Subminiature Directional Microphones*

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Subminiature directional microphones having physical volumes of approximately 0.12 cm^3 and masses of 0.3 gram have been designed using both ceramic and electret-condenser transducing systems. Computer-simulated original design data are compared with the experimental data and show the way to predict the range of performance that can be achieved with emphasis on special types for hearing aids.

INTRODUCTION: It is already fairly well established that monaural comprehension of a desired sound signal is easily degraded by a competing signal, and this is especially important to a handicapped person who already has trouble without the competing signal. Therefore a device that permits a hard-of-hearing individual to improve his signal-to-noise ratio beyond that obtained by the measures that he can usually take, ought to be welcome. When talking louder helps, at least part of the time, it is because it improves the signal-to-noise ratio. In many cases it may be more useful to improve the loudness of the desired signal relative to the other sounds than to make all sounds louder. A directional hearing aid which can be aimed at the desirable source of sound and thus discriminate against some of the other sources of sound provides a step in this direction. With such a hearing aid the desired signal can also be received preferentially to the reverberant sound which is frequently the major component of the competing signal. A major test of the utility of this reasoning is now in progress as various hearing-aid manufacturers offer the hard-of-hearing public a selection of directional hearing aids.

The central innovation at the core of this process is the introduction of several directional microphones that are small enough to be incorporated into head-worn hearing aids. This is being accomplished without emphasizing any of the negative factors that are known to count heavily in the mind of the ultimate user such as size, weight, visibility, or battery life. Fortunately this is one technical improvement that does not have to win its place at the expense of known desirable attributes.

The obtaining of directional effects from microphones is an an art almost as old as the making of microphones. The understanding of how to practice the art was advanced most rapidly in the decades of the thirties and forties and has been further refined since then. There have been attempts in the past to apply this art to hearing aids, but a large-scale attack on the problem had to await some technical advances, the most significant being the introduction for hearing-aid use of the broadband ceramic-piezoelectric microphone and later the electret-condenser microphone.

The theory of the approach that is used has been treated by many. A theoretical discussion was given by

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* Presented September 10, 1973, at the 46th Convention of the Audio Engineering Society, New York.

Bauer in the April, 1941, issue of the *Journal of the Acoustical Society of America*. For the purpose of this treatment, the process is easily understood with the use of the analog circuit of Fig. 1. It represents the processing of signals acquired from two sound ports a distance *d* apart. The network fed by the rearward port produces a phase shift almost proportional to frequency and an open-circuit pressure at the transducing diaphragm element that is almost unattenuated over a predetermined frequency range. For the purposes of an intuitive understanding of the functioning of the device this action is conveniently thought of as applying a time delay without attenuation to the sound entering the rear port before it is impressed on the rear side of the transducing element. When this delay coincides with the delay of the sound traveling from the rear port to the front port outside of the microphone, there is no difference in the sound pressure applied to the two sides of the transducing diaphragm element and there is no output. If the ports are lined up in the direction of the sound wave when these delays coincide to produce no output, the polar pattern is a cardioid. For this cardioid condition and with the sound arriving from the forward direction, the sound applied to the rearward side of the transducer diaphragm arrives later than the sound at the forward side by twice the time it takes for the sound to pass between the ports. Through the frequency range where the device is small compared to the wavelength of sound, the difference in the pressure amplitudes applied across the transducing diaphragm element is proportional to frequency. The result is that a piezoelectric or condenser type of transducer which has an output proportional to the net pressure across the diaphragm produces a frequency response that rises at 6 dB per octave throughout most of the passband. The sloping characteristic has merit in hearing-aid applications, though the optimum frequency response slope of the complete aid as worn will depend on the nature of the hearing impairment.

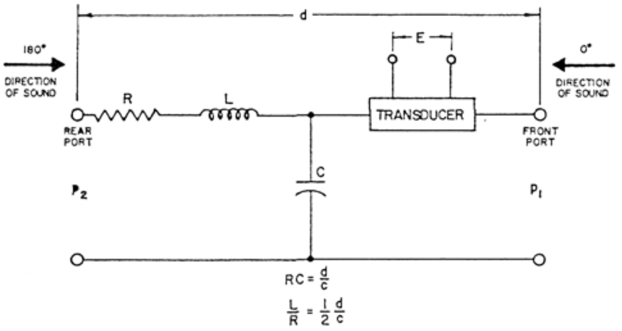

Fig. 1. Simplified electrical analog of directional microphone.

A PIEZOELECTRIC MICROPHONE

When the piezoelectric microphone appeared in suitable form for hearing-aid use, it was already quite small and was destined to become still smaller, the popular small unit being 0.312 in (7.92 mm) long by 0.220 in (5.59 mm) wide and 0.090 in (2.29 mm) thick. The development of this transducer provided the microphone designer with an unusual starting point for an approach to the design of a directional device. It appeared, at least for the first approximation, that the directional microphone should be larger than the limitations imposed by the basic microphone structure. This is an unusual circumstance for the designer of a hearing-aid component or for the designer of a directional microphone, since the normal influences are decidedly in the other direction.

The schematic illustration in Fig. 2 is a microphone design that produces the directional action. The structure shown is an implementation using a piezoelectric transducing element. The base distance between the ports to provide the cardioid performance was chosen as 0.61 in (15.5 mm). In part this is because it is the distance that provides approximately the same sensitivity at 1000 Hz that this same style of transducer has when used as a pressure (nondirectional) device and with an acceptable noise level. Another consideration was that after reviewing a substantial number of behind-the-ear hearing-aid shapes, making some allowance for diffraction effects, our opinion was that this would be a practical spacing. The basic microphone has a physical spacing from the front sound port to the rear sound port of only 0.322 in (8.18 mm). This is a smaller spacing than desired for the microphone to produce a cardioid polar pattern. For purposes of standardizing the measurement, a length of 0.076 in (1.93-mm) diameter (commonly known as #13) tubing is installed to extend the forward port 0.310 in (7.87 mm) from the wall of the housing. The apparent physical spacing shown is 0.560 in (14.2 mm), which has an effective spacing due to diffraction of 0.610 in (15.5 mm) when the piece of #13 plastic tubing is used as the extender tube to increase the base distance. In actual practice this effective distance is provided by several means which may include a similar tube, or a portion of one, and the remainder of the distance may be obtained by the effects of diffraction about the housing and the wearer's head. Different tubing lengths produce different directional characteristics and frequency responses.

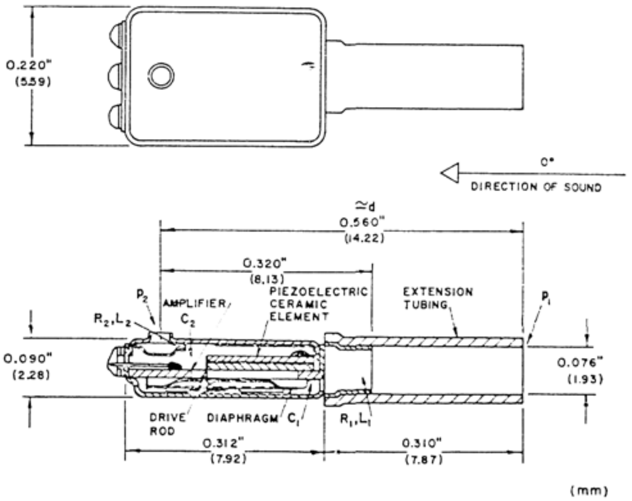

Fig. 2. Piezoelectric directional microphone construction.

The volume C_2 within the case provides the compliance to cooperate with the resistance R_2 and inertance L_2 of the slit inside the rear sound port to form the phase shift network that is shown in Fig. 1. The inertance L_1 and resistance R_1 of the tube and port configuration at the forward port are small enough that when cooperating with the volume C_1 on the forward side of the diaphragm they produce little amplitude and phase change in the pressure applied to the diaphragm from the forward port.

AN ELECTRET BIASED CONDENSER MICROPHONE

A different construction is shown in Fig. 3 utilizing an electret biased condenser transducer. The transducing means and the physical arrangement to obtain the directional effects are substantially independent features. The arrangement that was shown in Fig. 2 is also used with this condenser transducer. The construction of the transducer element is unusual in that the charge storage mechanism and the diaphragm function are separated permitting independent optimization. The diaphragm is not stretched as a membrane with the attendant tension-related stability problems. Because the electret polarized condenser and the piezoelectric ceramic transducers have very high electrical impedances, it is necessary to combine the first amplifier stage into the microphone. A thick film circuit is located on one side of a thin alumina ceramic plate.

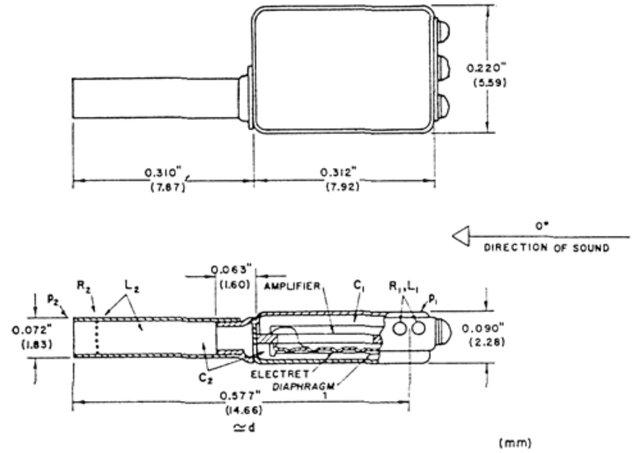

Fig. 3. Condenser directional microphone construction.

This microphone has an integral rearwardly extending tube to provide the base distance for cardioid performance. The phase-shifting resistance is located near the outer end of the tube so that the compliance C_2 also includes the volume of the tube. The inertance L_2 is partly in the resistance element and partly in the tube. In this construction it has been possible to adjust parameters such that the slope of the frequency characteristics above approximately 1500 Hz changes from 6 dB per octave to 3 dB per octave.

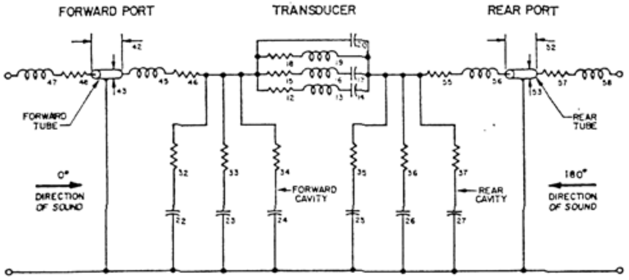

Fig. 4. Refined electrical analog of subminiature condenser microphone.

SIMULATION BY COMPUTER

Computer design techniques used in earlier microphone designs have been extended to simplify the making of rapid computations of alternative directional configurations. The program provides a view of a reasonable approximation of the result to be expected. Fig. 4 shows a circuit of one analog that has been useful. The small numbers associated with each element serve to identify the appropriate location of a value in a data file. Data files are maintained which adapt the analog circuit to the available basic structures and serve as points of departure for examining mutations for both design and diagnostic purposes. The use of the tubing has been simulated by transmission lines. The computer has a tireless tolerance for the repeated use of complex numbers and hyperbolic functions of complex numbers which make it easy to treat these tubes as transmission lines by including an approximation for the losses due to their small size. Because all portions of these devices are small, the usual assumption of adiabatic lossless compression of the air in the chambers is no longer an adequate analog. This problem is dealt with by using a finer approximation as produced by the capacitor–resistor combinations for forward (C_1) and rear (C_2) volumes. Our techniques for doing this are still evolving and being refined, but what we have seen to date indicates that the effort is useful. In addition, we have found it useful to treat the transducer as a composite structure to provide a better fit to the actual performance.

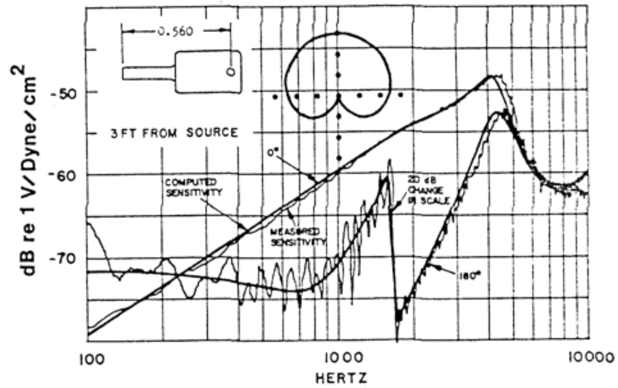

Fig. 5. Comparison of analog performance with actual performance at nominal test condition.

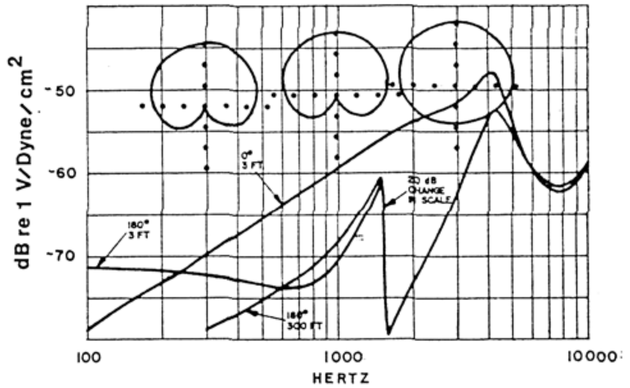

Fig. 6. Analog frequency characteristic illustrating the effect of source distance on 180° sensitivity.

The results of the computer approach are compared to the performance of a device in Fig. 5. The chart is the superposition of a measured frequency characteristic and the computer-plotted characteristic for sound waves arriving from 0° and 180° incidences. During the recording of the 180° characteristic the operator inserts 20 dB of

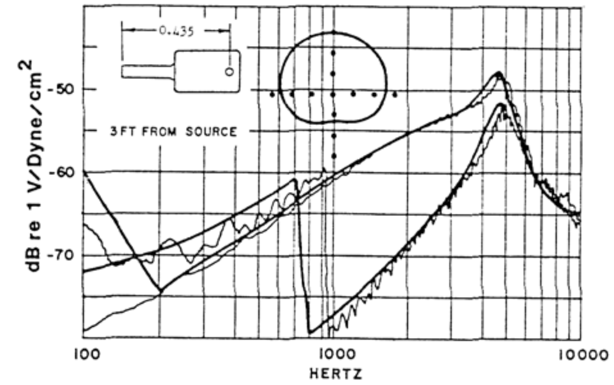

Fig. 7. Effect of a 22% decrease in sound port spacing.

additional gain at low frequencies to extend the range of the chart. The computer does this automatically. These charts are taken at a source distance of 3 ft, which is the cause of flattening of the response below 1000 Hz. The spacing between the sound ports at 3 ft from the sound sources causes a 1.7% difference in sound pressures at the two ports. This difference in pressure which is 35 dB below the pressures applied to the sound ports limits the degree of broadband balance that can be obtained to produce a good null. It also ultimately terminates the downward slope of the 0° sensitivity. The large oscillations evident in the 180° sensitivity below 1500 Hz are due to interfering signals in the anechoic chamber. The amplitude of the interfering pressures at 200 Hz is about 2% and at 1000 Hz it is about 0.6%. This means that the interfering energy that is being sensed is only 0.04% and 0.004%, respectively, of the 0° incident energy. This illustrates the severe demand placed on the anechoic room if meaningful response curves are to be obtained in directions of low microphone response.

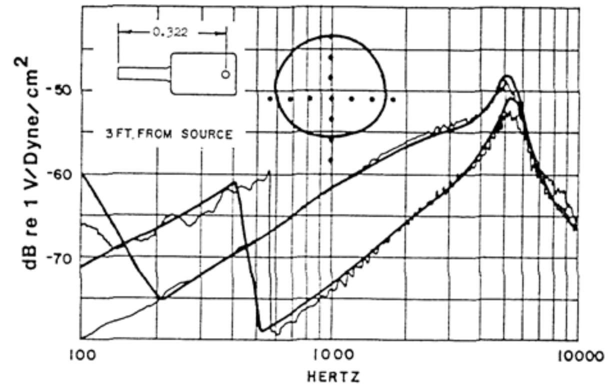

Fig. 8. Effect of a 43% decrease in sound port spacing.

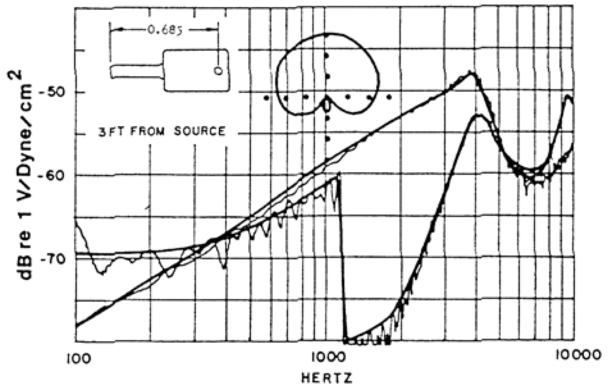

Fig. 9. Effect of a 22% increase in sound port spacing.

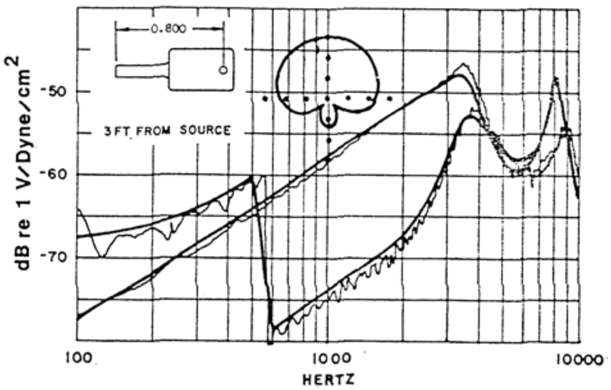

Fig. 10. Effect of a 43% increase in sound port spacing.

The chart of Fig. 6 again displays the computer-generated plots including the predicted effect of moving the source from 3 to 300 ft away. The polar characteristic has been calculated and computer plotted for frequencies of 300, 1000, and 3000 Hz. The dots forming the coordinate system are 10 dB apart, and all discriminations in excess of 30 dB are plotted at the origin.

Figs. 7 through 10 are comparisons of the measured and computed frequency response curves where the interport spacing has been changed by varying the length of the extension tube. This type of change alters the time necessary for sound to travel between the ports; therefore it alters the polar characteristic in the manner illustrated at 1000 Hz.

APPLICATION

Two of the simpler applications in hearing aids are shown. One is to provide directivity in a behind-the-ear type of hearing aid. This is illustrated in Fig. 11, where the hearing-aid housing has a truncated top on which the microphone is installed. A cap providing protection to the

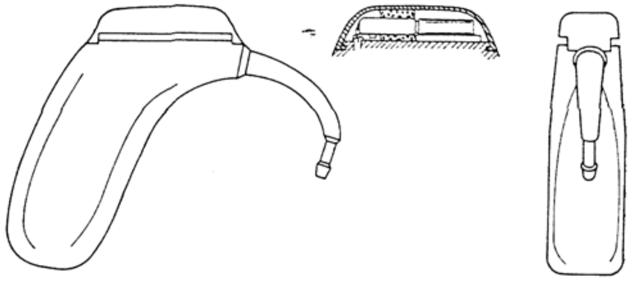

Fig. 11. Behind-the-ear hearing aid with microphone installed.

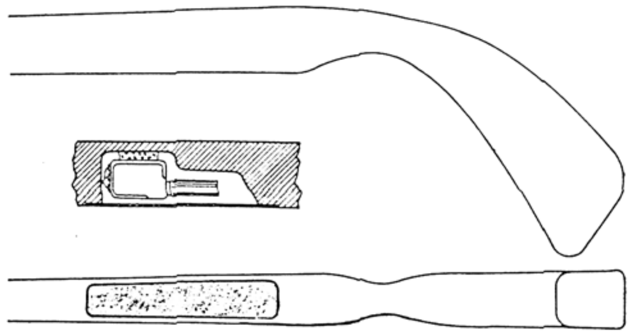

Fig. 12. Eyeglass hearing aid with microphone installed.

microphone is snapped over the top. The sound access is through the slits at the sides. A second type of application is in the eyeglass type of hearing aid. Fig. 12 shows how microphone construction in Fig. 3 can be adapted into a recess in the bottom of a temple piece.

ACKNOWLEDGMENT

The assistance of P. Madaffari and W. Peterson in the evaluation of the computer programs and obtaining the experimental data is happily acknowledged.

THE AUTHORS

Elmer V. Carlson received a BS at Chicago Technical College in 1940, and did additional graduate studies at the University of Chicago, Northwestern University, and Illinois Institute of Technology. He has had 30 years experience in research, development and production engineering of commercially produced electroacoustic transducers, including microphones, earphones, magnetic and disc recording heads, and phonograph cartridges. He has had the principal responsibility for the development of miniature microphones and receivers (earphones) for the past sixteen years at Industrial Research Products, Inc., where he is manager of development engineering.

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