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A small high-frequency headphone

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The construction and performance of a small electrostatic sound transducer are discussed. The transducer has strong power output, from 2,000 Hz to 70,000 Hz, and is simple to fabricate. Applications include a semi-insertion headphone for human audiology experiments and a compact sound source that can be flush mounted against an animal's auditory canal.

Investigators of human and animal high-frequency hearing are often limited by the lack of high-frequency sound output and the bulky size of commercially available headphones. The sound transducer described in this paper was designed in response to the problems of bandwidth and size. The device is a small disk about 12 mm in diam and 1 mm wide, and it has strong power output between 2 and 70 kHz. Furthermore, the transducer has relatively low distortion and is simple to fabricate and mount. Thus, this transducer has many applications in animal and human psychoacoustic experiments and is particularly valuable as a semi-insertion headphone which bypasses the directional filtering of the human outer ear or as a compact sound source that can be flush mounted against an animal's external auditory canal.

The transducer functions by electrostatic principles. As shown in Figure 1, a lightweight diaphragm is suspended between two field plates. The diaphragm is charged by a dc voltage supply through a very high-impedence resistor so that when an electric field is generated between the two field plates, the diaphragm is moved back and forth. Sound generated by the diaphragm's motion radiates out through holes in the field plates. The low inertia of the light diaphragm allows very high frequency sound to be generated. Low frequency sound output is constrained by the maximum possible excursion of the diaphragm and by the area of the diaphragm (sounds with wavelengths greater than 24 times the diameter of a diaphragm are poorly radiated). The output of the transducer is a function of the amount of static charge placed on the diaphragm by the dc bias supply and of the voltage between the two field plates. Thus, a high dc voltage supply and audio step-up transformer are desirable for strong sound output.

CONSTRUCTION

The elements shown in Figure 2, along with a case, are need to build the transducer. The lightweight conductive diaphragm is formed from .01-mm mylar film (Saran Wrap). Graphite (Dixon's Microfyne) is rubbed onto the film's surface until it has an even gray appearance and is conductive. The conductive film is then gently stretched, anchored, and glued to one of the insulating washers. This insulating washer and the other five are made from .1-mm sheet mylar. Metallic field plates are made from thin pieces of metal; we used .2-mm aluminum. Eight to 10 1.0-mm holes are drilled in each plate to allow sound to radiate from the diaphragm. To avoid warping the plates, care should be taken when drilling these holes. Warped plates may short out against the diaphragm and prevent the transducer's proper functioning. Wires are attached to the diaphragm and field plates with conductive, silver epoxy. The spacer which supports the diaphragm may need to have a sector cut out in order to attach a wire to the diaphragm.

The complete transducer is 1.0 mm thick and 12 mm in diam; the radiating area is 6 mm in diam. Dimensions

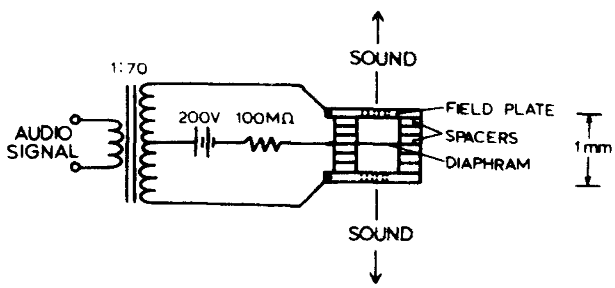

Figure 1. Schematic design of the transducer and power supply. A thin conducting diaphragm is supported by several insulating washers between two metallic field plates. The diaphram is charged and moves in response to an electric field generated by the two field plates. The power supply includes an audio transformer to increase the electric field potential and a dc bias supply to place a charge on the diagphram. Sound waves created by the moving diaphragm are radiated through holes in the field plates.

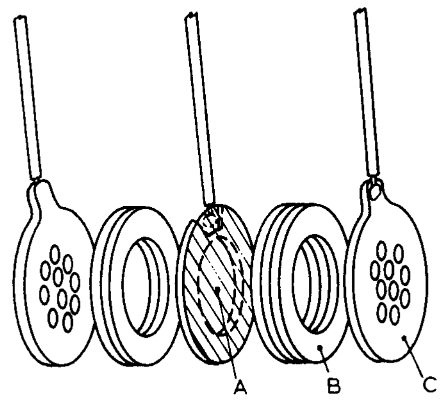

Figure 2. Transducer parts. The diaphragm (A) is stretched and glued to one spacer (B). Other spacers (B) separate the diaphragm from the two field plates (C). Wires are attached to the diaphragm and field plates with silver epoxy. Holes in the field plates (C) allow sound to radiate from the diaphragm.

of the transducer are not critical, but before major alterations are made in the dimensions suggested here, consult a good discussion on electrostatic transducer design (e.g., Matthys, 1964).

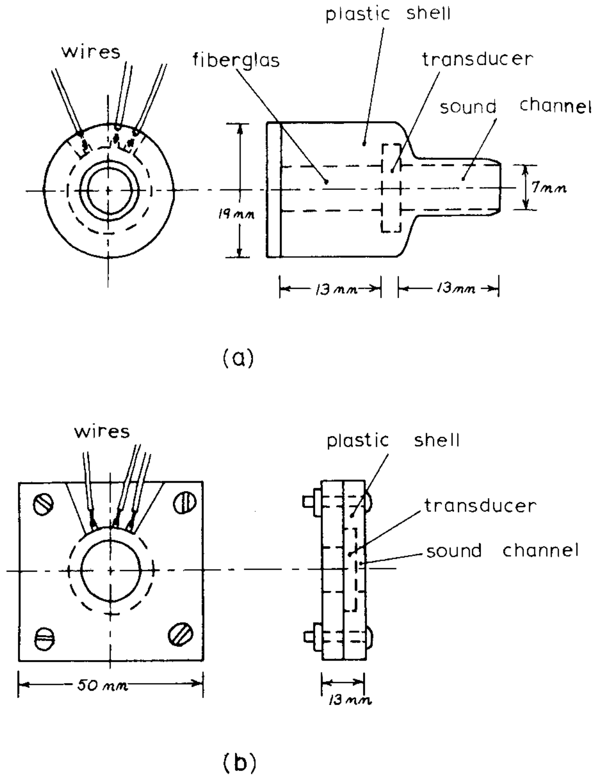

Figure 3. Shell details. Semi-insertion headphone consists of the shell, compressed fiber glass for damping, the transducer, and the sound channel connecting to the ear. The "free-field" shell consists of two pieces of Plexiglas which align and press together the transducer.

As shown in Figure 1, a dc bias supply and an audio step-up transformer are needed to operate the transducer. The dc charge is leaked onto the diaphragm via a 100-megohm resistor, eliminating shock hazard. The high-voltage supply and audio step-up transformer function to place a large static charge on the diaphragm and to create a large electric field between the field plates so that strong sound output will result. A power supply containing both the transformer and bias circuit is available from Janzen Speakers (Model 130) for about $25. To avoid high-frequency loss, wires connecting the transducer and power supply should be less than several meters long.

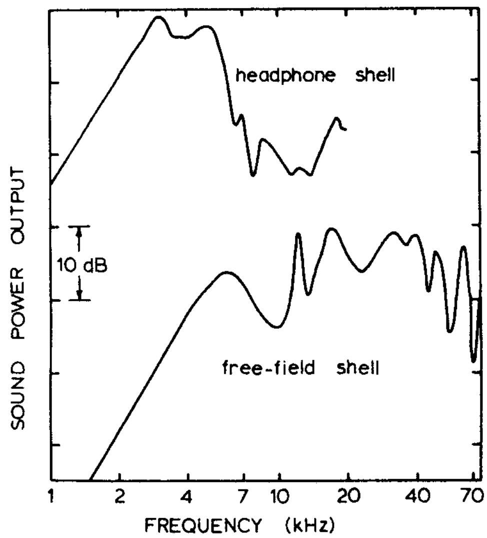

Figure 4. Frequency response of the transducer mounted in the semi-insertion shell connected to an artificial ear, and mounted in the "free-field" shell. Except for several resonances between 2 and 6 kHz in the sound channel and artificial ear, sound output from the semi-insertion headphone is relatively uniform from 2 to 20 kHz. Output from the free-field package is strong from 4 to 75 kHz.

The completed transducer must be mounted such that its elements are kept aligned and pressed together. We have experimented with two types of packaging for the transducer. The first package, shown in Figure 3a, allows the transducer to be used as a semi-insertion headphone for human high-frequency hearing experiments in which pinna filtering is to be avoided. In addition to supporting the transducer, the headphone shell also contains compressed fiber glass behind the transducer to help damp resonances in the sound channel. The second method of packaging (Figure 3b) allows the transducer to be flush mounted against an animal's external auditory canal or used as a free-field speaker. This "free-field" shell consists of two pieces of Plexiglas which sandwich the transducer's elements and align them. Both the semi-insertion and the free-field shells are simple to construct.

PERFORMANCE

Frequency response measurements of the transducer mounted in each shell were made using the power supply described. Measurements of the semi-insertion package with an artificial ear indicate a large resonance between 2 and 6 kHz caused by standing waves in the canals of the artificial ear and the headphone, relatively flat response (±5 dB) from 6 to 20 kHz, and little output below 1.0 kHz due to the small diameter of the diaphragm. Measurements of the free-field package show similar results. Response from 4 to 75 kHz was relatively uniform (±10 dB) and, below 3 kHz, response dropped off due to diaphragm size.

Output power from the semi-insertion headphone was measured as high as 75 dBA at 8.0 kHz, without audible distortion. The free-field shell allows sound energies of 80 dB (re .0002 dyne/cm^2) to be generated 2.0 cm from the shell. Distortion levels for sound outputs of 60 dB (re .0002 dyne/cm^2) measured 2.0 cm from the free-field shell range from less than 1.0% at 5.0 kHz to less than 4.0% at 20 kHz. Distortion decreases for lower sound power outputs.

Thus, the headphone is a valuable tool for high-frequency experiments.

REFERENCE

Matthys, R. J. Telstar-shaped electrostatic speaker (in two parts). Part I, *Audio*, 48 May, 19-24, 73-74, 1964. Part II, *Audio*, 48 June, 28-32, 47-48, 1964.

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