Chapter 5. Powered Subwoofer

Background

There are several ways one can accomplish the design of a powered subwoofer. Some systems relay on motional feedback to extend the frequency response. Other systems relay on the negative output impedance of the power amplifier. The approach facilitated by this program is based on electronic equalization of a properly designed woofer or bandpass subwoofer. Such equalization will effectively extend -3dB cut-off frequency on the low end side. In case of tunable enclosures, it can be observed, that system's frequency response is already down by 3-4dB at the enclosure tuning frequency. Without equalization, this would be the specified system -3dB cut-off frequency. However, cone excursion curve superimposed on the amplitude response plot reveals, that cone excursion is at its minimum at the enclosure tuning frequencies. One can take advantage of this an feed more power into the driver still avoiding mechanical failure and any significant increase in distortion. Obviously, the driver must be able to handle increased electrical power. One can take this concept even further and deliberately tune the enclosure to lower frequency than the optimum flat response would require. Any irregularities introduced in the frequency response this way can be equalized with the added advantage, that the cut-off 3dB frequency would be still lower.

For example: 300W driver can be safely used in 100W powered subwoofer system capable of 4.7dB equalization. Typically, the driver can be overloaded even more, as the low frequency program peaks are quite infrequent and the driver has sufficient time to cool down.

Amplifier used in the system must produce sufficient undistorted output power at the peak of the boosted frequency range. Therefore, if the 100W system with 4.7dB peak equalization is targeted, the amplifier must be able to produce at least 300W peak power. This power levels are readily achievable with current selection of semiconductor devices. Since it is desired to make the subwoofer as small as possible, the "isobarik" configuration of drivers is common. The user may recall, that "isobarik" configuration halves the Vas of the single driver while retaining the same Qt and Fs. As a result of this, the size of the enclosure can also be reduced by the factor of two. Additionally, bandpass subwoofers, if properly designed, are capable of providing higher SPL levels at the expense of bandwidth. Practical realizations can provide quite flat system frequency response down to 20Hz and below. Generally, the task of designing powered subwoofer can be concentrated on extending the low frequency output of the passive system by augmenting it with complimentary, properly designed active amplifier.

Design Example: Design of the powered subwoofer can be accomplished in three steps:

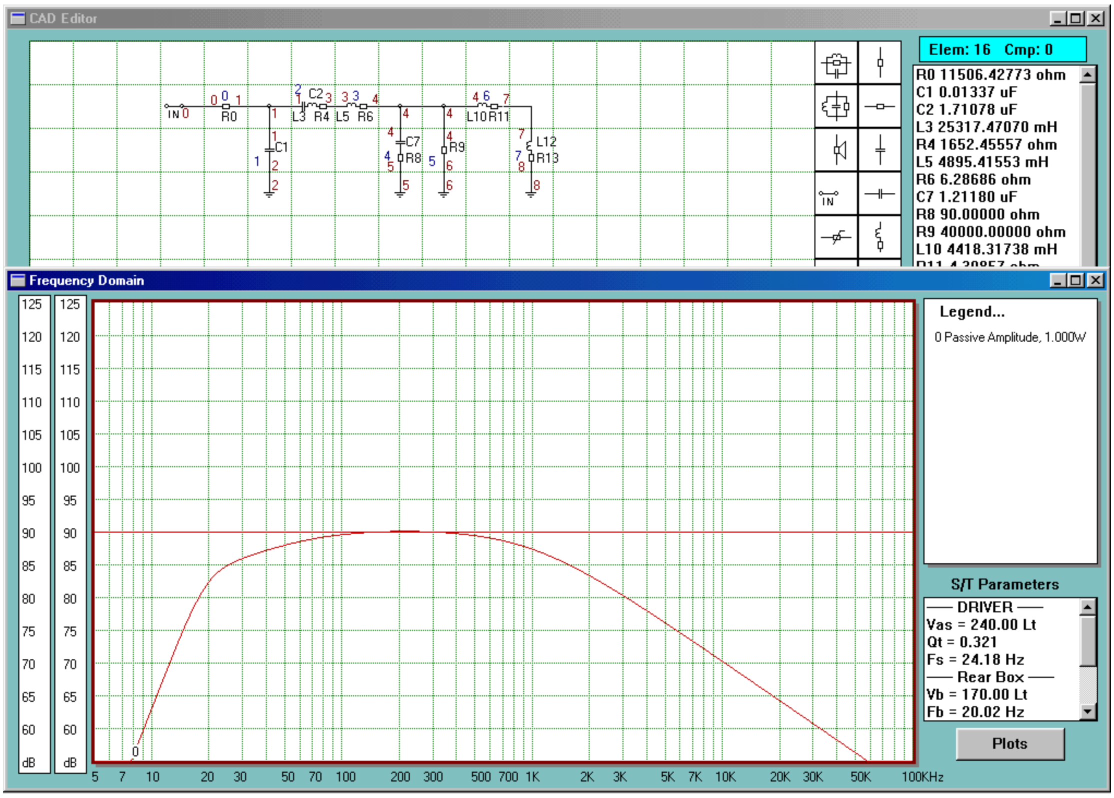
1. Design of a bandpass subwoofer/vented system (amplitude response is saved automatically, schematic needs to be saved).
2. Design of the active equilizer.
3. Combining the two frequency responses.

The design of bandpass enclosures was covered in details in the previous chapters. In summary:

1. Using calculators, enter driver and enclosures' parameters and convert them to acoustical impedance elements.
2. Use built-in models or create your own variations, remembering that acoustical impedance representation should be used.
3. Plot frequency response and modify component values to obtain desired or targeted 3dB bandwidth. When doing "what-if" analysis, you can change component values directly on the schematic. After that, it is recommended to confirm (using calculators) that selected value is in fact physically relizable. The frequency response is not saved to the file, it is kept in a temporary storage during the run of the program.
4. Save the final schematic using "Save As..." button, selecting "Acoustic Impedance" option from the floating menu. The schematic will be saved to the disk. When you re-load the datafile, you will need to re-plot the passive system frequency response before plotting combined (passive & active) system frequency response.

Typically, the power amplifier would have flat frequency response, but there is nothing stopping the user from incorporating the frequency correcting elements in the final amplifier negative feedback loop. Since the operating frequency range of the system is VERY low indeed, some form of high-pass filtering would be required to protect the drivers. Please note, that the new Dolby AC3 (c) standard provides Hi-Fi center channel producing frequencies between 3-120Hz specifically for loud effects such as explosions. The lower end of this range 3-15Hz can severely damage your driver's suspension if allowed to be amplified into enclosure capable of 25-150Hz frequency range. The design of active circuitry was covered in details in SoundEasy/SSD+. In summary:

1. Design the equalizing circuit around inverting or non-inverting OPAMP.
2. If deemed necessary, incorporate high-pass filtering. Please note, that some second order high-pass filters, having the 3dB cut-off frequency at 15Hz, can be designed to peak at 20Hz by 3-4dB. This would be the simplest configuration meeting both requirements at the same time.
3. Plot the frequency response of the active circuit using "Plots" button and "Active" option from the floating menu. You can change component values often and keep re-plotting the frequency response till the desired results are obtained. Formulas for active filter design are widely available in the literature.
4. In order to obtain combined (passive loudspeaker + active equalizer) system frequency response, use "Plots" button and "Combined" option from the menu.
5. Save the schematic using "Models" menu option, selecting "Save As Standard Network" option from the floating menu. The frequency response is not saved to the file. The schematic will be saved to the disk.



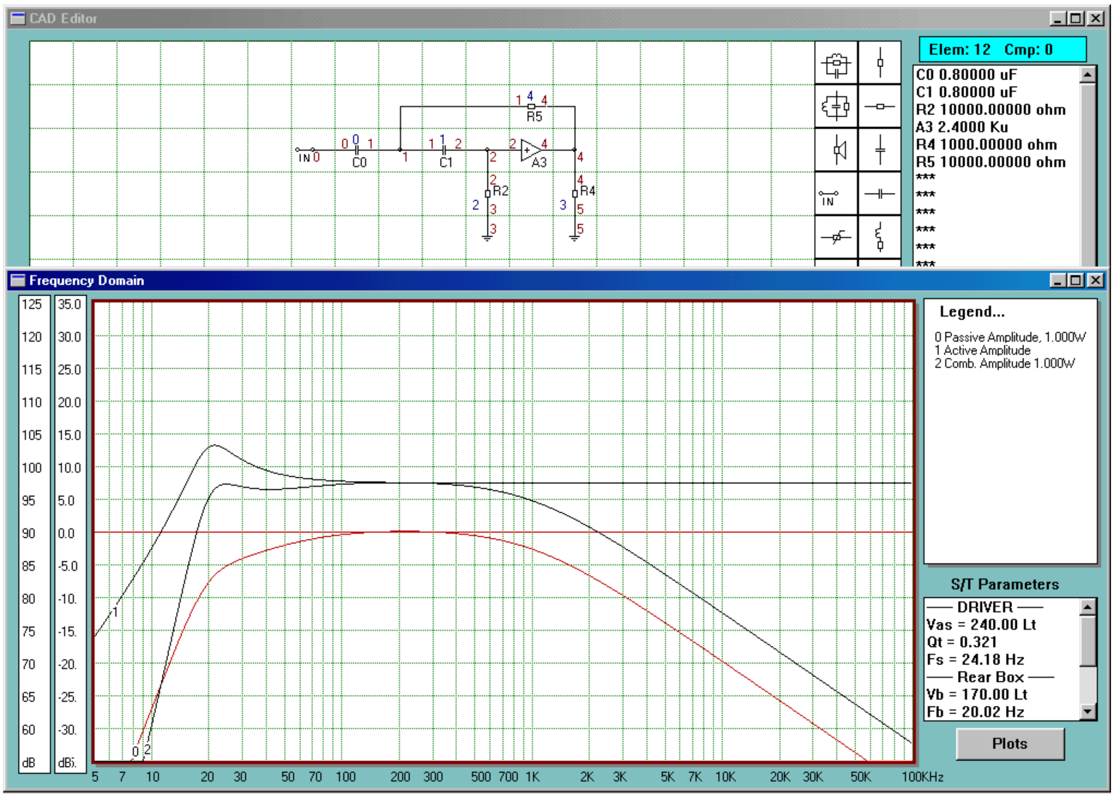
Elem: 16 Cmp: 0

R0 11506.42773 ohm
C1 0.01337 uF
C2 1.71078 uF
L3 25317.47070 mH
R4 1652.45557 ohm
L5 4895.41553 mH
R6 6.28686 ohm
C7 1.21180 uF
R8 90.00000 ohm
R9 40000.00000 ohm
L10 4418.31738 mH

0 Passive Amplitude, 1.000W

—— DRIVER ——
Vas = 240.00 Lt
Qt = 0.321
Fs = 24.18 Hz
—— Rear Box ——
Vb = 170.00 Lt
Fb = 20.02 Hz

Fig 5.1 Frequency responses of the passive driver enclosure tuned to 20Hz



Elem: 12 Cmp: 0

C0 0.80000 uF
C1 0.80000 uF
R2 10000.00000 ohm
A3 2.4000 Ku
R4 1000.00000 ohm
R5 10000.00000 ohm
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***
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0 Passive Amplitude, 1.000W
1 Active Amplitude
2 Comb. Amplitude 1.000W

—— DRIVER ——
Vas = 240.00 Lt
Qt = 0.321
Fs = 24.18 Hz
—— Rear Box ——
Vb = 170.00 Lt
Fb = 20.02 Hz

Fig 5.2 Frequency response of the de-tuned driver+EQ circuit

Example presented above shows very simple powered subwoofer. The passive system comprises vented box de-tuned to 20Hz and active system is a second order high-pass filter peaking at 20Hz. Unassisted passive system produces much less than optimal frequency response, but the important factor in de-tuning the enclosure was the cone excursion, which has to be minimized at around 20Hz. Optimally tuned passive system would result in 3dB cut-off frequency of 30Hz. The complete system would exhibit the following main characteristics:

1. Total -3dB frequency response of the system is extended down to 20Hz.
2. The amount of active boost is only around 5dB at 20Hz.
3. For 100W active subwoofer, the system would require 300W peak electrical (music) power. Many current designs easily provide this much “dynamic headroom”.
4. Peak electrical power handling of the woofer would have to be 300W or more.
5. The 12dB/oct high-pass filter protects the system against excessive infrasonic frequencies.

Fig 5.1 shows frequency responses of the passive driver enclosure tuned to 20Hz (curve 0 is the se-tuned response), Fig 5.2 shows the frequency response of the active equalizer and the combined frequency response. Powered subwoofer may additionally contain phase shifting circuitry for adjusting time delay between satellite speakers and the subwoofer.

Linkwitz-Riley Filter

When the subwoofer system is designed with the size in mind, it may happen, that the required enclosure volume causes a pronounced peak in response. This is an obvious sign, that the box is too small for the selected driver (its Vas). However, the peak can still be equalized and the low-end boost provided at the same time. The circuit recommended for this job is the Linkwitz-Riley filter and its example is shown on Fig 5.3. This circuit provides bass boost and correction for the peak. Design formulas are as follows:

1. Choose $f_{0,}Q_0, f_p, Q_p$,

2. $k = \dfrac{\dfrac{f_0}{f_p} - \dfrac{Q_0}{Q_p}}{\dfrac{Q_0}{Q_p} - \dfrac{f_p}{f_0}}$,

3. Choose C_2,

4. $R_1 = \dfrac{1}{2*\pi*f*C_2*[2*Q_0(1+k)]}$,

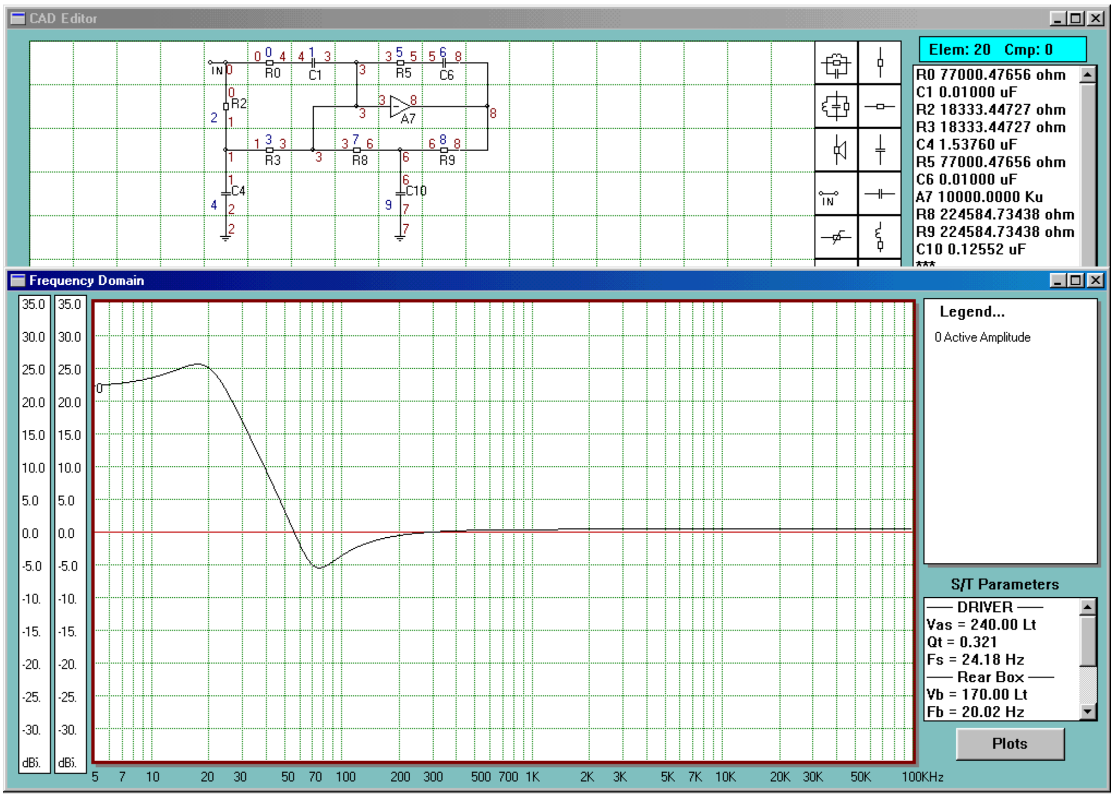
5. $R_2 = 2*k*R_1$,

6. $C_1 = C_2*[2*Q_0(1+k)]^2$,

7. $C_3 = C1*\left(\dfrac{f_p}{f_0}\right)^2$,

8. $R_3 = R_1*\left(\dfrac{f_0}{f_p}\right)^2$

Example presented on Fig 5.3 below, shows the Linkwitz-Riley filter calculated for Qo=2, fo=50, Qp=2, Fp=25 and C1=50nF.



Elem: 20 Cmp: 0

R0 77000.47656 ohm
C1 0.01000 uF
R2 18333.44727 ohm
R3 18333.44727 ohm
C4 1.53760 uF
R5 77000.47656 ohm
C6 0.01000 uF
A7 10000.0000 Ku
R8 224584.73438 ohm
R9 224584.73438 ohm
C10 0.12552 uF
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—— DRIVER ——
Vas = 240.00 Lt
Qt = 0.321
Fs = 24.18 Hz
—— Rear Box ——
Vb = 170.00 Lt
Fb = 20.02 Hz

Fig 5.3 Linkwitz-Riley filter

Since the design formulas follow the original Linkwitz's work, here is the translation of the component references.

Linkwitz Formula	SoundEasy Schematic Reference
R1	R2,R3
R2	R0,R5
R3	R8,R9
C1	C4
C2	C1, C0
C3	C10