Horn Project documentation package

I. Design

I.1. Design considerations.

Starting the development of this speaker, I had the following objectives:

1. Floor standing model of reasonable size, suitable for small to medium size rooms.
2. High efficiency (92 dB SPL, or better), capable of producing life-like sound levels with small-to-medium power amplification (no more than 30-35 Wpc).
3. Ability to reproduce real dynamics of live recordings.
4. Very good soundstaging and imaging.
5. Full-body midrange and upper bass.
6. Easy load for amplifier, including tube and switching types.
7. Reasonable price (under $1000 / pair).

As always in engineering, some compromises were necessary in order to reach the goals. I was ready to accept limited low-frequency extension: -3 dB at 60-70 Hz anechoic, which should provide real-life extension to 40-50 Hz in-room; slight roll-off in the heights, size in the upper range of reasonable.

One of the best choices to reach objectives 2 – 4 is a single-driver loudspeaker. Driven by a single voice coil, such a driver is intrinsically time-coherent. There is no crossover to introduce phase artifacts in transition from woofer to tweeter. All frequencies originate in a single point in space.

The most well known drivers, used in the speakers of this type, are Lowther, AER and Fostex. All of them share such common properties as lightweight paper dual-cone (with whizzer cone for high frequencies), cloth accordion surround, and powerful motor assembly. Advantages of this design include very high efficiency and resolution of details. Unfortunately, this comes with very low Q factor and very limited excursion capabilities. In addition, all of the above drivers are characterized with response, rising towards high frequencies, known as “Lowther shoutness”, “Fostex wail”, etc…

In my experience, reaching the goal #5 requires the use of 8”, or larger driver. Going larger than 8”, however, contradicts #1, so it had to be an eight-incher. Typical 8” driver from the brands mentioned above would have maximum excursion ($X_{max}$) of under 1.5mm one way. Such driver, used in a common ported enclosure will run out of excursion at a power level of 1W (frequently much lower) below 40-50 Hz. For this reason a ported enclosure was ruled out.

Another phenomenon to deal with is known as “baffle step response”. Briefly, any driver, mounted on the baffle can be considered as radiating in “half-space” at higher frequencies, where half-wavelength is shorter than the width of the baffle. As frequency goes down, the wavelength becomes long in comparison to the baffle width and looses the baffle support. The sound is radiated all around the speaker, in full space. This results in output dropping by 6 dB at low frequencies. With typical width of the baffle for an 8” driver, this happens gradually in the range from about 800 down to about 200 Hz. Combined with a rising response of the drivers mentioned above, this requires the use of “baffle step compensation” circuits. These devices attenuate the speaker output by 4 to 6
dB over the upper bass and midrange to flatten the response of the speaker. However, this results in lower overall sensitivity, negating the advantages of the drivers. In the following pages I will present the design that attempts to resolve these problems by some non-orthodox, but physically sound (pun intended) solutions.

The result is shown below:
I.2. The Hemp™ Driver

For this project I chose the Hemp™ FR8 full range driver. Unique paper cones of these driver use hemp plant fibers instead of regular cellulose, which provide higher stiffness to weight ratio. These cones are famous for especially good-sounding midrange. These drivers also have some other properties that make them particularly suitable for proposed design. Hemp™ FR8 has the following parameters:

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<th>Value</th>
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<td>Rated Power</td>
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<td>$F_r$</td>
<td>45 Hz</td>
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<tr>
<td>$R_e$</td>
<td>6.2 Ohm</td>
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<td>$X_{max}$</td>
<td>2 mm</td>
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<tr>
<td>BL</td>
<td>6.4 Wb/m</td>
</tr>
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</table>

Of particular interest here are $Q_{ts}$ value of 0.41 and $X_{max}$ of 2 mm, which we will discuss next.

I.3. Cabinet

For this design, I chose the so-called “Back-loaded horn” (BLH) acoustic alignment. In this alignment, the sound wave generated by the front side of the driver’s cone radiates directly towards the listener. The back wave of the driver is horn-loaded to produce additional output in low-frequency range.

For the starting point of this design I have used a popular design by Tony Gee from Netherlands, called “Solo-206”, which uses Fostex FE206E wide-range driver. This horn, in turn, is a modification of the old Fostex BK-201 enclosure. Please, visit Tony’s web site at this link: [http://www.humblehomemadehifi.com/Solo206.html](http://www.humblehomemadehifi.com/Solo206.html). I would like to use this opportunity to thank Tony for generous permission to use and modify his design and for valuable advice on this modification.

Using a relatively high $Q_{ts}$ driver in a BLH may sound controversial to some, so a short explanation is in order.

It can be frequently found on Internet forums, that only those drivers with $Q_{ts}$ of 0.15 to 0.25 are suitable for horn loading. Examples include certain model of Lowthers (PM2a, EX4, DX4, etc.) and Fostex (FE-206/207e, FE-208Σ, etc.) drivers. The popular myth states that they are designed specifically for front or back-loaded horns. As usual, this is the truth, but not the whole truth. What really happens, is that these drivers can only be successfully used in horn enclosures. They need horn loading in order to produce any reasonable amount of output at frequencies below 200-150 Hz. Even with the help of the horn, the use of BSC circuits is still required.

Increasing the Q of the driver increases both the output of the driver and the horn at low frequencies. Careful choice of the horn geometry and the size of the coupling chamber allows to achieve the combined response with 4-6 dB hump, located in the frequency
range to exactly compensate for baffle step loss. This way the efficiency of the driver is preserved and no additional circuit is required.

The drawing of the cabinet along with cross-section and parts list is presented here:

Fig. 2. Section view and cabinet parts list.

A full set of mechanical drawings, including assembly and all parts of this cabinet is included in a separate document.
It is important to note that presented design (as well as a vast majority of such designs) is not a full-size low frequency horn. Such a horn would have huge dimensions, most likely unacceptable for most domestic spaces. For a great example of a full size horn, please, check out the “Klein Horn” designed and built by Nelson Pass at http://www.passdiy.com/speakers.htm.

All the reasonably sized horns act as a horn only down to a certain range (about 70 Hz for this one). Below that range, the horn acts as a flared transmission line, still providing, however, an excellent acoustical damping of a driver’s low-frequency resonance.

The cabinet consists of two distinctive parts: the folded horn itself and the coupling chamber, which is the volume between the driver and the throat of the horn. Coupling chamber acts as a low-pass filter, limiting the frequencies exciting the horn. Proper choice of the size of this chamber is required in order to achieve flat response of the speaker, summing the driver output, the horn output and baffle step diffraction effect.

I have pretty much stayed within the overall size of the Solo-206 cabinet. Since I have used a ¾” (19mm) material, more commonly available in US, instead of Solo’s 22mm, the internal volume of the cabinet is larger. The basic geometry of the horn was preserved. I have extensively changed the coupling chamber and the front baffles arrangement. The volume of the coupling chamber is increased, providing earlier roll off of the horn, to sum correctly with the output of the driver. A stiffening brace (24) was added between the back panel of the box (16) and the back of the horn’s bend (11). All numbers reference Fig.2, or the Bill of Materials in the assembly drawing of the drawing package.

I.4. Measurements

All measurements, presented in this document, are made with Sound Easy software package using calibrated instrument microphone and preamplifier.

Fig.3. Near-field response of the horn mouth.
Measured frequency response of the horn is presented in Fig.3. There are several important observations we can make from this graph:

The response of the horn is practically flat from 80 to 200 Hz. Low frequency roll-off is around 10 dB/oct down to 20 Hz, which is slower than even closed box, thanks to the transmission-line behavior of the horn in this range. This should provide an excellent match to room gain, providing tuneful bass output in real rooms. High-frequency roll-off of the horn is close to 24 dB/oct from 200 to 400 Hz, ensuring that high-frequency content still exiting the horn is well below the driver’s output and will not muddy the midrange.

Near-field response of the driver is presented in Fig.4.

![Near-field response of the driver. Thick line – SPL, thin line – phase.](image)

Both Fig. 3 and 4 are near-field responses, which has some specifics. They are accurate in the low frequency range only (up to about 600-700 Hz), because of local irregularities developing in higher range. Taking advantage of this, these responses are measured with lower sampling rate, which provides higher resolution. They are also not referenced to the absolute scale. They will be scaled later, relative to the radiating area, then acoustically summed and spliced with far field response of the speaker.

Far-field response of the speaker is presented in Fig. 5. In contrast with near-field measurements, it is only accurate at higher frequencies (above 250-300 Hz), because it is gated to first 5 ms of arrival to the microphone, in order to cut out early reflections from
the floor and walls. This graph accurately represents sensitivity of the driver at 1W of input power (not 2.83 V RMS, as can be frequently found in manufacturer’s datasheets).

Fig.5. Far-field response of the speaker.

Finally, a fully summed quasi-anechoic response of the whole speaker is presented in Fig.6.

Fig. 6. Quasi-anechoic response of the complete speaker.
This response is called quasi-anechoic, because it was obtained not in the real anechoic chamber, but in the room of domestic dimensions, by splicing near-and far-field measurements at 325 Hz. This is the closest we can get, short of using a very expensive anechoic chamber, or going out far in the desert on an especially quiet day. These days it’s a standard form of measurement everywhere, but at the largest speaker manufacturers. Data of this kind are frequently presented in publications, like *Stereophile* and *Speaker Builder (Audio Express)*. It is important to remember, that this is still anechoic, not an in-room response.

As can be seen, the output of the speaker gradually falls down from 80 to 600 Hz. The fall is approximately 5 dB. This should very closely compensate the baffle step loss of the speaker with this geometry of the front baffle. Therefore, we don’t have to resort to the use of BSC circuits.

Average sensitivity of the speakers is around 95 dB SPL. To confirm this I ran a pink noise at a power level of exactly 1W, and measured a C-weighted SPL level with Radio Shack SPL meter at 1 m distance. The reading was precisely 95 dB.

And last, let’s look at the impedance plot:

![Impedance vs. frequency plot](image.png)

Fig.7. Impedance vs. frequency plot. Thick line – impedance, thin line – impedance phase.

In low frequency range, this plot exhibits dual-peak response, typical of ported enclosures. The highest magnitude is just 16 Ohm. In addition, there is a third peak around 22Hz, which is very well damped at 11 Ohm. This is the result of damping materials, carefully placed within the enclosure. In comparison, the same plot taken from empty horn (prior to any damping materials installation), showed that peak at a higher frequency of 27 Hz and had a 17 Ohm magnitude. There were also numerous wrinkles in
the impedance curve of an empty cabinet – the result of standing waves in every bend of the horn. We will discuss the damping arrangement in the construction section. The impedance phase stays within ±35º through the whole audio band. This is an excellent result, really hard to achieve in multi-driver speakers. This speaker should present a friendly load to any amplifier.

Later, in the “Options” section we will describe several additional features that may improve this design.

**II. Construction.**

**II.1. Choice of material.**

This speaker is constructed from plywood. It is almost a common practice to construct speaker cabinet from MDF (medium density fiberboard) both in DIY and professional communities. I also frequently use MDF for construction of boxed speakers, such as closed or ported enclosures. For “open” cabinets such as this one, however, plywood is a better choice. Not every plywood is suitable for speaker construction. Most widely used type is called “Baltic Birch Plywood” (frequently abbreviated as BB). It is constructed from very thin birch plies, arranged in alternating orthogonal fashion. A ¾” (19mm) thick BB should have 13-15 plies. This grade of plywood is also void-free. The best grades are usually sourced from Finland or Russia and, therefore are frequently available in 60”x 60” (actually 1.5m x 1.5m) size. Standard American size of 4’ x 8’ is becoming more easy to find lately. Unfortunately, you are not going to find this plywood in Home Depot or Lowe’s. Check better local Lumberyards – they may be able to get it. When ordering, make sure the plywood is void-free, has no less than 13 plies per ¾” and has a one-piece ply at least on one face.

Even better choice from aesthetic point of view is Appleply. This is essentially a BB constructed from 1/16”(1.5mm) thick birch plies, with smooth maple veneer on both faces. Appleply is more expensive than plain BB, but can be beautifully finished, eliminating the need to veneer the cabinet.

Finally, marine grade plywood is also a very good choice. Some marine grades are made with dark phenolic glue and look attractive enough without any additional finish.

If you cannot find any of these grades of plywood locally, one place to check on the Internet is Anderson International Trading, Inc at: [www.aitwood.com](http://www.aitwood.com).

Presented on the following pages are two suggested part’s layouts: for three sheets of 60”x 60”, or two sheets of 48”x96”.

Please, keep in mind that these drawings only show how to allocate the plywood. Some parts of this design require edges to be cut at an angle, other then 90º. Please, double-check the drawing of every part, before actually cutting the wood.

**Tip:** when cutting side panels, cut them slightly oversized by couple of millimeters on each side. When you glue-up the cabinet, edges will be sticking out above the adjacent flat panels. Edges are fast and convenient to sand flash with the flat panels. Otherwise, if one of the flat panels ends up above the edge, you would have to sand the whole flat to be flash with the edge. This is a lot of work and you may sand off part of the ply, which would look awful after finishing.
Baltic Birch 5x5: 3/4" x 60" x 60"

Vendor: Bin:

1 of 3 this size

Qty this diag.: 1

Grain: Horizontal

Stock Trim: 0"::0"

Max. Bottom Off-Cut

Kerf: 3/16"

Part Trim: 0"

Waste: 33.4%

Actual Dimensions

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Baltic Birch 5x5: 3/4" x 60" x 60"

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Kerf: 3/16"  Part Trim: 0"  Waste: 29.3%  Actual Dimensions
**Baltic Birch 5x5: 3/4" x 60" x 60"**

- Vendor: Bin:
- 3 of 3 this size
- Qty this diag.: 1
- Grain: Horizontal
- Stock Trim: 0" : 0"
- Standard Layout

**Kerf:** 3/16"
**Part Trim:** 0"
**Waste:** 24.3%

**Actual Dimensions**

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### Baltic Birch 4x8: 3/4" x 48" x 96"

- **Vendor:** Baltic Birch 4x8: 3/4" x 48" x 96"  
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#### Standard Layout

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10/4/2006  
- Meniscus Audio Group, Inc -  
Layouts: 1
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2 of 2 this size

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II.2. Cutting parts

The most complicated parts are the sides, with grooves to fit other parts of the horn. The easiest way to transfer the layout on plywood is to print the drawings full size. The drawings of the sides are E-size and are drawn to actual scale. Check with local printing shop to see if they have a plotter, capable of printing E-size drawings. When printing make sure to set 100% scale, not “fit to printer margin”. Also, check the calibration of the plotter. Small inaccuracy of several percent will actually show on the drawing of this size. Divide the largest dimension on the plot by the dimension marked on the drawing and enter this scale factor into the plot dialog screen.

If you cannot get access to a plotter, all dimensions necessary to draw the grooves are presented on the drawing of the left side. The right side is a mirror image of the left.

When marking the cuts on the plywood use soft (#2 or softer) sharp pencil. Do not push hard on the pencil, since it will leave marks on the wood, which are very hard to sand off. For this same reason, do not use hard pencils. Never use markers, or anything that draws with ink. Ink will be absorbed deep in the wood and virtually impossible to sand out. The remaining ink may be dissolved during the application of stain or other finishes and produce very ugly spots.

If you followed my advice and cut the sides oversized, do not forget to offset the drawing by this amount. Also, if only one side of the plywood has a one-piece face, make sure the grooves will be cut on the other (inside) face.

If you are planning to finish the plywood itself, here is a useful tip. Once the outer perimeter of the side is cutout, use a sanding block with #100 paper to put small chamfers on all edges of the outer (better) face. This will prevent the outer ply from accidentally chipping-off, while handling this large piece. However, if you plan to veneer the cabinet, never do this. The edges in this case should remain as square and sharp as possible.

The nominal inset of horn braces into the sides is ¼”. Either cut the grooves just a hair deeper than this, or cut the sides a hair narrower, to make sure the sides would fit square on the top, back and bottom that are not inset.

The cutouts for the driver have to be rounded on the inside, to help driver to breathe. The front fascia has chamfers all around. Please, do not skip this feature. It minimizes the diffraction effects around the front baffle and greatly contributes to the excellent imaging of this speaker. If more convenient, or aesthetically preferable, these chamfers can be replaced by round-over no less than ½”.

Cut all the rest of the parts according to the drawing.

II.3. Assembly.

After all parts are cut, assemble all the parts dry, without the glue. Make sure all parts fit in their appropriate places, sides are square and no flat side is protruding above the adjacent edge. Make adjustments as necessary. Disassemble the cabinet, taking out one part at a time. While doing this, mark each part in pencil, indicating top/bottom and front/rear position. Put these marks in a way that they will not be visible from the outside after final assembly.

For gluing up this cabinet, I recommend polyurethane glues. The most well known glue of this type is “Gorilla Glue”. I have used Elmer’s “Ultimate Glue” with very good results. Titebond brand has recently also introduced one. These glues expand during setting, tightly filling any gaps and producing a very strong bond.
Please, follow the instructions on the can. For proper set, the mating surfaces have to be damp. Wiping them with a lightly wet lint-free rag works fine. The temperature in the room should be between 40 and 90°F (5 – 32°C), but better to stay closer to the upper range.

To properly glue this cabinet you will need plenty of clamps and several right-angle l-shapes (see Fig. 8 for example). Squarely cut block of metal or hardwood may work too. Put one side panel on a flat, clean horizontal surface. First panel to glue is the Top (3). After dampening the mating surfaces, apply a bead of glue in the middle of both and clamp the parts. Since this is the first joint, the accuracy of the whole cabinet depends on it. Take your time and do this accurately. If you have cut the side panel correctly, the grooves should extend a little under the top piece. See Fig. 8:

Fig. 8. Gluing the Top (3).

Next one is the Middle Horn Brace (6). Since it’s hard to clamp down, put a bead of glue around the perimeter of the groove and another in the middle of the Brace’s edge. Ask a helper to push down on the Brace, while clamping it exactly perpendicular. Try-fit the other side panel, to see that it’s square with the front and back edges of the top. Finally, clamp it to the Top using a long clamp. Position this clamp in such a way that it prevents the Brace from moving up. Glue will expand and fill the gaps. See Fig. 9:
After these two parts are done, the work becomes easier. Clamp each part vertically, then put the other side-panel on top, make sure it’s square, and put some weight on it. In the area where this side-panel may get in contact with glue in the vertical joint, put a piece of plastic bag in the groove. Plumbing Teflon tape works very well too, since no glue sticks to it.

Next panels are Bend Bottom (8) and Throat Brace (7):

Fig 10. Gluing of parts (8) and then (7).
Another tip: when you clamp the part, some glue will be squeezed out of the joint. More may appear later, when the glue starts to foam and expand. Do not wipe it off with a dry or wet rag. This will form a thin layer of glue that would be hard to sand-off from the large surface. Just let it dry. Without pressure, the glue dries to a foamy substance, which is easy to remove with sharp wood chisel. Remaining footprint is also easy to sand-off.

Continue gluing all other pieces, except second side-panel, spacer (18), plinth (19) and fascia (23). Don’t glue more parts at a time than you can keep square. Always check the alignment by second side-panel. Approximate sequence of assembly is depicted in the following pictures.
Finally, glue the Bottom (17). Make final dry fit of the second side-panel. Now we will switch to installation of damping and sound absorption materials.

II.4. Wall damping.
Damping of the cabinet resonances is extremely important for reduction of “box colorations” and enabling the speakers to disappear into acoustic space. For damping of the driver’s back-wave we will use Spectra Dynamics’ Deflex™ standard panel, 8.25” x 11” (28 x 21 cm). Use 3M™ Super77 spray adhesive, or equivalent, to attach it directly behind the driver.

For the rest of the cabinet walls, use Black Hole™ Pad, available from E-Speakers (www.e-speakers.com):

It comes in 27” x 24” (60 x 70cm) size. Three sheets are enough if you are careful and plan ahead. Otherwise, get four sheets. This material can be easily cut with scissors or utility knife. It has protective film on one side. Peel it off and stick to the panel. Use wallpaper plastic or wood roller to firmly press the damping sheet to the panel. You don’t have to cover the whole panel from joint to joint. Vibration amplitude of the panel is negligible close to the joints, so damping has no effect in these areas. Therefore, you can cut the damping pieces at least ¼” smaller on each side and don’t have to be that precise while attaching them. Damping material also doesn’t have to be all in one piece. These facts significantly simplify installation.

Put Black Hole™ Pad on one side of each panel, including the side-panel, which is not glued to the cabinet yet. For aesthetic reasons, I would not recommend installing damping sheets on the walls that form the mouth of the horn. This area will be visible from the outside. The surface of this material remains sticky and would attract the dust. Fortunately, as the cross-section of the horn grows, the acoustic pressure drops, so panel vibration is much less of a problem in this area. Brace 21 adds stiffness here. Installed damping is shown in Fig. 11 and 12.

Put damping sheet on the top of the compression chamber and on the back sides of the panels 14 and 15.
II.5. **Acoustic damping.**

Acoustic damping of a back-loaded horn is the most important (and tricky) part of voicing this kind of speaker. It smoothes out the resonance peaks and standing waves, always present in such design, and tailors the speaker’s response to the desired sound. By using a lot of damping, it is possible to get a very smooth response, however, this would kill the dynamics and liveliness, for which the horns are famous.

The arrangement, presented here is the result of many trials and long hours of listening. In the end, I preferred quite minimalist arrangement, trading some smoothness for excitement. You can use different materials in different places, but you will get a different speaker.

To line some of the walls, use synthetic felt, found at any flooring store. This is a wool-like material, about $\frac{1}{2}$” thick. Different densities are available. Use medium or light density stuff. High-density felt is not suitable for this application. Line the top and sides of the compression chamber, the throat side of the brace 6 (below the “Deflex” panel) and both bends of the horn – see Fig.12. Use 3M™ Super77 spray adhesive. Do not forget the other side of the compression chamber on the still not glued side-panel (see Fig. 11).
Finally, long hair wool should be installed in the lower portion of the compression chamber and in the throat of the horn. The best material to use here is Visaton’s lamb wool, available from E-speakers. See Fig. 13.

Do not pack wool tightly in these spaces. The highest density should not exceed ½ lb/cu.ft. Just let the wool lay flat for a while, cut to size and insert without compression. No glue is needed here. See Fig. 14 for complete damping arrangement.
II.6. Finishing the assembly.

Now, it is time to glue the remaining panels. Double check that the second side-panel fits over all the panels of the assembled cabinet and its edges are flash or somewhat protruding over all flat surfaces.

Put the side-panel down on a flat surface. Apply a bead of glue around the perimeters of all grooves and in the areas, where top, back, bottom and front baffle will contact the side. Do not put any glue on the area of the horn mouth. Put a bead of glue in the middle of matching panels on the cabinet. Now, turn the cabinet up side down (get help if possible) and put it on the side panel, inserting all protruding parts in the grooves. Putting side-panel on top of the cabinet is not a good idea, since the excess glue will flow down all around and may compromise the acoustic damping installed. Put some weight on top of the cabinet. Four 18-pound bags of garden topsoil worked fine for me.

After the glue is set, remove all overflows with sharp wood chisel.

Next, sand all the edges of the plywood flash with adjacent flat panels. Use #80 or 100 sand paper. Belt sander is OK for this operation. If you are planning to finish the plywood itself, sand the front baffle farther, going to finer grit, until you get down to #220. It is better to do this by hand with rubber sanding block. Sand only along the wood grain. Sand fascia to the same grit.

Now, it’s time to attach the fascia. Dry fit it to the cabinet, keeping in mind that it is not square. The fascia should be attached with hard glue, such as Titebond, or Elmer’s. You may tighten it with flat-head wood screws, installed in the holes for the grill fasteners.
I would recommend attaching the bottom spacer (18) and the plinth (19) only after finishing these parts and the cabinet separately.
Go around the whole cabinet and remove any overflows of the glue. Sand off all the footprints of the glue, going only along the wood grain.

Fig.15. Filling the gaps.

There would be some gaps, where the lateral parts are inserted in the grooves. They have to be filled. If you are planning on painting or veneering the cabinet, any wood filler will work. If finishing the plywood itself, use wood filler, such as Minwax “Stainable wood filler”. Keep in mind, that any filler will absorb finish somewhat differently from the plywood and produce a color difference. One way to avoid this is more time-consuming, but gives good results. While sanding the cabinet, collect the sanding dust. Dilute white PVA glue with water (50/50) and mix it with dust to paste consistency. Use this paste to fill the gaps. Mix only small amounts at a time.
In the same way, fill any cracks or chip-offs that appear on the walls.

II.7. Finishing options.
This cabinet may be painted, veneered, or the plywood itself may be finished to quite attractive look. My personal preference goes to this last option. If this option looks appealing, Appleply should be seriously considered to construct the cabinet.
To achieve good results for finishing plywood, the cabinet should be sanded down to at least #400 grit. Than, either a stain, or an oil-based finish may be applied. Some kind of protective layer: polyurethane, lacquer or wax should go on top to protect the plywood.
Finish, shown on Fig.1 in the beginning, was done using Watco “Danish Oil Finish” of Cherry color and “Watco Satin Wax”. An excellent tutorial on applying this finish can be found on John Paquay’s web site: http://home.insightbb.com/~jpaquay/oil_fin.txt.
II.8. Driver installation.
Glue the same synthetic felt, used on the walls of the cabinet, to the motor of the driver. Apply plenty of spray glue to the strip of felt and wrap it around the magnet. Tightly wrap a suitable piece of fabric around the felt and then wrap that with Scotch tape. Wait for the glue to set, and then remove the tape and fabric. Glue a round piece of felt to the back of the motor. **DO NOT** spray glue on the driver! See Fig.16.

![Damping of the driver’s motor](image)

Apply foam weather-stripping material to the cutout in the fascia. Alternatively, Black Hole™ Pad makes an excellent driver-mounting gasket. In this case, the cutout must be deeper (and definitely, get 4 sheets for the project). Mount the driver using wood screws.

**III Options.**

**III.1. Connections.**
After the cabinet is finished, connectors and wire should be installed. To make speaker wires invisible from the outside, install thru-the-wall binding posts just below the brace (24) on the back of the cabinet (see Fig.12). Use at least 14 gage good-quality wire to connect the driver. A Van Den Hul CS 14 Hybrid wire available from E-speakers, is a very good choice:
If you are going to use an optional filter (see below), an interesting idea is to use a large square bi-wire input cup, installed in the cutout below the back panels (14 and 15) of the horn. Then the filter can be mounted in that cavity and wires routed through the holes in panel 14 and along the back wall. You can connect one pair of contacts directly to the driver, and use the second pair to route the signal through the filter. Now it is easy to switch between the two variations, especially if the speaker cables are terminated with banana plugs. Obviously, all this is more convenient to do before gluing the second side-panel.

III.2. Floor spikes.
Floor spikes can significantly improve the sound of the speaker, especially if installed on the carpeted or any kind of suspended floor. Even on the hardwood floors, they are still effective, if used with matching brass floor disks. I have used Visaton’s spikes (Art. No.5170), available from E-Speakers, shown on Fig.17.

![Floor spikes](image)

Fig.17. Floor spikes.

The frequency response of this speaker can be farther improved with a notch filter, lowering the driver’s output in the range from 1 to 10 kHz. The schematic of the filter is shown below:

![Schematic of the notch-filter](image)

The values of the components are:
- C = 0.75 µF
- L = 0.7 mH
- R = 14 Ohm
Response of the speaker with and without the filter is shown on Fig.19.
Please, note that this filter is not a crossover. The speaker still remains a time-aligned point source device. It does not introduce phase mismatches, associated with 2- or 3-way crossovers. The overall efficiency of the speaker drops only by about 1 dB. Since all components of the filter are in the signal path at all times, the quality of the components should be as high as possible. The resistor should be non-inductive with power rating of at least 10 W. For the capacitors I would recommend Clarity Cap SA line, or Mandorf’s Supreme. Inductor should have as low a DCR as possible. Any resistance, connected in-series with the speaker increases its Q-factor, and this one already has Q high enough. Air-core inductors are recommended for lowest distortion levels. All these components may be obtained from E-speakers.

**III.4. Under the horn cavity.**

Lower braces of the horn (14 and 15), together with bottom (17) and back (16) panels form a substantial cavity. This cavity may be filled with sand for added damping and stability of the speaker. Optional notch-filter may be located in there as well. If you decide to fill this cavity with sand, the sand should be baked in the oven for sanitation. After it’s cooled, pack the sand into several zip-lock bags and place them into the cavity. This can be done before the second side-panel is glued to the cabinet. Alternatively, if large enough input cup is used for connectors, bags with sand can be inserted through its cutout at a later time, even on top of the notch-filter. Lead-shot may be also used for this purpose. In my experience, mass-loading a speaker in this way has a very positive effect on the tightness of the bass and on stability of the stereo image.
IV. Setting-up the speaker.

IV.1. Positioning.
These speakers are capable of exceptionally good presentation of the sound stage, both width and depth, and deserve careful location in the room. Each room has positions that may emphasize bass aberrations, while proper positions would eliminate them. Unlike other single-driver horns, they do not need back wall reinforcement to produce good bass output. Start with speakers at least 3-4 feet away from the back wall, 6-7 feet apart and slightly toed-in. Move speakers around the room in one-foot increments, then in 6” increments, until the buss is tight and clean. Then, adjust the toe-in in small increments until the image is focused and the soundstage is wider than the distance between the speakers. Finally, the floor spikes may be adjusted to put the image to a proper height. When all is done right, the soundstage should be mainly behind the speakers, extending all the way to the back wall, with solo instruments or voices in the plane of the speakers. As the old saying goes: when you get it – you will know it.

IV.2. Speaker cables.
Another horn-speaker myth states that they benefit from very thin speaker cables. In case of popular speakers, mentioned in section I, this is true, because additional series resistance raises very low Q of these speakers and helps to elevate the bass output. Our speakers do not need this help, especially if used with tube amplifiers. Good cables for these speakers should have high cross-section (at least 12 gage) and be as short as possible.

IV.3. Amplifiers.
These speakers were voiced with both tube and solid-state amplifiers. Regular tube amp (with output transformer), produces exceptionally good midrange. The bass was on a warm side. In this case, farther distance from the room boundaries will benefit the sound. Solid-state amplification provided tighter and somewhat drier bass. In this case, speakers may be positioned closer to the back wall. If your room requires placing speakers close, or right on the back wall, the sound may become bass-heavy. To fix this problem, the output of the horn may be attenuated acoustically. Take some wool stuffing (the same that was used in the throat of the horn) and insert it through the mouth of the horn as high as you can reach along the back brace (24). Do not pack it tightly; try to make it as fluffy as possible. Upper holes in the brace 24 may be used to secure this staffing from falling down. Start with a small amount and keep adding in small increments, until desired attenuation is reached.

In a small to medium size room, just a few Watts of power would be enough to produce a very loud sound. This is especially true with tube amplification.
I have also tried a small switching SONIC IMPACT 5066 amp from Parts Express (P/N 300-952). With just 6 Watts of power per channel, it was capable of very loud and lively sound with plenty of bass output. However, switching directly between this amp and my Fisher X-100-B tube amp was not in favor of the switching technology. The sound of tubes was much more natural and pleasant.
As a final note, I would like to thank you for choosing to build this speaker and wish you good luck in achieving the desired results. It is my sincere hope that you will enjoy the sound of these speakers for years to come.

Vadim Boguslavskiy.