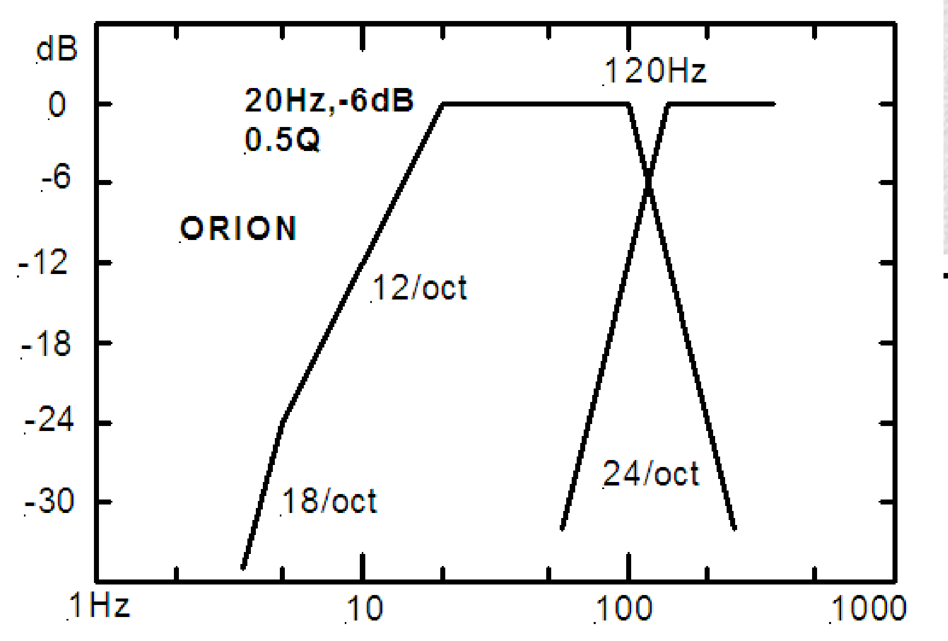
Electrical, Mechanical and Acoustic Filters in the Design of a Loudspeaker with Dipole Woofers

Siegfried Linkwitz

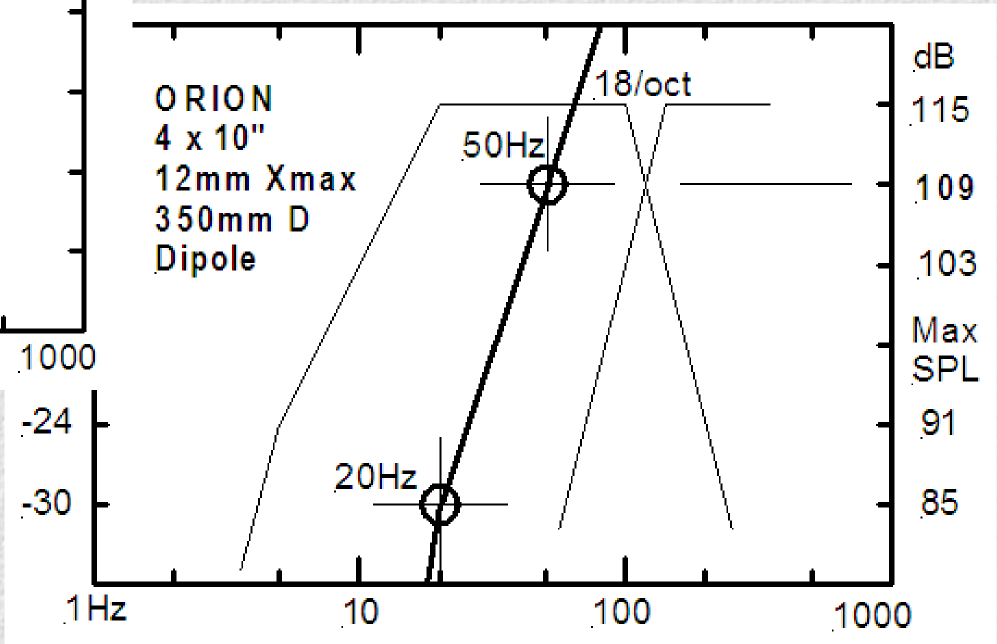
Why dipole woofers?

- ❖ 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

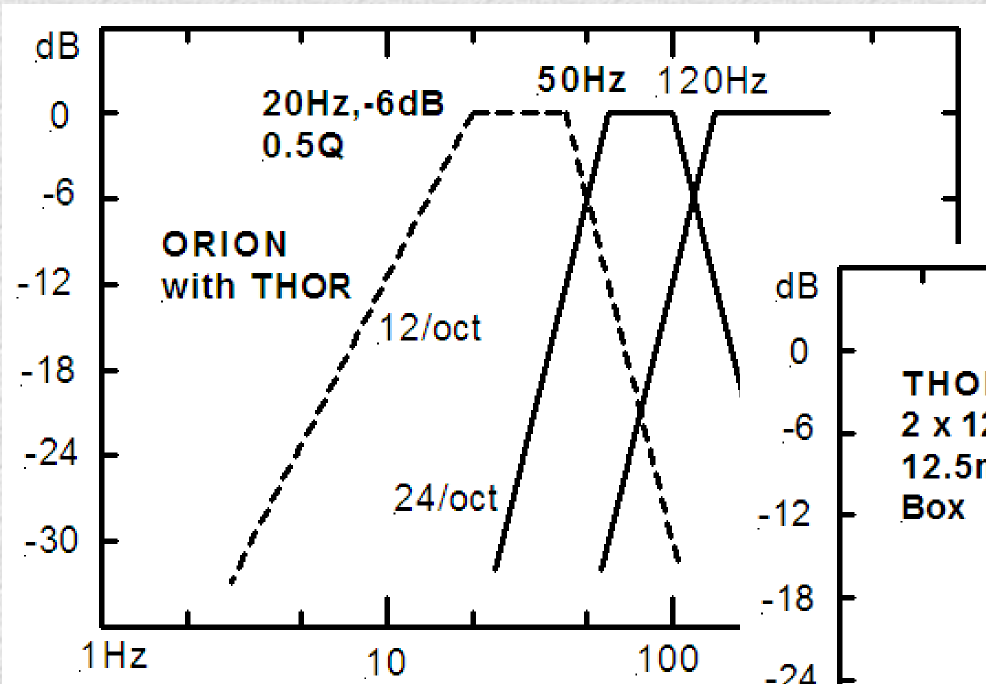


Max SPL Estimate

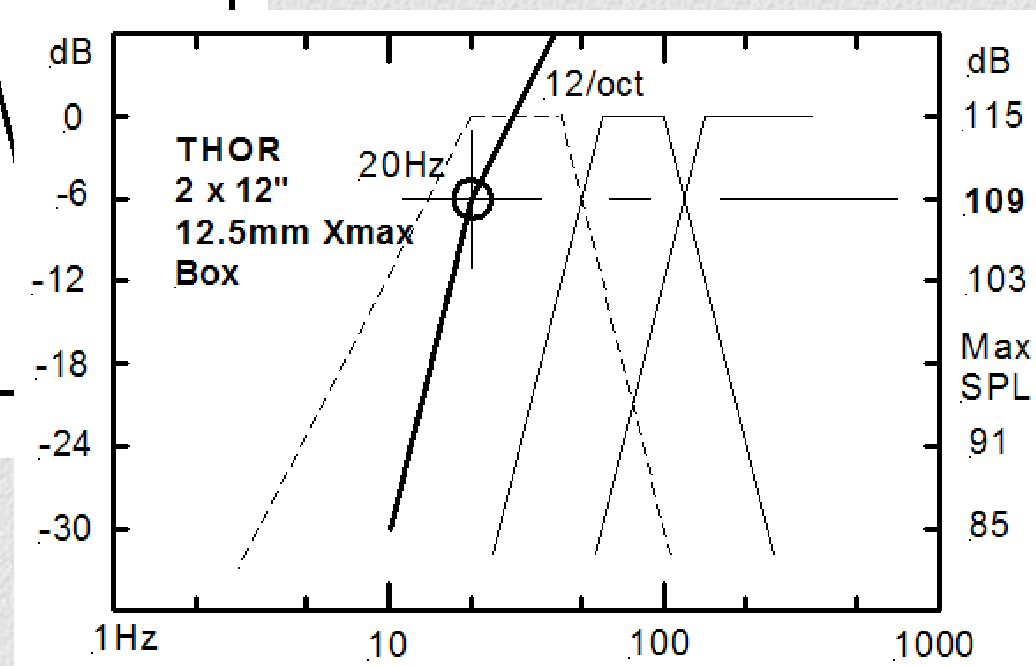


Ref: www.linkwitzlab.com/spl_max1.xls

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

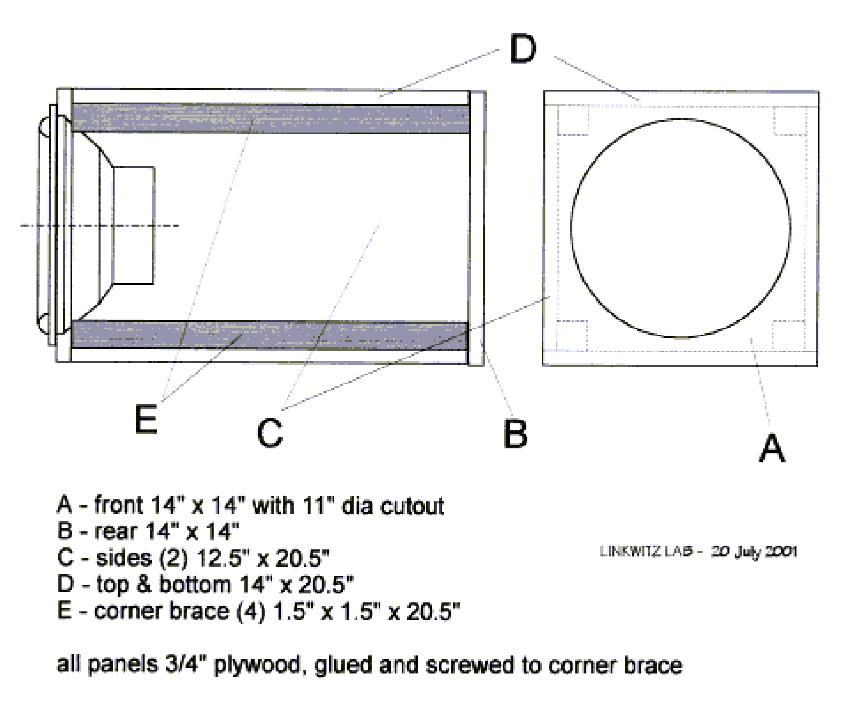


Max SPL Estimate



Ref: www.linkwitzlab.com/spl_max1.xls

Sealed Box Woofer Construction
V_B = 47 Liter



Driver parameters

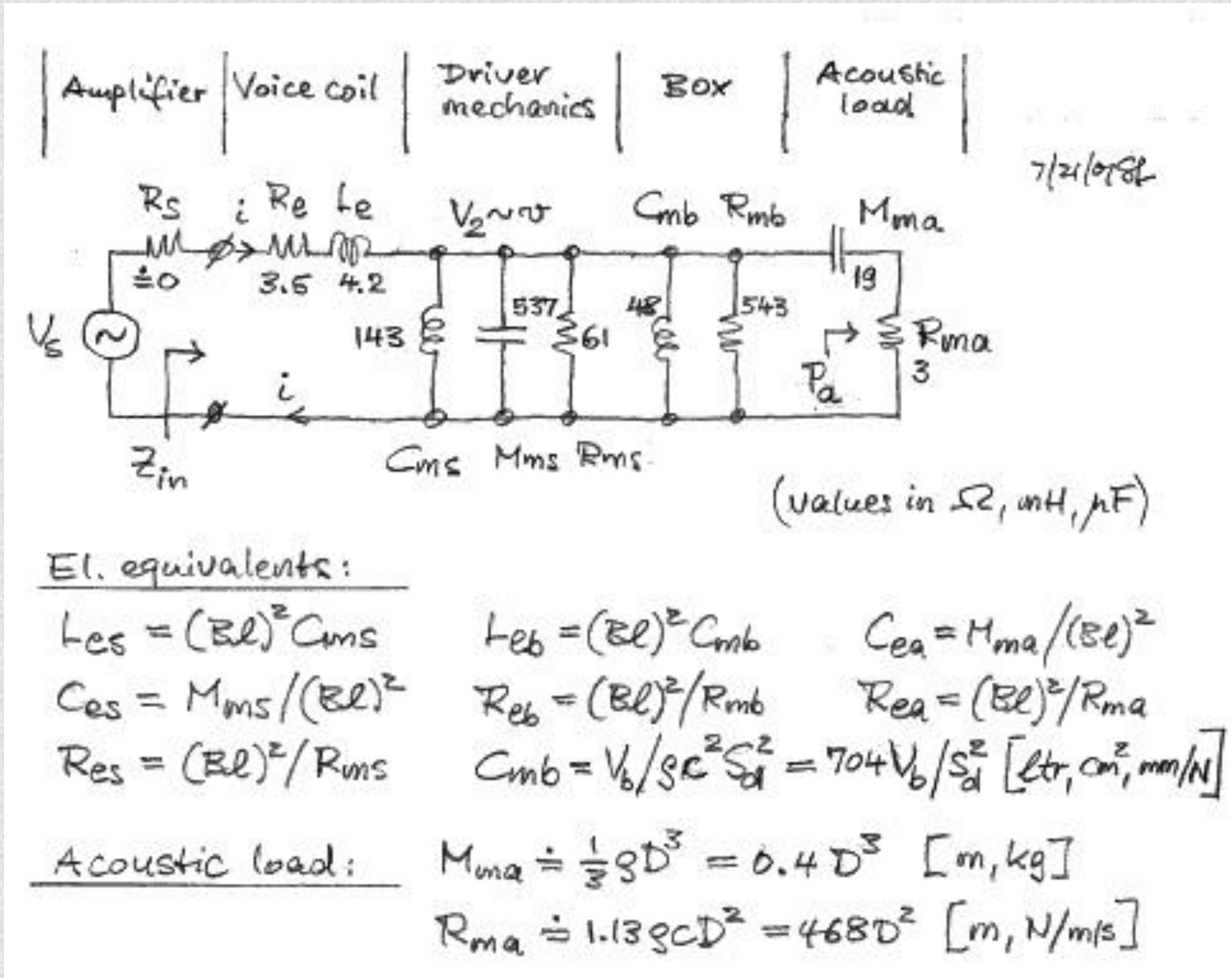
- Fs = 18 Hz
- Sd = 466 cm^2
- Xmax = 12.5 mm
- Bl = 17.6 Tm = 17.6 N/A
- Mms = 163 g
- Vas = 139 Liter
- Qts = 0.2

Estimates

F_B = Fs*sqrt(1+Vas/VB) = 36 Hz

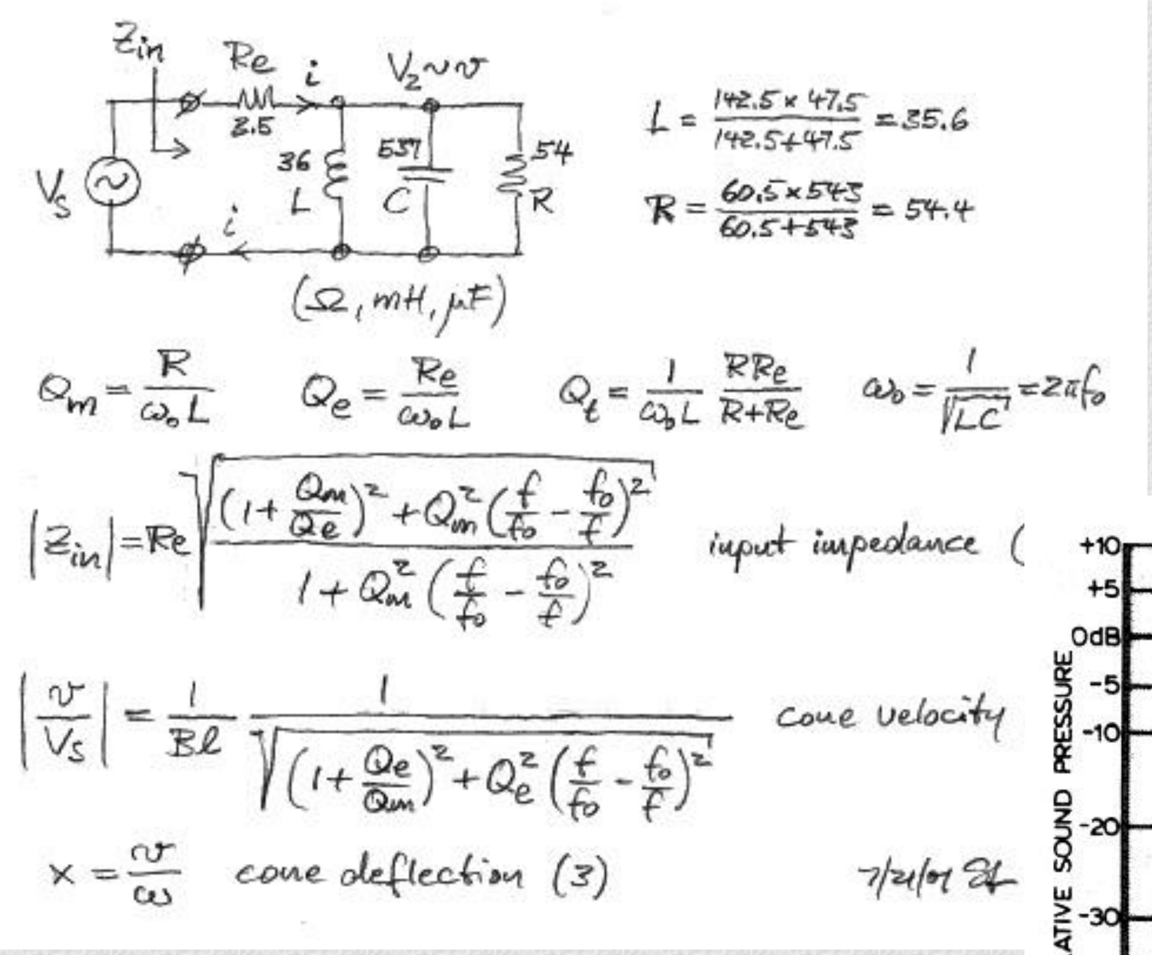
Q_t = Qts*(Fs/F_B)(1+Vas/V_B) = 0.4

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

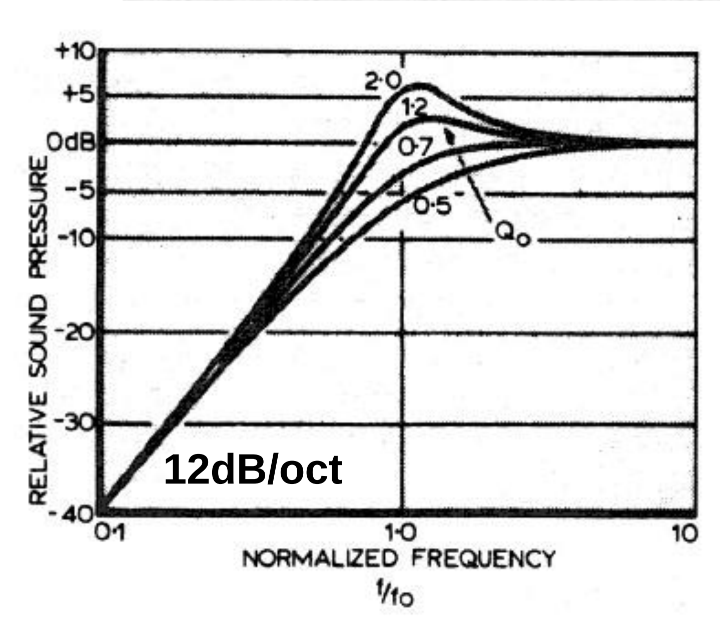


Ref: www.linkwitzlab.com/thor-design.htm

Low frequency model



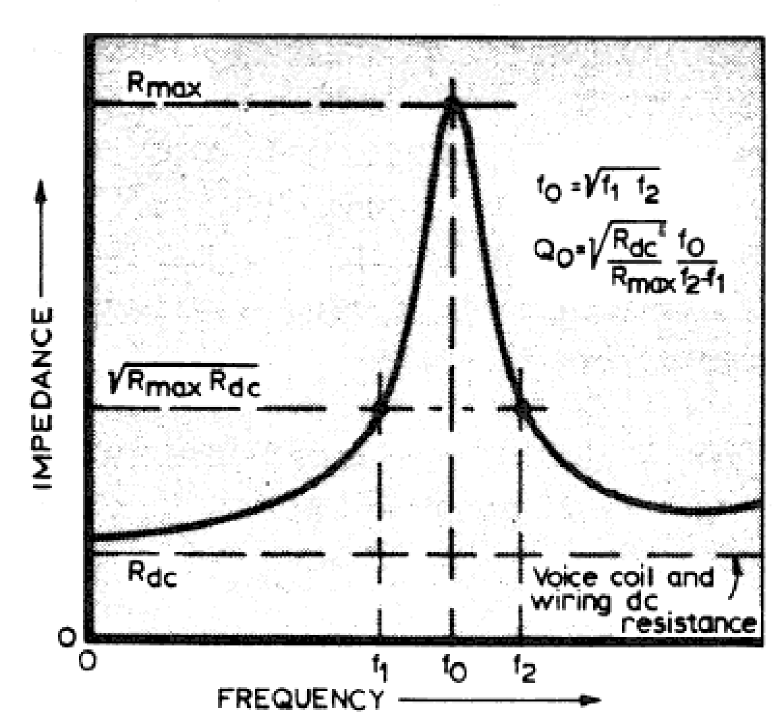
Sealed box frequency response = 2nd order highpass filter with f_0 and Q_0

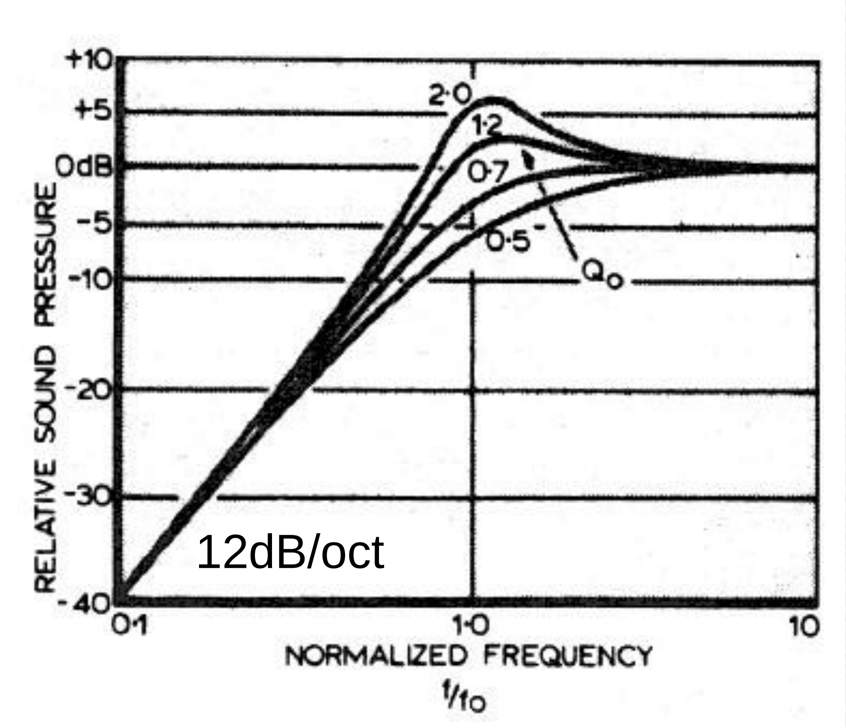


Determine f_0 and Q_0 from a measurement of Z_{in}

$f_0 = F_B = sqrt(f_1 * f_2) = 37.2$ Hz

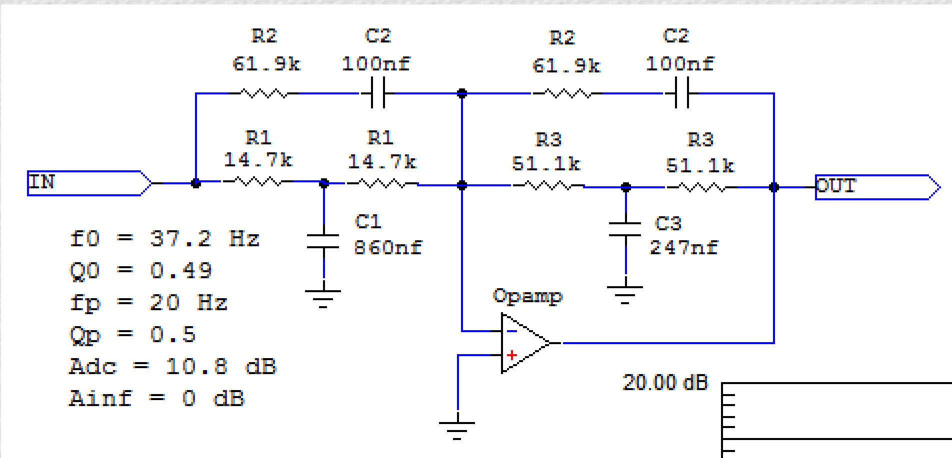
$Q_0 = Q_t = (f_0/(f_2 - f_1))*sqrt(R_{dc}/R_{max}) = 0.49$





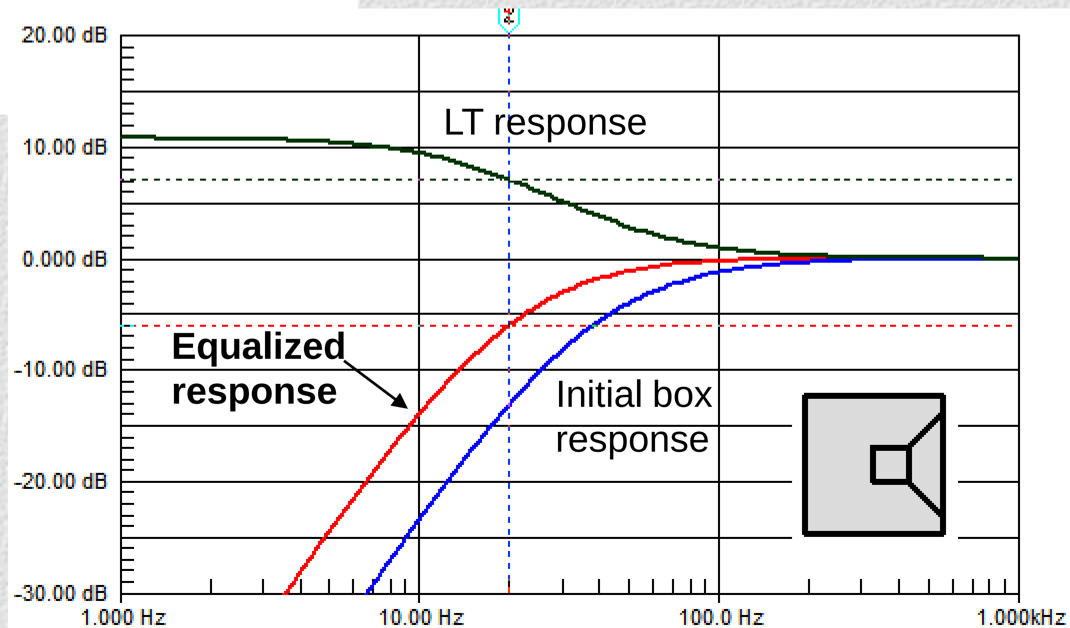
Ref: www.linkwitzlab.com/images/graphics/f0Q0.gif

Low frequency extension with a biquad circuit (Linkwitz Transform)

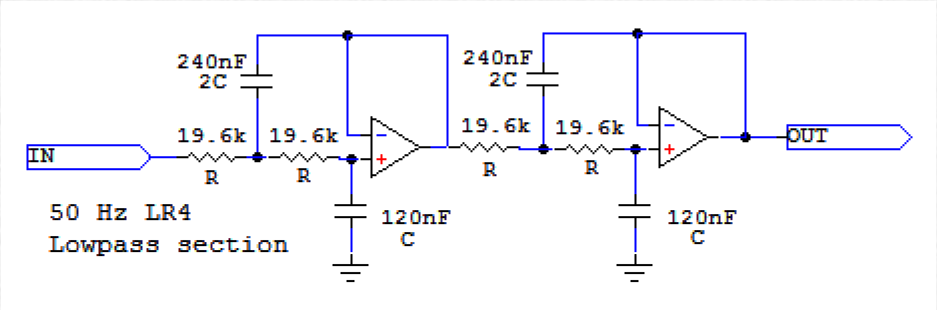


Equalized = Target

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

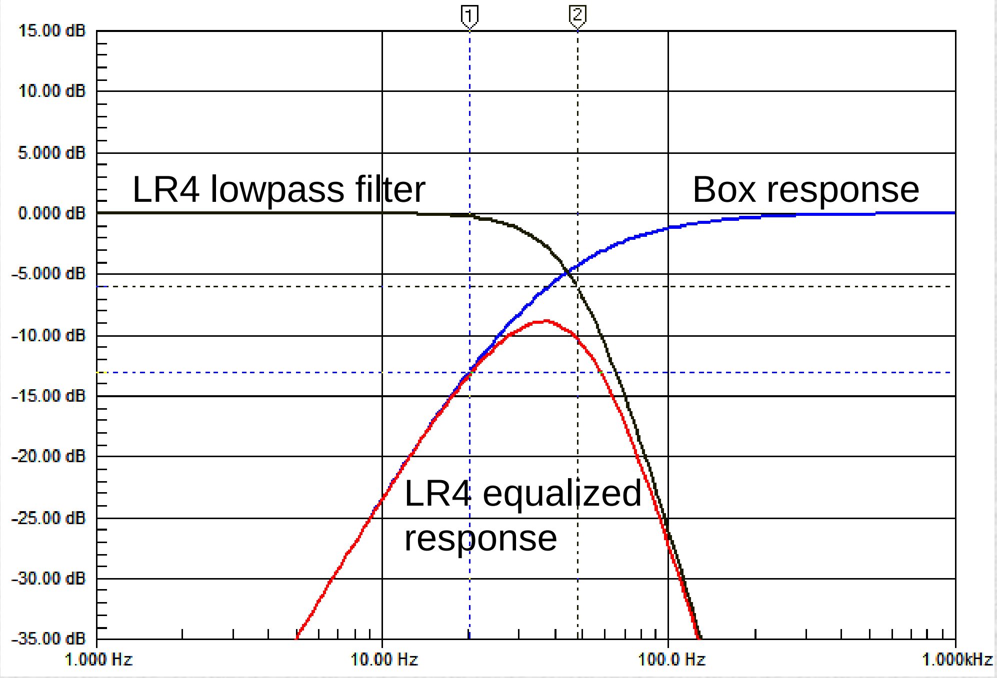


LR4 lowpass filter at 50 Hz

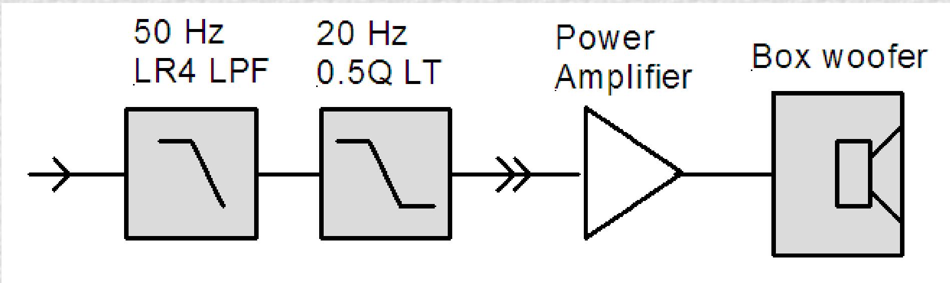


Ref:
www.linkwitzlab.com/filters.htm#3

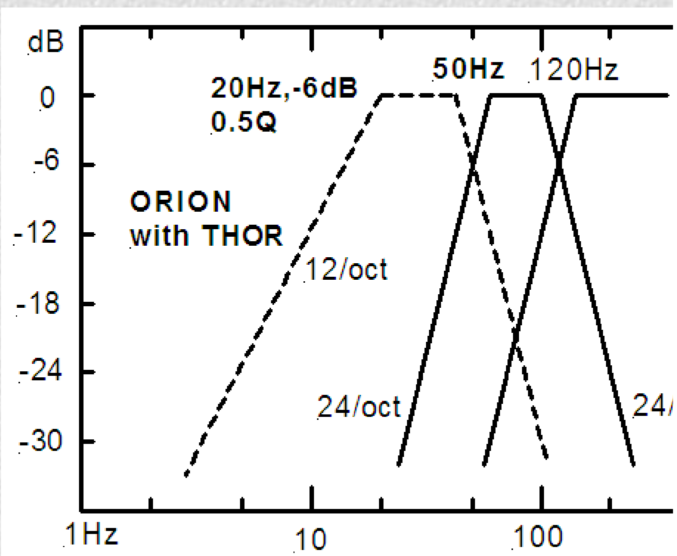
F_p = 1 / (8.89 RC) = 48 Hz

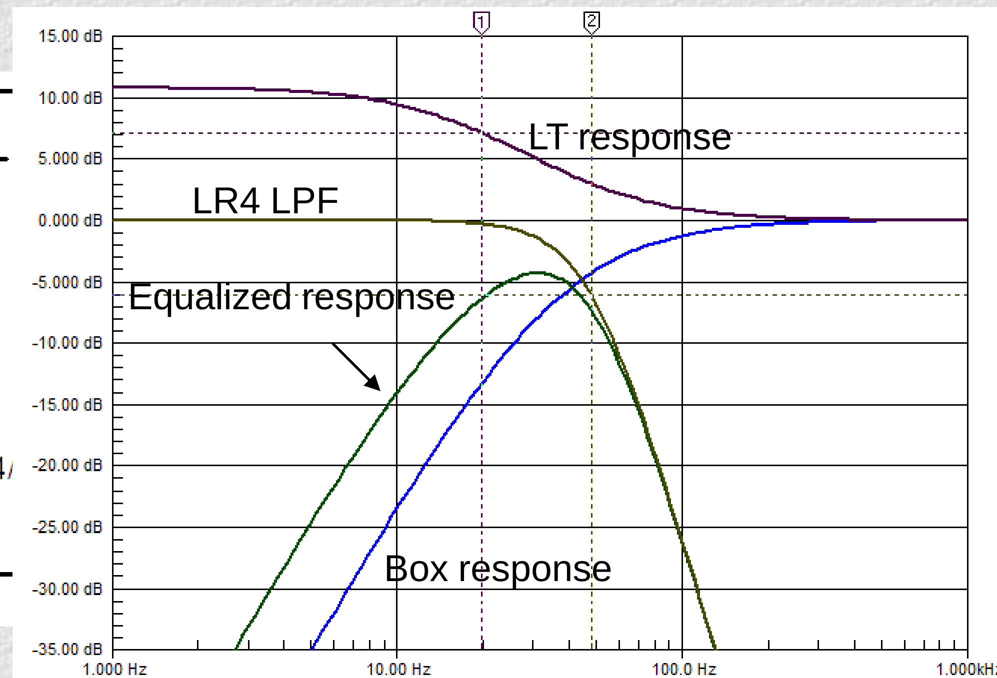


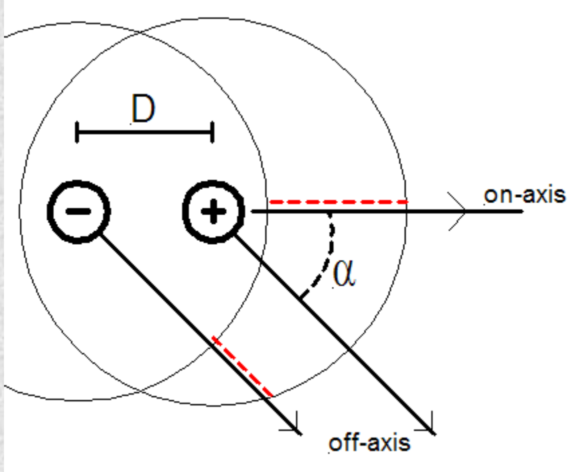
Equalized sealed box woofer



Equalized response
= Target



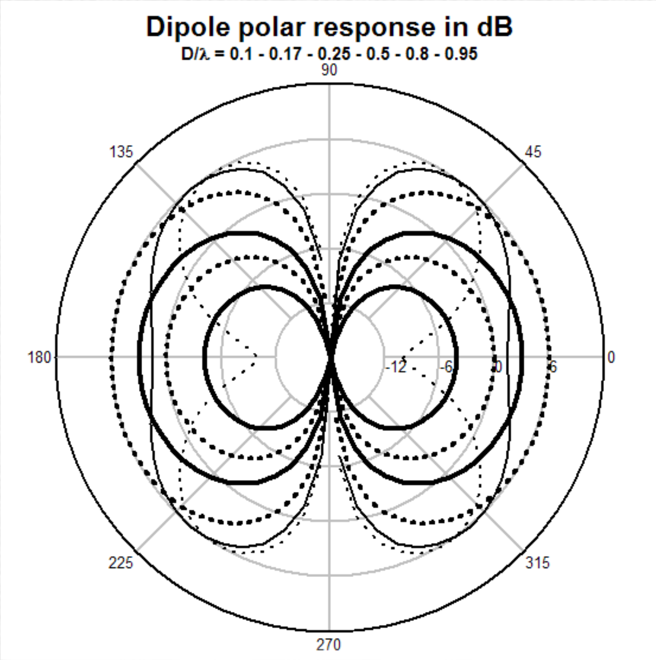


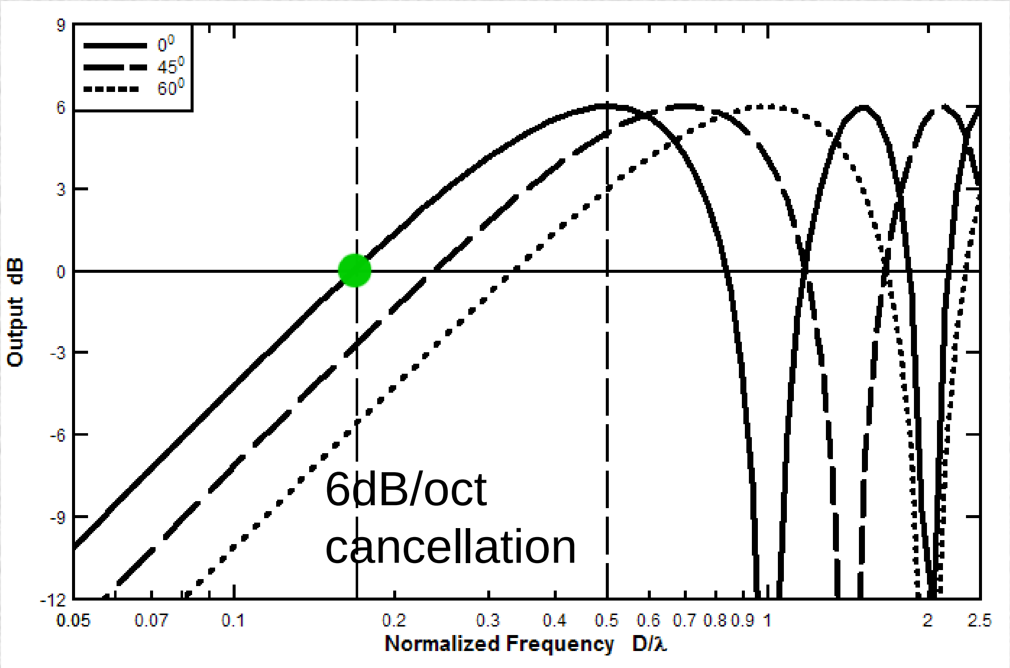


Theoretical Dipole Source

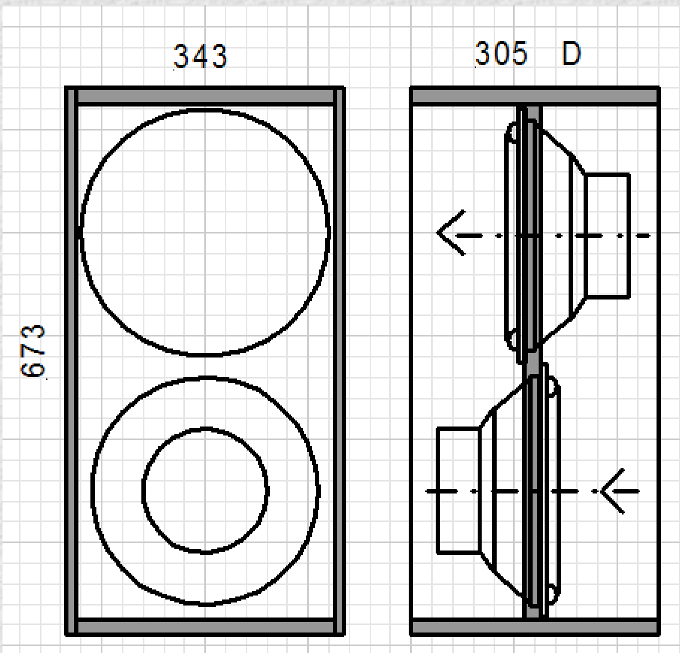
$|H(\omega)| = 2 \sin[\pi D/\lambda \cos(\alpha)]$

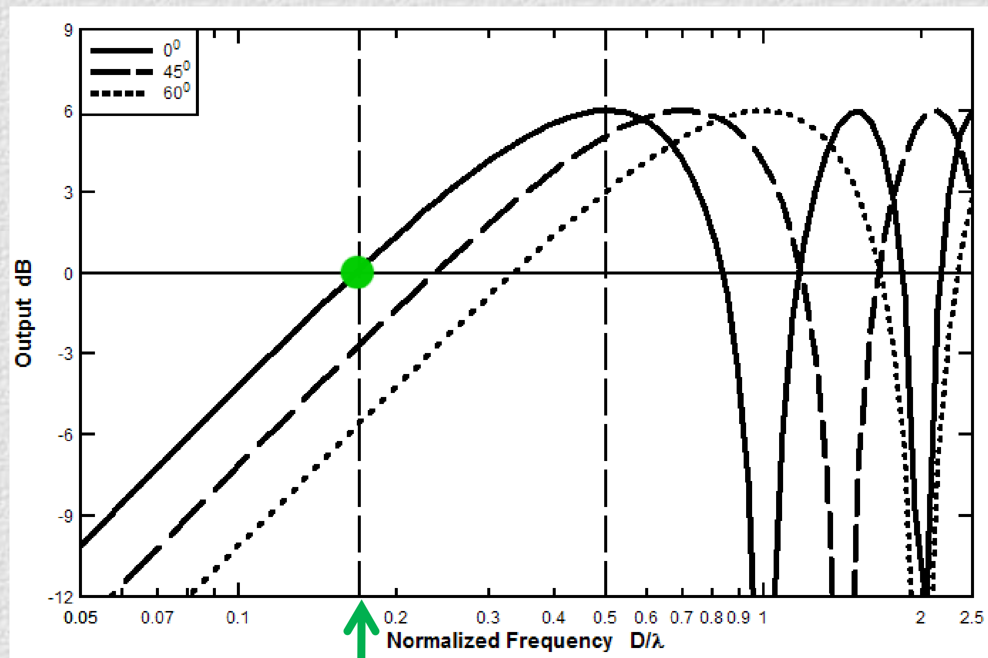
$|H(\omega)| \doteq 2\pi D/\lambda \cos(\alpha)$ for $\lambda >> \pi D$





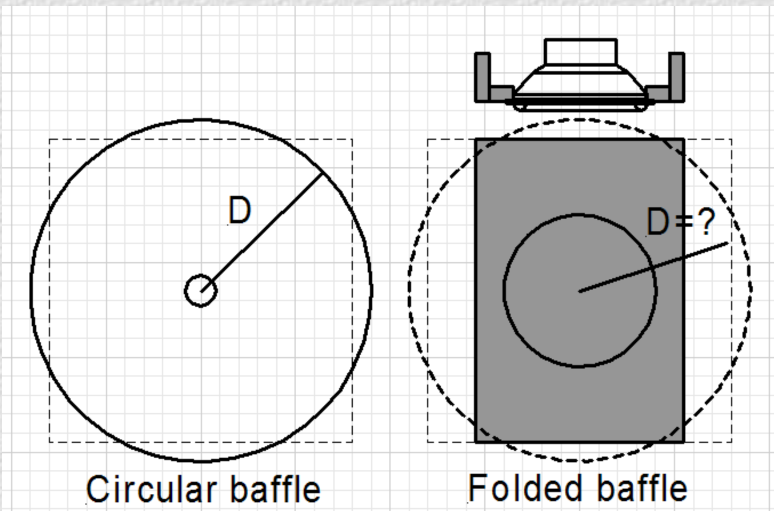
Practical dipole source
-- Bass frequency range --

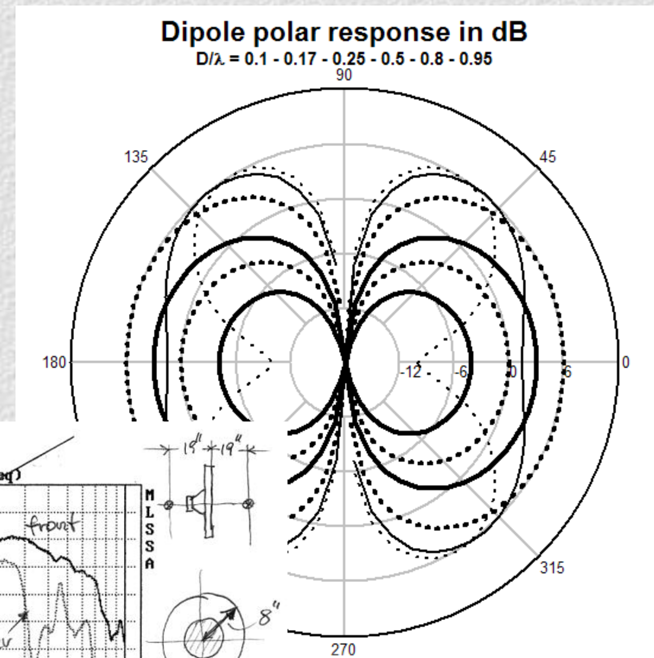


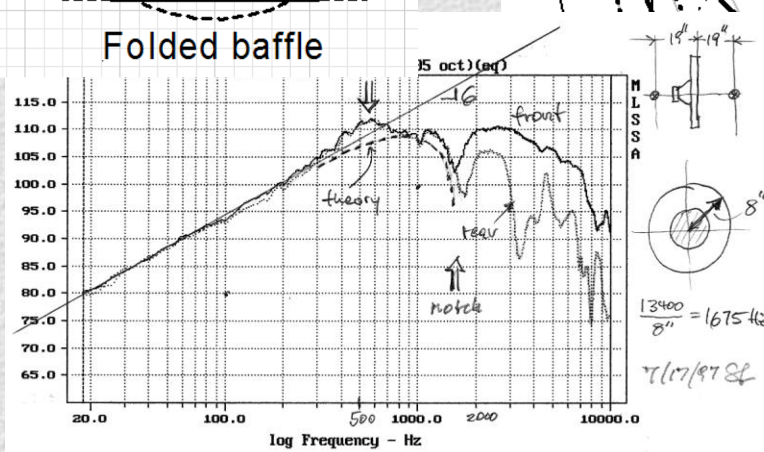


Fequal @ D = λ/6

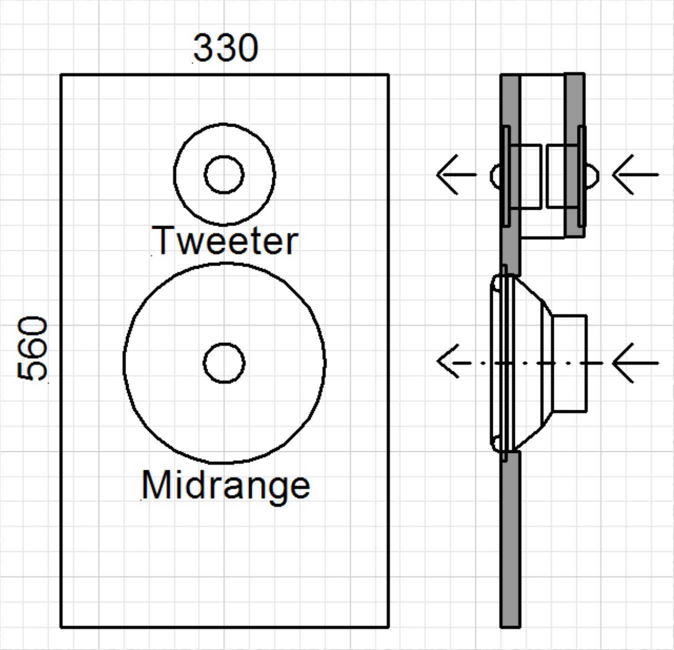
Practical dipole source
-- Mid frequency range --

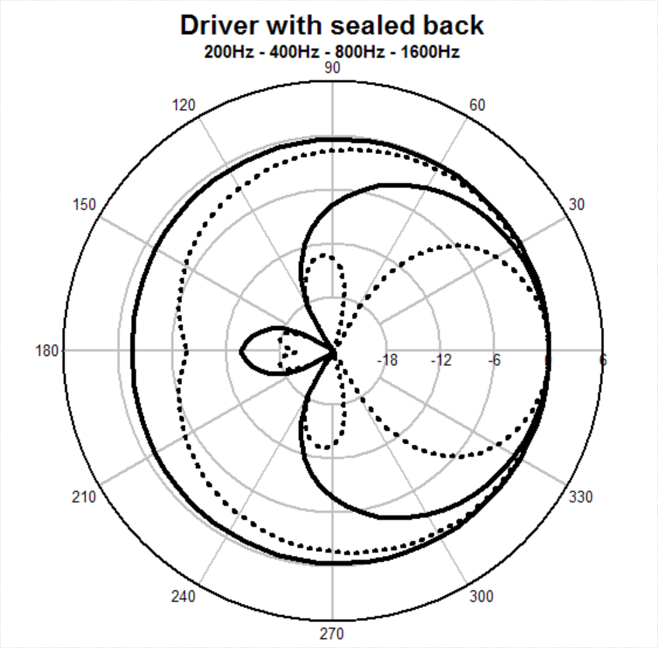




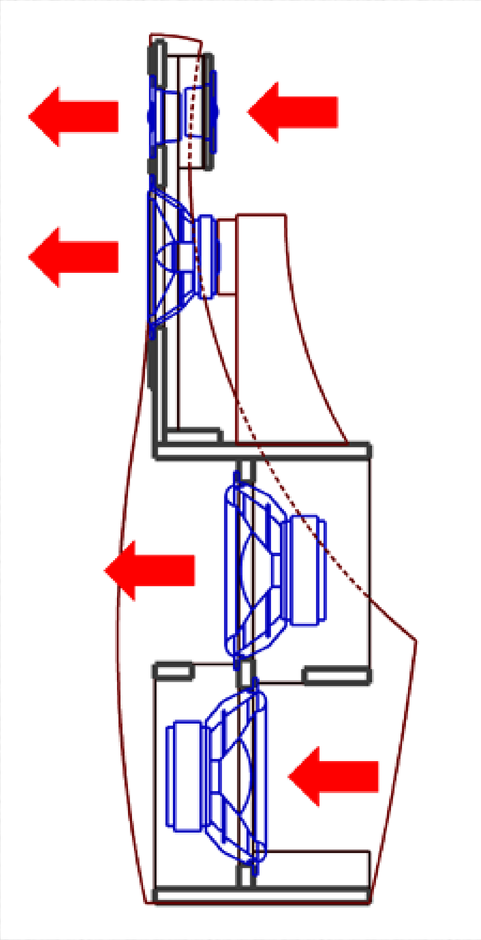


Practical dipole source
-- Tweeter frequency range --

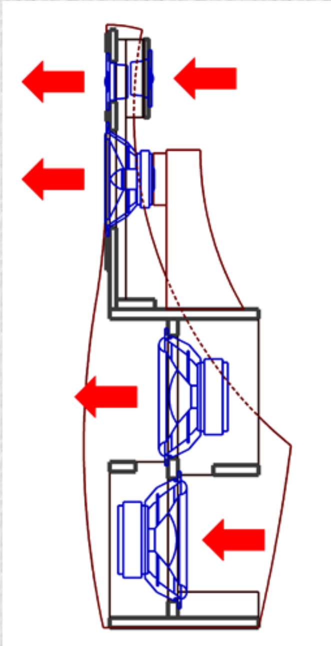




ORION+ Open-Baffle Loudspeaker



Linkwitz Lab



H-frame woofer

$F_B \leq$ Fs due to air mass loading

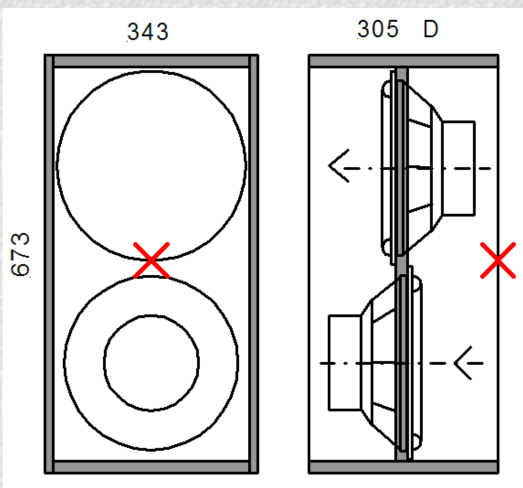
$\lambda/4$ transmission line resonance limits top end

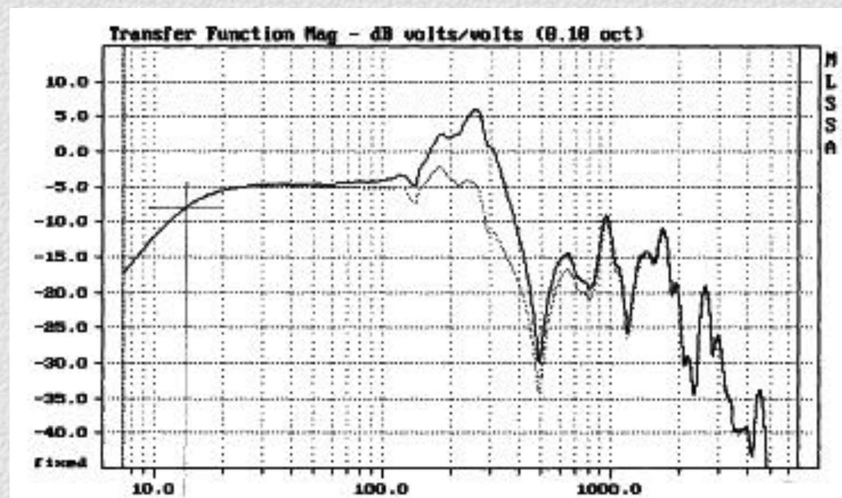
Driver bottoming limits low frequency output

Even order distortion reduction

No vibration cancellation

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

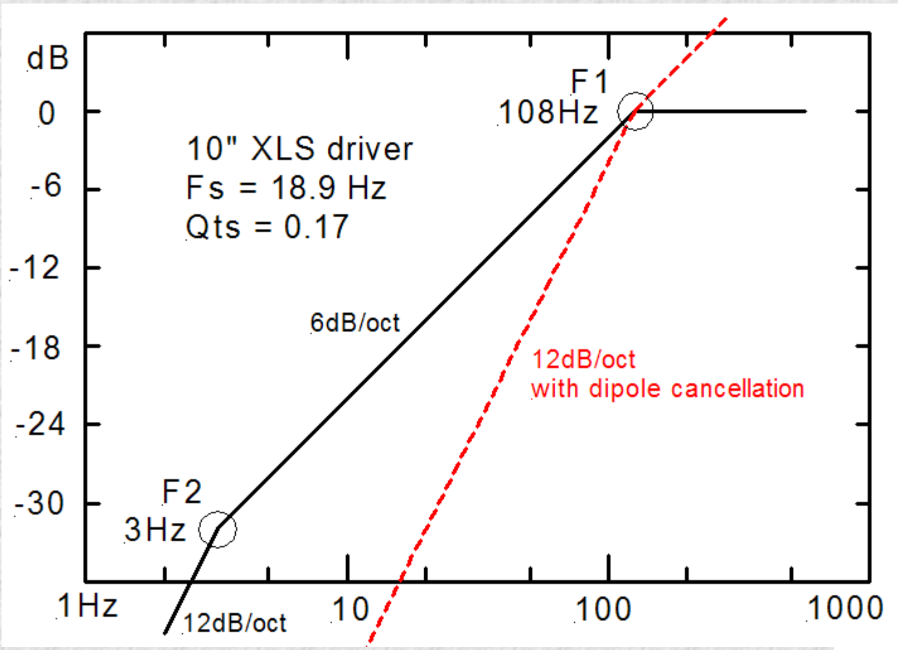




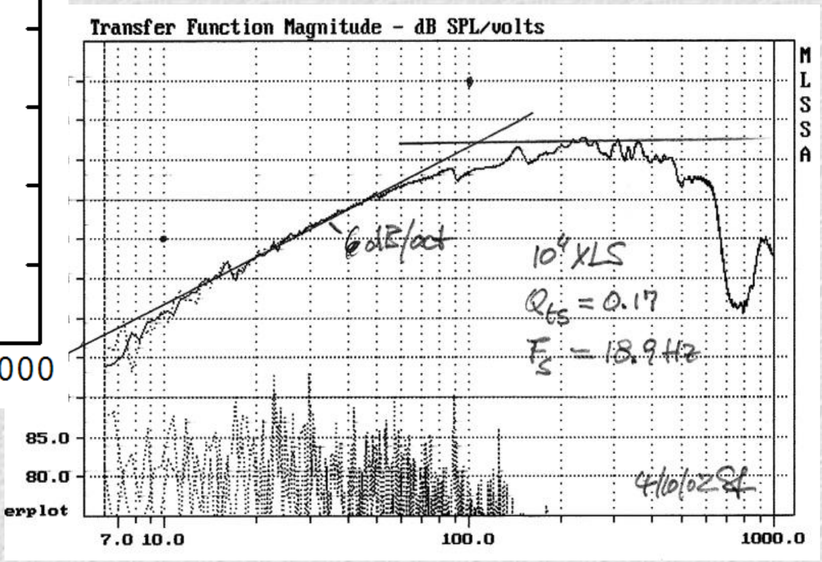
Low Q driver in open baffle

2nd order Highpass Poles:

F1, F2 = Fs/2Qts [1$\pm$ sqrt(1-4Qts^2)] = 108Hz, 3.3Hz

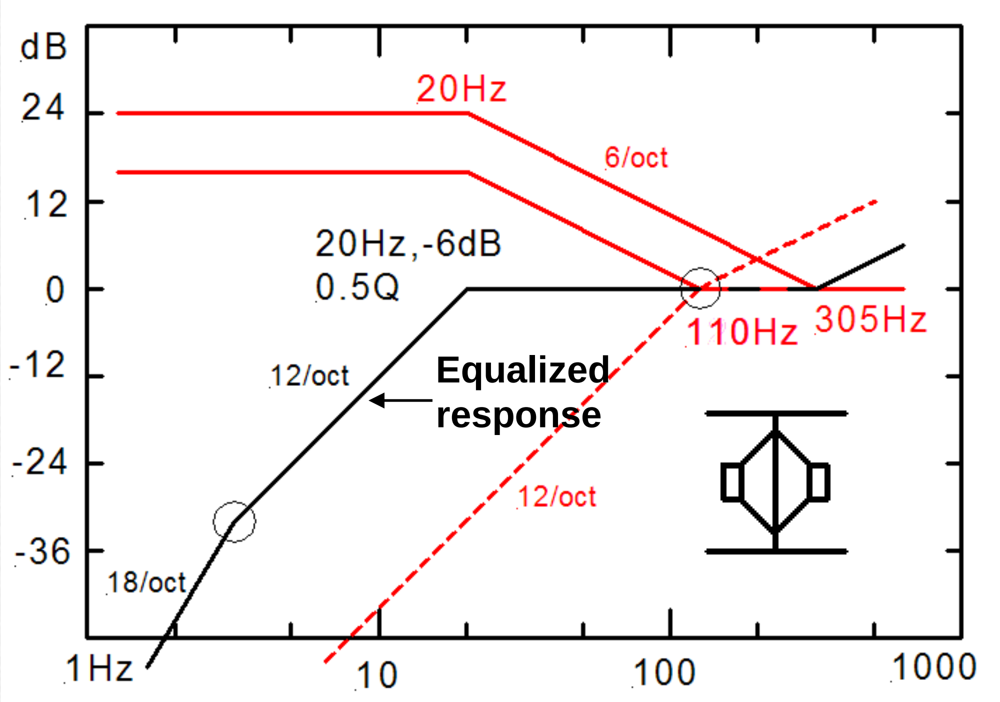


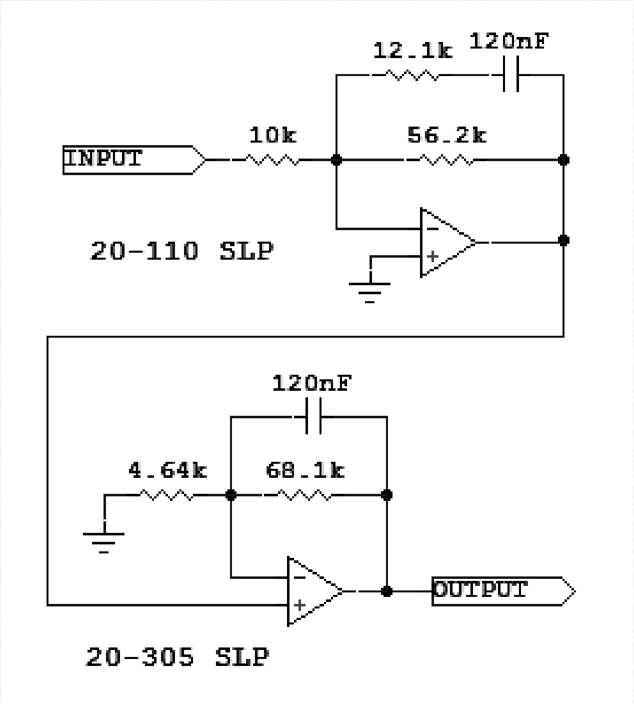
Measured at H-frame opening



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

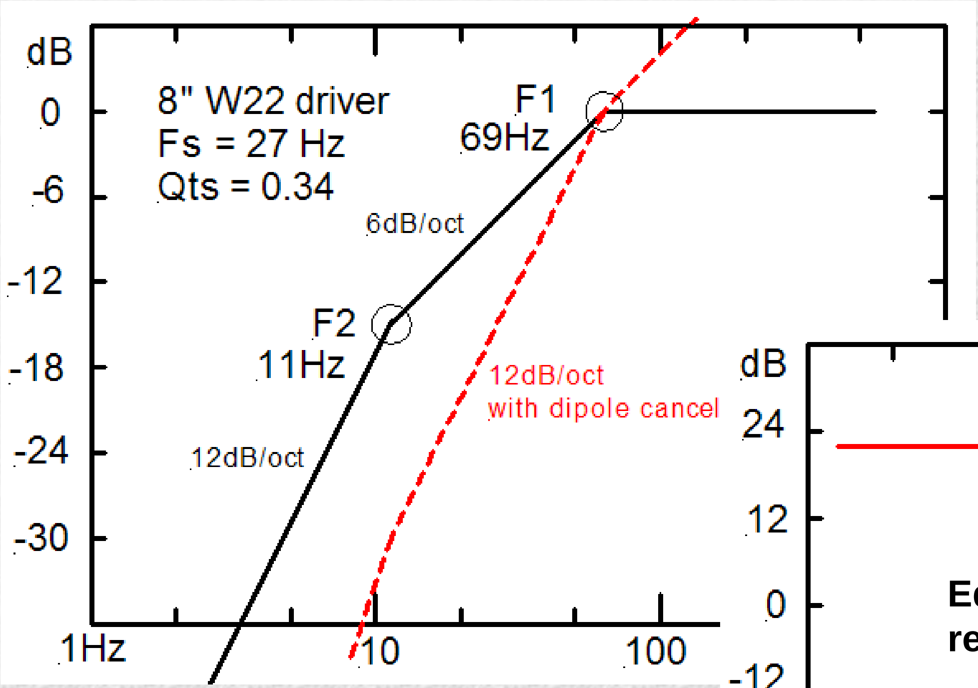
ORION woofer response equalization





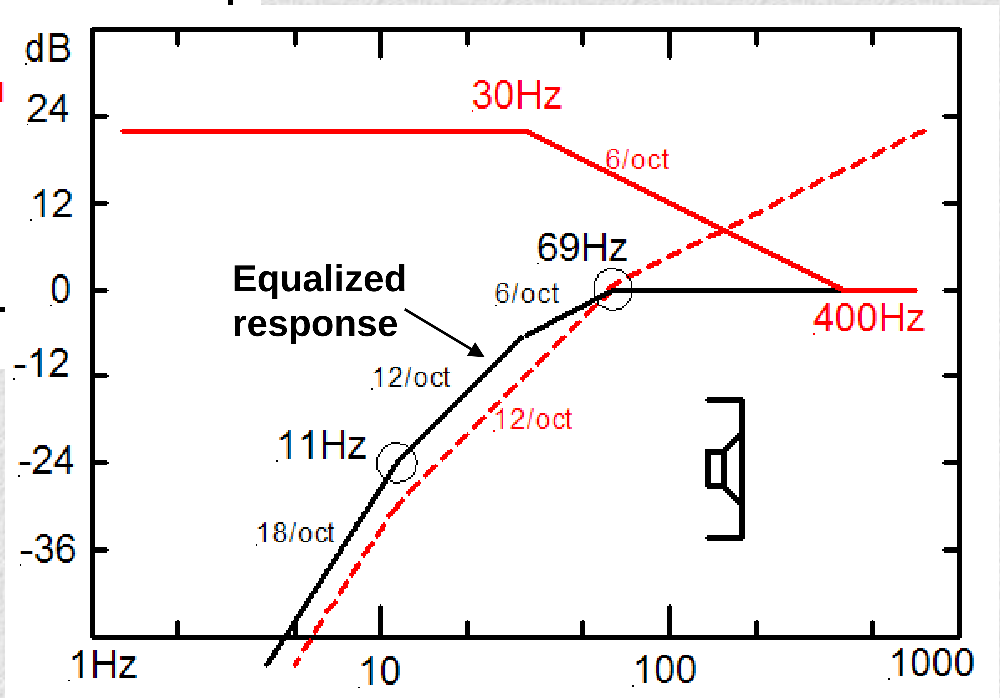
Ref: www.linkwitzlab.com/filters.htm#5

Midrange: Low frequency equalization

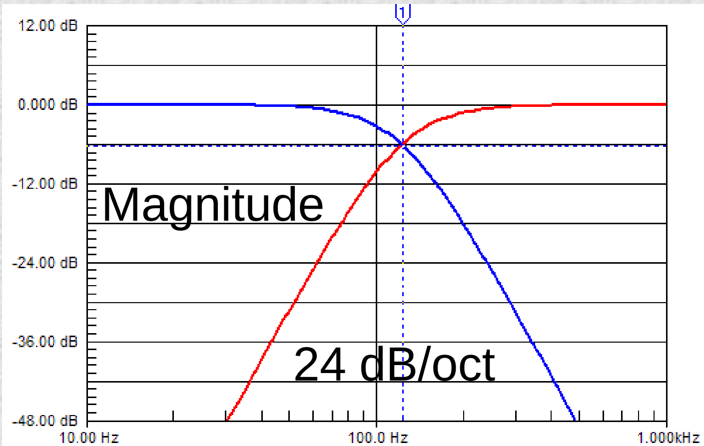


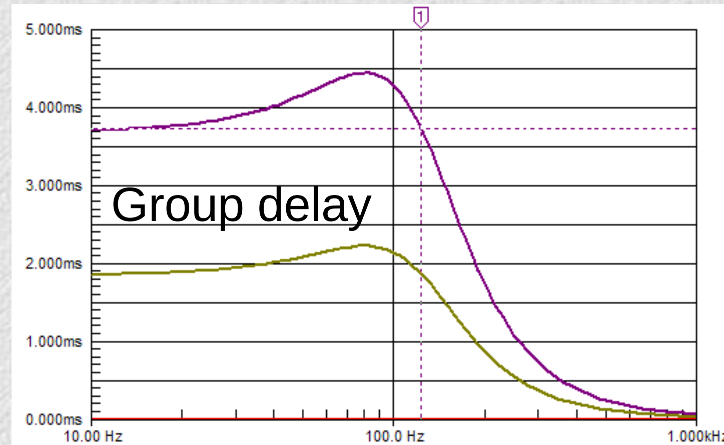
8” driver in open baffle

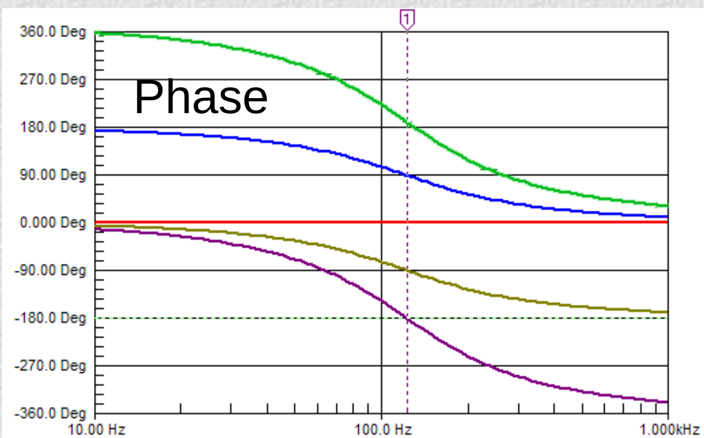
Equalized with 30-400 SLP

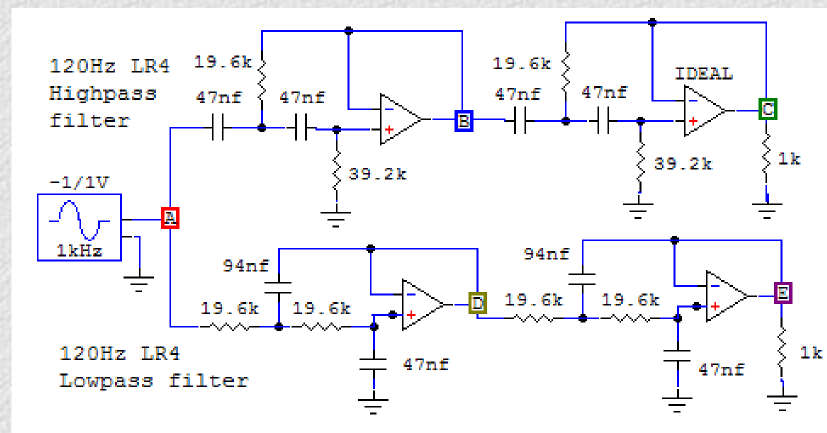


LR4 crossover filter function





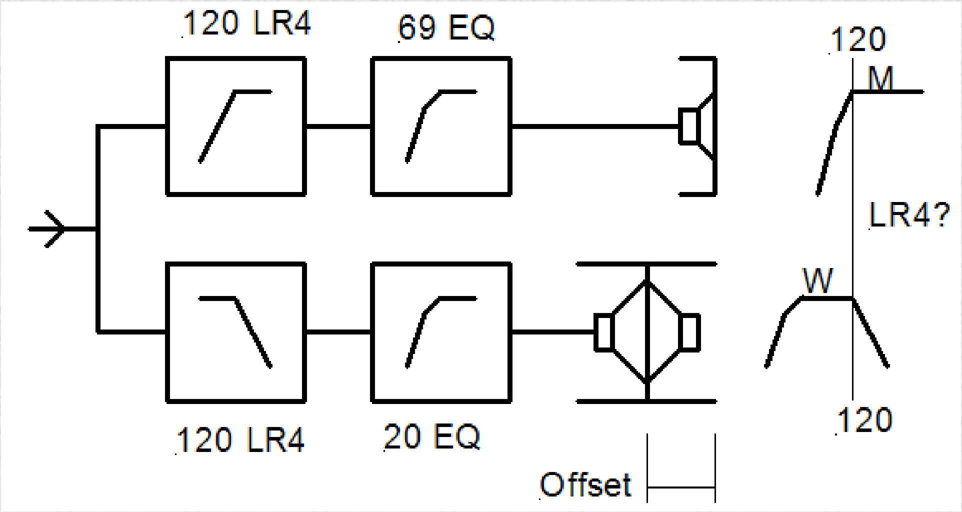




Electrical filter realization

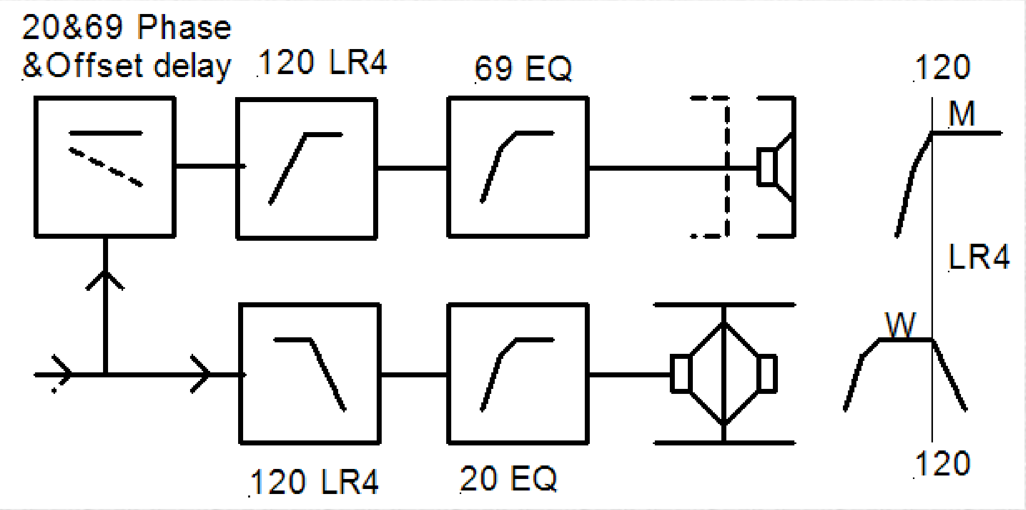
Ref: www.linkwitzlab.com/filters.htm#3

Woofer to midrange crossover

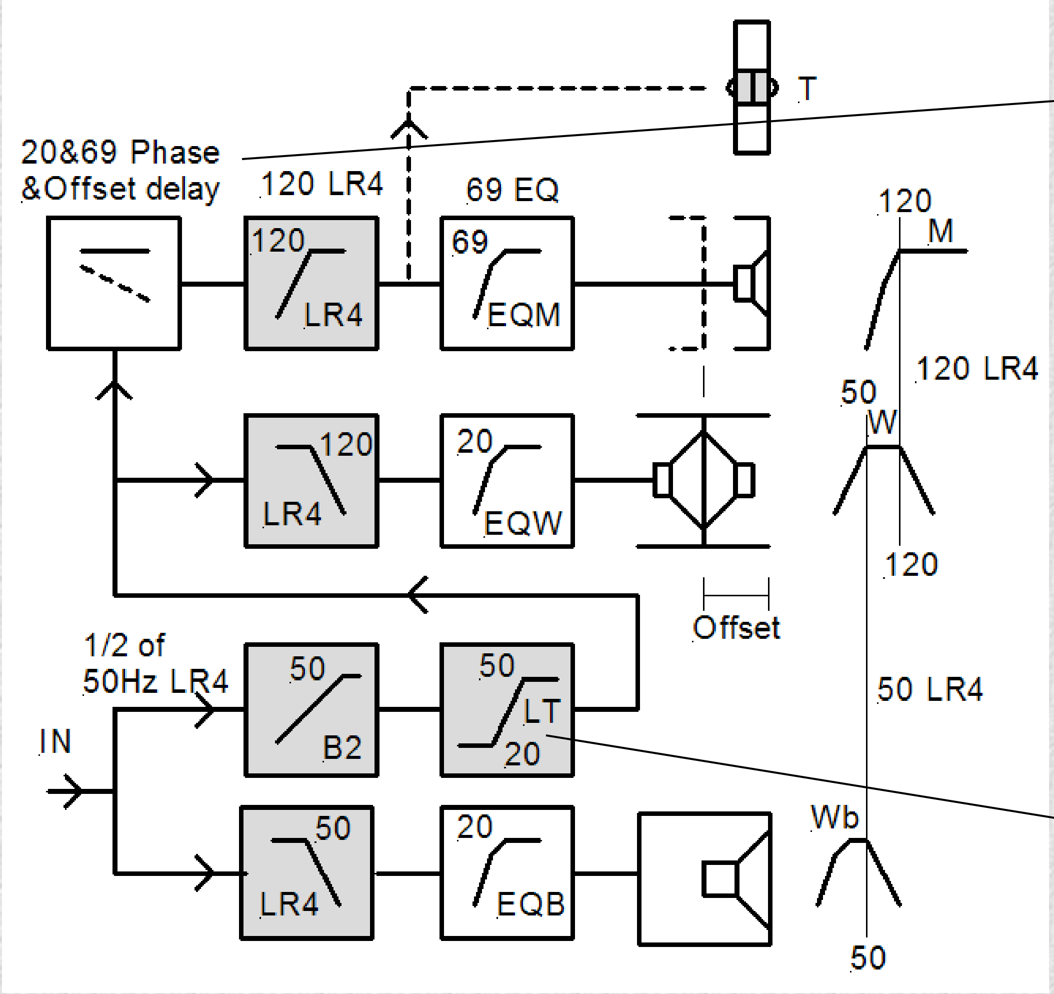


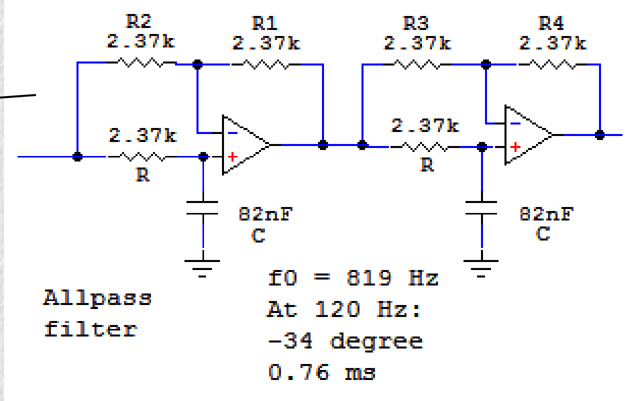
Outputs W & M will not add to a flat response

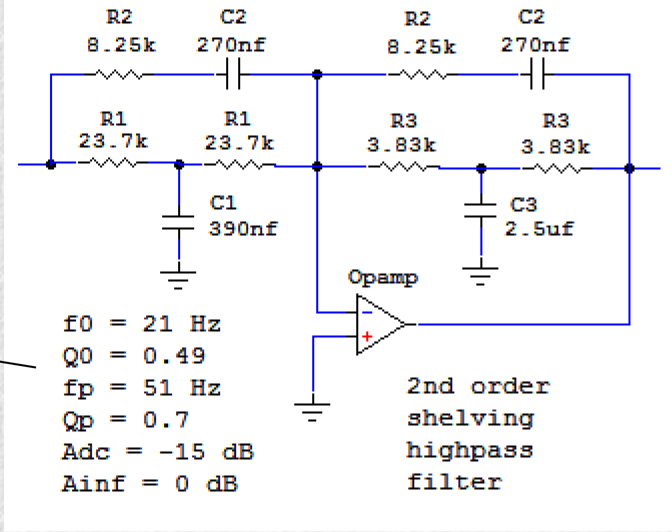
Phase correction in Mid channel for Woofer & Mid highpass & Woofer acoustic offset with el. allpass filters



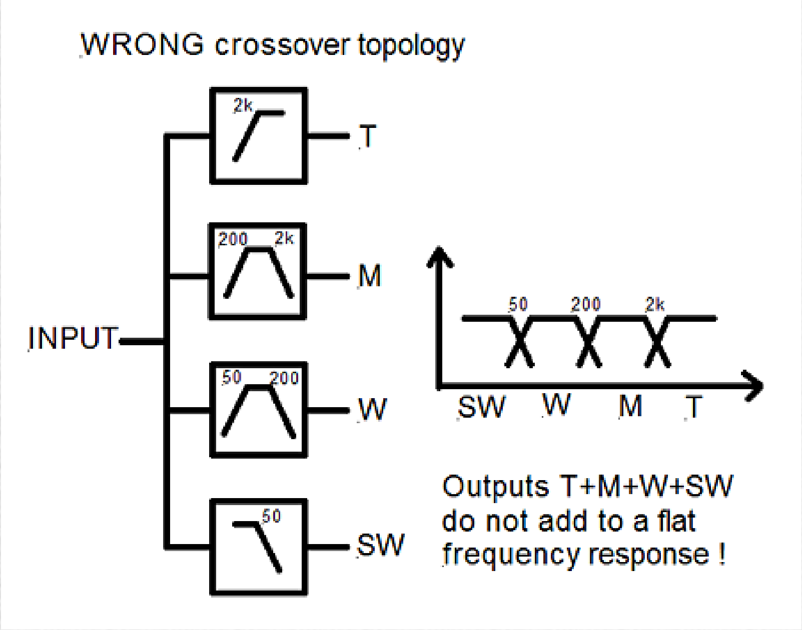
Addition of a box woofer

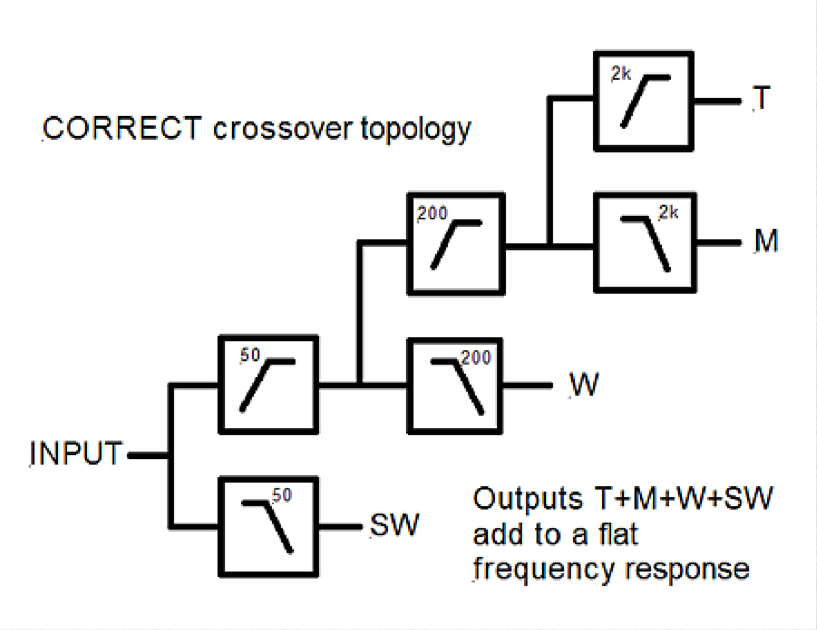






General arrangement of crossover filters





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