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[54] ACOUSTIC FEEDBACK STABILIZATION SYSTEM PARTICULARLY SUITED FOR HEARING AIDS

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[51] Int. Cl. **H04r 25/00**

[58] Field of Search .... 179/107, 1 F, 1 FS

[56] **References Cited**

UNITED STATES PATENTS

3,439,129 4/1969 Knauert .... 179/107 R

3,578,913 5/1971 Ufkes .... 179/1 F

FOREIGN PATENTS OR APPLICATIONS

1,551,250 11/1967 France .... 179/107 S

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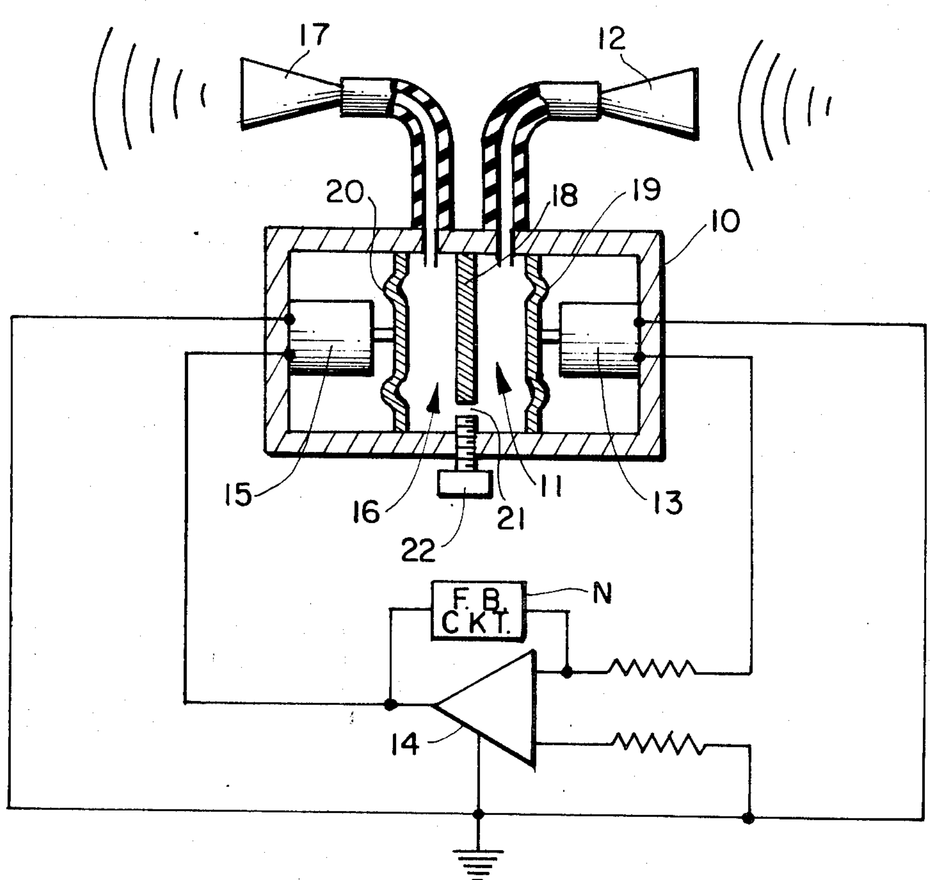
[57] **ABSTRACT**

Linearity is increased and distortion reduced in a miniature acoustic amplifying system by providing an acoustically communicating passage between the microphone and speaker diaphragms to define a negative acoustic feedback loop for the amplifying system. The negative acoustic feedback is feasible because of the miniature arrangement itself of the microphone and speaker wherein the distance of the acoustic passage can be made a small fraction of the wave length of the highest frequency in a given frequency range to be amplified. An adjustment is provided for changing the acoustic coupling between the microphone and speaker diaphragms to thereby adjust the negative feedback loop. This adjustment can also serve as a volume control and the entire system is highly suitable for use in hearing aids wherein miniature microphones and speakers are utilized in close physical proximity.

5 Claims, 3 Drawing Figures



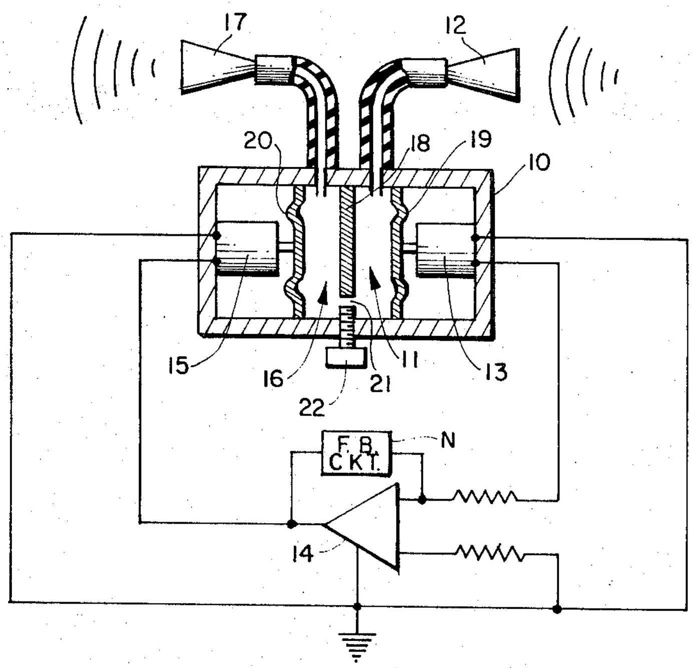


FIG. 1

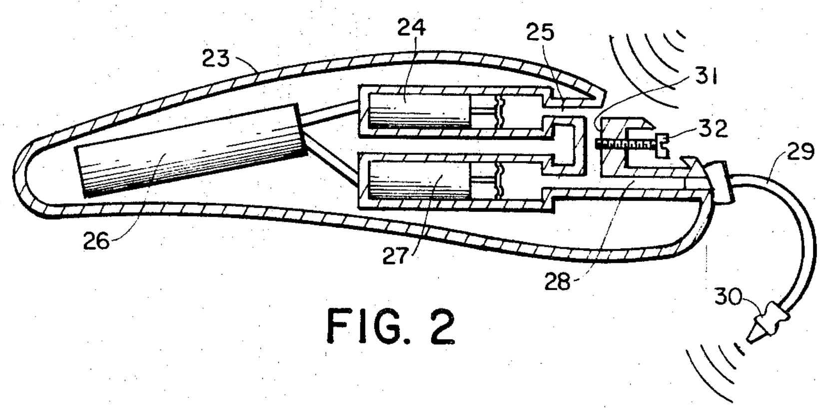


FIG. 2

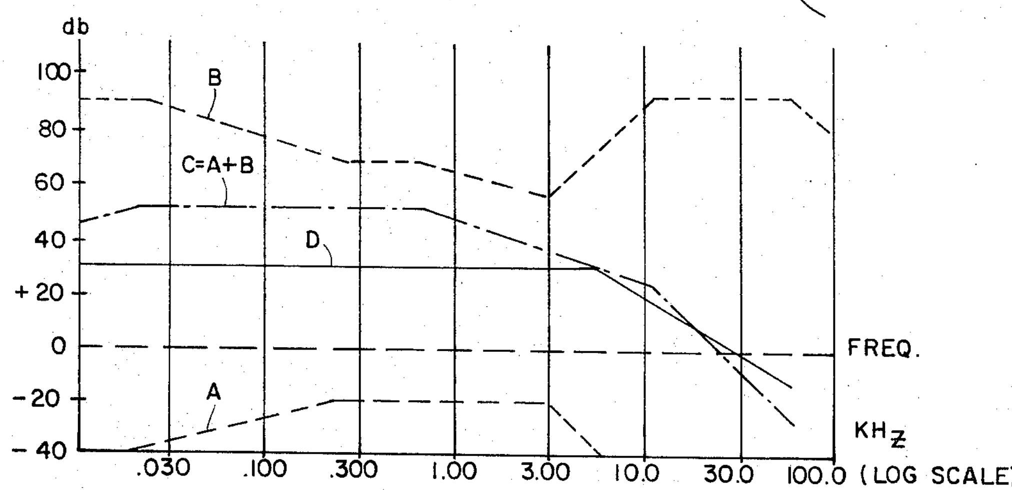


FIG. 3

ACOUSTIC FEEDBACK STABILIZATION SYSTEM PARTICULARLY SUITED FOR HEARING AIDS

This invention relates to stabilization techniques in amplifying systems and more particularly to a novel method and apparatus for increasing linearity and reducing distortion in miniature type amplifying systems such as used in hearing aids.

BACKGROUND OF THE INVENTION

Present day miniature amplifying systems such as utilized in hearing aid devices incorporate a sub-miniature microphone usually acoustically coupled to a pick-up horn through a fine section of tubing. The electrical output from the microphone is amplified through an electronic circuit and the amplified signal in turn drives a receiver or speaker acoustically coupled to an earpiece through another fine section of tubing. In certain types of hearing aids all of the components are packaged in a relatively small enclosure adapted to fit in or adjacent to a person's ear.

Typically, the microphone introduces distortion of the order of 5 percent. The distortion in the electronic amplifier or amplifiers may range between 1 percent and 10 percent depending upon the quality of the circuit and the amount of negative feedback utilized in the amplifier. Because of the relatively small size of the receiver or speaker, approximately 10 percent additional distortion is introduced.

From the foregoing, it will be evident that a substantial improvement in overall performance with respect to distortion as well as linearity would be highly desirable. Limitations are placed on the amount of electronic sophistication that can be introduced not only because of the desirability of maintaining a small package particularly in the case of a hearing aid but also from an economic standpoint.

BRIEF DESCRIPTION OF THE PRESENT INVENTION

The present invention contemplates a novel method and means for accomplishing negative feedback around the entire amplifier chain including the microphone and speaker for increasing linearity and minimizing distortion. This type of feedback control operates directly on the acoustical input into the microphone from the acoustical output by means of an acoustically communicating passage between the responsive diaphragms for the microphone and speaker. The concept of acoustical feedback only becomes feasible when the coupling between the diaphragms takes place over a distance a small fraction of the signal wave length at the highest frequency of the frequency range to be amplified. Such conditions prevail in miniature amplifying systems such as utilized in hearing aids.

In addition to the method step of providing an acoustically communicating passage between the responsive diaphragms of the microphone and speaker, the degree of acoustic coupling between the diaphragms can also be varied by, in effect, varying the physcial cross-section of the passage itself. This variation not only permits adjustment of the negative acoustic feedback loop but also serves as a volume control.

In an actual system including a microphone, amplifier and speaker, the electronic negative feedback loop around the amplifier has its response adjusted to compensate for the response of the microphone and

speaker which responses are relatively poor, to thereby control the overall amplifier gain roll-off characteristics and permit stable closed loop operation with a substantial amount of the negative acoustic feedback taking place.

BRIEF DESCRIPTION OF THE DRAWINGS

A better understanding of the invention will be had by now referring to the accompanying drawings in which:

FIG. 1 is a highly diagramatical showing of a miniature type amplifying system useful in explaining the basic principles of the present invention;

FIG. 2 is a partial cross-section of the manner in which the system of FIG. 1 might be packaged in a typical miniature type device such as a hearing aid; and,

FIG. 3 is a series of curves constituting mathematical representations of frequency responses useful in explaining the manner in which improved performance is obtained in accord with the invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 1 there is schematically depicted an enclosure **10** defining an interior microphone acoustic chamber **11** receiving an acoustic input through a horn **12.** A microphone **13** transduces acoustic signals into electrical signals which pass through an amplifier **14** to a receiver or transducer **15** converting the electrical signals back into acoustic energy within a speaker acoustic chamber **16.** These sound signals may be passed out through a horn **17.** The chambers **11** and **16** have a common wall defined by a rigid partition **18,** the other wall portion being defined by a microphone diaphragm **19** and speaker diaphragm **20** schematically shown as mechanically connected to the microphone **13** and receiver **15** respectively.

The partition **18** of the enclosure **10** includes an acoustically communicating passage **21** between the chambers or diaphragms **19** and **20,** the length of the communicating passage or distance between the diaphragm being substantially less than the wave length of the highest frequency in a contemplated signal frequency range to be amplified.

Means are provided in the form of a threaded member **22** for attenuating the acoustic coupling through the passage **21** in a controlled manner. Essentially, the cross-sectional area of the passage is varied by threading the member **22.**

The amplifier **14** itself includes an electronic feedback loop indicated by the block N adjusted to provide a frequency response characteristic which compensates for the combined response characteristics of the microphone **13** and receiver **15** and their associated diaphragms **19** and **20.** This compensation permits a stable closed loop operation of the amplifying system with a substantial amount of negative acoustic feedback taking place through the passage **21.**

Referring to FIG. 2, there is illustrated a practical packaging for the various components described in FIG. 1. In FIG. 2 there is shown an enclosure **23** dimensioned and shaped to fit behind a person's ear, although the shape can be such as to fit within the ear. As shown, the enclosure includes a microphone **24** and associated diaphragm communicating with an input acoustic passage **25.** The output of the microphone passes into a housing **26** to a suitable amplifier circuit from which amplified signals are passed to a receiver **27.** The housing **26** may incorporate a battery or other equivalent power supply means. The receiver **27** and its associated diaphragm connect with an output acoustic passage **28** through fine tubing **29** to ear piece **30.**

The portion of the enclosure **23** defining an acoustically communicating passage is shown at **31** extending transversely between the input and output acoustic passages **25** and **28** respectively. As in the discussion of FIG. **1,** the length of the acoustically communicating passage from the speaker diaphragm, through passage **31** to the microphone diaphragm is a small fraction preferably less than a quarter wave length of the highest frequency in the contemplated frequency range of signals to be amplified.

Adjustment of the acoustic coupling through the passage **31** is achieved by a threaded member **32** extending partially into a side of the passage as shown. This member **32** is accessible from the exterior of the enclosure **23** so that the effective cross-section and thus acoustic coupling through the passage **31** can be adjusted.

While the theoretical principles involved in the acoustic feedback approach described above are relatively straight forward, realization of a practical system is not obvious or simple because of the mechanical and electromechanical constraints in the acoustic coupling passage and the electrical circuits and mechanical characteristics of the microphone, receiver and associated diaphragms.

As will be appreciated from the previous description, phase shift due to acoustic lag can be minimized by making the dimensions of the acoustically communicating passage very small in comparison with the wave length of the highest frequency in the range under consideration, that is, where the open loop gain is in excess of zero db. In the case of a hearing aid, the upper frequency limit is normally about five KHz. The wave length corresponding to this frequency is close to two and a half inches and in the case of miniature hearing aids, there is no problem in dimensioning the distance between the diaphragms through the passage to a small fraction of this wave length.

On the other hand, phase shift due to electromechanical resonances is critical because the frequency response characteristics of both the microphone and speaker usually roll-off at −12db/octave at the upper end of the design frequency range. This roll-off characteristic usually results from design trade offs aimed at maximizing microphone sensitivity and receiver efficiency, especially in sub-miniature designs. The combined roll-off of −24db/octave must be compensated to yield an overall roll-off for the system of −6db/octave which should extend well above the usable frequency range.

The range over which phase compensation must be accomplished depends on the desired feedback ratio which in turn depends on the desired ratio of inherent open loop distortion to closed loop distortion requirements.

By way of specific example such as for the microphone, amplifier, receiver and acoustical passage characteristics of the embodiment shown in FIG. **2,** assume the following conditions:

1. L_a = 20db, where L is the combined microphone and speaker acoustic input to acoustic output loss.
2. D_o = 15 percent, where D_o is the maximum open loop distortion.
3. D_c = 1.5 percent, where D_c is the desired maximum closed loop distortion.
4. G_c = 30db, where G_c is the closed loop acoustic gain.
5. Range of frequency of signal F is from 0.3 KHz to 5 KHz.

Under the foregoing conditions, certain design parameters may be established as follows:

If G_o is the open loop gain and M is the feedback ratio, which should be approximately 20db for a ten to one reduction in distortion, then:

$G_o = G_c = M$ and the electronic amplifier gain is:

$G_o + L_a$ = 70db.

A closed loop stabilized amplifier is thus required including the necessary shaping networks.

The open loop frequency response must be compensated for −6db/octave roll-off starting at 0.5 KHz.

Referring now to FIG. **3,** there are diagramed the loop response characteristics. With reference to the bottom dashed curve A, there is represented, approximately, the combined average frequency response of the microphone and receiver.

The top dotted line curve B represents the necessary closed loop response of the electrical amplifier circuit after adjustment of the electronic negative feedback to compensate for the response of the microphone and receiver or speaker shown in dashed curve A.

The dash-dot curve C represents the resultant system open loop response; that is, the sum of the curves A and B. This frequency response characteristic is thus tailored to ensure stability.

The sold curve D represents the complete closed loop response for the entire amplifier system when the negative acoustic feedback is applied and it will be noted that the response is substantially flat from 0.030 KHz to 5 KHz.

The negative acoustic feedback technique thus reduces substantially distortion and erratic response variations normally contributed by the microphone and receiver and associated diaphragms. In addition, an increase in linearity is provided. With respect to improved linearity, it is to be understood that by increasing the linearity it is then possible to more easily maintain a desired amplitude contouring.

While the invention has been described with respect to hearing aids, it will be evident that the principles are applicable to any acoustic amplifier system wherein the microphone and receiver are physically disposed in close proximity such as might be the case in earphones used for high fidelity sound reproduction or in industrial applications where it is desired to add cordless amplification or response shaping to counteract ambient noise conditions or enhance sensitivity of hearing in particular frequency zones.

What is claimed is:

1. A method of increasing linearity and reducing signal distortion over a given frequency range in a miniature acoustic amplifying system comprised of a microphone, amplifier and speaker, including the steps of:

a. providing an acoustically communicating passage between the responsive diaphragms for the microphone and speaker of length less than one quarter of the signal wave length of the highest frequency in said range; and

b. varying the degree of acoustic coupling between the diaphragms to provide an adjustable negative acoustic feedback loop for said amplifying system.

2. The method of claim **1,** including the step of providing an electronic negative feedback loop around said amplifier having its response adjusted to compensate for the response of the microphone and the speaker to thereby control the overall amplifier gain roll-off characteristics and permit stable closed-loop operation with a substantial amount of said negative acoustic feedback taking place.

3. A miniature acoustic amplifying system having a microphone, amplifier and speaker and including:

a. an enclosure for the microphone and speaker diaphragms, a portion of said enclosure defining an acoustically communicating passage between the diaphragms of length substantially less than the wave length of the highest frequency in a contemplated signal frequency range to be amplified to thereby provide acoustic coupling between the microphone and speaker; and

b. means in said passage for attenuating the acoustic coupling through said passage in a controlled manner whereby a negative acoustic feedback loop is provided for said amplifying system to increase linearity and reduce distortion.

4. A system according to claim **3,** in which said amplifier includes an electronic negative feedback loop adjusted to provide a frequency response characteristic which compensates for the response characteristics of the microphone and speaker to permit stable closed loop operation with a substantial amount of said negative acoustic feedback taking place.

5. A system according to claim **3,** in which said enclosure is dimensioned and shaped to fit a person's ear, and includes an input acoustic passage communicating with said microphone and an output acoustic passage communicating with said speaker, said acoustically communicating passage extending between the input and output passages; and in which said means in said passage for attenuating the acoustic coupling includes a threaded member extending partially into a side of the passage and accessible from the exterior of said enclosure for threaded adjustment whereby the effective cross-sectional area of the passage is adjustable by the degree of threading of the member into the passage, so that a hearing aid is provided in which the volume can be adjusted by said member.

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