Application note for Peerless XLS 12" subwoofer driver

Introduction:
The following is an application note of how to use the Peerless XLS 12" driver especially designed for subwoofers. The application note is meant as a starting point and as inspiration for the designer who wishes to build a subwoofer using a Peerless XLS driver. The driver mentioned in this document are the distribution driver as Peerless has a broad range of specially developed OEM products to suit special requirements and we are able to tailor make almost any request for the industrial costumer.

Peerless XLS subwoofer family:
The Peerless XLS family consists of a range of drivers especially developed for the high performance subwoofer application. The goal with the design has been to produce drivers with an unexcelled long excursion performance with low distortion. Using Strontium Ferrite Magnets and Finite Element Analysis to optimise the iron circuit, high levels of BL have been obtained. With the high BL available, Peerless has been able to design drivers with a high moving mass and low fs but without high Qt and low sensitivity.

Mechanically the subwoofers offer a strong base, which will provide many years of high performance bass reproduction. The aerodynamic cast aluminium frame supports the vented Nomex spider and rubber surround for a heavy-duty suspension that will not fatigue. The rigid fibre reinforced and deep impregnated cone will produce low distortion bass without coloration.

Design goals:
This application note will describe one design of a subwoofer with the following specifications:

· Compact design sealed box for the 12" XLS driver.
· Compact design vented box for the 12" XLS.
· Compact design passive radiator box for the 12" XLS driver using the 12" passive radiator.

A closed box high performance subwoofer system using Peerless XLS driver 830500:
The closed box application is not so common for subwoofers. This is mainly because the air spring behind the cone results in a high fsb for the system. The SPL from a closed box will decrease by 12 dB/oct below fsb and therefore heavy equalising is necessary to obtain what corresponds to a flat 2p anechoic response.

However one important feature of the closed box concept is that the "in-room" response can be flat to very low frequencies in a normal living room. This is because there is a bass boost from the room by up to 12 dB/oct below the first standing wave. Equalisation for flat anechoic response therefore leads to a low frequency boost that is not always desirable.

Benefits and drawbacks of closed box systems:
The closed box subwoofer has some important benefits:
+ With low Qt drivers in small boxes a very good transient response is possible.
+ No port noise.
+ The air spring inside the box will limit excursion of the driver at low frequencies.

Some of the drawbacks of the closed box system are:
÷ Heavy equalisation needed.
÷ Excursion must be very high at low frequencies to obtain flat response because there is no port

or passive radiator to assist the low output from the box.
÷ Low efficiency at low frequencies.

Tuning the system:
Tuning a closed box system is straightforward with a pocket calculator.
The following general formulas can be used to predict the response of a closed box. If damping material is not taken in to account. See the literature about the effects of damping material.

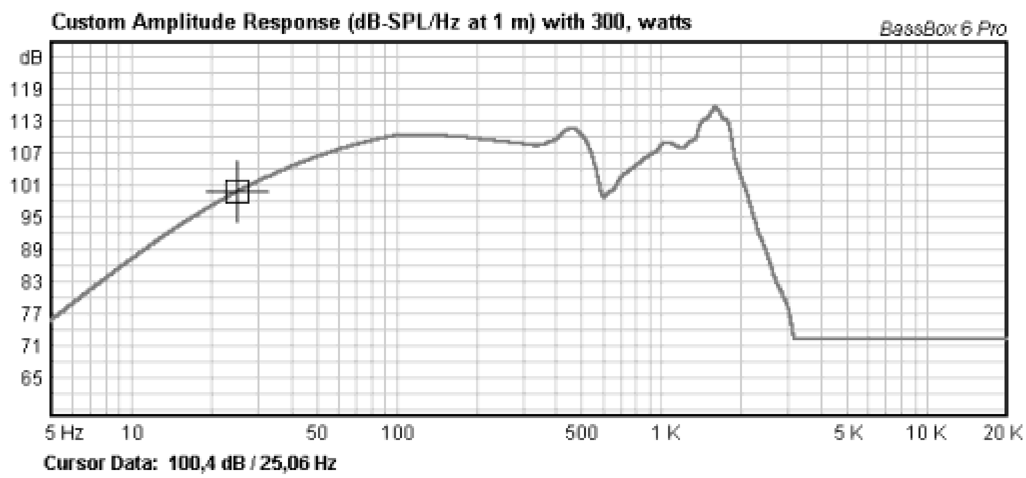
$$Q_{tB} = Q_t \cdot \sqrt{1 + \frac{Vas}{V_B}} \qquad f_{sB} = f_s \cdot \sqrt{1 + \frac{Vas}{V_B}}$$

Where Qt, Vas and fs are the datasheet values and QtB and fsB are the resulting data for the box.

Putting the 12" XLS driver 830500 in to a 30-litre box with no damping material inside results in the frequency response below when a small box loss has been incorporated.

FsB is around 43 Hz and QtB is around 0.48 based on the above formulas.

The maximum sound pressure level with a 300W RMS amplifier and no equalising will be like the following graph.



From the graph we see that it is necessary to boost by about 10 dB at 25 Hz with a low pass slope of 12 dB/oct. to achieve a flat response.

Conclusion for closed box subwoofer:
From the above simulations it can be concluded that even with a very powerful amplifier of 300 W it is not possible to achieve over 100 dB at 25 Hz.

Using a larger cabinet or counting on the bass boost of all living room environments with the boundaries contributing to amplification of the lowest frequencies a very good transient response can be achieved with the sealed enclosure.

Box data:

Type: Sealed
Volume: 30 l
Qt: 0,48

A vented high performance subwoofer using Peerless 12" XLS driver 830500:
The vented subwoofer is a popular way to achieve high performance at a reasonable cost. Some considerations regarding the vented approach are however necessary before choosing this design.

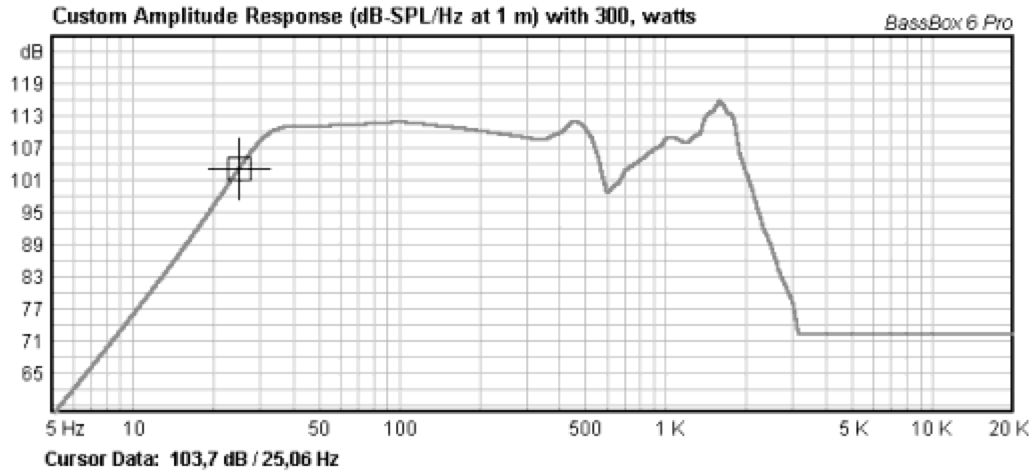
Benefits and drawbacks of vented systems:
The vented system has many benefits here are a few important ones:
+ It is typically inexpensive to build.
+ Properly tuned results in high performance.
+ High efficiency at low frequencies.
+ Cone excursion is low at the tuning frequency.

Some of the drawbacks of the vented system are:
÷ Low tuning in a small cabinet means long ports.
÷ Long ports means complex construction, which increases cost.
÷ Long ports may have port resonances in the frequency range where the system should work.
÷ Reduction of port noise means large cross section, which again means longer ports.
÷ Large excursion of the drive unit at frequencies below tuning. High pass filter highly recommended set just below the tuning frequency.

Tuning the vented subwofer:
The basic theory of vented systems has been studied for many years and the literature is rich of articles describing the various designs possible. General formulas for the vented system exist but it is outside the scope of this application note to describe the mathematics behind the vented systems. It is strongly recommended that a PC simulation program be used for the tuning of vented systems.

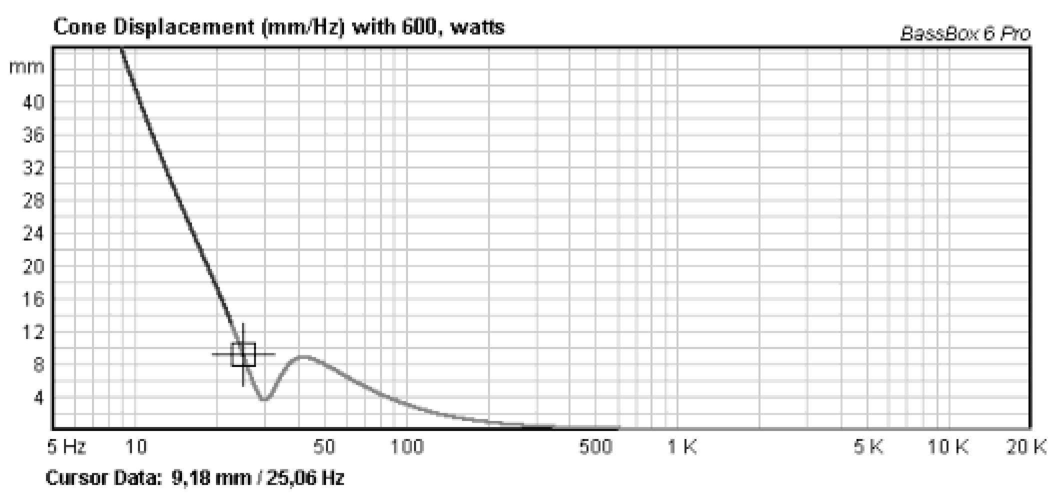
Normally a large cross section of the port is recommended to avoid port noise and turbulence. With the simulation program used here it is possible to ask the program for a cross section that will not produce too much turbulence in the port thus the port diameter is fixed. Using so-called "flared" ports where both the inside edge of the port and the outside edge of the port has a radius greatly reduces port noise.

Putting the 12" XLS driver 830500 in to a 40 litre box with no damping material inside results in the frequency response below when a small box loss has been incorporated.



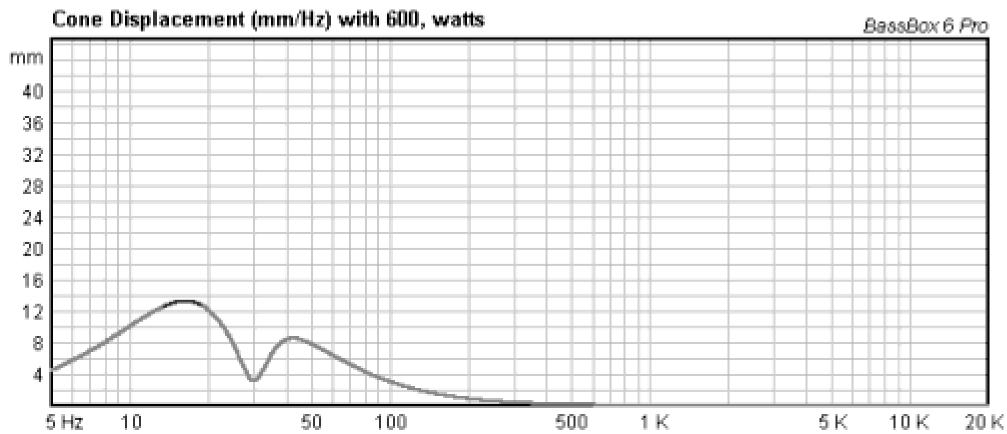
From the simulation it can be seen that the system response is up by about 3 dB at 25 Hz compared to the sealed box. We get about 104 dB with 300 W RMS at 25 Hz.

Before proceeding we need to check that the maximum excursion of the driver has not been exceeded. It is normal for a vented system to have two excursion regions of importance. One excursion region is where the drive unit alone is producing the SPL this is above tuning. The second excursion region is below tuning at 25 Hz where the excursion rises rapidly. A good simulation program will be able to simulate the excursion of the drive unit. The program used for the simulations here does not have the ability to run Peak displacement simulations but only simulates RMS excursion. This is no good because it will give the user the feeling that everything is OK but in real life the peak displacement is what overloads the driver, not the RMS displacement. However it is possible to simulate peak values, we just need to use the peak power instead of RMS power. The difference between peak and RMS power is simply that peak power is two times the RMS power. Therefore the peak displacement can be simulated using 2 times the RMS power or in this case 600W peak power.



In the 12" case the first maximum appears around 38-40 Hz. From the graph it can be seen that the design is safe in this region reaching about +- 9,2mm.

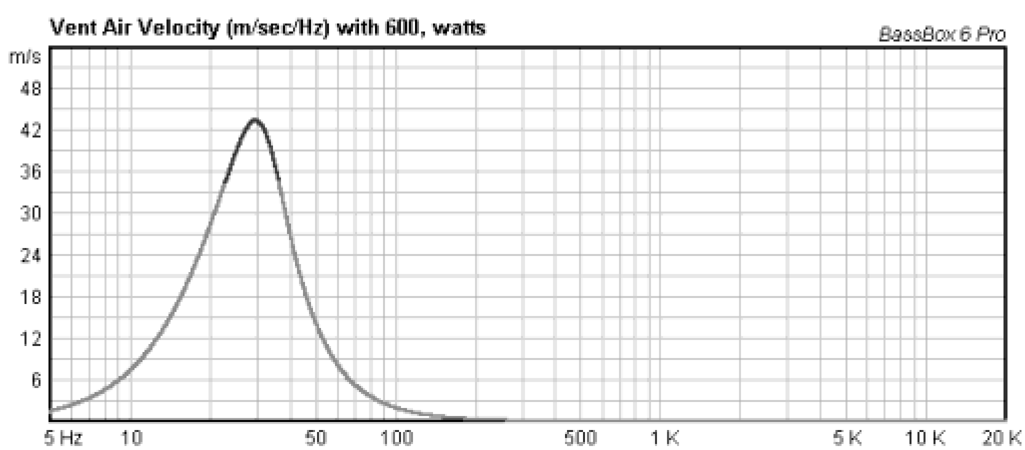
The other excursion region is below tuning at 25 Hz where the excursion rises rapidly reaching the 12.5 mm limit at approx. 22Hz. The max allowable excursion of the driver (+- 22 mm is reached at 18 Hz. Therefore it is highly recommended to limit the excursion below 20 Hz by a high pass filter. Choosing a sixth order vented system approach with a second order high pass filter is therefore recommended. The high pass filter has a Q of 0.7 and -3 dB at 20 Hz.
The resulting displacement can be seen on the graph below.



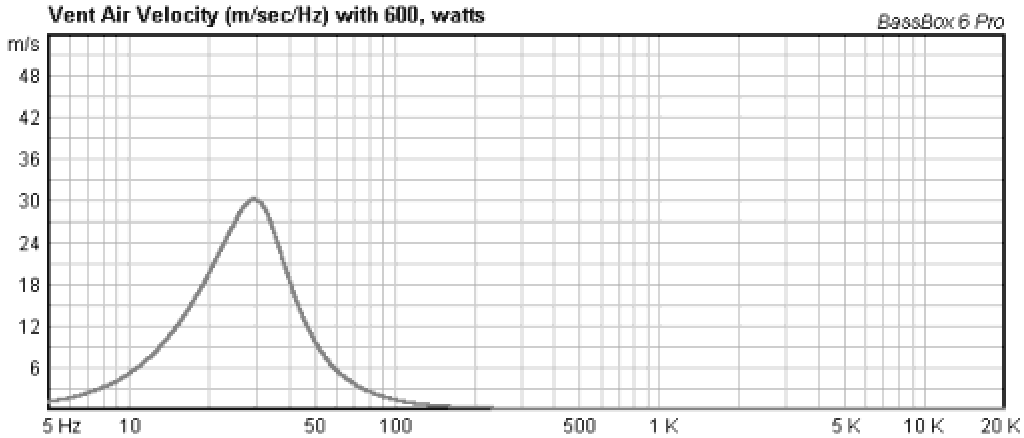
The fist peak is the same around 9,2 mm but the uncontrolled rise in displacement below tuning is now controlled so that the maximum is reached at about 17 Hz and is below 14 mm. It should be clear to everyone that the high pass filter is a great improvement especially considering that the system is not able to produce any SPL below 20 Hz anyway.

The next step of the design processes it to configure the port. To keep the velocity of air in the port low is of great importance to achieve a system without port noise. Typically the air velocity should be kept below 1/10 of the velocity of sound in air or approx. 35 m/s. Using flared ends in the port also reduces port noise as mentioned before.

From the graph below it can be seen that Ø75 mm port with 349 mm length does not fulfill this demand because the maximum velocity is about 44 m/s peak with 600W.



This means that a larger diameter of port is needed, which will require that the port is longer. Using a Ø90 mm port and 510 mm of length turns out to be a good choice:



Now the velocity is below 35 m/s and if a double flared port is chosen a good result should be possible.

Conclusion and data for the vented system:
Using the 12" XLS driver in a vented cabinet can produce some high sound pressures and low distortion is possible with a high pass filter and good port design.

It has been shown that a high pass filter for the system is highly recommended to reduce the excursion below tuning.

Vented cabinet data:

Total volume: 40 litre
Port diameter: Ø90 mm (double flared recommended)
Port length: 510 mm

Tuning frequency: 30 Hz

High pass filter (highly recommended):

Q: 0.7
Fo: 20 Hz

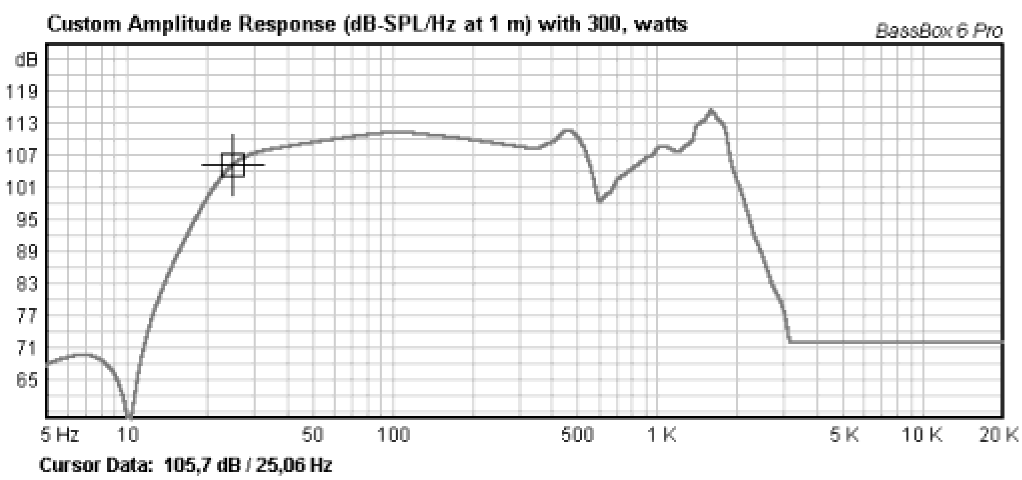
A passive radiator high performance subwoofer using Peerless XLS driver 830500:
The passive radiator subwoofer is a way to achieve high performance at a reasonable cost. Some considerations regarding the passive radiator approach is however necessary before choosing this design. Low tuning of the passive radiator system is possible by using heavy moving mass in the slave.

Benefits and drawbacks of passive radiators:
The passive radiator system has many benefits here are a few important ones:
+ Low tuning in small cabinets possible.
+ Properly tuned results in high performance.
+ Low distortion and no port noise.

Some of the drawbacks of the passive radiator system are:
÷ Sometimes a little more expensive than vented systems with similar performance.
÷ Improper tuning may result in bad transient response.
÷ The passive radiator will run out of excursion at low frequencies.

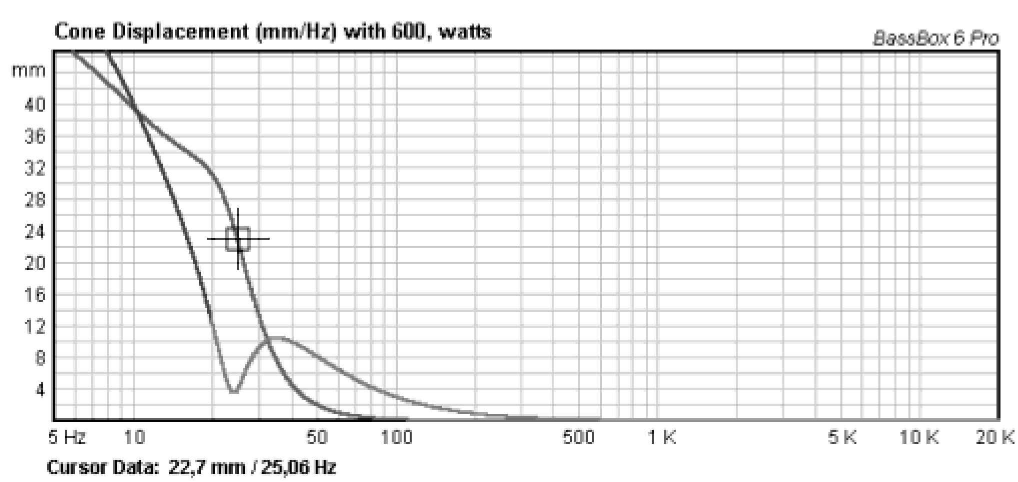
Tuning the passive radiator system:
The passive radiator system works in a way similar to the vented system. The impedance curve will have two peaks like the vented system. A simulation package capable of simulation of passive radiator systems is needed to simulate the system.

Simulating a 35 liter nominal box with a 12" XLS slave with 425g moving mass results in the frequency response below:



At 25 Hz the maximum is around 106 dB, but we need to inspect the cone and slave excursion before proceeding with the design.

Again remembering the limitation of the simulation program regarding RMS and Peak displacement the power is increased to 600 W which is the peak output of the 300 W nominal power.



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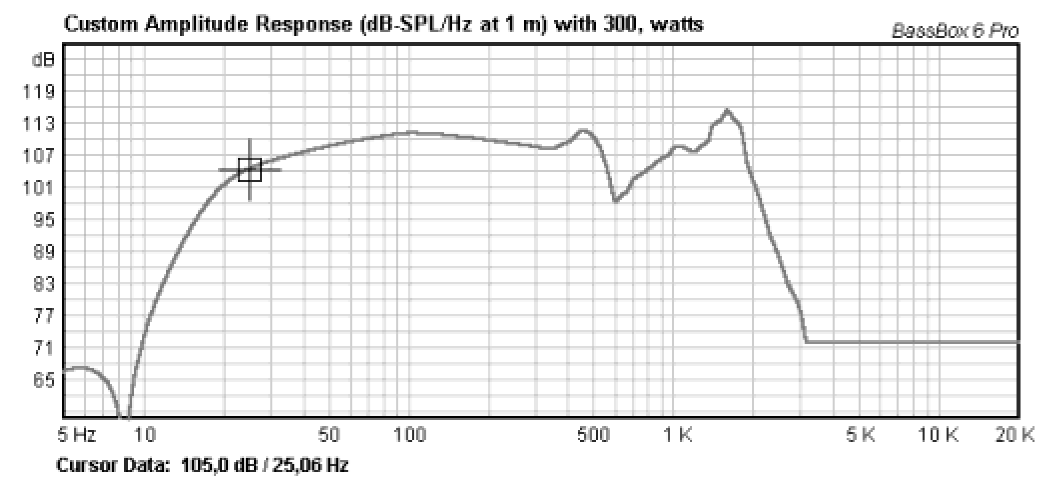
From this simulation we see that the maximum excursion of the driver is well within the linear limits down to about 20 Hz where the linearity limit of 12.5 mm is reached.

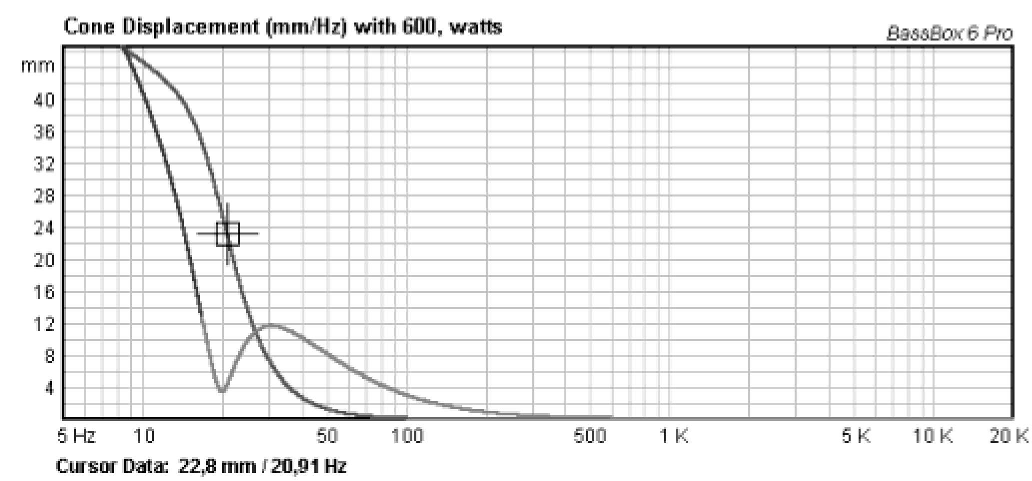
For the slave the mechanical limit of the excursion is around 22 mm which occurs at approx. 25 Hz. This means that the system with a 425g moving mass on the slave is close to maximum allowable load with a 300W amplifier.

If we choose a lower tuning frequency the active driver will take more of the load utilising the full potential of the active driver and reducing the needed excursion of the passive driver.

This system will need a 625 g mass on the slave to achieve the desired performance and low tuning in the 35 litre cabinet.



The response of the system will be extended to 20 Hz but the efficiency is lower than the previous. Inspecting the cone displacement results in the following result.



The cone displacement of both the passive and active driver is OK within the safe operating limits of the drivers. However it can be seen that the cone displacement rises steeply below 20Hz meaning that a high pass filter to protect against overload is highly recommended.

The simulation program is not able to incorporate the second order high pass filter in to the passive radiator system but similar results as for the vented system are possible. The high pass filter should be set for 17 Hz and a Q of 0,7.

Conclusion for Passive radiator system:
Special considerations regarding overloading of the passive radiator is needed for passive radiator systems. Careful selection of limiting circuits and tuning frequency is needed to avoid unwanted noises from the system.

It has been shown that the tuning of the box is possible but that the user need to invest some time in adjusting the filters and limiters to achieve the goal. A high pass filter is highly recommended like used for the vented system above.

Passive radiator system data:

Total volume: 35 litre

XLS 12" slave with 625g Mms Order Id 830549

Tuning frequency: 20 Hz

High pass filter:
Cut off frequency: 17 Hz
Q: 0,7

General notes about power requirements:
The XLS family has large excursion headroom and will handle high levels of power. In a typical application the amplifier will begin to clip before the driver reaches the maximum level of excursion. Low frequency amplifier clipping sometimes sounds as if the driver is overloading. Therefore it is recommended to check the amplifier output with an oscilloscope to look for clipping if the system sounds bad.

Using a limiter that controls the excursion and the loading of the amplifier is highly recommended.

General notes on excursion limitation:
From the simulations above it has been shown that it is possible to overload the drive units at frequencies close to and below the system tuning frequency. Therefore a high pass filter set closely below the tuning frequency where the sound pressure level decreases rapidly anyway, is highly recommended. There is no need for the drive units to overload at frequencies where the system produces no sound.

A high pass filter with cut off frequency just below the tuning frequency of the system is therefore highly recommended.

General notes regarding filters and noise for subwoofers to avoid localisation:
It is a known fact that the human hearing looses the sense of direction for frequencies below approximately 150 Hz. We are therefore not able to tell the position of a subwoofer that only produces sound below this frequency. This means that we have freedom of placement. However, above 150 Hz the human hearing starts to localise the source. This means that if the subwoofer produces higher frequencies than approximately 150 Hz, the user will notice the position.

To avoid localisation a sharp low pass filter is needed. A 12 db/oct@150 Hz filter will only attenuate the lower midrange (300 Hz) by typically 15 dB. This means that the lower midrange will radiate from the subwoofer thus revealing the position.

Using a 24 dB/oct or even 36 dB/oct filter greatly improves the midrange attenuation.

Other sources to reveal the subwoofer position are distortion and noise.
Amplifier clipping or distortion will produce higher harmonics that will radiate from the subwoofer thus revealing the position.

The Peerless XLS woofer are very "silent" low inherent distortion and noise subwoofer drive units. This means that with careful design of amplifiers, limiters and filters the designer is able to achieve a very good result without localisation.

Port noise is another source for localisation because this noise is wideband and revealing. Port noise must be avoided. Two sources of port noise is the velocity of air in the port and turbulence at the port ends.

Using a large diameter port will reduce the velocity, but requires a longer port. Double flared ports where both ends are flared greatly reduce turbulence at the port ends.

Conclusion and disclaimer:
It has been shown that it is possible to achieve high sound pressure levels using the 12" XLS drive unit in three different configurations.

Proper filters and limiters are highly recommended and this is an important but often overlooked detail in high performance subwoofers.

The port design in small vented box systems is complicated because the length has to be very long. Labyrinth or tubes with bends must be used.

The information contained herein is provided for the designer to have a starting point for future development on high performance subwoofers. We believe the information to be true and reliable, but there are many ways to design subwoofer systems. We cannot assume responsibility for the results obtained by others over whose methods we have no control.