Earendel Sub

Earendel (Eärendil) is a character in Tolkien's works, the name however goes even more back in history in Norse mythology, then as Aurvandill. The name is said to mean 'Rising star'.

The Hubble telescope spotted WHL0137-LS which was nicknamed Earendel. The star is 28 billion light-years away and is the earliest known star. The star saw its youth when the universe, as we know it today, was still a baby.

This loudspeaker project complements the earlier presented Earendel full range with a subwoofer capable to play down 10Hz. The objective is to reproduce the LFE channel in movies. The LFE channel is specified for the frequency range up to 120Hz and can contain audio down to 3Hz (is 3Hz audio anymore?).

Good reproduction of low frequencies is supposed to give more truthful sound effects. One challenge is that it takes a lot of power and displacement of air to achieve any meaningful sound pressure at very low frequencies, despite what they all say, size matters!

Volume displacement is achieved in two ways, large linear voice coil displacement or large cone area, preferably both. Large linear displacement (large Xmax) inherently requires large magnet systems. Low frequency extension requires high cone mass, which in turn means even larger magnet systems for an acceptable efficiency (read keep the electricity bill low)

The following sections describe the subwoofer. The loudspeaker design is done in LspCAD 6 with the accompanying justMLS tool for the measurements. CAD drawings of the cabinet are shown later.

Initial study

An initial study was done on a few loudspeakers, the author only considered 15” or larger units. Of all the loudspeaker units considered, the three below were selected as final candidates.

- 21” Beyma 21LEX1600Nd
- 21” Dayton Audio HTS545HE-4 Kraken
- 15” Dayton Audio MX15-22

A Hypex FA502 plate amplifier is considered for the design, it can deliver 1000W RMS in bridged mode to a 4ohm load. This corresponds to ~60Veff.

For comparison, the same amplifier is considered for all loudspeakers even though the Dayton Kraken and Beyma unit can handle way higher input power. The main reason is that the wall outlet fuse can only handle 10A (2200W) and there is a need to allow power for other amplifiers and a TV.

All units are in closed cabinets. A relevant question is if one can consider bass reflex or passive radiator boxes, as these can output a higher SPL around the tuning frequency?.
The challenge is that reflex loading requires large port areas to avoid chuffing noise and port compression and then the ports become quite long. Passive radiators add an extra cost to the project, and it requires quite large passive radiators to avoid over excursion.
Most important is however that the cone excursion becomes uncontrollably large below the tuning frequency for both ported and passive radiator boxes. This makes high pass filtering to cut off frequencies below the tuning frequency necessary as the LFE channel can extend to very low frequencies.
In comparison, a closed box inherently limits the cone excursion because of the compliance in the box.

The three alternatives are compared against one another in LspCAD at 60Veff, which equals to 900W over a 4ohm load. The 21” units are placed in a 120 litre box whereas the 15” unit is placed in a 55 litre box. All the units manage the input power without exceeding their respective Xmax.
The 21” units are capable of up to 10dB higher SPL than the 15” around 100Hz. The interest is however in reproducing low frequencies. The Beyma 21” does only give ~2dB higher SPL than the 15” Dayton at low frequencies, and given the more than twice as large box, this is ruled out. The 21” Dayton Kraken is definitely interesting, and it can handle up to 2000W. But… a closer look in the specs reveals that it weights 53kg. A complete box would likely weight up to 90kg, a bit too much brokeback for the author.

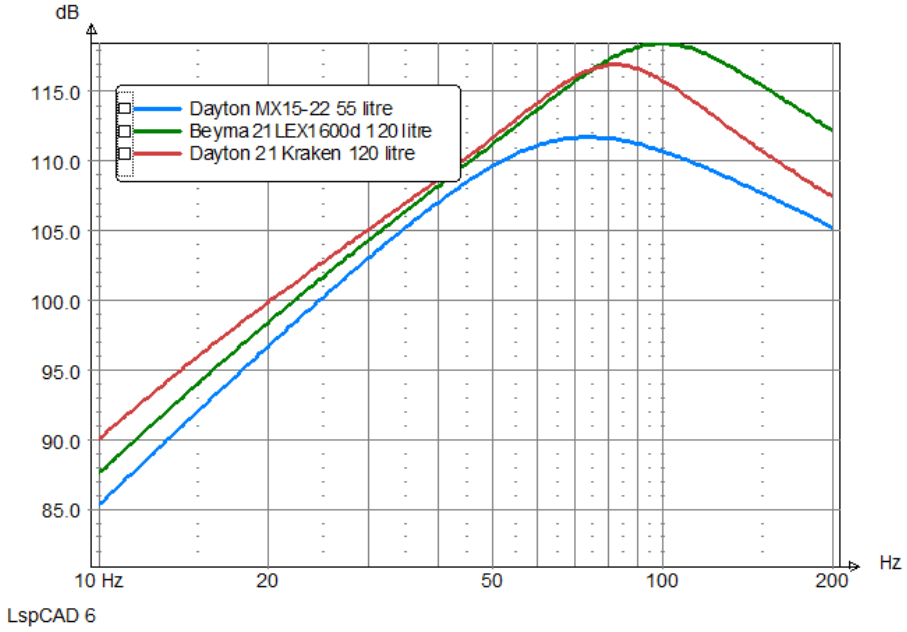


Figure 1 SPL at 60Veff

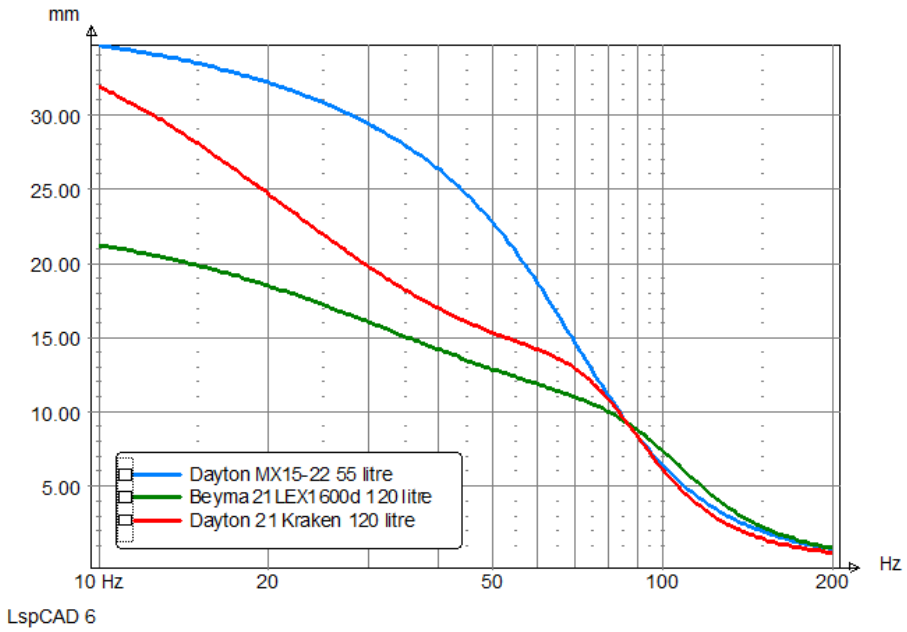


Figure 2 Cone excursion mm p-p

This leaves us with the Dayton MX15-22.

Design of loudspeaker with Dayton audio MX15-22

The question is if the volume is enough. Figure 3 shows the SPL at 1m with 60Veff (900W) input and different cabinet volumes. A 95 litre box gives 3dB higher SPL at 10Hz than a 55 litre box. Here we need to consider the SAF (Spouse Admittance Factor). So we settle for the smallest box. The building plans are seen in Figure 12. The internal volume is 64 litre, the loudspeaker unit and internal bracing is expected to take ~9 litres, which leaves a box with a volume 55 litres.

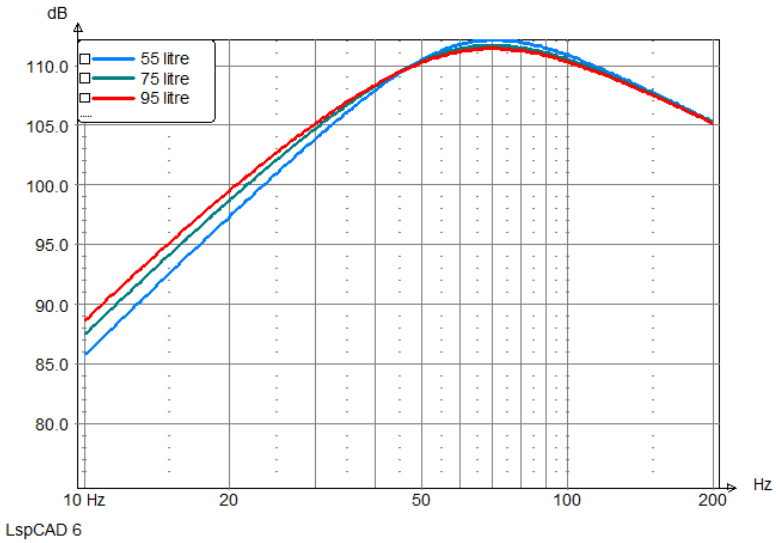


Figure 3 Dayton MX15-22 at 60Veff (900W) and different box volumes

The Hypex FA502 has a built in DSP that can be used to flatten out the frequency response a bit. The first step is to add a modelling of baffle diffraction and reflections from the closest walls. In this case the subwoofer will be placed in a corner

The schema in LspCAD for this is shown in Figure 4.

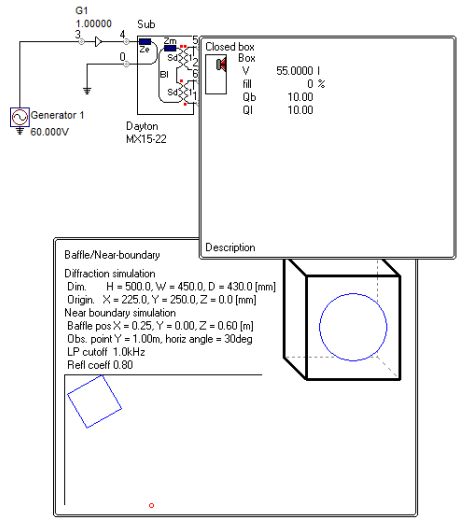


Figure 4 LspCAD schema for closed box loudspeaker with diffraction and near boundary modelling.

The output SPL at 1m and 60Veff is shown below. The max SPL is 121dB at 75Hz.

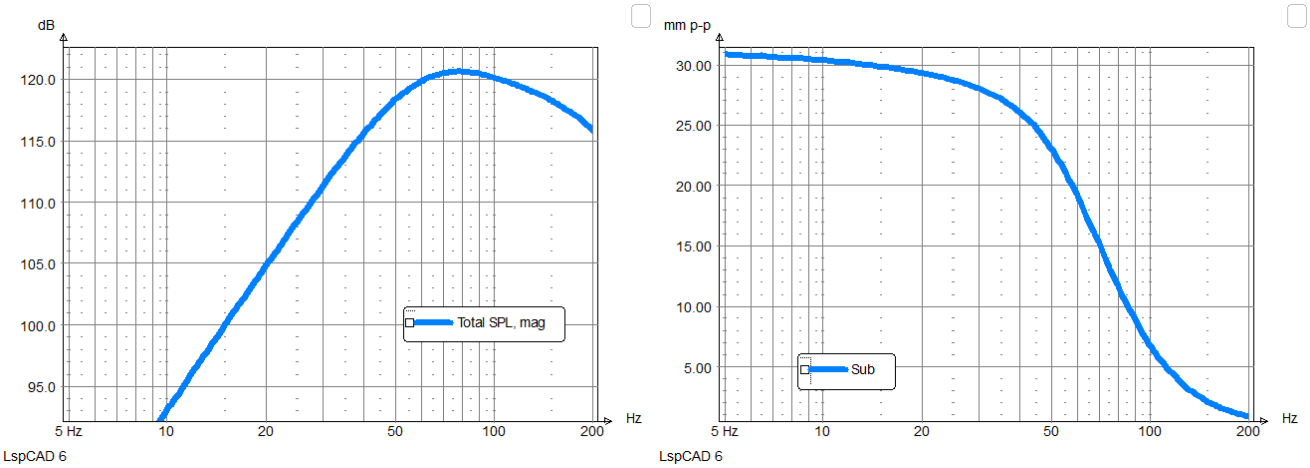


Figure 5 Simulated SPL and Cone excursion @60Veff (900W into 4ohm). Distance 1m

Worth notice is that these figures are estimated with the subwoofer placed in a corner and the measurement microphone 1m away. Actual SPL in a room is both higher and lower, lower because the distance is more than 1m (3m is more likely), and higher because an actual room has more boundaries than the floor and the two closest walls that modelled in LspCAD.

The subwoofer is measured placed in a corner in a 25 m^2 room with the microphone 3m away in listening position. The response shows a large bump at 35Hz, in addition the response fall with a modest 5dB/octave towards lower frequencies, which shows that there is a considerable room gain towards very low frequencies.

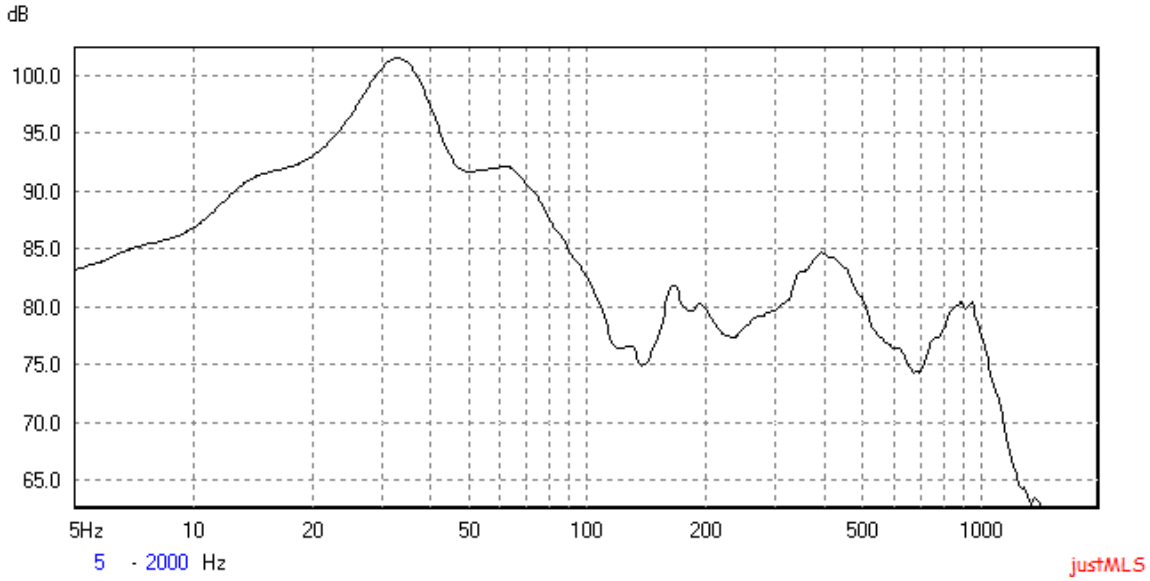


Figure 6 Frequency response at listening position without frequency equalization. The dB measure is not the actual SPL.

Filter design

Figure 7 shows 4 BiQuad filters to equalize the response and get a reasonably flat response in the passband. The resulting transfer function is shown in Figure 8. A lowpass filter is added to remove possible higher frequency noise induced in the signal cable.

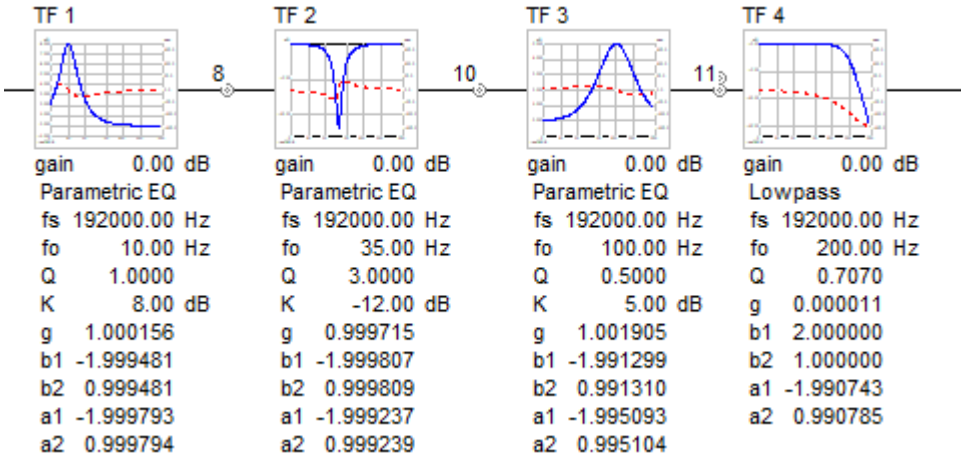


Figure 7 BiQuad filter links.

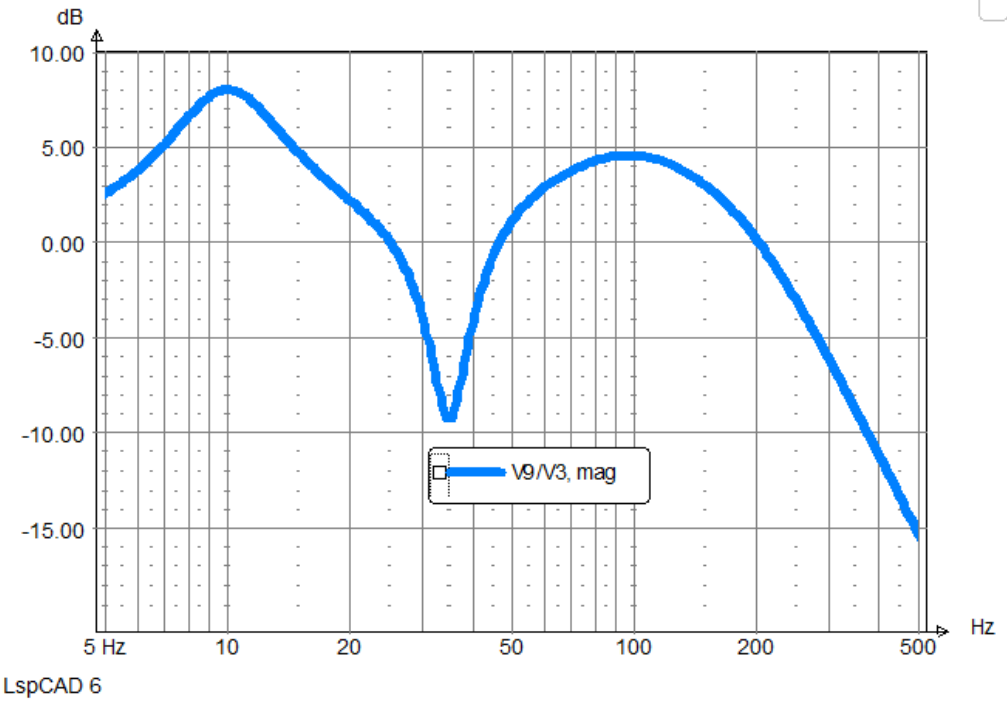


Figure 8 Transfer function of final filter and equalization.

The resulting room response is shown in Figure 9.
The subwoofer plays down to ~12Hz -3dB with a -12dB point at ~8Hz.

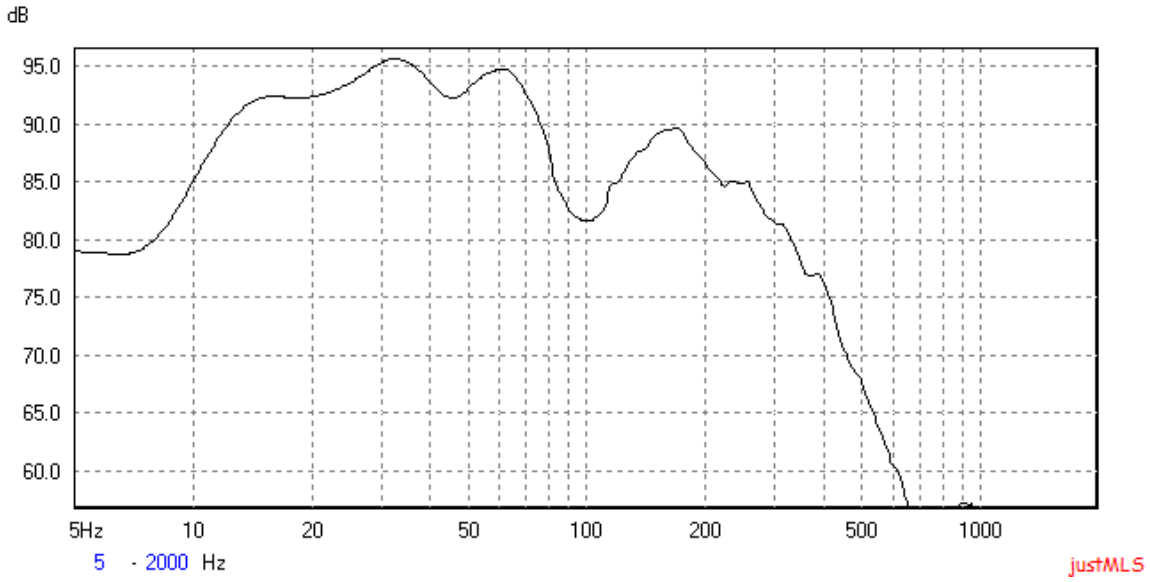


Figure 9 Frequency response at listening position with equalization. The dB measure is not the actual SPL.

The Hypex FA502 amplifier is configured in bridged mode for the desired transfer function The amplifier has a built-in limiter. Without the limiter the power amplifier can enter protection mode and shut down briefly (~1 second) when overloaded, the short shutdown can be quite annoying. The limiter is thus configured at roughly 80% of max power, with a relatively short attack time to avoid the shut down effect. Some additional experimentation is needed to get the proper behaviour; the current settings was evaluated to work fine when trying out with the atomic bomb explosion sequence in the movie “Oppenheimer.”

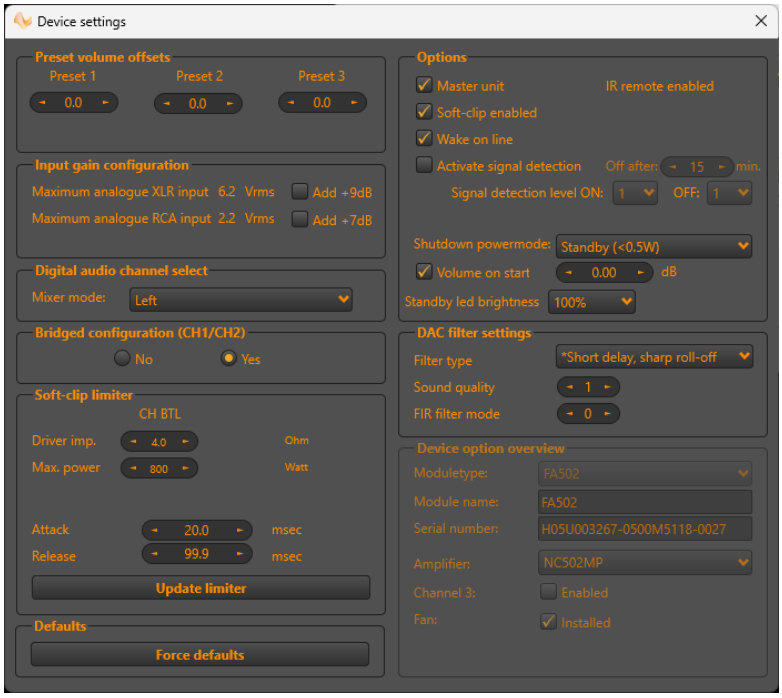


Figure 10 Hypex device settings.

The filter settings are shown in Figure 11. A 3500us delay is added to align the subwoofer with the Earendel full range loudspeakers as the latter use FIR filters for the midrange-treble cross over. These delay the signal by 5ms, the subwoofer is located ~0.5m (1.5ms) behind the full range speaker, the resulting delay is thus 5.0-1.5 = 3.5ms.

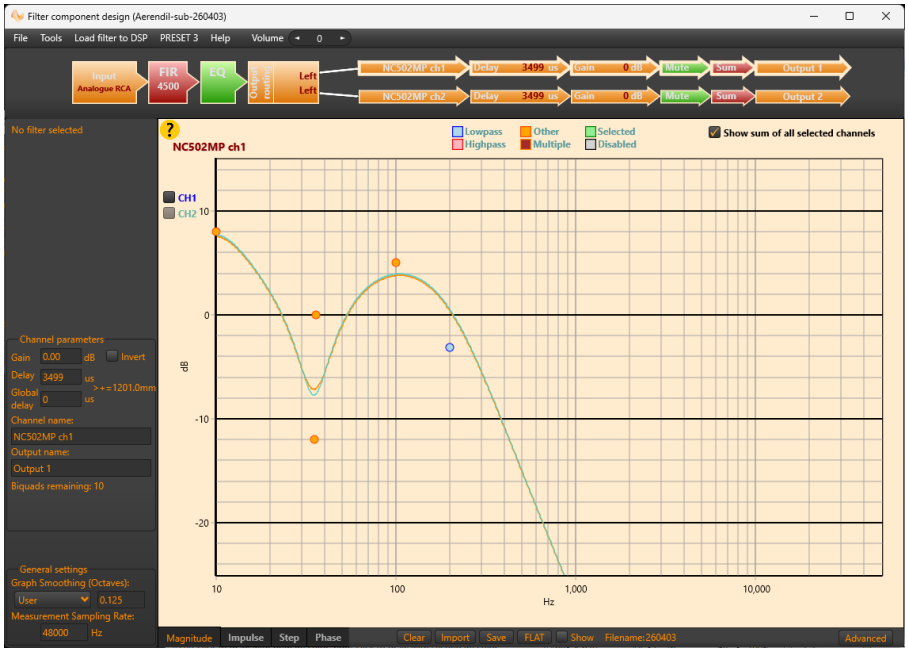


Figure 11 Filter design in the HA502.

Loudspeaker cabinet

The subwoofer cabinet is designed with an inner cabinet of 12mm plywood and an outer cabinet of 18mm stave glued beechwood. The inner cabinet is glued and screwed while the outer cabinet is only glued. It is very important to get the box rigid as the loudspeaker unit can give quite large pressure variations in a relatively small cabinet.

The resulting internal volume is roughly 55 litres when all internal bracing and space for the loudspeaker has been accounted for. Also, the Hypex FA502 amplifier needs a small inner cabinet (roughly 2 litres) to avoid that air leaks out, the small cabinet for the Hypex FA502 is not shown in the drawing.

The total weight is 42kg. More than enough to give an aching back, so be careful. It is recommended to add handles to the box to avoid accidents.

Total cost of this project

The total budget for this project is:

- Dayton audio MX15-22: 315€
- Hypex FA502: 700€
- Wood, glue: 200€

It is a bit hard to judge what commercially available subwoofer with similar performance would cost but a rough guess is in the range 4000€ to 5000€

Drawings

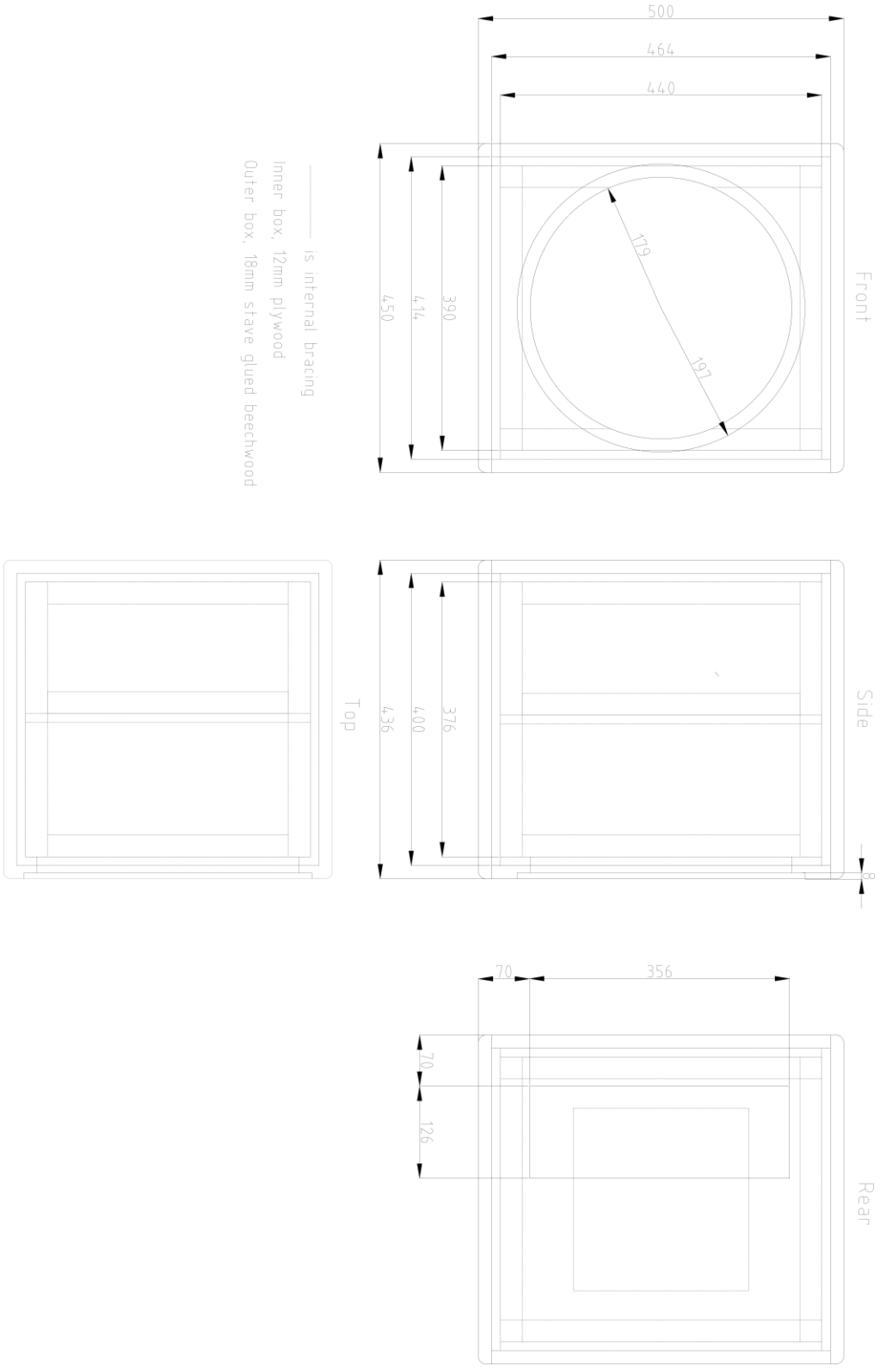
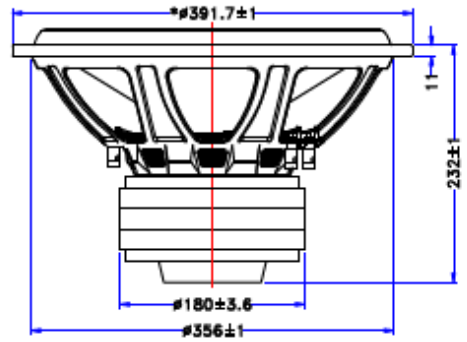


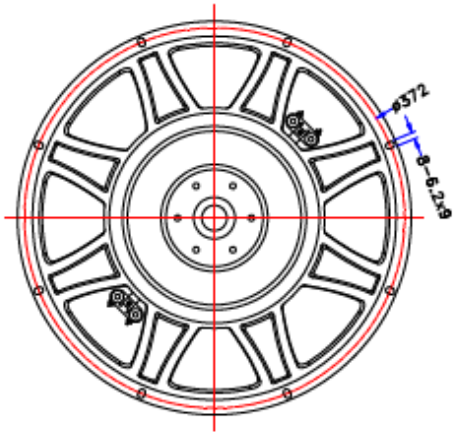
Figure 12 Cabinet drawings.

DAYTON AUDIO

15" Max-X High Excursion DVC Subwoofer 2 Ohms Per Coil

MX15-22

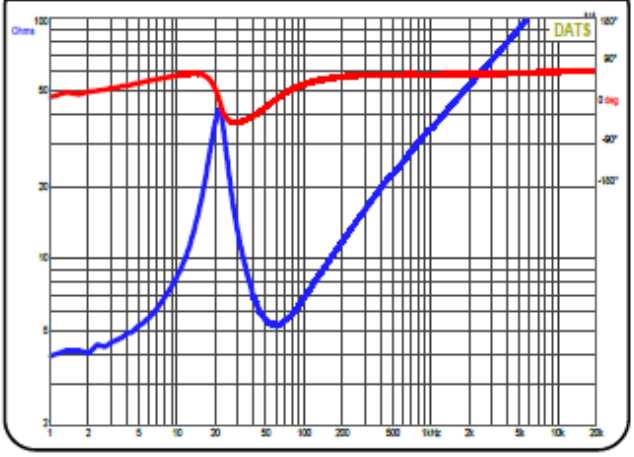




PARAMETERS

Impedance	2+2 ohms
Re	3.99 ohms
Le	5.51 mH @ 1 kHz
Fs	21.7 Hz
Qms	4.27
Qes	0.46
Qts	0.40
Mms	348 g
Cms	0.16 mm/N
Sd	819.8 cm²
Vd	1558 cm³
BL	20.6 Tm
Vas	146 liters
Xmax	19 mm
XBL (Klippel verified excursion @ 70% BL)	24.4 mm
VC Diameter	2.5"
SPL	90.2 @ 2.83V/1m
RMS Power Handling	800 watts
Usable Frequency Range	18 - 400 Hz

IMPEDANCE/PHASE



FEATURES

- High excursion and maximized surface area for excellent displacement capability
- Seamless dish cone is extremely rigid and durable with a sleek and modern look
- Custom tooled surround allows long throw without sacrificing cone area
- Extensive venting cools the voice coil enabling high power handling with low power compression
- Dual spiders maintain linear excursion for lower distortion even when pushed to the limit
- The dual 2 ohm voice coils give you the ability to get the most out of any amplifier

FREQUENCY RESPONSE