Subtractive Crossovers by Bansuri

1st Order BW

A **subtractive** crossover doesn't introduce additional phase change or delay, a square wave is perfectly reproduced, the drivers have to be wired in phase.

It has a flat impedance and power curve, perfect for tubes; but what happens when speakers and enclosures are added?

Each speaker has a low and high frequency -3dB point. The low end is well defined of at least second order and easily measurable. The upper limit has to be guessed from a frequency plot.

Several effects like cone break-up, cone shape, resonances and reflections on small obstacles (screws, gaps) and baffle/waveguide superimpose with the inductive impedance rise. Generally a 2nd order low-pass plus a notch filter can approximate radiation sufficiently.

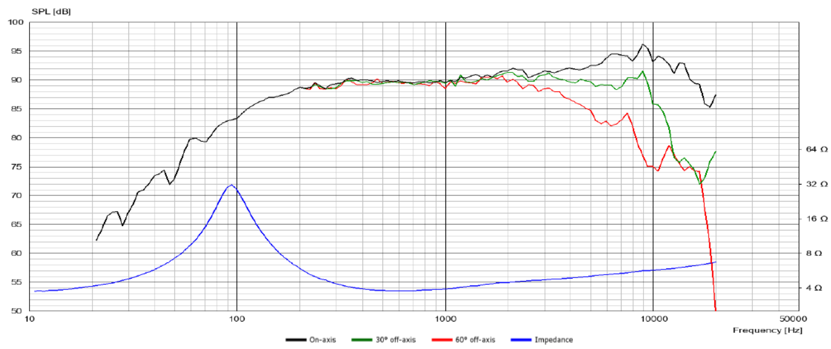
Driver Selection

Tweeter: Scan-Speak 10F4424-01 one of the finest fullrange drivers

With a notch at 9kHz a very linear response.

2L closed with 20g Angle-Hair damping

125Hz, Q= 0.48



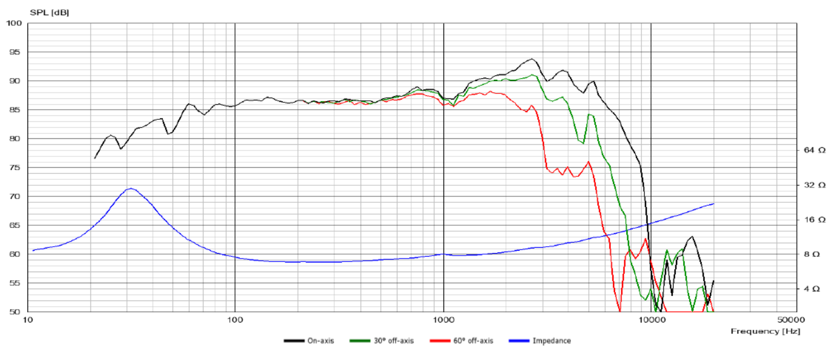
Woofer: Scan-Speak 18W8535-01 wideband and linear, 2 in parallel

2x28L vented f-3= 38Hz

2x20L closed f-3= 50Hz

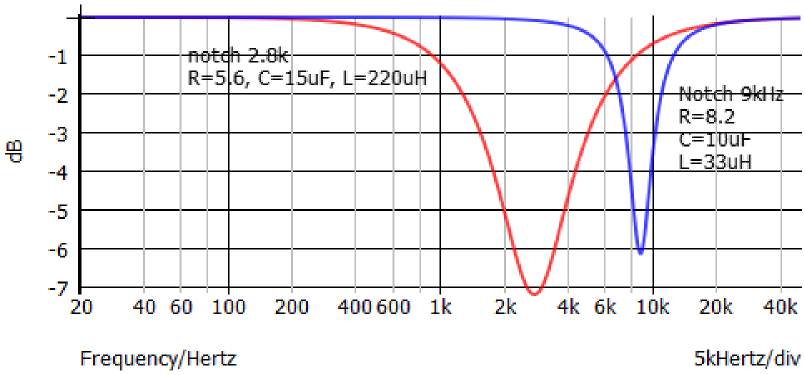
2x11L closed + serial C f-3= 48Hz, 1200uF

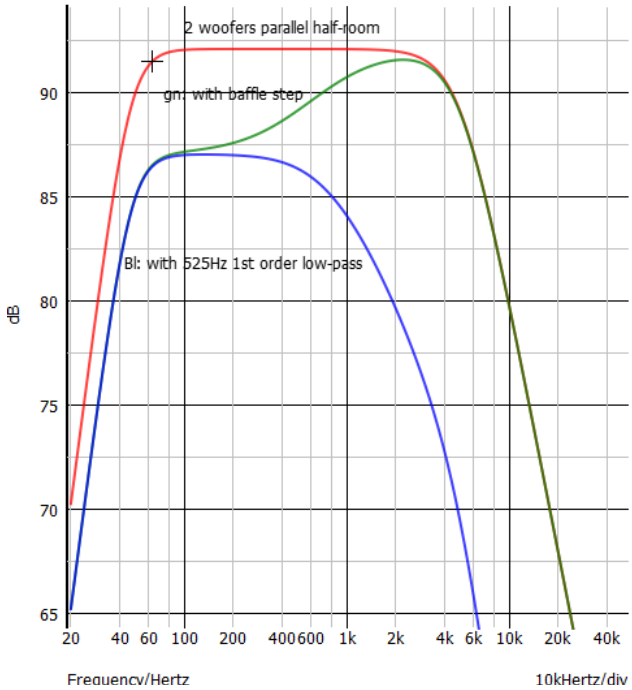
With 5mm excursion only 96dB SPL @45Hz can be reached in a closed enclosure ⇒ dual 102dB.

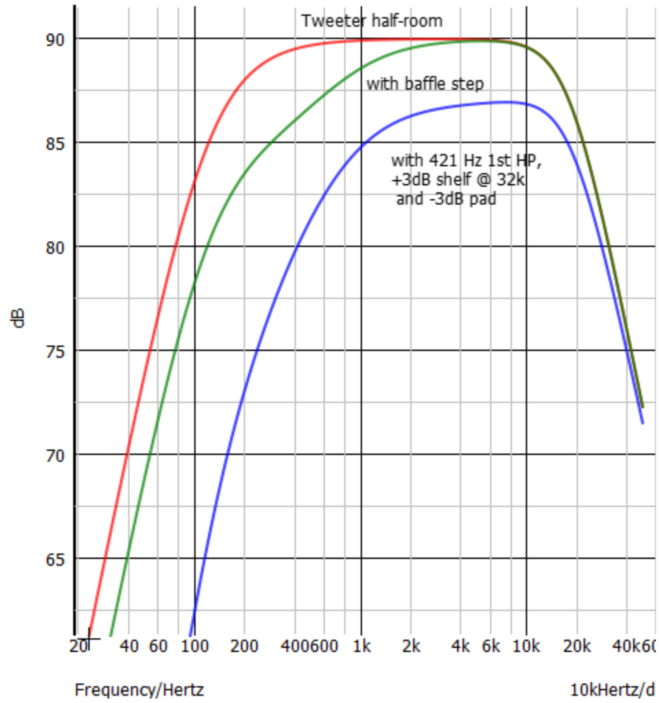


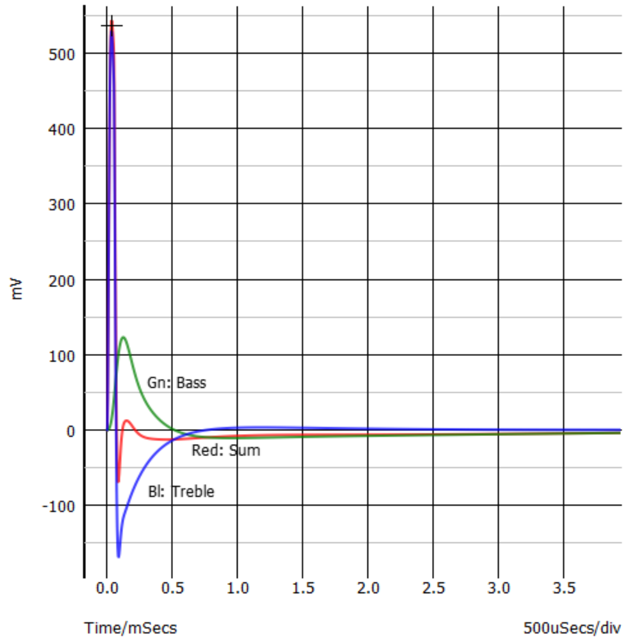
Notch filters, better all active to avoid interaction with XO components.

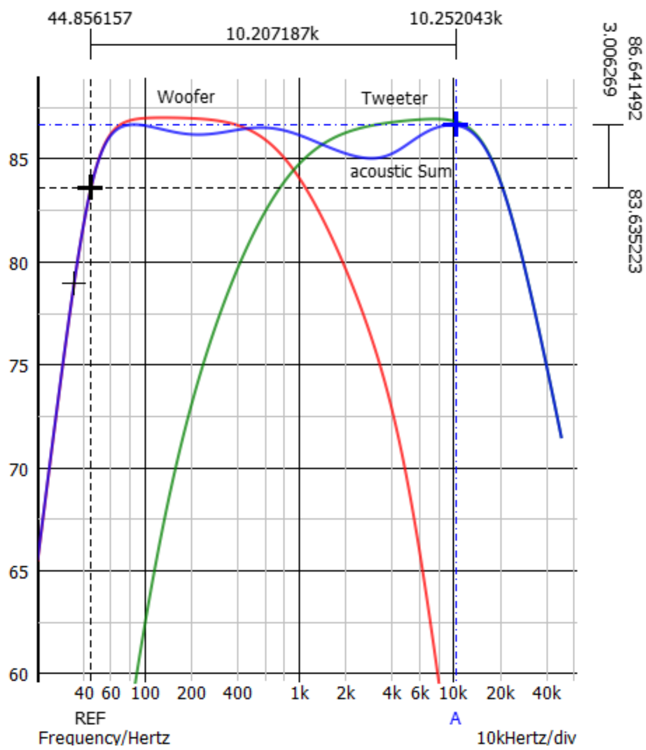
Some simulations with the smallest enclosure.

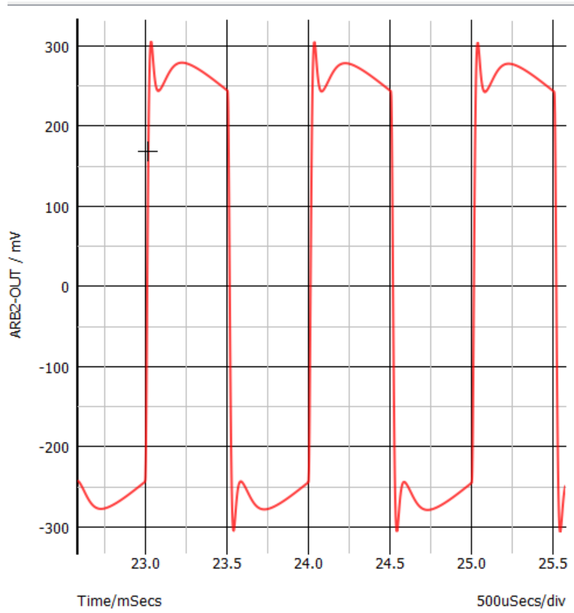












Baffle 25cm wide

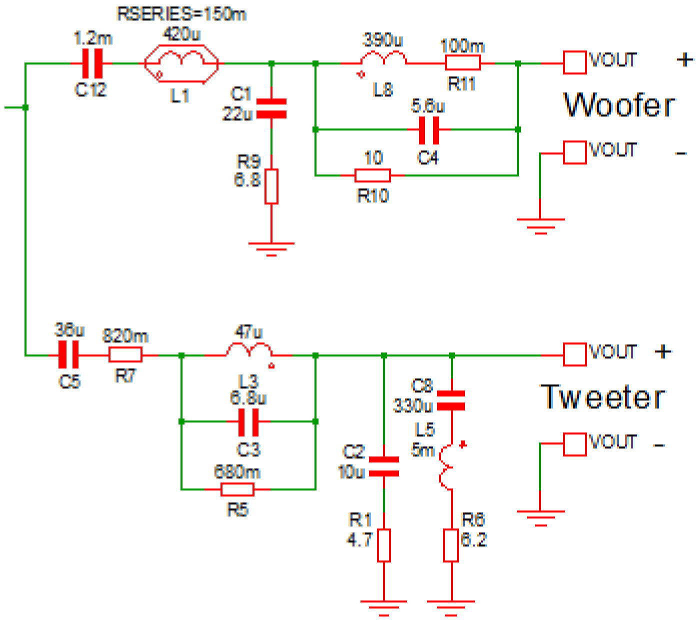
Pulse response and 1k Square show the advantage of subtractive X-overs. No pre-echo or additional delay.

The effect of the low end resonance of the tweeter and f_high of the woofer is visible as (small) dips in the response.

It can be realized with passive components.

Just a rough estimate of values for a passive implementation.

With a 100W amp 102dB SPL is reached.



2^{nd} Order modified Gauss

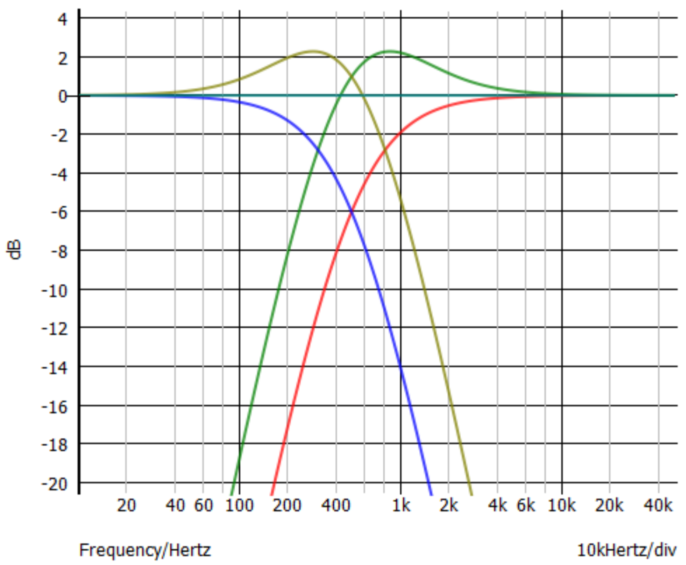
Laplace: $1 = (1+s)^4/(1+s)^4 = (1+4s+6s^2+4s^3+s^4)/(1+s)^4$
cutting: $(1+4s+3s^2)/(1+s)^4 + (3s^2+4s^3+s^4)/(1+s)^4$

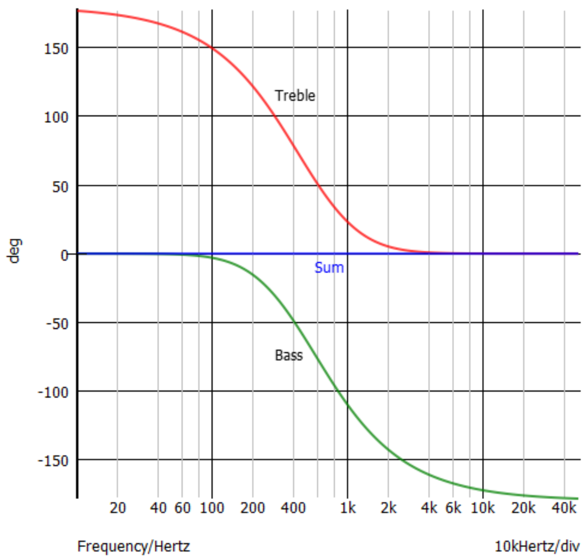
1^{st} part = Woofer $(1+4s+3s^2)/(1+s)^4 = (1+s)+3s(1+s)/(1+s)^4$

$= (1+s)(1+3s)/(1+s)^4 = 1/(1+s)^2 * (1+3s)/(1+s)$

So the 2^{nd}Gauss $1/(1+2s+s^2)$ multiplied with a shelf $(1+3s)/(1+s)$

2^{nd} part = Tweeter $s^2/(1+2s+s^2)*(3+s)/(1+s)$

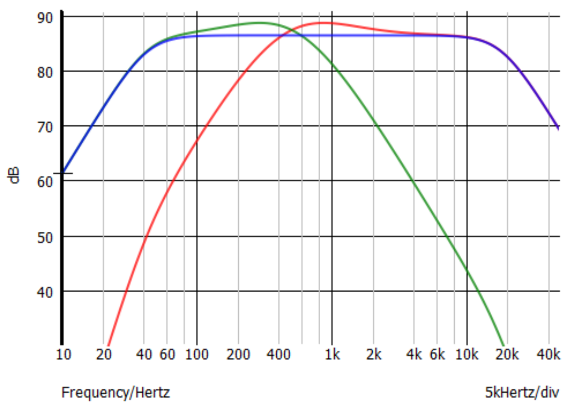




Theoretically 100% flat frequency- and phase-response. XO=500Hz

When we add the drivers low and high ends need to be perfectly matched, to avoid a boost or dip at the xover frequency.

The drivers overlap from 100Hz to 2kHz, the boost is +2.2dB near the XO frequency.



The woofers were limited by the excursion, there is no problem to boost the treble with a bigger amp, but the tweeter would not allow the boost because of thermal limit.

It is easy to add a midrange which could work together with the tweeter:

$$s^2/(1+2s+s^2)*(3+s)/(1+s)=$$

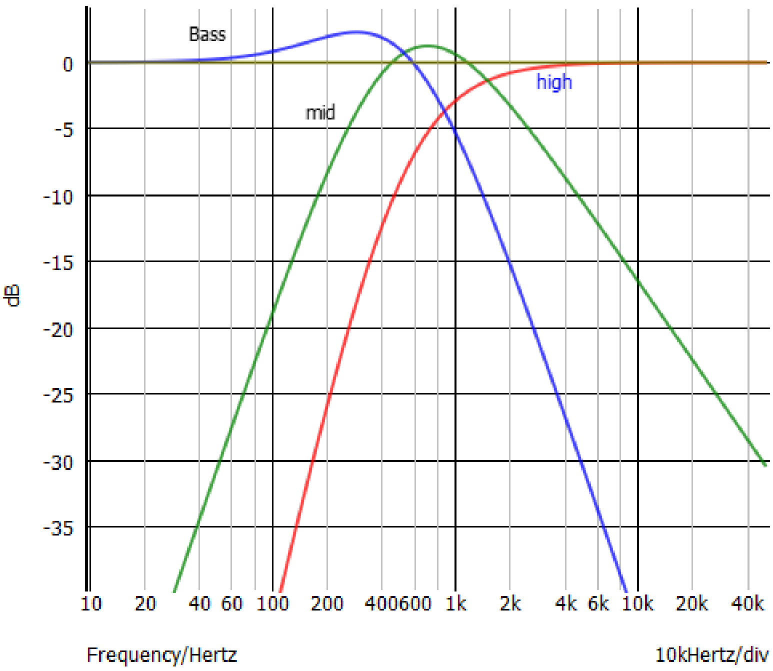
$$s^2/(1+2s+s^2)*s/(1+s) + s^2/(1+2s+s^2)*3/(1+s)$$

tweeter midrange

This solution is very convenient, the tweeter can output a higher level 105dB.

The mid should be very broadband, as the slope to the tweeter is only 6dB/oct

We could do the same with the bass and have a 4-way XO with a single 500Hz crossover frequency.

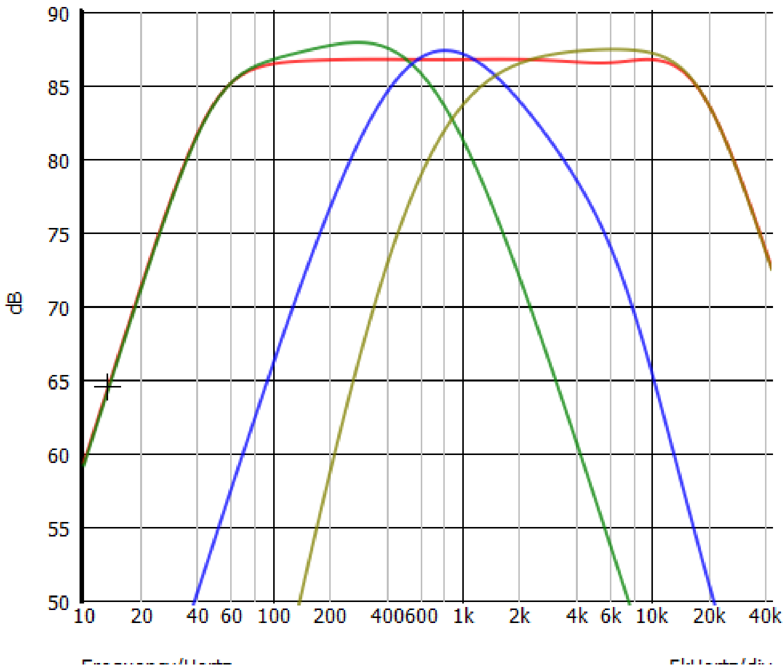


A perfect pulse response and square wave reproduction would result, but we have to consider the lower and upper end of each driver and the Baffle Step.

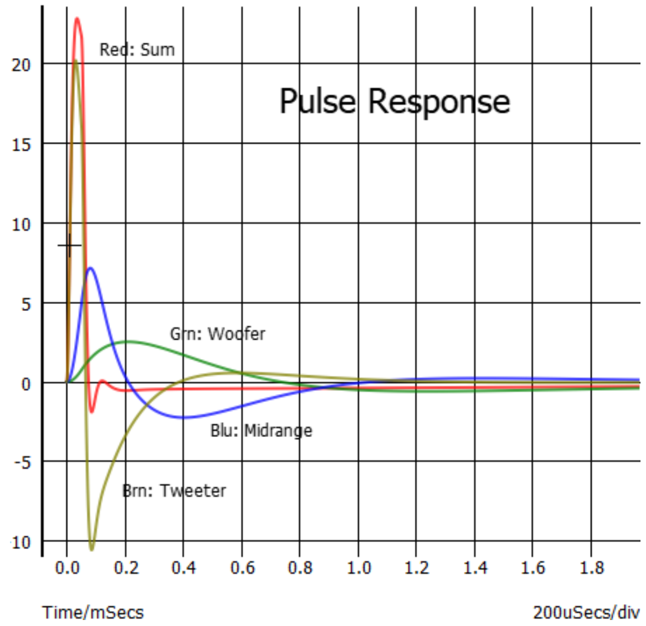
Combining and eliminating several filters without major effect on the sum we arrive at 7 BiQuads for X-Over + 3 BiQuads (not shown) to linearize the response.

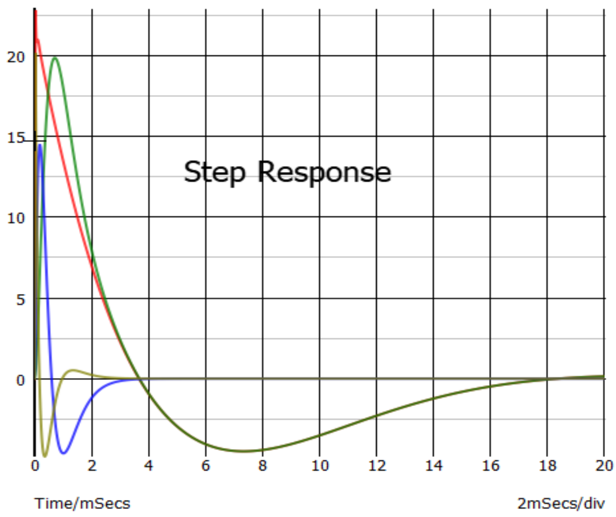
The Woofer boost above the output level is now halved.

A passive implementation is not possible because of the required gain for the Mid.



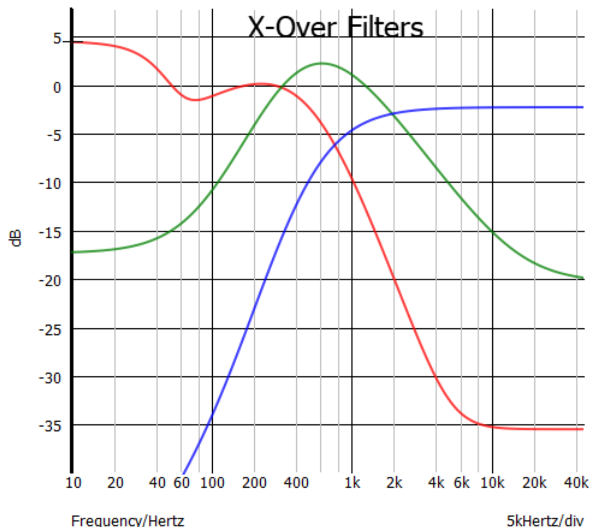
The baffle step (0.5+s)/(1+s) 796Hz for 25cm width has been included.





Here the incredible advantage subtractive Xos provide, only the swing-out behaviour of the bass cannot be compensated. This is unavoidable, a physical necessity.

Another advantage is the perfect rising edge where our ears are very sensitive.



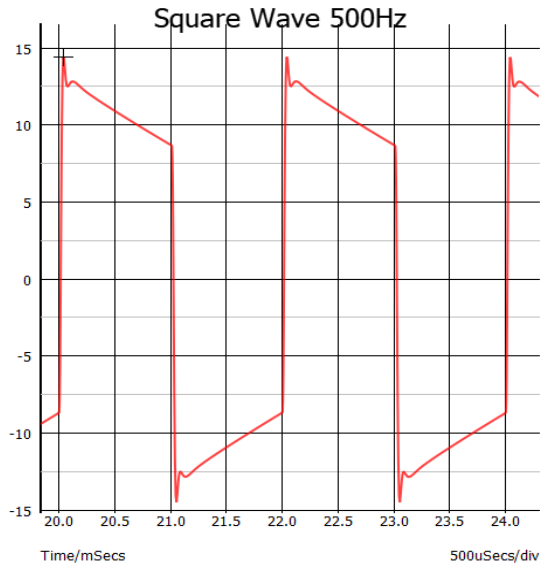
Bass: 2x 18W8535-01 2x11L closed,
fc=62.7Hz Qtc=1, Gain= 0dB

$(1+0.141s+0.01s^2)/(1+2*s+s^2)$ 500Hz
Q=0.5 Asymmetric High Shelf -40dB

$(1+1.7s)/(1+s)$ 302Hz
High Shelf(6dB/oct) +4.6dB

$(1.7+1.304s+s^2)/(1+1.414s+s^2)$
48.1Hz Q=0.71 Asymm Low Shelf +4.6dB

Peak/RMS Power 105dB: 331W/104W



Mid: 15w-8424g00 4L closed,
fc= 91Hz Qtc= 0.5, Gain= +13dB

$(0.0308+0.351s+s^2)/(1+2s+s^2)$ 500Hz
Q=0.5 Asymm Low Shelf -30dB

$(1+0.0218s)/(1+s)$ 333Hz
High Shelf(6dB/oct) -33.2dB

Peak/RMS Power 105dB: 132W/28.4W

High: 10F4424-01 2L closed,
fc=127Hz Qtc=0.4, Gain= -2.2dB

$(0.0625+0.5s+s^2)/(1+2s+s^2)$ 500Hz Q=0.5
Asymm Low Shelf -24dB

$s/(1+s)$ 366Hz High-Pass

Peak/RMS Power 105dB: 51.4W/4.45W

The RMS Power has been calculated with a loud Trance track, it may differ from other material, but is rather less.

Comparison with a two-way LR4 at 500Hz.

The same frequency response, but the pulse response is not that good. Instead of 0.18ms we have 14ms of artefacts from earlier signal superimposed,

The woofer and tweeter low and high limits do not need to be corrected, you can only see a miniscule boost at the XO frequency.