



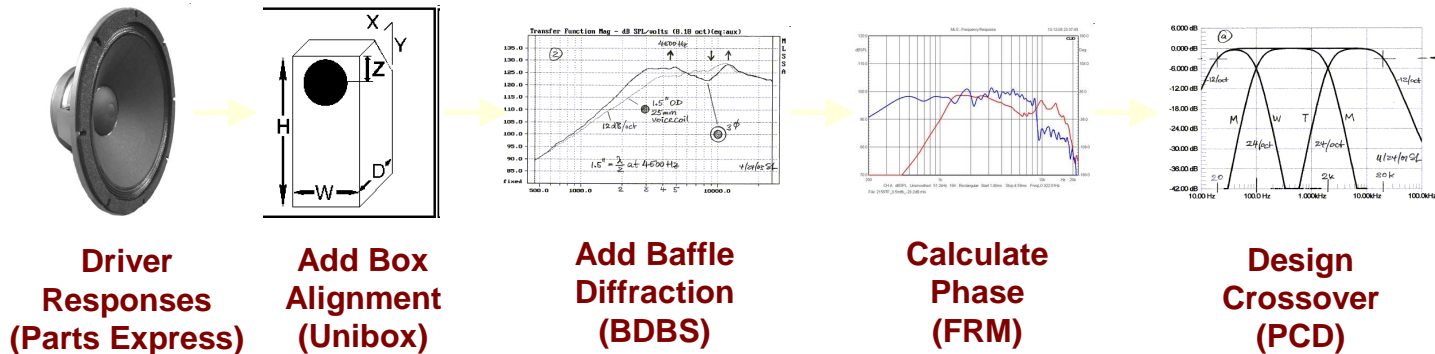
# Simple Loudspeaker Design

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January 2011

# Design Approach

- A speaker design can be created with minimal measurements using free applications
  - While actual measurements will always provide more accurate results, this has been shown to be accurate as long as your drivers are close to manufacturer specs
  - When in doubt, a good resource for driver actual measures is DIYAudio or Parts Express (see slide 9)
  - All programs shown require Excel
  - I've verified the high accuracy of each of the following tools personally, using anechoic data and personal measurements



# Design Example

- Presented here are a series of steps to design a loudspeaker using free tools. More detailed example steps are found in the accompanying file folders
  - 2-Way Vented with the Usher 8945A 7" Carbon Fiber Mid/Woofer, and the Dayton RS28A Aluminum dome tweeter







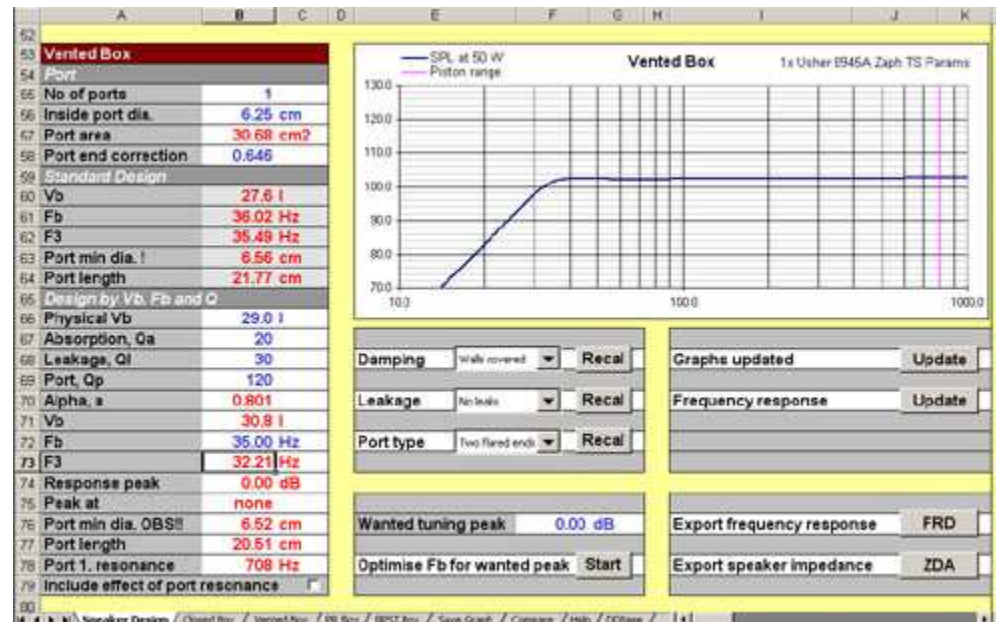
# But First: FRD File Format

- All Response curves will be saved as text files
  - <http://www.pvconsultants.com/audio/frdis.htm>
  - File extension is “.frd”. Save as text then change .txt to .frd
  - Three columns: Frequency, SPL, Phase
  - The impedance file equivalent is “.zma”
  - Ensure there are no hidden carriage returns at end of file
  - Asterisks indicate comment lines

```
Usher 8945A 296-602F - Notepad
File Edit Format Help
*MANUFACTURER : Usher          MODEL : 8945A
*
* Freq          dB          Phase
20.0            74.9          135.96
20.3            74.9          135.18
20.5            74.9          134.75
20.8            75.0          134.32
21.1            75.0          133.90
21.3            75.1          133.47
21.6            75.1          133.06
21.9            75.2          132.64
22.2            75.2          132.23
22.4            75.3          131.82
22.7            75.3          131.41
23.0            75.4          131.00
23.3            75.4          130.60
23.6            75.5          130.20
23.9            75.5          129.80
24.2            75.6          129.41
24.5            75.6          129.01
24.9            75.7          128.62
25.2            75.7          128.19
25.5            75.8          127.72
25.8            75.8          127.26
26.2            75.9          126.80
26.5            75.9          126.34
26.8            76.0          125.88
```

# Low Frequency Box Design

- Closed, Vented, Band Pass or Passive Radiator
  - Unibox: <http://audio.claub.net/software/kougaard/ubmodel.html>
  - Enter TS params, box dimensions, stuffing and power input
  - Hit all “recal” and “update” buttons for box type considered
  - “Export Frequency Response” for .frd file (FRD button)
  - Better to use measured TS parameters as manufacturer specs are “optimistic”: <http://www.zaphaudio.com/>



# Design Box Dimensions

- Use Boxcad to determine Box Shape
  - <http://audio.claub.net/software.html>
  - Use cabinet volume determined in Unibox
  - Boxcad calculates bill of materials, box weight, driver mounting locations and more
  - Baffle dimensions will be used next to simulate diffraction



**Driver Size and Placement Control**

Driver	Width	Height	Radius
Driver 1	0	7	1.5/2
Driver 2	0	4.1/5	2.1/1/5
Driver 3			

**Material Density**

Total Box Weight: 38.9 Pounds

**Drilling**

Width	Length	Depth	Spigots
8	27	1	1
8	9.1/4	1	1

**Outside Box Dimensions (Inches)**

Width	Height	Depth	Material
10	29	1.5/4	23.2/9
10.3/4	10.3/4	1	6.12/10
24.3/4	4.3/4	1	6/16

**Driver Height**

Driver	Radius	Center	Offset
1	1.5/2	0	0
2	2.1/1/5	0	0

3D Model of a rectangular speaker box with two circular driver cutouts on the front face.

**Bill of Materials**

Part	Width	Height	Thickness	Qty
Front/Rear Baffles	10	29	1/8	4
Side Panels	9 1/4	29	1/8	4
Top/Bottom Panels	9 1/4	8	1/8	4
Bracing	27	8	1.00	2
<b>Total Sq.ft</b>	<b>20.0</b>	(Full Sheet is 40sq ft - 68"x96")		(30 Sheet is 60" x 96")

**Vertical Center Line**

From Top	From Bottom
Driver 1 center location: 10.1/4	18.3/4
Driver 2 center location: 4.1/4	24.3/4
Driver 3 center location:	

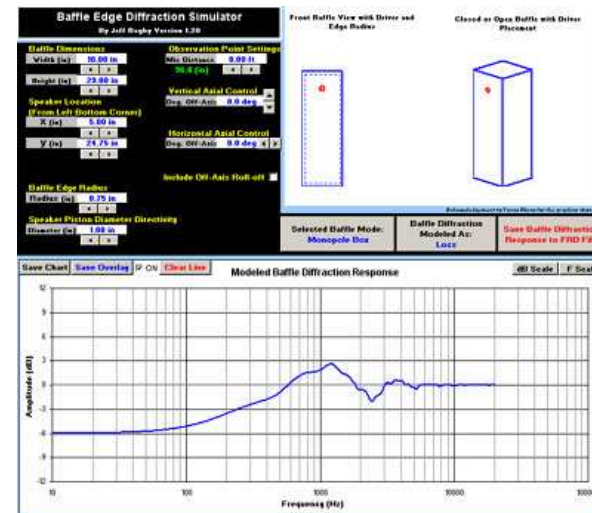
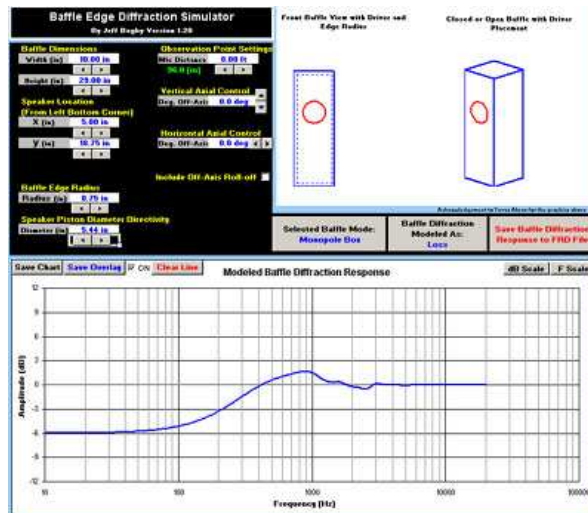
**Inside Dimensions**

Width	Height	Depth
8	27	1.5/8

**Note:** Build the top/bottom/center to a box with 1/8" gap. Cut the baffle pieces by about 1/2 inch and glue or weld smoothed on all sides. Use a thick wire blade to bring the baffle square with the other panels.

# Woofers Box Diffraction

- Calculate Baffle Diffraction using “Baffle Diffraction and Boundary Simulator”:
  - <http://audio.claub.net/software/jbabgy/BDBS.html>
  - Make sure graph is shown as “loss”
  - Use box dimensions, driver location and diam from Boxycad
  - Enter speaker diameter, as it affects directivity and diffraction
  - “Save Baffle Diffraction Response to FRD File”
  - Repeat for woofer and tweeter

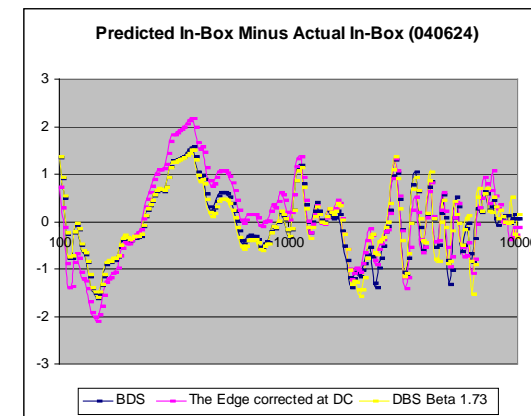
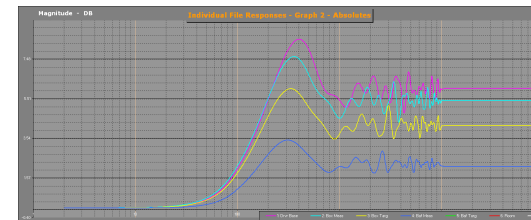
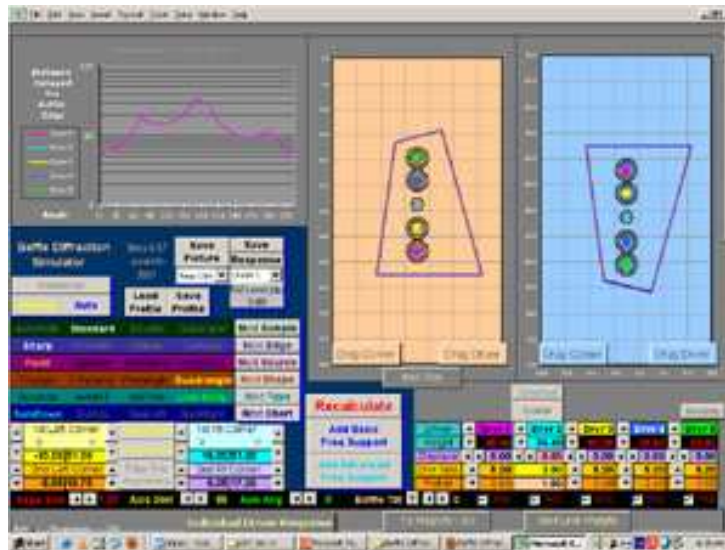




# Woofers Box Diffraction

- For more ornate baffle shapes and edges, use the Baffle Diffraction Simulator:

- <http://www.pvconsultants.com/audio/diffraction/downloadbds.htm>
- Tragic UI but very powerful, flexible and accurate
- Detailed but cumbersome User Guide
- Sims shown compared against anechoic tests. Hash above 1kHz is woofer surround reflection and cone diffraction, not error

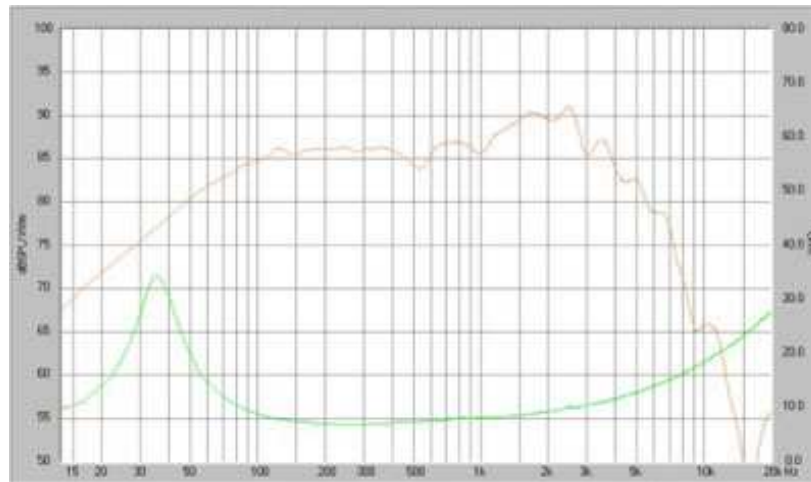




# Driver Responses

- If you can't measure, use Manufacturer curves
  - Use manufactures “infinite baffle” or “2pi” data
  - Create a .frd file of the on-axis response from the graph
  - Can also use “SPL Trace” at <http://www.pvconsultants.com/audio/utility/spl.htm>
    - Instructions: <http://72.9.35.76/showthread.php?t=182411>
  - Repository of FRD files:
    - <http://sites.google.com/site/brianpowers27speakers/diy-resources/speaker-measurements>

Example: Usher 8945A



□ Dave Dal Farra, January 2011

# Prepare Woofer FRDs

- Adjust each FRD to use the same frequencies
  - For each of the 3 FRD files, use “SPL Viewer”  
<http://www.pvconsultants.com/audio/utility/spl.htm>
  - File->Open Frequency Response File. Tools->Normalize Data. For each file, choose same frequency start freq, stop freq, log axis and # of points per decade
  - “Save as”.  
Result is new FRD file with same response as that input, but interpolated to new frequency data points common to each frd
  - Each file will use the same frequencies, so they can be easily spliced together. Shown is Usher before vented box and diffraction are added



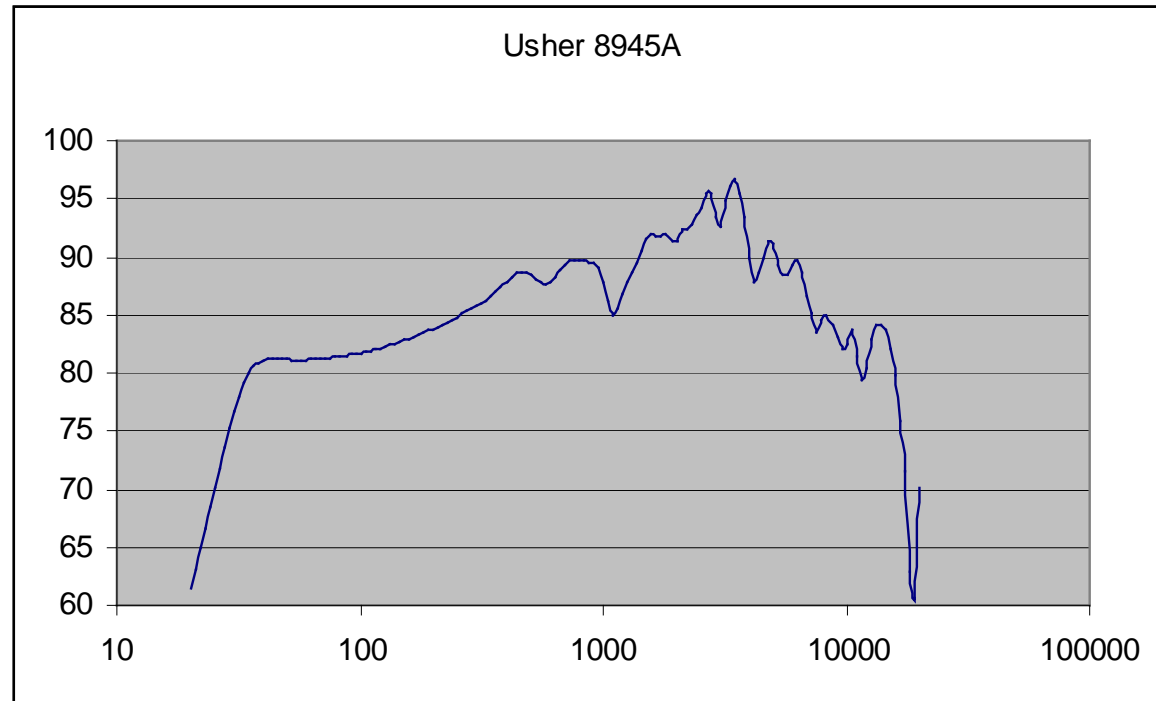


# Create Woofer Response

- Splice Together Diffraction and Unibox file
  - Create an FRD where the diffraction curve is simply added frequency by frequency to the Unibox curve
- Splice Together Diffraction and Driver Response Curves
  - Create an FRD where the diffraction curve is simply added frequency by frequency to the “infinite baffle” woofer response curve
- Splice together these two new curves
  - Pick a point to add them together by adding an offset in dBs to one of the curves so each have the same magnitude at the splice frequency
  - Choose a splice frequency where the Unibox curve is within 0.5dB of it’s high frequency asymptote. For woofers, a good splice frequency is usually ~ 300Hz
- Result is the final woofer response curve as an frd file, but with valid magnitude data only

# Example: Usher 8945A

- Created Using the Technique Shown
  - Usher 8945A free field spliced with vented box bottom end and diffraction added





# Create Woofer Phase

- The previous frd had magnitude response only. Now the phase response is to be calculated.
- Since all drivers are “minimum phase”, the Hilbert Transform is used
  - Use the “Frequency Response Modeler” at: <http://audio.claub.net/software/jbabgy/FRM.html>
  - Keep fft.dll in same folder as excel file
  - Load the woofer FRD file and calculate phase “Auto Extract Phase from FRD File”.
  - Reload the frd with phase and add a small amount of delay (“User Adjustable Delay”) to compensate for the woofer acoustic center being further behind the baffle than the tweeter’s:
    - 6.5” to 7” driver (24mm) = 0.07ms; 5” driver ~ 0.061ms (21mm)
  - “Save Modified Result to FRD File”. New file will now include proper phase data with driver baffle offset
  - This is a powerful program with many functions, but don’t get intimidated by the UI.

# Create Mid Response

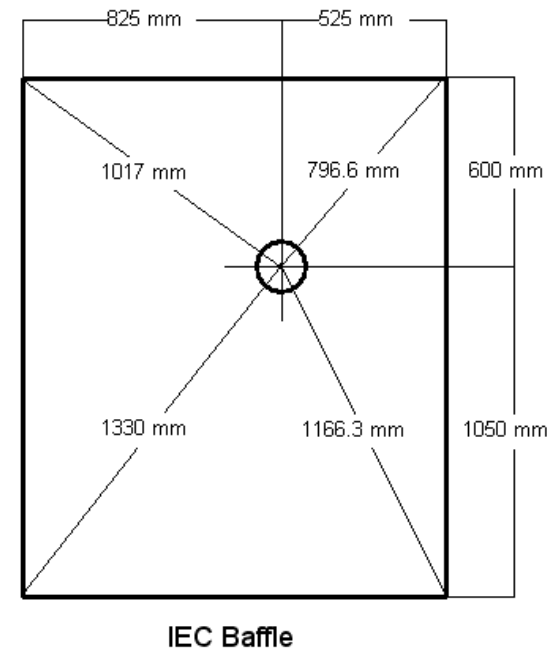
- If using a Mid, calculates it's in-box frd response using the exact same technique as the woofer
- For multiple mids, calculate the diffraction response for each unique mid location so that each mid has its own response
  - Same would apply for two woofers in an MTM
- If mid was measured by the Manufacturer on an IEC baffle, subtract out the IEC baffle response (see tweeter slide)





# Create Tweeter Response

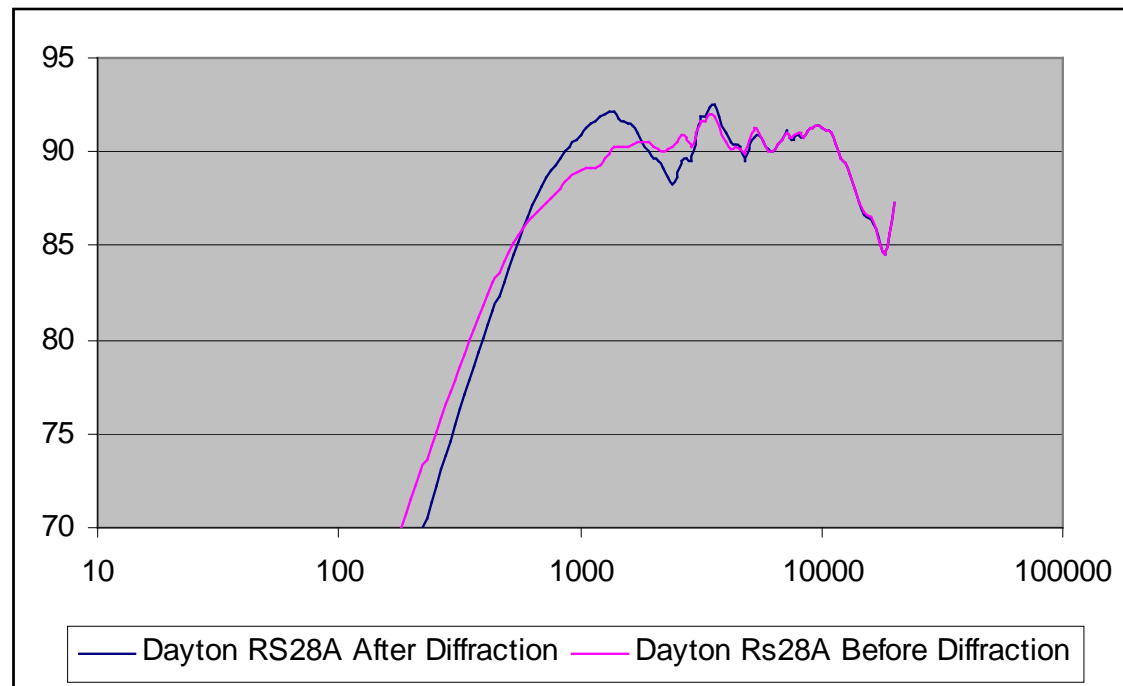
- Repeat for the tweeter
  - Tweeters are complicated by the fact that manufacturers almost always measure on an IEC baffle:
    - First calculate the diffraction of the IEC baffle and subtract it from the manufacturers curve, to arrive at the infinite baffle response
  - The IEC baffle is modeled in the diffraction program using the following dimensions
  - Calculate the box diffraction (for the tweeter location) and splice to the infinite baffle data, then calculate phase
  - Choose the same frequencies as for the woofer in SPL View
  - Make sure to add the tweeter high frequency roll to the frd file (“tail the tweeter”) or the phase at crossover and the crossover summation will be incorrect:



[http://www.speakerdesign.net/phase\\_error/phase.html](http://www.speakerdesign.net/phase_error/phase.html)

# Example: Dayton RS28

- Created Using the Technique Shown
  - Dayton RS28A free field spliced with diffraction







# Measure Driver Impedances

- Impedance can be modeled from manufacturer's data, but my experience is that this isn't accurate
  - Non linear flux in woofers leads to hard to model high frequency inductance
- There are numerous resources for how to measure impedance on the web, from using soundcards to external voltmeters
  - Many use Speaker workshop for the task:
    - <http://www.speakerworkshop.com/>
    - <http://www.rjbaudio.com/Audiofiles/SWsetupProcedure.html> or <http://www.claudionegro.com./>
  - Or you can try old-school:
    - [http://www.fixya.com/support/t174447-measure\\_speaker\\_impedance](http://www.fixya.com/support/t174447-measure_speaker_impedance)
  - Save impedances as .zma files.
  - If desperate, use “canned” zmas from the following, but they won't have the box effect on woofer phase
    - <http://sites.google.com/site/brianpowers27speakers/diy-resources/speaker-measurements>

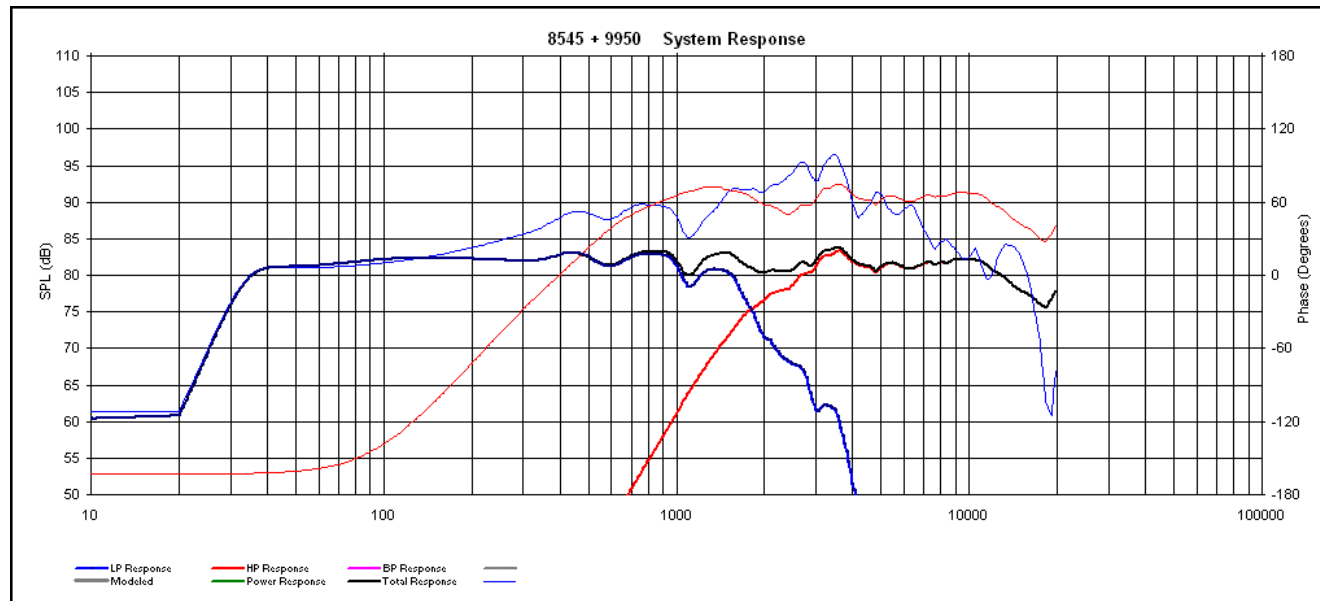
# Design The Crossover

- All Hail The “Passive Crossover Designer”
  - Use the PCD to design Xovers. It’s found at:  
<http://audio.claub.net/software/jbabgy/PCD.html>
  - The tool comes with a good user guide but its really quite simple: “Load Woofer FRD”, “Load Tweeter FRD”, “Load Midrange FRD” (if applicable), “Load Woofer ZMA”, “Load Tweeter ZMA”, enter the listening location and the driver mounting locations. Woofer z offset (i.e. acoustic center offset) doesn’t need to be entered, if it was entered earlier in Response Modeler.
  - Start spinning the arrows under the crossover section!
    - A target response can be added to guide the tweaking
    - On the graphs there are hot buttons to display phase, etc. Click them on or off the add detail or remove clutter as you design
  - One Note: PCD doesn’t include inductor resistance in parallel traps. Compensate by subtracting inductor resistance from resistor branch value



# PCD Screen Shot

- 10 minutes with PCD produced the following Usher 8945A + Dayton RS28A. A few hours of tuning would clean this up nicely.



# Tips



- To avoid audible peaks off axis, consider setting the combined response 6 dB higher than the individual drivers where they cross over (where driver responses intersect)
- By changing the roll off rate of the drivers near crossover, you also change how they sum together. Very often the tweeter roll off is made slightly faster than the woofers, to result in summed response 6 dB above the individual drivers. The faster roll off rate adds time delay to the tweeter, to equal the woofer delay.
- The maximum summation at crossover is achieved when, with one driver out of phase, the deepest notch is shown in the combined response (“reverse notch”)
- Don’t get hung up on too deep a reverse notch. Excellent results can also be obtained with the combined response only 3 or 4 dB above crossover, if the combined response is also 2 to 3 dB less than flat at crossover
- Tweeters radiate much more energy off axis than woofers, at crossover. Consider designing a slight 2 or 3 dB depression at crossover if they sum 6 dB, to result in a “neutral” sounding speaker in a live room. If they sum 3 dB at crossover, consider a 5 dB depression
- You may find that a response that is perfectly flat also sounds bright (I do). Consider setting the tweeter level 2 to 5 dB below the woofers. Detail will be less, but average and poor recordings will sound smoother and more natural
- Some people like the sparkle from a response that rises 3 dB above 7 kHz.
- Vocals are more intelligible with a small peak at 3 to 5 kHz, but it adds sibilance