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R 31  
Cap. 2

JAN 19 1967

## AN ULTRASONIC SPEAKER FOR STUDIES OF THE ACOUSTIC SENSITIVITY OF TYMPANATE MOTHS<sup>1</sup>

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### INTRODUCTION

A speaker was developed with a wide frequency range [10 to 100 kilohertz (KHz)] and high sound level output [80 to 100 decibels (db)]. It is being used successfully in the study of the effect of ultrasound on the sensory physiology and behavior of moths of the bollworm [*Heliothis zea* (Boddie)] and the tobacco budworm [*H. virescens* (F.)] in progress at the Southeastern Cotton Insects Investigations Laboratory at Florence, S.C. The design was based on the theory of electrostatic speaker operation discussed in detail by Kuhl et al.<sup>4</sup> and Wright.<sup>5</sup>

### DESIGN OF ULTRASONIC SPEAKER

The speaker described here is the most efficient of several that were constructed by using the theory of electrostatic speakers described by Kuhl et al.<sup>4</sup> and McCue.<sup>6</sup> It is of simple design, and the items used in its construction are relatively inexpensive.

The speaker consists of an aluminum body, a metalized Mylar diaphragm, a sintered brass backplate, a plexiglas backplate and cup, and an adjustment bolt to regulate tension on the diaphragm. The front and back sides of the speaker, with a disassembled unit in the rear, are shown in figure 1; figure 2 shows a detailed drawing of the components.

The stock materials used to produce the speaker are as follows:

(1) Speaker body: Half-hard aluminum bearing stock, 5-inch-diameter, and tapped to receive six 6-32 socket head cap screws (cost \$40 per 13-inch length).

(2) Plexiglas backplate: 1/8-inch-thick sheet Plexiglas, \$1.75 per square foot.

(3) Plexiglas cup: 1/2-inch-thick Plexiglas machined to hold the diaphragm against the speaker body, recessed to receive the brass and plastic backplates, and threaded to receive the adjusting bolt, \$5 per square foot.

(4) Adjustment bolt: 1/2-inch aluminum rod, threaded.

(5) Diaphragm: Metalized Mylar polyester film with 6 holes punched to aline with the holes in the body, 1/2 and 1 mil available from the Dow Chemical Co., 2600 Wilshire Blvd., Los Angeles, Calif. 90057 (1/2 mil \$5.55 per pound, 1 mil \$4.40 per pound).

(6) Backplate: Sintered brass filter (Oilite Bronze Filter Discs: 1/16-inch-thick, 3 11/16-inch-diameter, Part No. LS-7503-2, Grade 2000, super fine, \$1 each. Beemer Engineering Co., Industrial Park, Fort Washington, Pa.

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<sup>4</sup> Kuhl, W., Schodder, G. R., and Schroder, F. K. Condenser Transmitters and Microphones with Solid Dielectric for Airborne Ultrasonics. *Acoustica* 4: 519-532. 1954.

<sup>5</sup> Wright, W. M. High-frequency Electrostatic Transducers for Use in Gases. Harvard Univ. Div. Engin. and Appl. Physics, Acoustics Res. Lab. Tech. Memo, 47, 61 pp. Cambridge, Mass. 1962.

<sup>6</sup> McCue, J. J. G. Ultrasonic Instrumentation for Research on Bats. *International Conv. Rec.* 6: 310-315. 1961.

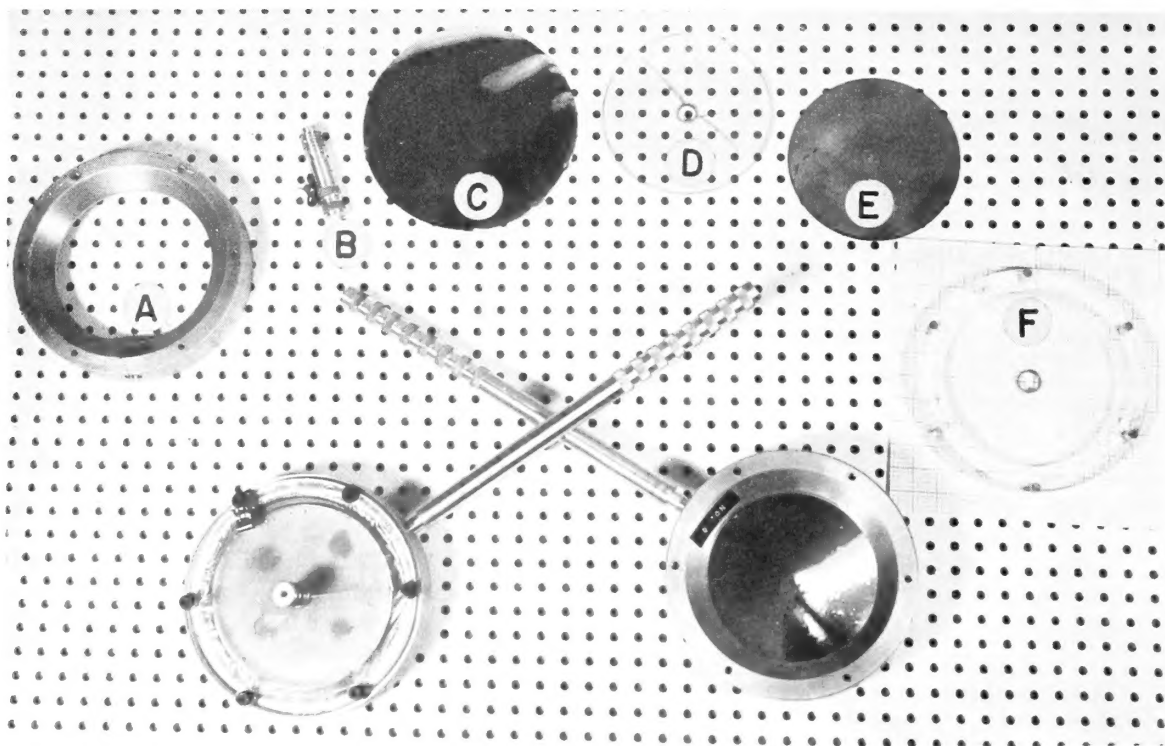


Figure 1.--Back and front view of assembled speaker in the foreground and, in the background, a disassembled speaker showing (A) aluminum body, (B) adjustment bolt, (C) metallized Mylar diaphragm, (D) Plexiglas backplate, (E) brass backplate, and (F) Plexiglas cup.

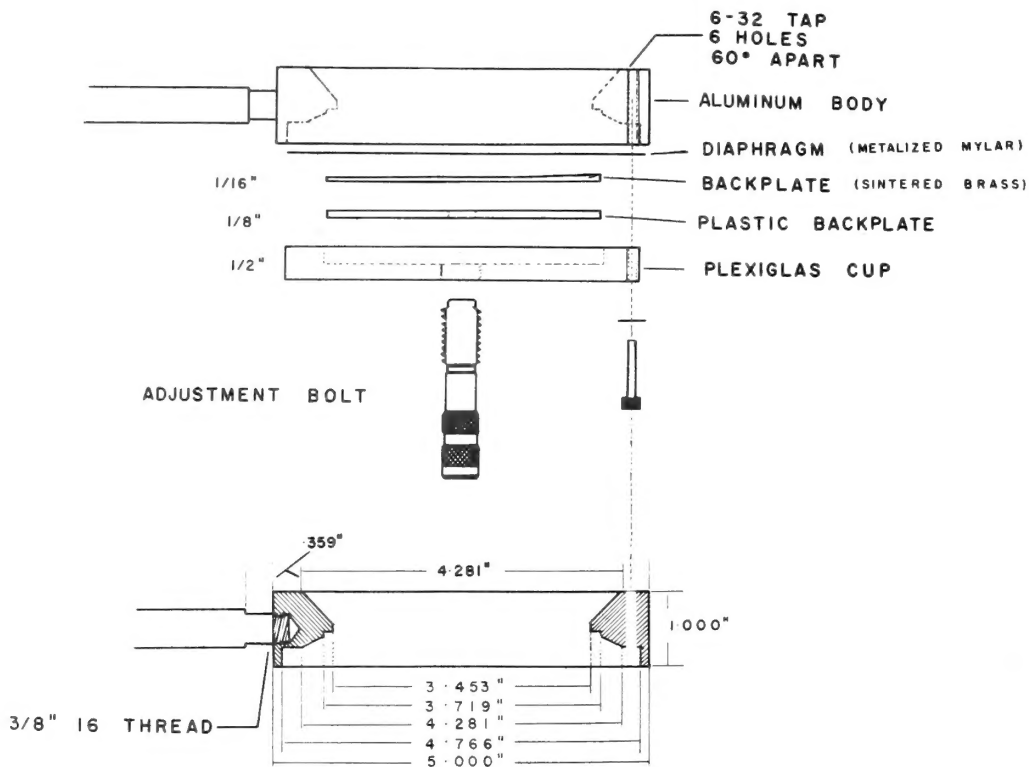


Figure 2.--A detailed drawing of the ultrasonic speaker components. A cross-sectional view of the aluminum body is shown at the bottom of the drawing. The 1/2-inch-diameter adjustment bolt is threaded 13 threads per inch. One-inch-long Allen-type head bolts hold the Plexiglas cup against the aluminum body.

Materials for each speaker cost approximately \$6.50, and labor for machining cost \$35, for a total cost of \$41.50 in 1966.

The Mylar diaphragm is placed with the metalized side in contact with the body and the holes are alined. The sintered brass filter serves as the backplate for the speaker; the commercially available item we used requires only sanding with fine sandpaper to remove the sharp edges (the normally textured surface provides the minute and rounded projections necessary for operation of the electrostatic speaker); then, after it is cleaned with 100 percent ethyl alcohol, it is placed with the smoothed side toward the diaphragm. The Plexiglas backplate is placed against the brass backplate so that it exerts a slight pressure, and the Plexiglas cup is positioned on the body and bolted in place. The tension on the diaphragm is adjusted with the adjustment bolt until wrinkles in the diaphragm are eliminated. Although tension on the diaphragm is not critical for sound-level output, the output can sometimes be increased by 2 to 3 db by careful adjustment.

## INSTRUMENTATION

The speakers were calibrated with the equipment shown in the photograph in figure 3 and in the diagram in figure 4. RCA signal generator model WA-44C produced the signal to drive the driver amplifier. The output signal was monitored on RCA vacuum tube voltmeter (VTVM) model WV98B, Tektronix oscilloscope model 502, and Hewlett Packard electronic counter model 523D.

The driver amplifier was the type described by McCue<sup>7</sup> with a wide frequency range and an output impedance capable of driving our electrostatic speaker. It drove the speaker directly and was also equipped with a 220-volt d.c. power supply for the necessary polarization voltage.

Bruel and Kjaer (B&K) 1/4-inch condenser microphone type 4135 with a cathode follower was used as the transducer for B&K microphone amplifier type 2604. The output of the microphone amplifier read directly in decibels, and the waveform, voltage, and frequency from the output were monitored on the oscilloscope, the VTVM, and the frequency counter.

## CALIBRATION PROCEDURES

A calibration chamber was designed and constructed so that stray or reflected signals could be attenuated or eliminated (fig. 3), and a microphone mount was installed in the rear of the chamber so that only the active portion of the microphone was contained in the chamber. A small lamp was installed 1 inch above the center of the microphone and focused on the Mylar diaphragm at the front of the speaker; when the light beam was reflected into the source, the speaker was assumed to be properly alined with the microphone. The speaker mount, equipped with adjustments for vertical and horizontal alinement and built to be rotated 360° in the horizontal plane, held the speaker 1 meter from the front plate of the microphone.

The driver amplifier was calibrated with a constant 2-volt peak-to-peak (p-p) sine wave signal from the oscillator that was monitored by a VTVM. The waveforms and frequency were monitored at the oscillator on the oscilloscope and electronic counter, respectively. The signals were also monitored at the output of the driver amplifier and the microphone amplifier. The waveforms were compared for distortion at all three points (fig. 5). Frequency response of the driver-amplifier is shown in figure 6.

The condenser speaker was calibrated by using a constant 100-volt p-p signal from the output of the driver amplifier, and the frequency response of the speaker was measured at frequencies from 10 to 100 KHz (fig. 7). The directional characteristics of the output of the speaker were determined in the horizontal plane at angles between 0° to 90° in relation to the plane of the microphone; the data (fig. 8) show a typical response curve for this type of speaker and

<sup>7</sup>See footnote 6.

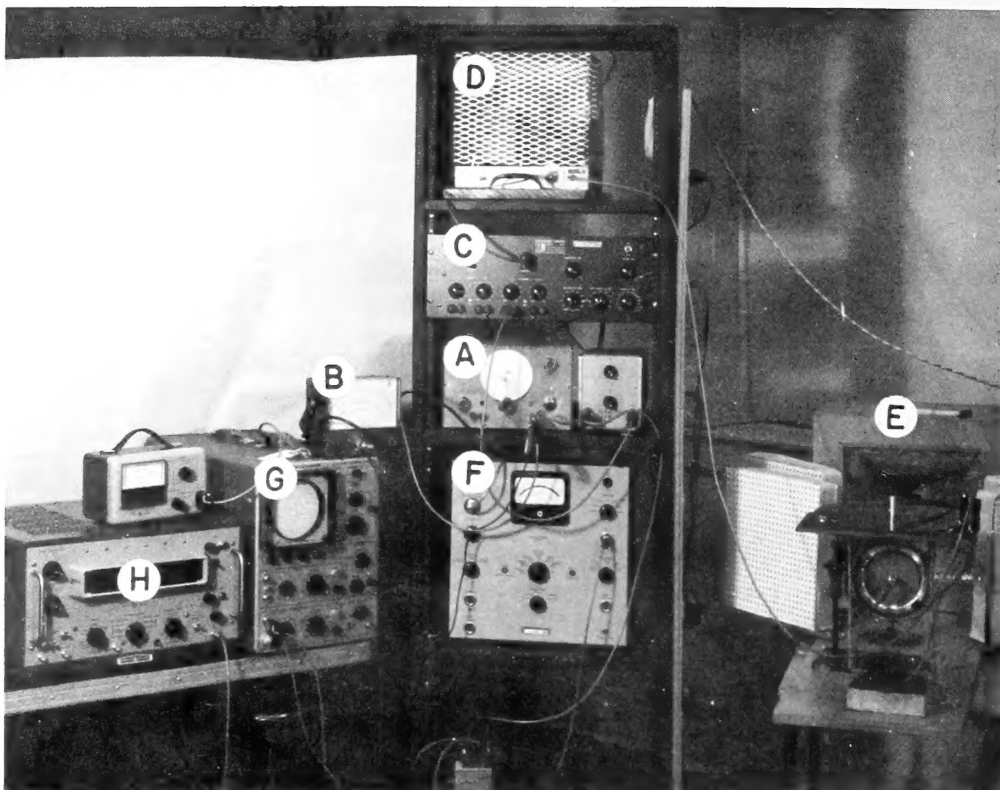


Figure 3.--Instruments used in speaker calibration: (A) Signal generator, (B) VTVM, (C) electronic switch, (D) McCue driver amplifier, (E) speaker calibration chamber, (F) sound level meter, (G) oscilloscope, and (H) frequency counter.

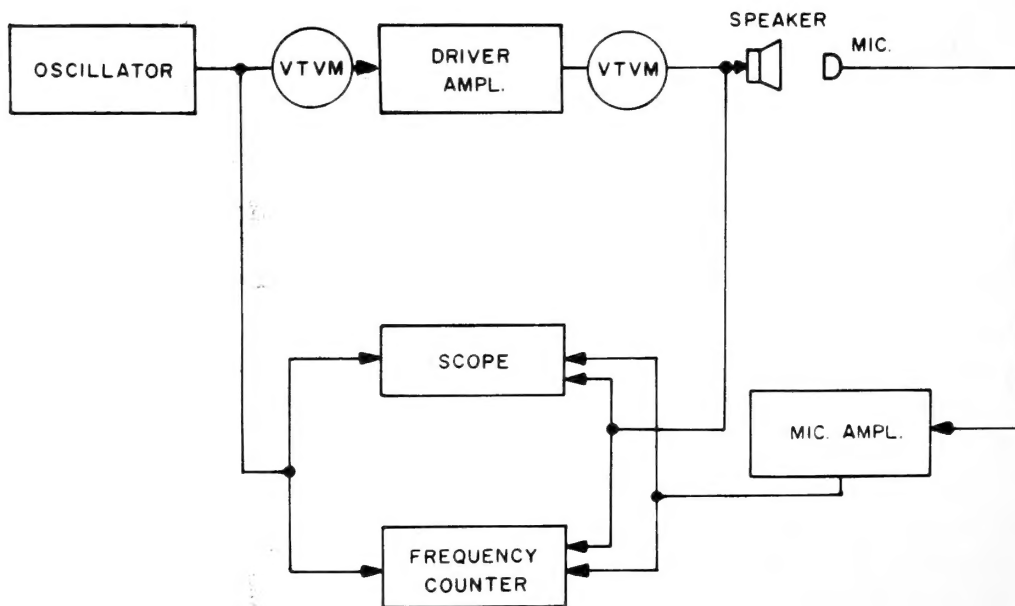


Figure 4.--Block diagram of instrumentation used in speaker calibration.

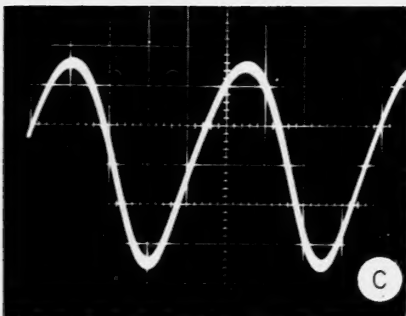
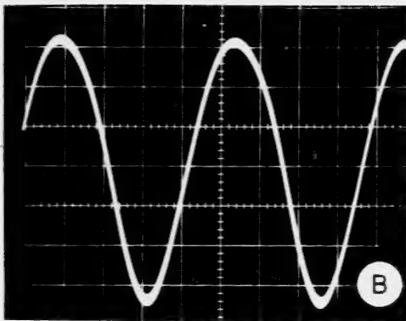
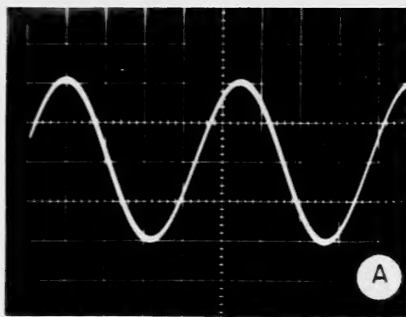
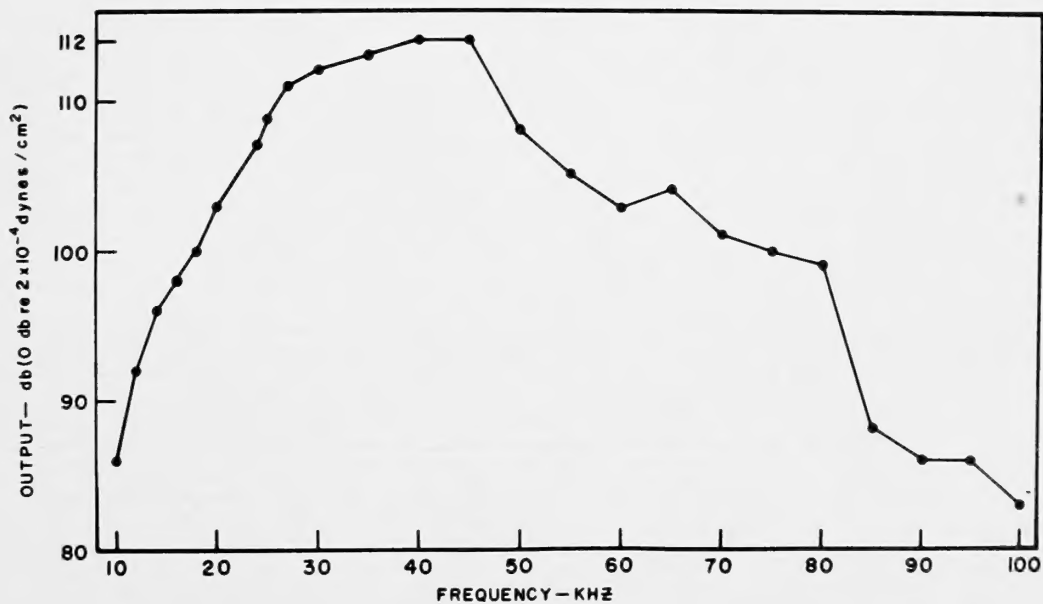


Figure 5.--A comparison of the 22 KHz distortion-free waveforms from (A) oscillator, (B) driver amplifier, and (C) microphone amplifier. Each vertical scale division represents 1 cm. In A the scale is 0.5 volt per centimeter; in B the scale is 20 volts per centimeter; and in C the scale is 2 volts per centimeter.

Figure 6.--Driver-amplifier frequency response with a 2-volt p-p input.



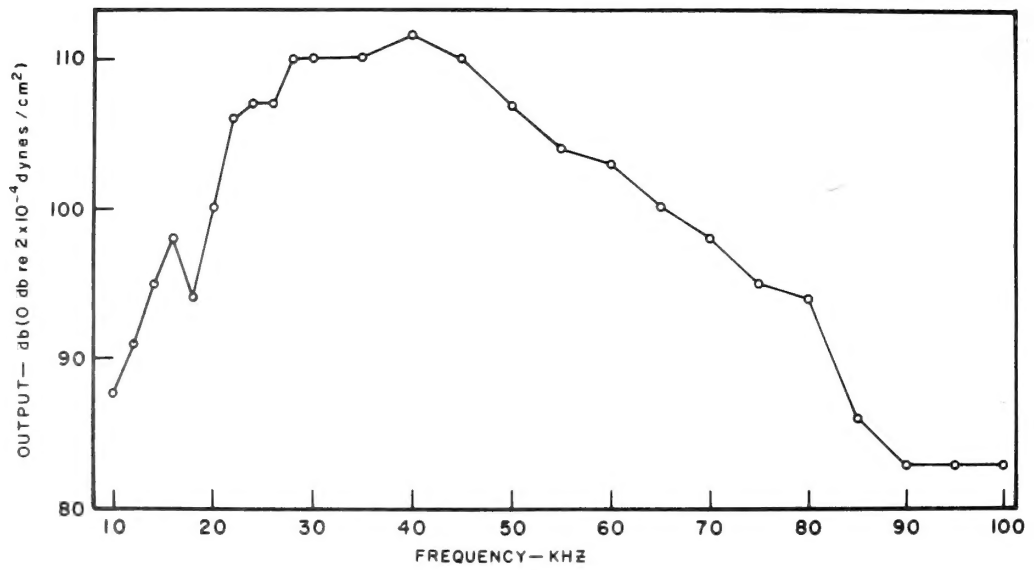


Figure 7.--Frequency response of ultrasonic speaker with a polarization voltage of 220 volts d.c. and a 100-volt p-p input.

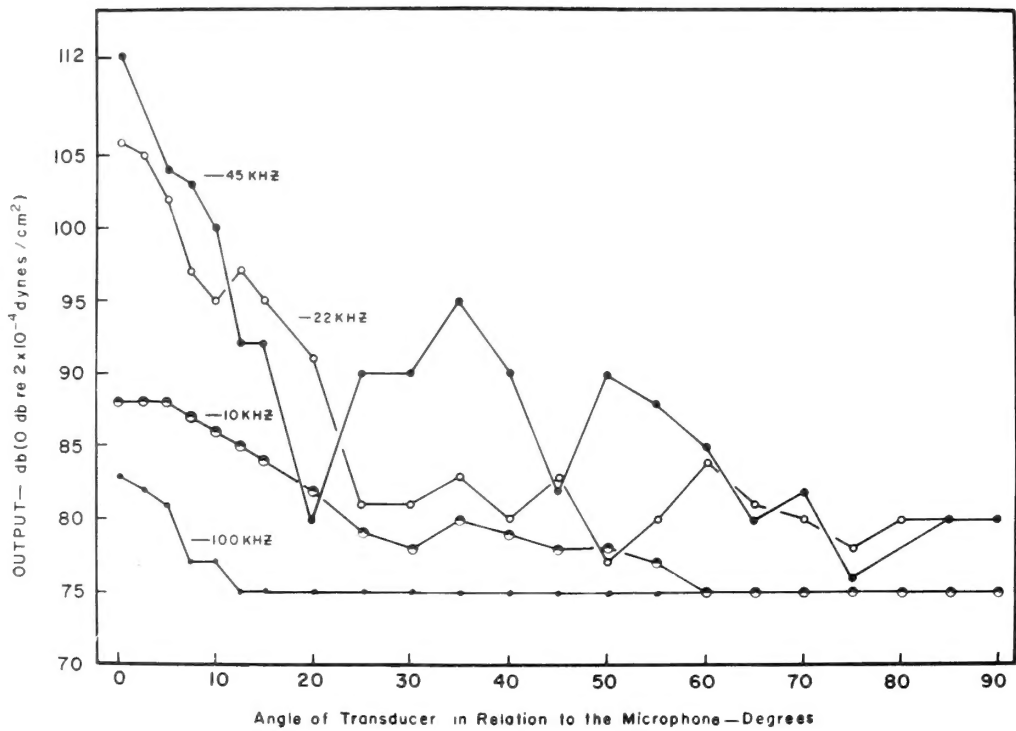


Figure 8.--Directional characteristics of ultrasonic speaker at frequencies of 10, 22, 45, and 100 kHz.



agree closely with response curves for such equipment cited in the literature.<sup>8</sup> Also, since the ultrasonic speaker is very directional, the output dropped off sharply (fig. 8) as it was rotated from 0° to 90°. The speaker proved to have a sound-level output greater than 80 db at all frequencies between 10 and 100 KHz.

## DISCUSSION

In the study of ultrasound speaker characteristics made at Florence, S.C., the speaker driving voltage was 100 volts p-p. Higher voltages gave higher sound level outputs--for example, at 45 KHz, 150 volts p-p produced a sound level of 115 db at 1 meter at 0° incidence relative to the microphone. Driving the voltages above 150 volts p-p tended to cause waveform distortion and frequency doubling, and arcing between the diaphragm and the brass backplate at the sharp raised points on the backplate, destroying the diaphragm.

The speaker described here was one of the essential units used to produce ultrasonic stimuli for acoustic sensitivity studies on bollworm and tobacco budworm moths. With it, the senior author determined that the most sensitive acoustic sense cell (first A-cell) of these moths could detect ultrasound stimuli of 45 to 50 db at frequencies between 18 to 25 KHz. At intensities of 100 db, the first A-cell responded to stimuli from 10 KHz to 100 KHz.

## ACKNOWLEDGMENTS

The metalized Mylar samples for the diaphragms were furnished by Charles Howle and Bob Garey of E. I. du Pont de Nemours & Co., Florence, S.C.

Our appreciation to R. E. Hanna and his students for machining the speaker parts and to J. A. Gupton for his help in assembling and testing the driver amplifier (all of the Florence-Darlington Technical Education Center, Florence, S.C.). Also the assistance of Frank Shelley and Herbert Elder of the Agricultural Engineering Research Division and the Southeastern Cotton Insects Investigations Laboratory, ARS, respectively, Florence, S.C., is commended and gratefully acknowledged.

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<sup>8</sup> See footnote 5.

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