

A PUSH-PULL PLANAR SPEAKER QUEST

By Daniel Patten

Ever since I acquired my first set of ribbon speakers, I have been experimenting with their design. I know many speaker builders who have heard ribbon speakers and really like them. However, it's difficult for the home builder to construct a good set of ribbon speakers. Through much trial and error, I developed some suggestions on how to build a high-quality do-it-yourself WPS40 (Wire Planar Speaker 40" diaphragm).

BACKGROUND

My first attempts, about eight years ago, included Radio Shack magnets, Plexiglas™, aluminum foil, Handi-Wrap™, and lots of rubber cement. They actually worked for a few minutes! I burned up a lot of plastic in

those early years. It was difficult to control my urges to turn up the volume or to ask myself, "How will it sound full-range?" Giving in to these urges always resulted in (poof) my conductors burning through the plastic.

If it wasn't the dreaded burn-up, it was one of a myriad of other problems: all the magnets meeting in the center of my speaker, the plastic stretching, the supporting structure for the magnets bending and falling apart, the amplifier overheating from driving too low of an impedance, or the bond between the ribbon and diaphragm coming apart (this sounds the worst of any of these problems).

Although quite crude, some of my first attempts showed promise as high-frequency

speakers. Encouraged by this limited success, I planned to achieve something bigger with my next design: a 1kHz–20kHz response.

AT THE SHOP

I convinced a local sheet-metal shop to help with my next experiment. I drew up rough plans, from which they constructed a unit for about \$150 that consisted of 3/32" sheet steel cut in 3/8" wide strips 24" long. They also supplied aluminum cross bars to hold the strips in place on a wood frame. This experiment actually worked, if I handled the speakers very carefully, but if I flexed the metal strips at all, the magnets would pop off. Sometimes, one magnet falling off the structure caused a chain reaction, and several magnets ended up in a pile.

I tried several glues, including Super Glue® and several different types of epoxy. Nothing seemed to work very well.

The first hurdle in constructing a reliable set of WPS40 speakers is to build a strong structure. I talked with a few machine shops and received bids in the \$500–\$1,000 range! Well, you guessed it. I put the project on hold for a couple of years.

I resurrected the WPS40 project when my employer discovered a company that does laser cutting directly from CAD drawings. I asked a work associate to draw my dream magnet structure in AutoCad (thanks, G.B.) and delivered the plans (Fig. 1). The prices were very reasonable.

DESIGN CRITERIA

I designed this WPS40 to solve all my previous problems, and identified the following requirements:

1. Massive structure to keep the magnets a constant distance from each other;

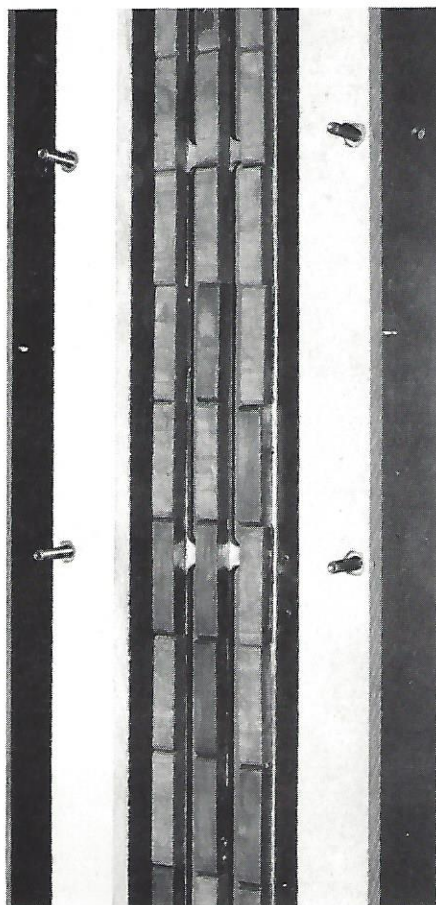


PHOTO 1: Magnets and spacers.



PHOTO 2: Attaching Mylar.

ABOUT THE AUTHOR

Dan Patten currently works at DAS, an electrical engineering firm specializing in very high speed data acquisition. He recently finished the design and prototype of a parallel-processing engine (having 32 individual 32-bit processors) to handle data from a 500MHz ADC. He holds Bachelor of Science in E.E.T. and Master of Technology Management degrees. His hobbies include speaker design and high-end audio electronics design.

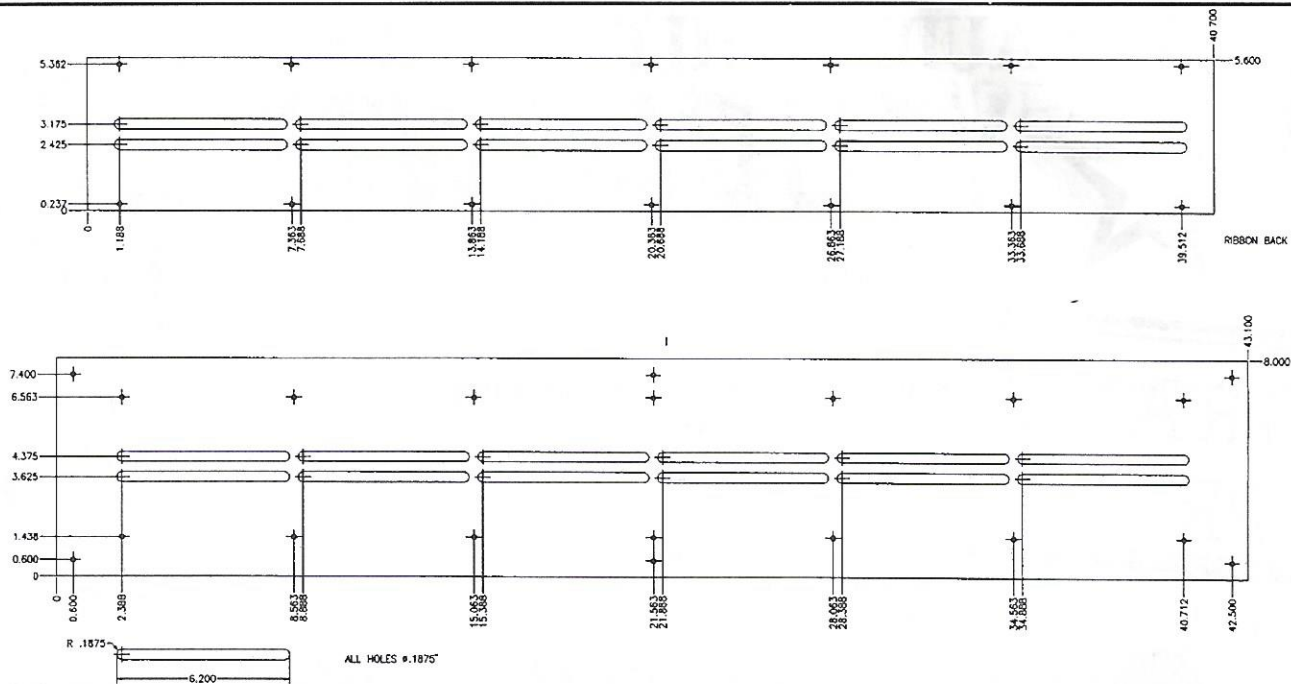


FIGURE 1: Front and rear plates.

2. Rigid, inflexible structure to prevent glued magnets from breaking off;
3. Large diaphragm to reproduce low frequencies;
4. Non-melting plastic;
5. Non-stretching plastic;
6. Conductor bonded to the diaphragm;
7. Increased impedance;
8. Light diaphragm for a good high-frequency response;
9. Speaker efficiency;
10. Powerful magnets at low cost.

STRUCTURE

My solution to the first three problems is

TABLE 1

PLASTIC THICKNESSES

MATERIAL	THICKNESS (1,000s OF AN IN, MIL)
Kitchen plastic (e.g., Handi-Wrap™)	0.4
Mylar®	0.5
Window covering	0.8

TABLE 2

MAGNETIC PROPERTIES

MATERIAL NAME (GENERIC)	MAX. ENERGY PRODUCT
Alnico 5 (sintered)	3.40
Ceramic 5 (barium iron strontium)	3.40
Alnico 5	5.50
Alnico 8	5.30
Alnico 9	9.00
SMCO 18 (samarium cobalt)	16.00
SMCO 20 (samarium cobalt)	20.00
NDFeB 27 (neodymium iron boron)	27.00

shown in Fig. 1. I designed this structure for a diaphragm of approximately 40" and machined it out of 1/8" steel. I fed the AutoCad drawing into the shop's computer and a very powerful laser sliced it out in a few minutes. The total price was a couple of hundred dollars!

Figure 2 shows a cross section of the plate assembly. Once you bolt this structure together, it is very rigid, not flexing at all. This keeps the magnets in place and prevents them from breaking off. The diaphragm spacers are made with 7/16" x 1" wood. I plan to make these spacers out of aluminum for even greater strength.

The WPS40 design uses a 3.5" wide x 40" long diaphragm, for approximately 140 in² of piston area, which is more surface area than a 12" woofer (approximately 113 in²). There is approximately 1/16" clearance from magnet to diaphragm to allow for plenty of diaphragm movement before it hits the magnet structure. You can use different spacer widths to adjust for either higher efficiency with less clearance or high-power handling capacity with more clearance.

PLASTIC

Handi-Wrap™ is inexpensive, and actually worked quite well for my initial experiments because it is very thin and can readily be stretched over the diaphragm spacers. However, it also melts and seems to stretch over time. I also tried the window-covering plastic found in hardware stores. This is convenient to work with because you can use a heat gun to make sure the diaphragm is tight.

My current choice of plastic is Mylar®, which has a very high tensile strength (will not stretch over time), while still being very thin. This is my solution to problems 4, 5, and 8. Table 1 lists some thicknesses of other plastics I tried.

CONDUCTOR

I originally experimented with foil conductors, using kitchen-type aluminum foil, with an average thickness of 0.8 mil, and metal foil capacitors. These worked well, but gluing the ribbon to the plastic was labor-intensive. Also, the ribbon would detach, and it was difficult to achieve a suitable impedance. I experienced limited success using 1 mil thick and 7/32" wide copper foil, which I purchased from a stained-glass shop. This foil is handy because it is adhesive-backed. However, it was a little thick, and reduced the high-frequency response because of its high mass.

Why use foil? Why not wire? The speakers are not true ribbon speakers because they have a diaphragm. It seemed to me that wire would be easy to work with, and desired impedances were achievable. But how could it be bonded to the diaphragm? I used thin 0.5 mil packing tape, which worked very well (Fig. 3).

Using wire and tape solved several problems (6, 7, and 8): it is easy to achieve any desired impedance; you can make as many turns as desired in the magnetic gap; manufacture is simple; attaching the wire to binding posts for the amplifier interface (a difficult task with aluminum foil) is simple; and the wire is very light.

MAGNETS

Powerful magnets and their proper alignment are paramount to achieving high sensitivity. I arranged the magnets in this structure in a push/pull fashion (Fig. 2). Remember the "right-hand rule" when arranging the magnets in relation to current flow of the conductor. Some magnetic properties are listed in Table 2.

I used Ceramic 5 magnets with a dimension of $3/8" \times 3/8" \times 1.875"$ from The Magnet Source, Model CB-65E. My design requires a total of approximately 120 magnets per speaker, with a cost of \$45 per speaker. You can use more powerful magnets; however, they are typically more expensive. If you used the Alnico magnets, the cost would be approximately \$400 per speaker, almost ten times the cost for twice the energy product. If you wish to build this speaker with samarium cobalt or neodymium magnets, it would cost thousands of dollars.

To make sure all the magnets are correctly oriented, I used my trusty Boy Scout compass to determine the poles of the magnets, which must be polarized along their lengths with the poles perpendicular to the speaker diaphragm (Fig. 2). When arranging the magnetic structure, I had trouble gluing the magnets correctly. I suggest arranging all the magnets for proper orientation *before* starting the gluing process. Figure 4 shows my procedure to determine the poles of each magnet.

As I mentioned earlier, there are several trade-offs in clearance between the magnets and the diaphragm. I determined that $1/16"$ clearance was acceptable for adequate sensitivity. (Reducing the clearance seemed to increase the sensitivity.) However, more problems than diaphragm displacement exist. The magnets I received had some tolerance problems; I rejected several because they were too thick (the more clearance you allow, the easier it is to put together).

COST

My prototype speakers' costs were relatively low. The approximate cost breakdown for two speakers is as follows:

Metal work	\$300
Wire	1
Mylar	2
Ceramic magnets	100
Hardware (bolts, nuts, banana plugs)	20
Total	\$423

At higher quantities, these prices would probably drop by at least 25%.

SOUND

These are some of the better-sounding speakers I have heard, with the open/natural sound that is typically associated with rib-

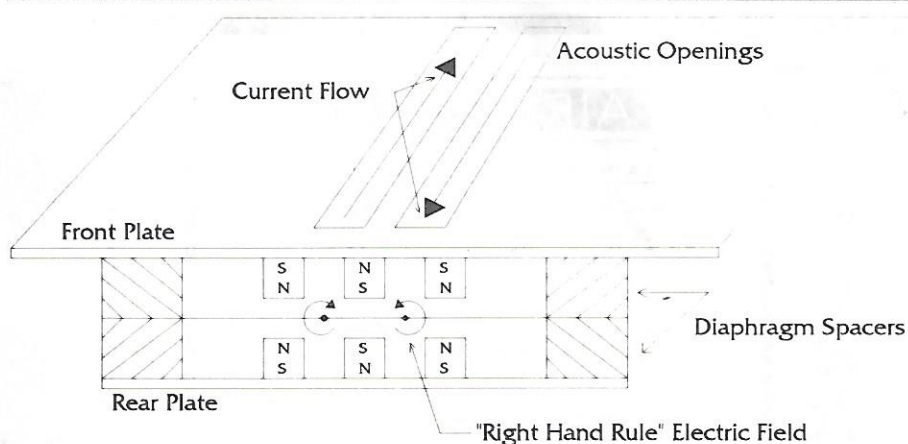


FIGURE 2: Cross section.

bons and electrostatics. I enjoy listening to jazz with saxophones, and these speakers excel in reproducing the sax. In fact, they will probably replace the Acoustat 2200 electrostatic speakers in my listening room. (Anyone interested in a used pair of Acoustats, please let me know.)

The only problem with the WPS40 may be its radiation pattern. As shown in Fig. 5, the horizontal dispersion is very good; however, the vertical dispersion is quite limited. This is usually not a problem if you mount the WPS40 so the center of the speaker is at ear level when you are seated.

DESIGN ADVANTAGES

Mass: A typical speaker is pretty heavy and, like a train, once it starts moving it's difficult to stop. Signal overshoot and undershoot are big problems in conventional speakers. The damping factor of the amplifier helps minimize this problem. The mass of the WPS40 speaker is so low it can basically "start and stop on a dime."

Line Source: It exhibits "line source" capability and therefore can add to the realism of the musical presentation.

Push/Pull Design: In both directions of movement, the diaphragm is under full control of the magnetic fields. This typically leads to a more accurate response.

Impedance: Its impedance is purely resistive (i.e., very amplifier friendly). Most amplifiers do not like to drive capacitive or inductive loads. In fact, most amplifiers include a resistor and inductor (yuck) in parallel at their output to compensate for capacitive and inductive loads.

Crossovers: As we all know, coils phase-lead and capacitors phase-lag. So with a cap on the tweeter and coil on the woofer, the signals can be 180° out of phase. This out-of-phase relationship changes as the input frequency changes. If you use a nearly full-range speaker, such as this one, you can keep

these phase problems out of the critical midrange and high-frequency areas.

Crossovers: In a conventional speaker, the crossover point between a tweeter and woofer might be 2kHz, *sometimes*. A nominal 8Ω speaker may vary as much as

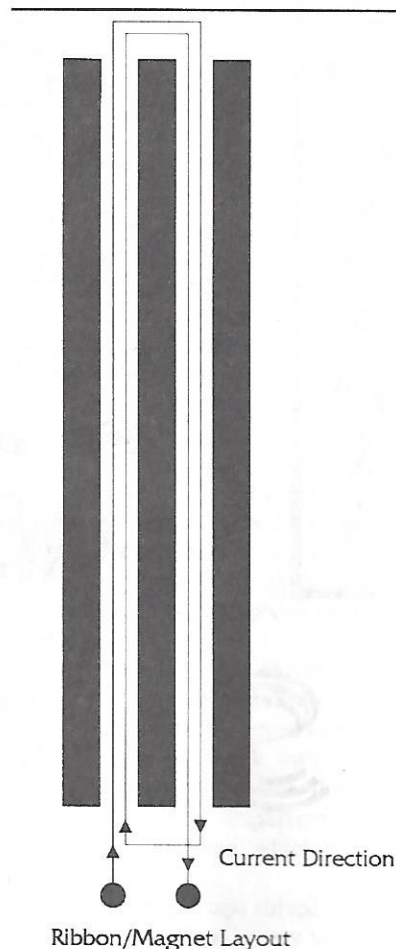


FIGURE 3: Conductor/magnet layout. Keep all current flowing the same direction in each magnetic gap. Two turns with 30 AWG = 1.6Ω , with 32 AWG = 2.2Ω , with 34 AWG = 3.6Ω

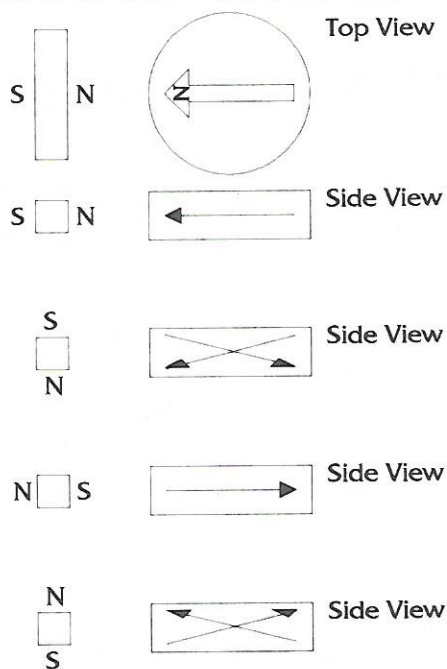


FIGURE 4: Magnet pole orientation.

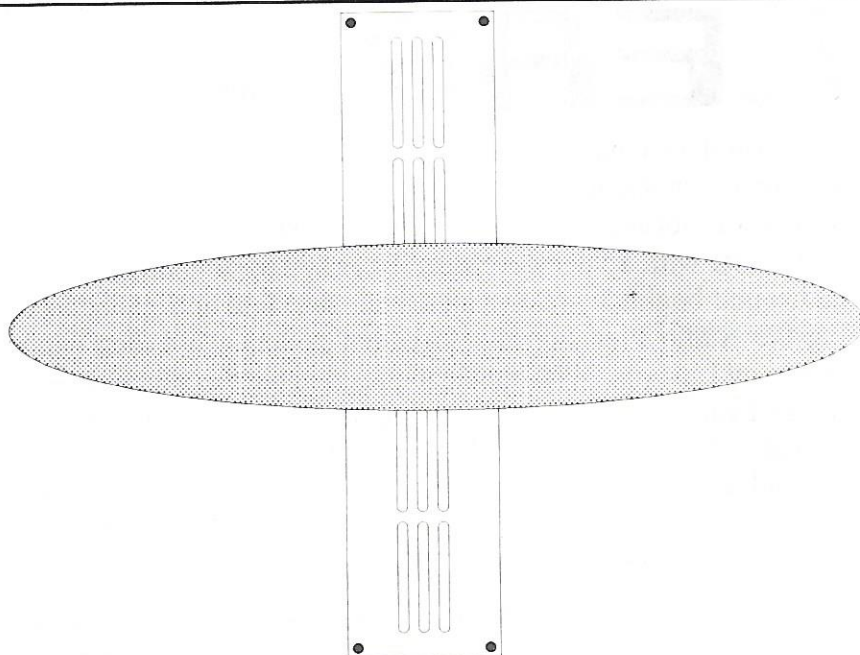


FIGURE 5: Radiation pattern.

2–30Ω. Given the tweeter crossover formula: $F = 1/(2 \times 3.14 \times C \times Z)$, the crossover point will change, which will also affect the speaker's radiation pattern. This planar speaker allows the single crossover point to be below 300Hz.

CONSTRUCTION

1. Glue the magnets to the metal plates. As shown in *Fig. 4*, find the poles of all the magnets you are going to use. It's best to line up all the magnets on the sides of the plate and hold a magnet above the rows to ensure the magnetic field is the same for the full row of magnets. Arrange the rows of magnets so when the front and rear plates are assembled, the faces of each row have the same pole (*Fig. 2*). It is paramount to follow the "alternating pattern," which keeps all of the diaphragm moving in the same direction.

Before you glue the magnets to the metal, clean the surfaces with solvent. As shipped from the wholesaler, the magnets are quite dirty with an oily film, which prevents any glue from working very well. I used a paint thinner and a lot of rags to clean the magnets.

2. Attach the spacer to the front plate. I countersunk the nuts in the spacer to accommodate the diaphragm. I used 1.5" 10–32 hex cap bolts, which are easy to work with, and the exposed cap looks quite nice. The front plate with magnets and spacers are shown in *Photo 1*.

3. Brush the rubber cement onto one spacer, and quickly place the Mylar, which can be

punched over the exposed bolts (*Photo 2*). Place the rear-plate spacer over the Mylar and tighten down with nuts. Now do the other

side and pull it tight. Wait approximately one hour for the glue to set. Use a heat gun or hair dryer to remove the rest of the wrinkles.

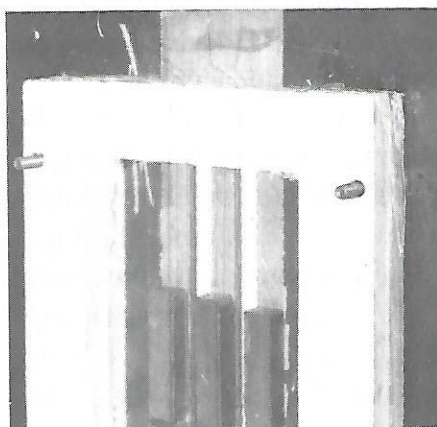
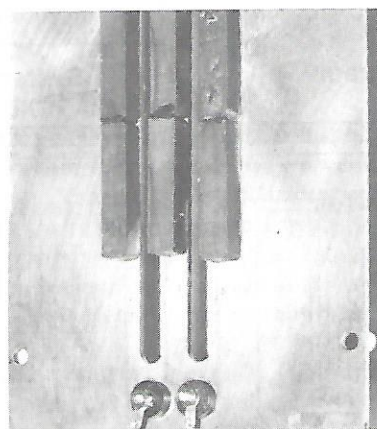


PHOTO 3: Binding post connections.

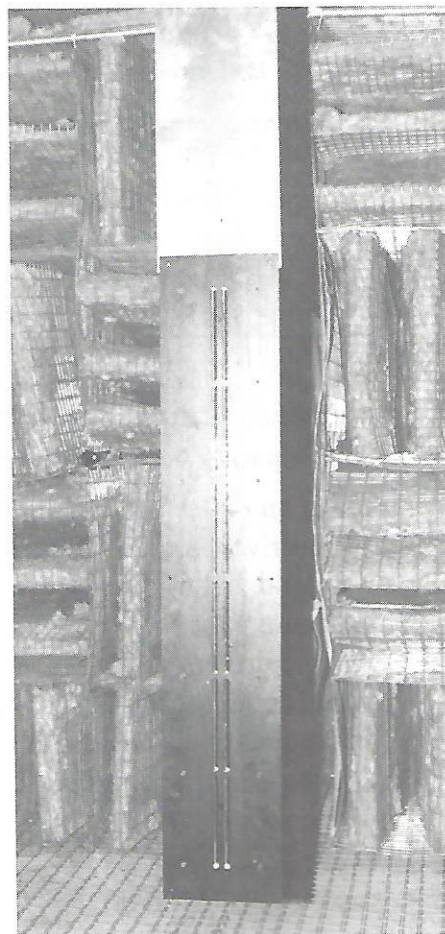


PHOTO 4: Anechoic chamber measurements.

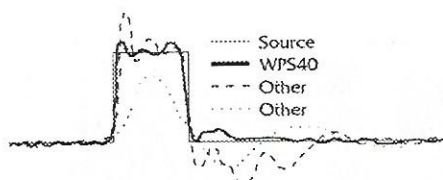


FIGURE 6: Impulse response.

4. Lay down the wire as shown in *Fig. 3*. Thumbtacks pushed into the wood at the ends will hold the wires in place. I used a thin packing tape, approximately 0.5 mil thick and 2" wide, to laminate the wires to the diaphragm. Then attach the wires to the binding posts (*Photo 3*).

5. The next step, attaching the two plates to each other, is rather difficult, and might require assistance from another person. Since all the magnets are the same pole, the two plates do not go together easily. Start by fastening the end with the binding posts and work your way down to the other end. Tighten all the nuts down at similar rates.

6. Mount the WPS40 speaker in some type of enclosure so the center of the panel is near ear level. Use either a sealed or open enclosure; I prefer the latter. The WPS40 provides a low-end frequency response of

approximately 400Hz in open air, and down to 300Hz in my frame. The lower frequency response in the frame is due to the longer path the rear sound-pressure wave must travel before it cancels with the front wave. *Photo 4* shows my finished prototypes in an anechoic chamber. *Photo 5* is the finished WPS40 speaker in the prototype frames.

MEASUREMENTS


Preliminary measurements are:

Frequency response	400Hz–18kHz ± 3 dB
Impedance	3.6 Ω (pure DC)
Sensitivity	87dB @ 1W/m
Power handling	>200W

Figure 6 shows an initial measurement of the WPS40 speaker as compared to a reference square wave and other popular speakers. This measurement reassured me my ears and ego weren't deceiving me.

I have access to an anechoic chamber and should be able to make some interesting measurements and comparisons of planar speakers to conventional cones. I plan to compare the WPS40 against other well-known raw drivers, such as the Dynaudio D54, Dynaudio D52, Dynaudio D28, Dynaudio 21W54, Focal 5K013, Audax HD100 series, and Audax MHD12P25FSM.

Part 2 offers these measurements as well as other technical results of this design.

I hope this article helps builders interested in planar-speaker design, and I invite comments or suggestions regarding this speaker, which is capable of high-quality sound reproduction. 

SOURCES

The Magnet Source

(800) 525-3536

Magnets (240 pieces CB-65E)

Newark

(801) 261-5660

Wire 30¢ 34 AWG (part #36F1320)

Radio Shack

Binding posts (two sets)

Available from author:

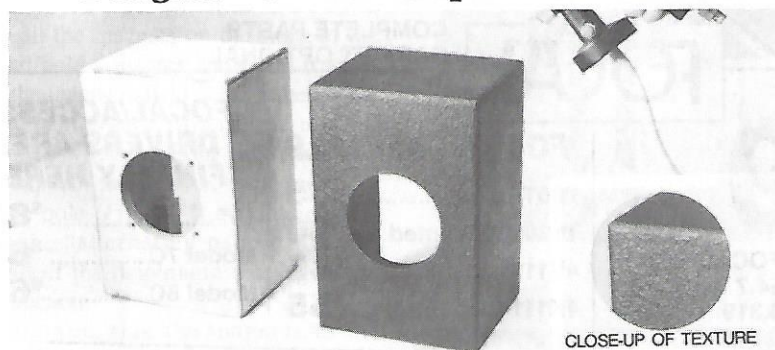
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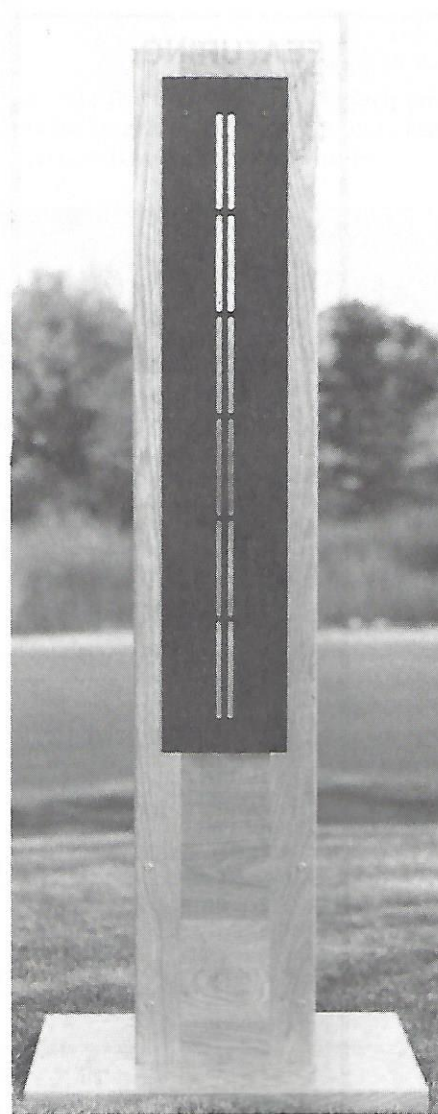


PHOTO 5: Finished WPS40 speaker in frame.