

Audio-Wizard

Purpose:

1. Conversion RCA unbalanced_in to XLR balanced_out
2. Stereo Volume-control with passive Potentiometer
3. Limiter
4. Bass-Extension and linearisation for closed cabinet speakers.
5. Precision adjustments of Bass-Boost and Q.

The gadget targets DJs, Hi-Fi Freaks and Live Musicians. It is connected between Computer, Sound-card, CD-player, Mixer or Electronic Crossover and Power-Amplifier at the output.

Operation is very simple, reference voltage (+4dBu) and time constants are internally set to optimum values. Modifications are easily implemented.

The **Limiter** has an bypass switch only, also in "off" an overload is indicated by the red LED. When active, it protects the amp or speaker from over-voltage. +20dB cracks, pops and switching transients are instantly attenuated to linear range protecting the tweeters. Also useful with mixers where the output can be cranked up to +12dB or more. When driven from a sound-card, CD-player or DSP-Xover the maximum level is fixed and the limiter can be bypassed.

Volume-control useful when driven by CD-player or computer.

Bass-Extension can linearize the Woofer when using smaller enclosures and allow a much lower (more than an octave) cut-off frequency. The circuit works perfectly with closed enclosures, but also Transmission-lines can gain from it.

It requires a bit of individual configuration for the woofer with values found by an impedance sweep (no mike needed). It can be pre-configured for commercially available woofers and sub-woofers.

Bass-Extension for Closed Cabinet Speakers:

In a Closed Cabinet the radiation of a speaker behaves like a 2nd order high-pass. It is described with 2 numbers, the **resonant frequency f_c** and the **Q-factor**. Both values can be calculated for any size of box (with TSP from the data sheet) or measured with an impedance sweep.

Below f_c the SPL falls off with -12dB/octave. With an inverse filter and powerful amp the woofer can reproduce much lower frequencies than f_c .

Linearising the Q-Factor:

Different **Q-Factors** for $f_c=100\text{Hz}$ (**Q=0.71** has the most linear response). For very small enclosures a high Q-Factor might result, it should be compensated with a filter, since our hearing is more sensitive for boosts in the frequency response.

With a proper filter (**red**) the loudspeaker response (**grn**) is linearised (**blu**). The “boomy” sound of $Q=1.41$ is compensated to $Q=0.71$

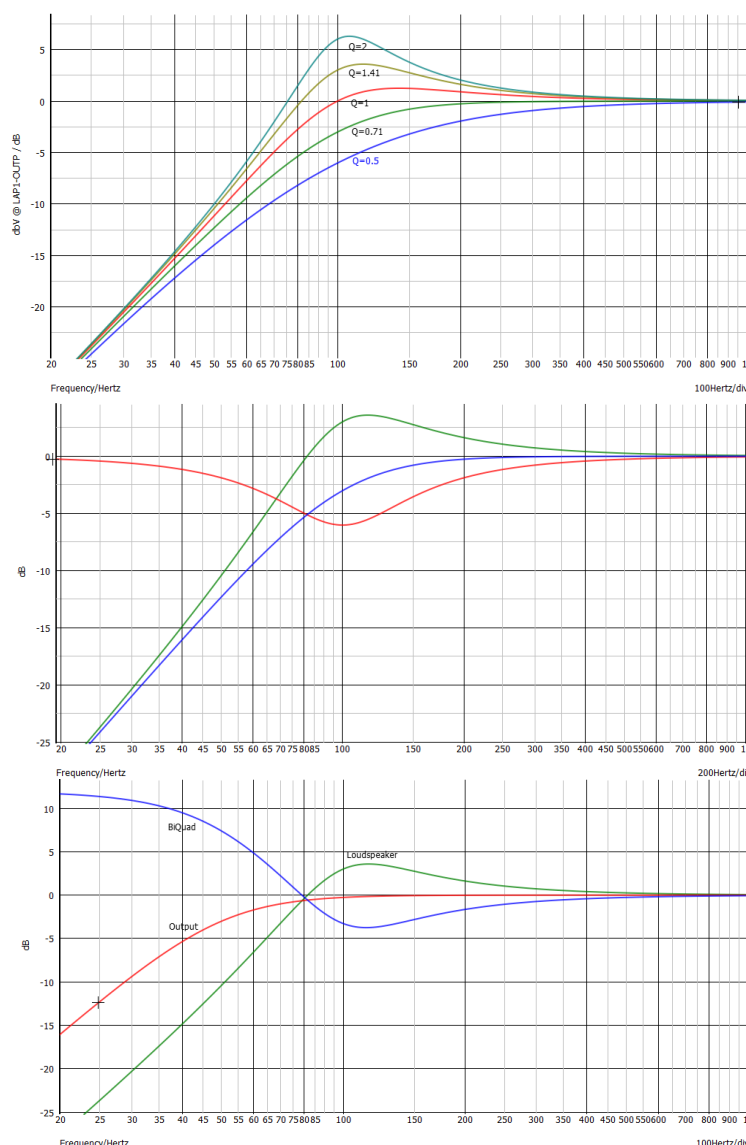
Bass Extension:

This time additionally the low end is extended by an octave from 100Hz to 50Hz . $12\text{dB} = 4\times$ gain is needed at 0Hz .

Grn Loudspeaker

Blu Filter

Red Resulting Sound Pressure



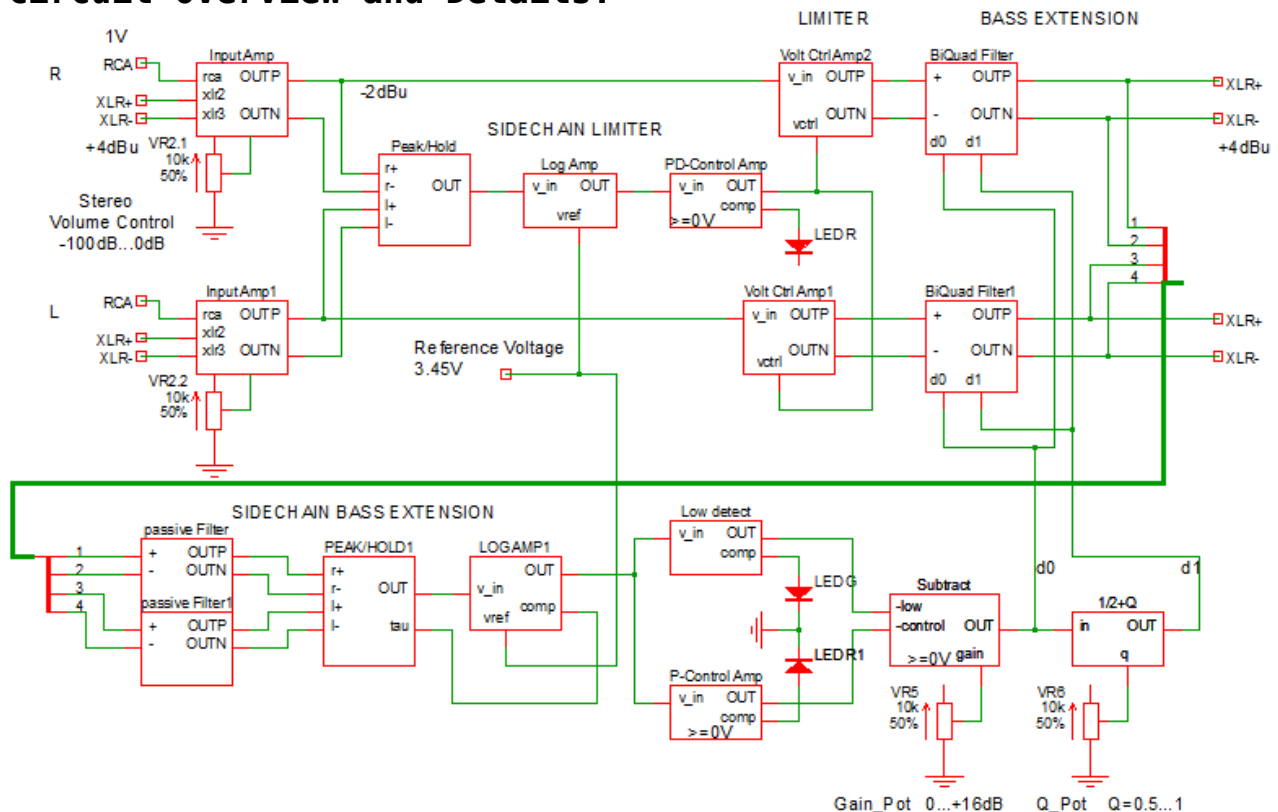
Most DSPs offer this kind of filter (asymmetric shelf), sometimes 2 filters have to be combined. But it only works at low volumes. 12 or more dB are used up to amplify the low end and distort at higher levels.

The Audio-Wizard contains **variable** filters, which process the output level and reduce the gain accordingly, so the peak is always in the linear region of amp and speaker. Unlike a compressor it doesn't change the loudness or dynamics, **only the low end slides up and down**. A single BiQuad is used to achieve this. With 16dB of bass-boost the resulting low end is $0.4 \cdot f_c$.

The Audio Wizard works **completely analogue** without delays (latency), so it can be used with live music as well.

I haven't met a digital implementation of this principle. Most DSPs calculate beforehand a pulse response and cannot “live” update it, also at low frequencies the resolution is limited by FFT length or latency.

Circuit Overview and Details:



The Audio path is straight forward: the Limiter VGA is controlled by the side-chain measuring the **peak** voltage at its input, comparing it with the threshold and calculating the control voltage. Thus its output is limited to the threshold (-2dBu). It is followed by the BiQuad filter with d0 and d1 varied by control voltages derived from the output. Threshold is -1.33dB.

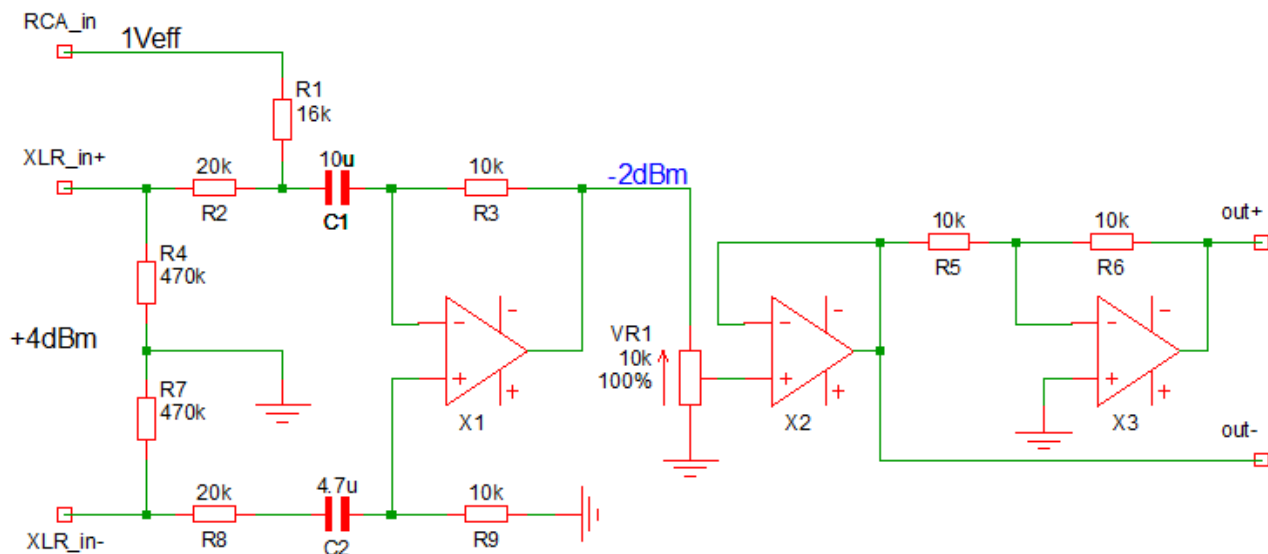
The **2nd side-chain** starts at the BiQuad output. A passive filter is followed by a 2-way Rectifier which charges the timing capacitor to the peak voltage (0.3ms). Release is very slow with 2 time constants: First -2.5dB/s until gain reduction is 0, then -5dB/s.

The next stage calculates the **logarithm** of the rectified peak Voltage/Threshold. A VGA is used to perform the conversion. The control amp amplifies to the required voltage (0...+535mV). Below 0V a comparator toggles the time constant, above 0V the **red LED** is lit to indicate gain reduction active.

The "low-level" comparator toggles when the log-amp output goes above $+1.35V \pm -40dB$. A capacitor charges and slowly(4s) reduces the gain to unity. The **green LED** is lit. Control amp out and low-level out both reduce the preset Gain voltage and the result of the subtraction is the control_voltage for "**d0**".

To perform the square root we only need to half the control voltage. The Q-pot voltage is then added. "**d1**"

Input stage:



For use with a sound-card there are RCA-inputs and balanced XLR inputs. A passive Stereo-pot (VR1) controls the Volume. The XLR_in is attenuated by -6dB to -2dBu, the RCA_in by -4.2dB. Only one kind of input (XLR or RCA) should be used.

X1 forms a differential amp with different input impedances of the inputs (30k vs. 15k) $f_u=1\text{Hz}$, so the caps C1 and C2 need to be of different size. X3 inverts as the Rectifier requires a balanced input signal. The polarity is maintained when using the out+.

Limiter:

Peak Full-Wave Rectifier:

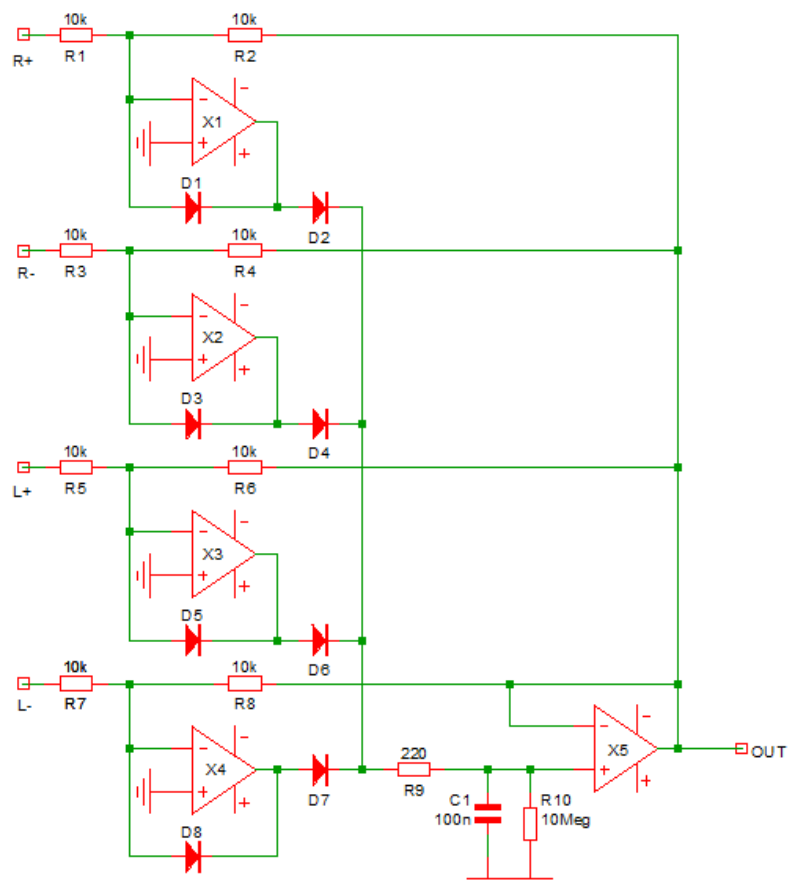
X1 to X4 are inverting and charge capacitor C1 to the highest positive voltage at any negative input.

R10 discharges C1 slowly.

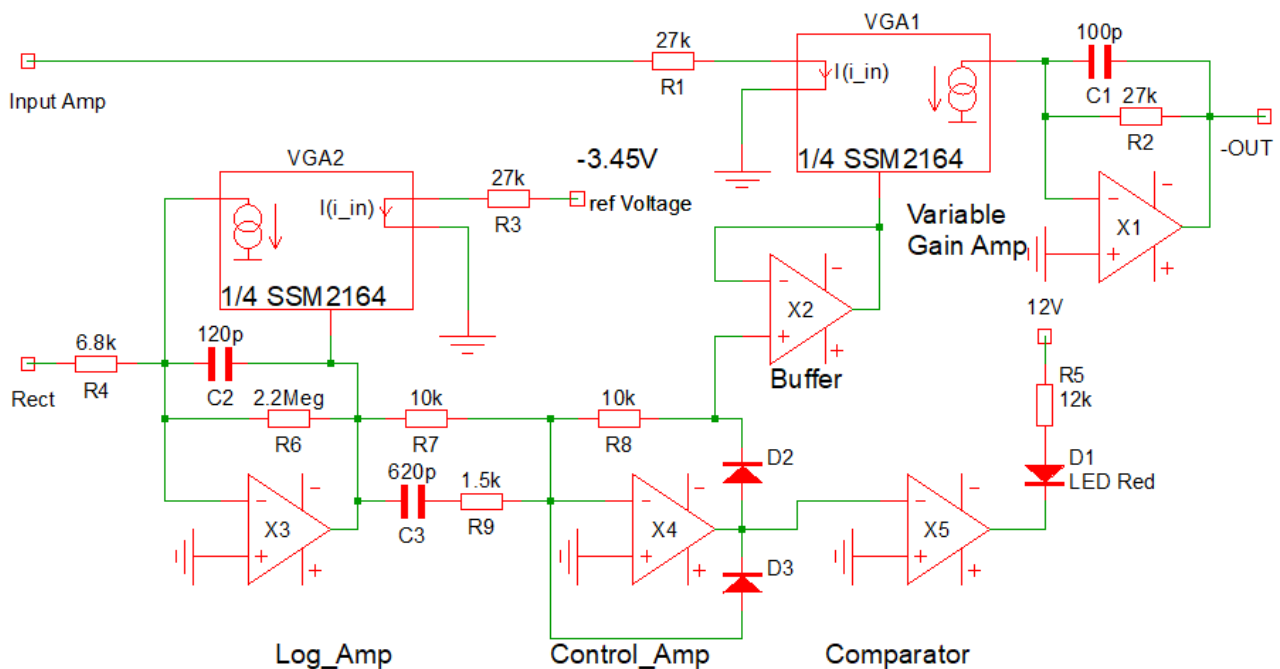
D1,3,5,8 avoid the saturation of the opamps at negative rail speeding up response.

[ADA4177-4](#) precision opamp

X5 is a BiFet opamp with high input impedance.



The rest of the Limiter circuit.



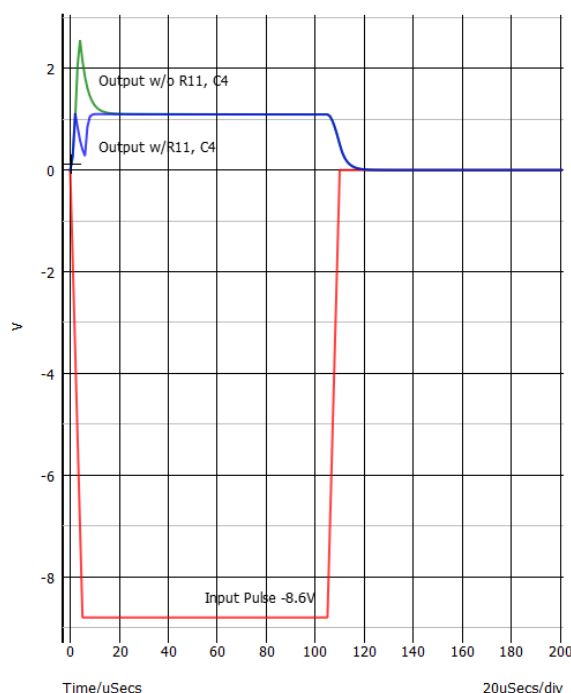
Log Amp:

At maximum overload the rectifier will output a DC signal jumping from 0V to +8.8V with 2.2us rise time and injects a current of +100uA into R4.

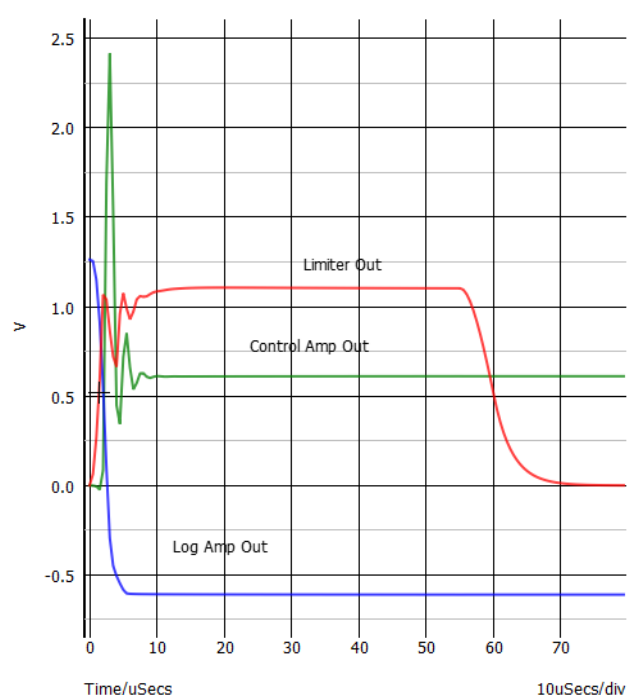
Opamp X2 out ([blue right pic](#)) moves negative until the negative current out of VGA2 equals -100uA being 8x the reference current through R3.

With a sensitivity of -33mV/dB this is $16 \times -33 = -533\text{mV}$.

When the Rect is 0V, X2_out goes positive and settles at +1.8V due to the leakage through R5 and max. -55nA output offset of VGA2.



Limiter response to overload



enlarged, higher resolution

Control Amp:

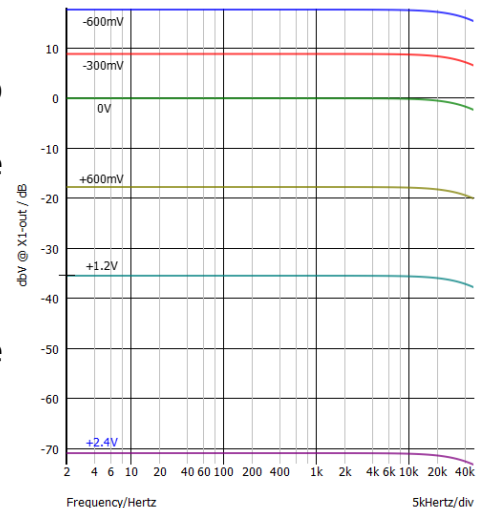
Inverts the X2 signal and adds a differential part through C3 R9 (green) speeding up the attenuation of VGA1.

Only positive polarity out.

The comparator activates a red LED when attenuation is applied.

Variable Gain Amp: [SSM2164](#)

The heart of the limiter: VGA1 input audio alternating current gets amplified or attenuated by control voltage CV. Positive values attenuate (-100dB max), 0 unchanged, negative amplify (+20dB max). In our application we only need to lower the input signal when overload, the control voltage is 0V (normal) or positive (overload). Control voltage needs a low impedance driving source (Buffer).

**Bass Extension:****Control Requirements:**

There is a lot of similarity between our task and a Compressor.

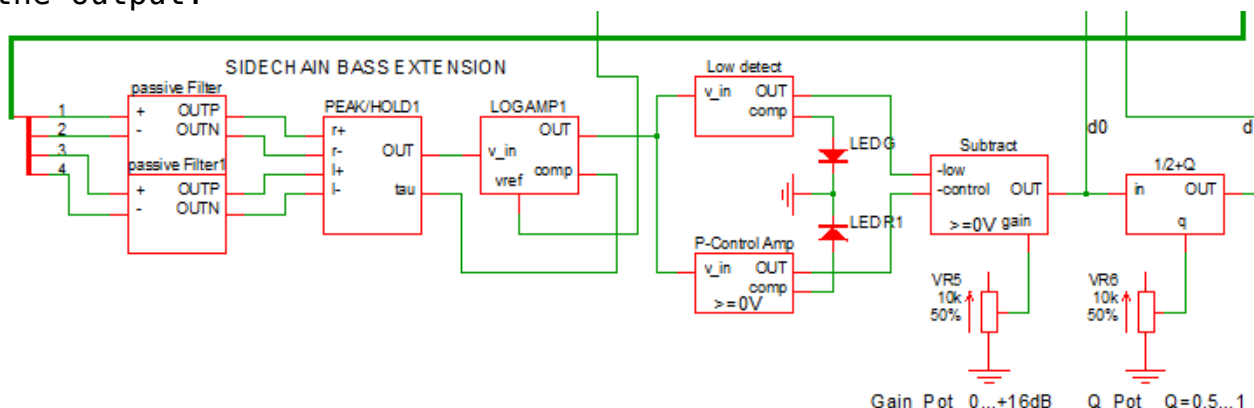
1. **Threshold level:** When a peak crosses the level, action is taken. Threshold needs to be lower than the max, to have enough time to react, but not too low to prevent triggering too often (-1.33dB).
2. **Attack Time:** As short as possible, so the control can react before the peak value is reached and attenuates it accordingly to avoid clipping. The control circuitry itself only adds a short (<0.3ms) delay and the BiQuad needs some time to settle (6ms).
3. **Release Time:** Very long to reduce regulation artefacts and ripple. 3dB/second or less. Limited by the capacitor C1 size to allow fast charging and by its leakage current.
4. **Ratio:** If our threshold is -1.33dB and the control range is 16dB → Ratio = 1:12 = Gain of Control_Amp.
5. **Bass-Boost:** dB-linear adjustable with a pot 0...+16dB.

Additional elements:

- 2nd Control_Voltage Vd1
- dual time_constant
- At low levels (<-40dB) or silence the gain is reduced to unity, so switching noises or hum are not amplified, similar to an Expander or Noise-Gate. Attack and release time are long (4s/8s).
- A dual LED lights red when the threshold level is reached, it also indicates the low level bypass (green).

Bass Extension Overview:

A look at the **side-chain** first, this time the signal is sensed at the output.



The same blocks used as the Limiter with the additional elements.

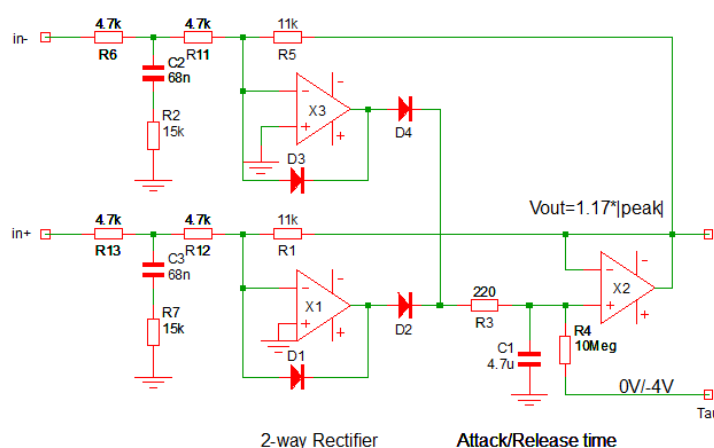
2-way Peak Rectifier with passive Filter:

Overload occurs for two reasons, either the maximum output voltage of the amp is reached, or the excursion (stroke) of the bass speaker leaves the linear range indicated in the data sheet. In both cases the **peak** voltage corresponds to the situation.

X1 and X3 low offset, noise and >35mA driving capabilities for C1.
[ADA4177](#) precision opamp.

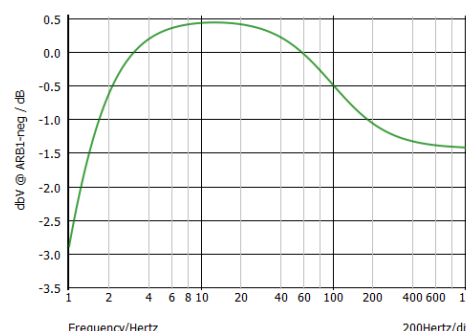
The 2 rectifiers of the right channel are connected in parallel like in the limiter circuit.

X2 is a high impedance BiFet opamp not to load the timing Cap C1. The circuit is fed back over 2 stages, so its offset gets compensated.



Output_Voltage for +4dBu_input is $11k / (4.7k * 2) * 0.868V = 1.02V \triangleq +1.33dB$. This way we can use the same reference as the Limiter; thus threshold is -1.33dB.

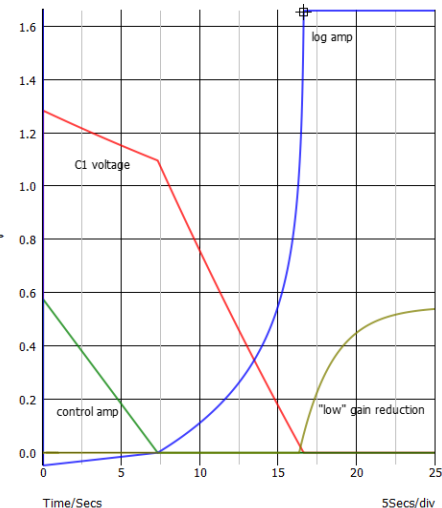
The passive Filter (R6, C2, R2, R11) attenuates higher frequencies, so they do not reach the threshold and trigger any action. It introduces very little delay (150 μ s @10Hz). Response together with the input stage (1Hz high-pass).



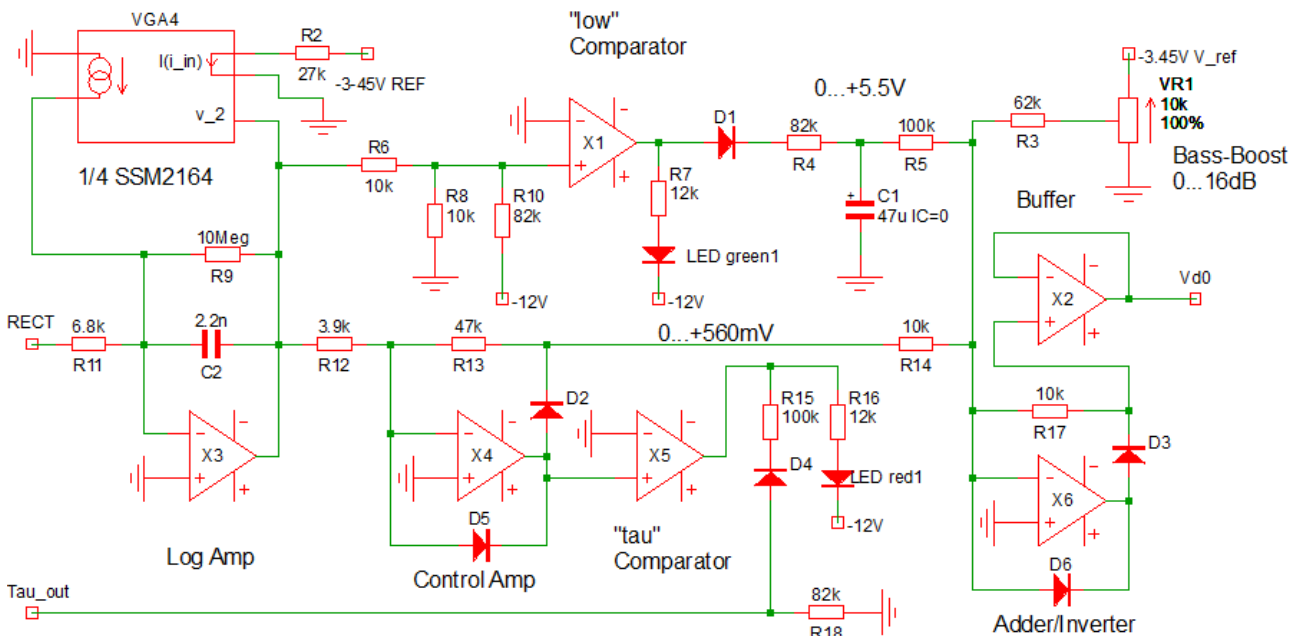
Decay of C1 with two $\tau = 47/12\text{sec}$ time constants (red) after a +4dBu burst. The timing cap C1 should have a low leakage not to alter the release time, multilayer ceramic X7R or X5R size 1206, $4.7\mu\text{F}/25\text{V}$.

The foot-point of R4 is switched from 0V to -4V when the log amp (blue) gets positiv, when it reaches +1.4V the "low" comparator charges C2 (beige).

The green and beige voltages get subtracted from the Bass-Boost voltage.



The VGA needs to be driven with a low impedance source (buffer). The buffer is either grounded through R17 or positive when D3 is conducting.



Conversion to Logarithm:

This facilitates the signal processing immensely:

Adding/subtracting instead of multiplying/dividing.
 Square root is just a division by 2.
 Linear pots get a dB-linear scale for Gain and Q.
 The loop is linearised.

The spare VGA4 is used. X1 regulates the control voltage, so that the input current through R5 equals the output current of the VGA.

$V_{in} = 1.02\text{V}$: $V_{out} = -44\text{mV}$
 $V_{in} = 0.87\text{V}$: $V_{out} = 0\text{V}$
 $V_{in} = 0\text{V}$: $V_{out} = +1.8\text{V}$
 $V_{ref} = 0.87\text{V} \cdot (27\text{k}/6.8\text{k}) = -3.45\text{V}$

Control Amp:

X4 **Proportional-Controller** amplifying the signal x12 for maximal +533mV reduction without overshoot.

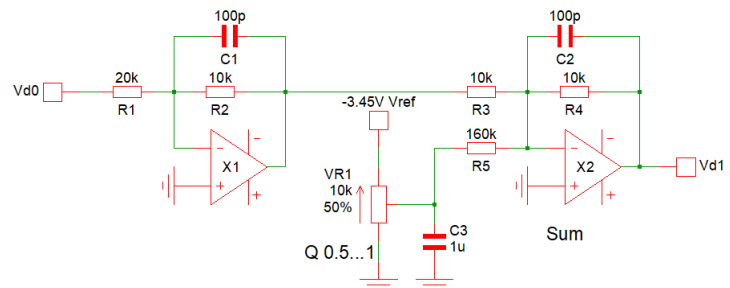
The bass-boost is set with the pot so Vc_d0 is 0...+545mV. To this R14 adds the reduction signal in opposite polarity. The diodes prevent the result going negative.

When the level is very low, Log_out gets more and more positive until at +1.35V the comparator switches to high(+10.8V). C1 gets charged to +5.6V in 4sec reducing gain to unity. When the level is again above -41dB (12mV~) C1 discharges through R3 and slowly (8sec) augments the gain to the desired level.

Vcontrol_d1:

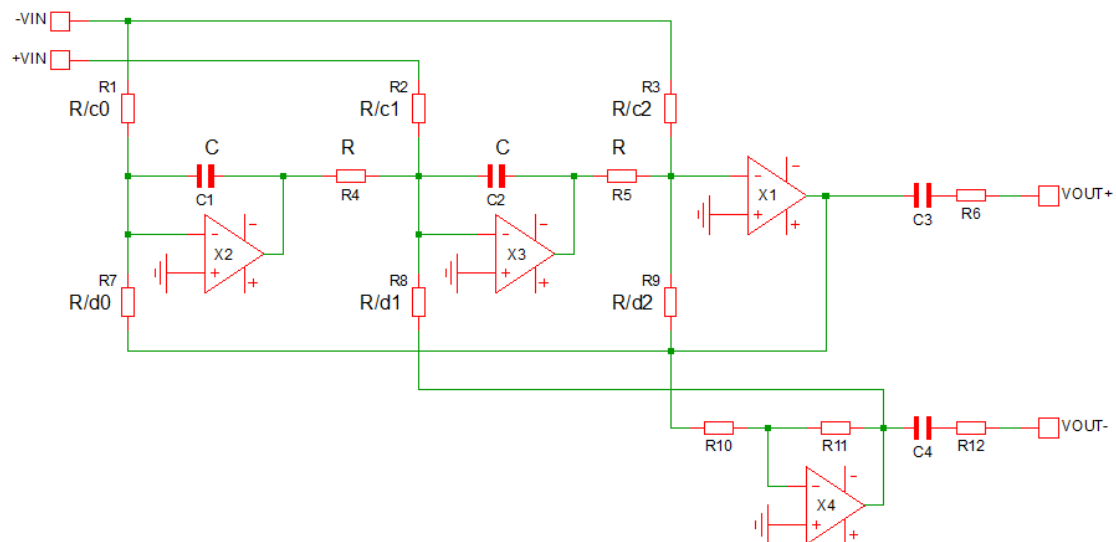
In logarithmic space a division by 2 will result in the square root in linear space.

X2 adds 0...200mV, which in linear space is a multiplication with x1...x2.



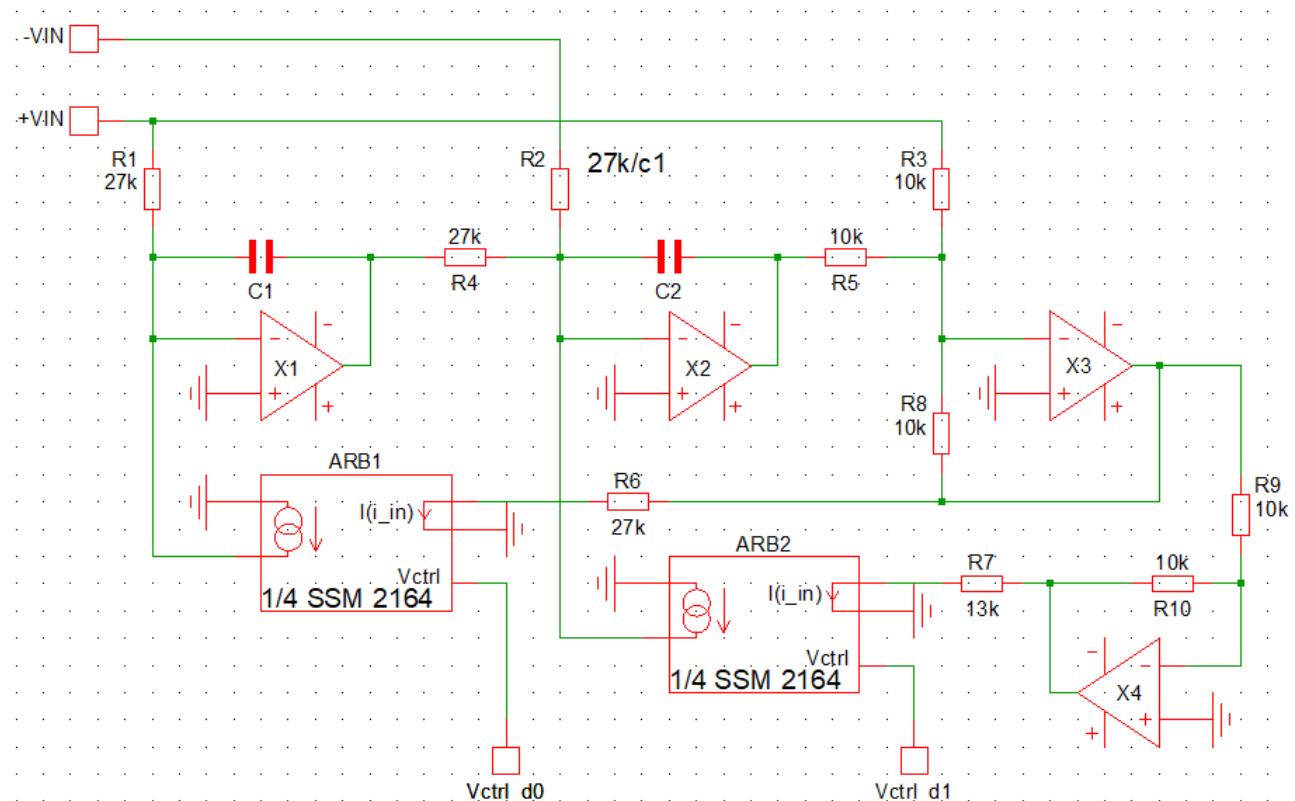
Analogue BiQuad Filter and Output Stage:

My favourite filter circuit.



- Perfectly mirrors the Laplace-Transform

$$L(f) = (c_0 + c_1 * S + c_2 * S^2) / (d_0 + d_1 * S + d_2 * S^2)$$
- All kinds of first and second order filters can be realized.
- A single resistor controls each coefficient independently.
- Easy to tune and modify with variable resistors.
- No stored energy, smooth and fast transitions.
- Low noise and distortion, balanced out operation.
- Opamp count of 5 (with input inverter), the price to pay.



Stages: 2 Integrators, 1 sum/inverter.

Each gets the Input- and Output-signal (feedback).

1st Integrator → DC to f_{res} ; 2nd Integrator → f_{res} ; Sum → $f > f_{res}$.

The op-amps are inverting, so the middle stage gets negative phase signals. Each stage adds part of the input signal and subtracts part of the output signal.

R6, R7 and R8 are all in the feedback loop of X1, which is a dividing function.

X3 adjusts the gain so that the current through R1 equals $d0 \cdot \text{current through R6}$, same with $I(R2) = d1 \cdot I(R7)$ and $I(R3) = I(R8)$. The resistors for $d0$ and $d1$ have been made variable, controlled by voltages. Positive control voltages only attenuate the feedback current through R6 and R7.

C1 C2: $C = 1/(2 \cdot \pi \cdot f_c \cdot R)$ $R = 27k\Omega$, f_c : Woofer resonance in box.

$R2 = 27k \cdot Q_{tc}$

Both coefficients $d0$ and $d1$ have to be varied simultaneously to achieve the bass boost.

For $f_c = 50\text{Hz}$:

Gain	d0	d1	F_low	Gain	d0	d1	F_low
0dB	1.000	1.000	50.0Hz	12dB	0.251	0.501	25.1Hz
3dB	0.707	0.841	42.1Hz	15dB	0.178	0.422	21.1Hz
6dB	0.501	0.707	35.4Hz	16dB	0.158	0.398	19.9Hz
9dB	0.398	0.596	29.8Hz				

Additional Circuitry and Semiconductors:

Power Supply:

AC/DC switcher $\pm 15V$ 5W followed by linear regulators to $\pm 12V$.
Line X2 cap and varistor for mains transient protection.
Reference voltage 3.45V.

Capacitors for supply and reference filtering, RC combinations for SSM2164, Cs across opamp feedback path.

Mains-connector, RCA_in, XLR_in/out on back panel.

1 Audio-pot 2x10k_log, 2 Pots 10k_lin, 2 LEDs, Lim_bypass and temperature switch on front panel.

4 [OPA1678](#), 1 OPA1679, 4 [ADA4177-4](#),
2 [TL074](#) BiFet Buffer and Comparator
2 [SSM2164](#) quad VGA (Variable Gain Amp) replace with [V2164](#)
12 [BAV199](#) dual diodes, 1 [TLV432](#) adjustable reference diode
Fits on 100x160mm² dual layer PCB with SMD-parts.

Installation and Calibration:

The **BiQuad has to be configured** (4 C, 2 R) with data (fc, Q) of our loudspeaker mounted and dampened.

[REW](#) is a free app, a sound-card with stereo input and headphone output is needed and a resistor (around 47 Ω 1%).

Alternately we can insert the values calculated from data-sheet.

fc	105Hz	87Hz	72Hz	60Hz	50Hz	40Hz
C1, C2	56nF	68nF	82nF	100nF	120nF	150nF

$R = 27k\Omega$ C1 C2: $C = 1/(2*\pi*fc*R)$ $R2 = 27k*Qtc$

Provision to parallel another capacitor for precise adjustment.

Make sure your amp is adjusted to 4dBu input sensitivity and do not move the pots any more.

Use the sound-card output with a 0dB sine burst 20-30Hz, amp off, Lim bypass, Volume-control max, Gain 0dB. If the Limiter LED lights up, reduce the sound-card output slowly until it just remains off or use the Volume-control. Leave the setting once calibrated.

Examples:

The Audio-Wizard allows using many more speakers in closed cabinets, even if they were designed for reflex enclosures. High efficiency drivers with hard suspension and low moving mass have a relatively high resonance and can produce high SPL, but are usually not usable as a subwoofer in closed enclosures.

A big (Ø46cm) but very light and efficient driver, Neodymium magnet, 200€. Feital [18FH500](#)



Name	Dia	SPL @P	fu Q	Box	Gain	Stroke	Boost fu	fo
15LEX1600 Beyma	15" 6.1Ω	123.9dB 3200W	69.3Hz 0.60	40.3L	-9dB 115dB	±11mm 3200W	11dB 36.8Hz 16dB 27.7Hz	1200Hz 423€
18XL2000 Feital	18" 7.0Ω	127dB 4000W	59.7Hz 0.58	65.5L	-12dB 115dB	±14mm 4000W	14dB 26.7Hz 16dB 23.9Hz	700Hz 500€
18FH500 Feital	18" 6.0Ω	125.2dB 1430W	75Hz 0.88	80L	-10dB 115dB	±7.7mm 1430W	12dB 37.5Hz 16dB 30.0Hz	700Hz 200€
18PWB1000 Beyma	18" 6.8Ω	123dB 2000W	55.8Hz 0.78	97L	-8dB 115dB	±9.7mm 2000W	10dB 31.4Hz 16dB 22.3Hz	700Hz 344€
18LX60 Beyma	18" 7.1Ω	123dB 1400W	60Hz 0.91	126L	-8dB 115dB	±6.6mm 1400W	10dB 33.8Hz 16dB 24.0Hz	250Hz 290€
LF21N451 RCF	21" 7.1Ω	126.5dB 3000W	55.3Hz 0.48	156L	-11.5dB 115dB	±11mm 3000W	14dB 24.7Hz 16dB 22.1Hz	250Hz 469€

For the list I corrected the sensitivity and chose the box size to reach maximum **linear** excursion with the stated amplifier.

Boost fu: the upper value can be reached continuously at 115dB, the lower when the level is lower.

Since we attenuate the channel, the mid-bass frequencies need a lot less power and do not contribute much heat. Cross-over frequency can be higher and smaller mid- or full-range speakers can be used.

Another advantage is that the **baffle-step** will cause less than -6dB sensitivity loss at higher frequencies, with **50cm width** the -5dB point will be around 100Hz, -3dB at 260Hz and -1dB at 600Hz. 1KHz+ has half space efficiency.

All this considered the next table shows a few mid- and one full-range driver. Interesting a combination 18FH500 with 3x 3FE22 in a line array. The other midrange speakers need additionally a treble system.

Name	Dia.	SPL	Fc/Qtc	X-over	Box	Amp	fo	Price
8LW30 Beyma	8"	116.6dB	134Hz 0.71	134Hz ±3.9mm	6.04L	500W	2.5kHz	179€
8PE21 B&C	8"	121.5dB	324Hz 0.71	>430Hz ±0.5mm	1.0L	400W	2kHz	123\$
6MCF200 Beyma	6"	120.4dB	406Hz 0.72	406Hz ±0.8mm	Sealed Back	400W	3kHz	250\$
5MDN38 B&C	5"	116.0dB	377Hz 0.71	377Hz ±0.8mm	0.41L	200W	4kHz	92\$
3FE22 Feital	3x 3"	115.0dB	165Hz 0.71	>598Hz ±0.5mm	0.87L	3x 40W	20kHz	3x 33\$

Conclusion:

Unfortunately very few drivers are suitable for closed cabinet mounting, you need higher Qts and lower fs than vented. To reach <30Hz is almost impossible with a box of manageable size.

With the Wizard many more models can be used and the cabinet size reduced.

Generally very low frequencies <33Hz are recorded way below 0dB, so a medium gain setting would not even trigger the reduction (red LED) even at higher levels.

That makes it ideal for HiFi home use without the low-cut filter with side-effects on delay and transient response. Group-delay is a good quality measure. Above 10ms at 40Hz or 20ms at 20Hz it becomes noticeable, deep bass doesn't integrate and seems to leap behind.

Green: Frqu. closed (32Hz)

Beige: Delay closed 11ms

Red: Frqu. vented (32Hz)

Blue: Delay vented 48ms

with HP 24dB/oct 28Hz
(vented) and 125Hz L_R 4th LP

