Dec. 22, 1942. R. LEE 2,305,626

ELECTRO-ACOUSTIC APPARATUS

Filed Oct. 26, 1940

FIG. 1

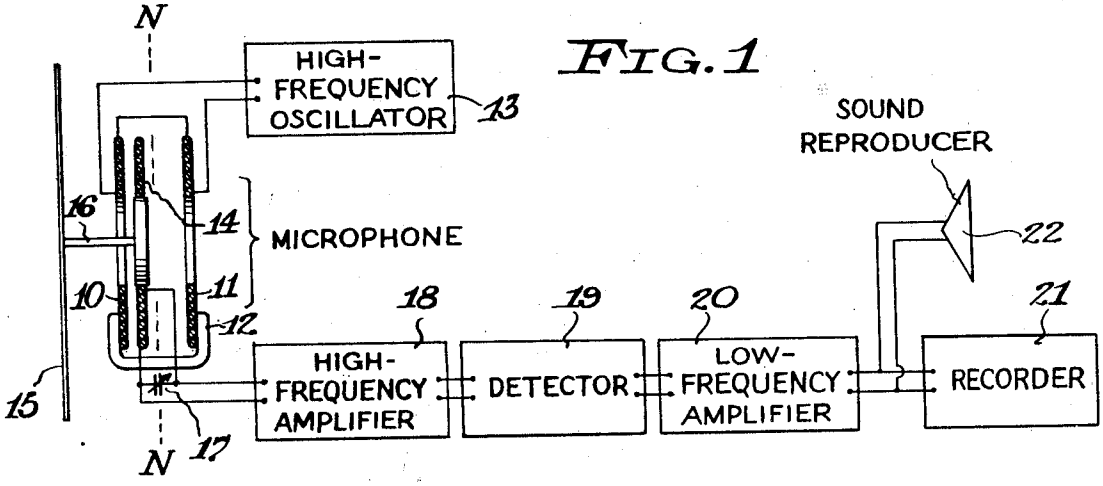


FIG. 2

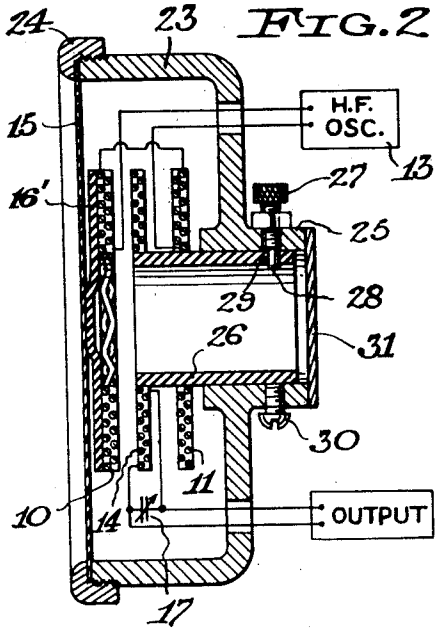


FIG. 3

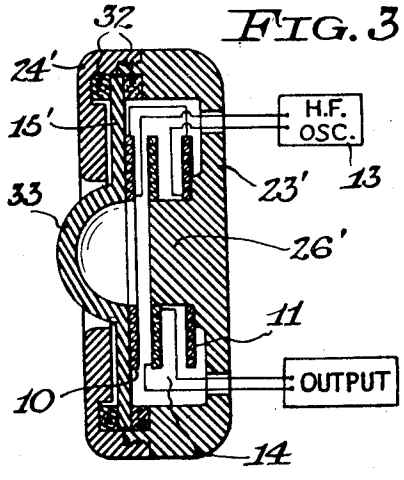


FIG. 4

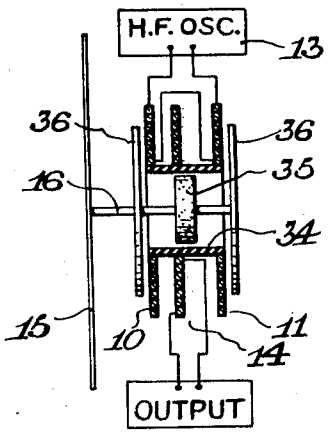


FIG. 5

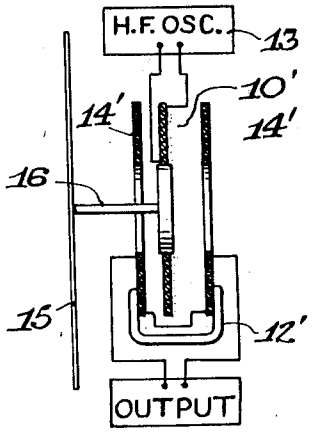


FIG. 6

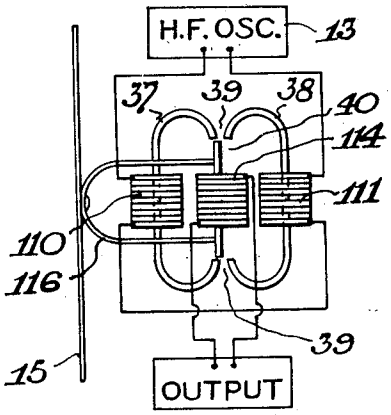
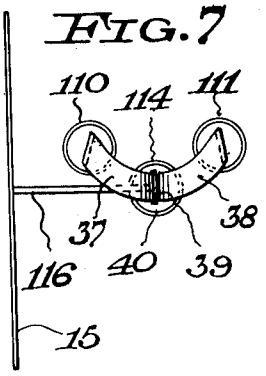


FIG. 7



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ELECTROACOUSTIC APPARATUS

Royal Lee, Milwaukee, Wis.

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11 Claims. (Cl. 179—171.5)

The present invention relates to electroacoustic apparatus, and more particularly to microphones and the like.

It is an object of the invention to provide an improved microphone or the like which is of rugged and inexpensive construction, which possesses good sensitivity, and which has a satisfactory response to impressed vibrations of low frequency.

Another object of the invention is to provide a microphone which will produce a modulated high-frequency electrical output and which is capable of a relatively high degree of modulation.

The invention further consists in the several features hereinafter described and claimed.

In the accompanying drawing, illustrating certain embodiments of the invention,

Fig. 1 is a diagrammatic view of an electroacoustic system including a microphone of the invention, parts of the microphone being shown in sectional elevation;

Fig. 2 is a sectional elevation of a modified form of microphone;

Fig. 3 is a sectional view of another modified form of microphone;

Figs. 4 and 5 are diagrammatic views of further forms of microphones, parts being shown in section;

Fig. 6 is a diagrammatic side view of a still further form of microphone, and

Fig. 7 is a top view of the microphone of Fig. 6.

In carrying out the invention, an electrical conductor, preferably in the form of a coil, is subjected to the influence of an alternating magnetic field having a frequency substantially higher than that of the mechanical vibrations which are to be converted into electrical vibrations. The influence of the high-frequency field on the conductor is varied in accordance with the mechanical vibrations, thus inducing in the conductor a high-frequency voltage which is modulated in accordance with the mechanical vibrations. The modulated high-frequency voltage is then utilized or translated in various ways and is normally subjected to demodulation to produce an electrical replica of the mechanical vibrations.

In the form of microphone shown in Fig. 1, a pair of axially spaced coils 10 and 11 are rigidly carried on a support 12 and are supplied with high-frequency current. These coils are arranged so that they produce opposing high-frequency fields and so that there is a neutral plane of zero or minimum flux about midway between the coils, this plane being normal to the axis of the coils and being represented by the dotted line N—N. The two field coils are preferably connected to the same source of current, such as a high-frequency oscillator 13, and are preferably connected in series, as shown, so as to insure proper phase relations. However, in some instances the coils may be connected in parallel. The effect of the opposing field coils is to "compress" their respective fields in the space between the coils and thus provide a steep flux gradient.

A vibratory output coil 14 is placed coaxially between the field coils 10 and 11 and is displaced from the neutral or zero flux plane N—N toward one of the field coils, say the field coil 10, so as to lie in the field of the latter coil. The mechanical vibrations to be electrically converted are impressed on the output coil by any suitable means such as a diaphragm 15 which has a rigid connection 16 with the output coil and which is movably supported in any well known manner. The vibration of the output coil 14 brings it alternately into stronger and weaker regions of high-frequency flux of the field coil 10, thus varying the coupling between these coils and inducing in the output coil a high-frequency voltage which is modulated in accordance with the mechanical vibrations. The maximum amplitude of vibration of the output coil is confined to the space between the field coil 10 and the zero-flux plane N—N. If desired, a condenser 17 may be connected across the output coil to form therewith a tuned circuit adjusted approximately to the field or carrier frequency. The modulation is of the amplitude type, although some frequency modulation may also occur. If a high degree of frequency stability is desired, the oscillator may be crystal-controlled. The position of the output coil is not critical, although the coil has an optimum position which can be determined by experiment. Instead of actuating the output coil, it will be obvious that either or both of the field coils may be vibrated by the diaphragm. It will also be obvious that the device may be actuated in the manner of a phonograph pick-up.

The modulated high-frequency voltage appearing across the output coil 14 is impressed on a high-frequency amplifier 18 to which is connected a detector or demodulator 19, thus producing an electrical replica of the mechanical vibrations. The detector output is amplified by a low-frequency amplifier 20, and the resulting current is then applied to a recorder 21, or to a sound reproducer 22, or to both.

In some instances, the modulated voltage appearing across the output coil **14** may be applied directly to the detector or demodulator, thus dispensing with the use of the high-frequency amplifier. For some purposes, as in radio transmitters or in phonograph pick-ups, the modulated high-frequency output of the coil **14** can be utilized as such or in amplified form.

A good response to mechanical vibrations of low amplitude is made possible by the opposing relation of the two fields and more particularly by the use of coil windings of the spirally wound flat or pancake type for the field coils and output coil, a relatively small amplitude of vibration effecting a substantial change in the degree of coupling. The output coil preferably has a short spacing from the adjacent field coil **10**, say on the order of $\frac{1}{8}$ inch for coils having a diameter of about one inch. The high-frequency field flux distribution is preferably symmetrical about the neutral plane, as by providing identical field coils. The field frequency is not critical and may be selected from a wide range of values, such as from 30 kilocycles per second to 5000 kilocycles per second, although these are not to be regarded as limiting values. In general, the use of the higher frequencies is desirable as the microphone coils can then be made small and light. For some purposes it is desirable to select a field frequency which lies in the range of 550 to 1500 kilocycles, so as to permit the associated use of broadcast receiving equipment. Microphone cable of the usual type is generally suitable for connecting the microphone to the oscillator and to the high-frequency amplifier.

In the form of microphone shown in Fig. 2, the output coil **14** is arranged between the field coils **10** and **11**, as in the device of Fig. 1, but the output coil is stationary and the field coil **10** is carried on the diaphragm **15**, either directly or by an interposed mounting disk **16'** of non-metallic material which is rigidly attached to the central portion of the diaphragm. In general, the attachment of the diaphragm to one of the field coils involves less complication than attachment to the output coil. The vibratory movement of the field coil **10** varies the influence of its high-frequency field on the output coil **14**, so that a modulated high-frequency voltage is induced in the output coil. The microphone includes a casing **23**, either metallic or non-metallic, to which the diaphragm is marginally secured by a retaining ring **24**. The diaphragm may be either metallic or non-metallic. The casing **23** has a central hub **25** in which a tubular support **26** is slidably mounted, the support preferably being formed of non-metallic material. The field coil **11** and output coil **14** are rigidly mounted on the inner end of the support. The support is axially adjustable to place the output coil in its optimum position. This adjustment can be effected in any suitable manner, as by means of a screw **27** mounted in the casing hub and having an eccentric inner end **28** disposed in a transverse slot **29** in the support, the adjustment being retained by a set screw **30**. The various pancake coils are preferably of the basket-wound or universal-wound type, as shown, to minimize distributed capacity, reduce high-frequency resistance, and increase rigidity. A tuning condenser **17** is connected across the output coil, as in the device of Fig. 1, and the output system may be similar to that of Fig. 1. When the casing and diaphragm are formed of metal they will constitute a shield for the coils. To improve the shielding effect a metal plate **31** closes the outer end of the hub **25**.

The use of the microphone as a contact device, in the manner of a stethoscope, may tend to bias the field coil **10** from its normal position, and thus change its relative position with respect to the output coil **14**. This effect, however, can be compensated for by axially adjusting the tubular support **26** carrying the field coil **11** and the output coil.

In the form of microphone shown in Fig. 3, the output coil **14** and field coil **11** are rigidly carried on a central inner embossment **26'** of a casing **23'**, such as of moulded insulating material, while the other field coil, **10**, is carried on a rigid disk-like diaphragm or piston member **15'**, the edges of which are supported by sponge rubber rings **32**. The diaphragm member is preferably formed of moulded insulating material and is retained in position by a guard ring **24'** secured to the casing. The diaphragm member is here shown to carry a rounded central embossment **33** to facilitate the application of contact pressure and to provide stiffness. The operation of the device of Fig. 3 is generally similar to that of Fig. 2.

In the embodiment of the invention shown in Fig. 4, the opposing field coils **10** and **11** and the intermediate output coil **14** are fixed with respect to each other, as by mounting them on a tubular insulating support **34**, the output coil being disposed in the flux of the field coil **10**. The diaphragm **15**, which is movably supported in any usual manner, carries a central stem **16** on which is mounted a permeable or magnetizable member **35** and a pair of metal eddy-current disks **36**. The magnetizable member is here shown to be disposed adjacent the plane of the output coil, while the metal disks are adjacent the outer sides of the respective field coils. To avoid excessive losses the magnetizable member is made of finely laminated or finely powdered magnetic material suitably bonded together. The effect of the vibratory movement of the magnetizable member **35** is to shift or modify the high-frequency field flux and thus induce a modulated high-frequency voltage in the output coil **14**. The vibratable metal disks **35** have a shifting, weakening, or modifying action on the field flux which will result in the appearance of a modulated high-frequency voltage in the output coil. A single metal disk will also have this effect. The magnetizable member and metal disks may be used conjointly, as shown, or they may be used alternatively.

In the modified form of microphone shown in Fig. 5, a single high-frequency movable field coil **10'** is placed coaxially between two stationary output coils **14'**, the latter being mounted on a suitable support **12'** and being connected in series opposing relation. When the field coil **10'** is at rest it is unequally spaced from the output coils, and the high-frequency flux has unequal effects on the differentially connected output coils, so that a certain net high-frequency voltage is induced in the output coils. The field coil is vibrated by a diaphragm **15**, thus varying the effect of the high-frequency field flux on the output coils and inducing therein a modulated high-frequency voltage.

In the embodiment of the invention shown in Figs. 6 and 7, a pair of stationary high-frequency field coils **110** and **111** are connected in series and supplied with high-frequency current from an oscillator **13**. Magnetizable core members **37** and

38 extend through the respective field coils and are of C-shaped formation. The core members are arranged in opposed relation with air gaps 39 between their corresponding free ends. The core members, at least at their end portions, are of plate-like shape, and the air gaps are in the form of slots. It will be obvious that these "air" gaps may be occupied by insulation or other non-magnetic material, if desired. An elongated magnetizable armature 40 extends between the ends of the core members and is of plate-like shape, at least at its end portions. The narrow flat end faces of the armature are adjacent the core member ends and have a width approximately equal to the width of the air gaps 39. The magnetizable material of the core members and armature is suitably subdivided to reduce core losses. The armature is translatable transversely of its length and width by means of a diaphragm 15 connected to the armature, as by a forked strut or stem 116. The entire armature is here shown to be movable but in some cases only one or both of its end portions may be displaceable. The air gaps between the ends of the armature and each core member are somewhat smaller than the air gaps 39 beytween the core members. The armature passes through a stationary output coil 114 which is connected to suitable output apparatus such as that shown in Fig. 1. In some instances, two of the adjacent ends of the core members may be brought together so as to have only one air gap 39.

In accordance with one method of operation, the adjacent core member ends are of opposite polarity during the magnetizing cycle, there being a certain amount of flux along the armature when the latter is in the normal position shown in Fig. 6. In this normal position the narrow end faces of the armature are somewhat offset with respect to the air gaps 39. When the armature is vibrated the reluctance of the air gaps between its ends and the ends of the core member 37 is varied, thus causing a varying high-frequency magnetic flux to traverse the armature and to induce a modulated high-frequency voltage in the output coil. At the maximum amplitude of armature vibration and at one side of armature travel, the armature ends become centered with respect to the air gaps 39. If and when this position is reached, no high-frequency flux passes along the armature, since the magnetic potentials at opposite ends of the armature are then equal.

The several microphones above described are capable of responding to mechanical vibrations of rather low frequency, even extending well below audibility. The reason for this characteristic is that the high-frequency voltage induced in the output coil depends on the relative position of this coil with respect to the high-frequency field and not on the relative velocity of the coil and field. Theoretically, the relative velocity of the output coil and field also results in an induced voltage in this coil, but this effect is quite small compared with the "relative position" effect, especially at the lower frequencies.

The frequency response of the several instruments above described can be modified or adjusted by any one or more of the various expedients known in the art, such as diaphragm suspensions, damping devices, and acoustic and electric filters.

The several embodiments of the invention above described are so arranged that a high-frequency voltage will be induced in the output coil during the absence of modulation. In the device of Fig. 1, for example, the output coil is axially displaced from the neutral or zero-flux plane N—N. It is also possible to transmit intelligence with the device when the output coil is placed in the zero-flux plane. In this event, no high-frequency voltage will be induced in the output coil when this coil is at rest, and the excursions of this coil during vibration will carry it into the field flux of the opposing high-frequency fields. While a doubling effect with respect to the modulation frequency will be present, this is not objectionable in certain cases.

What I claim as new and desire to secure by Letters Patent is:

1. A microphone for converting mechanical vibratory energy to electrical vibratory energy, comprising means for producing a high-frequency magnetic field, an electrical conductor subject to the influence of said field, means controlled by mechanical vibrations for varying the influence of said field on said conductor at the frequency of said vibrations to induce in said conductor a high-frequency output voltage modulated in accordance with the mechanical vibrations, and means for confining the portion of said field in which the conductor is placed to provide a relatively steep flux gradient.

2. Apparatus for converting mechanical vibratory energy to electrical vibratory energy, comprising means for producing opposing high-frequency magnetic fields having between them a region of minimum flux, a conductor disposed in one of said fields adjacent said region of minimum flux, and means actuated by mechanical vibrations for varying the influence of said last-named field on said conductor at the frequency of said vibrations to induce in said conductor a high-frequency voltage modulated in accordance with the mechanical vibrations.

3. Apparatus for converting mechanical vibratory energy to electrical vibratory energy, comprising a pair of field coils for producing opposing high-frequency magnetic fields and having between them a region of minimum flux, an output coil between said field coils and subject to one of said fields, and means actuated by mechanical vibrations for varying the influence of said field on said output coil at the frequency of said vibrations to induce in said output coil a high-frequency voltage modulated in accordance with the mechanical vibrations.

4. Apparatus for converting mechanical vibratory energy to electrical vibratory energy, comprising a pair of field coils for producing opposing high-frequency magnetic fields, and an output coil between said field coils and subject to the flux of one of said fields, one of said field coils being vibratable toward and from said output coil under the influence of mechanical vibrations to induce in said output coil a high-frequency voltage modulated in accordance with the mechanical vibrations.

5. A microphone for converting mechanical vibratory energy to electrical vibratory energy, comprising a coil for producing a high-frequency magnetic field, and a second coil adjacent to and approximately coaxial with said first coil and relatively vibratable in an approximately axial direction under the influence of impressed mechanical vibrations to induce in said second coil a high-frequency voltage modulated in accordance with the mechanical vibrations.

6. Apparatus for converting mechanical vibra-

tory energy to electrical vibratory energy, comprising a pair of coils for producing opposing high-frequency magnetic fields and having between them a region of minimum flux, and an output coil extending between said field coils and subject to the flux of one of said field coils, said output coil and at least one of said field coils being relatively vibratable toward and away from each other under the influence of mechanical vibrations to induce in said output coil a high-frequency voltage which is modulated in accordance with the mechanical vibrations.

7. A microphone for converting mechanical vibratory energy to electrical vibratory energy, comprising a field coil for producing a high-frequency magnetic field, an output coil adjacent said field coil, said coils being of the pancake type and arranged side by side in approximately coaxial relation, and means controlled by mechanical vibrations for varying the influence of the field on said output coil at the frequency of said vibrations to induce in said output coil a high-frequency voltage modulated in accordance with said vibrations.

8. Apparatus for converting mechanical vibratory energy to electrical vibratory energy, comprising a pair of field coils for producing opposing high-frequency magnetic fields, and an output coil extending between said field coils in the field of one of said field coils and being approximately coaxial with said field coils, one of said coils being axially vibratable under the influence of mechanical vibrations to induce in said output coil a high-frequency voltage modulated in accordance with the mechanical vibrations.

9. Apparatus for converting mechanical vibratory energy to electrical vibratory energy, comprising a pair of field coils for producing opposing high-frequency magnetic fields having between them a region of minimum flux, an output coil between them and approximately coaxial with said field coils and in the field of one of said field coils, one of said coils being axially vibratable under the influence of mechanical vibrations to induce in said output coil a high-frequency voltage modulated in accordance with the mechanical vibrations, and means for relatively axially adjusting the normal position of said output coil with respect to said region of minimum flux.

10. A microphone and the like, comprising three approximately coaxial coils one of which is disposed between the others, said outer coils constituting one coil means and being electrically connected in opposition, and said inner coil constituting a second coil means, one of said coil means forming a high-frequency field winding, and the other coil means forming an output winding, and means actuated by mechanical vibrations for displacing one of said coils in a generally axial direction to induce in said output coil means a high-frequency voltage modulated in accordance with the mechanical vibrations.

11. A microphone comprising a plurality of approximately coaxial substantially flat spirally wound coils arranged side by side in electromagnetically coupled relation and adapted to be traversed by high-frequency currents, and means controlled by mechanical vibrations for relatively vibrating said coils in an approximately axial direction to vary the coupling thereof in accordance with the mechanical vibrations.

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