Design Proposal

A horn-loaded full-range, single-driver setup.

Nathan P. Miller
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Design Specifications

- Stereo pair (2.0 system) of horn-loaded single-driver tower speakers.
- Folded rear-loaded tractrix horn system.
- A single full-range driver per tower – two transducers in total.
- Extremely sensitive, use in low-wattage systems.
- Relatively flat frequency response from $50\,\text{Hz}$ to $20\,\text{kHz}$.
- Hopefully maintain a budget below $500.
- Maintain a size smaller than 18” wide, 24” deep, and up to 72” tall.
  - These numbers are flexible and may change to suit the horn.

Driver Selection/Specification

- The 8” Fostex FE206E has been chosen as the full-range driver.
  - Available for $92.20$\(^1\) from Madisound.com as of February 11, 2010.
  - Sensitivity of 96dB $\text{W/m}$ naturally.
    - Horn will increase sensitivity of this in the lower frequencies ($< 300\,\text{Hz}$).
  - A 30W amplification system should be able to increase my response to 105dB at two meters
    - Plan to temporarily use AES’ two tube amp mono-block MacKit 30’s by McIntosh.
  - A Decware phase plug will be used to reduce mid range shouting.\(^2\)
  - See Appendix page A1, Figure A1 for 206E frequency response

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Introduction: Having been in the Audio Engineering Society for nearly three years now and through my general curiosity of speakers throughout my life, I have seen a lot of designs for different loudspeakers and none have intrigued me more than horn-loaded speakers. I don’t quite know what it is, but there is something special to me about a single driver being able to nearly reproduce the entire spectrum of human hearing. From the perspective of a designer this comes as a rather tall challenge, and that’s why single-driver systems aren’t nearly as popular as other formats – and this challenge is really what drove me to want to design one. There are many fundamental problems that a single driver faces when reproducing such a large frequency range and one of the main purposes of a horn is to help one of those: the bass response.

A horn, when correctly used, can increase the efficiency of a driver significantly, up to ten times the power output when compared to a direct-radiating driver.\(^3\) A problem arises, however, when you start talking about the cut-off frequency which is governed by how large the horn is and more specifically, the rate at which it expands.\(^4\) This means that if I wanted a driver to respond at very low frequencies (less than 50 Hz), I would need to build a very large horn to accommodate. One of the design requirements I have is to make reasonable sized tower-esque enclosures that can be moved relatively easily.

Design goals: The goal of my design is to build a loudspeaker that can be used in a normal media setup which includes cinema, television, radio, and the occasional streamed media source. My current house is a bit limited in the space department, so I am hoping to build enclosures that will be able to translate to a larger environment rather easily. This, and the fact that I want to build a horn, is about the only specific requirements I have, other preferences are secondary to these. Although this isn’t necessarily favorable

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\(^4\) p100
from a designing perspective, the lack of direction and requirements isn’t necessarily as negative as it would be with non-horn loaded speakers.

Horn thoughts: In order to fulfill my desire to have a small horn loaded system with a full-range driver, I am rather limited in my choices of design. The first thing out of the question are front-loaded horns – which are always straight, not folded – as these would take up the entire length of my current living room. Also, front-loaded horns aren’t usually made to increase the low frequency response as much as they are useful for directivity – they would have to be absolutely massive otherwise: 7 ft diameter and 6.5 ft long tractrix horn for around a 50 Hz cut-off frequency\(^5\). So to be able to achieve the desired bass response (any), I will have to rear-load my horn.

A rear-loaded horn’s only purpose is to increase the bass response and overall efficiency of a driver, and so they are normally perfectly suited for full-range drivers which just need a bit of a boost in the low frequency ranges. This lets the drivers radiate normally at higher frequency – where it has a relatively flat response, depending on the driver – and then boost the bass which is so hard to get with a very lightweight, small \(X_{\text{max}}\) (the range of the cone movement vertically), small piston area full-range driver. The most common technique of designing rear-loaded horns is folding the actual horn; this lets you have a larger horn in a smaller footprint and also lets you keep the horn exit within a reasonable distance to your driver. So this rear-loaded folded horn plus my full-range driver should result in about the correct sized enclosure I am looking for.

\(^5\) Forker. Microsoft Excel document: Tractrix Horn Calculator v1.3a. (see bibliography for link)
The main equation (in a standard Cartesian coordinate system) for the tractrix curve is given by
the formula \( y(x) = d \cdot \cosh^{-1} \left( \frac{d}{x} \right) - \sqrt{d^2 - x^2} \) where \( d \) is given by the mouth radius (usually 1 to
normalize). This can be seen in Figure 6 to the left. The general idea
with the tractrix curve is that all sound waves maintain a spherical
wave front throughout the expansion of the horn.\(^6\) It’s debated
whether or not this curve is better for use in a horn than other
curves, but it has proven itself over the years in various speaker manufacturers including Klipsch.

**Bandwidth:** I want to use a full-range driver in the design of my loudspeaker, the question of bandwidth isn’t
as applicable as other multi-way systems. A full-range driver is supposed to be able to radiate the entire
spectrum of human hearing and this means that you will have nearly no phase interference issues
because all of the sound is coming from one source. Other multi-way systems will often have weird
phase cancellations at different points in a room because of crossover network problems and/or of
simple multi-source constructive and destructive interference.

In any case, the ideal situation is to have a single driver producing the entire range of
frequencies which is exactly what a full-range driver is set out to do. Another big plus is the elimination
of a traditional crossover which produces a lot of interesting reactive feedback. So my goals for
bandwidth are rather simple, I would like to see the full-range driver perform well down to 50 – 60 Hz
in a proper rear-loaded horn setup and then up to its acoustical roll off which is usually 18k – 20kHz.\(^7\)

**SPL thoughts:** The goal of how loud I want this design to be is a little bit more malleable than my other
requirements. I mostly just want everything to perform well and if it can get loud too, then it’s a plus.

The full-range drivers aren’t normally rated for higher wattages; the Fostex FE206e that I am looking at

\(^6\) Kolbrek. "Horn Theory: An Introduction."

is only rated at $30 - 90W$ and so is not meant for extremely high volumes. These drivers are meant to be placed into an enclosure to gain the most efficiency as possible and so these low wattages don’t necessarily relate to loudness.

Putting some numbers together, we have a $96\, \text{dB/W m sensitive speaker}^8$ - and a reasonable listening distance of $2\text{m (my current situation)}$ which will drop our output to $90\, \text{dB/W}$. Now given the equation $10 \log(30W) \cong 14.8\, \text{dB}$, the output of this system at its $30\, \text{W power handling}$ is $105\, \text{dB}$ at two meters. This is a fairly respectable number and will certainly be loud enough for normal movie and television settings. Bob Katz and the K-system metering techniques suggest headroom of $20\, \text{dB}$ for a dynamic movie and setting the volume at a very respectable $85\, \text{dB}$ will still give us plenty of room to breathe.

**Other thoughts:** Aesthetically speaking, I’m not too concerned about how things look. I hope to use fairly expensive birch plywood which naturally looks good, and a stain is not out of the question. I personally like the looks of full-range drivers with wizzer cones and phase plugs – they seem complex in contrast to the otherwise blank/flat enclosure design. Finally, one of the biggest concerns with any project is the budget. I hope not to have a huge budget, but I do not have any specific goals other than to not go over the top when other comparable options are available. This was the main reason why I chose the drivers I plan on using.

**Drivers:** The biggest problem with designing full-range loudspeakers is that there aren’t that many reasonably priced drivers to look at. One of the largest companies that deals with full-range drivers is Fostex, and they’ve been doing it

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8 *Id.*

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Figure 7: A pretty ugly picture of the Fostex FE208Σ.
for long enough that they’ve built up a rather substantial fan base. Specifically, I looked at their FE206E 8” driver\textsuperscript{10} and their FE208E\textgreek{S} 8” driver\textsuperscript{11}. Both of these have gotten excellent reviews from random fellows on the internet forums and the biggest difference between them is the price. The Sigma series (FE208E\textgreek{S}) are almost all twice as expensive as similar drivers in the same size and this was the case between these two drivers as well; the 206e is around $92 while the 208e\textgreek{S} is $190.

As for other drivers I have looked at, the Tang Band W8-1808 8” full-range drivers found on Parts-Express.com is very comparable to the FE208E\textgreek{S} in every manner and most importantly is basically the same price. If someone handed me an extra $200 to use just for this project, I would probably use these, but with a frequency response and other specs so similar to the FE206E it’s just not worth it. I do like how the magnet system and phase plug look, but I would rather save money than to buy good looks. One comp any that I contemplated buying from other than Fostex was Audio Nirvana.

Audio Nirvana is a small full-range single-driver based company out of St. Louis, MI. Their main goal is to compete with the likes of Fostex, Lowther, and other full-range focused companies by selling them through their front-end company of CommenSense Audio by David Dicks\textsuperscript{12}. One driver made by Audio Nirvana, in particular, is basically the sister driver when compared to the Fostex FE206E. This “Super 8 Cast Frame” has a few benefits to speak of including a cast aluminum frame compared to the Fostex which features just a pressed frame, a lower moving mass ($M_{\text{ms}}$), and a larger

\begin{figure}[h]
  \centering
  \includegraphics[width=0.4\textwidth]{tang_band_w8_1808}
  \caption{Tang Band W8-1808}
\end{figure}

\begin{figure}[h]
  \centering
  \includegraphics[width=0.4\textwidth]{audio_nirvana_super_8}
  \caption{Audio Nirvana Super 8”}
\end{figure}

\textsuperscript{10} Fostex FE206E Spec Sheet.
\textsuperscript{12} http://www.commonsenseaudio.com/about.html Accessed: 02/10/2010
and more powerful magnet. If I plan to build another set of full-range drivers in the future I will have to try these out, the problem is that they just don’t have the community support when compared to the Fostex.

**X-over thoughts:** Because I’m doing a full-range system, I don’t have to be concerned as much about a crossover as I would in a multi-way system. One thing that I do need to consider is general response shaping circuitry. This could help flatten my over-all frequency response; if you look at the Fostex FE206e spec sheet you’ll see that there is an increase of almost $10\,dB$ from $2kHz$ to $10kHz$. It would probably be advantageous to flatten this out, to reduce listening fatigue, and so that lower frequencies stand out better.

**Conclusion:** The biggest thing I still need to work on is the actual modeling of the horn itself. That should prove to be the most exhaustive aspect of this entire project, but being that I don’t have to work on crossovers the same as multi-way systems it should balance itself out in the end. I will be using a general tractrix formula for my folded horn and will try to fit it within reasonable dimensions. I feel confident – mostly by seeing so many other people do similar projects with Fostex drivers – that my loudspeaker system will work very well and put other multi-way systems to shame. You just can’t match the clarity of having the entire frequency range produced by one driver; nevertheless it should be an interesting experience to build.

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14 Dickason. *Loudspeaker Design Cookbook*. p181
15 Fostex FE206E Spec Sheet.
Works Cited


**Figures**

Figure 1: http://www.frugal-horn.com/ronhorns.html
Figure 2: http://diyaudioprojects.com/Drivers/FE206E/
Figure 3: DECWARE eBay Auction #220320970313, otherwise: http://i15.ebayimg.com/04/i/001/20/72/14b2_12.JPG
Figure 4: http://www.diyaudio.com/forums/multi-way/48588-300-1500-hz-horn-vs-open-baffle-mids.html
Figure 5: http://www.frugal-horn.com/ronhorns.html
Figure 6: http://www.wolframalpha.com/input/?i=ArcCosh(1%2Fx)-Sqrt(1-x)
Figure 7: https://www.wilmslow-audio.co.uk/catalog/product_info.php?products_id=103
Figure 8: http://www.parts-express.com/pe/showdetl.cfm?Partnumber=264-894
Figure 9: http://www.tnt-audio.com/casse/t-speakers_e.html

Figure A1: http://www.madisound.com/catalog/PDF/fostexdrivers/FE206E.pdf
Figure A2: http://www.madisound.com/catalog/PDF/fostexdrivers/fe208ez.pdf
Figure A3: http://www.parts-express.com/pe/showdetl.cfm?Partnumber=264-894
Figure A4: http://www.commonsenseaudio.com/an8cfspecs.jpg
Appendix A: Tables, Charts, and Figures

Figure A1: FE206E Frequency Response

Figure A2: FE208E Frequency Response

Figure A3: Tang Band W8-1808 Frequency Response
Figure A4: Audio Nirvana “Super 8 Cast Frame” Frequency Response