Acoustic Image®
Musical Amplification:
Setting The Standard

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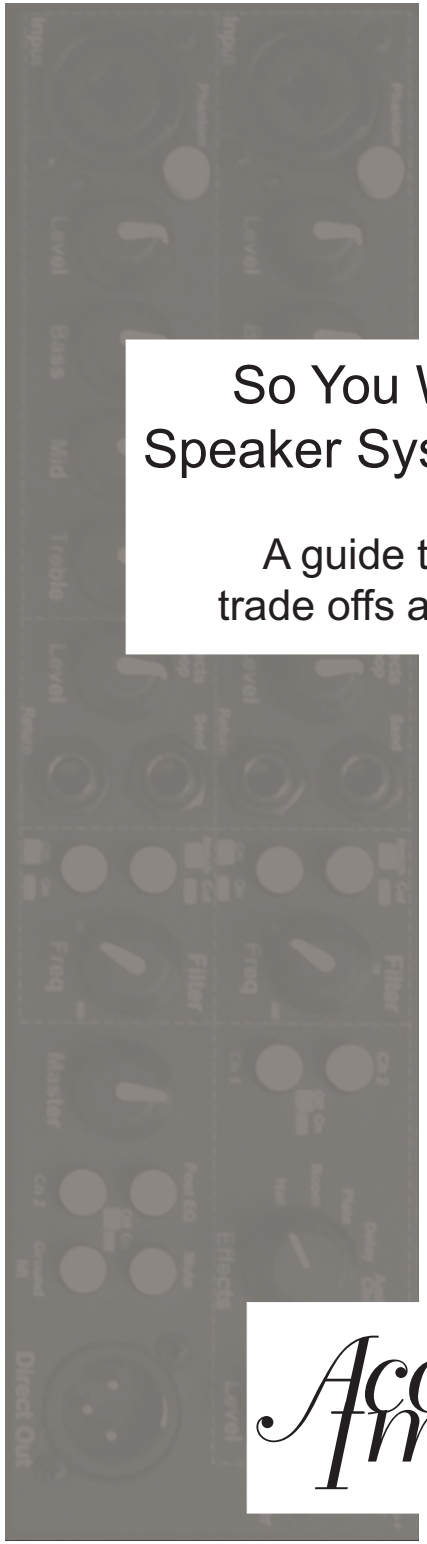

So You Want To Design A Speaker System For Your Bass …

A guide to understanding the trade offs and avoiding the pitfalls

Rick Jones

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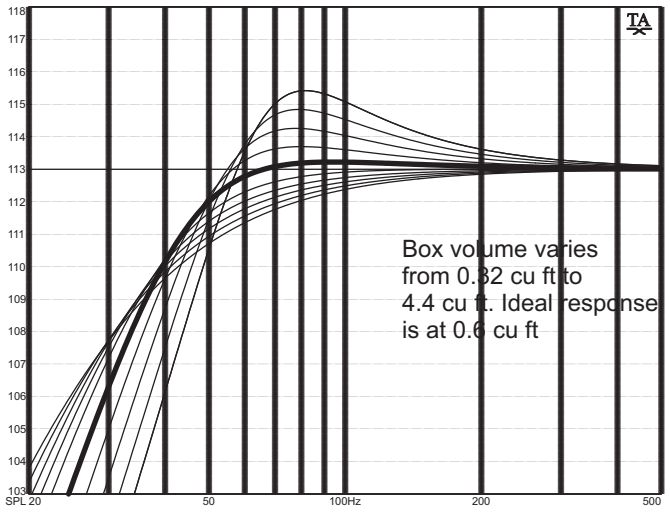
1. Introduction

- It's not easy, there are many trade offs to consider
  - The laws of physics keep you from "perfection"
  - Example: "good low frequency response, small cabinet, high efficiency: pick any two"
- My purpose is to provide insight into the trade offs and guidance into what constitutes a good design

2. Example

- "I'm going to build my own speaker cabinet, I've got this expensive EV 12 inch driver and I'm going to put it in a small cabinet so it is easy to carry"
- Let's see what the result is:

35. Custom Woofer Results



36. References

- Books
  - Advanced Speaker Designs, Ray Alden
  - Speaker Building 201, Ray Alden
  - Loudspeaker Design Cookbook, Vance Dickason
  - Designing, Building and Testing Your Own Speaker Systems, David Weems
- Speaker Design Programs
  - WinSpeakerz, BassBox

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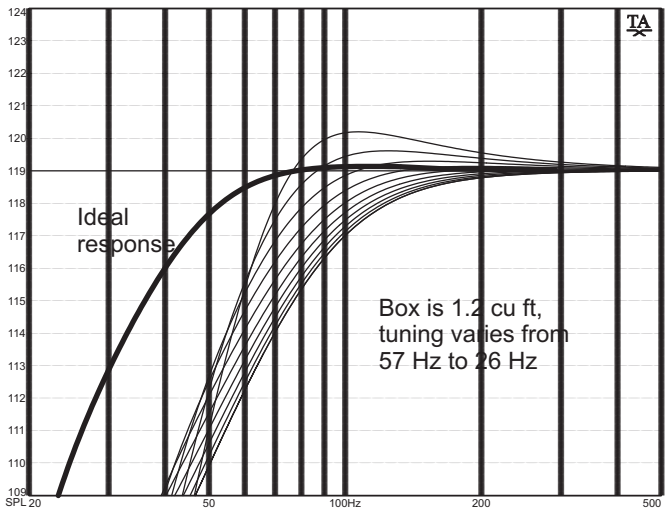
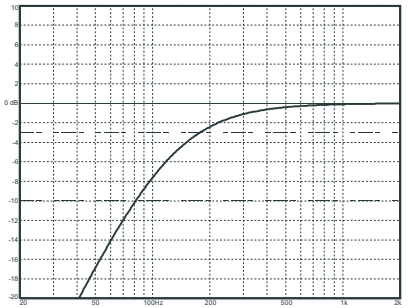
33. Vented Box Examples



3. EV 12 In Small Cabinet

- Check out the frequency response:



EV 12 in small box

This would sound terrible, no bottom

34. Custom Woofer Example

- Custom 10 inch woofer
  - Fs = 22 Hz
  - Qt = 0.4
  - Vas = 2.5 cu ft

4. EV 12 In Small Cabinet

- What went wrong?
  - The speaker and cabinet interact to make the combination a poor performer
  - The system has to be “designed” to make it work correctly
- Let’s talk about what’s involved in the design process

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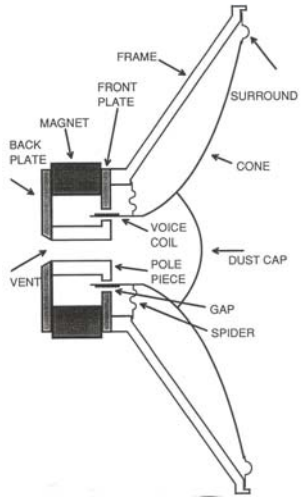
5. Design Aspects

- Driver operation
- Frequency response
- Polar response
- Transient response
- Cabinet design
- Number of drivers

6. Driver Operation

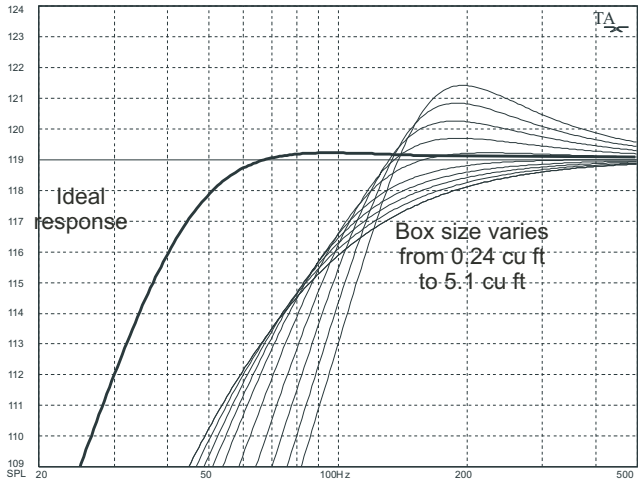
- Parts of a driver



31. Design Example

- Eminence Basslite CH 2010
  - Fs = 58 Hz
  - Qt = 0.44
  - Vas = 1.5 cu ft
- Results obtained using WinSpeakerz

32. Closed Box Examples



29. Design Process, con't

- Here are the steps
  - Choose driver(s)
  - Select box type (keep in mind, not all drivers work in all box types)
  - Use software to examine design trade offs
    - LF cutoff, SPL, box size, Q of system, etc
  - Repeat until you are satisfied with the design
  - Design crossover network (another iterative process)
  - Build a prototype and find out that you have more work to do

7. A Speaker Acts Like An Instrument

- It has a resonance
  - Resonance is frequency where inertia and compliance balance each other
- It has a volume displacement
  - To move the same amount of air as a bass, it has to have a large excursion since its radiating area is smaller
- It has an efficiency that is controlled by the materials it is made of
  - Typical speaker efficiencies are 1% or lower

30. Remember The Old Adage

- "Good LF response, small cabinet, high efficiency; pick any two"
- Let's look at some examples
  - Sealed cabinet, 0.6 cubic feet, 40 Hz LF cutoff, 90 dB sensitivity
  - Vented cabinet, 1.2 cubic foot, 63 Hz LF cutoff, 96 dB sensitivity

8. Important Parameters Of A Speaker

- Compliance
  - Determined by the "stiffness" of the spider and surround
  - Compliance is the reciprocal of stiffness
- Resonant frequency
  - Determined by the mass of the cone/voice coil and the compliance
- "Quality" of the resonance (damping of resonance)
  - Determined by the magnet strength
- Efficiency
  - Determined by the resonant frequency and the compliance

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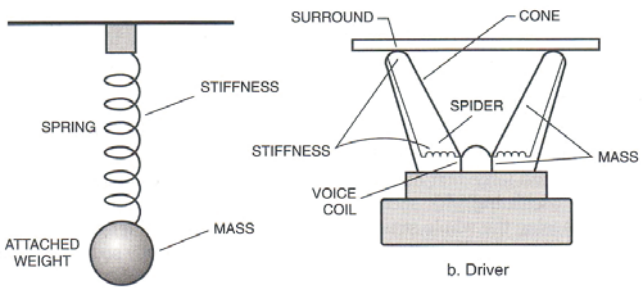
9. Think Of A Speaker As A Mass On A Spring



a. Spring and Weight

$$F_S = \frac{1}{2\pi}\sqrt{\frac{k}{M}}$$

F_S = natural resonant frequency in **Hz**
k = stiffness of spring (newtons/meter)
M = mass of weight in **kilograms**
2π = 6.28, the number of **radians** in 360° (one cycle)

b. Driver

$$F_S = \frac{1}{2\pi}\sqrt{\frac{S}{M}} = \frac{1}{2\pi}\sqrt{\frac{1}{M\,C_{MS}}}$$

F_S = natural free-air resonant frequency of driver in **Hz**
S = stiffness of surround and spider
C_{MS} = compliance (the reciprocal of stiffness) in **meters/Newton**
M = mass of cone and voice coil in **kilograms**
2π = 6.28, the number of **radians** in 360° (one cycle)

10. Efficiency Illustrates The Trade Offs

- Here's a simple equation that shows the trade offs

  Efficiency is proportional to (resonant frequency)^3 times compliance divided by quality of resonance

- This shows that for every octave that you lower the resonance, the efficiency drops by 9 dB
  - Keep in mind that the bass frequencies are in the lower octaves—the low efficiency region

27. What's The Best Approach?

- See, I told you it was a complex set of trade offs
  - You can get the "best" approach several ways
  - What you get depends on what is most important
    - Cabinet size
    - Transient response
    - LF fidelity
    - Loud

28. Design Process

- Several software programs are available that do the heavy lifting
  - See the references for specific programs
- To proceed with a design, you need to know:
  - Speaker parameters:
    - Fs, Vas, Qt (plus other parameters if you are doing a more complicated design
    - You can get these from the driver manufacturer or you can measure them yourself
  - Cabinet parameters (volume, resonance)
  - Crossover parameters (frequency response, power handling)

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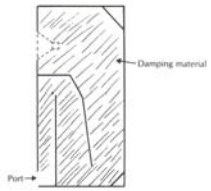
25. Properties Of Vented Cabs

- Here's what a vented cab looks like:

- The air in the cabinet has a resonance due to the vent that is selected to enhance the low frequency response of the cabinet
  - In one approach, it is set at the driver's LF resonance
  - This is done by adjusting the volume of the cabinet and the area and length of the vent
  - The result is enhanced LF response due to the in-phase output from the vent
  - But, because of the effect of the vent on the driver damping, the transient response is worse than the sealed cabinet

26. Properties Of The Transmission Line Cabinet

- Here's what a transmission line cabinet looks like:

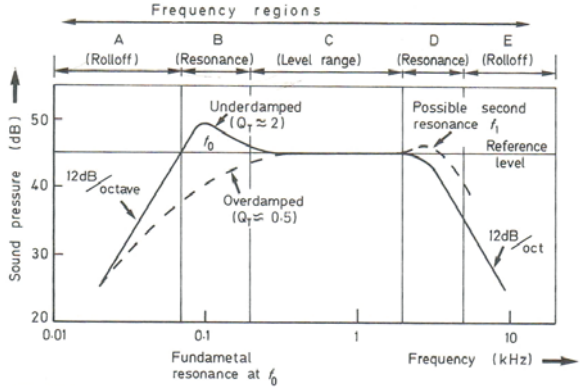


- The goal with this approach is to totally absorb the rear wave so that the driver's parameters are not changed by the cabinet
  - That would take an infinitely long transmission line so absorption takes place over only a narrow band of frequencies
  - So you get the properties of the driver, but the cabinet is complex

11. Frequency Response

- Fundamental tones on a bass range from 41 Hz (31 Hz for a 5 string electric) to 392 Hz (higher if you pluck or bow above the octave)
  - Want to also reproduce harmonics and transients so response to 5 kHz would seem to be enough (one more octave to 10 kHz is even better)

12. Frequency Response Of Generic Loudspeaker



13. High And Low Frequency Limits Of A Loudspeaker

- Every driver has a low frequency and a high frequency resonance
  - Response drops off below the LF resonance due to mechanical effects of the compliance and above the HF resonance due to mechanical effects of the mass
  - If either resonance is not well controlled, a "hump" in the response can occur

14. Can One Driver Cover The Full Range?

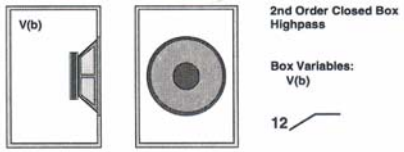
- Large mass is necessary for good low frequency response but results in poor high frequency response
  - So, a one driver system is always a compromise, either at the low end or the high end of the frequency range
- The limitations of one driver can be overcome by using two or more to better cover the frequency range

23. Types Of Cabinets

- The cabinet type comes from how the rear wave is handled
- There are many types but three are the most widely used for musical instrument amps
- Sealed cabinet
  - "Absorbs" the rear wave and provides additional compliance due to the air in the box (raises the resonance of the driver)
- Ported cabinet
  - "Reflects" the rear wave through a port so it comes out of the cabinet in phase with the front wave (this happens only over a limited band of frequencies) to reinforce the output
- Transmission line cabinet
  - Does a better job of absorbing the rear wave than the sealed cabinet which results in less loading of the driver by the cabinet (ideally, does not raise the resonance of the driver)

24. Properties Of Sealed Cabs

- Here's what a sealed cab looks like:



- The air in the box acts like a spring that adds compliance to the driver when it is mounted in the box
  - That raises the resonance of the driver
  - The ratio of the box compliance and driver compliance determines how much the resonance is raised and determines the shape of the low frequency response
  - A "stiff" box (small) can affect the LF damping and cause a large hump in the response
  - There is a "just right" cabinet size for a given driver that results in smooth LF response and excellent transient response
    - The sealed cabinet has the best transient response of all approaches

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21. How A Driver Impacts Transient Response

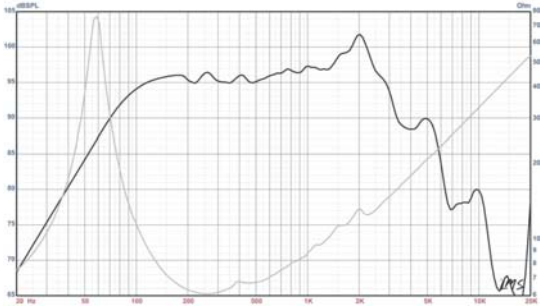
- Mass of the cone/voice coil
  - High mass can cause both slow starting and ringing
  - That's why a 10 sounds better than a 15 for mid bass
- Damping of LF or HF resonance
  - If the magnet doesn't control the cone, it can ring (like a wolf tone)
  - If the spider is too tight or loose for the mass of the cone, ringing can occur
- The damping of the cabinet also has an effect
  - More about that later
- So, one has to select a driver with the right resonant frequency, the right compliance and the right damping and then put it in a cabinet with the right damping to get good transient response
  - This optimization is one of the most overlooked in the speaker design process

22. Cabinet Design

- The driver must be mounted in a cabinet, otherwise, low frequency cancellation occurs
  - When a positive pressure wave leaves the front of the cone, a negative wave simultaneously leaves the rear of the cone
  - At low frequencies, those waves can cancel each other resulting in poor LF response
    - Have you ever played bass through an open back guitar cabinet?

15. Response Of A Typical Driver

- Here is the response of a 10 inch woofer
  - Note the "hump" due to the underdamped HF resonance



16. Impact Of The "Hump"

- Some like it
  - It boosts midrange so you can hear the amplified bass better
  - But, it's not a natural sound
- You can get rid of it by using a two-way system
  - A crossover network is used to filter the top end of the woofer and blend in a midrange driver
  - As a result, the hump is gone and the response is extended
  - It's "better" but it's more complex and it costs more

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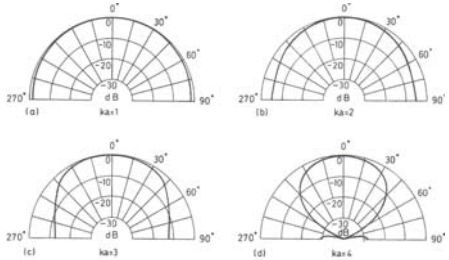
17. Polar Response

- At low frequencies, the output of a driver is non directional, it radiates equal power in all directions
- As frequency increases, the output of a given driver becomes directional
  - More energy is concentrated in a narrow beam coming from the front of the driver
- This effect begins to occur when the wavelength of the sound wave is equal to about 3 times the diameter of the driver

18. Directivity Pattern

- Here is how the directivity changes with frequency



- ka is pi times diameter divided by wavelength
  - For a 10 inch driver, ka=3 occurs at 1300 Hz

19. What Is The Impact Of Beaming?

- The amplified sound becomes harder to hear unless you are in the beam
- How do you fix this problem?
  - Use a two-way system where the midrange driver is crossed over before the LF drive begins to beam
  - Use multiple LF drivers pointed in different directions
  - Use a downfiring LF driver

20. Transient Response

- Music is mostly transients: plucked strings, crashing cymbals, mallets on bars….
  - It is critical that a speaker be able to reproduce these sudden changes in level
- Two things can happen when the cone of a driver tries to reproduce a transient
  - It can be slow to start so the “edge” is taken off the transient
  - It can keep moving once the transient has stopped so that the sound is “smeared”

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