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APPLICATION NUMBER	PATENT NUMBER	GROUP ART UNIT	FILE WRAPPER LOCATION
60/368,209			9200Q 0021 001 06



Correspondence Address/Fee Address Change

The following fields have been set to Customer Number 98195 on 08/09/2010

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Apd

Transmittal of Provisional Patent Application for Filing

Certification under 37 CFR §1.10 (if applicable)

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March 27, 2002

Date of Deposit

I hereby certify that this Request, enclosed application and any other documents referred to as enclosed herein, are being deposited in an envelope with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR §1.10 on the date above and addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231.

Jennifer L. Mahoney

(Print Name of Person Mailing Application)

Jennifer Mahoney
(Signature of Person Mailing Application)

Request for Filing a Provisional Patent

Application Under 37 CFR §1.53(c)

**Box Provisional Patent Application
Assistant Commissioner for Patents
Washington, D.C. 20231**

Sir:

This is a request for filing a Provisional Application for Patent under 37 CFR §1.53(c).

1. Title of Invention:

**MICROPHONE AND VOICE ACTIVITY DETECTION (VAD) CONFIGURATIONS FOR USE
WITH PORTABLE COMMUNICATION SYSTEMS**

2. Inventor Applicant(s):

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4. Enclosed documents accompanying this transmittal sheet:

☒ Return Post card for USPTO Date Stamp ☒ Certificate of Express Mail
☒ Application Number of pages: 26 ☐ Other: _____

PROVISIONAL APPLICATION FILING ONLY

Page 1 of 2

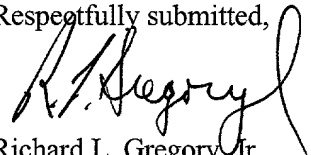
5. **Government Interest**

- ☐ This invention was made by an agency of the United States Government, or under contract with an agency of the United States Government. The name of the U.S. Government Agency and the Government contract number are:

6. **Method of Payment:**

- ☐ Applicant claims small entity status. See 37 CFR §1.27
- ☒ Please charge the Filing Fee (\$160.00) and any other fees necessary for timely filing of this application to Deposit Account 50-0665.

Respectfully submitted,



Richard L. Gregory, Jr.
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PROVISIONAL APPLICATION FILING ONLY

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Patent

Certification Under 37 C.F.R. §1.10 (if applicable)

March 27, 2002

Date of Deposit

Jennifer L. Mahoney

Jennifer Mahony
(Signature of Person Mailing Application)

(Signature of Person Mailing Application)

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MICROPHONE AND VOICE ACTIVITY DETECTION (VAD) CONFIGURATIONS FOR USE WITH PORTABLE COMMUNICATION SYSTEMS

RELATED APPLICATIONS

This application relates to and claims the benefit of United States Patent Application Numbers 60/294,383 filed May 30, 2001, 09/905,361 filed July 12, 2001, 60/335,100 filed October 30, 2001, 60/332,202 and 09/990,847 both filed November 21, 2001, the application titled PATHFINDER-BASED VOICE ACTIVITY DETECTION (PVAD) USED WITH PATHFINDER NOISE SUPPRESSION (Application Number to be assigned; attorney docket number 37212.8015.US.00), filed March 5, 2002, the application titled ACCELEROMETER-BASED VOICE ACTIVITY DETECTION (VAD) (Application Number to be assigned; attorney docket number 37212.8016.US.00), filed March 5, 2002, the application titled ACCELEROMETER-BASED VOICE ACTIVITY DETECTION (VAD) AND PATHFINDER NOISE SUPPRESSION (Application Number to be assigned; attorney docket number 37212.8017.US.00), filed March 5, 2002, the application titled ARRAY-BASED VOICE ACTIVITY DETECTION (AVAD) AND PATHFINDER NOISE SUPPRESSION (Application Number to be assigned; attorney docket number 37212.8018.US.00), filed March 5, 2002, the application titled PATHFINDER NOISE SUPPRESSION USING AN EXTERNAL VOICE ACTIVITY DETECTION (VAD) DEVICE (Application Number to be assigned; attorney docket number 37212.8019.US.00), filed March 5, 2002, the patent application titled ECHO SUPPRESSION USING PATHFINDER NOISE SUPPRESSION (Application Number to be assigned; attorney docket number 37212.8021.US.00), filed March 26, 2002, and the patent application titled TWO-MICROPHONE FREQUENCY-BASED VOICED ACTIVITY DETECTION (VAD) (Application Number to be assigned; attorney docket number 37212.8022.US.00), filed March 26, 2002, all of which are currently pending and incorporated herein by reference.

DETAILED DESCRIPTION

This document describes the many different hardware implementations that work with the Pathfinder noise suppression system described in the Related Applications. As such, I will describe each implementation in detail and describe how it may be used in concert with

Pathfinder to reduce noise transmission in communication devices. The use of these physical configurations includes but is not limited to applications such as communications, speech recognition, and voice-feature control of applications and/or devices.

The headings provided herein are for convenience only and do not necessarily affect the scope or meaning of the claimed invention. The following description provides specific details for a thorough understanding of, and enabling description for, embodiments of the invention.

However, one skilled in the art will understand that the invention may be practiced without these details. In other instances, well-known structures and functions have not been shown or described in detail to avoid unnecessarily obscuring the description of the embodiments of the invention.

Unless described otherwise herein, the construction and operation of the various blocks shown in the Figures are of conventional design. As a result, such blocks need not be described in further detail herein, because they will be understood by those skilled in the relevant art. Such further detail is omitted for brevity and so as not to obscure the detailed description of the invention. Any modifications necessary to the blocks in the Figures can be readily made by one skilled in the relevant art based on the detailed description provided herein.

Each of the following implementations include at least two microphones and one “external” VAD (voiced activity detection) device, as described in the Related Applications. We will discuss both handsets and headsets. Handsets include communications devices including but not limited to microphones, speakers, communications electronics, radiofrequency (RF) transceivers, such as mobile phones, PDAs, wireline phones, Internet Phones. Headsets are self-contained devices including microphones and speakers normally attached to/worn on the body. Headsets will often physically plug into handsets in order to function, although they can communicate with the handset using RF technology. The difference is that the handset is normally capable of communicating with a communications network on its own, and the headset normally requires a handset or similar device to communicate over a communications network.

Our research has shown that: the physical implementation of a headset or handset with two microphones and an external VAD device is unique; the physical implementation of a headset or handset with two microphones and an external VAD device to enable noise suppression is unique; and the physical implementation of a headset or handset with two microphones and an external VAD device to enable noise suppression using the Pathfinder noise suppression algorithm (see the Related Applications) is unique.

The definition of “noise suppression” as used herein includes the suppression of acoustic noise from external sources as well as the suppression of noise coming from the headset or handset loudspeaker. The latter is normally referred to as “echo suppression”, but the Pathfinder algorithm treats the acoustic signal coming from the loudspeaker as just another noise source and removes it. For more information see the Related Applications. The external VAD device may include but is not limited to an accelerometer or electromagnetic device and associated software or acoustic microphones and associated software. For further information see the Related Applications.

Outline

I. Microphones

- a. Description of different types of microphones used in this disclosure
- b. Mixed OMNI and UNI microphones
 - i. UNI as signal microphone
 - ii. OMNI as signal microphone, UNI oriented away from speaker
- c. UNI and UNI
 - i. Noise UNI oriented away from speaker
 - ii. Array orientation
- d. OMNI and OMNI
 - i. Array orientation

II. VAD devices description

- a. Aliph GEMS
- b. Accelerometer based VAD

- i. In ear
 - ii. Out of ear
- c. Two-microphone acoustic VADs
 - i. Array VAD
 - ii. Pathfinder VAD
 - iii. Stereo VAD
- d. Other conventional acoustic VAD algorithms

III. Combinations of microphone and VAD configurations

IV. Conclusions

For each possible configuration herein, a handset and headset design is provided. The important part of each design is the locations and orientations of the microphones and VAD device. All other components (including the speaker and mounting hardware for headsets and the speaker, buttons, plugs, physical hardware, etc. for the handsets) are inconsequential for the operation of the Pathfinder noise suppression algorithm and will not be discussed in great detail.

Furthermore, the method of connection (either physical or electromagnetic or otherwise) of the headsets discussed is inconsequential. These designs will work with any type of connection, so they are not specified in this disclosure.

I. Microphones

The Pathfinder setup is sensitive to microphone type (omnidirectional or unidirectional, including the amount of unidirectionality) and orientation of the microphones, but it is not sensitive to the response of individual microphones. Thus the microphones do not need to be matched in terms of frequency response nor do they need to be especially sensitive or expensive. In fact, most of our designs use off-the-shelf microphones, which have proven to be very effective. As an aid to review, the Pathfinder setup is shown in **Figure 1** and is explained in detail in the Related Applications. However, the relative placement and orientation of the microphones do matter, and these issues will be addressed in the following section.

a. Description of microphones used in this disclosure

There are many different types of microphones in use today, but the ones we will focus on are omnidirectional (OMNI) and unidirectional (UNI). OMNI microphones are characterized by relatively consistent frequency response with respect to relative acoustic signal location, and UNI microphones are characterized by responses that vary with respect to the relative orientation of the acoustic source and the microphone. Specifically, they are normally designed to be less responsive behind and to the sides of the microphone so that signals from the front of the mic are emphasized. There are several types of UNI microphones made and the types are differentiated by the microphone response to environmental noise. Several types of microphones are listed in **Figure 2**. It has been found that both cardioid and super-cardioid unidirectional microphones work well in these implementations, but hyper-cardioid and bi-directional microphones may be used if oriented correctly. Also, “close-talk” microphones (which de-emphasize acoustic sources more than a few centimeters away from the microphone) can be used as the signal mic 102, and for this use the close-talk microphone is considered in this disclosure as a UNI microphone.

b. Mixed OMNI and UNI microphones

In this implementation, an OMNI and UNI microphone are mixed to form a two-microphone array to implement Pathfinder. There are many combinations, including:

i. UNI as signal microphone

In this configuration the UNI mic is used as the signal mic 102 and an OMNI is used as the noise microphone. They are normally used within a few centimeters of each other, but can be located 15 or more cm apart and still function adequately. **Figure 3** shows how the microphones may be oriented in a general fashion as well as a possible implementation of this setup for a headset and a handset. The important point here is that the UNI must point toward the user’s mouth. The OMNI has no specific orientation. This setup works well for the Pathfinder algorithm since the signal mic contains mostly signal and the noise mic mainly noise. Equivalently, the signal mic has a high signal-to-noise ratio (SNR) and the noise mic has a lower SNR. This enables the Pathfinder algorithm to be effective.

ii. OMNI as signal microphone, UNI oriented away from the speaker

In this implementation the OMNI microphone is used as the signal mic 102 and a UNI is positioned as the noise microphone 103. The reason for this is to keep the amount of signal in the noise mic small so that the Pathfinder algorithm can be simplified and de-signaling (the accidental removal of signal) can be kept to a minimum. This configuration has the most promise for simple add-ons to existing handsets, which already use an OMNI mic to capture speech. Again, the two microphones can be located quite close together (within a few centimeters) or 15 centimeters or more away. The best performance is seen when the two microphones are quite close (less than approximately 5 cm), but when the UNI is far enough away from the user's mouth (approximately 10-15 centimeters depending on the microphone) so that the UNI directionality functions efficiently.

In this configuration, where the signal microphone is an OMNI, the UNI is oriented in such a way as to keep the amount of signal in the UNI mic small compared to the amount of signal in the OMNI. This means that if the OMNI is oriented toward the speaker's mouth, the UNI will be oriented away from it, and the amount it is oriented away from the speaker is denoted by ϕ , which can vary between 0 and 180 degrees¹. **Figure 4** shows how the microphones may be oriented with the UNI at 180 degrees from the speaker and a possible implementation of this setup for a headset and a handset, and **Figure 5** shows the same configuration with the UNI oriented at about 90 degrees from the user's mouth. These implementations work well as long as the SNR of Mic 1 is greater than Mic 2. If ϕ gets too large the noise originating in front of the speaker may not be captured as well, leading to slightly reduced denoising performance. In addition, if ϕ gets too small a larger amount of signal will be captured by the noise microphone, increasing computational expense. Therefore it is recommended for maximum performance that the angle of orientation for the UNI microphone in this configuration to be approximately 90-135 degrees, as shown in **Figure 5**. This allows the noise originating from the front of the user to be captured more easily, improving the denoising performance. It also keeps the amount of speech signal captured by the noise microphone small so that the more computationally intense full Pathfinder implementation does not have to be used. Experimentation can quickly determine the optimal angle for any UNI/OMNI combination desired.

¹ ϕ describes the angle between the direction of one microphone and the direction of another microphone. ϕ can be specified in any plane.

c. UNI and UNI

In this implementation two UNI microphones are used, one for the noise and one for the signal. The same type of orientations for the noise mic as discussed in **I-b-ii** can be used for the UNI noise mic in these configurations, as well as a different linear array type of configuration. In all of the following the signal UNI is oriented toward the user's mouth.

i. Noise UNI oriented away from speaker

Similar to **I-b-ii** above, orienting the noise UNI away from the speaker can reduce the amount of signal captured by the noise microphone, allowing a simpler version of Pathfinder to be used. Once again the angle of orientation with respect to the speaker's mouth can vary between 0 and 180 degrees. At or near 180 degrees noise generated from in front of the user may not be captured well enough by the noise mic to allow maximal suppression of the noise. Therefore if this configuration is used, it will work best if a cardioid is used as the signal mic and a super-cardioid as the noise mic. This will allow limited capture of noise to the front of the user, increasing the noise suppression. However, more speech may be captured as well and can result in de-signaling if the simple version of Pathfinder is used. A compromise must be sought between noise suppression, de-signaling, and computational complexity with this configuration. **Figure 6** shows an embodiment having a microphone orientation of 180 degrees as well as a possible implementation of this setup for a headset and a handset.

To increase the noise suppression performance, the noise UNI may (as above in **I-b-ii**) be oriented more toward the speaker to better characterize the noise coming from the front of the speaker. Once again, a ϕ between 90 and 135 degrees is recommended and this orientation is shown in **Figure 7** along with a possible implementation of this setup for a headset and a handset.

ii. Array orientation

In this configuration, the same type of UNI mic should be used. If this is not the case, one of them will detect signals that the other will not, causing a reduction in noise suppression effectiveness. They should be oriented in the same direction, toward the speaker. Obviously the

noise mic will pick up a lot of signal, so the full implementation of Pathfinder should be used to avoid de-signaling. This is discussed in the Related Applications for two OMNI microphones, but the procedure is the same for two UNI microphones. The microphones are placed on an axis that contains the user's mouth at one end and the noise microphone on the other. The spacing between the microphones should be multiples in space of a sample in time. This is so the full implementation of Pathfinder can operate at peak efficiency. As an example, if we are sampling the acoustic data at 8 kHz, the time between samples is a multiple of 1/8000 seconds, or 0.125 milliseconds. The speed of sound in air is temperature dependent, but in room temperature air is about 345 meters per second. Therefore in 0.125 milliseconds the sound will travel $345(0.000125) = 4.3$ centimeters and the microphones should be spaced either 4.3 centimeters apart, or 8.6, or 12.9, and so on. **Figure 8** shows how the microphones may be oriented in a general fashion as well as a possible implementation of this setup for a headset and a handset. It is not necessary for the microphones to be on exactly the same axis with the speaker's mouth, and they may be offset 30 degrees or more without significantly affecting the denoising. However the best performance is observed when they are directly in line with each other and the speaker's mouth.

The important thing about this implementation is the spacing between the microphones, as the orientations can be varied slightly (up to approximately 15 degrees or more) without significantly impairing the noise suppression process. This configuration simplifies the Pathfinder noise suppression calculation and can result in increased noise suppression. The two microphones can also act as a simple array that can be used to help calculate a VAD signal, as discussed in Section II-c-i. The downside to using this configuration is increased cost (UNIs are more expensive than OMNIs) and more difficult packaging, as UNIs must have two air ports to sample the acoustic data, one in front and another in back. This can make mounting the microphone difficult. This configuration will probably be the preferred one for a headset configuration since it is easier to mount UNI microphones in a headset.

d. OMNI and OMNI

i. Array orientation

This configuration is very similar to **I-c-ii** above, except the UNI microphones are replaced with OMNI microphones. The spacing requirements for optimal performance (i.e., the distance between the microphones needs to be a multiple in space of a sample in time) remain the same. This is the only configuration possible since orientation is irrelevant for OMNI microphones. The full implementation of Pathfinder is used as above. In fact, the only real difference here is that the SNR in both microphones is lower, meaning that for the same environmental noise there will be more noise in the microphones to remove. The packaging issue is simplified, as OMNI microphones only need a single port to sample the acoustic data. **Figure 9** also represents the possible implementation of this configuration. This configuration will likely be the preferred implementation for handsets, for both price and packaging reasons. Once again perfect alignment between the microphones and the speaker's mouth is not strictly necessary, although that alignment offers the best performance.

II. VAD devices description

In this section I will discuss the various types of external VAD devices envisioned for use in a noise suppression system and how they may be implemented for both a handset and a headset application.

a. Aliph GEMS

Aliph has developed its own non-acoustic voicing sensor, referred to as the General Electromagnetic Sensor (GEMS). It is a radiofrequency (RF) interferometer that operates in the 1-5 GHz frequency range at very low power, and can be used to detect vibrations of very small amplitudes. We have used it to detect vibrations of the trachea, neck, cheek, and head associated with the production of speech. These vibrations occur due to the opening and closing of the vocal folds associated with speech production, and detecting them can lead to a very accurate noise-robust VAD, as described in the Related Applications.

As the GEMS is an RF sensor, it uses an antenna. Very small (approximately 4 mm by 7 mm) micropatch antennae have been constructed and used by Aliph to allow the GEMS to detect vibrations. These antennae are designed to be close to the skin for maximum efficiency. Other

antennae may be used as well. Potential areas of use are shown in **Figure 10** along with possible antenna locations.

b. Accelerometer based VAD

As described in the Related Applications, accelerometers can be used to detect the skin vibrations that occur due to the production of speech. However, these sensors can be polluted by exterior acoustic noise, and so greater care must be taken in their placement and use.

i. Accelerometers in the ear

One method that can be used to cut down on the amount of external noise and assure a good fit is to place the accelerometer in the ear canal. This is already done in some commercial products, such as Temco's Voiceducer, where the vibrations are used as a microphone. We, however, just use the accelerometer signal to calculate a VAD signal. Therefore the accelerometer in the ear can be less sensitive and require less bandwidth, and thus less expensive.

ii. Accelerometer outside the ear

There are many locations outside the ear from which the accelerometer can detect skin vibrations associated with the production of speech. Some of these are shown in **Figure 11** and include the jaw, behind the ear, on the side and front of the neck, on the chest, and on the head. Any of these configurations will work with a headset, but a handset will require contact with the cheek, jaw, head, or neck.

c. Two-microphone acoustic VADs

These VADs operate without any external hardware, just using two microphones. Each takes advantage of the two-microphone configuration in a different way.

i. Array VAD

This VAD, described in the Related Applications, arranges the microphones in a simple linear array and detects the speech using the characteristics of the array. It functions best when the microphones and the user's mouth are linearly co-located and the microphones are located a

multiple of a sample distance away. That is, if the sampling frequency of the system is 8 kHz, and the speed of sound is approximately 345 m/s, then in one sample sound will travel

$$d = 345 \text{ m/s} \cdot (1/8000 \text{ s}) = 4.3 \text{ cm}$$

and the microphones should be separated by 4.3, 8.6, 12.9... cm. **Figures 8 and 9** show implementations for both handsets and headsets. Either OMNI or UNI microphones or a combination of the two may be used.

ii. Pathfinder VAD

This VAD, also described in the Related Applications, uses the Pathfinder technique itself to determine when voicing is occurring. As such, it can be used with any of the microphone configurations above with no modifications.

iii. Stereo VAD

This type of VAD uses the difference in frequency amplitude from the noise and the signal to determine when the signal is occurring. It requires only that the microphones be oriented and configured such that the SNR is larger in Mic 1 102 than Mic 2 103. Any of the microphone configurations above can be configured to work with this VAD technique.

d. Other conventional acoustic VAD algorithms

Any conventional acoustic method may also be used with either or both microphones (102 and/or 103) to construct the VAD signal required by Pathfinder for noise suppression. For example, the EVRC VAD may be used with Mic 1 (102) to construct a VAD signal for use with the Pathfinder noise suppression system.

III. Combinations of microphone and VAD configurations

Following is a list of the various combinations of microphone configurations and VAD configurations that can be used for noise suppression and VAD applications. Using the techniques disclosed herein, we can construct:

1. Handset with microphone configuration of section I-b-i with VAD of section II-a.
2. Headset with microphone configuration of section I-b-i with VAD of section II-a.

3. Handset with microphone configuration of section I-b-ii with VAD of section II-a.
4. Headset with microphone configuration of section I-b-ii with VAD of section II-a.
5. Handset with microphone configuration of section I-c-i with VAD of section II-a.
6. Headset with microphone configuration of section I-c-i with VAD of section II-a.
7. Handset with microphone configuration of section I-c-ii with VAD of section II-a.
8. Headset with microphone configuration of section I-c-ii with VAD of section II-a.
9. Handset with microphone configuration of section I-d-i with VAD of section II-a.
10. Headset with microphone configuration of section I-d-i with VAD of section II-a.
11. Handset with microphone configuration of section I-b-i with VAD of section II-b-i.
12. Headset with microphone configuration of section I-b-i with VAD of section II-b-i.
13. Handset with microphone configuration of section I-b-ii with VAD of section II-b-i.
14. Headset with microphone configuration of section I-b-ii with VAD of section II-b-i.
15. Handset with microphone configuration of section I-c-i with VAD of section II-b-i.
16. Headset with microphone configuration of section I-c-i with VAD of section II-b-i.
17. Handset with microphone configuration of section I-c-ii with VAD of section II-b-i.
18. Headset with microphone configuration of section I-c-ii with VAD of section II-b-i.
19. Handset with microphone configuration of section I-d-i with VAD of section II-b-i.
20. Headset with microphone configuration of section I-d-i with VAD of section II-b-i.
21. Handset with microphone configuration of section I-b-i with VAD of section II-b-ii.
22. Headset with microphone configuration of section I-b-i with VAD of section II-b-ii.
23. Handset with microphone configuration of section I-b-ii with VAD of section II-b-ii.
24. Headset with microphone configuration of section I-b-ii with VAD of section II-b-ii.
25. Handset with microphone configuration of section I-c-i with VAD of section II-b-ii.
26. Headset with microphone configuration of section I-c-i with VAD of section II-b-ii.
27. Handset with microphone configuration of section I-c-ii with VAD of section II-b-ii.
28. Headset with microphone configuration of section I-c-ii with VAD of section II-b-ii.
29. Handset with microphone configuration of section I-d-i with VAD of section II-b-ii.
30. Headset with microphone configuration of section I-d-i with VAD of section II-b-ii.
31. Handset with microphone configuration of section I-b-i with VAD of section II-c-i.
32. Headset with microphone configuration of section I-b-i with VAD of section II-c-i.
33. Handset with microphone configuration of section I-b-ii with VAD of section II-c-i.

34. Headset with microphone configuration of section I-b-ii with VAD of section II-c-i.
35. Handset with microphone configuration of section I-c-i with VAD of section II-c-i.
36. Headset with microphone configuration of section I-c-i with VAD of section II-c-i.
37. Handset with microphone configuration of section I-c-ii with VAD of section II-c-i.
38. Headset with microphone configuration of section I-c-ii with VAD of section II-c-i.
39. Handset with microphone configuration of section I-d-i with VAD of section II-c-i.
40. Headset with microphone configuration of section I-d-i with VAD of section II-c-i.
41. Handset with microphone configuration of section I-b-i with VAD of section II-c-ii.
42. Headset with microphone configuration of section I-b-i with VAD of section II-c-ii.
43. Handset with microphone configuration of section I-b-ii with VAD of section II-c-ii.
44. Headset with microphone configuration of section I-b-ii with VAD of section II-c-ii.
45. Handset with microphone configuration of section I-c-i with VAD of section II-c-ii.
46. Headset with microphone configuration of section I-c-i with VAD of section II-c-ii.
47. Handset with microphone configuration of section I-c-ii with VAD of section II-c-ii.
48. Headset with microphone configuration of section I-c-ii with VAD of section II-c-ii.
49. Handset with microphone configuration of section I-d-i with VAD of section II-c-ii.
50. Headset with microphone configuration of section I-d-i with VAD of section II-c-ii.
51. Handset with microphone configuration of section I-b-i with VAD of section II-c-iii.
52. Headset with microphone configuration of section I-b-i with VAD of section II-c-iii.
53. Handset with microphone configuration of section I-b-ii with VAD of section II-c-iii.
54. Headset with microphone configuration of section I-b-ii with VAD of section II-c-iii.
55. Handset with microphone configuration of section I-c-i with VAD of section II-c-iii.
56. Headset with microphone configuration of section I-c-i with VAD of section II-c-iii.
57. Handset with microphone configuration of section I-c-ii with VAD of section II-c-iii.
58. Headset with microphone configuration of section I-c-ii with VAD of section II-c-iii.
59. Handset with microphone configuration of section I-d-i with VAD of section II-c-iii.
60. Headset with microphone configuration of section I-d-i with VAD of section II-c-iii.
61. Handset with microphone configuration of section I-b-i with VAD of section II-d.
62. Headset with microphone configuration of section I-b-i with VAD of section II-d.
63. Handset with microphone configuration of section I-b-ii with VAD of section II-d.
64. Headset with microphone configuration of section I-b-ii with VAD of section II-d.

65. Handset with microphone configuration of section I-c-i with VAD of section II-d.
66. Headset with microphone configuration of section I-c-i with VAD of section II-d.
67. Handset with microphone configuration of section I-c-ii with VAD of section II-d.
68. Headset with microphone configuration of section I-c-ii with VAD of section II-d.
69. Handset with microphone configuration of section I-d-i with VAD of section II-d.
70. Headset with microphone configuration of section I-d-i with VAD of section II-d.

IV. Conclusions

We have discussed several different variations of implementations of microphone configurations and VAD configurations for the purposes of multi-microphone noise suppression and VAD detection.

The elements and acts of the various embodiments described above can be combined to provide further embodiments. Further, all of the above references and U.S. patents and applications are incorporated herein by reference. Aspects of the invention can be modified, if necessary, to employ the systems, functions and concepts of the various patents and applications described above to provide yet further embodiments of the invention.

Unless the context clearly requires otherwise, throughout the description and the claims, the words “comprise,” “comprising,” and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in a sense of “including, but not limited to.” Words using the singular or plural number also include the plural or singular number respectively. Additionally, the words “herein,” “hereunder,” and words of similar import, when used in this application, shall refer to this application as a whole and not to any particular portions of this application.

The above description of illustrated embodiments of the invention is not intended to be exhaustive or to limit the invention to the precise form disclosed. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the

[illegible]

Figure 1. Diagram of the Pathfinder noise suppression algorithm.

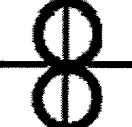
CHARACTERISTIC	OMNI-DIRECTIONAL	CARDIOID	SUPER-CARDIOID	HYPER-CARDIOID	BI-DIRECTIONAL
POLAR RESPONSE PATTERN					
COVERAGE ANGLE	360°	131°	115°	105°	90°
ANGLE OF MAXIMUM REJECTION (null angle)	—	180°	126°	110°	90°
REAR REJECTION (relative to front)	0	25 dB	12 dB	6 dB	0
AMBIENT SOUND SENSITIVITY (relative to omni)	100%	33%	27%	25%	33%
DISTANCE FACTOR (relative to omni)	1	1.7	1.9	2	1.7

Figure 2. The different types of microphones and their simplified polar response patterns. The patterns shown vary with frequency, but these give an idea of the behavior of the different types of microphones. From the Shure microphone company website at <http://www.shure.com/pdf/booklets/music.pdf>.

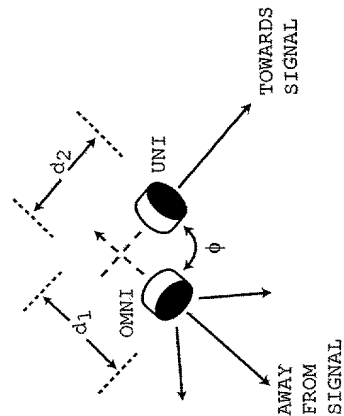
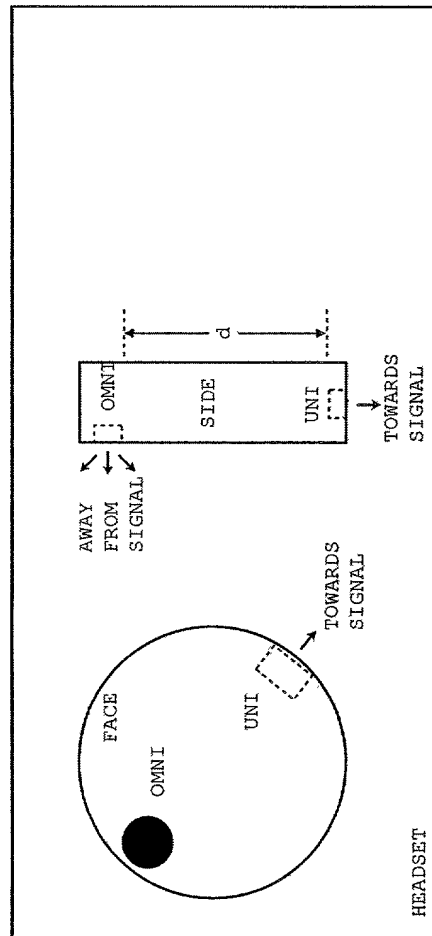
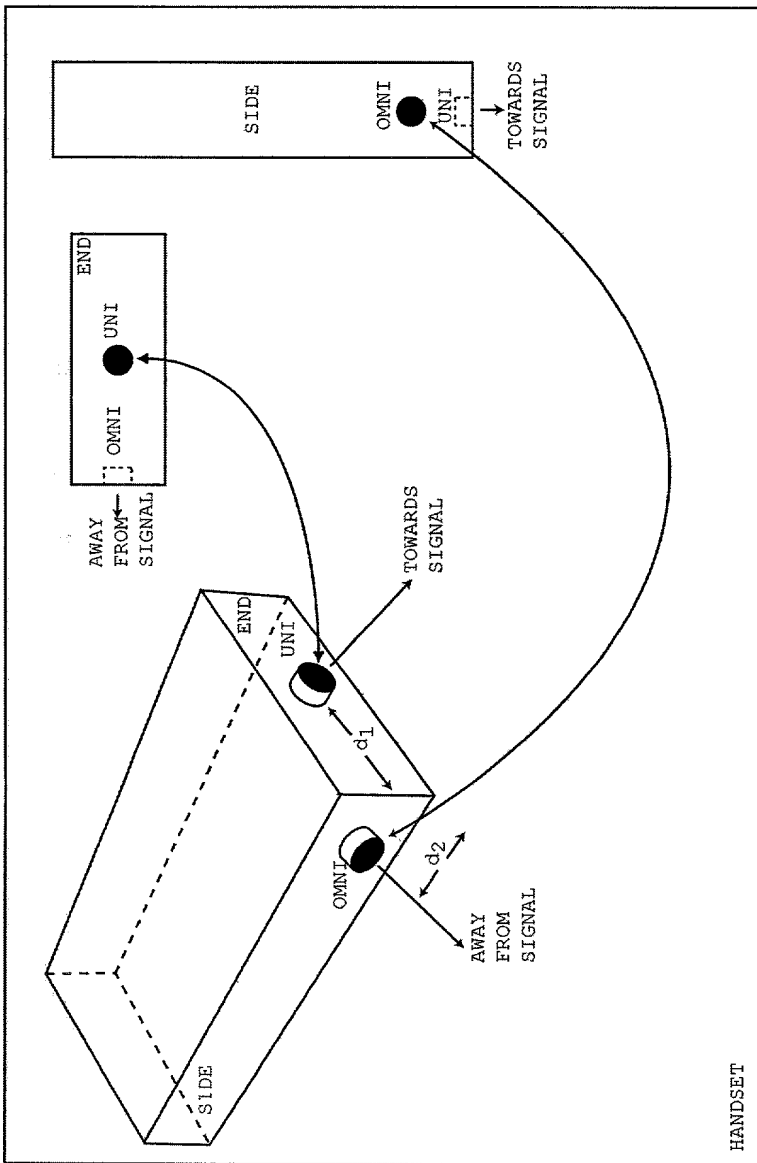
FIGURE 3

Notes:

Mic ventilation is required for some microphones -- knowledge of microphone operation is required to determine placement of mic ventilation holes.

d_1 & d_2 are recommended to be between 0-15cm

ϕ is recommended to be 90-135 degrees



GENERAL CONFIGURATION

FIGURE 4

Notes:

Mic ventilation is required for some microphones -- knowledge of microphone operation is required to determine placement of mic ventilation holes.

d is recommended to be between 0-15cm

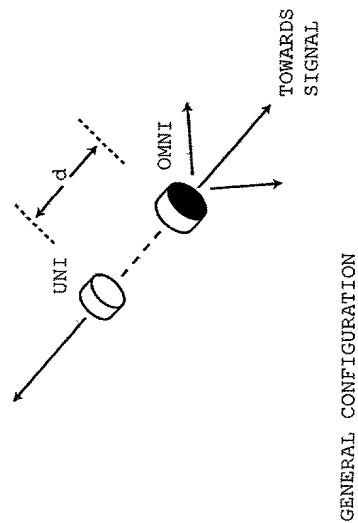
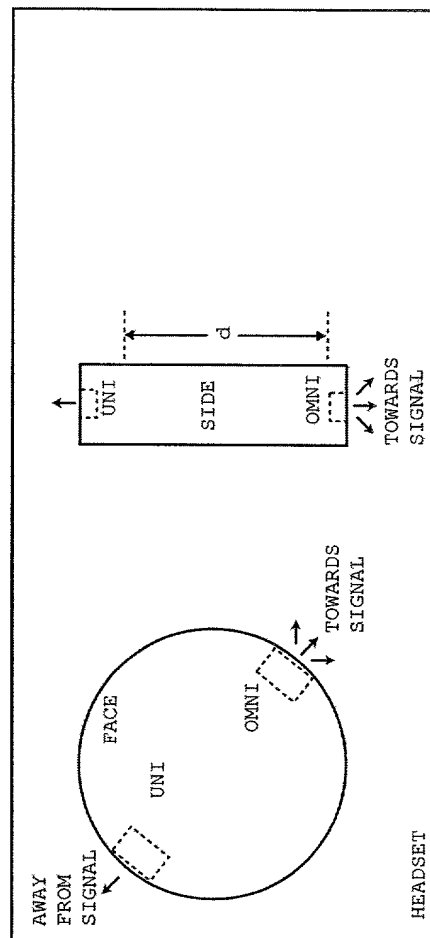
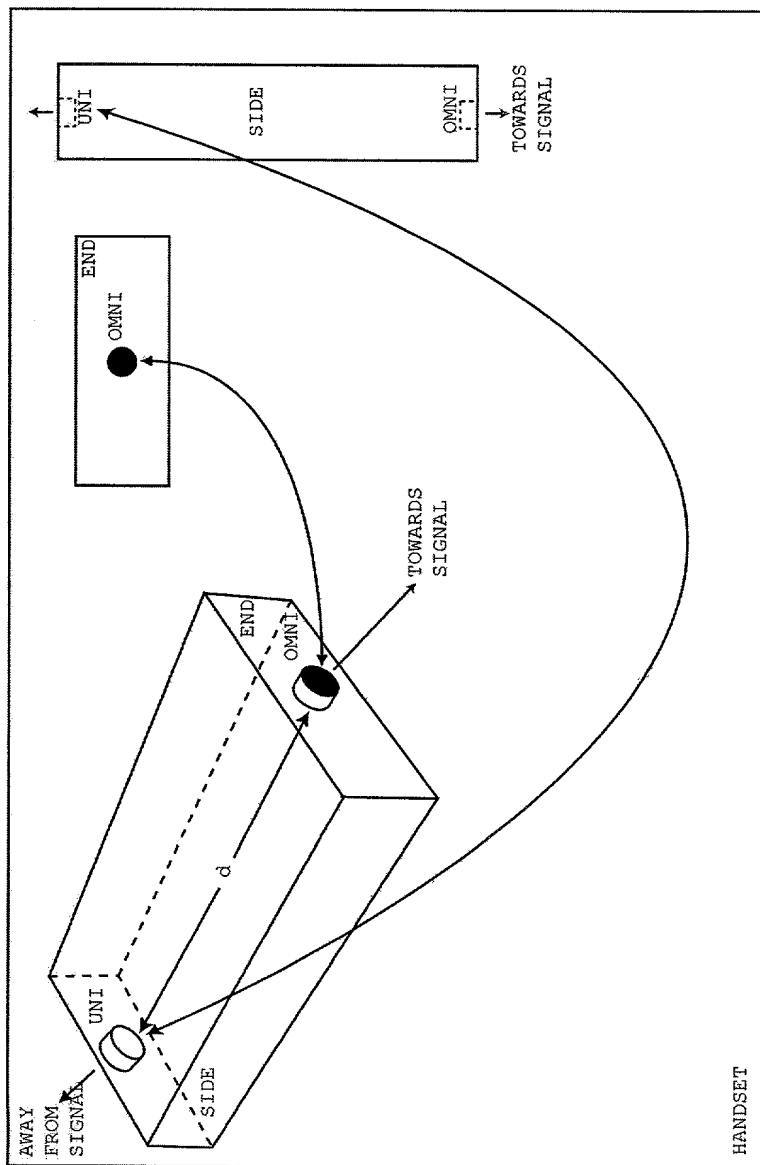


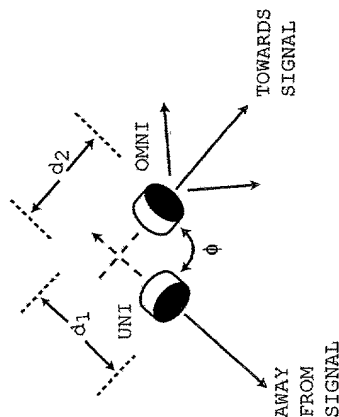
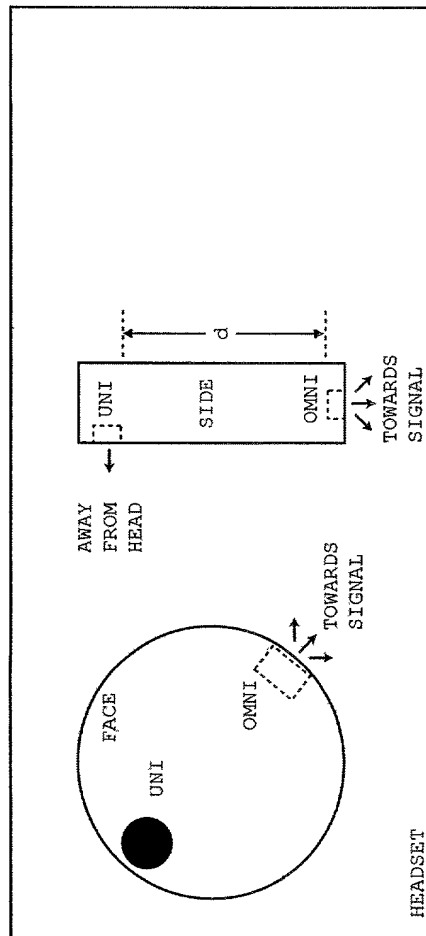
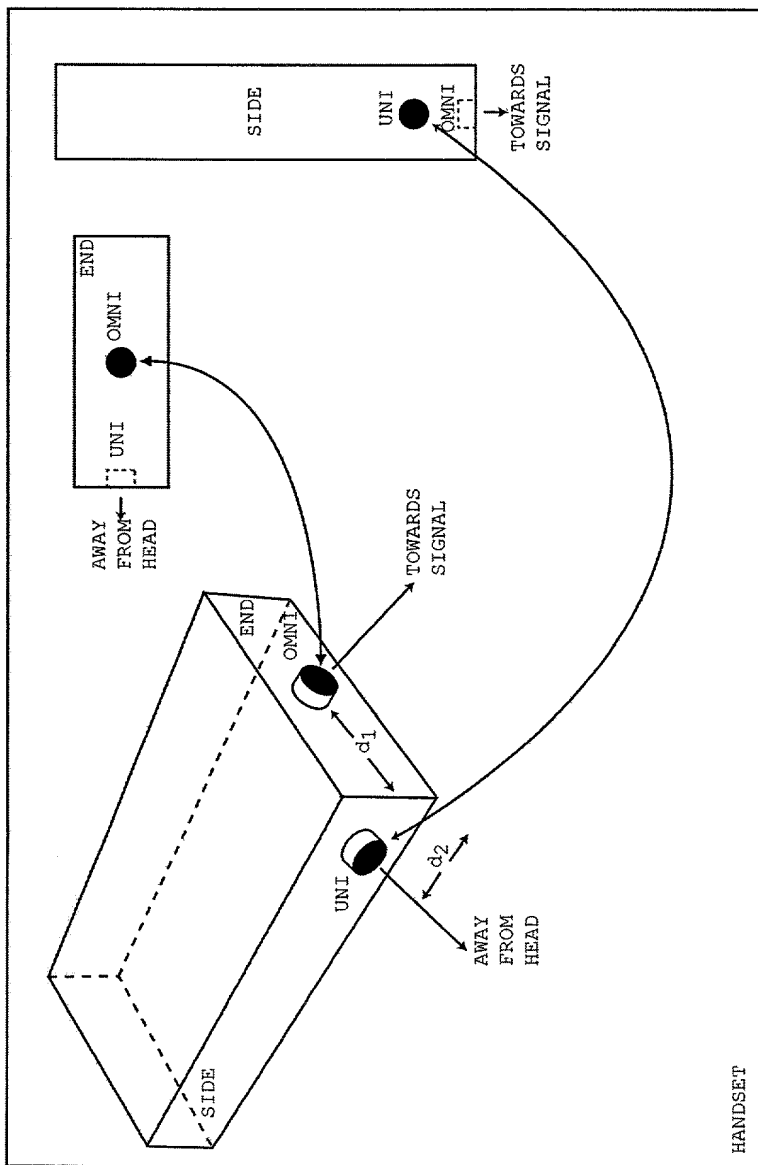
FIGURE 5

Notes:

Mic ventilation is required for some microphones -- knowledge of microphone operation is required to determine placement of mic ventilation holes.

d_1 & d_2 are recommended to be between 0-15cm

ϕ is recommended to be 90-135 degrees



GENERAL CONFIGURATION

FIGURE 6

Notes:

Mic ventilation is required for some microphones -- knowledge of microphone operation is required to determine placement of mic ventilation holes.

d is recommended to be between 0-15cm

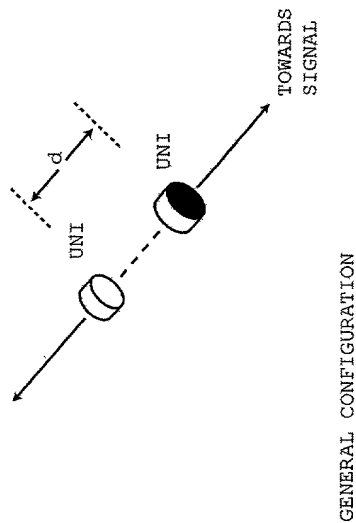
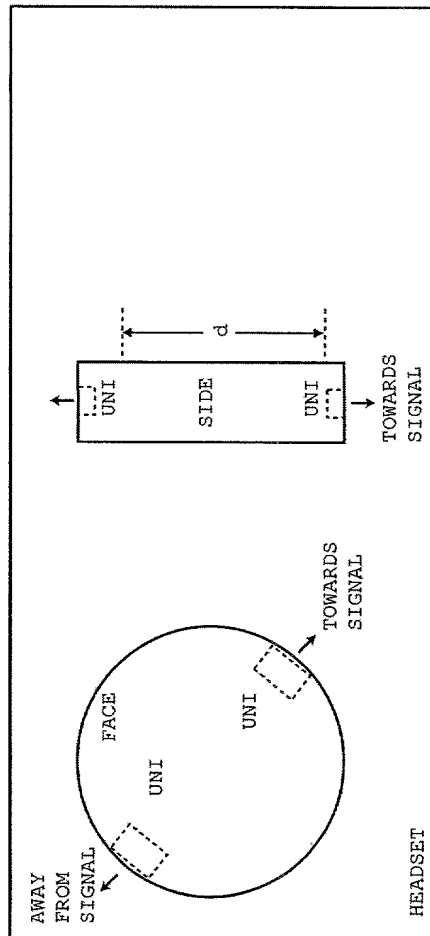
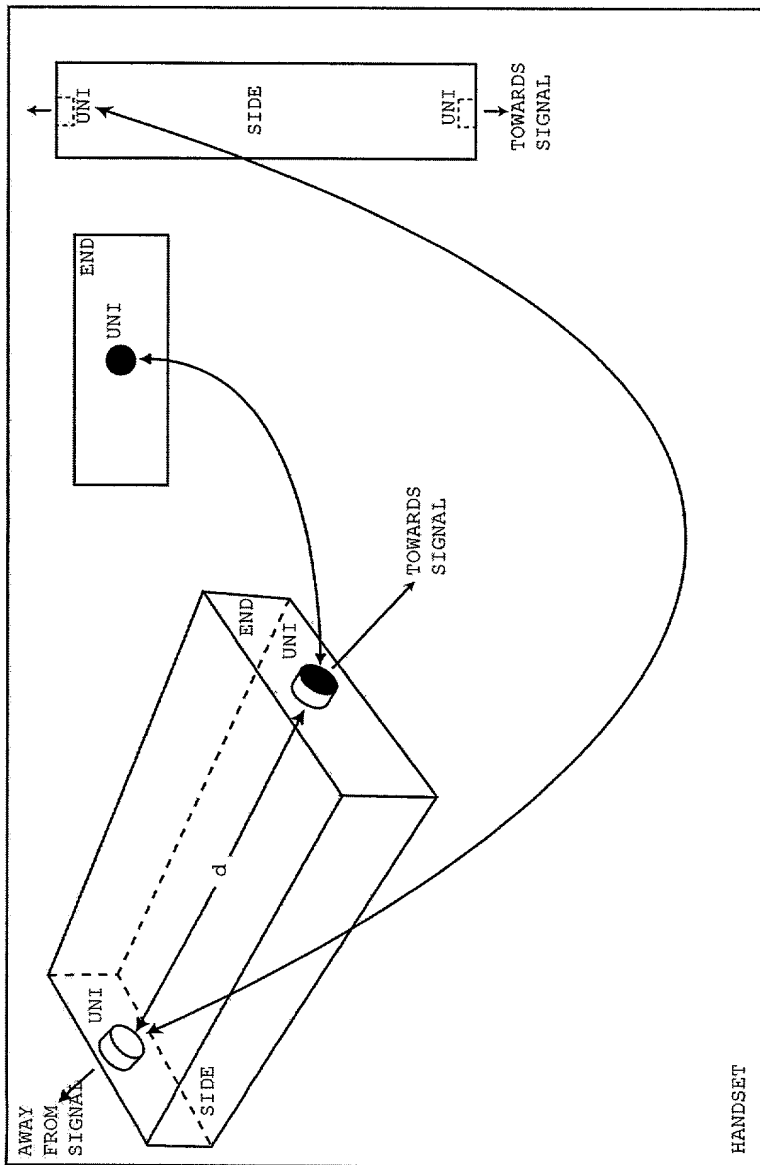


FIGURE 7

Notes:

Mic ventilation is required for some microphones -- knowledge of microphone operation is required to determine placement of mic ventilation holes.

d₁ & d₂ are recommended to be
between 0-15cm

ϕ is recommended to be
90-135 degrees

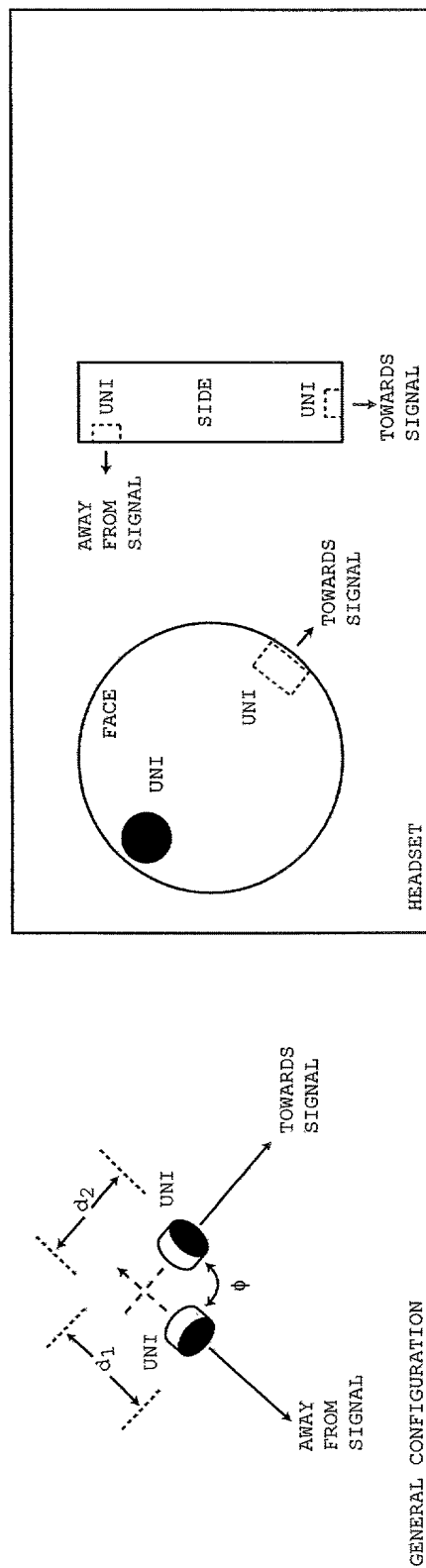
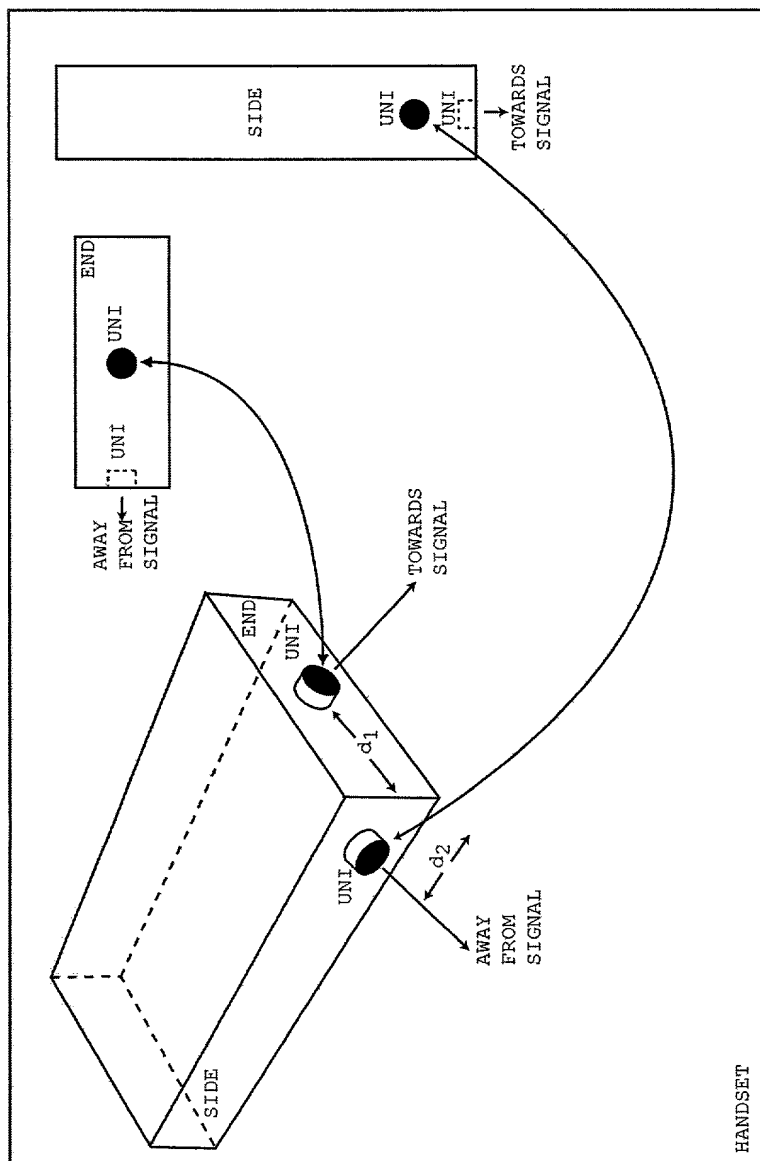
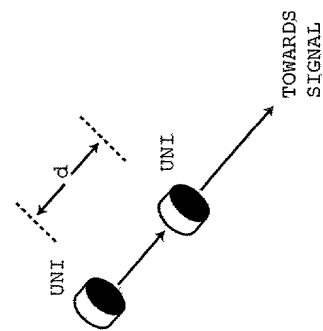
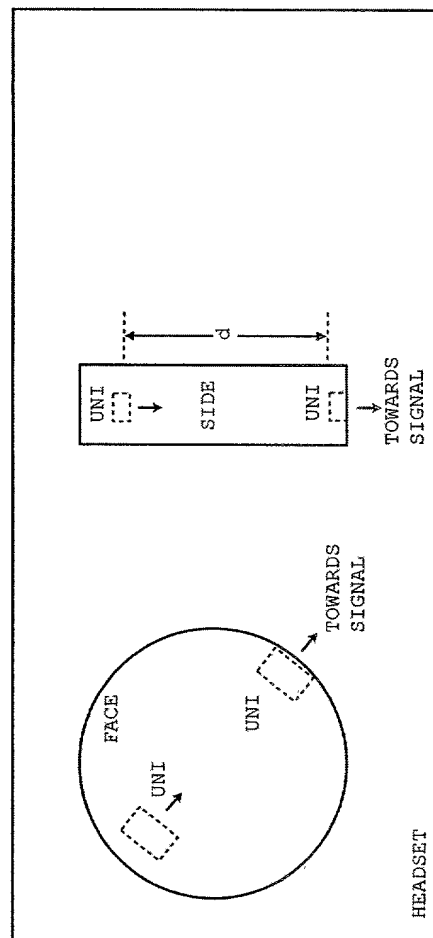
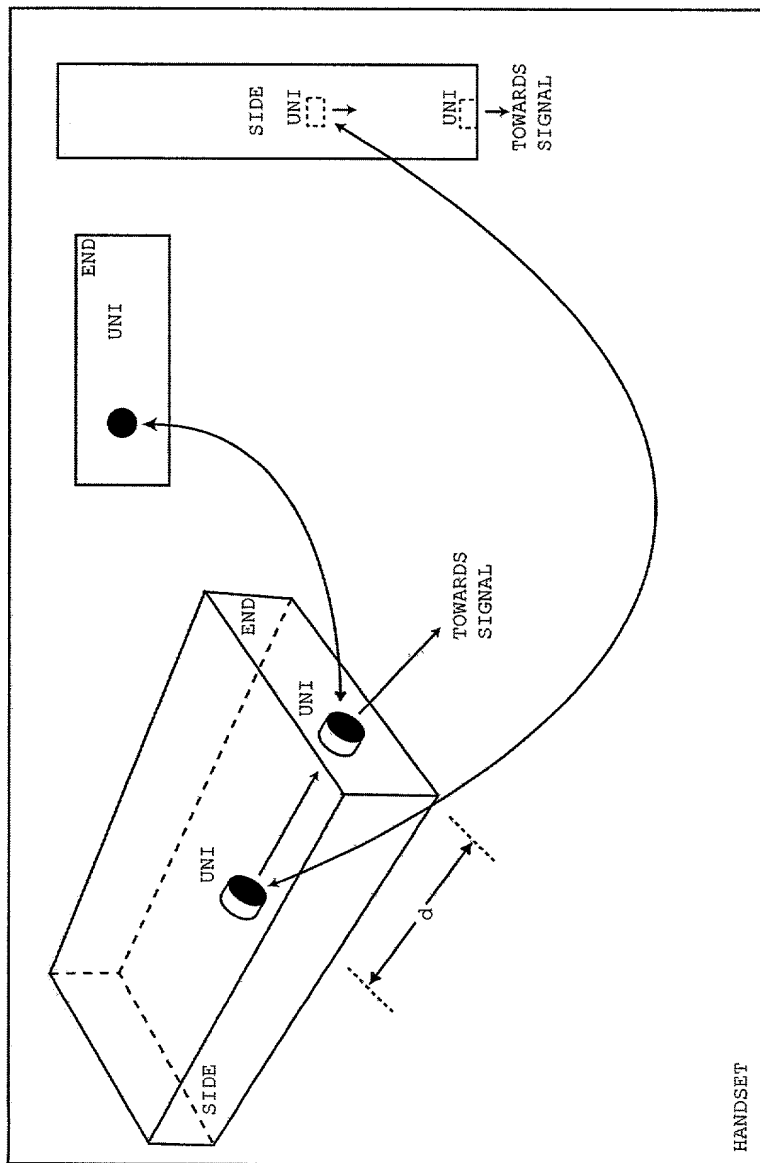


FIGURE 8

Notes:

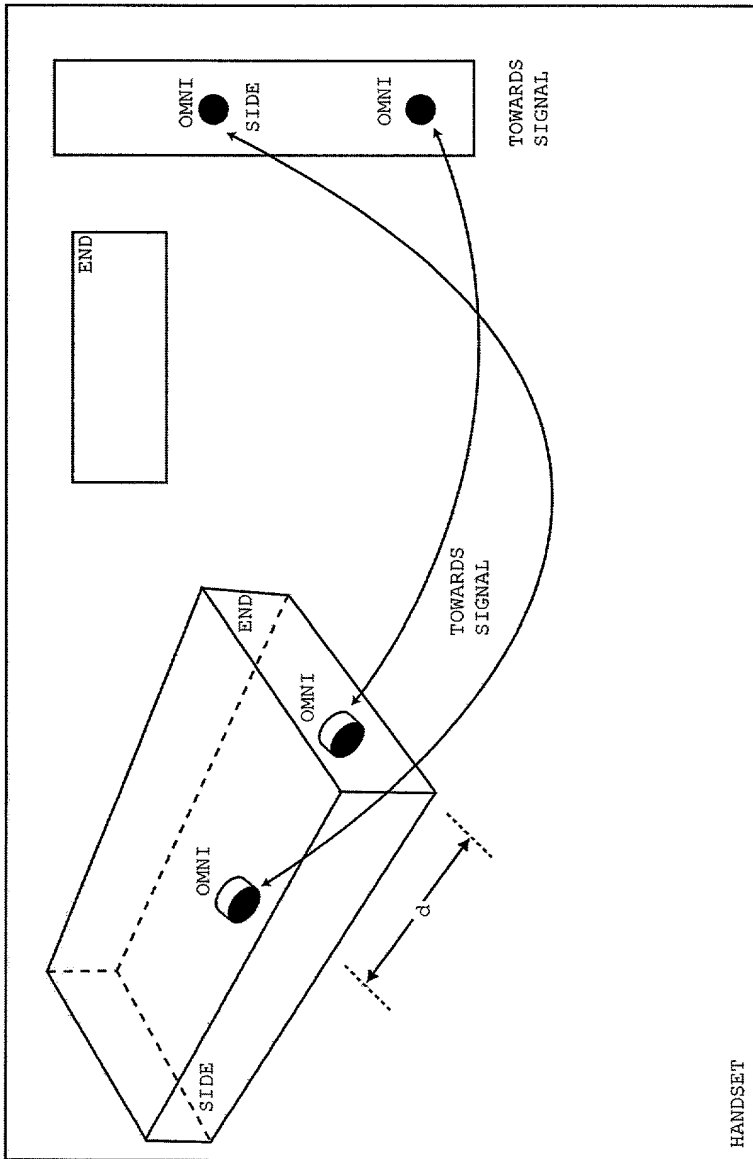
Mic ventilation is required for some microphones -- knowledge of microphone operation is required to determine placement of mic ventilation holes.

$d = n$ sample lengths
($n = 1, 2, 3, \dots$)
[see doc for details]



GENERAL CONFIGURATION

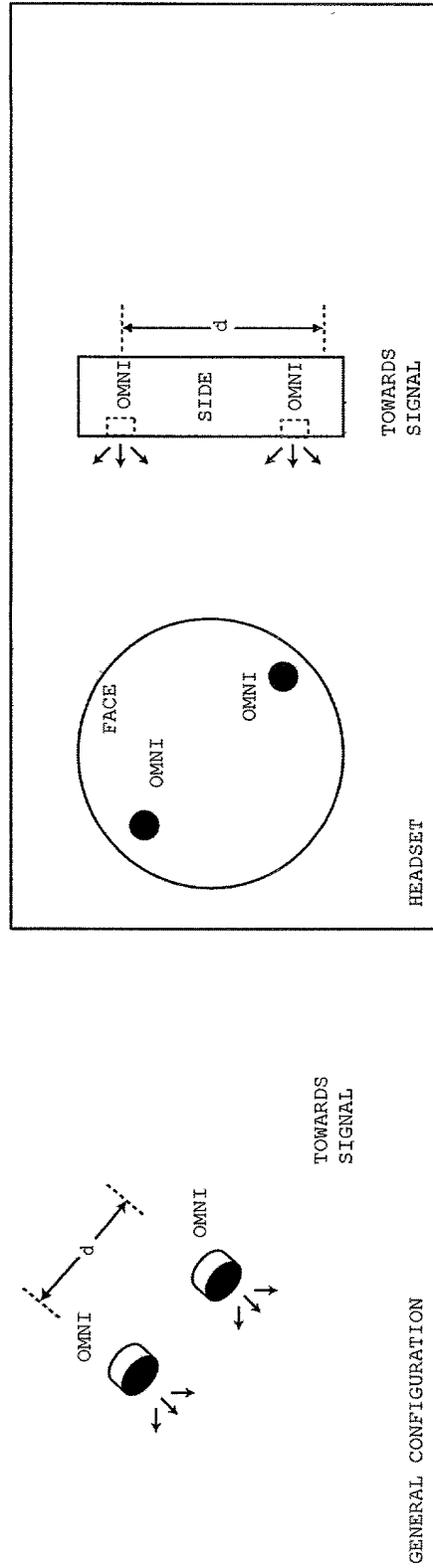
FIGURE 9



Notes:

Mic ventilation is required for some microphones -- knowledge of microphone operation is required to determine placement of mic ventilation holes.

$d = n$ sample lengths
($n = 1, 2, 3, \dots$)
[see doc for details]



GENERAL CONFIGURATION

FIGURE 10

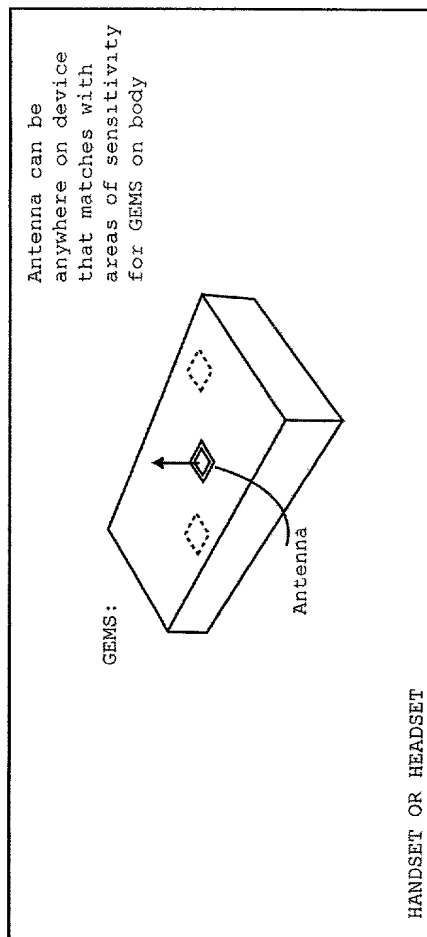
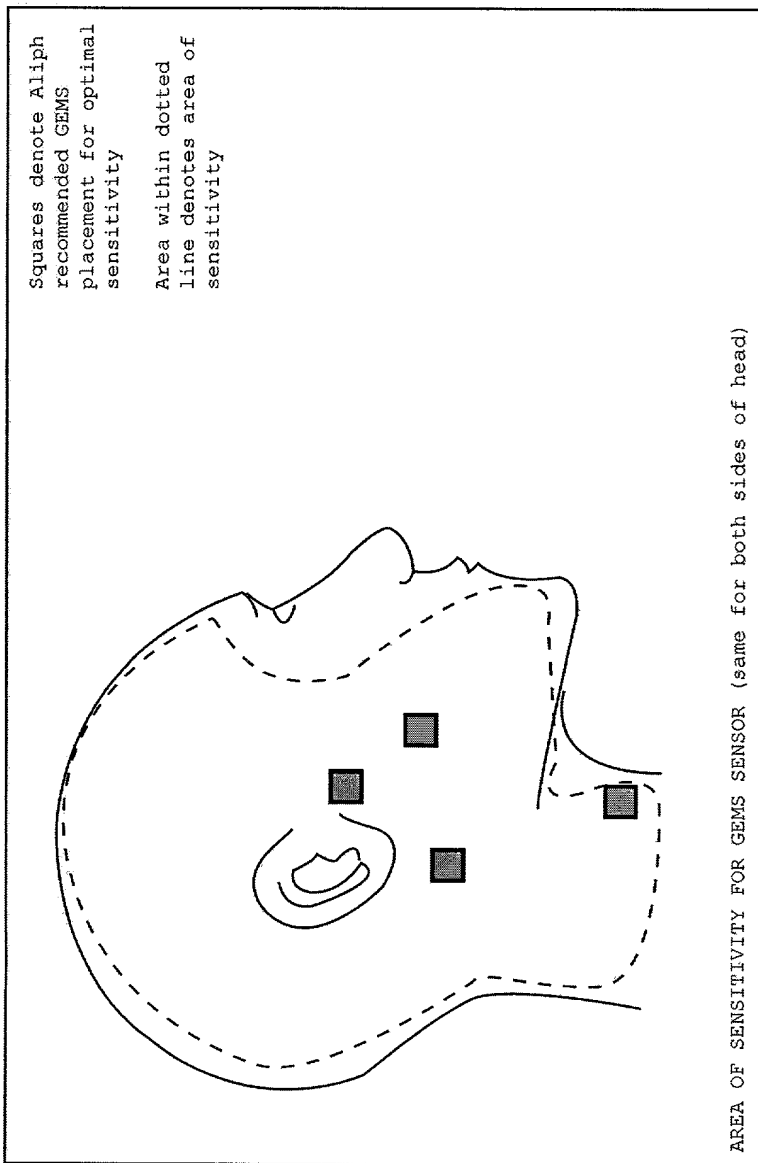


FIGURE 11

