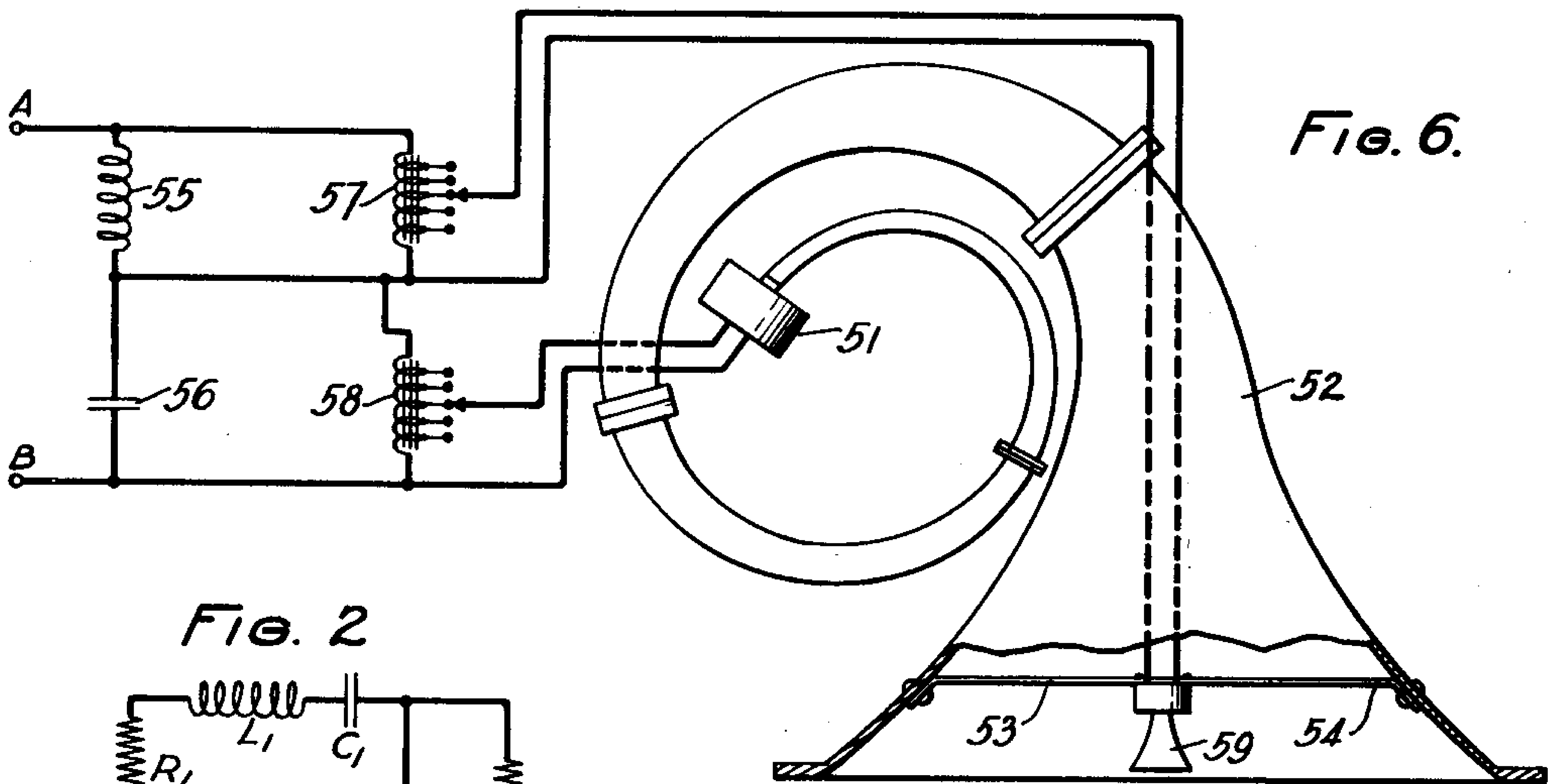

FIG. 2

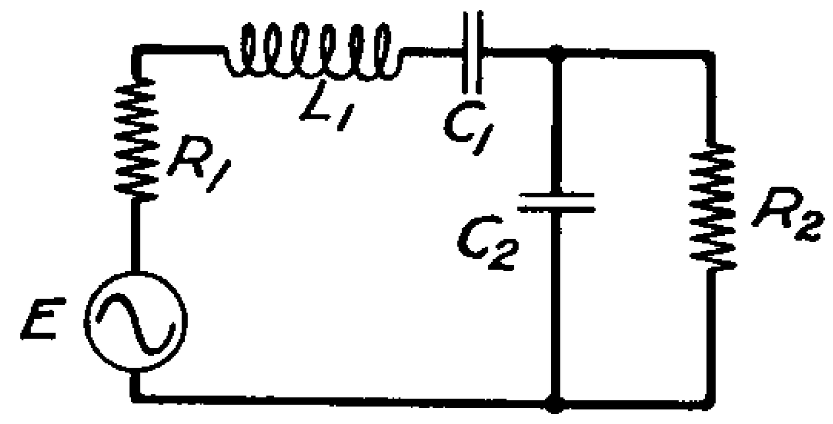

FIG. 3.

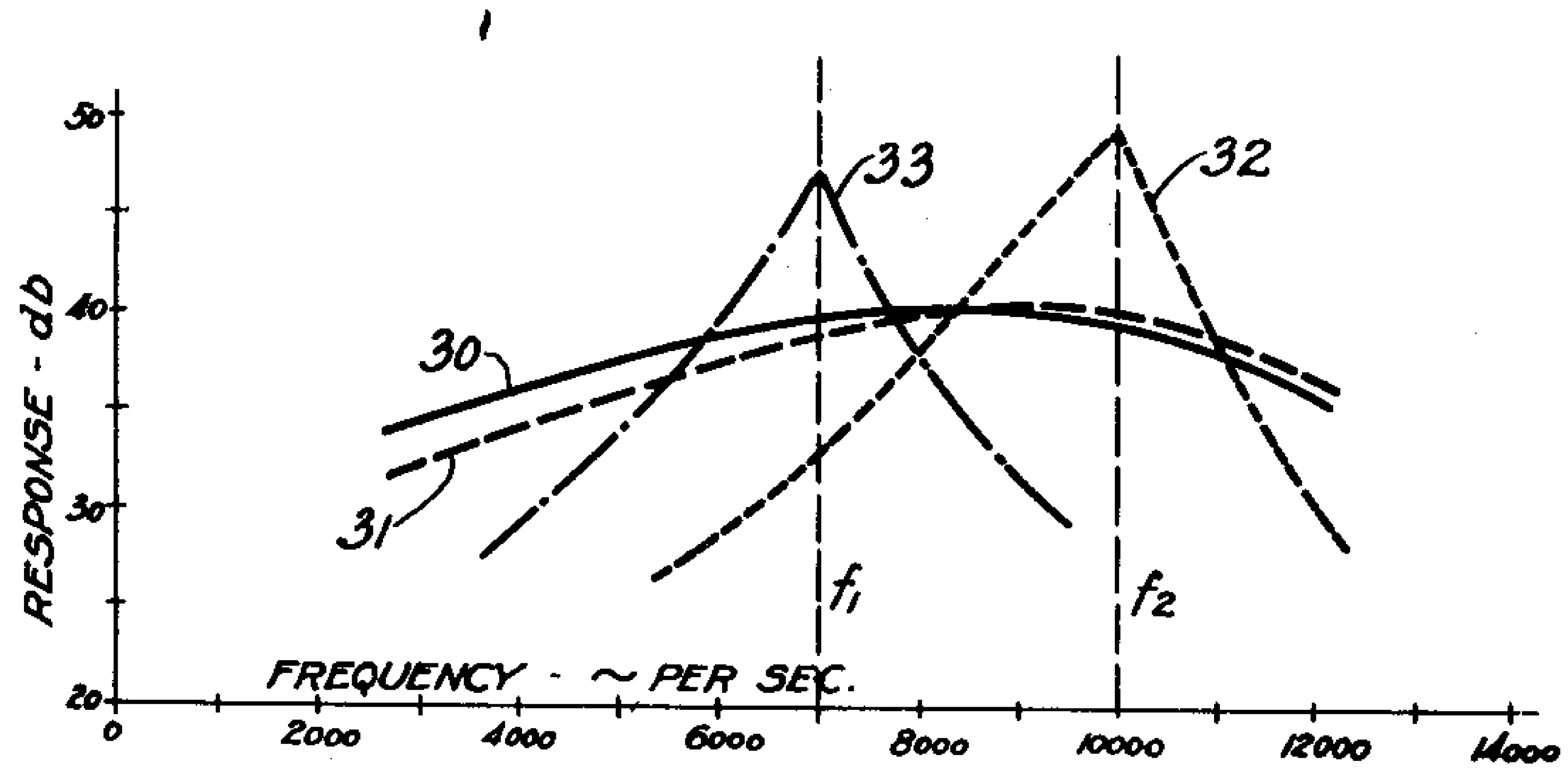

FIG. 7.

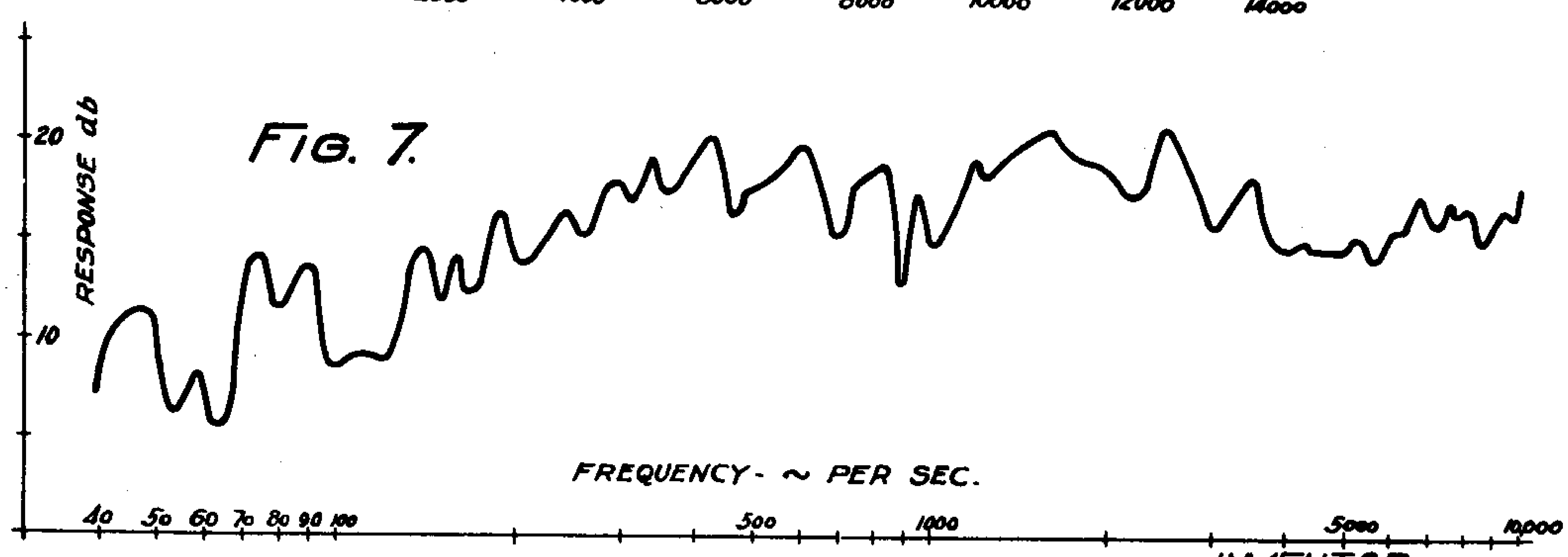

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FIG. 4.

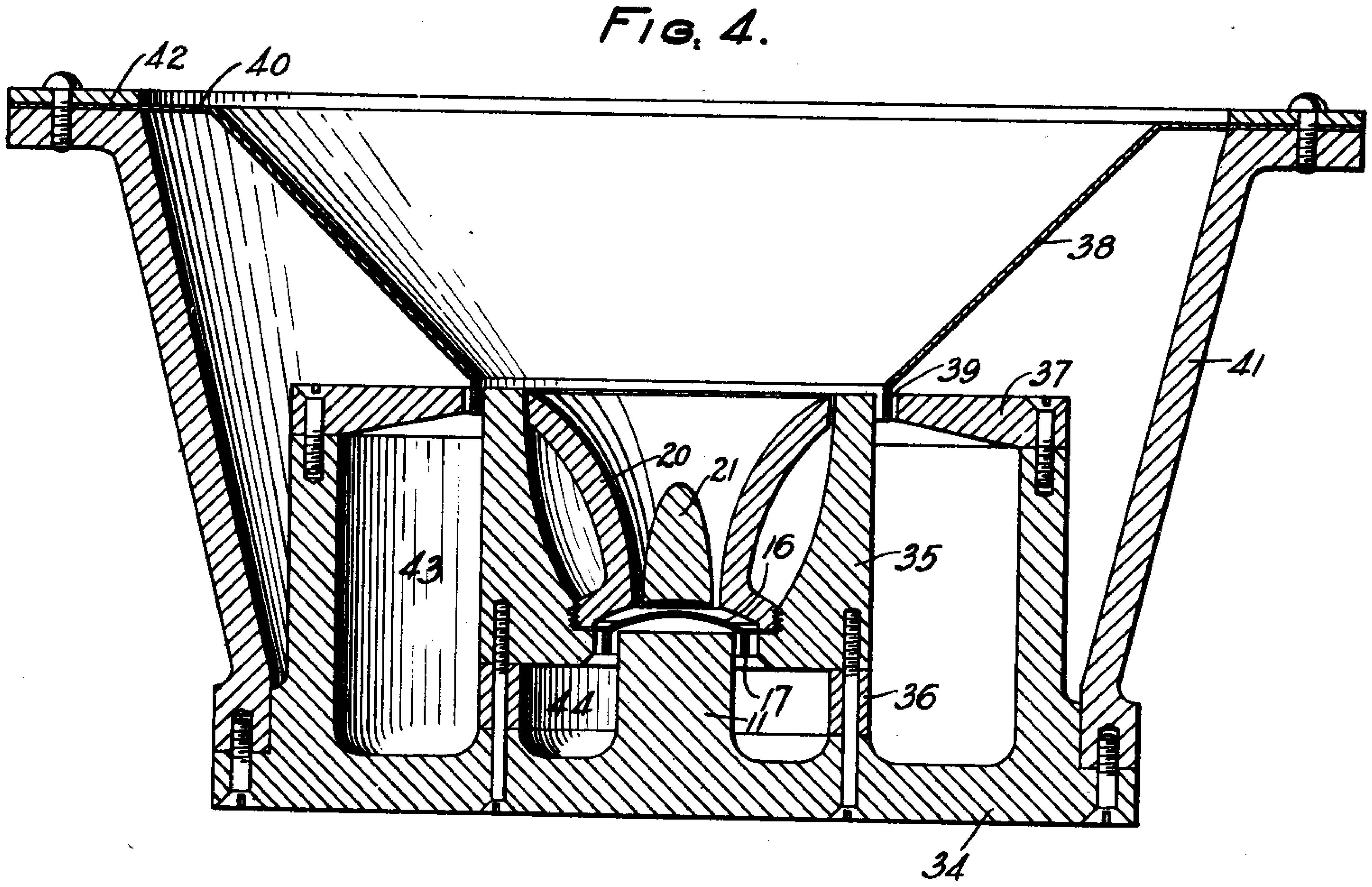
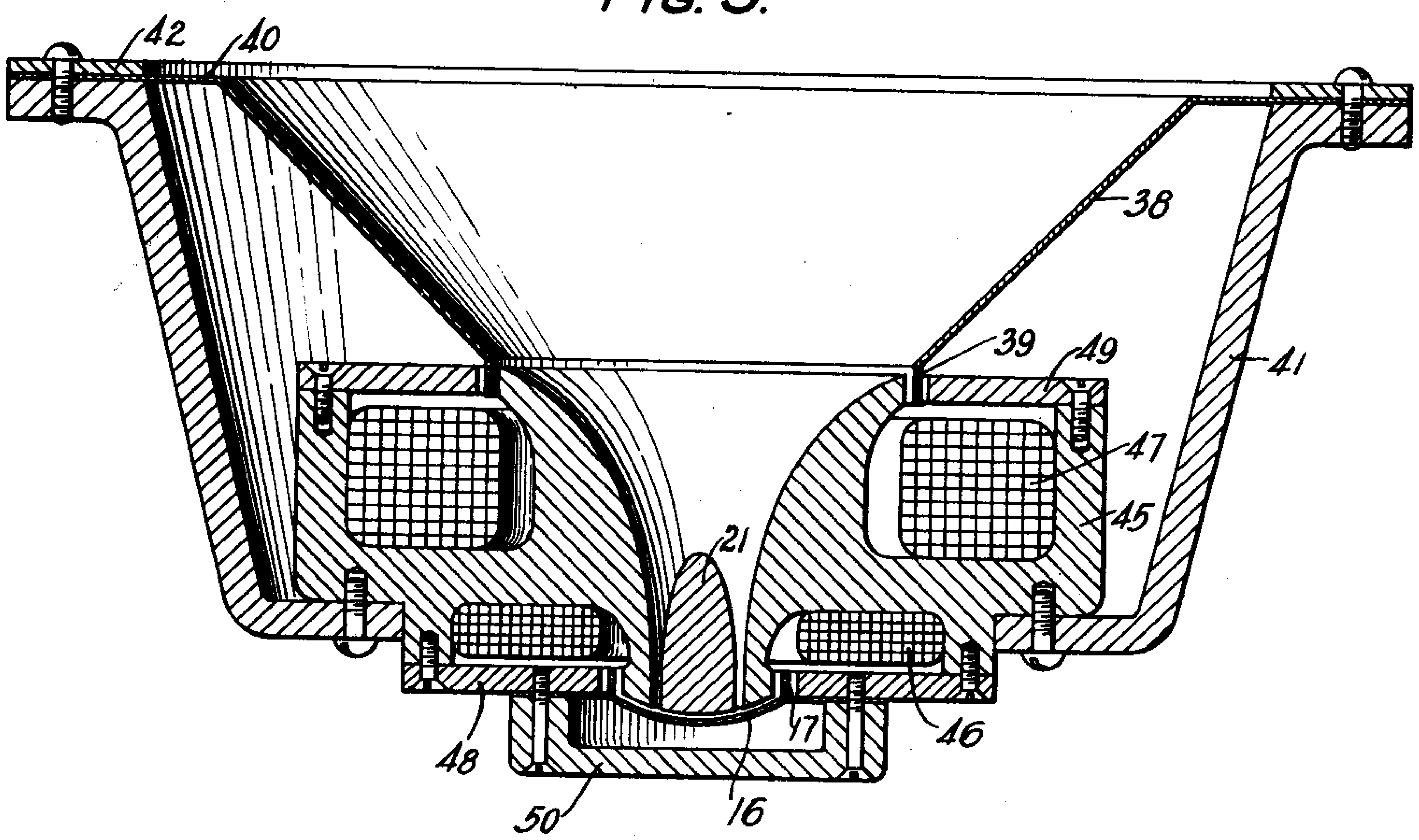


FIG. 5.



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Patented May 9, 1933

1,907,723

UNITED STATES PATENT OFFICE

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SOUND REPRODUCING DEVICE

Application filed September 28, 1929. Serial No. 395,802.

This invention relates to loud speaking telephone receivers and has for its principal object extending the range of efficient sound reproduction to include the highest frequencies of speech or music.

In order that high efficiency and uniformity in the response of a loud speaking receiver may be maintained at high frequencies it is necessary that the mass reactance of the radiating element, diaphragm or the like, should be small in comparison with the radiation resistance. The mass reactance does not itself absorb or dissipate the sound energy, but it acts to diminish the vibrational velocity and, in this way, to reduce the radiated energy to a low value in comparison with the loss in the source of vibratory force. It is for this reason that loud speakers of the type using a large free radiating diaphragm are in general low in efficiency, particularly at the higher frequencies of speech or music.

The use of an amplifying horn permits the vibrating system of a loud speaker to be made small and light and, hence, enables high efficiences to be achieved over a wide frequency range. However in this case there is necessarily interposed between the diaphragm and the horn an air chamber which acts as an elastic coupling element and which tends to absorb the high frequency vibrations before they reach the horn throat. To diminish this effect the air chamber volume may be reduced by reducing the chamber depth, but the extent to which improvement can be effected in this manner is limited by the consideration that the chamber must be deep enough to permit the free vibration of the diaphragm under the maximum power input.

Other factors tending to limit the frequency range of uniform response are, first, the tendency of a diaphragm to "break-up" at high frequencies, different parts vibrating in opposite phases, and, second, in the case of horn type speakers, the formation of stationary air waves in the air chamber when the wave length of the sound waves is shorter than the diaphragm diameter. These actions are productive of response irregularities having the character of resonance, certain frequencies being unduly amplified and other frequencies being almost completely suppressed.

Due to these limitations it has not been practicable to construct in a single unit a device capable of uniform response from the lowest frequencies of speech to a frequency greater than about 5000 cycles, whereas for faithful reproduction frequencies as high as 10000 cycles per second should be reproduced. The presence of this higher range gives the reproduced speech a very high degree of naturalness, the frequencies above 5000 cycles having the effect of removing the low pitched resonant quality which characterizes the reproduction of ordinary loud speakers.

In accordance with this invention a horn type loud speaking receiver is provided having a range of uniform response from a lower frequency less than 4000 cycles per second to an upper frequency greater than 10000 cycles per second. A feature of the invention relates to the diaphragm construction whereby the vibrating system has a very small mass and a very high elastic restraint, giving a resonance frequency greater than 5000 cycles per second, and at the same time is free from "breaking up" at any frequency below 1000 cycles per second. Other features relate to the design of the air chamber coupling the diaphragm to the horn whereby the range of uniform response is extended to above 10000 cycles per second, and to the proportioning of the electromagnetic driving elements to provide the optimum degree of damping for the diaphragm within the response range.

Since the high frequency reproducer of the invention is not responsive to low frequencies it is necessarily used in conjunction with a loud speaker adapted for the lower frequency range. The invention contemplates also improvements in the manner in which two speakers of different ranges are combined, particularly with respect to the mechanical features whereby the combination forms a unitary structure.

The invention will be more fully understood from the following detailed description and by reference to the accompanying drawings, of which

Fig. 1 shows in partial section one form of the high frequency reproducer of the invention;

Fig. 2 is a schematic impedance diagram representing the acoustic system of the device of Fig. 1;

Fig. 3 is a group of computed curves illustrating the operation of the device of Fig. 1;

Fig. 4 shows a combination loud speaker in accordance with the invention;

Fig. 5 shows a modified form of the combination of Fig. 4;

Fig. 6 shows an alternative method of combining the loud speaker of Fig. 1 with a low frequency reproducer; and

Fig. 7 shows a typical response characteristic of the combination device.

The sound reproducer of Fig. 1 is of the moving coil type, with magnetic field in which the coil moves being provided by means of an electromagnet. The magnet system comprises a hollow cylindrical casing 10, of high permeability steel or wrought iron, having a central cylindrical core 11 of the same material. The casing is closed in front by an annular face plate 12 of magnetic material, between the inner edge of which and the core 11 an annular air gap is formed. The inside of the casing is occupied by a magnetizing coil 13 the ends of which are brought out to terminals 14 and 15 on the side of the casing.

The vibrating system comprises a diaphragm 16 having a driving coil 17 rigidly attached, the ends of the coil being brought out to terminals 25 and 26 mounted on the face plate 12. The diaphragm, which for lightness is preferably made of thin aluminum alloy sheet, has a spherically embossed center portion and a flat edge, the diameter of the embossed portion being the same as the diameter of the magnetic air gap. The driving coil 17 is attached to the coil at the edge of the embossed portion. The diaphragm is held in position on the front of face plate 12 between a washer 18 and a clamping ring 19 and is accurately centered so that the coil moves freely in the air gap. The inside of ring 19 is threaded to receive the flanged end of a short exponential horn 20, the flange face being hollowed out to conform to the spherical form of the diaphragm. The outer edge of the flanged face is rabbeted to form a projecting ring 24 which serves to further clamp the diaphragm and also to space the horn at the proper distance therefrom. The throat of the horn 20 is enlarged to receive a plug element 21 which blocks the central part of the passage giving the throat opening the form of an annulus having a diameter slightly greater than half the diaphragm diameter. The plug is formed to maintain the exponential variation of the sound passage in the horn. The base of the plug is also formed to conform to the shape of the diaphragm. Crossed pins 22 and 23 serve to hold the plug 21 in its place.

The speech input circuit is connected to terminals 25 and 26 of the moving coil winding. An elementary form of circuit is shown in Fig. 2 comprising a wave source 28, the internal resistance of which is indicated by resistance 29, and a step-down transformer 27, the purpose of which is to match the impedance of the source to the impedance of the coil.

The design requirements of the system are most readily arrived at from a consideration of the impedances involved and the manner in which they react with each other. In accordance with the well known dynamical analogy between mechanical and electrical systems, the electrical circuit shown in Fig. 2 may be used to represent the vibrating system and its connected loads. Resistance R_2 corresponds to the acoustic impedance of the load due to the horn, capacity C_2 in shunt to R_2 corresponds to the reciprocal of the elasticity of the air chamber between the horn and the diaphragm, inductance L_1 and capacity C_1 correspond respectively to the mass of the diaphragm and coil and the reciprocal of the diaphragm edge elasticity, and R_1 to the mechanical damping resistance due to the electromagnetic coupling to the speech input circuit. The E. M. F. E of the source in series with R_1 corresponds to the driving force on the coil due to the current therein, the coil being assumed to be held stationary. If the coil and the supply circuit are substantially free from reactance, as is usually the case in well designed circuits, the driving force bears a constant ratio to the supply E. M. F. The current variations in the circuit of Fig. 2, assuming the E. M. F. E constant, therefore correspond to the velocity variations in the loud speaker vibrating system under a constant E. M. F. in the input circuit.

If the resistance R_2 is very low the maximum current and the maximum power therein occurs when L_1 and C_1 are in resonance and if R_2 is very high the maximum power occurs when L_1 is in resonance with capacities C_1 and C_2 in series. As the value of R_2 is varied the frequency of maximum power ranges between these limits, the resonance being less sharp for intermediate values of the resistance. The most uniform current characteristic is obtained when the resistances R_1 and R_2 are equal to the respective image impedances of the coupling network, L_1, C_1, C_2, at the mean of the two resonance frequencies. This condition gives rise to the relationships

$$R_1 = 2\pi(f_2 - f_1)L_1 \quad 1$$

and

$$R_2 = \frac{1}{2\pi f_2 C_2} = 2\pi f_2 L_1\left(1 - \frac{f_1^2}{f_2^2}\right) \quad 2$$

where f_1 is the resonance frequency of L_1 and C_1 and f_2 is the resonance frequency of L_1 with C_1 and C_2 in series.

For the mechanical system to which Fig. 2 corresponds, the resonance frequencies are given by

$$f_1=\frac{1}{2\pi}\sqrt{\frac{S_1}{m_1}} \quad 3$$

and

$$f_2=\frac{1}{2\pi}\sqrt{\frac{S_1+S_2}{m_1}} \quad 4$$

where S_1 is the edge elasticity of the diaphragm, S_2 the elasticity of the air chamber and m_1 the combined mass of the coil and diaphragm. The conditions for most uniform response, corresponding to Equations 1 and 2 are as follows:

$$R_d=2\pi(f_2-f_1)m_1 \quad 5$$

and

$$R_a=\frac{S_2}{2\pi f_2}=2\pi f_2 m_1\left(1-\frac{f_1^2}{f_2^2}\right) \quad 6$$

where R_d denotes the mechanical damping resistance due to the electrical circuits of the driving coil, and R_a is the acoustic load impedance on the diaphragm. Equation 6 states that the acoustic load should equal the stiffness reactance of the air chamber at the upper resonance frequency or the effective mass reactance of the diaphragm at the same frequency.

The value of R_d depends on the force factor of the moving coil, that is the mechanical force thereon due to unit current in the coil, and on the resistance of the complete electrical circuit. The value of the force factor is equal to the product of the flux density in the air gap and the length of conductor in the coil. In c. g. s. units it is given by

$$M=Bl \quad 7$$

where

M denotes the force factor,
B the flux density, and
l the conductor length.

If the coil is connected to a wave source of E. M. F. E_o and resistance R_o through a step down transformer having an impedance ratio φ^2, the total resistance of the input circuit is equal to

$$R_c+\frac{R_o}{\varphi^2} \quad 8$$

where R_c is the coil resistance. The value of the mechanical damping resistance R_d corresponding to this is given by

$$R_d=\frac{M^2}{\left(R_c+\frac{R_o}{\varphi^2}\right)} \text{ c. g. s.} \quad 9$$

The driving force on the coil is qual to the input current multiplied by the force factor and for the type of input circuit described above is given by

$$F=\frac{E_o M}{\varphi\left(R_c+\frac{R_o}{\varphi^2}\right)} \text{ c. g. s.} \quad 10$$

where F denotes the driving force. From Equation 10 it follows that the driving force for a given supply voltage is a maximum when the transformer ratio is such that

$$R_c=\frac{R_o}{\varphi^2} \quad 11$$

The total resistance of the input circuit being equal to $2R_c$. In general the maximum driving force is obtained when the impedance of the electrical source is matched to the coil resistance.

If the conditions of maximum driving force and greatest uniformity of response be combined the following equation is obtained in place of Equation 5

$$\frac{M^2}{R_c}=4\pi(f_2-f_1)m_1 \quad 12$$

or

$$f_2-f_1=\frac{M^2}{4\pi R_c m_1} \quad 13$$

The quantity

$$\frac{M^2}{R_c}$$

on the left of Equation 12 is the maximum damping resistance that can be introduced by the electrical circuit. It represents the value when the coil terminals are short circuited and is twice as great as the value obtained when the wave source impedance is matched to the coil resistance. The mass m_1 is made up of two parts, the coil mass, m_c, and the diaphragm mass, m_d. Further, the coil may be so wound that its mass is almost entirely that of the metallic conductor. Equation 13 may therefore be written as

$$f_2-f_1=\frac{M^2}{4\pi R_c m_c\left(1+\frac{m_d}{m_c}\right)}$$

which, if R_c, m_c, and M, are expressed in terms of the conductor dimensions, becomes

$$f_2-f_1=\frac{B^2}{4\pi\sigma\rho\left(1+\frac{m_d}{m_c}\right)} \quad 14$$

where σ and ρ are respectively the specific resistance and the density of the coil conductor.

Equation 14 determines how the mass of the moving system should be divided between the coil and the diaphragm to meet the requirements of maximum driving force and maximum uniformity between two given values of the resonance frequencies f_1 and

f_2. It also indicates that the range of uniform response may be widened by using the material for the coil having the smallest value of the product $\sigma\rho$, and by making the diaphragm as light as possible in comparison with the coil.

Equations 3 to 6 inclusive and Equation 14 set forth the essential relationships that should be fulfilled in the design of an efficient reproducer. The determination of an actual design, however, requires that other factors be taken into account, as is illustrated by the following numerical example.

Let the resonance frequencies f_1 and f_2 be set at 7000 and 10000 c. p. s. respectively. This will give a range of 3000 c. p. s. within which the response is substantially uniform and, since the response falls off slowly with decreasing frequency, will permit frequencies down to about 3500 c. p. s. to be reproduced without serious diminution. The free diameter of the diaphragm is determined by the consideration that the response shall not be diminished by wave interference effects in the air chamber at the highest frequency to be reproduced. When the horn throat opening is an annulus of diameter slightly greater than half the diaphragm diameter the wave interference effects will not be noticeable so long as the diaphragm diameter does not exceed the wave length at the highest frequency to be reproduced. On this basis the diameter of the diaphragm to operate at a maximum frequency of 1000 c. p. 's. should not exceed 3.0 cm. A suitable value may be taken as 2.8 cm. It has been found that a diaphragm of this diameter can be made from metal sheet, preferably aluminum alloy, .0025 cm. thick, rigidity being obtained by spherically embossing the central portion to a height of about .65 cm. The effective mass of a diaphragm of these dimensions is about .055 gram. The coil winding is preferably made of aluminum since the product of the density and the resistivity for this metal is about the smallest obtainable. Assuming a density of 2.8 and a resistivity of 2600 c. g. s. and, further, assuming that a flux density of 20000 lines per square centimeter can be maintained in the air gap, Equation 14 gives the ratio of the diaphragm mass to the coil mass as

$$\frac{m_d}{m_c}=.45$$

from which

$$m_c=0.12 \text{ gram}$$

and the total mass of the moving system is

$$m_1=0.175 \text{ gram}.$$

The values of the air chamber elasticity S_2 and the diaphragm edge elasticity S_1 follow from Equations 3 and 4; they are

$$S_1=340\times10^6 \text{ c. g. s.}$$

and

$$S_2=355\times10^6 \text{ c. g. s.}$$

The air chamber elasticity in terms of its dimentions is

$$S_2=\frac{1.4\times10^6 A_d^2}{V}$$

where A_d is the diaphragm area, and V the air chamber volume. For a diaphragm diameter of 2.8 cm. the area is 6.1 square centimeters. Substituting this in the above equations gives

$$V=.147 \text{ c. c.}$$

corresponding to a chamber depth of .0245 cm. or about .01 inch.

The edge elasticity, 340×10^6, is very high for a diaphragm made of material as thin as .0025 cm., but it has been found possible to obtain this value by reducing the flat portion around the embossed center to a very narrow ring, approximately .125 cm. wide, the embossed center being 2.55 cm. diameter. An advantageous result of this construction is that the rigid portion takes up practically all of the diaphragm area so that a true piston action is obtained. Moreover, by making the driving coil of the same diameter as the embossed portion and attaching it at the edge thereof, a drive is obtained which has no tendency to cause the diaphragm to "break-up" within the operating range of frequencies. The acoustic load impedance that the horn must furnish is found from Equation 6 to be

$$R_a=5650 \text{ c. g. s.}$$

In terms of the diaphragm and horn throat dimensions the load impedance is given by

$$R_a=\frac{41A_d^2}{A_h}$$

A_h being the area of the throat opening. Using the values already obtained for A_d and R_a, the throat area is found to be

$$A_h=0.275 \text{ sq. cm.}$$

For minimum wave interference in the air chamber the annular throat opening should have a diameter about 62 per cent of the diaphragm diameter, or 1.8 cm. Using this value the radial width of the opening is .05 cm.

The horn, since it does not have to radiate frequencies lower than 3000 c. p. s., may be of very small size. Preferably it is of the exponential type having a rather rapid flare corresponding to a cut-off frequency about 2000 c. p. s. and having a mouth opening from 5 to 7.5 cm. in diameter. The length of the horn need not exceed 7.5 cm. and may be as small as 6 cm.

The driving coil design is determined primarily by the requirement that the mechanical damping resistance R_d shall have the value required by Equation 5. With a matched impedance input circuit the damping resistance is

$$R_d=\frac{M^2}{2R_e}$$

or, in terms of the wire dimensions

$$R_d=\frac{B^2al}{2\sigma} \quad 15$$

From Equation 5 the required numerical value of R_d is found to be 3300 c. g. s. From Equation 15, assuming a flux density of 20,000 and a resistivity of 2600 c. g. s. the required conductor volume is found to be

$$al=0.043 \text{ c. c.}$$

The damping resistance is independent of the number of turns in the driving coil so long as the conductor volume is unchanged. The coil may therefore comprise a single conductor 2.55 cm. diameter, of axial length .25 cm., and radial thickness .023 cm. It is preferable, however, that the electrical resistance of the coil should be made high in order that the resistances of the conducting leads may be negligibly small and also to facilitate impedance matching. The preferred construction consists therefore of about 50 turns of flat ribbon conductor .023 cm. wide and .005 cm. thick wound with the ribbon lying flat in the plane of the coil. The turns may be held together with a suitable lacquer which also serves as an insulating covering. With this construction the insulation occupies a negligibly small space and does not noticeably increase the coil weight. With a coil thickness of .023 cm. a magnetic air gap .065 cm. wide has been found to provide ample clearance. The short air gap at the same time permits the flux density of 20000 to be easily obtained.

The computed response of a reproducer constructed in the above manner is shown by the curves of Fig. 3. The abscissæ of the curves are proportional to frequency and the ordinates to the logarithm of the pressure at a point in front of the reproducer for a given input voltage. The scale of the ordinates is in decibels, the zero being aribitrary. Curve 30 represents the response when the impedances are matched in the manner described. Curve 32 represents the response if the acoustic load impedance is very greatly increased and curve 33 the response with a very low acoustic load. The peak of curve 32 occurs at 10000 c. p. s., the upper resonance frequency, and the peak of curve 33 occurs at the natural period of the diaphragm. It may be desirable to favor somewhat the upper frequencies of the range and this can be done to a limited extent without noticeably diminishing the response at lower frequencies by increasing the acoustic load impedance slightly. Curve 31 shows the effect of raising the load impedance from 5600 c. g. s. to 8000 c. g. s. This change was effected in a device made to the foregoing dimensions by reducing the horn throat area by 30 per cent, the diameter of the annular opening being reduced from 1.8 cm. to 1.3 cm. and the width being maintained at .05 cm.

A combination reproducer in accordance with the invention is shown in section in Fig. 4. In this device a high frequency receiver of the general construction discussed above is combined with a coil driven loud speaker having a free radiating diaphragm of sufficient size for the reproduction of low frequencies. A single electromagnet provides the magnetic fields for the coils of both receivers.

The magnet system comprises a cylindrical casing 34 having a central core 11, as in Fig. 1, around which is the air gap for the coil 17, of the high frequency receiver. The air gap is formed between the core 11 and an inwardly projecting flange at the lower end of a cylindrical pole piece 35 which is supported on the base of the casing 34 by a non-magnetic spacing ring 36. Surrounding the upper end of the cylindrical member 35 is an annular face plate 37 which closes the front of the casing leaving an air gap for the coil of the low frequency receiver. The diaphragm 16 of the high frequency receiver is supported by the member 35, the upper side of the flange of this member being rabbeted and threaded to receive the end of the horn 20, which serves as a clamping means as in the device of Fig. 1. The horn fits snugly inside the cylinder 35 as shown in the drawings, the mouth of the horn coming level with the top of the magnet structure.

The low frequency receiver comprises a truncated conical diaphragm 38, and a moving coil 39, attached to the diaphragm at the edge of the central opening and centered in the gap between elements 37 and 35. The diaphragm is supported at its outer edge from a rigid conical casing 41, which also carries the magnet system, by means of a flat flexible rim 40 held at its outer edge by clamping ring 42. The magnetizing winding, not shown, occupies the space 43, between the casing 34 and the cylindrical member 35. If necessary an additional winding may be placed in the space between the central core 11 and the non-magnetic ring 36.

A feature of this structure is that the relative values of the flux densities may be varied to equalize the responses of the two devices. Ordinarily, due to its smaller area the air gap for the high frequency receiver will have the greater density, but some of the flux tends to follow the leakage path between the base of the cylinder 35 and the base of the casing 34. By changing the clearance between these parts the amount of the leakage can be controlled and the flux densities adjusted to suitable relative values. Alternatively the spacing ring 36 may be made of steel or iron so that it also forms part of the magnetic circuit. In this case separate exciting windings are required for the two air gaps, that for the inner gap being placed in the space surrounding core 11 and preferably being so poled that its magneto motive force opposes that of the main winding in the ring 36.

A modification of the foregoing structure, in which the high frequency horn is formed directly in the field magnet structure, is shown in Fig. 5. The magnetic circuit comprises a webbed casing 45 having a central core with a flaring opening therethrough to form the high frequency horn. The casing is provided with two recesses, one below and one above the web, for the accommodation of magnetizing windings 46 and 47. These recesses are closed by annular face plates 48 and 49, leaving air gaps around the central core for the two moving coils. The moving coil 39 of the free diaphragm 38 is located in the air gap surrounding the mouth of the horn and the moving coil 17 of the high frequency speaker is located in the air gap surrounding the horn throat. In this device the high frequency diaphragm and coil combination is turned upside down as compared with Figs. 1 and 3, the base of the horn structure being given a convex form to provide the necessary air gap dimension. An enclosing cover 50 protects the high frequency diaphragm and serves as a clamping means therefor.

In the design of the free radiating diaphragm and coil combination it is desirable that the mechanical damping resistance due to the electromagnetic coupling with the driving coil circuit should be large enough to render the motion of the diaphragm aperiodic. The moving system constitutes a simple resonant combination involving only the diaphragm mass and the elasticity of its support, the latter being so small that the resonance frequency is usually well below 200 cycles per second. The acoustic load is too small to give the desired damping which must therefore be provided by the electromagnetic coupling. Since the mass of the coil in devices of this type is small in comparison with the mass of the diaphragm, the coil may with advantage be wound with copper conductor thereby making very large damping resistances possible.

Fig. 6 shows the combination of a loud speaker of the type shown in Fig. 1 with another horn type speaker adapted particularly for low frequency reproduction. The low frequency speaker comprises a receiver 51 of the moving coil type disclosed in U. S. Patent to E. C. Wente No. 1,707,545 issued April 2, 1929, and a large exponential horn 52. The high frequency receiver 59 is mounted centrally in the mouth of the horn by means of metal strips 53 and 54. The figure also shows a suitable form of input circuit whereby each speaker is furnished with frequencies corresponding to its own particular range, and whereby a constant resistance load on the wave source is maintained. This circuit comprises an inductance 55 and a capacity 56 connected in series between two terminals A and B to which the wave source is connected. The high frequency speaker is connected to the ends of inductance 55 through a high impedance auto transformer 57 and the low frequency speaker is similarly connected to the terminals of capacity 56 through an auto transformer 58. Both auto transformers are provided with secondary taps, the receiver leads being connected at a suitable point to secure impedance matching between the moving coil and the source impedances. The total load impedance connected to the source thus comprises the resistance of the high frequency speaker coil shunted by inductance 55 in series with the parallel combination of the low frequency speaker coil and capacity 56. When the impedances are matched this combination gives a constant resistance load. At low frequencies practically all of the power goes to the low frequency speaker and at high frequencies the power goes to the high frequency speaker. There is no sharp frequency discrimination; the power in the one receiver increases gradually as the power in the other receiver falls, the two being equal at the resonance frequency of the inductance and capacity combination. This resonance frequency should correspond to the dividing frequency of the operating ranges of the speakers themselves, or, if the ranges overlap, to the central frequency of the overlapping range.

A measured response characteristic of a combination loud speaker in accordance with the invention is shown in Fig. 7. The range extends from 40 c. p. s. to 10000 c. p. s. with only slight irregularities such as are scarcely perceptible to the ear.

What is claimed is:

1. A sound reproducer comprising a diaphragm having a fundamental resonance frequency, due to its mass and edge elasticity, above 3000 cycles per second, an air chamber enclosing said diaphragm, and a horn having an operating range above 3000 cycles per second and having its small end opening into said air chamber, the opening of said horn being small enough to provide an acoustic load resistance for the diaphragm substantially equal to the effective mass reactance of the diaphragm at a frequency greater than 6000 cycles per second, and the volume of said air chamber being small enough to provide a

stiffness reactance substantially equal to the load resistance of the horn at the same frequency.

2. A sound reproducer comprising a diaphragm, an air chamber enclosing said diaphragm, and a horn having an operating range above 3000 cycles per second and having its small end opening into said air chamber, said diaphragm having a fundamental resonance frequency, due to its mass and edge elasticity, above 3000 cycles per second, and the volume of said air chamber being so small that its elastic reactance is equal to the effective mass reactance of the diaphragm at a frequency at least 2000 cycles per second above the fundamental resonance frequency of the diaphragm.

3. A sound reproducer comprising a diaphragm, an air chamber enclosing said diaphragm, and a horn having an operating range above 3000 cycles per second and having its small end opening into said air chamber, said diaphragm having a fundamental resonance frequency, due to its mass and edge elasticity, above 3000 cycles per second, and the volume of said air chamber being so small that its elasticity is at least as great as the edge elasticity of the diaphragm.

4. A sound reproducer comprising a diaphragm, a horn having an operating range above 3000 cycles per second, and an air chamber between the small end of said horn and said diaphragm, the mass and the edge elasticity of said diaphragm and the elasticity of said air chamber being such that the combination of the diaphragm and the air chamber has a fundamental resonance frequency greater than 8000 cycles per second and that the fundamental resonance frequency of the diaphragm alone is at least 2000 cycles per second lower than the resonance frequency of the said combination.

5. A sound reproducer in accordance with claim 4 in which the opening of the small end of the horn into the air chamber is small enough to provide an acoustic load on the diaphragm substantially equal to the effective mass reactance of the diaphragm at the resonance frequency of the diaphragm and air chamber combination.

6. A telephone receiver comprising a diaphragm and electromagnetic driving means therefor including a coil adapted to receive speech frequency currents and magnetic means for producing a force on said diaphragm in response to currents in said coil, said diaphragm having a fundamental resonance frequency greater than 3000 cycles per second and said driving means having a force factor M, representing the driving force in dynes per c. g. s. unit of current in said coil, such that the damping resistance

$$\frac{M^2}{R_c}$$

is greater than 25000 times the mass of the diaphragm in grams, R_c being the driving coil resistance in c. g. s. units.

7. A loud speaking telephone receiver comprising a diaphragm, electromagnetic driving means therefor including a coil adapted to be energized by speech frequency currents, a horn, and an air chamber between the small end of said horn and said diaphragm, said diaphragm having a fundamental resonance frequency greater than 3000 cycles per second and having in combination with said air chamber a fundamental resonance frequency greater than 8000 cycles per second, and said driving means having a force factor M, representing the driving force in dynes per c. g. s. unit of current in said coil, such that the damping resistance

$$\frac{M^2}{R_c}$$

is substantially equal to the product of the diaphragm mass in grams and 4π times the difference of the said two resonance frequencies, R_c being the resistance of the driving coil in c. g. s. units.

8. A loud speaking telephone receiver comprising a diaphragm, electromagnetic driving means therefor including a driving coil rigidly attached to the diaphragm, a horn, and an air chamber between said horn and said diaphragm, said diaphragm having a fundamental resonance frequency greater than 5000 cycles per second and having in combination with said air chamber a fundamental resonance frequency greater than 8000 cycles per second, and the conductor mass of said coil bearing a ratio to the combined mass of the coil and diaphragm equal to the ratio of the difference of said resonance frequencies to 4400.

9. A sound reproducer in accordance with claim 8 in which the coil mass is less than 0.2 gram.

10. A sound reproducer in accordance with claim 8 in which the combined mass of the coil and diaphragm is less than 0.25 gram.

11. A sound reproducer in accordance with claim 1 in which the horn has an exponential variation of its cross sectional area with distance along its axis, the rate of taper being great enough to give a cut-off frequency greater than 1000 cycles per second and the throat opening having an area of less than one twentieth of a square inch.

12. A sound reproducing system comprising in combination a loud speaking receiver having a diaphragm, a horn amplifier, and an air chamber between the horn and the diaphragm, said diaphragm and air chamber having a fundamental resonance frequency greater than 6000 cycles per second, and a second loud speaking receiver having a diaphragm resonant at a fundamental fre-

quency substantially below 3000 cycles per second, the horn opening of said first loud speaker being located centrally of the radiating surface of said second loud speaker.

13. A sound reproducing system comprising in combination a loud speaking receiver having a diaphragm and a horn amplifier and a second loud speaking receiver having a free radiating diaphragm, the diaphragm of said second receiver having a central opening substantially equal to the opening of the horn mouth of said first receiver and being located circumferentially around the mouth of said horn.

14. In combination a moving coil loud speaker having a horn radiator, a second moving coil loud speaker having a free radiating diaphragm, and a common field magnet system for the moving coils of both of said loud speakers.

15. In combination, a loud speaking receiver having a diaphragm and a horn radiator, and a second loud speaker comprising a diaphragm, a driving coil mounted on said last recited diaphragm, and a cylindrical shell type magnet providing a magnetic field for said driving coil, said magnet having a hollow central core the interior wall of which is formed to provide the horn for said first loud speaker.

16. A sound reproducing system in accordance with claim 15 in which the diaphragm of the second loud speaker is a free radiating cone having a central opening and is mounted circumferentially of the horn opening of the first loud speaker.

17. In combination, a loud speaking receiver having a diaphragm and a horn radiator, and a second loud speaking receiver comprising a free radiating diaphragm, a driving coil mounted on said free radiating diaphragm, and a cylindrical shell type magnet providing a magnetic field for said coil, the horn of said first loud speaker being located centrally and coaxially within said magnet and said free radiating diaphragm having a central opening substantially coinciding with the horn mouth.

In witness whereof, I hereunto subscribe my name this 27th day of September 1929.

LEE G. BOSTWICK.

DISCLAIMER

1,907,723.—*Lee G. Bostwick*, East Orange, N. J. SOUND REPRODUCING DEVICE. Patent dated May 9, 1933. Disclaimer filed March 28, 1934, by the assignee, *Bell Telephone Laboratories, Incorporated.*

Hereby enters this disclaimer to the subject matter of the said claims of said Letters Patent which are in the following words, to wit:

"13. A sound reproducing system comprising in combination a loud speaking receiver having a diaphragm and a horn amplifier and a second loud speaking receiver having a free radiating diaphragm, the diaphragm of said second receiver having a central opening substantially equal to the opening of the horn mouth of said first receiver and being located circumferentially around the mouth of said horn.

"14. In combination a moving coil loud speaker having a horn radiator, a second moving coil loud speaker having a free radiating diaphragm, and a common field magnet system for the moving coils of both of said loud speakers.

"15. In combination, a loud speaking receiver having a diaphragm and a horn radiator, and a second loud speaker comprising a diaphragm, a driving coil mounted on said last recited diaphragm, and a cylindrical shell type magnet providing a magnetic field for said driving coil, said magnet having a hollow central core the interior wall of which is formed to provide the horn for said first loud speaker.

"16. A sound reproducing system in accordance with claim 15 in which the diaphragm of the second loud speaker is a free radiating cone having a central opening and is mounted circumferentially of the horn opening of the first loud speaker.

"17. In combination, a loud speaking receiver having a diaphragm and a horn radiator, and a second loud speaking receiver comprising a free radiating diaphragm, a driving coil mounted on said free radiating diaphragm, and a cylindrical shell type magnet providing a magnetic field for said coil, the horn of said first loud speaker being located centrally and coaxially within said magnet and said free radiating diaphragm having a central opening substantially coinciding with the horn mouth."

[*Official Gazette April 17, 1934.*]