Jan. 10, 1950 W. R. HARRY **2,493,819**

STABILIZED FEEDBACK CONDENSER MICROPHONE

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FIG. 1

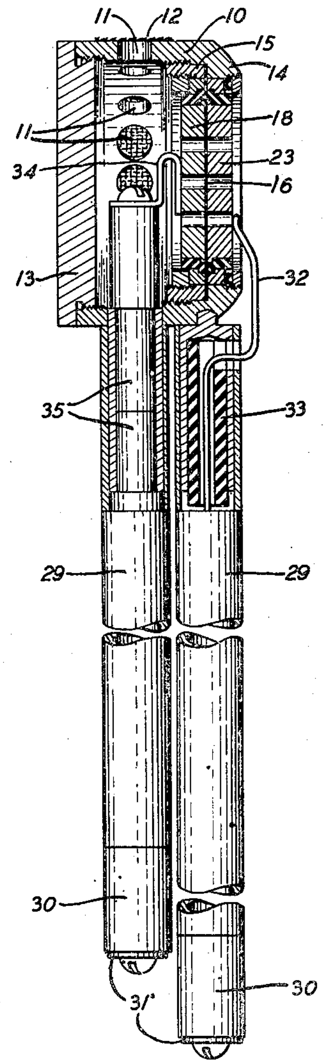

FIG. 2

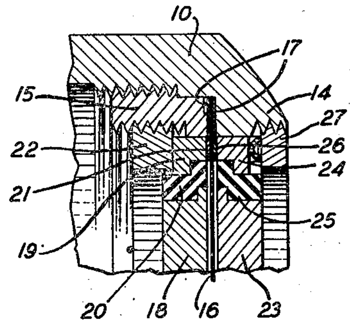

FIG. 3

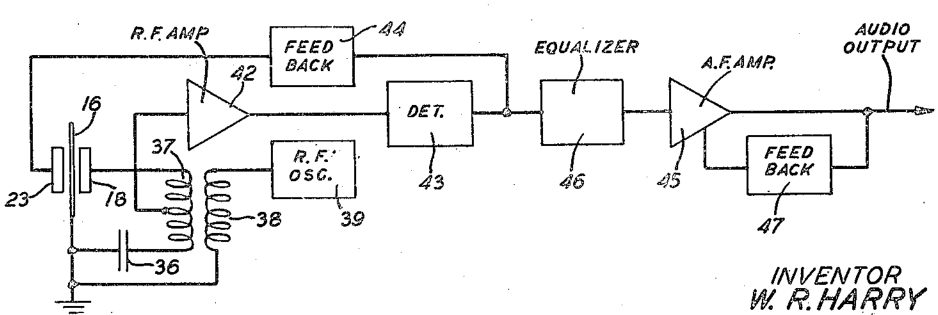

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FIG. 4

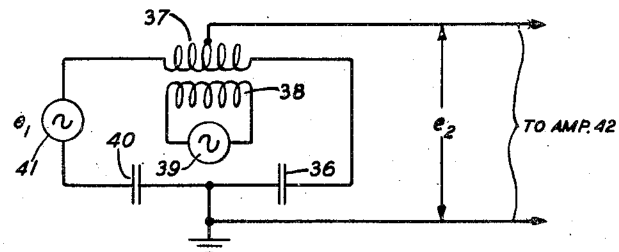


FIG. 5

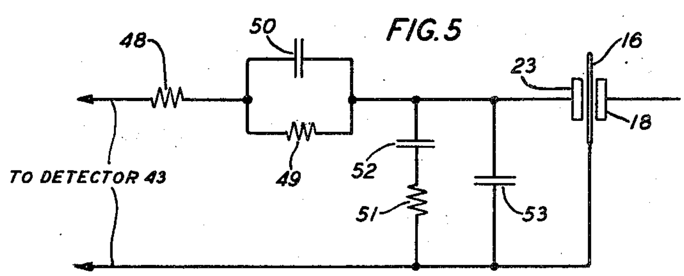
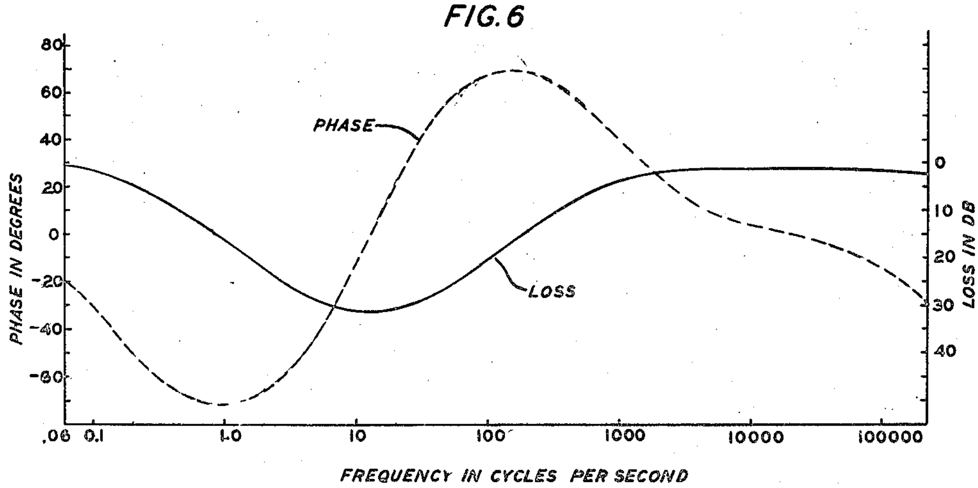


FIG. 6



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STABILIZED FEED-BACK CONDENSER MICROPHONE

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Application November 25, 1947, Serial No. 787,941

8 Claims. (Cl. 332—2)

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This invention relates to electro-acoustic transducers and more particularly to transducers of the type, such as disclosed in Patent 2,387,845 granted October 30, 1945, to William R. Harry, including a microphone having a directional response characteristic and associated with an amplifier to constitute a stabilized negative feedback system therewith.

General objects of this invention are to improve the performance and to facilitate the construction of electro-acoustic transducers and especially of such devices including an electro-static or condenser type microphone.

More specifically objects of this invention are to obtain a high signal-to-noise ratio for electro-acoustic transducers, to reduce distortion, due to wind noise, in such transducers, to lessen the susceptibility thereof to noise due to electrical leakage across insulators in the microphone and associated circuit elements, to relieve the stringency of mechanical design requirements in electro-static or condenser microphones having a diaphragm interposed between a pair of electrodes and to facilitate the realization of uniform response over a wide range of frequencies.

In one illustrative embodiment of this invention, an electro-acoustic transducer comprises a directional, specifically cardioidal, microphone including a diaphragm vibratile between a main and an auxiliary electrode, an amplifier energized in accordance with variations in the capacitance between the diaphragm and main electrode as the diaphragm vibrates in accordance with sound waves effective thereon, and a feedback circuit coupled to the auxiliary electrode and energized proportionately to the amplifier output for effecting control of the diaphragm motion.

In accordance with one feature of this invention, the condenser microphone is radio frequency polarized such that the input to the amplifier is a radio frequency carrier or signal amplitude modulated in accordance with vibrations of the diaphragm. Because of the low effective resistance in the input circuit to the amplifier, resulting from the low reactance of the microphone at the carrier and side-band frequencies, a high signal-to-noise ratio is obtained. Also, susceptibility of the circuit to noise due to leakage across insulators therein is lessened. In one specific form, the diaphragm and main electrode constitute one capacitative arm of a bridge circuit, the adjacent arm of which is defined by a condenser substantially balancing the microphone capacitance. The radio frequency polarizing voltage is applied across these two capacitative arms as by way of a center-tapped secondary winding of a transformer, the two halves of this winding constituting the other two arms of the bridge.

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In accordance with another feature of this invention, the output of the amplifier is detected to regain the audio frequency envelope and a portion of the detected output is applied between the diaphragm and the auxiliary electrode to apply feedback control effective upon the diaphragm down to zero frequency. Such feedback control at zero frequency tends to center the diaphragm whereby necessity for exact initial equality of the diaphragm to electrode spacings is reduced. Further, feedback at zero and low frequencies reduces distortion due to wind noise.

In accordance with a further feature of this invention, the feedback circuit includes a network for compensating, over a range of low frequencies in the band to be translated by the transducer, for the rising response characteristic of the microphone due to its directional character, whereby the response is equalized over this range, and an additional network is provided for equalizing the response at higher frequencies. This enables equalization over the entire band to be translated without degradation of the signal-to-noise ratio and simplifies the construction of the output audio amplifier energized from the detector by facilitating the realization of sufficient gain at this amplifier to enable use of local feedback for the reduction of noise and distortion thereat.

The invention and the above-noted and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

Fig. 1 is a side elevational view, mainly in section, of a condenser microphone which may be included in an electro-acoustic transducer illustrative of this invention;

Fig. 2 is an enlarged sectional view of a portion of the microphone illustrated in Fig. 1, showing details of the diaphragm and electrode mountings;

Fig. 3 is a circuit diagram, principally in block form, of a transducer illustrative of one embodiment of this invention;

Fig. 4 is a diagram illustrating the bridge circuit included in the transducer shown in Fig. 4;

Fig. 5 is another diagram illustrating the low frequency equalizer included in the transducer; and

Fig. 6 is a graph showing the transmission characteristics of the equalizer illustrated in Fig. 5.

Referring now to the drawing, the microphone illustrated in Figs. 1 and 2 is of the electrostatic or condenser type and comprises a metallic housing including a cylindrical body portion 10 provided with a plurality of apertures 11 covered with acoustic resistance material 12, such as acoustic silk. The housing includes also an imperforate rear closure 13 and an annular front flange 14. Affixed against the flange 14 by a locking ring 15 threaded to the housing portion 10 is a thin, disc diaphragm 16, for example of sheet aluminum substantially 0.00027 inch thick, gaskets 17, which also may be of aluminum, being provided on opposite sides of the diaphragm adjacent its periphery.

Opposite the inner face of the diaphragm 16 is a perforated, metallic main or back electrode 18 which is affixed rigidly to a metallic mounting ring 19 by an insulating annulus 20. In one construction, the annulus 20 may be a thermoplastic, such as polystyrene, which is molded to the ring 19 and back electrode 18 to form a unitary assembly. The front faces of the ring 19 and electrode 18, that is the faces thereof toward the diaphragm, are lapped to be accurately coplanar, whereby this face of the ring constitutes a reference surface for determining the diaphragm to back electrode spacing. This spacing is fixed by a metallic annular spacer 21 of preassigned thickness interposed between the ring 19 and the diaphragm. A pressure or clamping ring 22 is threaded to the housing portion 10 and bears against the ring 19 and by rotation thereof the diaphragm is tensioned to the desired degree and its resonance frequency fixed, for example at about 2,000 cycles per second.

A second unitary assembly is mounted opposite the other face of the diaphragm and comprises a perforated front or auxiliary electrode 23, a mounting ring 24 and an insulating, e. g. polystyrene, annulus 25 moulded to the electrode 23 and ring 24. The faces of the electrode 23 and ring 24 toward the diaphragm are lapped to be accurately coplanar; the spacing of the electrode 23 from the diaphragm is fixed by an annular metallic spacer 26 disposed between the diaphragm and the ring 24. The front electrode assembly is held in place by a locking ring 27 threaded to the flange 14 and bearing against an annular spring 28 which in turn bears against the mounting ring 24.

Electrical connection to the electrodes 18 and 23 may be established by way of coaxial lines the outer conductors 29 of which are connected to the housing and have at their outer ends insulating caps 30 carrying terminals 31 for the inner conductors. One of the inner conductors 32 is connected to the front or auxiliary electrode 23 and passes through an insulating sleeve 33 in the respective outer conductor. The other inner conductor is coupled to the main or back electrode 18 by a tie wire 34 and passes through insulating sleeves 35 in the respective outer conductor.

The stiffness of the chamber provided to the rear of the diaphragm by the housing is correlated with the mass and resistance provided by the acoustic material 12 and the external configuration of the housing is made such, both in ways known in the art, that the microphone has a prescribed directional response pattern, e. g. cardioidal, the response being a maximum for sound waves incident normal to the outer or front face of the diaphragm.

The microphone above-described is utilized as a portion of a stabilized negative feedback system in which the microphone is radio frequency polarized. Specifically, as illustrated in Fig. 3, the diaphragm 16 and main or back electrode 18 are connected by a balancing condenser 36 in series with a center-tapped transformer winding 37, the other winding 38 of the transformer being energized from a radio frequency oscillator 39. The oscillator frequency is not critical and may be, for example, between 0.5 megacycle and 5 megacycles. A frequency of one megacycle has been found satisfactory, particularly from the standpoint of transformer design. As illustrated in Fig. 4, the diaphragm 16, electrode 18, condenser 36 and transformer winding 37 constitute a bridge, the two halves of the winding 37 constituting two arms of the bridge, the capacitance 40, being that between the diaphragm 16 and back or main electrode 18, constituting the third arm and the condenser 36 constituting the fourth arm and balancing the capacitance 40. Advantageously, the bridge is slightly unbalanced in the direction such that an increase in the capacitance 40 results in a further unbalance.

The voltage e_1 across element 41 represents the carrier or radio frequency voltage due to the bridge unbalance plus that of sideband frequencies when sound waves are incident upon the diaphragm, and may be considered as the amplitude of the envelope modulation at audio frequencies. For 100 per cent coupling between the two halves of transformer winding 37, it is apparent from Fig. 4 that the output voltage e_2 is equal to

$$e_1\frac{x_{36}}{x_{36}+x_{40}}$$

where $x_{36}+x_{40}$ are the reactances of the condensers 36 and 40 respectively.

The amplitude modulated carrier or radio frequency voltage produced by the bridge circuit above-described is supplied to the wide band amplifier 42, designed to amplify the carrier and sidebands, and the amplified signal is passed to a detector 43 where it is rectified to regain the audio frequency envelope. A portion of the detector output is supplied to the front or auxiliary electrode 23 over a feedback circuit 44, thereby to produce a controlling force acting upon the diaphragm.

The remainder of the audio frequency output of the detector 43 is supplied to an audio frequency amplifier 45 by way of an equalizer 46 the function of which will appear presently. Advantageously, the amplifier 45 is provided with feedback 47 to attain high level undistorted audio output.

As is known, for example as pointed out in the William R. Harry patent heretofore identified, in a microphone having a directional, e. g. cardioidal response, the net acoustic force effective upon the diaphragm varies with frequency because of the dependence upon frequency of the relative phase of the acoustic forces acting upon opposite faces of the diaphragm. As pointed out further in that patent, this variation in net force may be compensated for by application of feedback of a prescribed character, to the auxiliary electrode.

In the transducer thus far described herein and neglecting the effect of feedback, the signal obtained at the output of the detector will increase with frequency, specifically will increase at the rate of approximately 6 decibels per octave. This increase and consequent non-uniformity in the frequency response characteristic theoretically might be accounted for by providing a single equalizer which would introduce a loss increasing at the same rate with frequency. Practically, however, this solution is not satisfactory for the reason, among others, that such an equalizer would yield a voltage so low that the noise generated in the first stage of the audio amplifier would be greater than the noise component at this point in the system due to the microphone, with the result that the signal-to-noise ratio of the transducer would be degraded.

In accordance with one feature of this invention, the desired compensation for the rising microphone characteristic is attained without degradation of the signal-to-noise ratio of the transducer and with the realization, expeditiously and economically, of adequate gain in the audio frequency amplifier to enable adequate feedback at this amplifier for the reduction of noise and distortion in this portion of the system.

Specifically, the feedback circuit **44** is constructed to equalize the response over a range of lower frequencies in the band to be translated and the equalizer **46** is constructed to compensate for the rising microphone characteristic at frequencies above this range. For example, in a typical transducer intended to translate faithfully all frequencies within the band from 30 to 15,000 cycles, the feedback circuit may be constructed to effect equalization in the response between 30 and 1,000 cycles and the equalizer **46** may be constructed to provide uniformity in the band from 1,000 to 15,000 cycles.

A suitable form of the feedback circuit **44** is illustrated in Fig. 5 and its transmission characteristics are illustrated in Fig. 6. It comprises a series resistor **48**, the parallel resistor-condenser combination **49**, **50**, the series resistor condenser combination **51**, **52** and the shunt condenser **53**, all connected as shown between the detector **43** and the diaphragm **16** and front or auxiliary electrode **23**. In a typical network having the phase and loss characteristics illustrated in Fig. 6, the parameters of the impedances of Fig. 5 are as follows:

Resistor **48**	ohms	110
Resistor **49**	megohms	0.5
Resistor **51**	ohms	4,000
Condenser **50**	microfarads	0.04
Condenser **52**	do	2
Condenser **53**	do	0.004

It will be seen from Fig. 6 that the loss introduced by the network illustrated in Fig. 5 increases substantially linearly over the frequency range from 30 to 1,000 cycles at substantially 6 decibels per octave and is substantially constant above this range. Thus, the network compensates for the rising microphone characteristic over this frequency range. The departure from linearity of the loss characteristic adjacent the lower extreme frequency, i. e. 30 cycles, is small and, if desired, may be corrected by design of the amplifier and feedback system.

This microphone, radio frequency supplier, detector and feedback in combination constitute an electromechanical system of the configuration of the $\mu\beta$ circuit described in the article "Stabilized feedback amplifiers," by H. S. Black in the Bell System Technical Journal, January 1934, page 1, the bridge **16**, **18**, **36** and **37**, amplifier **42** and detector **43** constituting the μ portion of the circuit and the feedback circuit **44** and electrode **23** constituting the β portion of the circuit. In general, the components are correlated in accordance with known principles, set forth in the Black article, so that they constitute a stabilized feedback system. That is to say, the phase and gain conditions in the system are made such that the $\mu\beta$ gain is substantially greater than unity over the requisite frequency range, bearing in mind that the phase conditions in the radio frequency circuit elements affect the phase of the audio frequency modulation envelope. In a specific circuit, a $\mu\beta$ gain of approximately 45 decibels at the diaphragm resonance frequency (about 2,000 cycles per second), sloping at a rate of 10 to 12 decibels per octave at higher frequencies to a value of unity at approximately 90 kilocycles, and, at frequencies below the diaphragm resonance, first falling to a minimum of 15 decibels at approximately 15 cycles and then rising again to 45 decibels at zero frequency, together with a phase which passes 180 degrees at approximately 200 kilocycles may be employed.

The equalizer **46** may be a resistance-condenser network having a loss characteristic which rises at substantially 6 decibels per octave above the frequency, e. g. 1,000 cycles, at which the loss characteristic of the equalizer in the feedback path **44** levels off, and, thus, compensates, above this frequency, for the rising characteristic of the microphone.

Certain characteristics of the transducer are to be noted particularly. Inasmuch as the microphone impedance is low at the high carrier frequency employed, the bridge circuit operates at a low impedance level. Hence, the effective input resistance for the transducer is small and additionally is substantially constant for the range of audio frequencies translated. Inasmuch as the amplifier **42** operates at radio frequencies, the low frequency fluctuation noise of the first stage tube thereof is of no moment. Consequently, a high signal-to-noise ratio is obtained.

Feedback control is obtained over the circuit **44** down to zero frequency. Hence, the feedback tends to center the diaphragm **16** between the electrodes **18** and **23** whereby stringency of equality of the two diaphragm-to-electrode spacings is reduced. Also, because of feedback at zero and very low frequencies, the signal level at these frequencies is reduced with consequent reduction in distortion due to wind noise and harmonics thereof.

Because of the low impedance level of the input circuit for the transducer at the frequencies of the carrier and its side-bands, the circuit is but poorly susceptible to noise due to leakage across the insulators in this circuit, the insulators including those in the microphone itself and others involved in this circuit.

Equalization for the lower frequencies is obtained without degradation of the signal-to-noise ratio.

Finally, the inherent rising characteristic of the microphone is compensated for over the entire range of frequencies to be translated and a uniform response is attained throughout this range.

Although a specific transducer has been shown and described, it will be understood that it is but illustrative of this invention and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. An electro-acoustic transducer comprising a condenser microphone having a diaphragm, a first electrode opposite one face of said diaphragm and an auxiliary electrode opposite the other face of said diaphragm, a bridge, one arm of which includes said diaphragm and said first electrode and another arm of which includes a condenser substantially balancing the capacitance between said diaphragm and said first electrode, means for applying a radio frequency polarizing voltage to said bridge such that the output of said bridge is a radio frequency signal amplitude modulated in accordance with vibrations of said diaphragm, a radio frequency amplifier energized in accordance with said signal, detector means coupled to the output of said amplifier, an audio frequency output circuit coupled to said detector, and a feedback coupling from said detector to said auxiliary electrode.

2. An electro-acoustic transducer in accordance with claim 1 wherein said microphone has a substantially cardioidal response pattern, said transducer comprising an equalizer network between said detector and said audio frequency output circuit for equalizing the response of the transducer for frequencies above a preassigned frequency in the range to be translated, and said feedback coupling including equalizer means for equalizing said response for frequencies below said preassigned frequency.

3. An electro-acoustic transducer comprising a diaphragm and an electrode adjacent thereto defining a condenser, a bridge circuit, one arm of which is constituted by said condenser, said circuit including a condenser defining an arm thereof adjacent said first condenser and substantially balancing the static capacitance of said first condenser, means for applying a radio frequency polarizing voltage across the two condensers in series, and connections to said circuit for deriving therefrom a signal of said radio frequency, amplitude modulated in accordance with vibrations of said diaphragm.

4. An electro-acoustic transducer in accordance with claim 3 comprising a radio frequency amplifier energized in accordance with said radio frequency amplitude modulated signal, an auxiliary electrode adjacent said diaphragm, and a negative feedback coupling between said amplifier and said auxiliary electrode.

5. An electro-acoustic transducer in accordance with claim 3 comprising means associated with said diaphragm and electrode defining therewith a directional microphone having a rising frequency response characteristic, and means energized in accordance with said amplitude modulated radio frequency signal for applying to said diaphragm a vibration controlling force to compensate for said rising characteristic over a portion of the operating frequency range of the transducer.

6. An electro-acoustic transducer comprising a condenser microphone having a directional response pattern and a rising frequency response characteristic, said microphone including a diaphragm and a main electrode adjacent thereto and defining a condenser therewith, said microphone including also an auxiliary electrode opposite said diaphragm, means for applying a radio frequency polarizing potential between said diaphragm and said main electrode whereby the output of said microphone is a radio frequency signal amplitude modulated in accordance with vibrations of said diaphragm, an amplifier energized in accordance with the output of said microphone, means for detecting the output of said amplifier, and a negative feedback coupling between the output of said detector and said auxiliary electrode, said coupling comprising a network having a loss characteristic which increases at substantially the same rate as the frequency response characteristic of said microphone, between preassigned frequencies in the lower portion of the range to be translated by said transducer.

7. An electro-acoustic transducer in accordance with claim 6 comprising an audio frequency amplifier, and equalizer means between the output of said detector and said audio amplifier for compensating for the rising microphone characteristic at frequencies above the higher of said preassigned frequencies.

8. An electro-acoustic transducer comprising a condenser microphone including a diaphragm and an electrode in juxtaposition thereto, a bridge circuit one arm of which is constituted by said microphone, said bridge circuit including a condenser balancing the static capacitance between said diaphragm and said electrode and defining an arm of the bridge circuit adjacent said microphone and including also a center-tapped winding connected across said microphone and condenser and defining the other two arms of said bridge circuit, means for energizing said winding at radio frequency, and an output circuit connected between the center of said winding and the common terminal of said condenser and microphone.

WILLIAM R. HARRY.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,209,541	Rust	July 30, 1940
2,321,370	Dubilier	June 8, 1943
2,371,373	Badmaieff	Mar. 13, 1945
2,387,845	Harry	Oct. 30, 1945
2,428,272	Evans	Sept. 30, 1947