

Electrical, Mechanical and Acoustic Filters in the Design of a Loudspeaker with Dipole Woofers

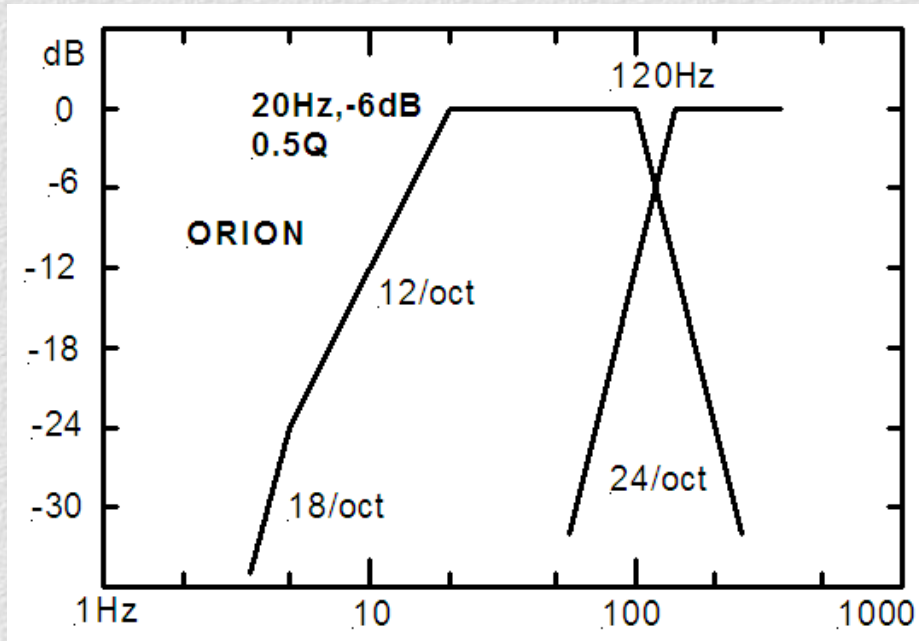
Siegfried Linkwitz



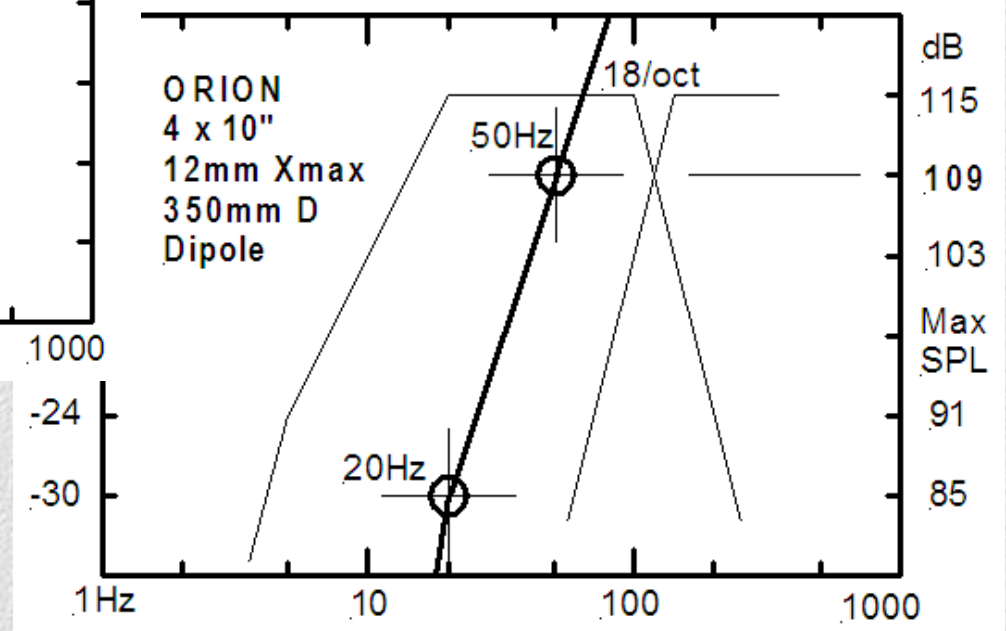
Why dipole woofers?

- ❖ **Accurate bass reproduction to very low frequencies without overhang from stored/resonant energy**
 - ❖ **Dipoles excite fewer room modes & interact less with the room**
 - ❖ **Simple open baffle construction**
- ❖ **Relatively low amplifier power requirements**
 - ❖ **Realistic reproduction of acoustic bass**

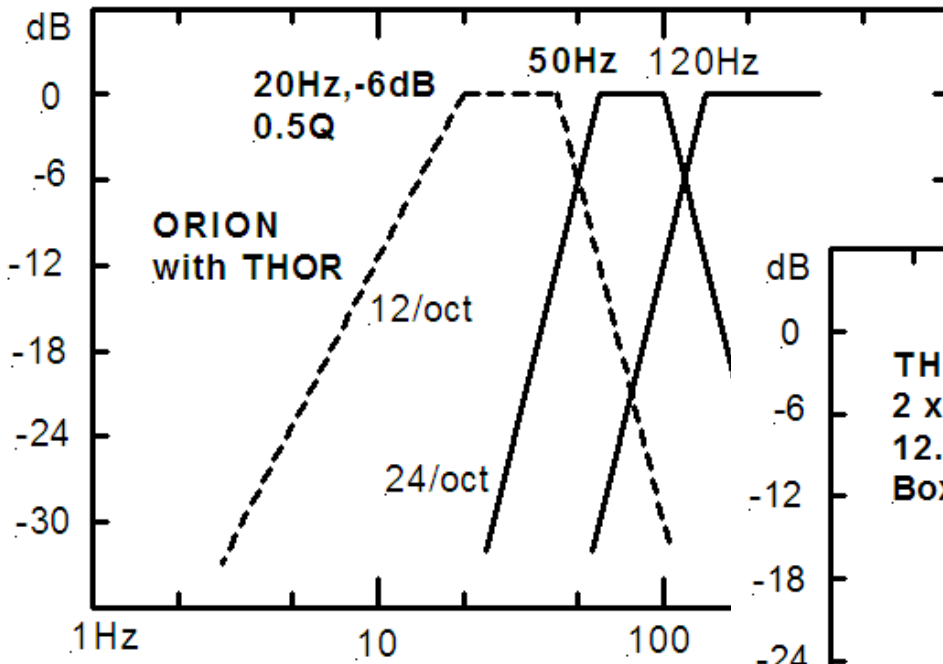
Targeted Low Frequency Response of the Dipole Loudspeaker



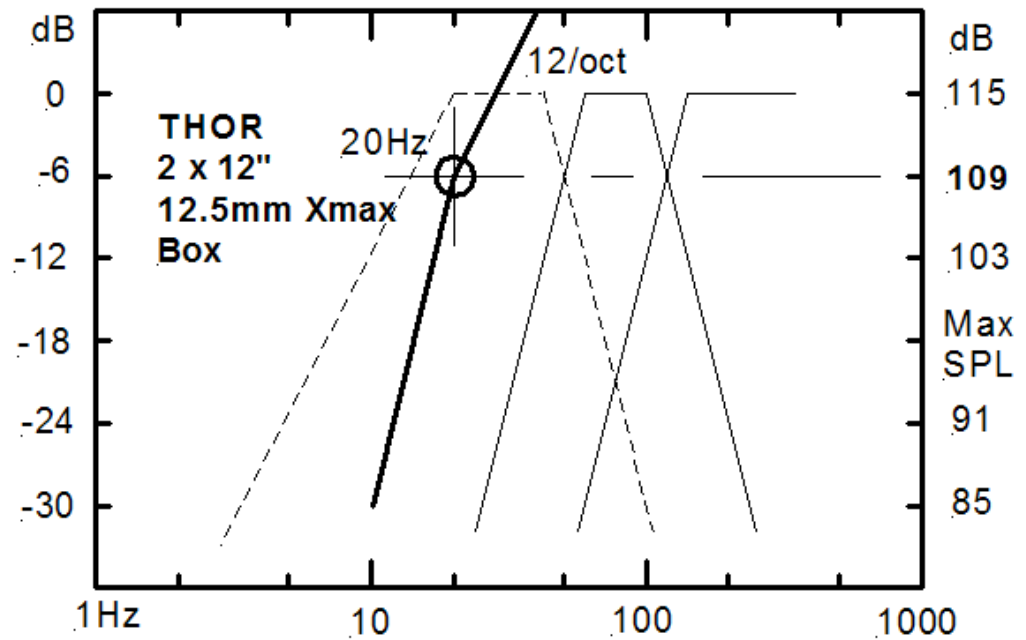
Max SPL Estimate



Crossover to Sealed Box Woofer for 109 dB SPL below 50 Hz

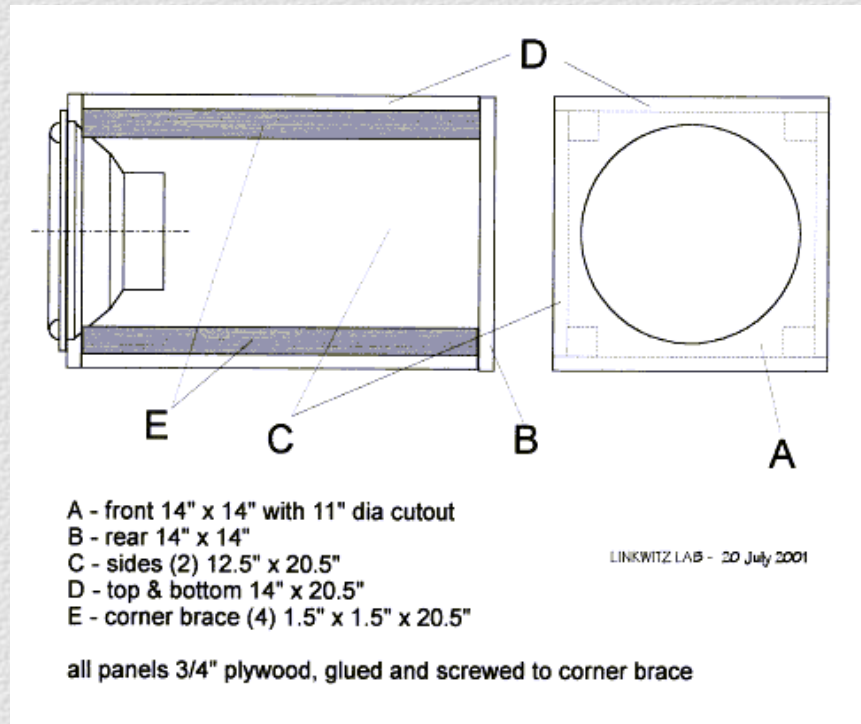


Max SPL Estimate



Sealed Box Woofer Construction

$V_B = 47$ Liter



Driver parameters

$F_s = 18$ Hz

$S_d = 466$ cm²

$X_{max} = 12.5$ mm

$Bl = 17.6$ Tm = 17.6 N/A

$M_{ms} = 163$ g

$V_{as} = 139$ Liter

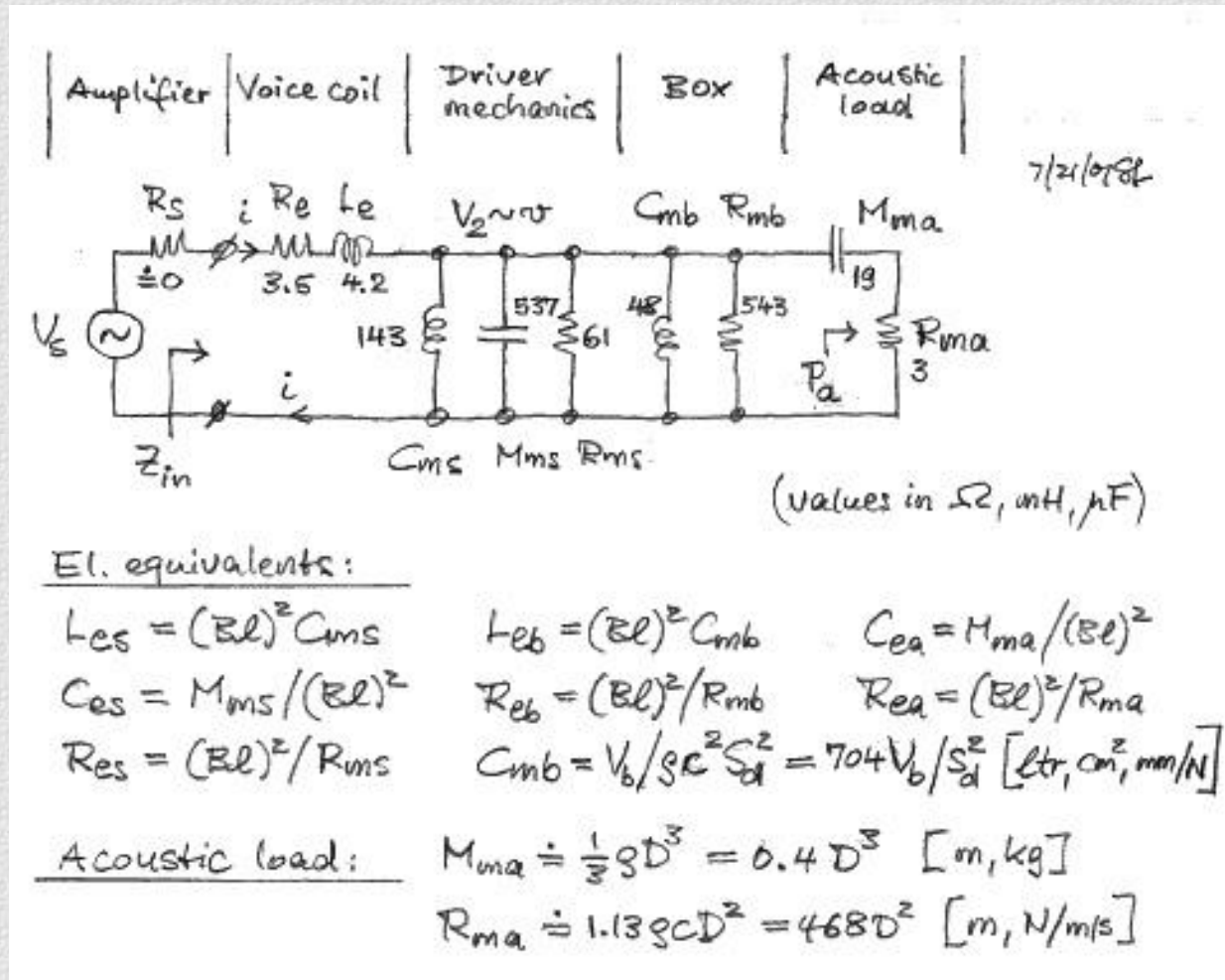
$Q_{ts} = 0.2$

Estimates

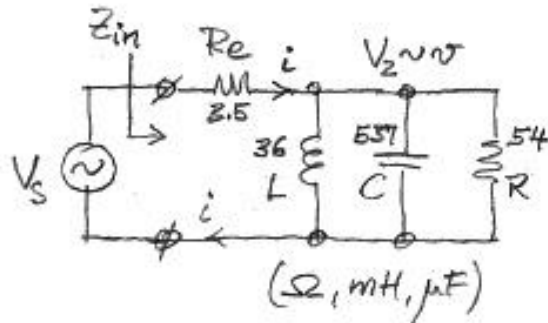
$$F_B = F_s \cdot \sqrt{1 + V_{as}/V_B} = 36 \text{ Hz}$$

$$Q_t = Q_{ts} \cdot (F_s/F_B) \cdot (1 + V_{as}/V_B) = 0.4$$

Electrical model of a driver in a sealed box (Thiele-Small parameters)



Low frequency model



$$L = \frac{142.5 \times 47.5}{142.5 + 47.5} = 35.6$$

$$R = \frac{60.5 \times 543}{60.5 + 543} = 54.4$$

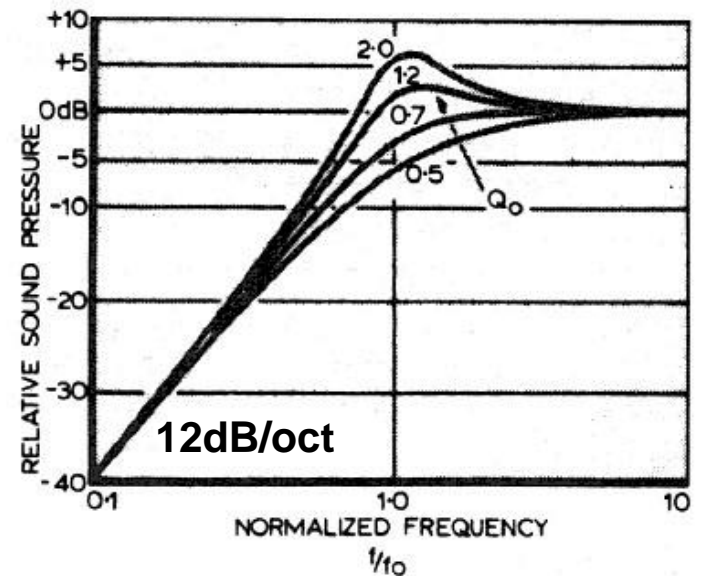
$$Q_m = \frac{R}{\omega_0 L} \quad Q_e = \frac{R_e}{\omega_0 L} \quad Q_t = \frac{1}{\omega_0 L} \frac{R R_e}{R + R_e} \quad \omega_0 = \frac{1}{\sqrt{LC}} = 2\pi f_0$$

$$|Z_{in}| = R_e \sqrt{\frac{(1 + \frac{Q_m}{Q_e})^2 + Q_m^2 (\frac{f}{f_0} - \frac{f_0}{f})^2}{1 + Q_m^2 (\frac{f}{f_0} - \frac{f_0}{f})^2}} \quad \text{input impedance (}$$

$$\left| \frac{v}{V_s} \right| = \frac{1}{Bl} \frac{1}{\sqrt{(1 + \frac{Q_e}{Q_m})^2 + Q_e^2 (\frac{f}{f_0} - \frac{f_0}{f})^2}} \quad \text{cone velocity}$$

$$x = \frac{v}{\omega} \quad \text{cone deflection (3)} \quad 7/21/01 \text{ St}$$

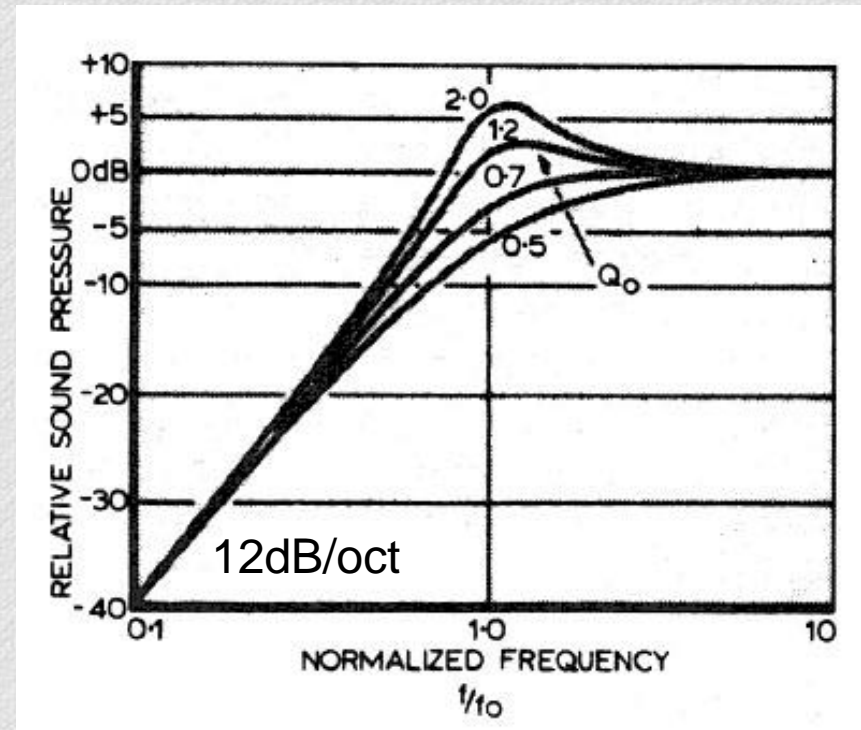
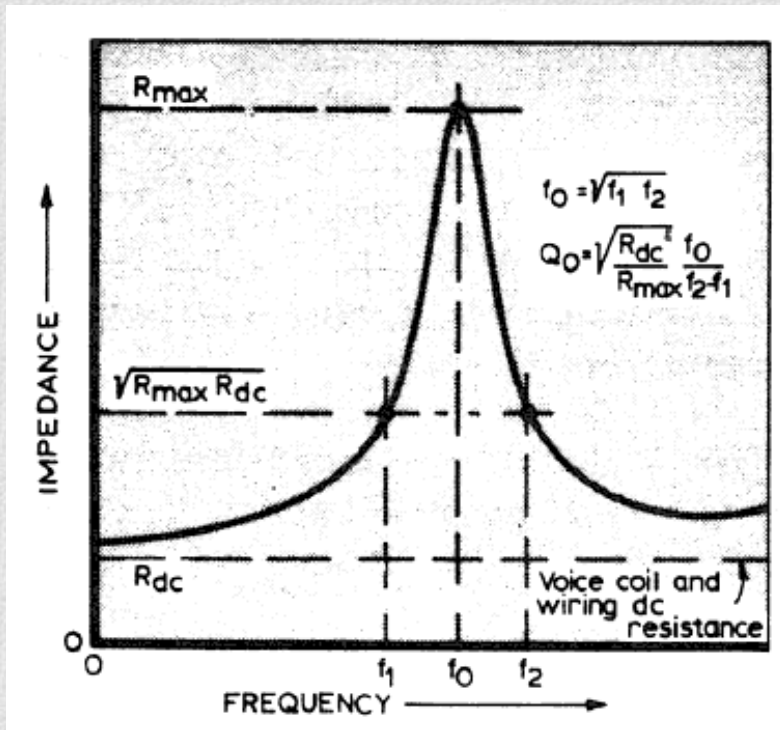
Sealed box
frequency response
= 2nd order
highpass filter
with f_0 and Q_0



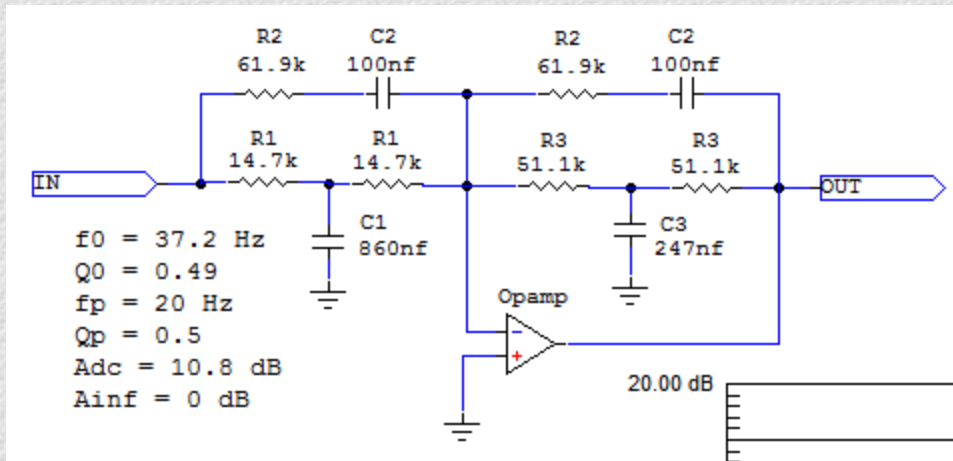
Determine f_0 and Q_0 from a measurement of Z_{in}

$$f_0 = F_B = \text{sqrt}(f_1 * f_2) = 37.2 \text{ Hz}$$

$$Q_0 = Q_t = (f_0 / (f_2 - f_1)) * \text{sqrt}(R_{dc} / R_{max}) = 0.49$$

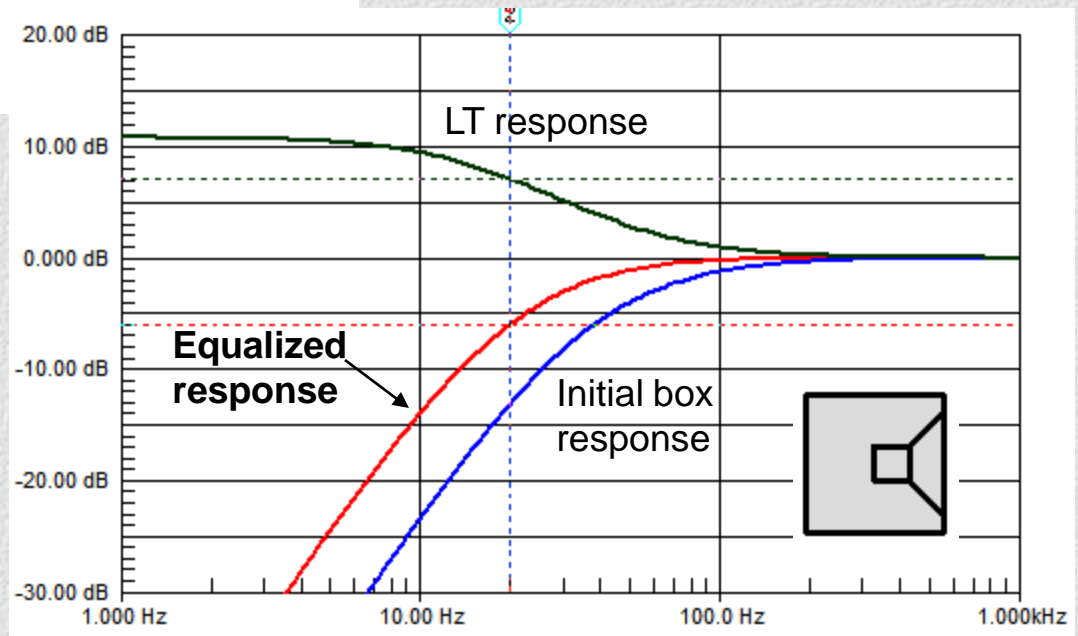


Low frequency extension with a biquad circuit (Linkwitz Transform)

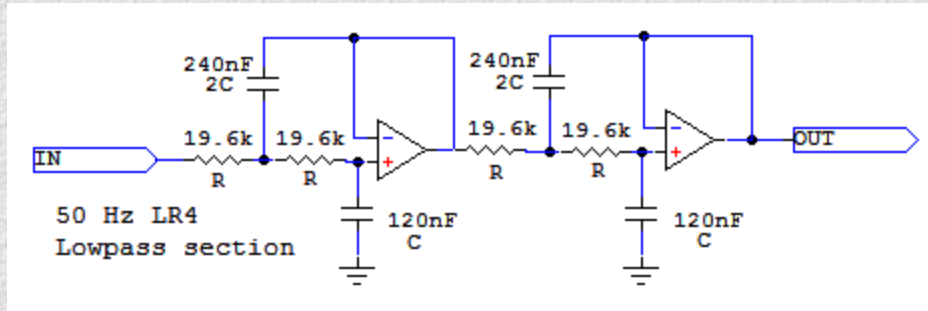


Equalized = Target

Ref:
www.linkwitzlab.com/filters.htm#9

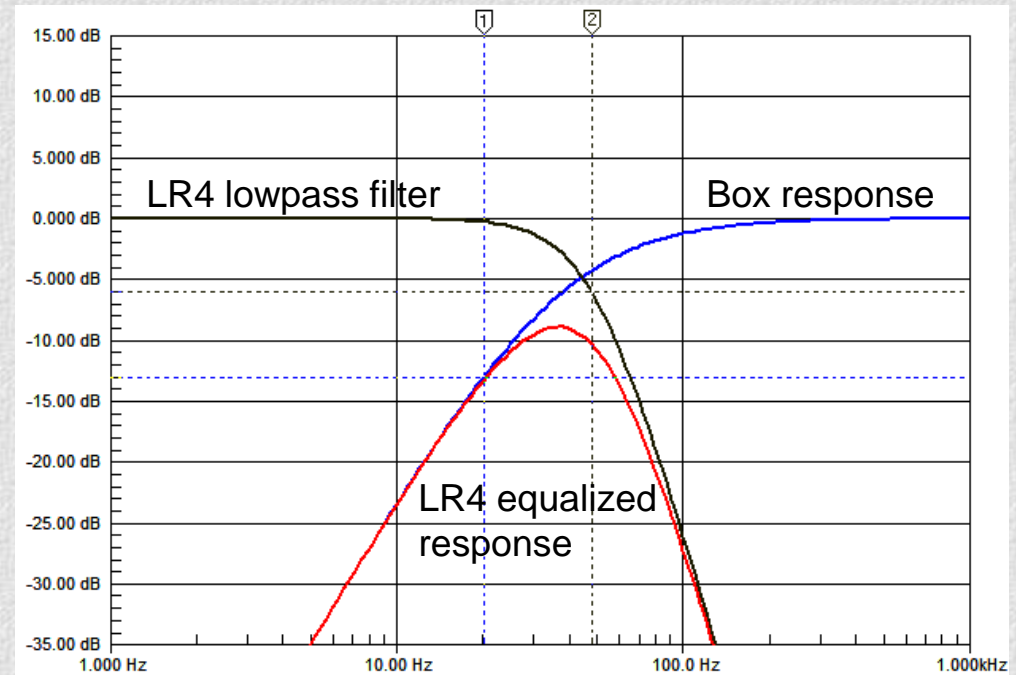


LR4 lowpass filter at 50 Hz

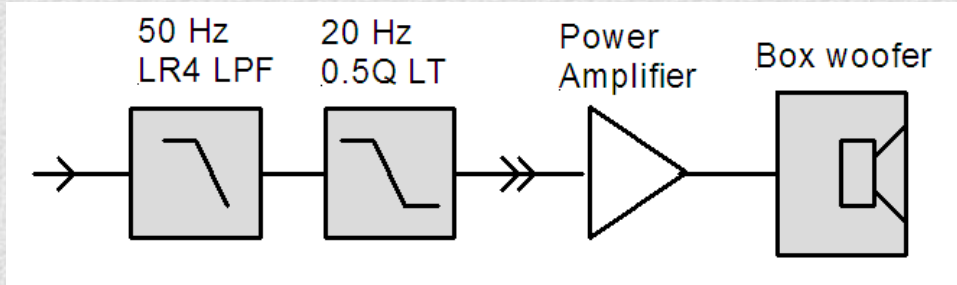


Ref:
www.linkwitzlab.com/filters.htm#3

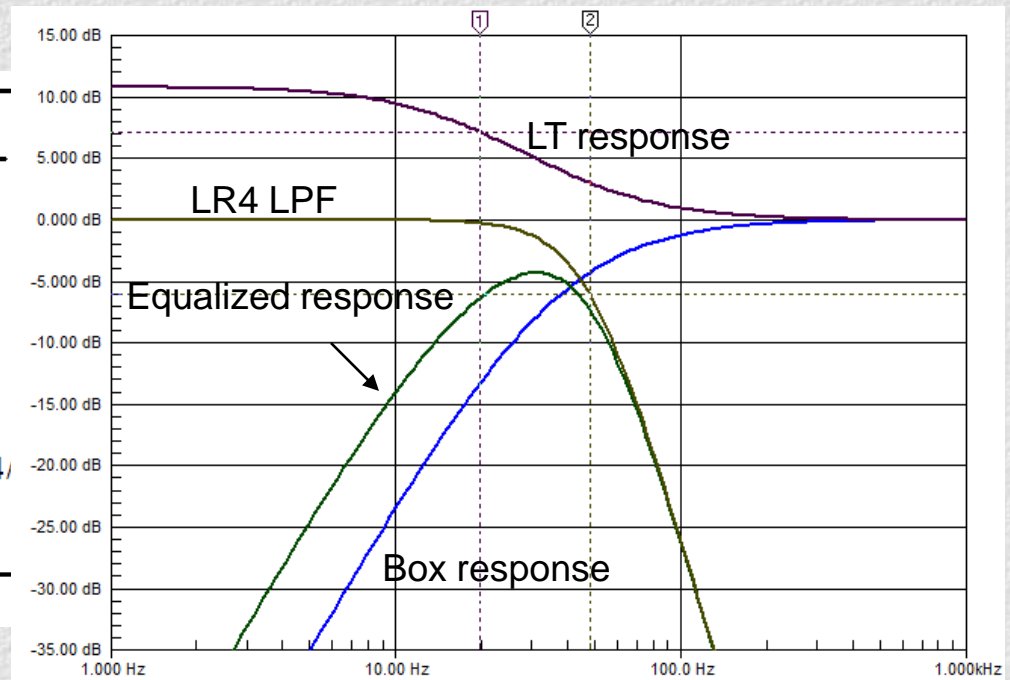
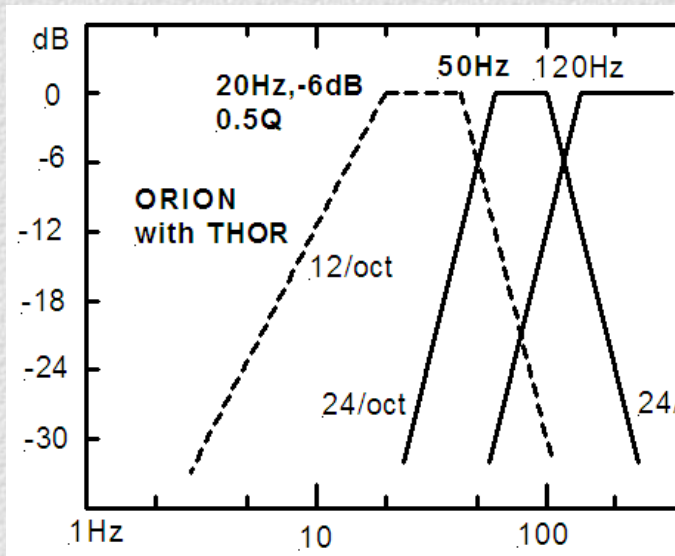
$$F_p = 1 / (8.89 RC) = 48 \text{ Hz}$$



Equalized sealed box woofer



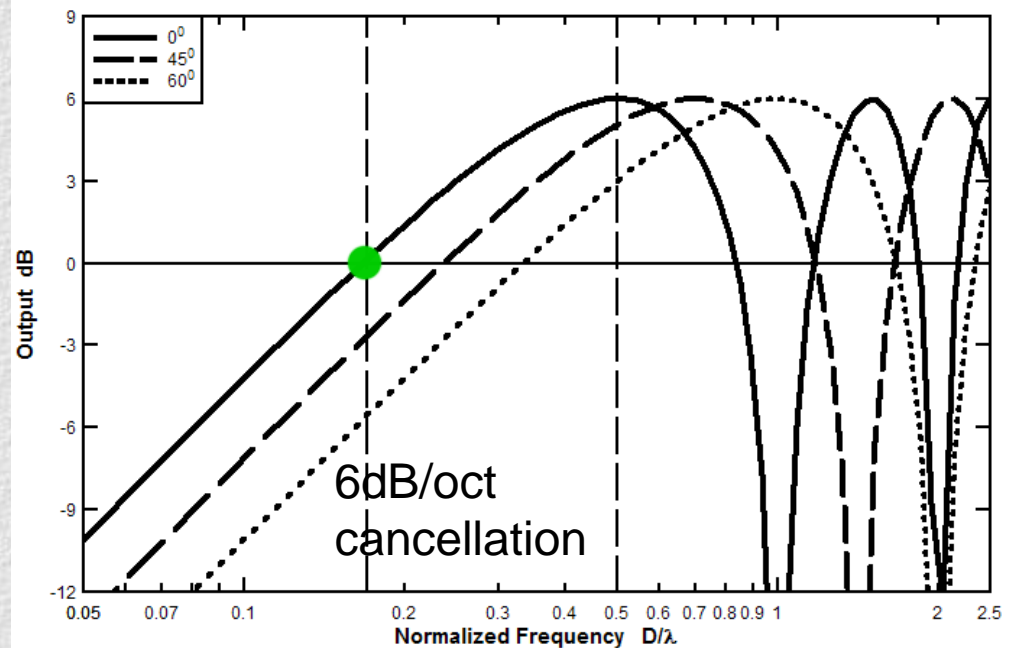
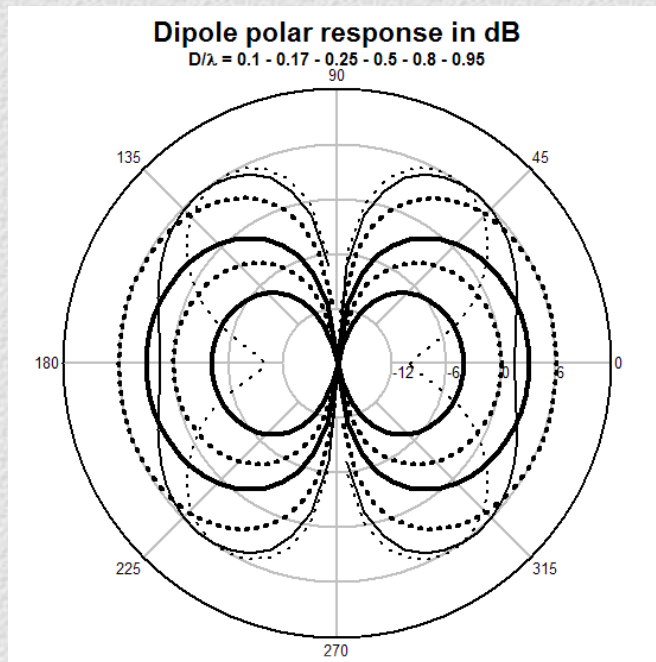
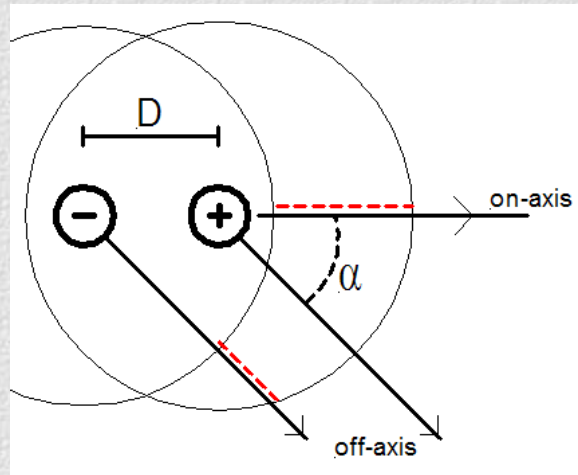
Equalized response = Target



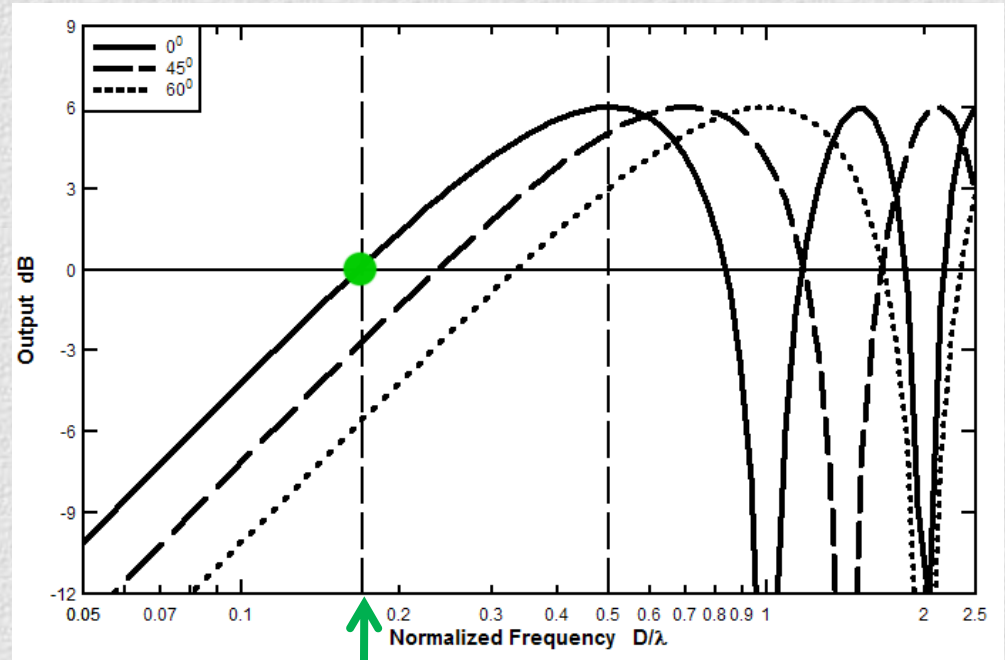
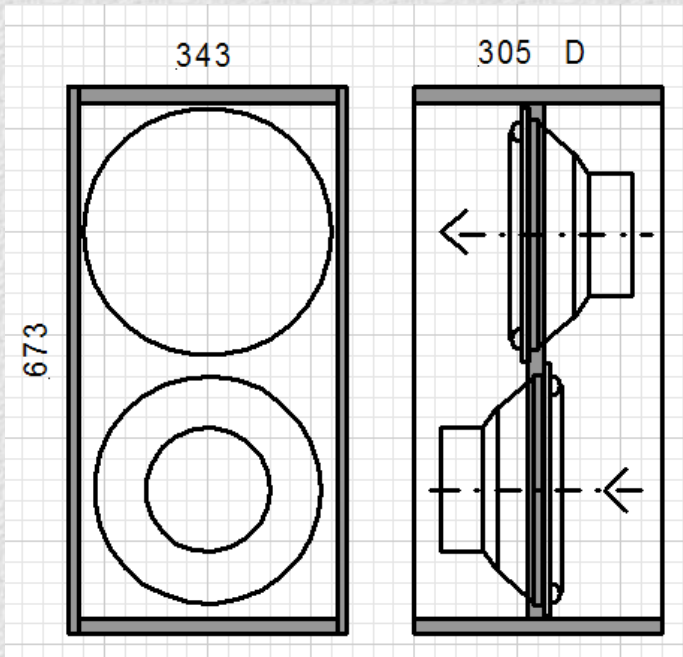
Theoretical Dipole Source

$$|H(\omega)| = 2 \sin[\pi D/\lambda \cos(\alpha)]$$

$$|H(\omega)| \doteq 2\pi D/\lambda \cos(\alpha) \text{ for } \lambda \gg \pi D$$

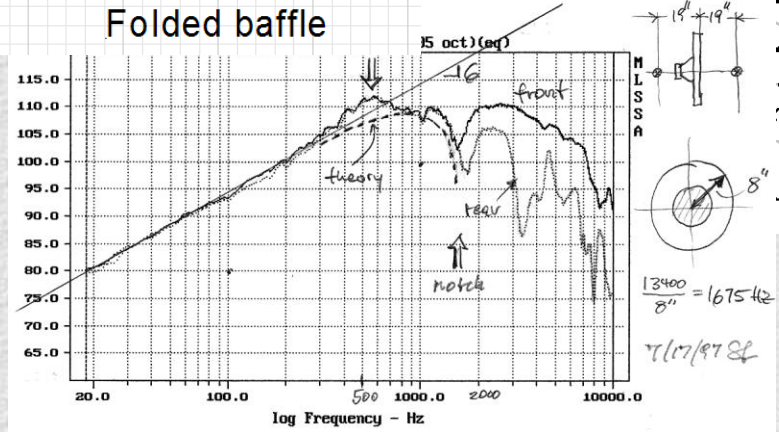
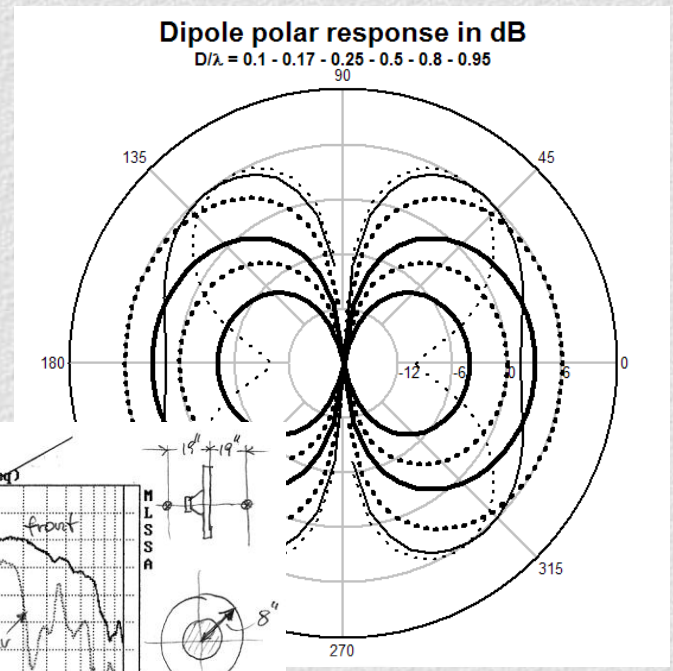
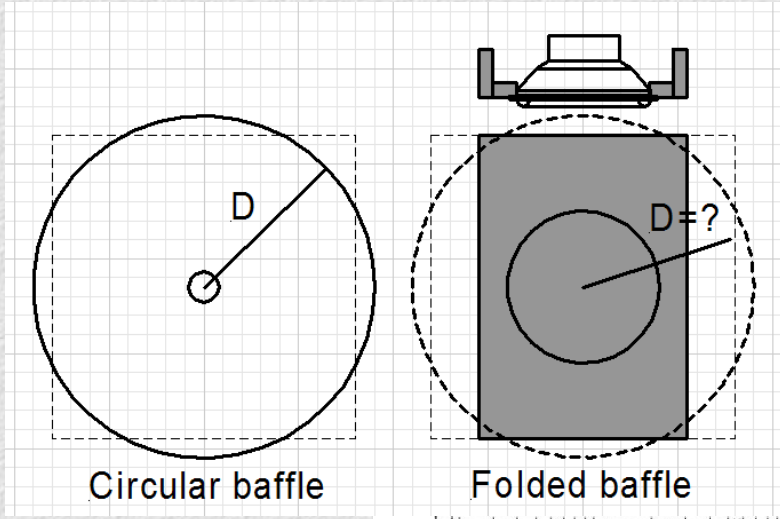


Practical dipole source -- Bass frequency range --

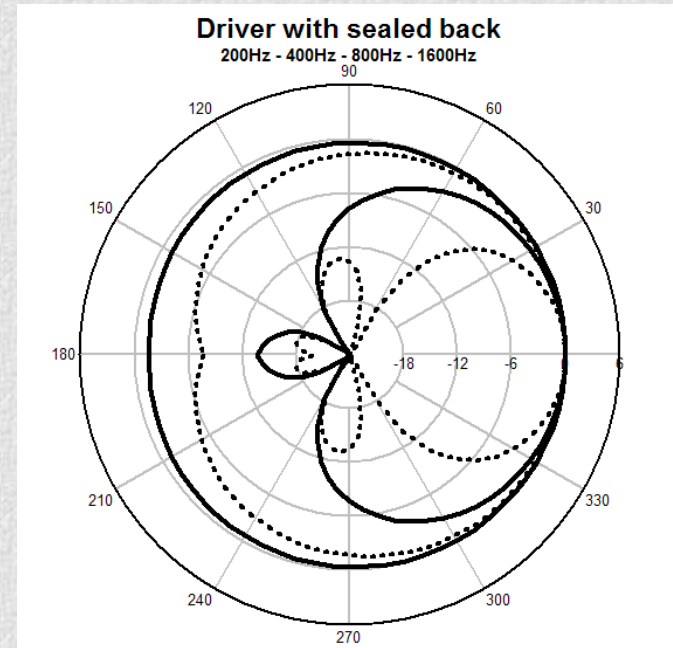
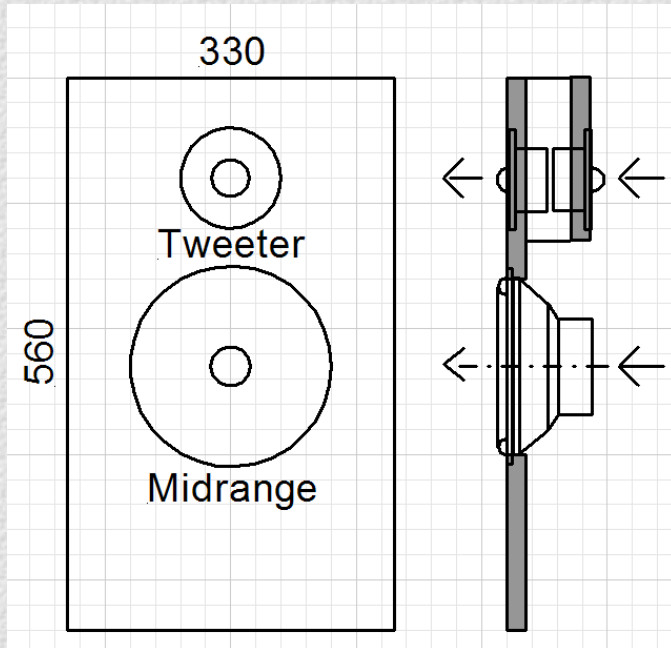


Fequal @ $D = \lambda/6$

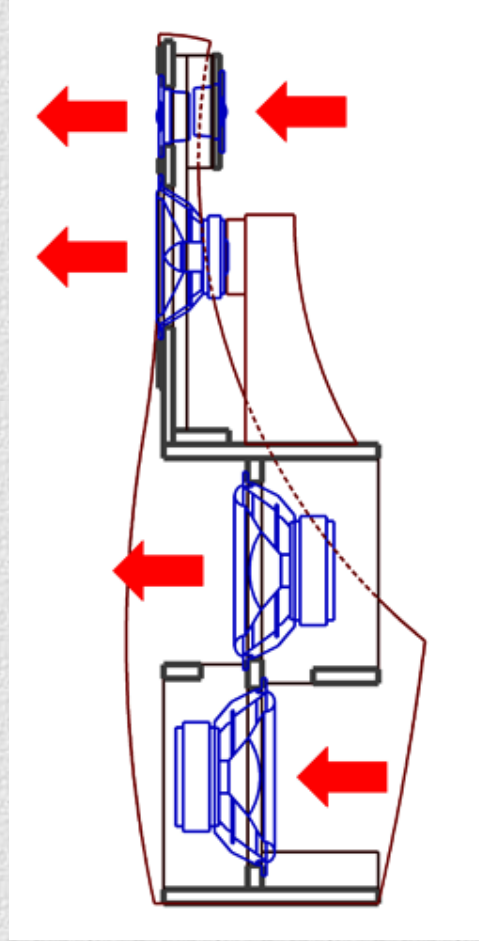
Practical dipole source -- Mid frequency range --



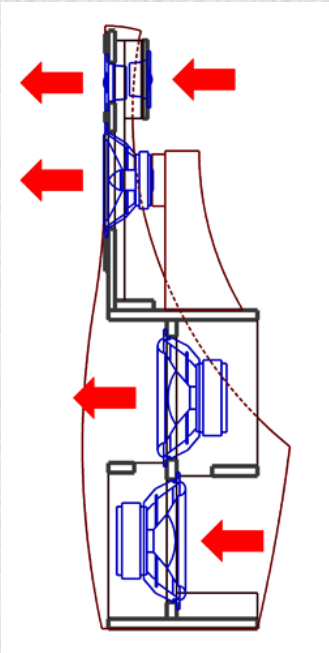
Practical dipole source -- Tweeter frequency range --



ORION+ Open-Baffle Loudspeaker



H-frame woofer



$F_B \leq F_s$ due to air mass loading

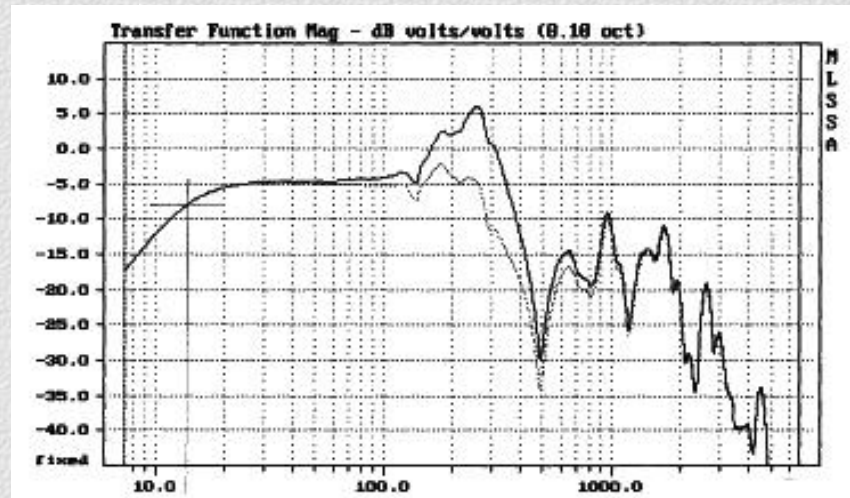
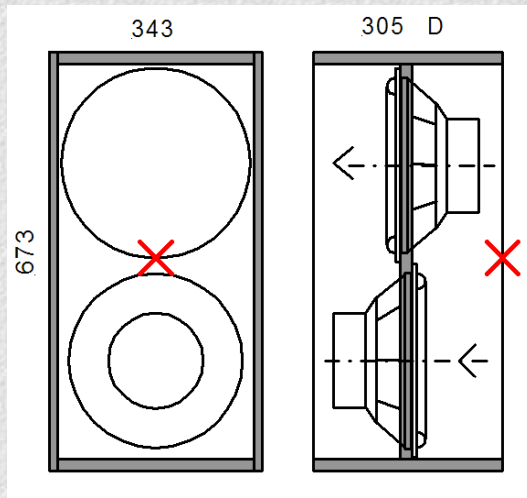
$\lambda/4$ transmission line resonance limits top end

Driver bottoming limits low frequency output

Even order distortion reduction

No vibration cancellation

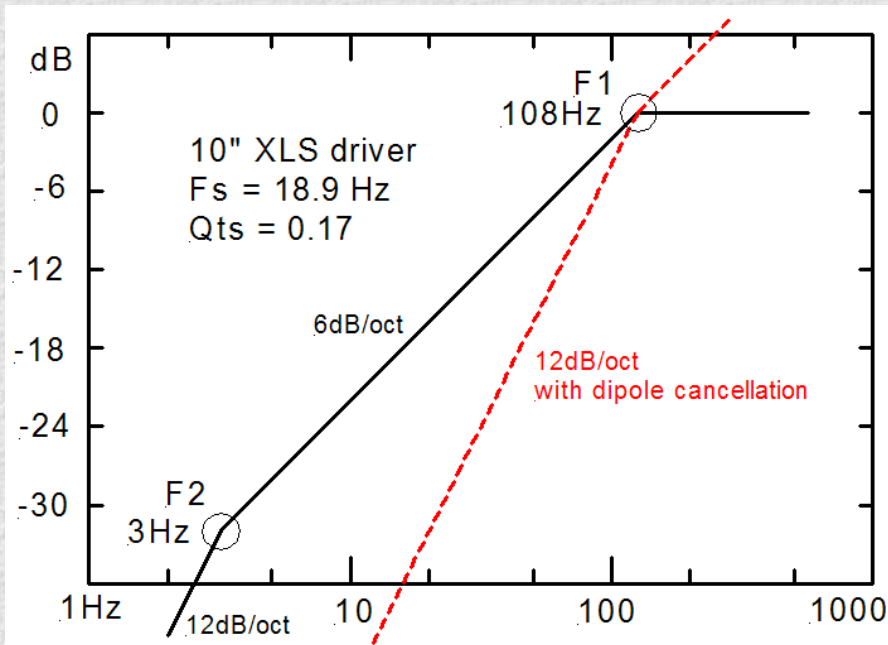
Measure in center of opening plane for a flat response without 6 dB/oct equalization applied



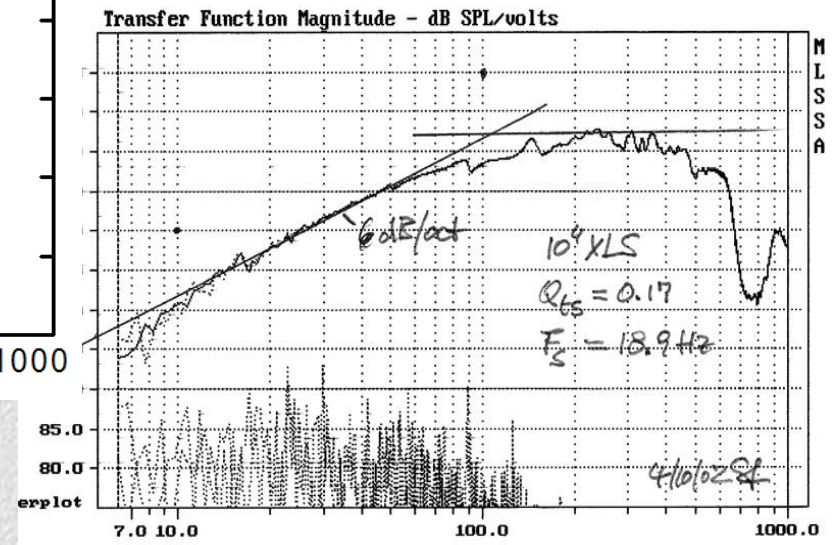
Low Q driver in open baffle

2nd order Highpass Poles:

$$F1, F2 = F_s/2Qts [1 \pm \sqrt{1-4Qts^2}] = 108\text{Hz}, 3.3\text{Hz}$$



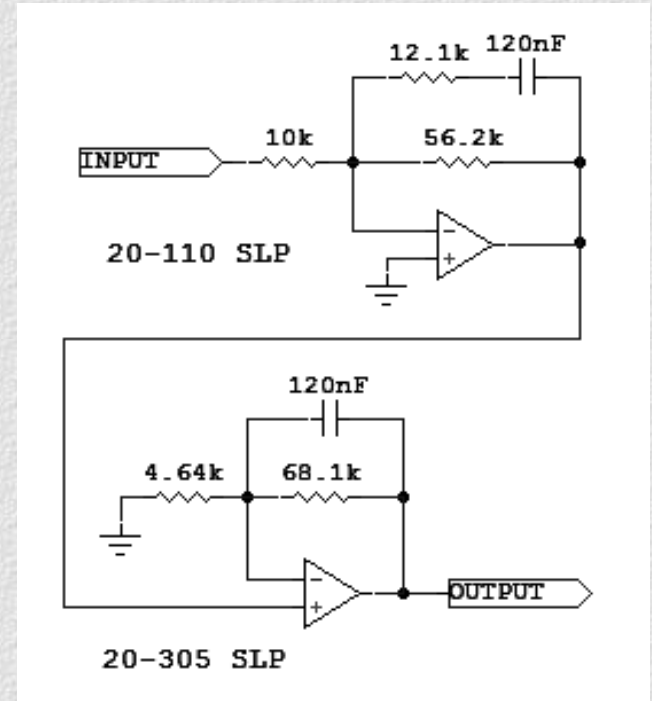
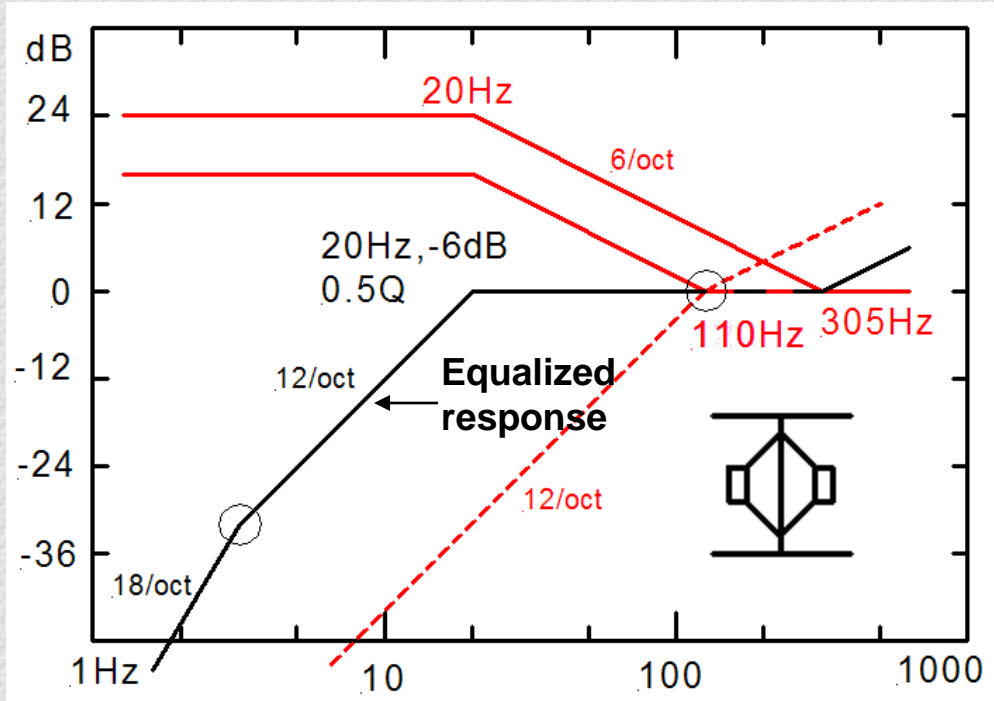
Measured at H-frame opening



Ref:

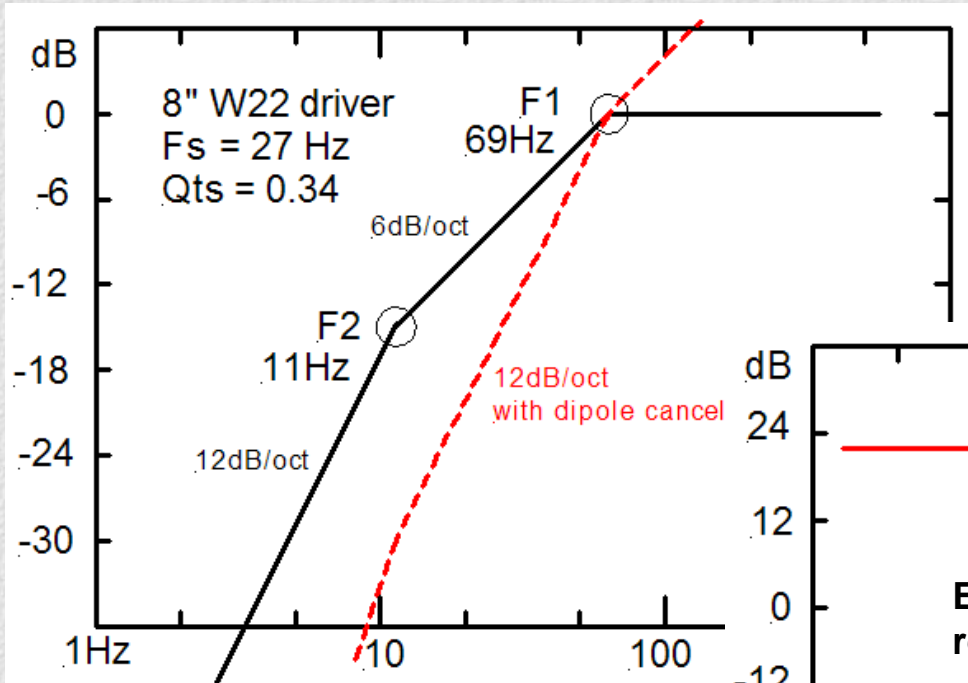
<http://www.linkwitzlab.com/images/graphics/12db-hpf.gif>

ORION woofer response equalization



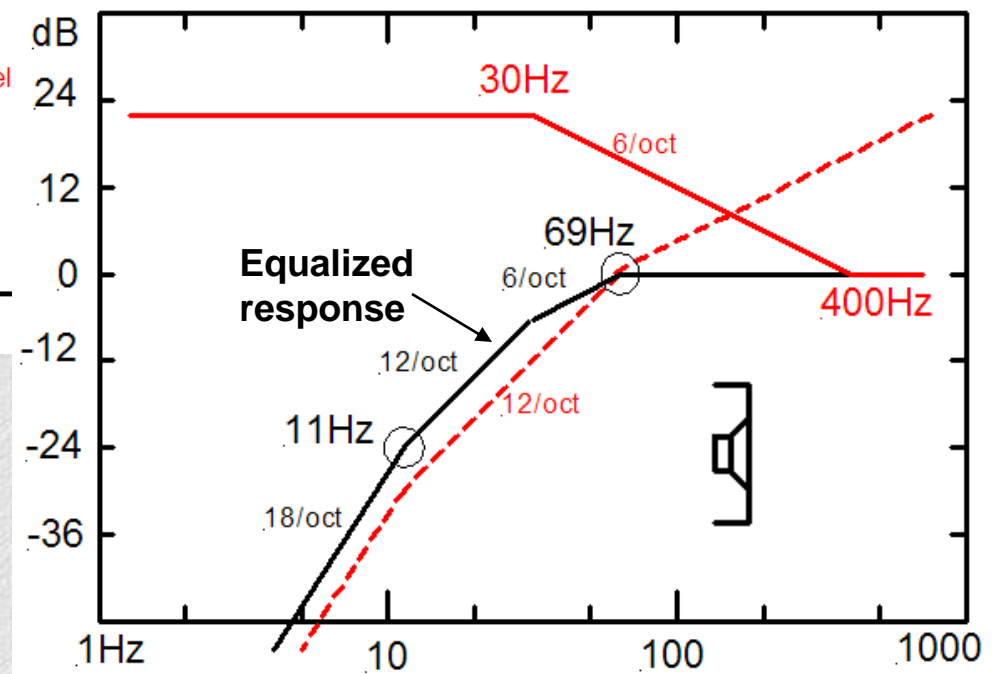
Ref: www.linkwitzlab.com/filters.htm#5

Midrange: Low frequency equalization

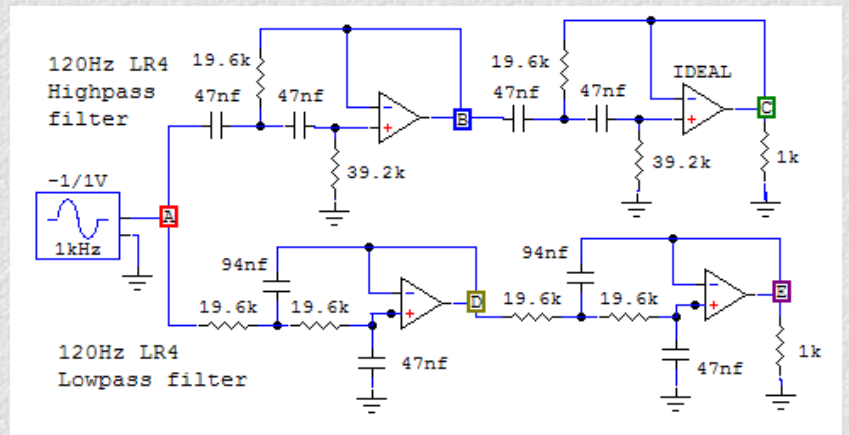
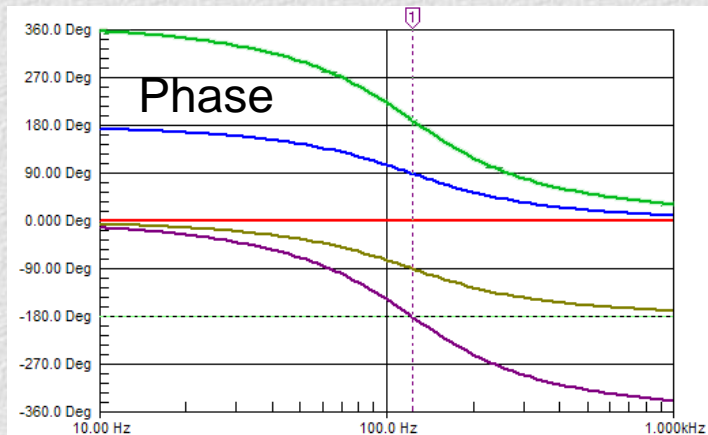
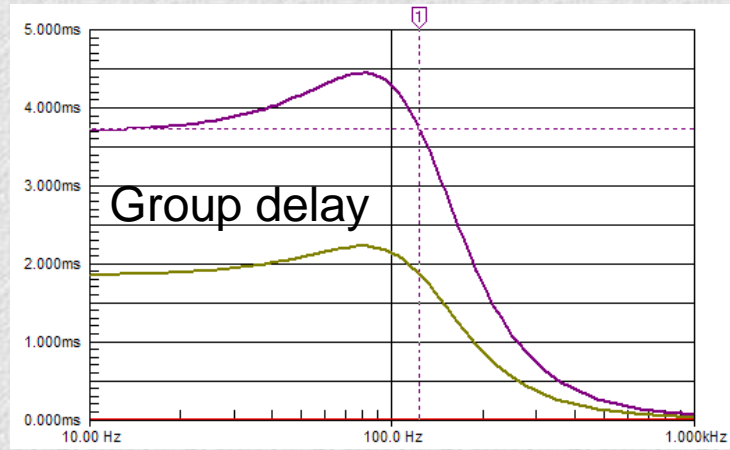
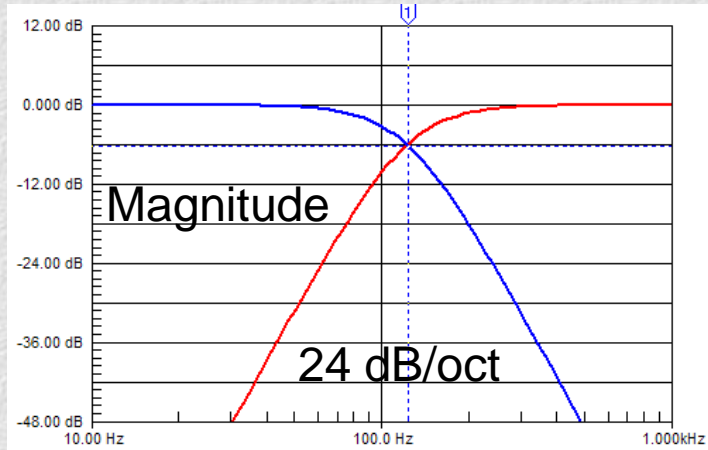


8" driver in open baffle

Equalized with 30-400 SLP



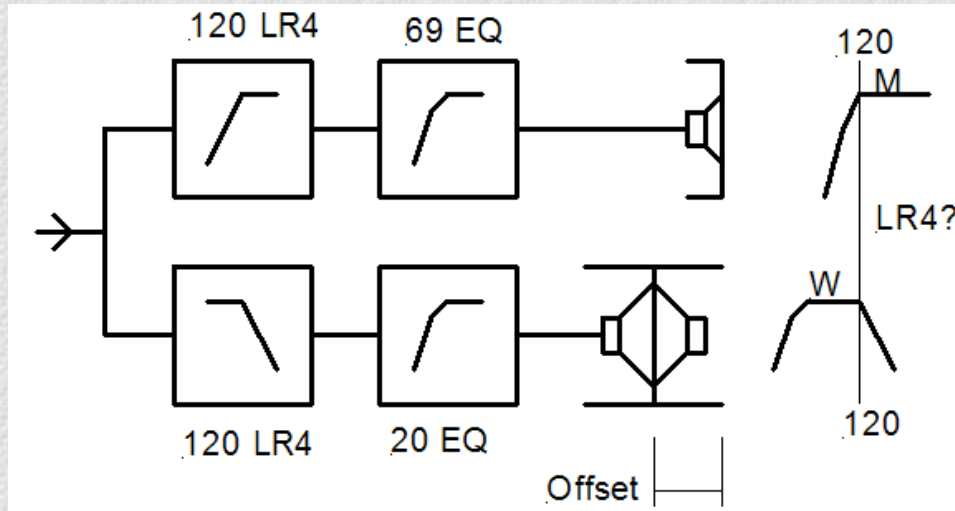
LR4 crossover filter function



Electrical filter realization

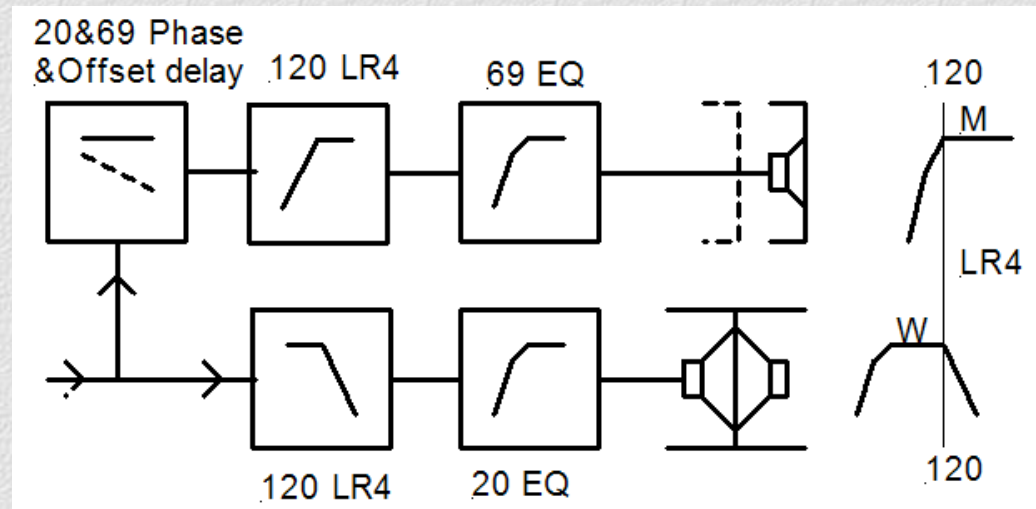
Ref: www.linkwitzlab.com/filters.htm#3

Woofer to midrange crossover

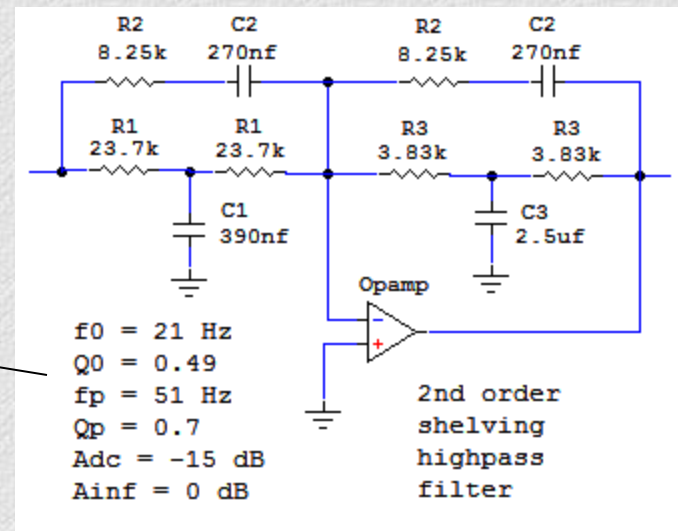
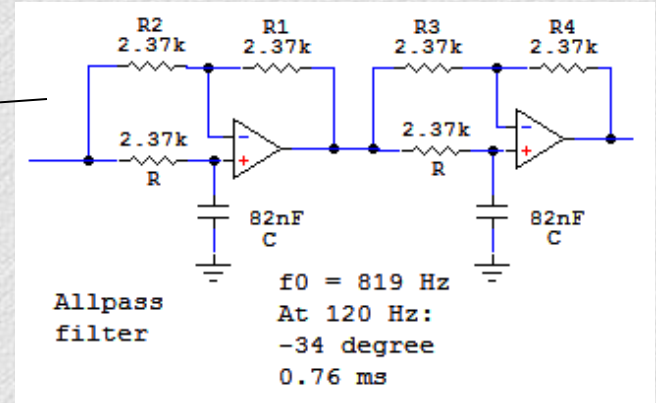
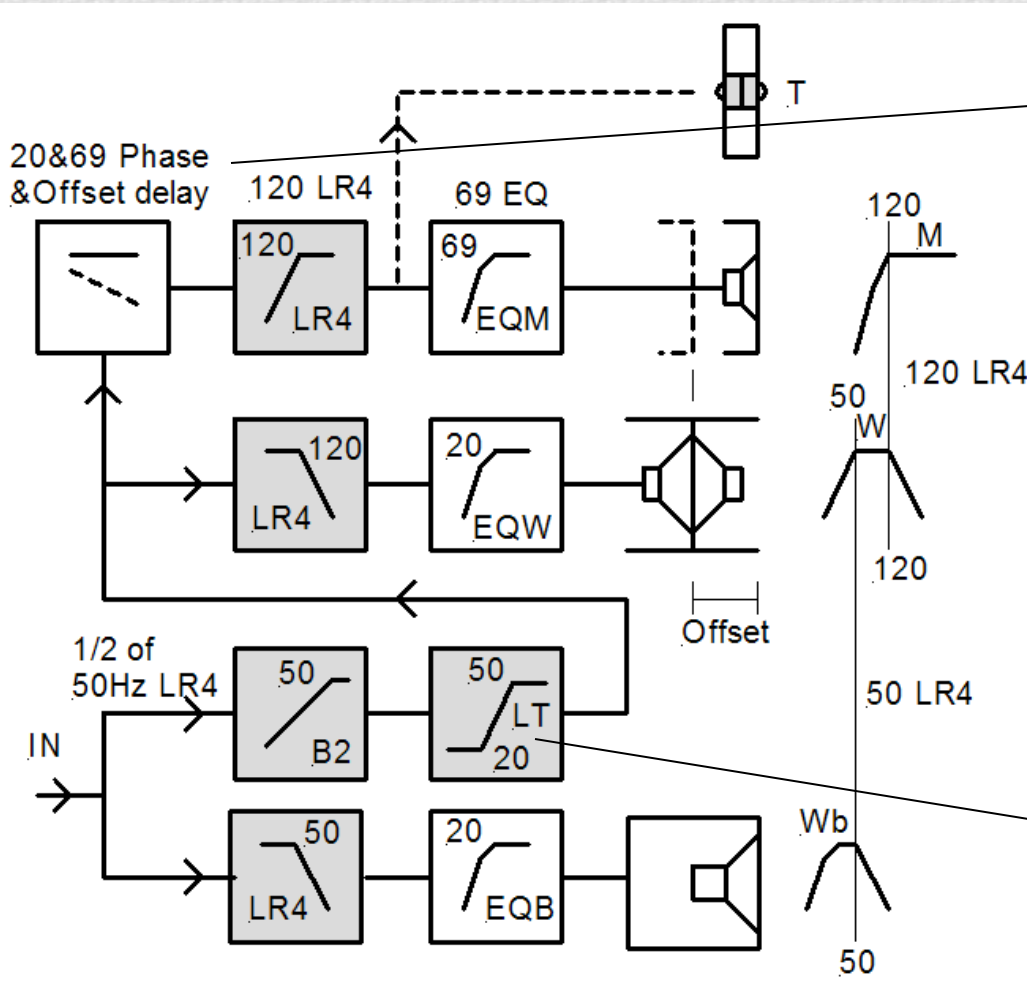


Outputs W & M will not add to a flat response

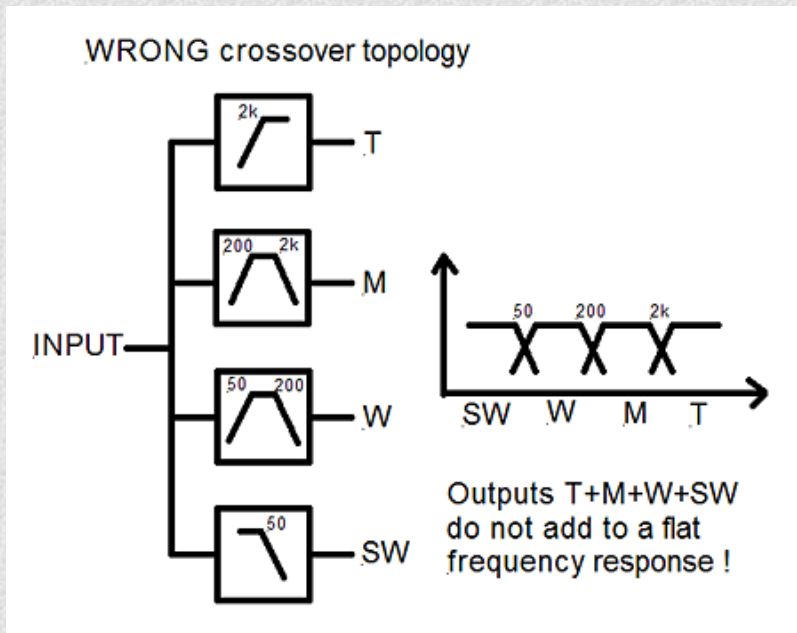
Phase correction
in Mid channel for
Woofer & Mid highpass
& Woofer acoustic offset
with el. allpass filters



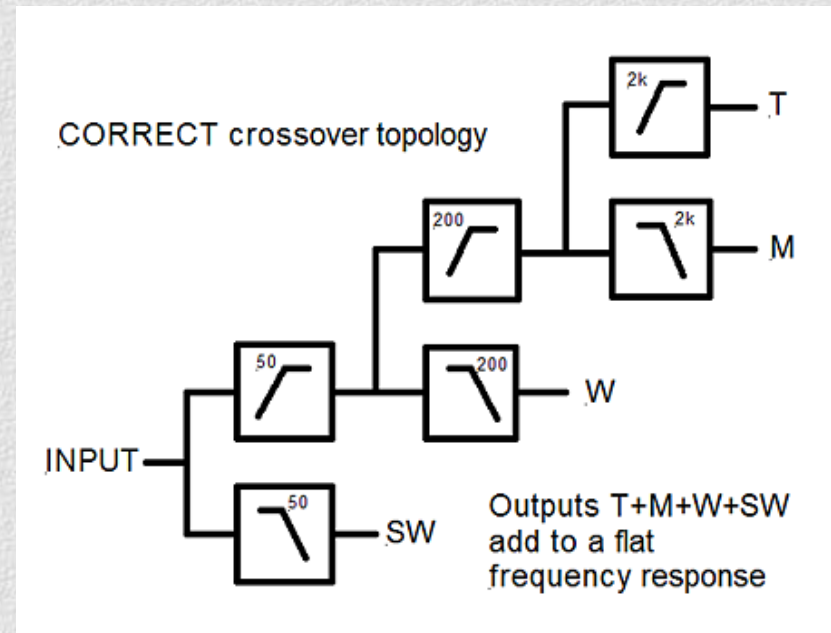
Addition of a box woofer



General arrangement of crossover filters



Popular, but filters interact !



Ref: www.linkwitzlab.com/frontiers_5.htm#V

Summary

- ❖ **Open baffle woofers require line level electronic equalization to compensate for acoustic cancellation**
- ❖ **Each electronic filter stage can be optimized for its clearly identified function**
- ❖ **Differences in driver sensitivity are compensated with electrical gain/attenuation**
 - ❖ **Power amplification is distributed efficiently to each driver**
 - ❖ **Various electrical corrections may be required to obtain the desired acoustic filter functions when the crossover frequencies are less than a decade apart**
 - ❖ **Low Qts drivers are simply equalized with shelving lowpass filters for low frequency extension**
 - ❖ **High level reproduction below 50 Hz may require a sealed box woofer to keep a limit on the number of dipole drivers that would otherwise be required**
 - ❖ **Dipole loudspeakers can be uniformly directional over a very wide frequency range. They then interact with the room in a perceptually beneficial way.**

Thank you for your attention

Questions?

www.linkwitzlab.com
Publications