

## A Guide To Build A High Quality Sub-Woofer

### Intro:

Every Bass-Driver needs some kind of enclosure to avoid movement of air from front to back of the cone (acoustic short circuit).

A **closed cabinet** is easy to calculate by hand and will bring predictable results even without using specialized software.

It is also much easier to build and smaller than other enclosures.

With the **Thiele-Small Parameters** (TSP) published by every manufacturer we can select a suitable driver and calculate frequency\_response, efficiency, net cabinet size and a lot more.

Closed cabinets allow the most linear response, shortest delay and cleanest sound reproduction, but give less power in the bass.

### Applications:

- **Professional** (disco, concerts, live gigs, cinema):  
high Sound Pressure Level (>110dB),  $\leq 33\text{Hz}$  f(-3dB),  
25Hz f(-3dB) cinema, max 125Hz, multiple units for higher SPL
- **Home theatre** (THX standard, 5+1, 7+1, 1 or more units)  
medium SPL (>105dB), low distortion,  $\leq 33\text{Hz}$  f(-3dB), 80Hz.
- **Stereo HiFi** (CD-player, Vinyl, HD)  
medium SPL,  $\leq 27\text{Hz}$  f(-3dB), 80-500Hz.
- **Car** The small cabin has a strong effect on frequency response and our method doesn't apply.

### Frequency and Level:

Adult (30+) human hearing ranges from 16Hz to 16000Hz. An octave interval has double the frequency. 16 to 32Hz or 8000 to 16000Hz contains the same number of tones, a **logarithmic** scale.

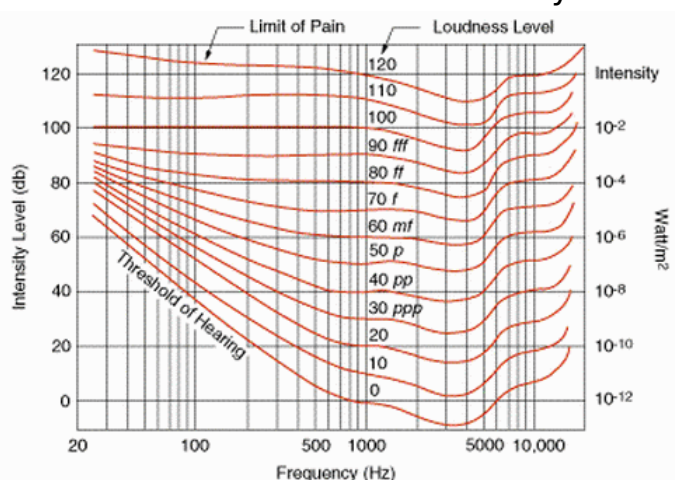
The very deep tones are more felt as a vibration in the belly.

Also the level is perceived logarithmically, range is 120dB = 1:1000000.

Our ears are super sensitive around 3200Hz, where higher harmonics of voices are situated, to instantly recognize the person.

In the deep bass the sensitivity is much less at low levels, to not hear the bumping of our steps or the heart beat.

Above 90dB our hearing is almost linear. An symphony orchestra creates 96dB peak (fff) in the first rows.



### Lowest Frequency of Assorted Instruments:

Big Pipe Organ	Keyboard 88	5-string Bass	4-string Bass
16.35Hz = C0	27.5Hz = A0	30.87Hz = B0	41.2Hz = E1
Bass Saxophone	Kick-Drum	Guitar	Male Voice
51.91Hz = Ab1	60Hz+	82.41Hz = E2	From 80...86Hz

A street musician (Gui, Voc) will be happy with 80Hz f(-3dB).

A classic rock band (Bs, Gui, Gui, Dr, Voc) needs 40-45Hz f(-3dB) with keyboard or 5-string bass  $\leq 33$ Hz.

THX surround requires 33Hz; effects (earthquake) will sound better with 25Hz.

The organ is challenging, a bass boost will be needed.

### The Most Important Parameters:

The resonant frequency **fs** and total quality factor **Qts** (datasheet) both rise by the same amount when the speaker is mounted in a closed cabinet, because of the spring action of the enclosed air.

$$1. Qts * \alpha = Qtc \quad \alpha = Qtc \div Qts$$

$$2. fs * \alpha = fc \quad \text{[TSP explanation](#)}$$

-s = free standing, -c = mounted in a case.

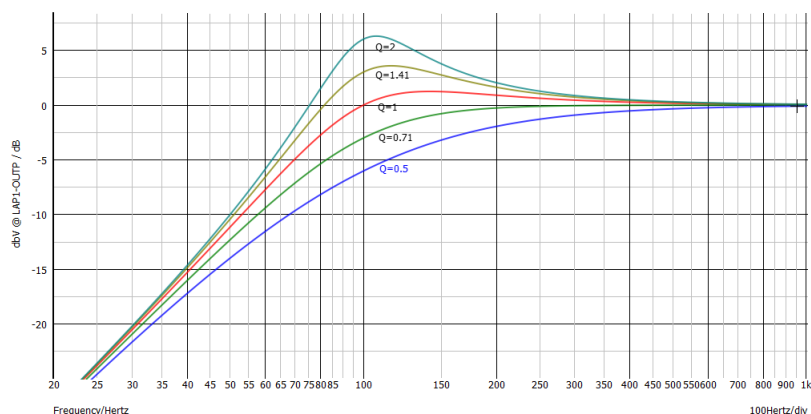
Response of different Q-factors for f=100Hz.

Q value  $\Delta$  amplitude at resonance

Most linear **Q=0.7071**, above more and more "boomy" sound, below early fall off, but better pulse response.

**Vas** = equivalent Volume in litres

$$3. Vas \div (\alpha^2 - 1) = Vc \quad \text{net enclosure size}$$



### Sensitivity:

The average SPL at 1m distance across the usable frequency range when applying 1W into the **minimal** impedance.  
(4Ω  $\Rightarrow$  2V~; 8Ω  $\Rightarrow$  2.83V~; 16Ω  $\Rightarrow$  4V~)

We have to be careful with the figures of the manufacturer, often 4Ω-speakers are measured with 2.83V which gives 3dB more.

Best is to determine Impedance ( $\Omega$ ) and level (dB) from the diagrams in our frequency range. The impedance is the minimum  $\Omega$  value after the resonance peak, usually between 50 and 200Hz.

The frequency response measurements are taken with the speaker mounted into an infinite baffle (wall). This prevents the pressure to propagate backwards and increases the bass level by 6dB, which have to be **subtracted** for a free standing box.

Sensitivity published value (dB) -  $\Omega$ -correction - **6dB** = dB/1W

### Maximum Sound Pressure Level:

The SPL is proportional to the driving voltage, so 4 times the voltage is 4 times the Level (+12dB). This requires 16 times the power, since also the current increased 4x.

power = voltage \* current. [dB-Calculator](#)

-20dB	-10dB	-6dB	-3dB	-1dB	Ref0dB	+1dB	+3dB	+6dB	+10dB	+20dB
0.100	0.316	0.501	0.708	0.891	1.000	1.122	1.412	1.995	3.162	10.000

dB-values always refer to a Reference Value(0dB), here it is "1".

When dBs are added or subtracted, ratio values are multiplied:

$$17\text{dB} = 20\text{dB} - 3\text{dB} \triangleq 10.0 * 0.708 = 7.08$$

$$60\text{dB} = 20\text{dB} + 20\text{dB} + 20\text{dB} \triangleq 10 * 10 * 10 = 1000$$

The data-sheet gives RMS Power and Peak Power (usually 2x RMS). The voice-coil can heat up to 200°C or more until it fails.

Inside a closed box the air gets warmer and has less cooling effect.

Power rises to the **square** when the SPL is increased. An amp of 700W  $\triangleq 20+20+20-3= 57\text{dB}$ . The square root is just **half** the dB value.  $57 \div 2 = 28.5\text{dB}$ . The SPL rises by 28.5dB.  $10*\log(\text{Power})$

This value is added to the Sensitivity (dB/1W) we calculated before to obtain the **maximum Sound Pressure Level**.

Choosing a proper amp is not difficult. Usually the recommended peak value is safe for the speaker even in a closed cabinet.

Sub-Woofer drivers have a low efficiency and require powerful **amplifiers** to reach higher SPL. With the advent of digital amps a lot of power at convenient price is available.

**NU12000** The specs give different values for different speaker impedances. 2x6000W into 2 $\Omega$ ; 2x3400W into 4 $\Omega$ ; 2x1700W into 8 $\Omega$ . For 6 $\Omega$  we can calculate 2x2266W.

Many cheap digital amps can not deliver full power at very low frequencies, this might or might not be a problem depending on the speaker impedance.

Digital pro-amplifiers tend to have a higher distortion which is usually not a problem for a sub, since the speaker produces already several % even at medium levels.

When using only a single sub-woofer 6dB higher level has to be reproduced. It also requires a low cross-over frequency of 80Hz (100Hz max), recommended in THX specs.

### Maximum Excursion:

$X_{max} (!cm!) \text{ from data-sheet} * S_d = V_d$

[dB-Calculator](#)

Rule of thumb:  $V_d * 0.37 * f_c^2 = \text{ratio} \triangleq \text{max linear level (dB)}$ .

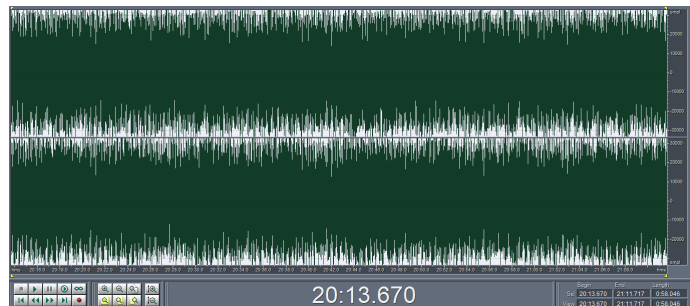
It needs to be **greater** than the max SPL calculated before.

### Four Factors Reducing Power Consumption:

#### 1. Program Material

I analysed the loudest 56 sec. of a powerful Goa Trance track with extreme Bass:

	Left	Right
Min Sample Value:	-32768	-32768
Max Sample Value:	32767	32767
Peak Amplitude:	0 dB	0 dB
DC Offset:	-.001	0
Minimum RMS Power:	-7.16 dB	-7.07 dB
Maximum RMS Power:	-4.37 dB	-3.95 dB
Average RMS Power:	-5.54 dB	-5.49 dB
Total RMS Power:	-5.53 dB	-5.47 dB
Actual Bit Depth:	16 Bits	16 Bits
Using RMS Window of 1000 ms		

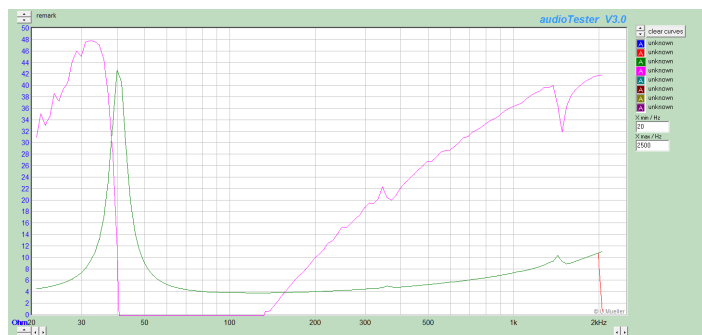


The Total RMS Power is **-5.5dB**. Some D&B tracks might go up to -3dB.

#### 2. Impedance

A look at the impedance plot of this 4Ω woofer in a box shows a minimum of 4Ω from 100-200Hz, but between 30 and 70Hz it is higher than 8Ω and less than half the power is absorbed.

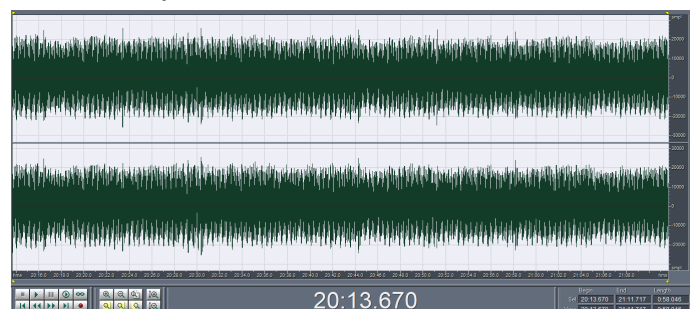
Power is reduced by **-3.5dB** for our track.



#### 3. Cross-over Frequency

Now the same track filtered with a low-pass 100Hz L-R 4<sup>th</sup>:

	Left	Right
Min Sample Value:	-24277	-24445
Max Sample Value:	26135	26170
Peak Amplitude:	-1.96 dB	-1.95 dB
DC Offset:	-.004	-.002
Minimum RMS Power:	-9.94 dB	-9.94 dB
Maximum RMS Power:	-5.81 dB	-5.47 dB
Average RMS Power:	-7.7 dB	-7.7 dB
Total RMS Power:	-7.68 dB	-7.67 dB
Actual Bit Depth:	16 Bits	16 Bits
1000ms Window		



Cutoff Frequency	Peak Amplitude	Maximum RMS Power	Total RMS Power
No Filter	0dB	-1.85dB	-5.78dB
500Hz	-0.51dB	-1.93dB	-6.10dB
125Hz	-1.89dB	-2.35dB	-7.11dB
100Hz	-2.40dB	-2.74dB	-7.64dB
80Hz	-2.87dB	-3.53dB	-8.56dB

Linkwitz-Riley high-pass of 4<sup>th</sup> order; 50ms Window

#### 4. Thermal Compression

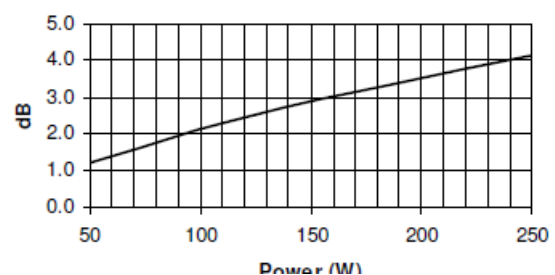
Only 1-2% of the power is radiated as sound, 98% are transformed into heat in the voice-coil.

Every metal increases its resistance when it gets hot and less current can flow.

At 200°C the maximum is reached and 4.1dB of compression occurs.

The average power is lower and we can assume a compression of **-2dB** with a fully driven amp.

#### POWER COMPRESSION LOSSES



Beyma 10" driver

The higher resistance increases the  $Q_{tc}$  by almost the same amount. When the box was designed to have  $Q_{tc} = 0.71$ , with 2 dB compression it will rise to 0.89 and a very "boomy" impression will result. An Equalizer can compensate for this.

#### Thermal Result:

Adding together: -5.5dB -3.5dB -2.2dB -2.0dB = **-13.2dB**.

For headroom (D&B) and warming of air inside the box we can add 3.2dB and get -10dB of 800W =  $0.316 * 800 = 252.8W$  which is far below the 400W specified.

Since after the x-over there is only -2dB peak Amplitude, 2dB gain could be applied in the x-over and still the specs are (just) met. A **limiter** should prevent occasional clipping and distortion.

With normal program material using an 800W amp is always secure, as long as no low frequency feedback occurs over extended time (turntable or live gig). A low cut at 20Hz is needed in these cases.

There is no danger of excessive excursion, which easily destroys vented speakers, as long as the box is **hermetically sealed**.

#### Driver Selection:

Only a few speaker models are suitable for closed cabinets, a low  $f_s$  (<30Hz) and a high  $Q_{ts}$  (0.40-0.55) are needed.

I designed a gadget (**Audio Wizard**) which dynamically boosts the low end to reach  $f(-3dB)$  more than an octave lower than the resonance. It can also compensate for the thermic increase of  $Q_{tc}$ .