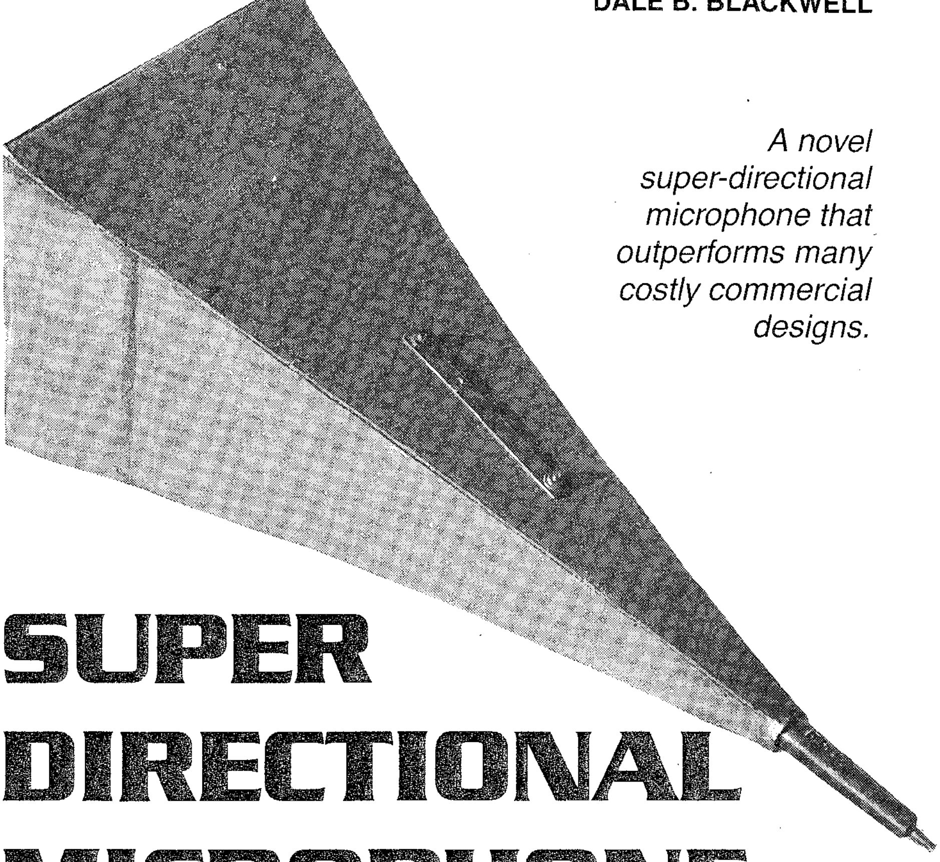
SUPER DIRECTIONAL MICROPHONE

DALE B. BLACKWELL

A novel super-directional microphone that outperforms many costly commercial designs.



THERE ARE SEVERAL WAYS TO CAPTURE and listen to sounds at a distance. Obviously, you could always set microphones at a location of interest, and transmit the sounds by wire or radio to your position. However, that's not always convenient or practical in certain cases of surveillance, or when dealing with bird calls or animal sounds.

Another option is to use a sensitive, directional microphone similar to those used in network TV broadcasts of football or other sporting events. Such microphones typically have parabolic reflectors for focusing sound onto them. The microphone we'll describe here uses a different approach, yet is perfect for long-distance monitoring or surveillance.

Theory

The major criteria that determine microphone performance are directional sensitivity and frequency response (bandwidth). Just as frequency response and directional sensitivity in antennas are changed by varying the lengths, diameters, and relative angles of metal radiators or reflectors, the analogous characteristics of microphones can be adjusted by similar geometric variations. One lesser known antenna type, normally used in microwave applications, is the horn antenna. The horn microphone presented in this article is designed using analogous principles which could, incidentally, also be applied with equal validity to the design of a loudspeaker, for reasons discussed below.

A very helpful concept in either acoustic or electromagnetic design is to think of a microphone, loudspeaker, or antenna, as just a transducer. This concept can be extended still further, if you consider a transducer of wave-propagated energy that focuses such energy onto a receptor to be a lens. Consider the similarities, taking the antenna first, since it's the more obvious. Both antennas and lenses focus and collect electromagnetic energy, the only difference being that light is at a much higher frequency range, and obeys the laws of optics. (Actually, microwave antennas also exhibit quasi-optical physical phenomena.)

Consider for a moment; don't both electromagnetic radiation and light exhibit the same phenomena of reflection, refraction, absorption or attenuation, and polarization? And in like fashion, acoustic energy also exhibits the same phenomena. Just as antennas are *electromagnetic* lenses, so too are microphones and loudspeakers *acoustic* lenses.

Not only are microphones and loudspeakers acoustic transducers or lenses, but also acoustic filters. Just as all filters have frequency and phase response, so too do microphones and loudspeakers. However, here, as with antennas, two types of filtering occur: directional and frequency.

Another term for directional sensitivity is directivity, often a desirable trait, since it prevents spurious sound from entering from undesired directions. A microphone with uniform directivity is termed omnidirectional; however, flat directional response doesn't imply flat frequency response. A microphone can either have a flat response over the audio spectrum (20 Hz–20 kHz), or be tailored for greater sensitivity over specific audio bands. The acoustic horn presented here has very high directivity over the entire audio spectrum.

The last property microphones and speakers have in common is reciprocity, which lets a microphone work equally well as a loudspeaker of identical design, both directionally and in frequency response; this property also holds true for antennas.

Different microphone types

Most microphones are omnidirectional, as shown in Fig. 1. Figure 1-*a* shows the basic shape of an omnidirectional microphone with the main axis, while Fig. 1-*b* shows a linear polar plot of relative sensitivity $P(\theta)$ (dynes/cm^2) as a function of angle θ about the main axis; all curves are normalized to 1 at the peak of the main beam. The main beam can be at any angle, although it's normally depicted at 0°. If several people sit around a table, an omnidirectional microphone at the center will pick them all up equally well. Any plane that passes through the main axis will exhibit this sensitivity response.

The second most common microphone type is the *cardioid*, shown in Fig. 2-*a*, which has greater directivity toward the front over most of the audio range. The sensitivity pattern shown in Fig. 2-*b* looks like the mathemati-

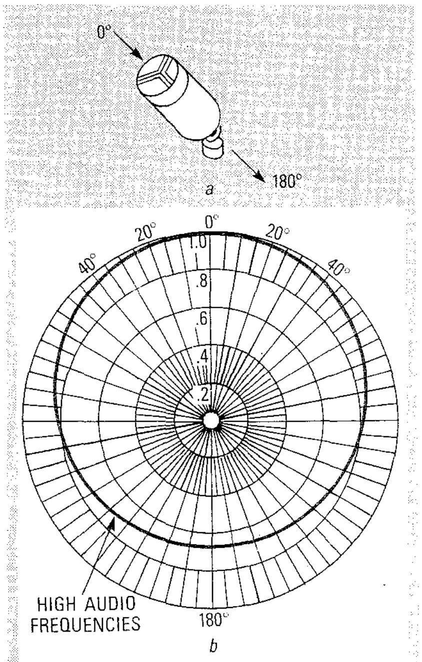


FIG. 1—AN OMNIDIRECTIONAL microphone, shown in (*a*), has uniform directional sensitivity to sound pressure P(θ); the main axis is out the indicated. In (*b*) is shown a polar plot of directional sensitivity; the response is identical in any plane through the main axis.

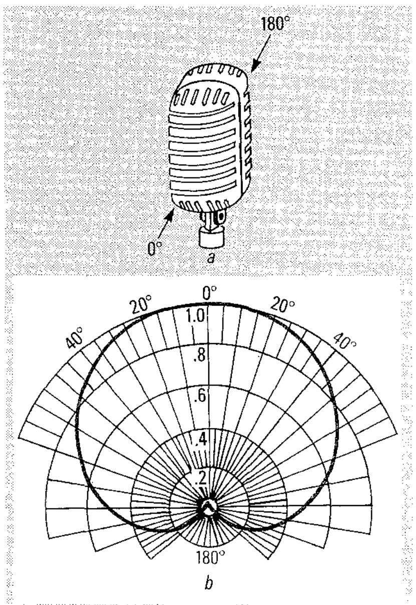


FIG. 2—A CARDIOID MICROPHONE, shown in (*a*), has greater sensitivity from the front than the rear. The 0° and 180° directions are along its main axis, pointing through the main face. The sound pressure sensitivity P(θ) shown in (*b*) was taken through a plane normal to the main axis.

cal curve called a cardioid (heart-shaped), hence the name. An orchestra in a night club might use a cardioid microphone so that only their music is picked up, not sounds from the audience. The power function is of the form:

$$P(\theta) = P_{ref}[1 + \cos(\theta)],$$
$$= 2 \times P_{ref}\cos^2(\theta/2).$$

At $\theta = 0°$, the sensitivity is maximized. The sensitivity goes to zero (a null) at $\theta = 180°$.

The ribbon element microphone shown in Fig. 3-*a* is the industry standard, well-known from all the photos of radio stars in front of them. It's sensitive from both front and rear, producing the figure-8 pattern shown in Fig. 3-*b*. A microphone that picks up equally well in opposite directions is advantageous in a talk show where the guest sits opposite the host.

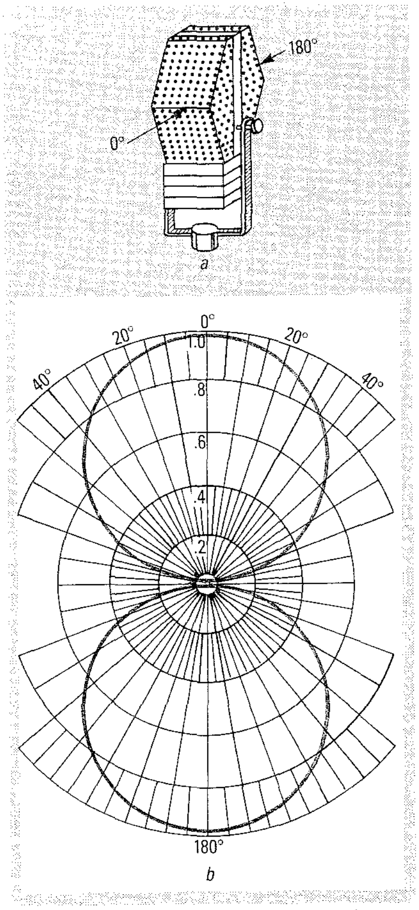


FIG. 3—A BIDIRECTIONAL microphone, shown in (*a*), is uniformly sensitive to sound from front and rear, but less sensitive from the side; the main axis is the same as that for a cardioid microphone. Note, however, that P(θ) in (*b*) has two lobes, not one, with two maxima and two minima (zeros, or nulls).

Increasing directivity

Experimenting with basic microphone directivity patterns yield more specialized designs that are much more sensitive from the front. Figure 4-*a* shows a parabolic reflector microphone; all parallel rays, wherever they strike the curve, are reflected to the focal point, where the microphone is located. Parabolic microphones are also especially directive at higher audio frequencies, as shown in the sensitivity patterns of Fig. 4-*b*.

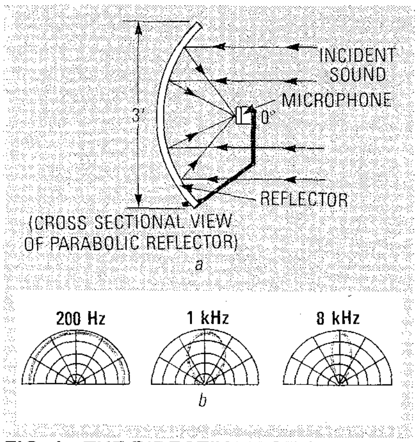


FIG. 4—THE DIRECTIVITY OF A parabolic reflector microphone increases with frequency. In (*a*), the incident parallel rays converge to the microphone at the focal point. In (*b*) are shown linear polar plots of acoustic power at four frequencies.

As shown in Fig. 5-*a*, the line (shotgun) microphone is another commercial directive version, albeit not quite as focused as a parabolic reflector. The line microphone has either a single long tube with spaced openings, or several tubes of increasing length, in front of the microphone element. The sensitivity patterns in Fig. 5-*b* *aren't* for differing frequencies, but for different tube lengths, being integral multiples of λ/2, or half a wavelength.

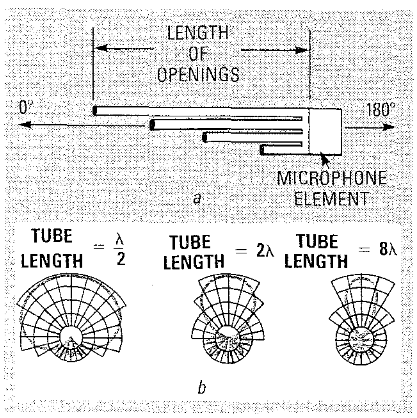


FIG. 5—A LINE (SHOTGUN) microphone becomes more directive as the length of its tubes increase. It's not as directive as a parabolic reflector, and either has one long tube with spaced openings, or several tubes of increasing length each with one opening, right in front of the diaphragm.

Both the reflector and line microphones are directive, but neither compares with the narrow beam of the horn shown in Fig. 6. Figure 6-*a* shows the geometry of the basic horn shell for the horn microphone prototype, without the screw-on extension piece, while Fig 6-*b* shows the directivity patterns for different frequencies.

All microphones, of whatever type, work equally well when the same basic shape is used in a loudspeaker due to reciprocity. The narrow beam of a horn stems from the ability to match the impedance between a small microphone diaphragm and free air, making the small microphone diaphragm (or receptor) seem as large as the mouth of the horn.

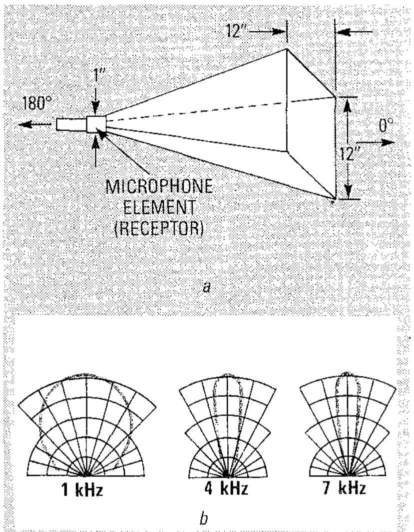


FIG. 6—HORN MICROPHONES ARE VERY directive; they match acoustic impedance from diaphragm to open air. In (*a*) are the prototype dimensions; the narrow beamwidth makes the receptor act as large as the mouth, due to phasing and pressure effects, so the incident volume is greater from the front, than sides or rear. In (*b*) are directivity plots for 1, 4, and 7 kHz.

Horn microphone

The high directivity of all horn microphones stems from phasing and pressure effects, making the volume at the receptor greater from the front, than from the sides or rear. The mouth, length, shape, and frequency range to be received, all determine the directivity. One reason for the high directivity is that audio wavelengths are made comparable to the mouth size. The relation is $\lambda = C/f$, where λ is wavelength (cm), C is speed of sound (340 m/s), and f is frequency in Hz.

Since 1 ft = 30.48 cm, then from 20 Hz to a few hundred Hz, the wavelengths are over a foot. At $f = 1.115483$ kHz, then $\lambda = 1$ ft, so the 1-foot diameter horn presented here should be quite directive at that frequency. Figure 7 shows additional directivity patterns, but not for explicit frequencies. Note that those patterns are for various mouth sizes relative to wavelength. As the ratio of mouth size to wavelength increases, so does directivity. Another way to achieve higher directivity is to increase horn length for a given mouth size. As shown in Fig. 8, to achieve this, the horn angle α must be reduced.

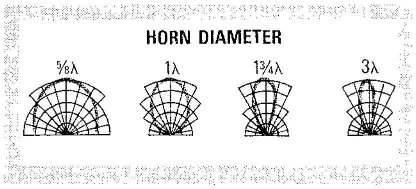


FIG. 7—AS HORN MOUTH SIZE increases relative to wavelength, directivity increases, since audio wavelength is comparable to mouth size. Shown are directional patterns of decreasing beamwidth, for four horn diameters relative to λ.

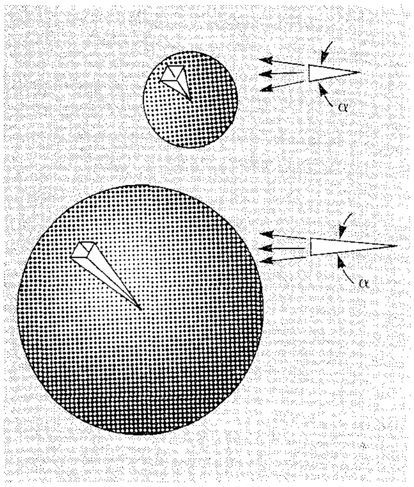


FIG. 8—ANOTHER WAY TO ACHIEVE directivity in a horn microphone is to increase length versus mouth size, requiring that horn angle α be reduced.

Horns of different shapes are commonly used as loudspeakers, with the exponential, hyperbolic, and conical versions the most common, in that order. Horns are uniquely able to transform and match acoustic impedances. The horn loudspeaker is an acoustic transformer, changing large pressures and small volume currents in the throat to small pressures and large volume currents in its mouth; horn microphones do the reverse.

As shown in Fig. 9, the conical horn has a gradual impedance-transformation curve as cutoff frequency is approached, with a smooth transition from a high-directivity pattern to one of lower directivity. Such smooth transitions are more desirable than the abrupt low-frequency cutoff of both exponential and hyperbolic horns.

In the horn of Fig. 6-*a*, the transition from square horn to receptor is smoothed into a cone using modeling clay. At the higher audio frequencies, the conical walls reflect the short wavelengths (a few inches or less) down to the microphone diaphragm, helping to optimize high-end audio directivity for a narrower beamwidth.

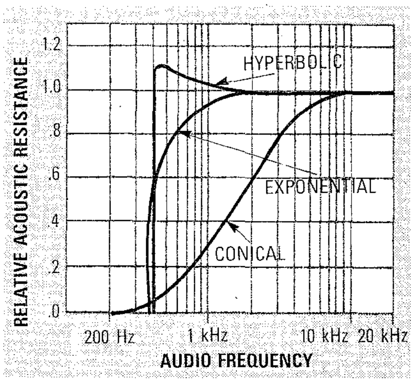


FIG. 9—RELATIVE ACOUSTIC resistance for several horn microphones of size and bandwidth similar to Fig. 6. Each works just as well as a loudspeaker by reciprocity, with the exponential, hyperbolic, and conical the most common.

Construction

The horn presented here can be made using low-cost materials and a little time. Because sound pressure waves exert low force, light-weight materials can be used. Figure 10 shows the prototype, made from cor-

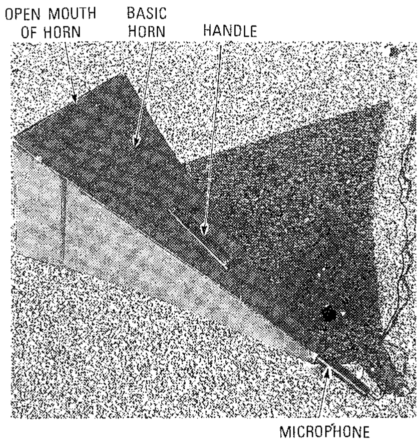


FIG. 10—THE PROTOTYPE HORN WAS made from corrugated cardboard; a removable extension with larger mouth and a carrying handle was added. At high audio frequencies, the walls reflect short wavelengths of a few inches or less to the diaphragm, to optimize directivity.

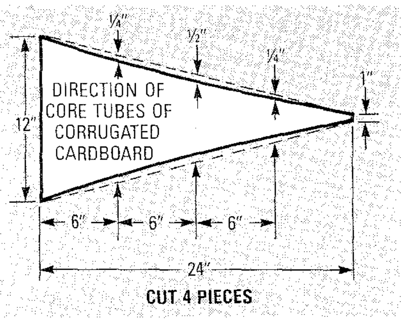


FIG. 11—HERE'S THE CUTOUT FOR ONE side of the basic horn; note the direction of the corrugated ribs. The edges have slight curvature so the sides have added strength, and don't resonate easily. The edges were taped, and paper glue was used on the inner and outer corners. The small end was cut to a 1-inch diameter, and the microphone slides in and is held by the four sides. A metal washer slipped into the throat face acts as a stop, yet lets the sound reach the diaphragm.

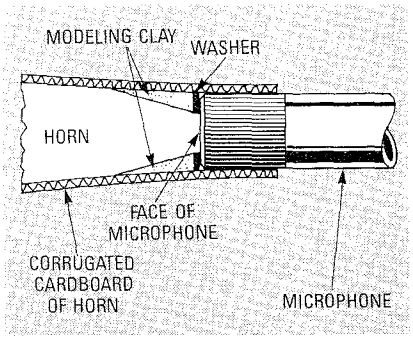


FIG. 12—WHEN MOUNTING THE microphone in the horn, the washer aperture should be at least 75% of the diaphragm diameter. The modeling clay smoothed the transition from the square horn to the washer opening, so that the sound wasn't restricted from reaching the diaphragm.

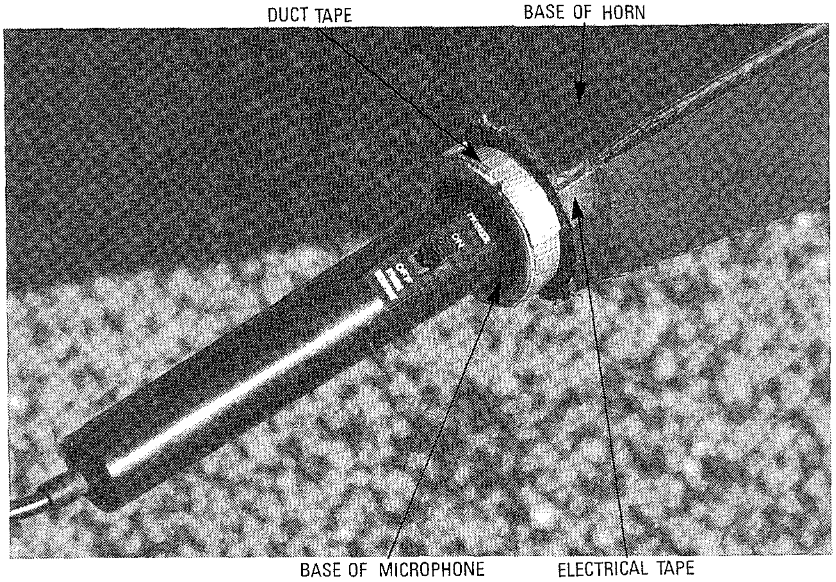


FIG. 13—A CLOSE-UP VIEW OF THE EXTERIOR of the neck. The carboard is tapered, producing an opening of proper size for the microphone, and the microphone is inserted. Note the silvery ring at the base of the horn, just behind the base of the horn. The bottom of the microphone protrudes from the base of the horn, and was sealed mechanically and acoustically with duct tape, while the base of the horn was stiffened with electrical tape.

rugated cardboard, cut to the correct size and glued together, with a carrying handle added. The horn was constructed, assembled, and tested; then, a removable extension was added to gauge the benefits of a larger mouth.

The basic horn was built with four sides from the pattern in Fig. 11. The edges have slight curvature for additional strength, so they won't resonate easily. The edges were taped enough to hold them in place, and simple white paper glue was applied to both the outside and inside corners. The small end was cut to a 1-inch diameter, letting the microphone slide in and be held by the four cardboard sides. A metal washer slipped into the throat against the microphone face acts as a position stop, while letting the sound reach the diaphragm.

As Fig. 12 shows, modeling clay smoothed the transition from the square horn to the round washer opening, so the sound wasn't prevented from reaching the diaphragm. The washer needs an opening at least 75% of the microphone diameter. Figure 13 shows a close-up view of the exterior of the neck of the horn. You can see how the cardboard is tapered to produce an opening of the proper size for the microphone, and how the microphone is inserted.

Note the silvery ring at the base of the horn in Fig. 13, just in front of where the microphone apparently ends. The base of the microphone protrudes from the base of the horn, and is sealed mechanically and acoustically with duct tape. The extension in Figs. 14 and 15 slips over the front of the basic horn, to extend the length and expand the mouth, and two 1/4-20 screws with washers hold both sections together.

By adding the extension, the mouth was increased in size from 1×1 ft to 2×2 ft, quadrupling the area. Also, the new size is one wavelength across at $f = 557.742$ Hz, matching wavelengths down to lower audio frequencies and increasing directivity beyond that of the basic horn alone. The larger diameter and greater total area improves pick-up, raising the theoretical pressure level by 3 dB. In practice, the horn picks up more at lower frequencies because the impedance matching at those frequencies is improved.

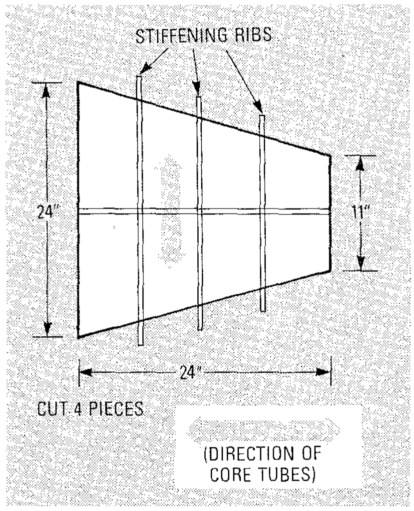


FIG. 14—HORN EXTENSION CUTOUT; the ribs stiffen the cardboard. The extension slips over the horn, extending its length and expanding its mouth, and two 1/4-20 screws with washers hold both together. The mouth is now 2×2 ft, one wavelength across at $f = 557.742$ Hz, matching wavelengths down to lower audio frequencies, improving directivity, raising the pressure level by 3 dB, and providing better low-frequency pick-up, since impedance matching is improved.

Testing

The preliminary tests were conducted at a large parking lot at a local beach. In actual use, aim the horn in the direction of the desired sound, and plug the microphone into a tape recorder, allowing playback later on. In evaluating the prototype, all tests were recorded to allow detailed sound pressure evaluation of an individual

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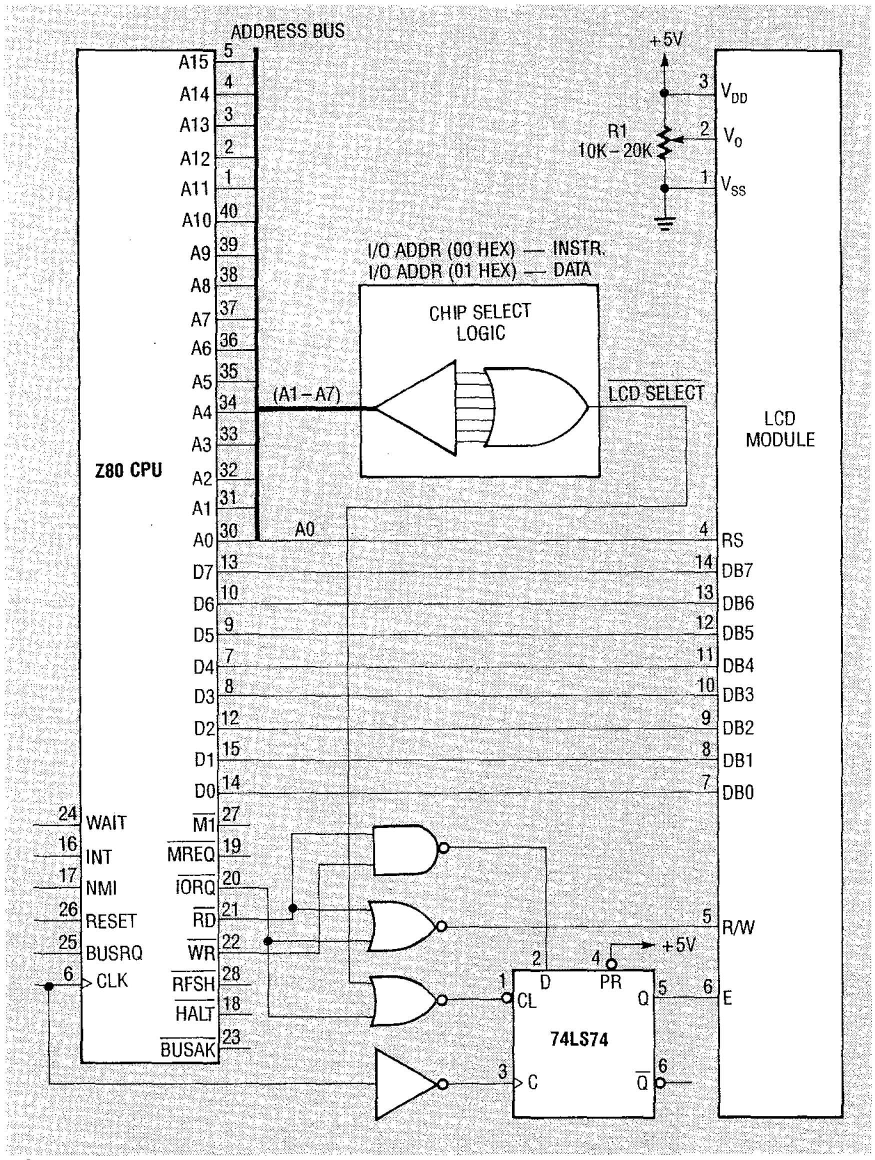

FIG. 6—INTERFACING THE HD44780-BASED LCD module to a microprocessor requires some additional logic.

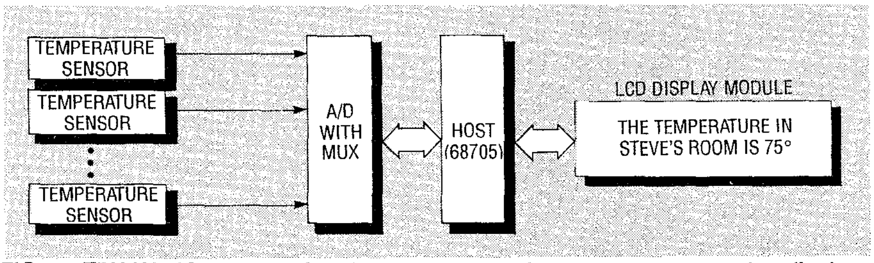

FIG. 7—TRY USING AN LCD MODULE to build a multi-zone thermometer that displays temperatures throughout your house with your own custom messages.

pability of the port pins of the microcontroller, the LCD is powered directly from a port pin of the microcontroller. That allows the convenient feature of letting the microcontroller power down the display when it's not needed in order to conserve battery power. It should be noted that the entire design uses fewer than thirty interconnecting wires.

As a suggestion for your own project using an LCD module, why don't you try to build a multi-zone thermometer that displays temperatures throughout your house with simple, non-cryptic messages. For example, you could display "THE TEMPERATURE IN STEVE'S ROOM IS 72°." A block diagram of such a project is shown in Fig. 7. **R-E**

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speaking, in a normal voice, 100 ft from the mouth. The resultant recording was quite intelligible even above seagulls squawking overhead, the surf, and car noises 500 ft away.

The higher audio frequencies so necessary for speech intelligibility tend to be very directive. Noticeable roll-off occurred 5° away from the main axis of the horn; in fact, speech wasn't understandable when the horn microphone wasn't pointed directly at someone. Beyond 10–15° off-axis, a voice vanished completely into background noise. However, seagulls and birds 75–100 ft away sounded like they were 2 ft in front of a regular microphone.

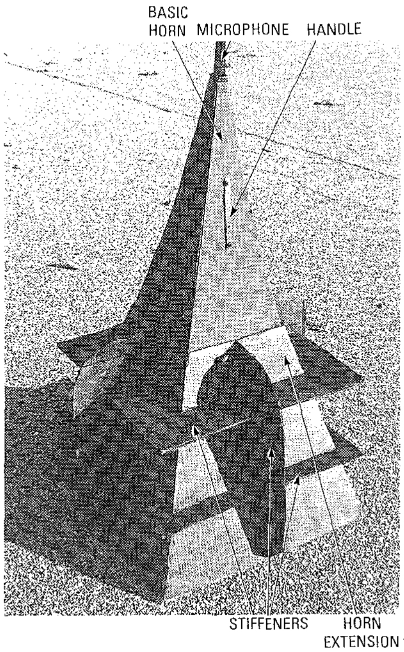

FIG. 15—HERE'S THE COMPLETED HORN MICROPHONE. At the top is the receptor microphone, then comes the basic horn, and lastly, the horn extension is shown with its support ribs.

Surprisingly, the extension didn't really improve directivity, and apparently wasn't worth the effort, given the time and effort needed, as well as its size. Frequency response tests with polar pattern measurements would be needed for verification of this, and to optimize the extension performance. However, recording bird calls and animal sounds is a perfect application for this horn, since both the horn and extension are small enough for field use, and give excellent performance over the full audio range. **R-E**