March 3, 1931. E. W. KELLOGG 1,795,214

SOUND REPRODUCING APPARATUS

Original Filed March 27, 1924 2 Sheets-Sheet 1

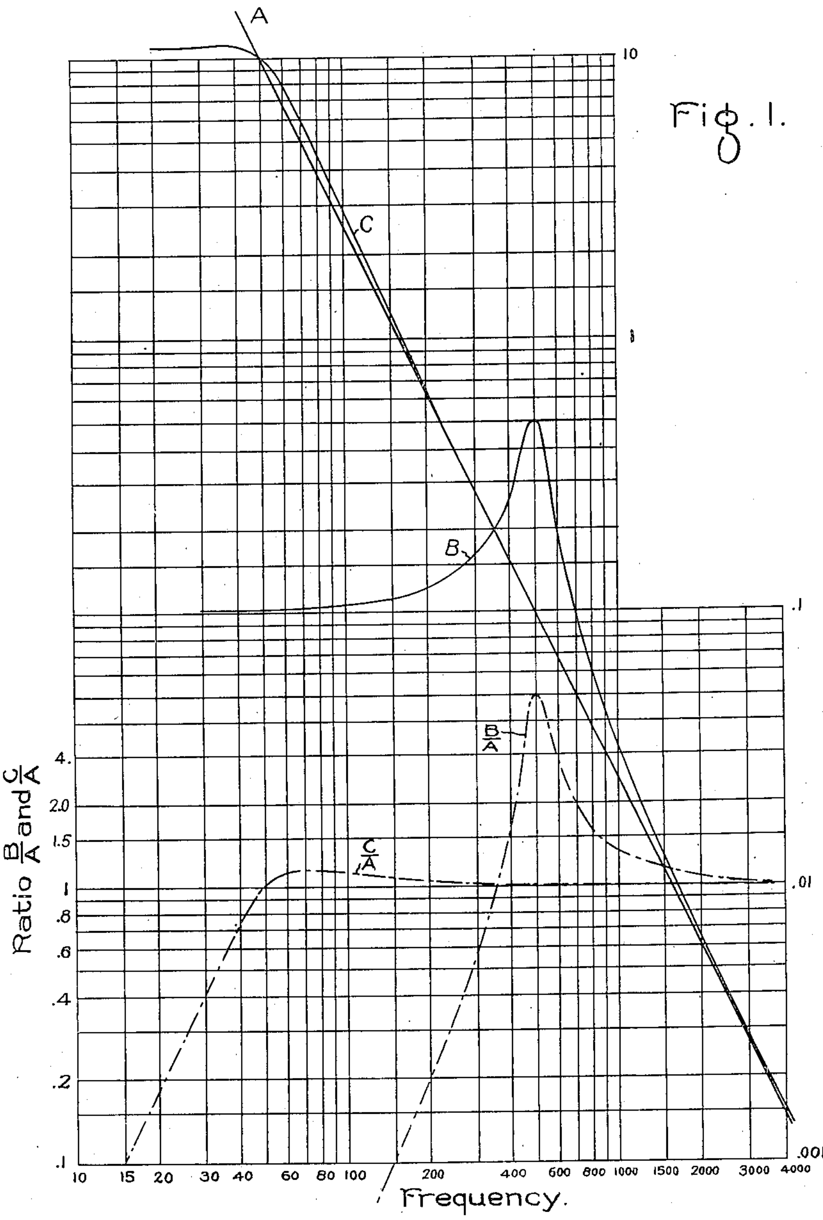

Fig. 1.

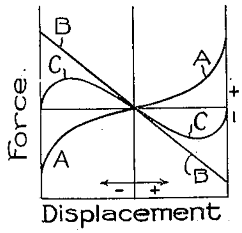

Fig. 2.

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by [signature]
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SOUND REPRODUCING APPARATUS

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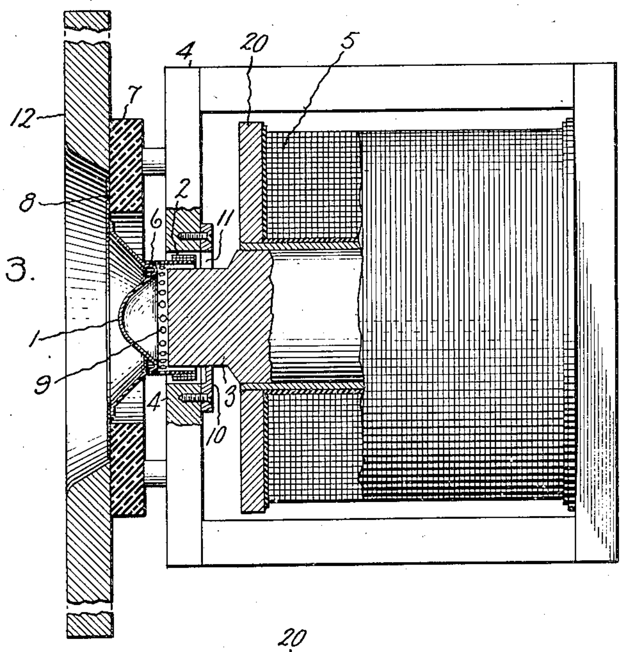

Fig. 3.

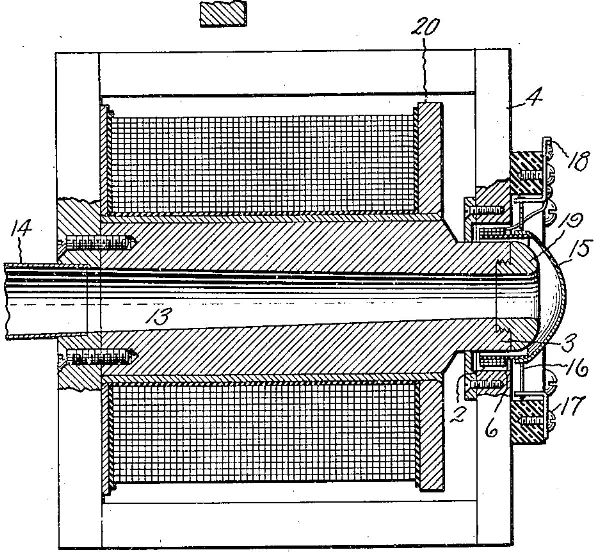

Fig. 4.

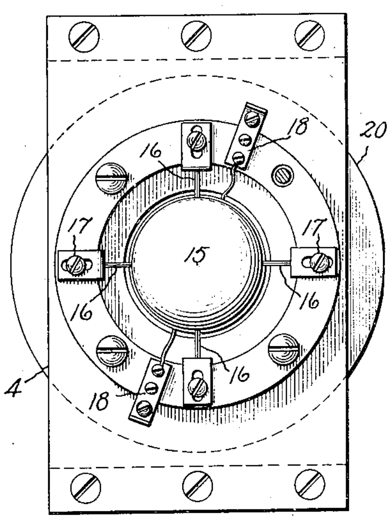

Fig. 5.

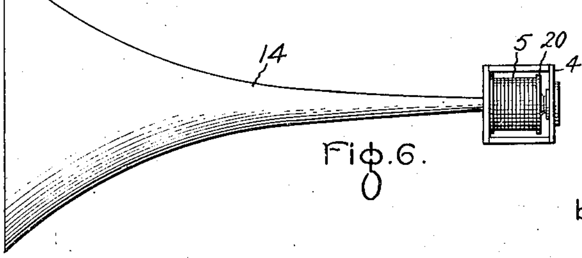

Fig. 6.

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Patented Mar. 3, 1931 1,795,214

UNITED STATES PATENT OFFICE

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SOUND-REPRODUCING APPARATUS

Application filed March 27, 1924, Serial No. 702,455. Renewed November 10, 1926.

My present invention relates to apparatus for producing sound from electric currents corresponding to original sounds, and more particularly to devices now commonly known as loud speakers.

The object of my invention is to provide devices of the class mentioned whereby the reproduction of sounds may be made with greater accuracy and fidelity than with devices of this class previously employed.

The novel features of my invention are pointed out with particularity in the appended claims. My invention itself, however, will best be understood by reference to the following description taken in connection with the accompanying drawings in which Fig. 1 consists of curves showing the relation between amplitude of vibration of the diaphragm and the frequency of vibration for diaphragms having different mechanical characteristics; Fig. 2 consists of curves showing the relation between force and displacement for vibrating members of the type ordinarily employed in telephones and loud speakers; Fig. 3 is a view partly in section of a device embodying my invention; Fig. 4 is a sectional view of a modification; Fig. 5 is an end view of the device of Fig. 4 illustrating the manner in which the diaphragm is suspended; and Fig. 6 is a view of the device of Figs. 4 and 5 with a preferred form of horn attached thereto.

The unnatural quality of such loud speakers, as have previously been used, is generally due to strong resonant points within the voice range and the failure of the loud speakers to radiate low tones adequately. The best quality microphones or pick-ups now in use for producing electric waves from sound waves operate with substantially the same efficiency over practically the entire working range of frequencies. In order, therefore, to effect a faithful reproduction of the original sound waves the loud speaker should show a uniform efficiency for all frequencies in the working range. To accomplish this the amplitude of vibration of the diaphragm, when the instrument is supplied with a current of constant strength with variable frequency, must follow a certain law with respect to frequency. This law is different for large and small diaphragms. For diaphragms, which are large in comparison with the longest wave lengths and which therefore produce plane waves, the amplitude of movement of the diaphragm must vary inversely as the frequency. For diaphragms, which are small in comparison with the shortest wave lengths so that they may be considered practically as point sources, the amplitude must vary inversely as the square of the frequency in order to radiate equal sound energies at different frequencies. This is the case which closely approximates the conditions under which the diaphragm of an ordinary loud speaker operates, and this is the condition which will be considered in the present case.

In curve A of Fig. 1, I have indicated the amplitude required for equal sound radiation at different frequencies, the ordinates of this curve representing the amplitude of vibration of the diaphragm in arbitrary units, and the abscissæ representing the frequencies of vibration.

Curve B shows the amplitude of vibration of a typical diaphragm of the type commonly employed in loud speakers, the fundamental resonance point of the diaphragm coming at about 500 cycles, which is near the middle of the usual voice frequency range. It is assumed in calculating the ordinates of curve B that the vibratory force applied to the diaphragm is the same for all frequencies represented.

Curve C shows the amplitude of vibration of the diaphragm whose fundamental resonance point is below the lowest important voice frequency. With no damping and no restoring force (i. e. with pure inertia control) the curve indicating the amplitude of vibration of the diaphragm would coincide exactly with curve A. Since damping tends to lower the curve in the neighborhood of the resonance point and restoring force tends to raise it above A we can make the diaphragm amplitude curve follow A very closely over the working range by adjusting the restoring force and damping. It is apparent from a comparison of curves A and B that any diaphragm whose fundamental resonance point comes within the working range will radiate, at frequencies materially below that at which the resonance occurs, very little sound in comparison with the amount of sound radiated at the resonance point, and at points above the resonance point.

To construct a small diaphragm loud speaker, therefore, which will radiate the lower tones in due proportion the diaphragm motion must be either purely inertia controlled, or if there is any elastic restoring force it must be so small in relation to the mass of the diaphragm that resonance will occur at a frequency lower than any of the important voice frequencies. This condition might be met by making the diaphragm heavy or the restoring force small. If the diaphragm is heavy the sensitiveness of the instrument is greatly reduced. It is therefore necessary to work with a small restoring force. It is impossible to employ a small restoring force if the common type of electro-magnetic drive is employed, in which an iron armature vibrates close to the poles of one or more polarized electro-magnets, as a strong elastic restoring force is necessary to prevent the armature from sticking to the pole tips.

Curve A of Fig. 2 shows, for the case of an iron armature between two pole tips, the nature of the magnetic pull tending to displace the armature from its normal position in either direction. Curve B shows the minimum elastice force which will prevent the armature from sticking to the poles. Curve C shows the resultant or net force holding the armature in its mean position. The slope of curve C where it crosses the axis in conjunction with the mass of the armature and diaphragm determine the fundamental resonance frequency. It will be seen from an inspection of these curves that curve C is nearly as steep as curve B. In other words, while the magnetic pull tends to lower the resonance frequency, this is a minor effect and it is not practically possible to obtain a very low resonance frequency by balancing the magnetic pull against the elastic restoring force.

One type of electromagnetic drive which permits of working with small restoring forces is the type in which a coil is caused to move in a constant magnetic field. This type seems to be most satisfactory for the construction of a loud speaker. With this type of drive there is no force tending to displace the diaphragm from its mean position except the alternating force which causes vibration, and there is no restraining or elastic restoring force required except what is needed to carry the weight of the diaphagm. For these reasons a fundamental resonance point may be obtained at as low a frequency as desired; for example, from 20 to 40 cycles and throughout the entire useful working range the motion of the diaphragm may be determined simply by the diaphragm inertia and the vibratory force applied, which is proportional to the voice current.

In Fig. 3 I have indicated one construction whereby the principles above outlined may be carried into effect. The essential features in this device are the diaphragm 1, the movable coil 2, which is suspended in the air gap formed by the two concentric pole pieces 3 and 4. These may be the pole pieces of a permanent magnet or the magnetic field may be produced by means of current supplied to an exciting coil 5 surrounding the inner pole piece. The coil 2 is secured to a ring 6 which in turn is attached to the diaphragm 1. A rigid supporting ring 7 is mounted upon the outer pole piece 4. A ring 8 of rubber or other flexible material is secured to the ring 7, and to the circumference of the diaphragm 1. The actuating currents may be supplied to the coil 2, either conductively or inductively.

It is not sufficient to construct a diaphragm whose fundamental natural frequency or resonance point is below the working range of frequency, but the first over-tone or higher mode of vibration must be at a frequency above the working range, if uniform sound radiation throughout the working range is to be attained. A flat circular plate has a series of overtone modes of vibration with successive numbers of circular nodes. Other shapes of diaphragm can vibrate in various manner depending on their shape and the place where the actuating force is applied. When the frequency becomes high enough to cause the diaphragm to break up into vibrations of the kinds described, the diaphragm no longer acts as a simple plunger, but parts of it are moving in the opposite direction to other parts, and the net motion of the working surface may be much greater or less than would be the case if the diaphragm continued to act as a rigid plunger.

If the driving force is distributed around a circle as is possible with the moving coil drive, and as is indicated in Fig. 3, the first resonance point to appear, or the point at which the diaphragm ceases to act as a rigid plunger, will be at a higher frequency or else the resonance will be the less pronounced than with the driving force concentrated at or near the center. To avoid such resonance points it is evident that the diaphragm should be made as rigid as possible, and at the same time in view of other considerations it should be made as light as possible. The form shown in Fig. 3, which is the general form of two intersecting conical surfaces, I have found to be particularly suitable as it is possible to make a diaphragm of this form very light and at the same time very rigid. A diaphragm of this form is much more rigid than a simple conical diaphragm of the same diameter and weight.

Another feature which is essential to the satisfactory operation of a loud speaker is the avoidance of resonant air chambers next to the diaphragm. For example, if the space behind the diaphragm is completely enclosed there will be a certain frequency at which the enclosed air will furnish an elastic restoring force to the diaphragm causing a strong resonance effect, and other frequencies at which the air will so resist motion of the diaphragm as to greatly reduce its amplitude of vibration. Similar effects may occur with partially enclosed spaces behind the diaphragm. To avoid difficulties of this kind the air spaces may be damped with energy absorbing material. Preferably, however, they should be so proportioned that their fundamental resonance frequencies will be so high as to be practically out of the working range of frequency. Adequate venting of the air spaces behind the diaphragm appears to be the most satisfactory solution since it raises the resonance frequency and reduces the sharpness of resonance at the same time.

In the form of device shown in Fig. 3, it will be perceived that since the air gap between the poles 3 and 4 must be small in order to secure the best efficiency, the space between the diaphragm 1 and inner pole 3 will be almost completely closed. Suitable venting of this space may be furnished by means of the holes 9 in the ring 6. The centering ring 10 which is provided for maintaining the proper space relation between the poles 3 and 4 may also be cut away as indicated at 11, to permit air to more readily circulate between the sleeve 6 and the pole piece 3.

The device shown in Fig. 3 may be used with a suitable design of horn if desired. In place of a horn, however, a baffle board 12 arranged as indicated, may be used. This baffle board should be of such size that the path by which air can pass from the front to the back of the diaphragm is of a length at least equal to a wave length of the sound to be radiated. The baffle should be made of fairly stiff or heavy non-resonant material.

In Figs. 4, 5 and 6, I have shown a modification which is especially designed for use with a horn. In this case the inner pole piece 3 has a longitudinal opening 13 through which the sound can escape. The horn 14 is fitted into this opening 13. In this case I have shown a diaphragm 15, which is in the form of a spinning, which is approximately parabolic in shape. This form gives the desired rigidity with small mass. The driving coil 2 is attached to the edpe of the diaphragm 15 by means of a sleeve 6 in substantially the same manner as in the form indicated in Fig. 3. The diaphragm 15 in this case is held in position by four threads 16 attached to the edge thereof and exerting a tension in four directions perpendicular to the axis of motion of the diaphragm. The tension of these threads may be adjusted by loosening the screws 17, and shifting the springs. Current may be supplied to the driving coil 2 from the terminals 18, which are mounted upon a ring of insulating material attached to the outer pole piece 4. The clearance between the pole pieces 3 and 4 should in this design be made as small as possible while permitting free movement of the driving coil 2 in order that the leakage of air past the edge of the diaphragm may be reduced to a minimum. A cap 19 of non-magnetic material secured to the end of pole piece 3 reduces the volume of the air cavity at the entrance to the horn to improve the acoustic properties of the device. A similar cap may, if desired, be employed in the form illustrated in Fig. 3 for the purpose of reducing the volume of the air cavity behind the diaphragm, and thereby raising the resonance frequency of the air in the cavity.

In the type of loud speaker which I have described and illustrated, a strong magnetic field is required and this necessitates supplying to the exciting coils a current of considerable strength. In some cases it may be desirable to produce the field by means of rectified alternating current. The rectified current will normally be a pulsating current but the magnetic field in the air gap must be practically constant in order to avoid modulation of the tones produced by the loud speaker and the production of tones which are harmonics of the frequency supplied by the rectifier. This difficulty may be avoided by making the end 20 of the field coil spool constitute a short circuited turn of very low resistance, for example, by making it a heavy ring of copper. This acts as a short-circuited turn for the variable current supplied to the coil and greatly reduces the pulsations in the magnetic flux. This short-circuited turn should be as close to the air gap as possible and need not necessarily constitute the spool head. In fact, a space between the coil and the short-circuited turn would still further reduce the flux pulsations by increasing the inductance of the winding, and thereby steadying the current. Such a construction, however, would increase unnecessarily the size of the instrument as the construction illustrated has been found to be very satisfactory. On the other hand, the spool head at the end farthest from the working air gap should be so constructed that it will not act appreciably as a short-circuited turn. It should preferably be of iron or else of a non-conducting material in order to give as large a flux linkage with the winding as possible and hence a high inductance.

What I claim as new and desire to secure by Letters Patent of the United States is:—

1. In a loud speaking apparatus a diaphragm which is so flexibly supported that its

fundamental natural frequency of vibration is below the lowest important voice frequency, said diaphragm being so mounted that the front is freely exposed to unconfined air, and a comparatively small air cavity is formed behind the diaphragm, and means for venting said air cavity whereby the resonance frequency of the air confined therein will be above the useful range of voice frequencies.

2. In a loud speaking apparatus, a diaphragm which is so flexibly supported that its fundamental natural frequency of vibration is below the lowest important voice frequency, and means for actuating said diaphragm comprising a movable coil located in an annular air gap between two concentric pole pieces, the air cavity formed between said diaphragm and the inner of said pole pieces being so vented that the resonance frequency of the air confined therein will be above the useful range of voice frequencies.

3. In an apparatus for sound reproduction, a diaphragm which is so flexibly supported that its fundamental natural frequency of vibration is below the lowest important voice frequency, said diaphragm being so mounted that the front is freely exposed to unconfined air and a comparatively small air cavity is formed behind it, and means for venting said air cavity in order to prevent the air therein from assuming a resonant condition which would affect unfavorably the motion of the diaphragm.

4. In an apparatus for sound reproduction, a diaphragm having the general form of two intersecting conical surfaces, and means for applying a driving force thereto uniformly around the line of intersection of the two surfaces.

5. In an apparatus for sound reproduction, a diaphragm having the general form of two intersecting conical surfaces, and means for actuating said diaphragm comprising a coil to which actuating currents may be supplied, said coil being secured to said diaphragm along the line of intersection of the two conical surfaces.

6. In an apparatus for sound reproduction, a diaphragm having the general form of two intersecting conical surfaces, and means for actuating said diaphragm comprising a coil to which actuating currents may be supplied, said coil being located in a constant magnetic field and being secured to said diaphragm along the line of intersection of the two conical surfaces.

7. In an apparatus for sound reproduction, a diaphragm having the general form of two intersecting conical surfaces, and means for actuating said diaphragm, comprising a coil to which actuating currents may be supplied, said coil being attached to a ring and said ring being secured to said diaphragm along the line of intersection of the two conical surfaces.

8. In an apparatus for sound reproduction, a diaphragm having the general form of two intersecting conical surfaces and means for actuating said diaphragm, comprising a coil to which actuating currents may be supplied, said coil being located in an air gap between two concentric pole pieces, and being secured to said diaphragm along the line of intersection of the two conical surfaces.

9. In an apparatus for sound reproduction, a diaphragm having the general form of two intersecting conical surfaces, and means for actuating said diaphragm, comprising a coil to which actuating currents may be supplied, said coil being located in an air gap between two concentric pole pieces and being attached to a ring and said ring being secured to said diaphragm along the line of intersection of the two conical surfaces.

10. In an apparatus for sound reproduction, a diaphragm having the general form of two intersecting conical surfaces and means for actuating said diaphragm, comprising a coil to which actuating currents may be supplied, said coil being located in an air gap between two concentric pole pieces and being attached to a ring and said ring being secured to said diaphragm along the line of intersection of the two conical surfaces, said ring being provided with openings for venting the air space between the diaphragm and the inner pole piece.

11. In an apparatus for sound reproduction the combination of a diaphragm and actuating means for said diaphragm comprising a pair of concentric pole pieces separated by an annular air gap, an actuating coil located in said air gap, and an energizing coil surrounding a core which terminates in one of said pole pieces, said coil being wound on a spool the end of which nearest the air gap forms a short circuited turn of low resistance, and the opposite end of which is of comparatively high resistance material.

12. In an apparatus for sound reproduction, the combination of a diaphragm, an actuating means for said diaphragm comprising a pair of concentric pole pieces separated by an annular air gap, an actuating coil located in said air gap, an energizing coil surrounding a core which terminates in one of said pole pieces, and a short circuiting turn of low resistance located between said energizing coil and said air gap.

13. In an apparatus for sound reproduction, the combination of a diaphragm, an actuating means for said diaphragm comprising a pair of concentric pole pieces separated by an annular air gap, an actuating coil located in said air gap, an energizing coil surrounding a core which terminates in one of said pole pieces, and a ring of low resist-

ance metal located between said energizing coil and said air gap.

14. In an apparatus for sound reproduction, a diaphragm having the form of a truncated cone which is so supported that it is capable of vibrating as a whole, and means for actuating said diaphragm comprising a coil surrounding the top thereof.

15. In an apparatus for sound reproduction, a diaphragm having the form of a truncated cone which is so supported that it is capable of vibrating as a whole, a cylindrical sleeve attached to the top thereof, and means for actuating said diaphragm comprising a coil secured to said cylindrical sleeve.

16. In an apparatus for sound reproduction, a diaphragm having the form of a truncated cone which is so supported that it is capable of vibrating as a whole, a cylindrical sleeve attached to the top of said diaphragm, and means for actuating said diaphragm comprising a coil which is secured to said cylindrical sleeve.

17. In an apparatus for sound reproduction, a rigid diaphragm having the form of a truncated cone, the base of said diaphragm being so flexibly supported that the diaphragm is capable of vibrating as a whole means for actuating said diaphragm comprising a pair of concentric pole-pieces separated by an annular air gap and an actuating coil secured to the top of said diaphragm and located in said air gap.

18. In an apparatus for sound reproduction, a diaphragm having the form of a truncated cone, which is so rigid in comparison with its supporting member that when a driving force is applied thereto at its top all parts thereof will have substantially equal movement, means for suspending said diaphragm having so low a restoring force that its natural rate of vibration as a whole will be below the lowest important voice frequency, and means for actuating said diaphragm comprising a coil attached to the top thereof.

19. In an apparatus for sound reproduction, a diaphragm having the form of a truncated cone which is so rigid in comparison with its supporting member that when a driving force is applied thereto at its top all parts thereof will have substantially equal movement, means for suspending said diaphragm having so low a restoring force that its natural rate of vibration as a whole will be below the lowest important voice frequency, a cylindrical sleeve attached to the top of said diaphragm, and means for actuating said diaphragm comprising a coil secured to said cylindrical sleeve.

20. In an apparatus for sound reproduction, a diaphragm having the form of a truncated cone which is so rigid in comparison with its supporting member that when a driving force is applied thereto at its top all parts thereof will have substantially equal movement, means for suspending said diaphragm having so low a restoring force that its natural rate of vibration as a whole will be below the lowest important voice frequency, a cylindrical sleeve secured to the top of said diaphragm and means for actuating said diaphragm comprising a coil which is secured to said cylindrical sleeve.

21. In an apparatus for sound reproduction, a diaphragm having the form of a truncated cone which is so rigid in comparison with its supporting member that when a driving force is applied thereto at its top all parts thereof will have substantially equal movement, means for suspending said diaphragm having so low a restoring force that its natural rate of vibration as a whole will be below the lowest important voice frequency, and means for actuating said diaphragm comprising a pair of concentric pole pieces separated by an annular air gap, and an actuating coil secured to the top of said diaphragm and located in said air gap.

22. In an apparatus for sound reproduction, the combination of a diaphragm, an actuating means for said diaphragm comprising a pair of concentric pole pieces separated by an annular air gap, an actuating coil located in said air gap, an energizing coil surrounding a core which terminates in one of said pole pieces, and a flat ring of low resistance metal closely surrounding said core and located in the space between said energizing coil and the second of said pole pieces and said air gap.

23. In an apparatus for sound reproduction, the combination of a diaphragm, an actuating means for said diaphragm comprising a pair of concentric pole pieces separated by an annular air gap, an actuating coil located in said air gap, an energizing coil surrounding a core which terminates in one of said pole pieces, and a ring of low resistance metal closely surrounding said core and located in the space between said energizing coil and the second of said pole pieces and said air gap, said ring being substantially coextensive in area with the end of said energizing coil.

24. In a signal-translating device, a diaphragm comprising two intersecting surfaces, and energy-translating means attached to said diaphragm only along the intersection of said surfaces.

25. In a signal-translating device, a diaphragm comprising two intersecting conical surfaces, and a coil attached to the diaphragm throughout the intersection of said surfaces.

26. In a signal-translating device, an annular flexible support, a diaphragm carried thereby and having an edge defined by two intersecting conical surfaces outside the plane of said support, and a coil secured along said edge.

27. A diaphragm comprising a conical surface terminating in an open end to form an edge within its margin, an open-end conical surface secured along its free edge to said first named edge, and means along said common edge whereby said diaphragm may be agitated.

28. A diaphragm having an edge defined by two intersecting conical surfaces within its margin, and means along said edge whereby said diaphragm may be agitated.

29. As an article of manufacture, a diaphragm comprising a substantially conical base portion and an open ended reentrant apex portion, and having an energy-translating device affixed thereto along the edge defined by said reentrant portion.

30. As an article of manufacture, a diaphragm comprising a substantially conical base portion and a reentrant apex portion, and having a coil secured thereto along the edge defined by said reentrant portion.

In witness whereof, I have hereunto set my hand this 26th day of March, 1924.

EDWARD W. KELLOGG.