CYLINDRICAL SYMMETRIC GUITAR TLs

BY GLENN DeMICHELE

I am an electric bassist, and when practice fails to yield any discernable results, I work on my equipment. In a performance situation, technical flaws in the amplifier/speaker system can be positive attributes. A contemporary lead guitarist, for example, relies heavily on amplifier clipping and cone breakup to achieve a desired sound. A band's public address system may sound great when people are singing through it, but any recorded music played through that system during the band's break may reveal a less than ideal frequency response.

Musical instrument amplifiers are producers, not reproducers, of sound. This fact makes it difficult to design a musical instrument system using the same goals you would use in the design of a high-fidelity system. Fortunately, the bass guitar sound in today's music often has a very pure and hi-fi quality.

You might say the same of most synthesized keyboard sounds. In the recording studio, these instruments often feed directly into the mixing board, arriving at the tape uncolored by any artifacts of mechanical origin. Thus, the sound of the bass guitar is often produced for the first time by speakers which have been designed to audiophile criteria. My goal in the design of my bass guitar system was, in effect, to build a giant pair of stereo speakers.

NEW DEMANDS. Recently, I made the transition from a four to a five string bass. The addition of the low B string (30.9Hz) has placed new demands on my sound reinforcement system. My electronics are DC coupled all the way up to my Carver PM-1.5 power amp which is capable of delivering 450W/channel into 8Ω at 20Hz, and has a −3dB frequency of 3Hz. I had been using a single JBL EB-140 15 inch driver in a 5 cubic foot ported enclosure made of half inch particle board. With a 6dB boost at 30Hz, the speaker sounded fine at moderate volumes, but when the band was really cranking, the boost bottomed out the driver, causing a loss of clarity in the midrange without a substantial enhancement of the low end. At high SPLs, I therefore had to remove the 30Hz boost.

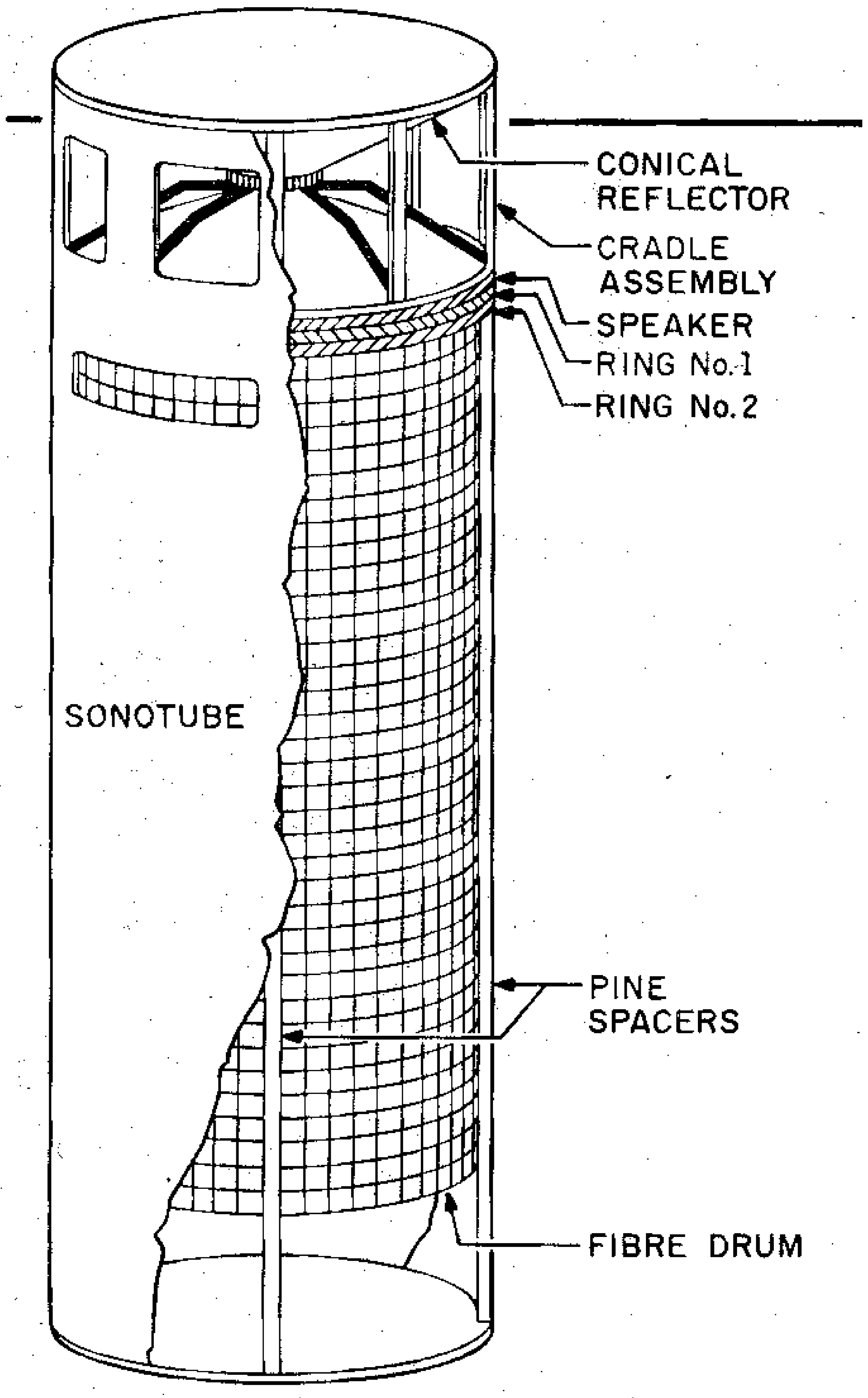

FIGURE 1: Drawing of completed cabinet.

Any speaker I was to design for this application must meet the following criteria:

1. The smaller the better. I generally use only one cabinet (and one power amp channel) on a job, but for the big gigs, I would like to use two cabinets. This also allows me to electronically alter one side for stereo effects, such as chorus or delay. I must therefore be able to fit two completed cabinets, as well as my guitar, my electronics, and myself, into my car. A large cabinet is difficult to roll through the finer hotel kitchens (on the way to the party) without eliciting some kind of snobbish remark from the chef. On stage, there are often width and depth restrictions, but I can always go as high as the ceiling. This implies a tall narrow structure rather than a cube.

2. The lighter the better. I use a two-wheeler (a dolly), but I must sometimes carry my equipment up and down stairs.

3. Efficiency is important. I often have no idea how big the band or the room is until I arrive at the job. Since I do not want to carry around both cabinets all of the time, an efficient design will enable a single cabinet to cover a greater variety of performance situations. The driver must be capable of handling the full power output of my amplifier.

The Electro-Voice EV18B 18 inch driver can conservatively handle 400W RMS, and weighs only 22 pounds. The Theile/Small parameters as supplied by Electro-Voice are:

Q_{ES} = 0.376	Q_{MS} = 8.37
V_{AS} = 18.22 cu. ft.	f_S = 33Hz
R_E = 5.2Ω	S_D = 176.7 sq. in.
n_0 = 4%	X_{MAX} = 0.13 in.
P_E = 400W	

The BOXRESPONSE program (*SB* 1/84)

ABOUT THE AUTHOR

Glenn DeMichele, the Midwestern Field Applications Manager for Harris Semiconductor, is currently pursuing his MSEE at the Illinois Institute of Technology in Chicago. In addition to music and electronics, he manages to find time to eat and sleep. His goals include getting a social life and making his audio equipment smaller and louder.

indicated that a vented-box design which would give me reasonable output at 30Hz would have to have a volume of about 18 cubic feet. I figured out a way to fit this into my car by making it out of three smaller boxes which fit inside each other, and telescope to full size upon arrival at the job. This idea however, was discarded after imagining the horrified look on the hostess' face as this monster expanded to refrigerator size at her society cocktail party. The optimum closed-box alignment yields a smaller box, but the low frequency corner would be around 50Hz.

LINE TAPERING. Even after eight years of listening, the set of transmission line (TL) loudspeakers (DCM Time Windows) in my living room continue to impress me with their bass accuracy. A quarter wavelength at 30Hz in free air is 9.4 feet. If one follows the rule of thumb that the TL cross-sectional area should be at least equal to the diaphragm area, the total volume of a 30Hz TL enclosure for the Electro-Voice 18 inch speaker would be about 11 cubic feet. In practice, sound travels more slowly in the stuffed line than in free air, so the line may be physically shortened, yet still satisfy the quarter wavelength requirement. A further volume reduction may be realized by tapering the line to a smaller cross section as the line moves away from the speaker.

Any vibration of the enclosure walls is undesirable. In this application, any cabinet resonances in the bass and low midrange regions are readily apparent, and I have found them difficult or impossible to control with equalization. The walls of a woofer enclosure must be particularly rigid, and big woofer cabinets are often constructed of ¾ inch or thicker particle board with extensive internal bracing. This type of construction however, produces very heavy cabinets. At lower frequencies, the internal walls are subjected to pressure variations which are evenly distributed across the internal surface area of the cabinet walls.

In a cabinet with a rectangular cross section, any increase in internal pressure will cause the sides to bow. In a cylindrical enclosure however, the resistance of the walls to pressure-induced motion is dependent upon the material's tensile elasticity rather than its stiffness. Aside from threading problems, this is why high pressure pipes do not have a rectangular cross section. The high internal rigidity of a cylindrical structure may be easily demonstrated by speaking into a cylindrical garbage can or a cardboard paper tube. The sound produced is far more resonant than that produced by similar materials fashioned into a rectangular shape.

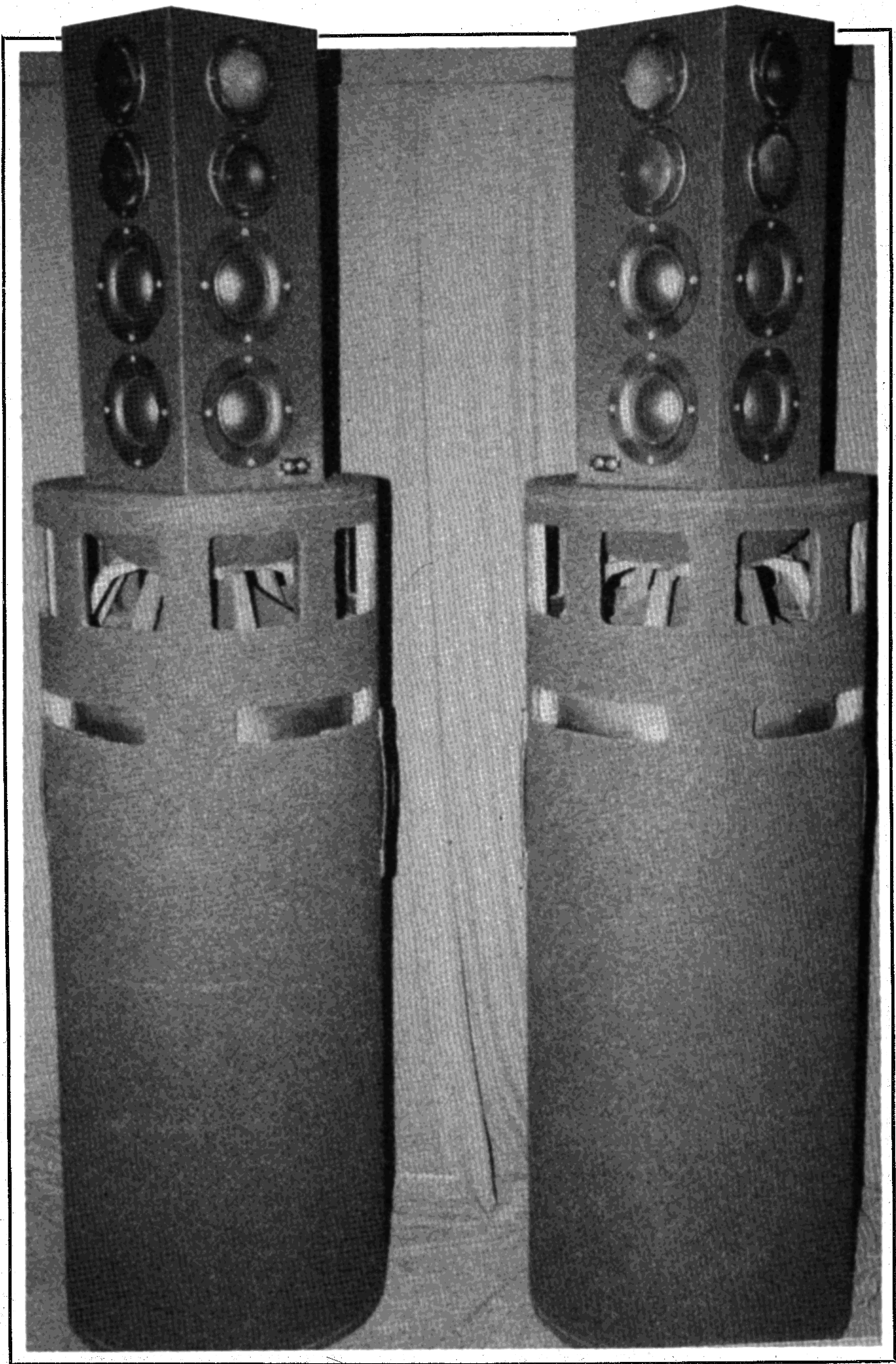

PHOTO 1: The completed pair of speakers, with tweeter cabinets.

CYLINDERS. This resonant quality is indicative of a high Q, and therefore low loss structure. In a rectangular enclosure, you may excite and hear the resonances of the various panels by tapping on the panels with your finger. Tapping on the side of a cylindrical enclosure however is not a valid test, since the asymmetrical application of force causes an acoustic wave to be sent around the circumference of the tube. These resonances would not be induced by the evenly distributed audio pressures normally present in a low-frequency speaker enclosure.

In my search for a suitable cylinder, I investigated plastic garbage cans, storage drums, large diameter PVC pipe, wooden musical drum shells, and even a hot water heater. Any cylindrical object was fair game. I finally discovered fiber drums, and thanks to Mr. Muller's tip in *SB* 2/85 (Tools, Tips & Techniques, p. 45), Sonotubes.

Fiber drums are normally used to hold dry goods. These ⅛ inch thick cardboard cylinders come in a wide variety of sizes and are inexpensive (a 15 inch diameter by 3.5 foot high cost me $3). The fiber drums are rigid enough to function well acoustically, but too flimsy to be used as an outer shell for a transportable cabinet. Sonotubes are ¼ inch thick, wax-impregnated cardboard tubes used as molds for concrete pillars. With an appropriate cloth covering, the Sonotubes withstand the rigors of transportation if moved carefully. They come in 12 foot lengths in diameters from 6 to 48 inches. The inner diameter of an 18 inch Sonotube fits exactly the outer diameter of the EV18B woofer.

My basic design consists of the driver radiating downward into a 15 inch inner tube. The sound wave hits the bottom of the cabinet, travels upward between the 15 inch inner tube and the 18 inch outer tube and escapes from vents cut in the outer tube. Although I initially had misgivings about using the rear of the speaker as the radiating surface, this mounting arrangement offered several distinct advantages.

First, I am a "measure once, cut twice" kind of guy, and this mounting arrangement eliminated an additional spacing ring necessary to keep the speaker basket from interfering with the 15 inch inner tube. Second, I surmised that the rear of the cone would be more effective in directly radiating any midrange output to the listener. Mounting the speaker in a horizontal plane preserves cylindrical symmetry, and hence produces an omnidirectional system. A directional speaker does offer an efficiency advantage when one is playing outside to a localized audience, and sometimes you may aim it to minimize the excitation of room resonance modes.

In most performance situations I have my back to a wall (literally and figuratively), so a lack of efficiency due to the omnidirectionality of the system would not be apparent. This nondirectional pattern would also allow any other band members to clearly hear me even if they were sitting beside or behind my cabinet.

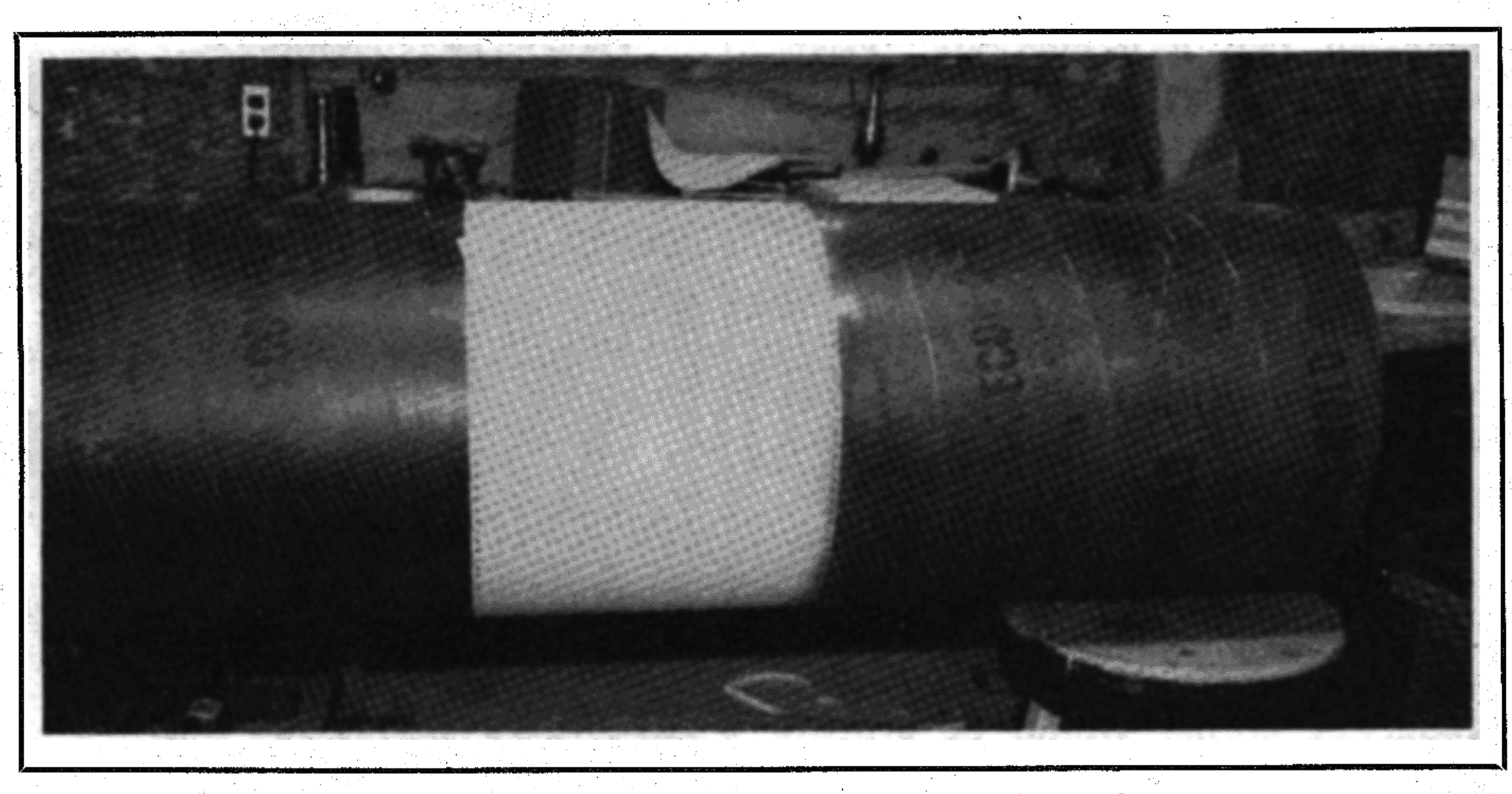

PHOTO 2: To cut the large diameter tubes squarely, use a piece of computer paper, spray paint, and a jigsaw.

CONSTRUCTION TIPS. The Sonotubes may be purchased from many construction supply companies. I asked around for Sonotubes, and everybody knew what I meant, but I ended up with "Econ-O-Mold" tubes made by the Deslauriers Company in Bellwood, IL. These are functional equivalents. To find the fiber drums, just look in the Yellow Pages under "Fiber Drums."

To cut these large diameter tubes squarely, I wrapped a large piece of continuous form computer paper tightly around the tube and carefully lined up the edges of the overlapping ends of the paper. I marked the cutting line with spray paint, using the paper as a mask.

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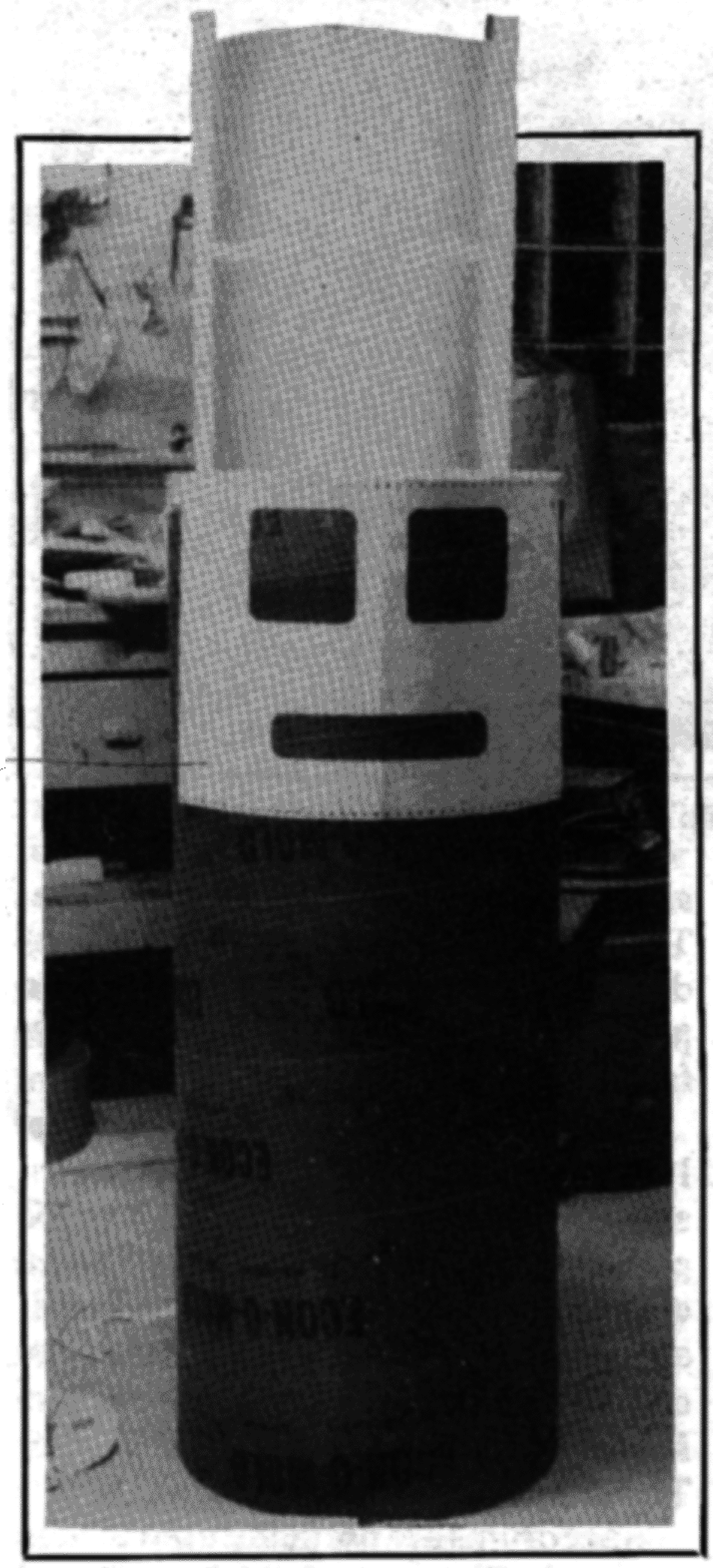

PHOTO 3: Use this template for cutting the vents in the outer tube.

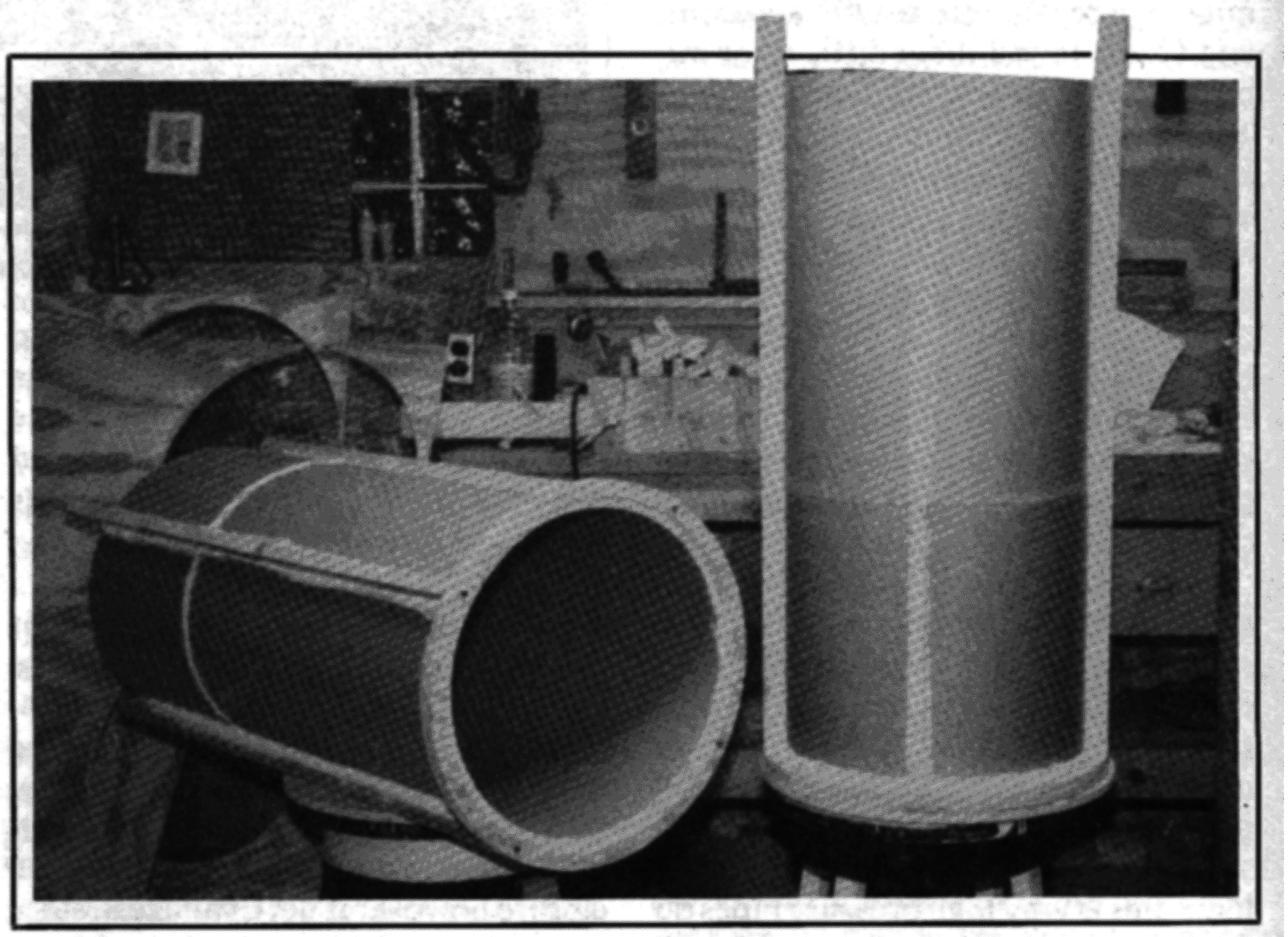

PHOTO 4: The inner tube assemblies, complete with pine spacers, ready for installation into the outer tubes.

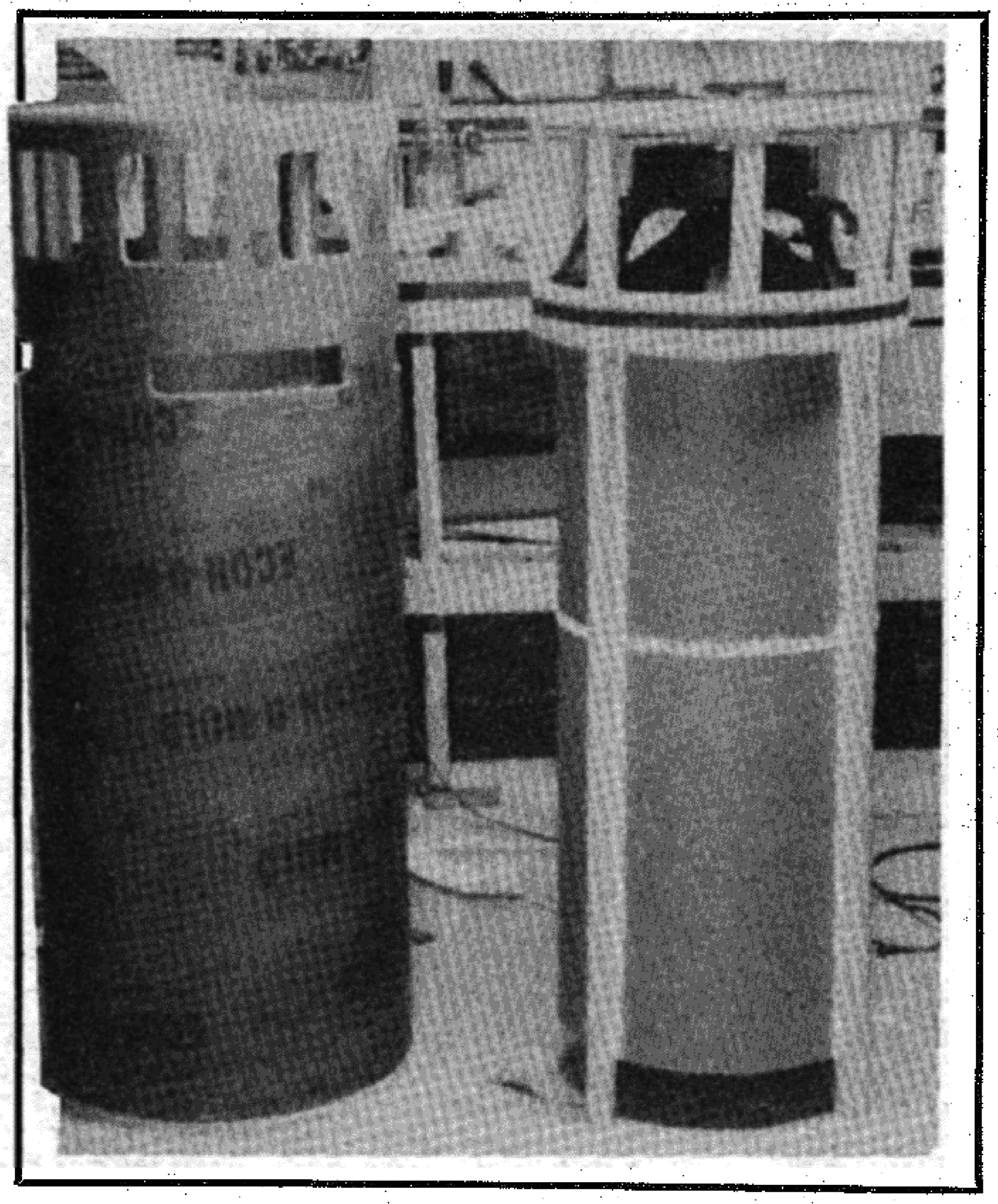

PHOTO 5: The outer shell and inner assembly. The speaker cradle, driver, and inner tube will eventually mount inside the outer tube.

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My plans indicated that the outer cylinder was to be 48 inches long, but I failed to account for the bad end on my tape measure, and they came out an inch short. I used 0.75 by 1.5 inch pine boards for the spacers between the inner and outer cylinders, as well as for the internal bracing struts. The bracing struts are required only for rigidity during transport, and not for sonic reasons. I also attached handles to the cabinet to facilitate transport.

The construction of the cylinders proceeded as follows:

Cut the Sonotubes to the correct length, and cut the vents.

Make the speaker mounting ring from two plywood rings, and affix the four spacers with screws and glue.

The fiber drums I used came with a thin steel bottom and clips at the top to hold a cover. After I cut off the bottom and removed the clips, the "raw" cylinder was only about 30 inches long. I therefore had to use two fiber drums to produce one 35 inch long inner cylinder. Affix the two fiber drum sections to the speaker mounting ring/spacer assembly with silicone sealant. Also seal the seam between the two fiber drum sections. Immediately slide the entire assembly into the Sonotube, making sure the inner tube is not out of round, and the spacers are spaced evenly. While the Sonotube acts to hold everything in place, let the silicone cure.

Make the speaker cradles.

Apply silicone sealant to the spacers and slide the inner assembly into the Sonotubes, making sure the vents line up. Screw through the Sonotubes into the spacers, thereby affixing the inner assembly to the Sonotubes. The silicone does not stick very well to the Sonotubes, but it serves as a gasket and eliminates any rattles.

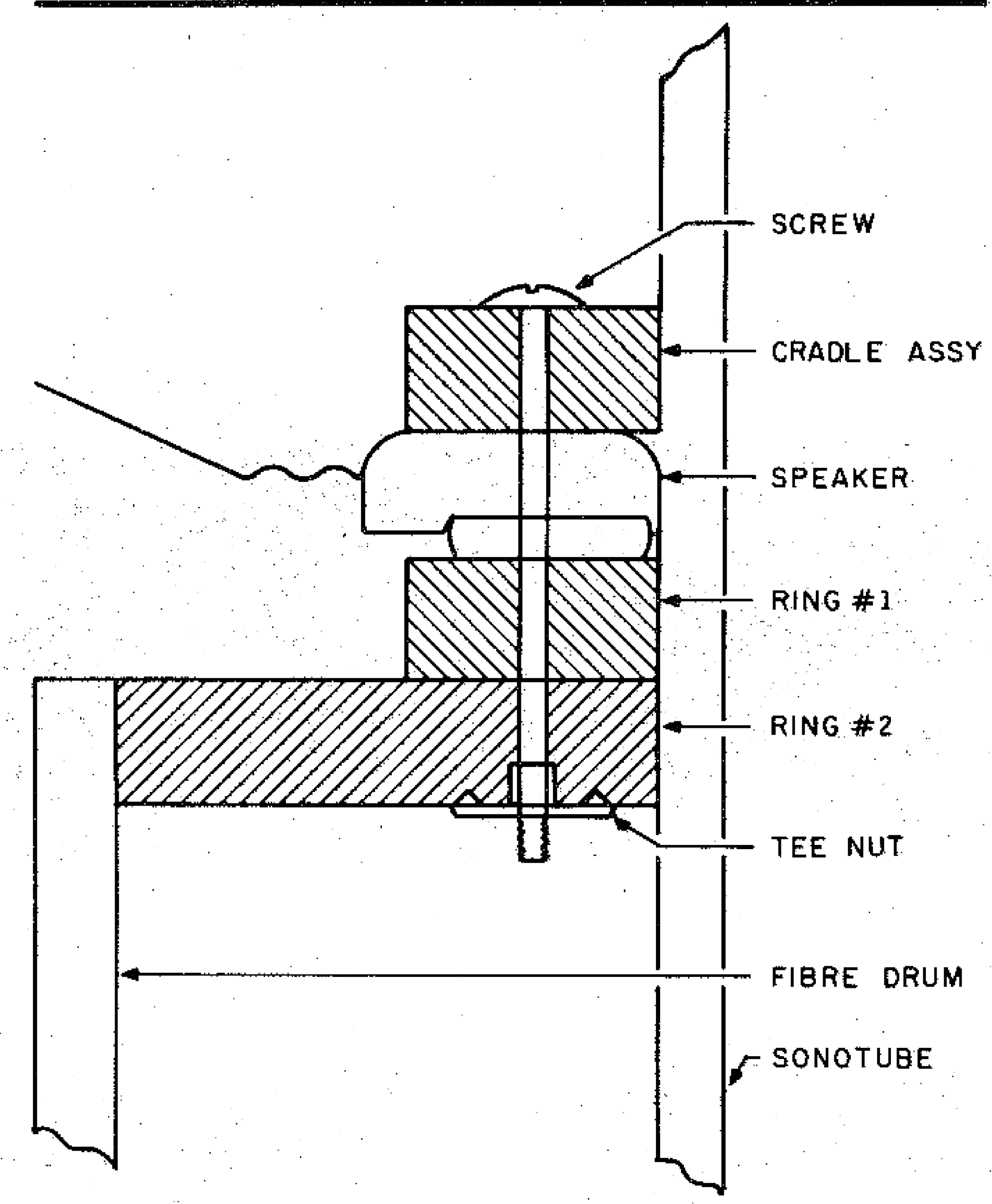

FIGURE 2: Mounting detail of speaker.

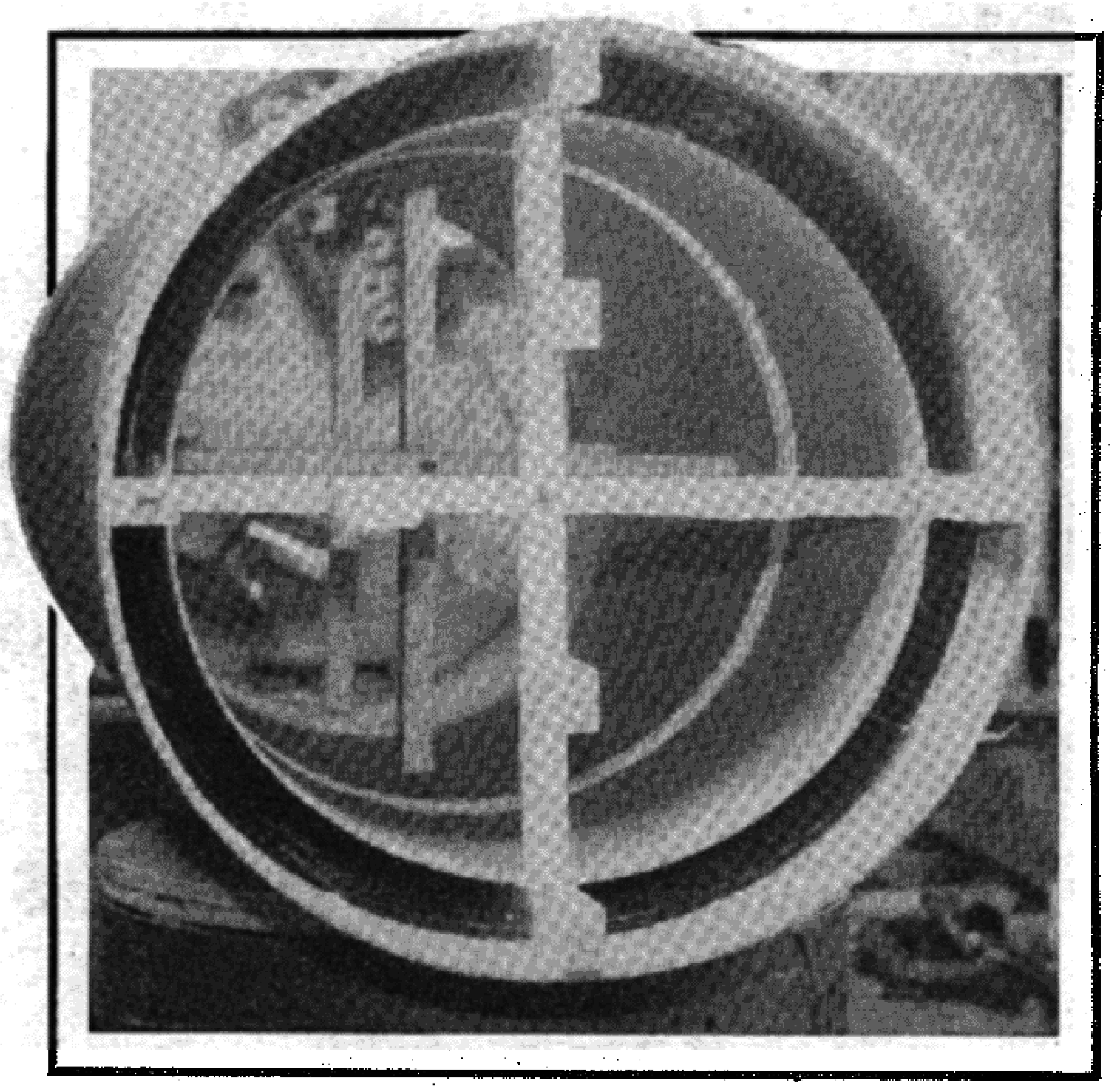

PHOTO 7: A bottom view of the interior of the cabinet after the inner tube assembly has been mounted, and the pine structural supports have been installed.

Using contact cement, glue the fabric to the outside of the cabinets. Also apply cement to the inside of the enclosure and stuff it with long fiber wool. Don't forget to put wool in the space between the two cylinders. I stuffed the cabinet with wool at a rate of 1.4 pounds/cubic foot (ten pounds of wool per cabinet).

LISTENING TESTS. After I assembled the cabinets, I ran several frequency response and listening tests. The low frequency response was smooth enough, but I measured and heard a large peak around 400Hz. This peak was apparently due to standing waves being generated between the speaker cone and the flat inside surface of the speaker cradle. I added a conical reflector to this inside surface, which nearly eliminated this peak. The conical reflector was made with cardboard from a fiber drum, and covered by fabric for aesthetic reasons.

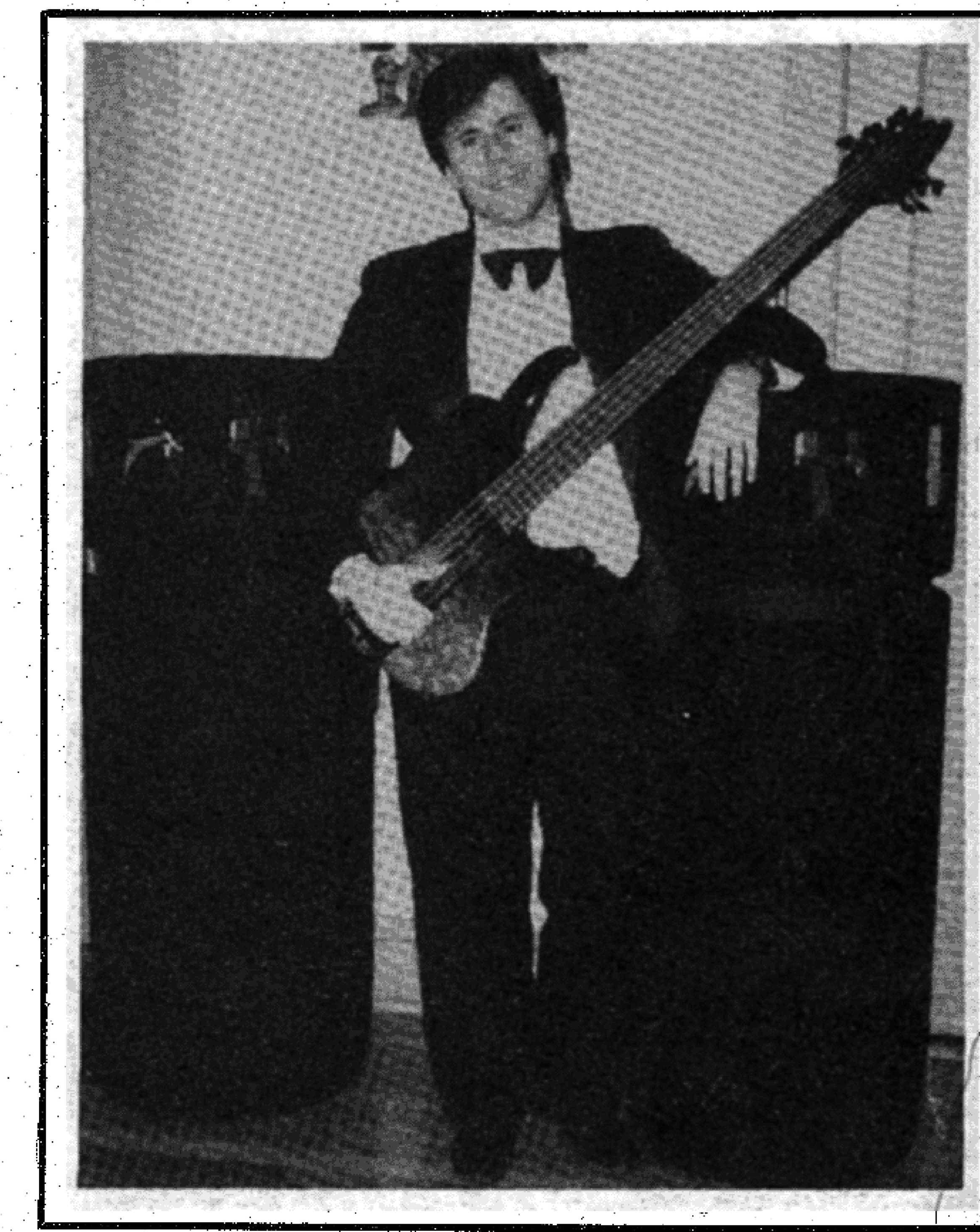

PHOTO 6: The author on his way to the maiden bar mitzvah. Note the absence of the reflecting cones above the woofers.

With this modification in place, I took one of the cabinets out on its first gig. It was an afternoon bar mitzvah with a seven piece band, and my audience was 200 caffeine- and sugar-fed 13 year olds who I'm sure immediately recognized the clarity and acoustic perfection of my cabinet. The transient response of the cabinet was very good, and it produced a tight, well controlled bass. Since the majority of the high frequencies are radiated by the metal dust cover on the front of the 18 inch driver, the high frequency response left something to be desired.

I compensated for it with equaliza-

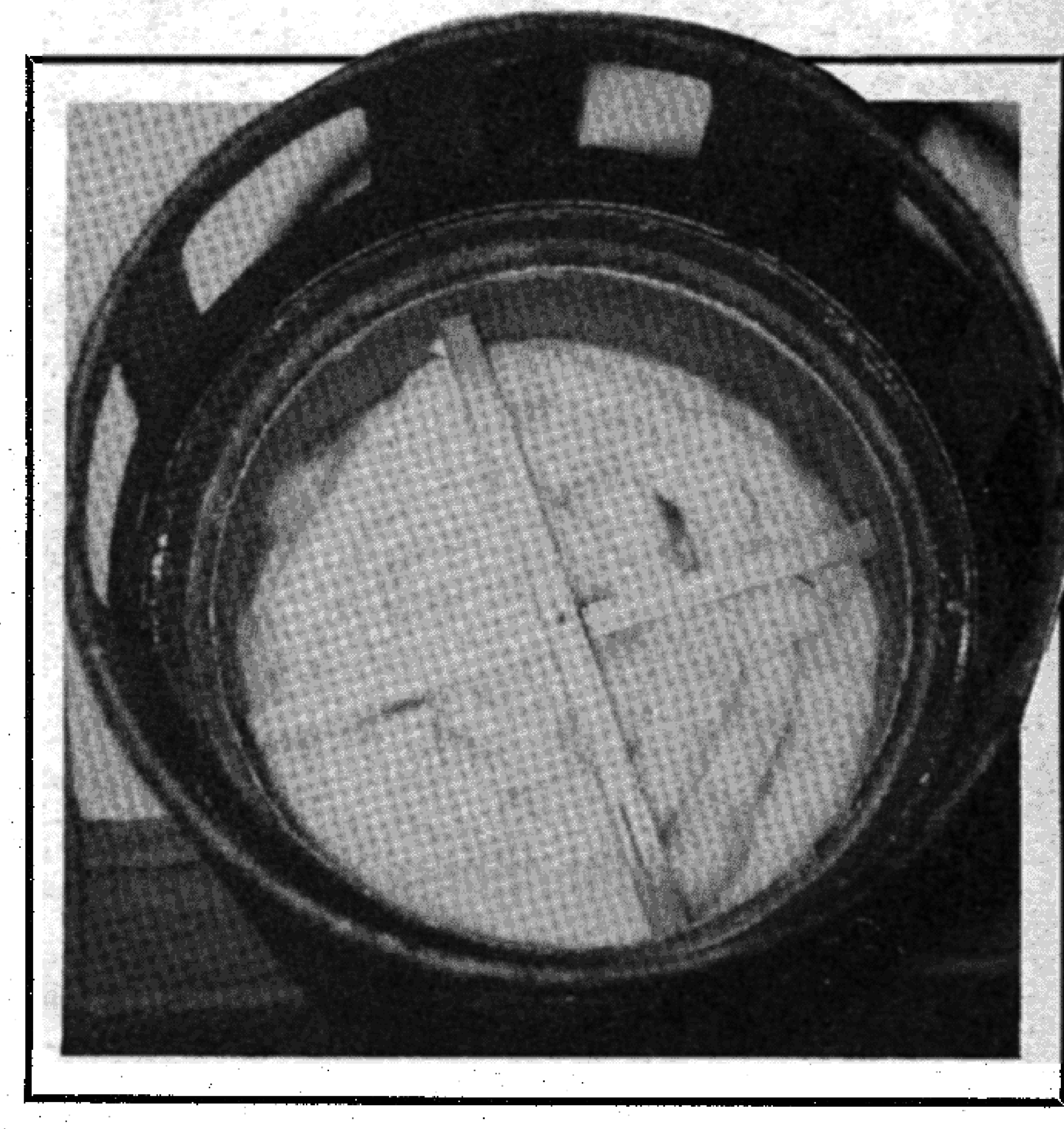

PHOTO 8: A top view of the cabinet with the driver and speaker cradles removed, showing the packing of the long fiber wool.

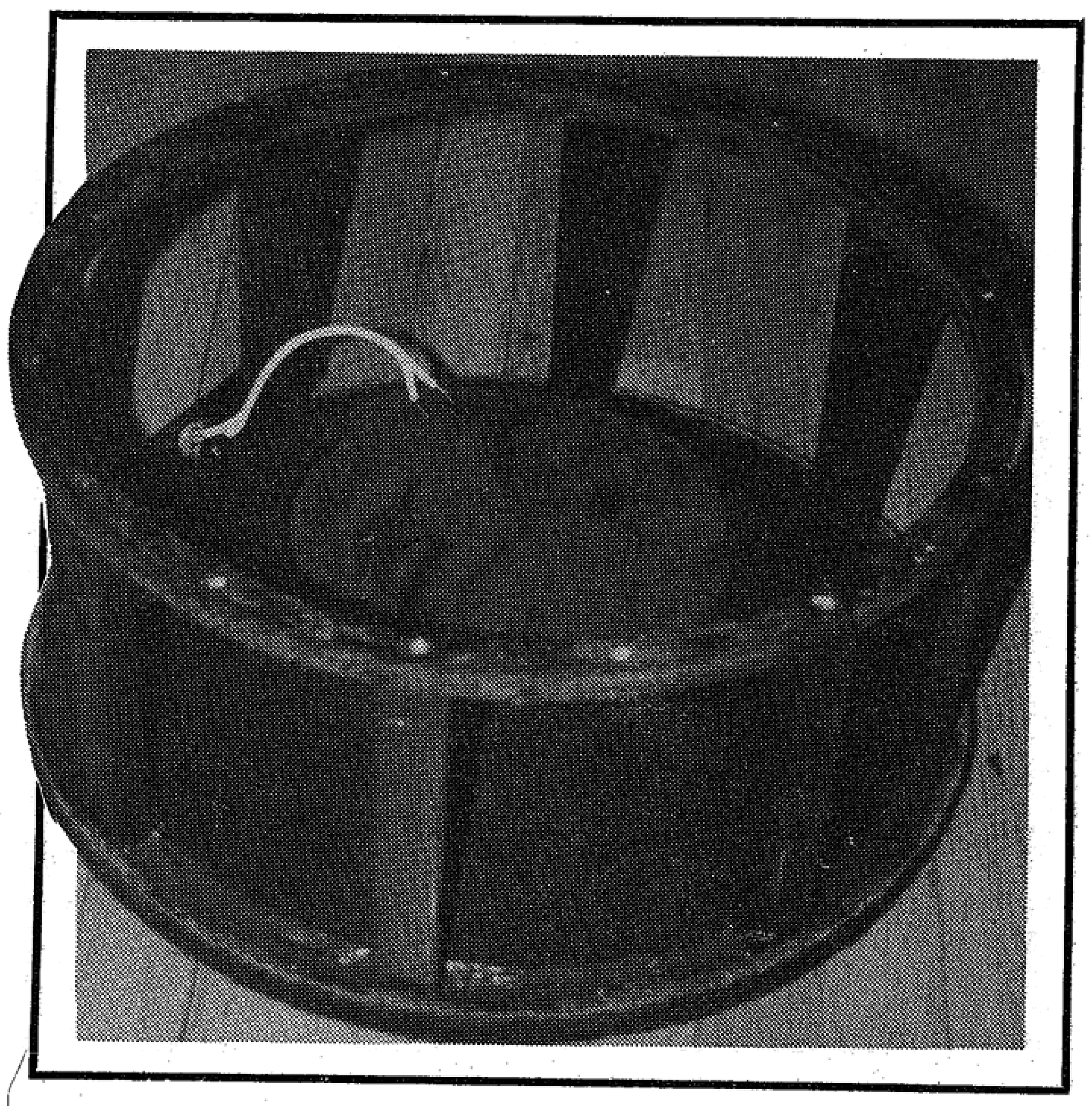

PHOTO 9: A completed revised speaker basket with the reflecting cone epoxied in place. The interior of the cone is stuffed with wool, and black grille cloth holds the wool inside the cone. Note the input jack and wire terminations for attachment to the woofer.

tion, but to get the hi-fi sound I was looking for, it was apparent that I needed to add some tweeter cabinets. In addition, the EV18B driver has an unmanageable response peak at about 1kHz. This is fine for a musical instrument application (EV states that the EV18B is designed to produce "a traditional bass sound"), but hi-fi demands that I cross the cabinet over at about 800Hz.

The omnidirectionality of the cabinet produced an unforeseen effect. I placed the cabinet about a foot from the rear wall, and stood 3 feet in front of it. Everybody in the band could hear me well, and the sound in the audience was excellent and well balanced. Our drummer however, who was sitting only a foot from the rear wall, and a full 6 feet from my cabinet, claimed to be deafened by my output. My cabinet was generating very high sound pressure levels along the rear wall.

Moving my cabinet four feet away from the wall dramatically reduced the SPL at the drummer. Also, I placed the speaker upside down, with the driver on the floor. This helped a little, since the speaker was no longer at the drummer's ear level. I have seen this effect in many rooms. The high levels along the rear wall do not seem to be frequency dependent, and I suspect they are due to horn-like interactions between the driver and the wall.

TWEETERS. Omnidirectionality in a midrange/tweeter enclosure offered no apparent construction or sonic advantages, so it was decided to proceed with a more conventional design. I have always been of the opinion that industrial strength midrange horns sound harsh and metallic. This bias prompted me to use dome midranges and horn loaded dome tweeters in my design. The tweeter enclosure has a triangular cross-section and is constructed of quarter inch plywood internally braced by left-over segments of the pine spacers used in the woofer cabinets.

The two front surfaces are 9.5 inches wide, and the back of the cabinet is 13 inches wide, with the enclosure being 24 inches tall. The enclosure is then equipped with four Vifa D75MX-31 3 inch midrange domes and four Vifa H25TG-35 horn loaded tweeters. The driver aggregate should easily handle 400W of program material. These particular drivers were chosen for their comparable efficiencies and similar acoustic centers in an attempt to minimize time alignment problems.

The two faces upon which the drivers are mounted are at right angles. This simplified construction of the cabinet, and the angle also allowed the two halves of the radiation pattern to merge without any noticeable amplitude ripples when standing directly in front of the cabinet.

The crossover network is a three-way, two-pole design, mounted in the tweeter cabinet. The crossover frequencies are 500Hz and 6kHz. Two jacks are mounted on the tweeter cabinet. I fed the power amplifier output to the input jack and connected the woofer cabinet to the low output jack. I used a stereo type jack for the woofer connection to prevent the power amplifier from driving the undamped low-pass filter section if a woofer is not connected to the crossover.

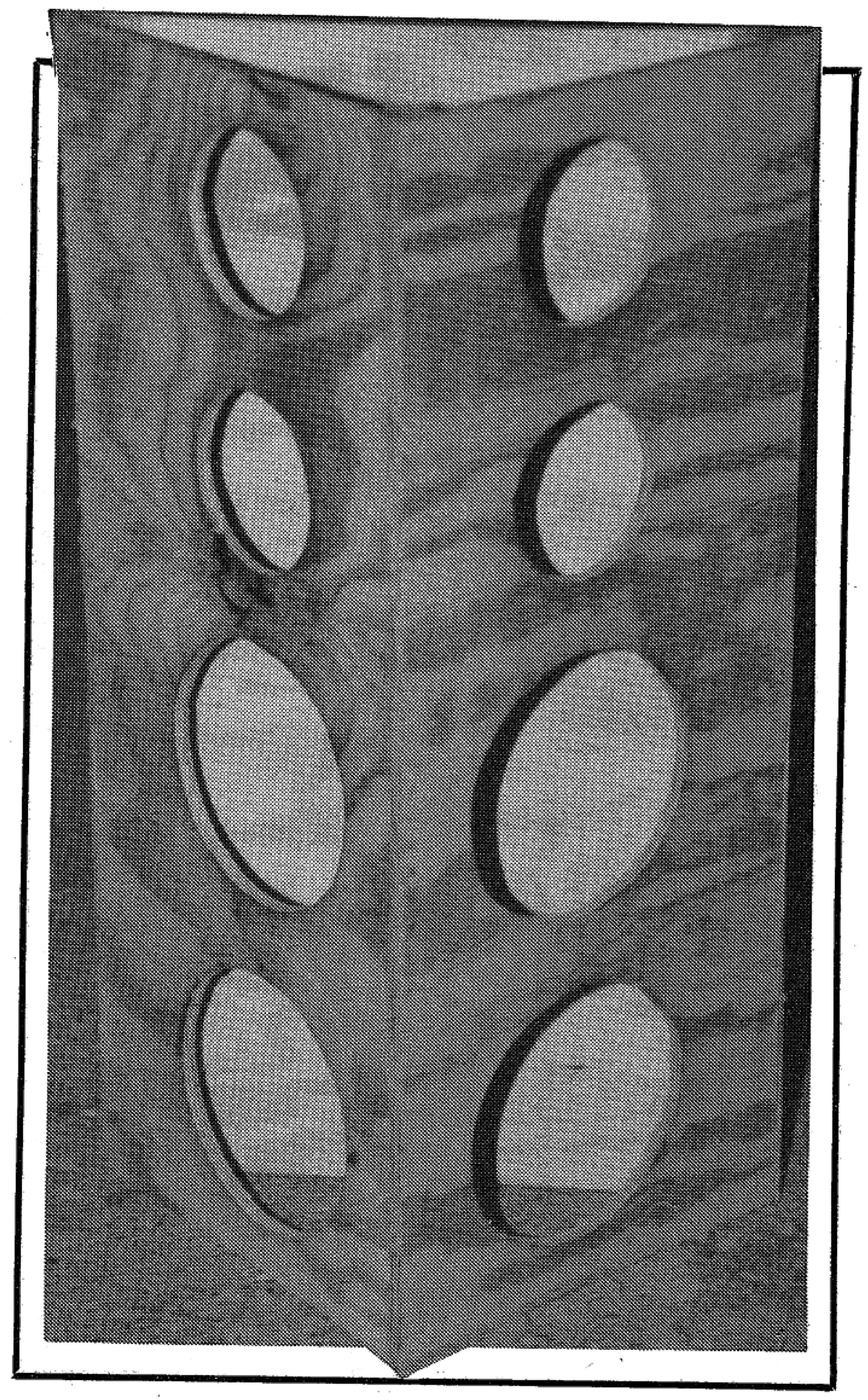

PHOTO 10: A *tweeter cabinet in the early* phases of construction.

When the woofer is plugged in, the sleeve of the phone plug connects one end of the capacitor in the low-pass LC filter to ground through the ring connection on the stereo jack. This allows the stand-alone operation of the tweeter cabinets for use in a biamped system. I stuffed the tweeter cabinets with long fiber wool and covered them with the same fuzzy material as the woofer cabinets.

PERFORMANCE. I set up my new pair of speakers in my 20 by 15 foot liv-

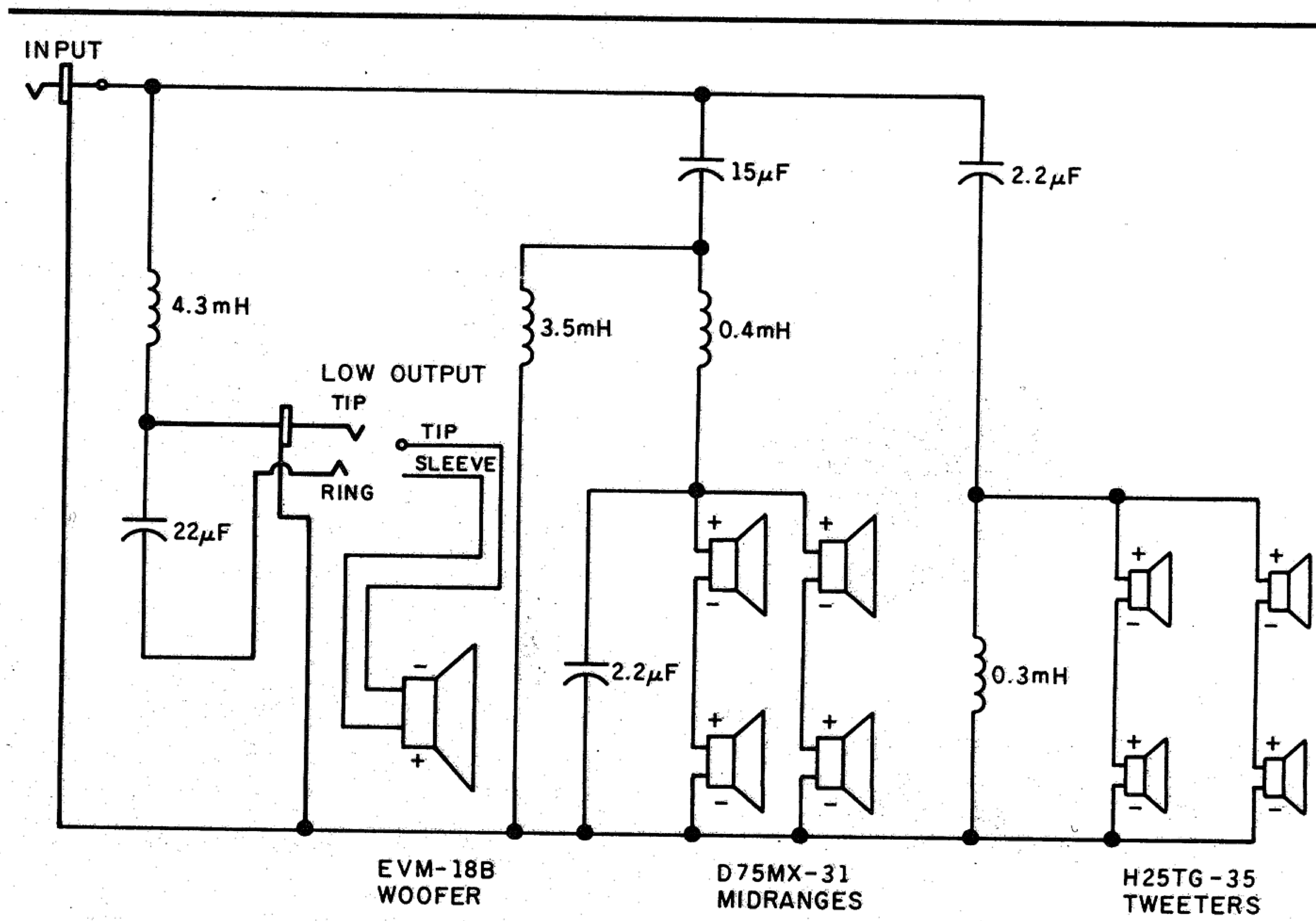

FIGURE 3: Crossover schematic.

PHOTO 11: A completed tweeter cabinet.

ing room, hooked them up to my Hafler DH-220 (100W/channel) and listened to some music. They are loud. The bass was tight, but I think the tweeters were a little too loud for the woofers—nothing an attenuator couldn't fix. Percussion sounded terrific, and the vocals and brass were very clear. The speakers imaged well, but everything sounded "larger than life" perhaps due to the sheer size of the system. The efficiency of the system is impressive, being 6 to 10dB better than my hi-fi transmission lines. I had succeeded in building a pair of giant stereo speakers, fit for a king (and his king-sized living room).

Their performance in the situation for which they were designed is even more surprising. The completed woofer cabinets weigh only 60 pounds each, and the tweeters each weigh only 20 pounds. The system is noticeably more efficient than the 15 inch cabinet I had been using, and the high end produced was very clear without sounding forced or edgy.

This new assertiveness in the low end and clarity in the high end has even altered my playing style. Every nuance of my playing (both positive and negative) is accurately projected to the audience. Drive them with 400W per side, and people have to dance. Although the quality of the sound they produce is remarkable, their appearance tends to elicit the most comment. When I wheel my black fuzzy cylinders into a party, people invariably say "What are those?" and run right up to touch them.

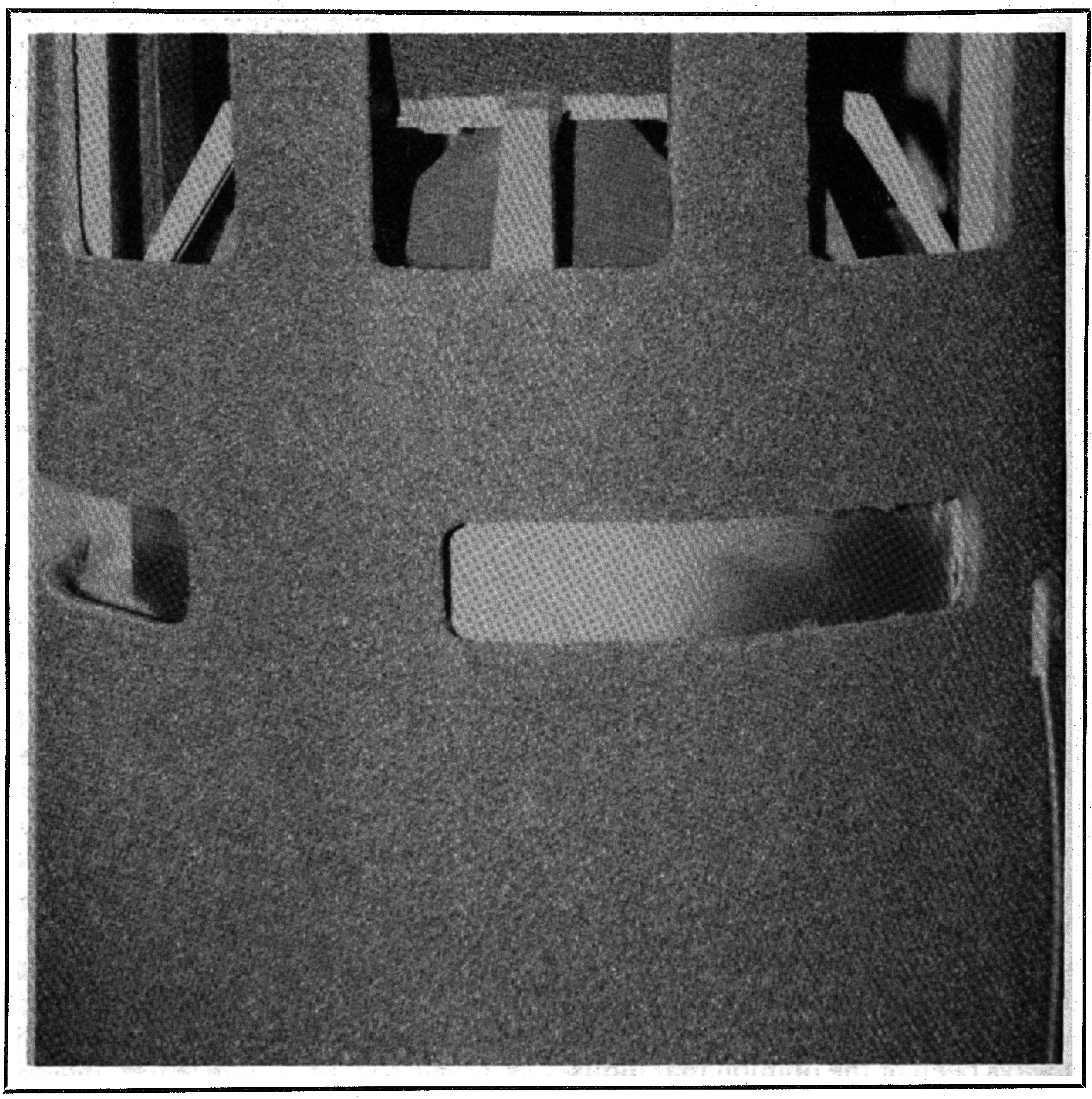

PHOTO 12: A close-up of woofer and tweeter. Note the reflective cone mounted at the rear of the woofer, and the pair of jacks on the tweeter cabinet.