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DIRECTIONAL MICROPHONE WITH FREQUENCY INDEPENDENT BEAMWIDTH

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FIG. 1

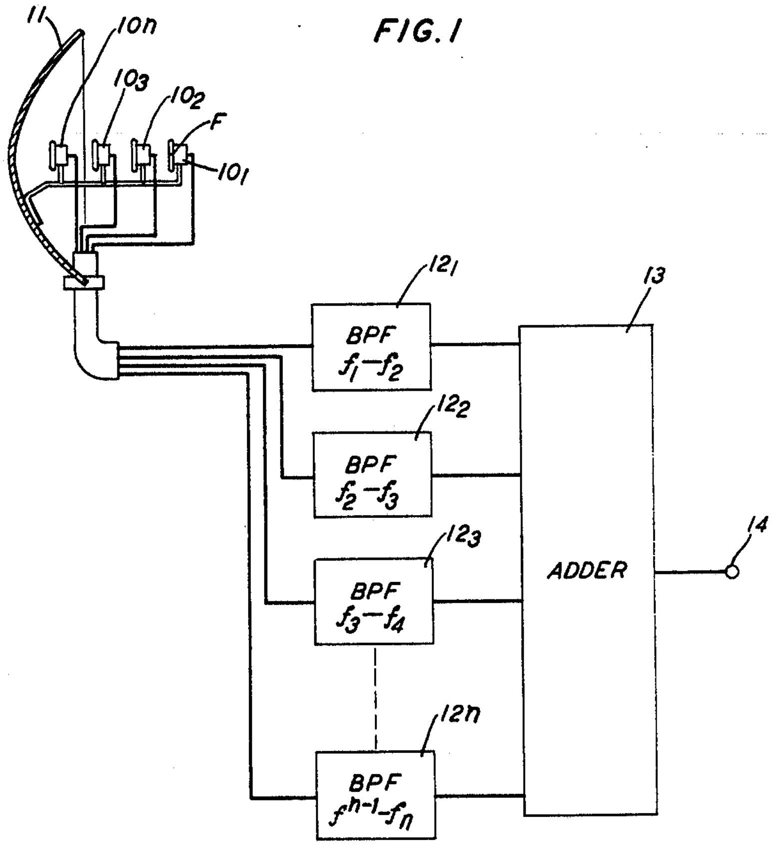


FIG. 2

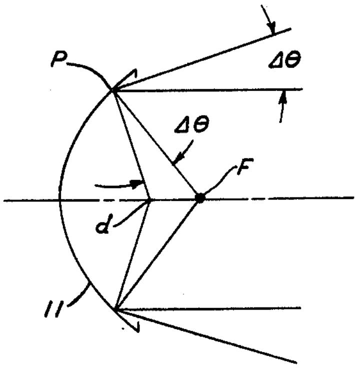
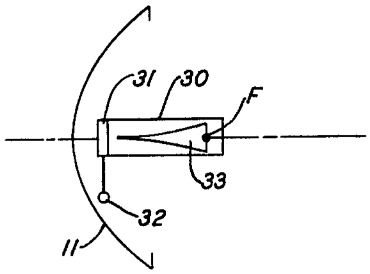


FIG. 3



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DIRECTIONAL MICROPHONE WITH FREQUENCY INDEPENDENT BEAMWIDTH

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U.S. Cl. 179—1 **12 Claims**

ABSTRACT OF THE DISCLOSURE

Fall-off of beamwidth with frequency in a directional microphone system employing a signal receptor located at or near the focus of a reflector is overcome by using, effectively, a number of transducers spaced along the axis of the reflector. The frequency range of the system is divided into a number of subbands and signals are developed individually for each. Since defocusing broadens the width of the acceptance beam, the individual points of reception are selectively spaced along the reflector axis to achieve sufficient defocusing to assure a constant beamwidth for all subbands. All subband signals are added together to produce an output signal.

BACKGROUND OF THE INVENTION

This invention relates to techniques for concentrating sound for selective reception and, in particular, to improved directional microphones arranged to exhibit appreciable gain over a broad frequency range of sounds emanating from within a relatively narrow acceptance beam.

Field of the invention

Directional microphones find use in a variety of services, for example in broadcasting, in conference telephone systems, and, in general, wherever it is necessary to select certain received sounds from among others. Since the apparent intensity of received sounds is dependent upon the beamwidth of the microphone, it is generally desirable, for directional reception, that the beamwidth be extremely narrow, of the sort normally defined as a "pencil" beam. Although concentration of sound into such a narrow beam is relatively simple at selected frequencies, the degree of concentration falls off, and the beamwidth expands, as the frequency range is enlarged toward lower frequencies.

Discussion of the prior art

Although directional microphones have assumed a number of configurations in the art, one effective arrangement employs a microphone element placed at the focus of a reflector. By using a relatively large reflector, the beamwidth of the system may be made arbitrarily narrow at a given frequency in order to concentrate sound reaching the system at its focus. Thus, the surface of the reflector is shaped so that all of the various pencils of incident sound are concentrated at the focus, i.e., the reflector has a parabolic shape.

Unfortunately, the directional characteristic of such an arrangement is a function of frequency. For a microphone element located at the focus of a large reflector system, a beamwidth of satisfactorily narrow proportions is achieved for high frequencies but is considerably broadened for lower frequencies. If a fairly broad-band signal, such as speech, is to be picked up by the microphone, such a variation of beamwidth with frequency is undesirable. High frequency signals within a relatively narrow beam are directionally received, but low-frequency signals from a much broader beam are also received.

Conversely, low frequencies from a sound source somewhat off the axis of the reflector will be received fairly well but high-frequency components will be lost. As a result, the unique directional properties of the system are lost for a broad-band signal.

The beamwidth of the directional microphone system is, furthermore, dependent upon diffraction effects and is defined precisely only in perfectly focused systems, i.e., in systems in which the microphone element is at the focus of the reflection. The beam can be broadened to accommodate a different range of frequencies by defocusing the system. This is generally accomplished by moving the microphone along the axis of the reflector away from the focal point. The farther the microphone is moved from the focal point, the broader the beam becomes. Moreover, the amount of beam broadening that can be accomplished by defocusing increases with increasing frequency. Defocusing, although effective to broaden the beamwidth for a wide range of frequencies, nevertheless reduces the over-all effectiveness of the microphone and is, at most, a compromise measure.

SUMMARY OF THE INVENTION

It is thus a principal object of this invention to overcome the frequency dependence of prior art directional microphone arrangements. It is another object to achieve a highly directional microphone characteristic that is essentially independent of frequency.

According to the invention, these and other objects are attained by developing signals from energy reaching locations along the axis of symmetry of a reflector system as a function of frequency and combining all of the signals to form a composite output. Since defocusing broadens the width of the acceptance beam of such a directional system, distributing the points of reception of energy according to frequency assures a proper degree of defocusing for signals of differing frequencies to yield a substantially constant beamwidth for all signal frequencies.

In one embodiment of the invention a parabolic reflector system is equipped with a separate transducer element for each of several discrete frequency ranges established for the system. The transducer element for signals in the lowest frequency range is placed at the focus of the reflector, and the signals developed by it are passed through a bandpass filter with frequency limits defined for a specified beamwidth. A second transducer is positioned substantially on the axis of the reflector at a point between the focus and the reflector, and signals derived from the second transducer are supplied to a second bandpass filter whose frequency limits are selected to assure an equivalent beamwidth for signals of that frequency. Thus, the inherent focusing of higher frequency signals is compensated by sufficient defocusing to maintain a specified beamwidth. Similarly, a separate transducer is employed for each band of frequencies selected for the system, each transducer being placed between the focus and the reflector at a point selected to yield substantially uniform beamwidth.

In accordance with another embodiment of the invention, a coupling system is employed for recovering energy as a function of frequency along the axis of a reflector. The coupling system, typically a cavity with a tapered port, acts much as a waveguide with a distributed frequency characteristic, that is, as a low pass filter with continuously decreasing cut-off frequency along its length. By supporting the coupler in substantial alignment with the axis of symmetry of a reflector, received energy is developed at defocused points along the axis to maintain a uniform beamwidth as a function of frequency. Energy recovered by the coupler is supplied to a transducer.

Similarly, any form of distributed transducer system that develops signals of different frequencies along its length may be employed in the practice of the invention.

DRAWINGS

This invention will better be understood by reference to the following detailed description of the drawings, in which:

FIG. 1 is a schematic representation of a directional microphone system which illustrates the principles of the invention;

FIG. 2 is a diagram which illustrates certain relations between beamwidth and the degree of defocusing obtained in the apparatus of FIG. 1; and

FIG. 3 is a diagram which illustrates another form of a distributed transducer which may be used in the practice of the invention.

DETAILED DESCRIPTION

FIG. 1 illustrates a suitable arrangement for achieving a highly directional microphone characteristic that is essentially independent of frequency. A plurality of individual transducers, such as microphone elements $\mathbf{10_1}$, $\mathbf{10_2}$, . . . $\mathbf{10_u}$, are supported axially with relation to a reflector system **11**. Preferably reflector **11** is a section of a paraboloid whose focus is at F. Each microphone supplies a signal individually to one of bandpass filters $\mathbf{12_1}$, $\mathbf{12_2}$, . . . , $\mathbf{12_n}$. Filters **12** are selected to divide the frequency band to be accommodated by the system into a number of subbands, each one of which is respectively associated with one of microphones **10**. Signals passed by filters **12** are supplied to an algebraic combining network, e.g., adder **13**, to form a composite signal which is delivered to output terminal **14**.

In a system of the type illustrated in FIG. 1, the half power beamwidth of a microphone placed at the focus F of reflector **11** is given roughly by the formula:

$$\theta=\frac{59\lambda}{d}$$

where d is the diameter of parabolic reflector **11** and λ is the wavelength of sound being received when measured in the same units as d. Consider, for example, a reflector 6 feet in diameter. Beamwidth for a perfectly focused system as a function of frequency will be approximately as shown in the table below.

f in Hz.:	Beamwidth in degrees
300	37
600	18.5
1200	9.2
2400	4.6
4800	2.3

As the system is defocused, as by moving a microphone element nearer to the reflector, the beam becomes broader.

In accordance with the invention, these considerations are turned to account, in one embodiment, by placing the microphone corresponding the lowest band, e.g., $\mathbf{10_1}$, at the focus F of reflector **11**. Signals developed by microphone $\mathbf{10_1}$ are accordingly passed through filter $\mathbf{12_1}$, and restricted to a relatively narrow band of frequencies at the low end of the system response band. The microphone corresponding to the next higher band, e.g., $\mathbf{10_2}$, is placed between the focus and the surface of the reflector at a position such that the beamwidth for signals received by microphone $\mathbf{10_2}$ is the same as that for signals received by microphone $\mathbf{10_1}$, at the focus. Signals from microphone $\mathbf{10_2}$ are accordingly delivered to bandpass filter $\mathbf{12_2}$ and limited to the next higher contiguous band of frequencies. The remaining microphone elements, $\mathbf{10_3}$, . . . , $\mathbf{10_n}$, are similarly placed at points along the axis of reflector **11** to assure equal beamwidths for corresponding frequency bands.

Because of diffraction effects, beamwidth still may vary somewhat with frequency across each subband. However, the amount of variation can be made as small as is desired by making the bands sufficiently narrow. In the lowest band the beamwidth is determined entirely by diffraction and varies inversely with frequency. In the next band, however, defocusing as well as diffraction contribute to bamwidth determination. Defocusing is approximately independent of frequency and beamwidth is due essentially to diffraction; hence, it varies somewhat with frequency. This means that the variation with frequency is not so rapid and that a broader subband can be used. At higher frequencies, the contribution of diffraction to beamwidth is even less important and the bands can be made even broader.

In a typical microphone system, a variation of beamwidth of any one transducer by a factor of two is considered acceptable. This means that the lowest band is made, for example, one octave wide. For simplicity, the frquencies corresponding to the edges of this band are designated 1 *f* Hz. and 2 *f* Hz. The corresponding beamwidths for signals at these frequencies are designated 1.0 radian and 0.5 radian. It is desirable that the beamwidth for the next higher band also varies from 1.0 radian to 0.5 radian. At the lower edge of the band, beamwidth due to defraction is 0.5 radian, so that an additional 0.5 radian of beamwidth must be obtained by defocusing. As frequency is increased above 2 *f* Hz., the 0.5 radian beamwidth due to defraction decreases, but the 0.5 radian beamwidth due to defocusing remains constant. Thus, all frequencies above 2 *f* Hz. can be included in one frequency band.

A typical two-microphone system of this construction divides the frequency band into two parts. Assuming that the frequencies to be accommodated by the system are all above 600 Hz., the first range is established betwen 600 Hz. and 1200 Hz. In the example of FIG. 1, this range is established by one of the bandpass filters, e.g., $\mathbf{12_1}$. All frequencies above 1200 Hz. are accommodated in the second channel; this range is established by filter $\mathbf{12_2}$. For a reflector **11** with a diameter of approximately 12 feet, the beamwidth for such a system varies from approximately 9 degrees to 4.5 degrees.

If a smaller variation of beamwidth with frequency is desired, more bands are employed, e.g., additional microphone elements and corresponding bandpass filters are used. For example, if the beamwidth is to be held within a range of 1 to 1.4, four bands are employed as follows:

Lowest band—1 *f* to 1.4 *f* Hz.
Second band—1.4 *f* to 2.4 *f* Hz.
Third band—2.4 *f* to 8.4 *f* Hz.
Fourth band—8.4 *f* to upper limit of system response.

In a typical system of this sort in which frequencies above 600 Hg. are to be accommodated, the appropriate bandwidths are as follows:

Lowest band—600–840 Hz.
Second band—840–1440 Hz.
Third band—1440–5040 Hz.
Fourth band—5040 Hz. to upper limit of system response.

FIG. 2 illustrates the angular defocusing produced by a given displacement of a microphone **10** from the focus of reflector **11**. The pencil beam of energy reaching a point P on the surface of the reflector, selected to divide the area of the reflector into two equal parts, from a line parallel to the axis of the reflector, is directed to focus F of the system. A signal "ray" from a broader beam, e.g., $\Delta\theta$ degrees from a line parallel to the axis of the reflector, reaches point P at a greater angle and hence is directed to point d on the axis of the reflector nearer the reflector surface. Consequently, a microphone located at point d, spaced away from focus F, is responsive to signals from a beamwidth of $2\Delta\theta$ degrees greater than the beamwidth given by the formula

$$\theta=\frac{59\lambda}{d}$$

That is, the defocused beamwidth is approximately

$$\theta_d = \frac{59\lambda}{d} + 2\Delta\theta$$

It must, of course, be recognized that the formula which relates broadening of the beam to axial defocusing is not exact. It is, therefore, best to approximate the positions of the several transducer elements in a new system according to the formula, and, finally, to determine experimentally the exact microphone positions which produce the desired amount of beam broadening. Moreover, the system achieves the best results when the diameter of the dish is large compared to the longest wavelength of interest. With this relationship, beamwidth is restricted to a few degrees.

FIG. 3 illustrates another suitable technique for recovering signals from points along the axis of a reflector system as a function of frequency. In this embodiment, a distributed port coupler **30**, or the like, is supported (by means not illustrated) substantially in alignment with the axis of symmetry of reflector **11**. Coupler **30** is equipped with a tapered port or slot **33**. The largest opening of port **33** is made to coincide with the focus of the reflector system and progressively narrower openings are thus placed between the focus and reflector **11**. Consequently, coupler **30** acts as a low pass filter with a continuously decreasing cut-off frequency. Energy at the lowest frequency are received at the opening coincident with focus F, and energy with progressively higher cut-off frequencies are received nearer the reflector surface. By suitably proportioning port **33**, a desired characteristic is achieved for received energy such that uniform beamwidth across the band is maintained. Transducer **31**, associated with coupler **30**, supplies an output signal by way of terminal **32**. Techniques for constructing suitable couplers are well known to those skilled in the art and follow, in large measure, comparable techniques used in the field of microwaves.

It is evident that a variety of techniques may be employed for receiving individual signals from selected points along the axis of the reflector system. Thus, although a distributed transducer system or individual transducers are conveniently employed, a single transducer of a line-form with individual segments of response may also be employed. Alternatively, an electrostatic transducer with a common electrode but individually responsive segments is satisfactory. A tubular transducer with frequency responsive elements axially spaced may also be employed. Furthermore, additional equalization and amplification elements may be employed in the several signal channels, if desired, to develop a composite signal with any desired frequency characteristic, and any desired form of algebraic combining means may be used.

Numerous other variations may therefore be made by those skilled in the art without departing from the spirit and the scope of the invention.

What is claimed is:

1. A device of the character described which comprises,
reflector means having an axis of symmetry, and
means in substantial alignment with said axis of symmetry for developing signals representative of energy received at locations along said axis as a function of frequency.

2. A device as defined in claim **1** wherein said reflector means comprises,
a paraboloid.

3. A device as defined in claim **1** wherein, said means for developing signals comprises,
a plurality of transducers,
means for supporting said plurality of transducers in spaced relation along said axis of symmetry, and
means for combining selected frequency components derived from each of said transducers.

4. A device as defined in claim **1** wherein,
said means for developing signals comprises,

distributed coupling means responsive along its length to signals as a function of frequency, and
transducer means associated with said coupler for developing signals in response to energy received by said coupler.

5. A device of the character described which comprises,
reflector means having an axis of symmetry,
distributed trandsucer means,
means for supporting said transducer means in substantial alignment with said axis of symmetry, and
means for combining select frequency components derived from said distributed transducer means.

6. In combination,
a reflector,
a trandsucer system responsive to sound energy as a function of frequency along its length,
means for positioning said transducer system between said reflector and its focus along a line substantially congruent with the axis of said reflector,
means for selecting signals developed by said transducer system to assure substantially the same acceptance beamwidth for all frequencies within a prescribed band of frequencies, and
means for combining all of said selected signals.

7. In combination,
a parabolic reflector,
a plurality of acoustic transducers,
means for deriving signals from each of said transducers within prescribed frequency bands contiguous to one another within a specified frequency range,
means for positioning individual ones of said transducers at selectively-spaced intervals between said reflector and its focus along a line substantially congruent with the focal axis of said reflector,
said intervals being selected to establish substantially the same acceptance beamwidth for each of said transducers regardless of the frequency band prescribed for said transducers, and
means for combining signals developed by all of said transducers.

8. A directional microphone, which comprises,
a concave reflector,
a plurality of transducers responsive to sound energy for developing signals within contiguous frequency ranges in the passband of said energy,
at least one of said transducers being positioned by the focus of said reflector and the others of said transducers being positioned at spaced intervals along the axis of said reflector between said reflector and its focus,
said intervals being selected to establish substantially the same acceptance beamwidth for all of said frequency selective trandsucers, and
means for combining signals developed by all of said transducers.

9. A directional microphone as defined in claim **8**, wherein,
said reflector is a sector of parabola of revolution.

10. A directional microphone as defined in claim **8**, wherein,
said plurality of transducers comprises two elements, the first being responsive to acoustic energy in the range of 600 Hz. to 1200 Hz., and the second being responsive to acoustic energy above 1200 Hz.

11. A directional microphone as defined in claim **8**, wherein,
said plurality of transducers comprises four elements responsive, respectively, to acoustic energy in the ranges of 600 Hz. to 840 Hz., 840 Hz. to 1440 Hz., 1440 Hz. to 5040 Hz., and the ranges above 5040 Hz.

12. A directional microphone as defined in claim **8**, wherein,
said means for combining signals developed by said transducers comprises,

an algebraic network for linearly adding together said developed signals.

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U.S. Cl. X.R.

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