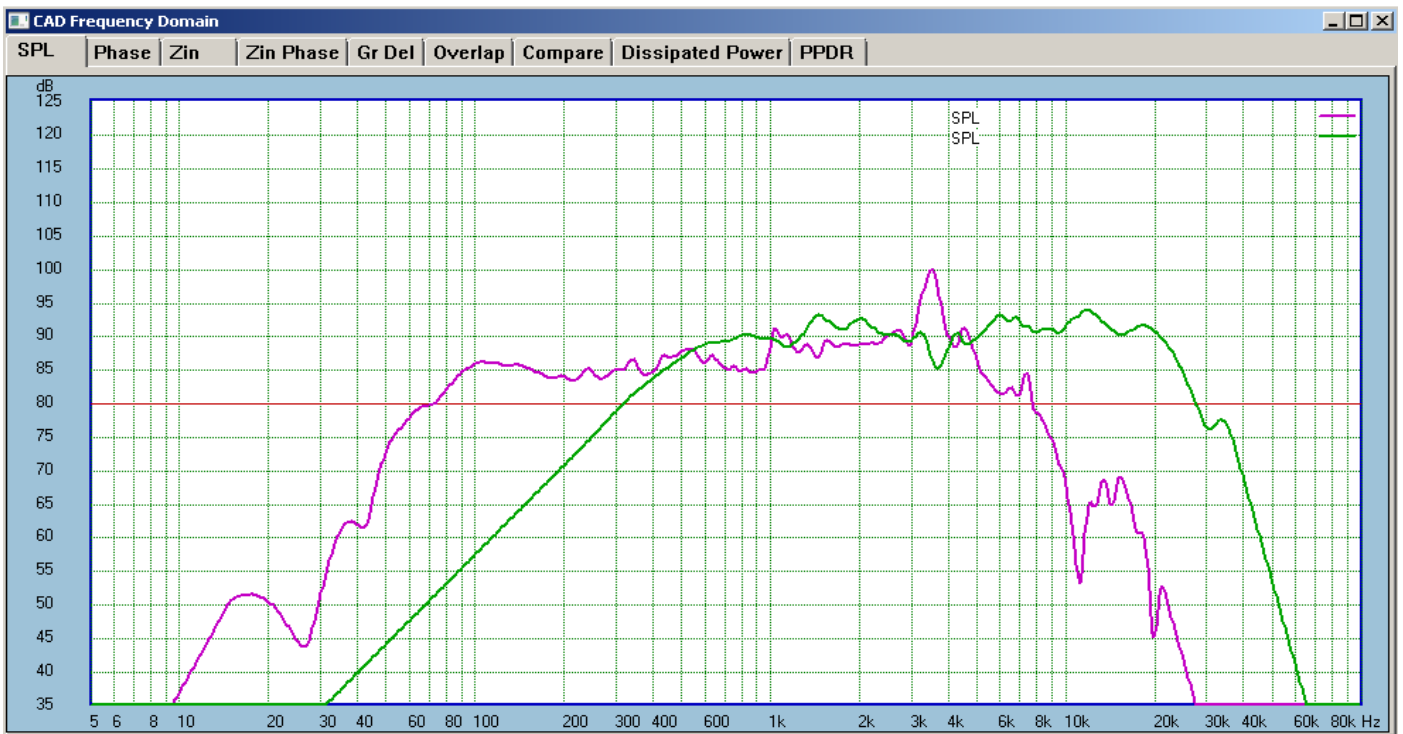


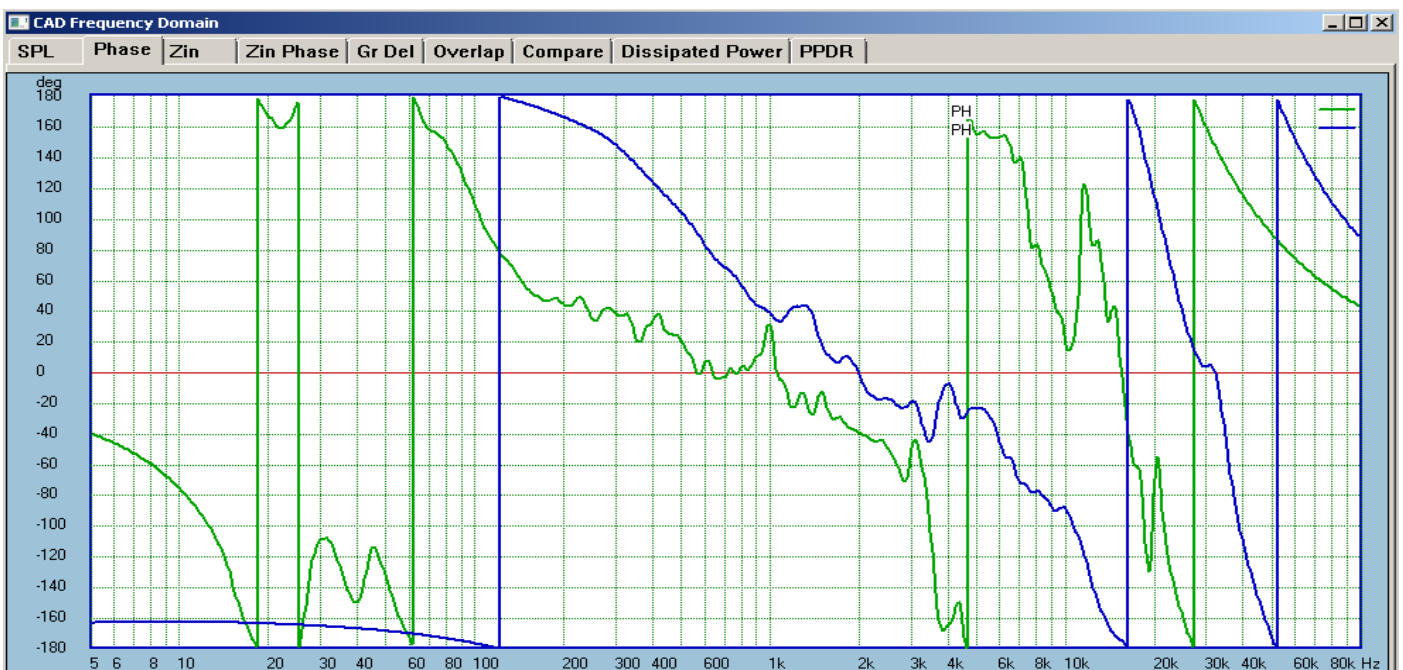
## Using SE Optimizer For Quick Loudspeaker Design

This short paper, describes a couple of issues frequently encountered during loudspeaker design process. (1) An example design of a two-way loudspeaker system, with Linkwitz-Riley , 4th order crossover at 1.5kHz, and (2) amplitude peak equalization. The tool used for both processes is the Optimizer Function. Since the crossover is of the 4<sup>th</sup> order, the drivers are connected in-phase for normal operation. At this stage, we are not concerned about the availability of components with exact calculated values. Capacitors are easily paralleled, and coils can be easily modified to the required values.

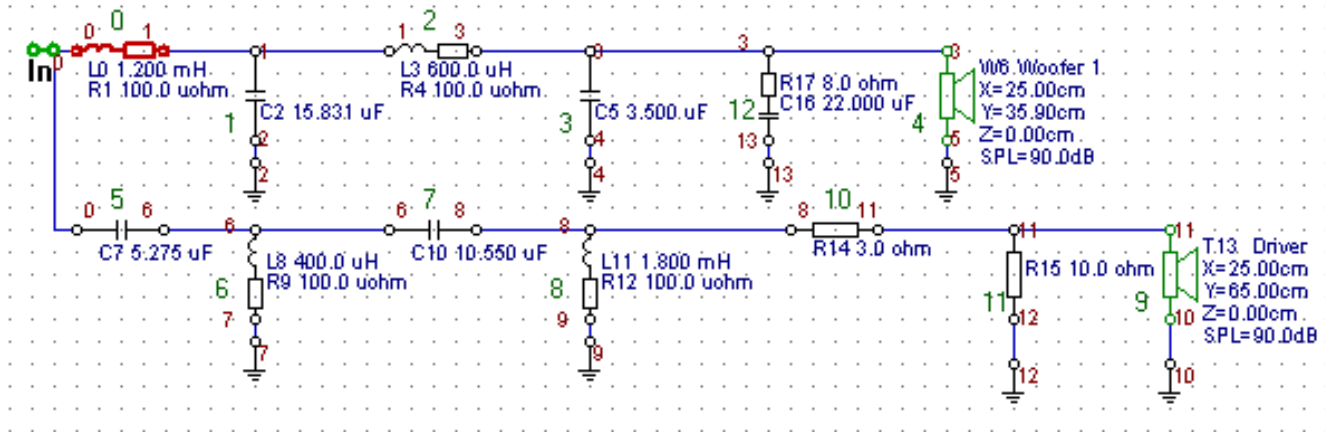
Our drivers are: Woofer (pink) and Tweeter (green) SPL curves. Drivers have been fully edited and are minimum-phase.



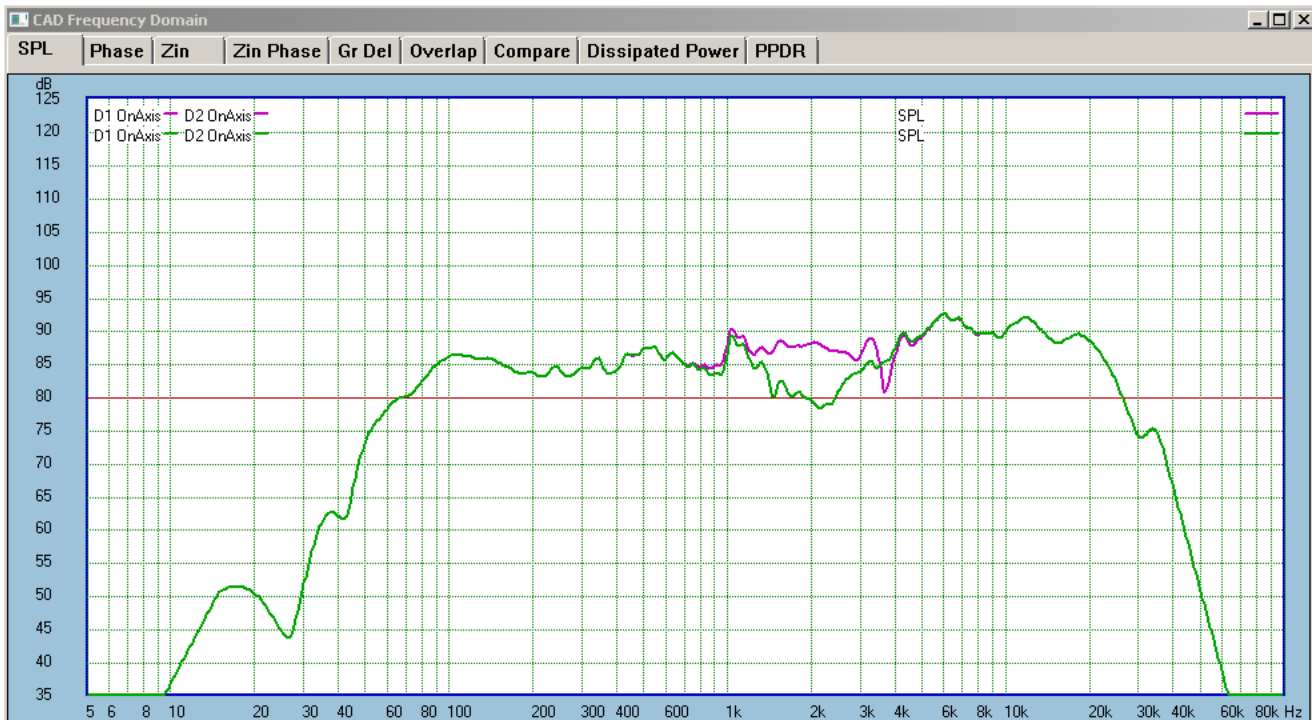
Woofer (green) and Tweeter (blue) Phase response curves



## Crossover Original Values

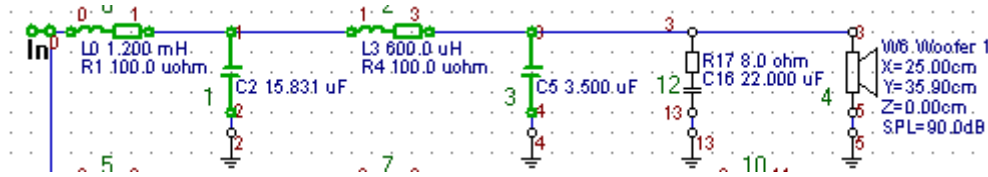


## Original System Frequency Response (pink) and Reverse Null (green)



It is observable, that raw frequency response of the system is tilting upwards. This suggests, that tweeter efficiency is too high for the given woofer. Also, the "reverse null" is non-existent. This suggests, that phase responses at the crossover frequency are not 180deg and amplitudes are not -6dB both drivers. This loudspeaker would be lacking bass and sound overly bright.

## Optimizing Acoustic Response of the Woofer



Optimization Parameters – 4 components: L0, C2, L3, C5. This is the whole low-pass section.

**CAD Optimization Control**

Targets Optimization Nodes

Reference Configuration: L-P Passive, -12dB/oct; L-P Passive, -18dB/oct; L-P Passive, -24dB/oct

Reference Type: Bullock selected; Butterworth selected; Linkwitz selected

3. Reference Filter Cut-Off: High-Pass F3dB: 1500 Hz; Low-Pass F3dB: 1500 Hz; Qo Target: 0.333

4. Optimize Within This Frequency Range: From: 100.0 Hz To: 10000.0 Hz

5. BUT Exclude This Frequency Range: From: 6.0 Hz To: 10.0 Hz

6. Additional Reference Curve Shape Control: From: 0.0 Hz To: 0.0 Hz; Roll-off: 0.0 dB/dec; Attenuation: -5.0 dB, positive number for gain

Show Target Clear Print

**CAD Optimization Control**

Targets Optimization Nodes

Doubleclick to Highlight ==> Optimize These Items

L0 = 1.200000 mH; R1 = 0.000100 ohm; C2 = 15.83125 uF; L3 = 0.600000 mH; R4 = 0.000100 ohm; C5 = 3.500000 uF; W6 Woofer 1; C7 = 5.275000 uF

L0 = 2.169759 mH; C2 = 20.07399 uF; L3 = 0.686296 mH; C5 = 0.080736 uF

Optimize Abort Lock ALL New Val Old Val Accept New Values Print Clear Step = 25 %

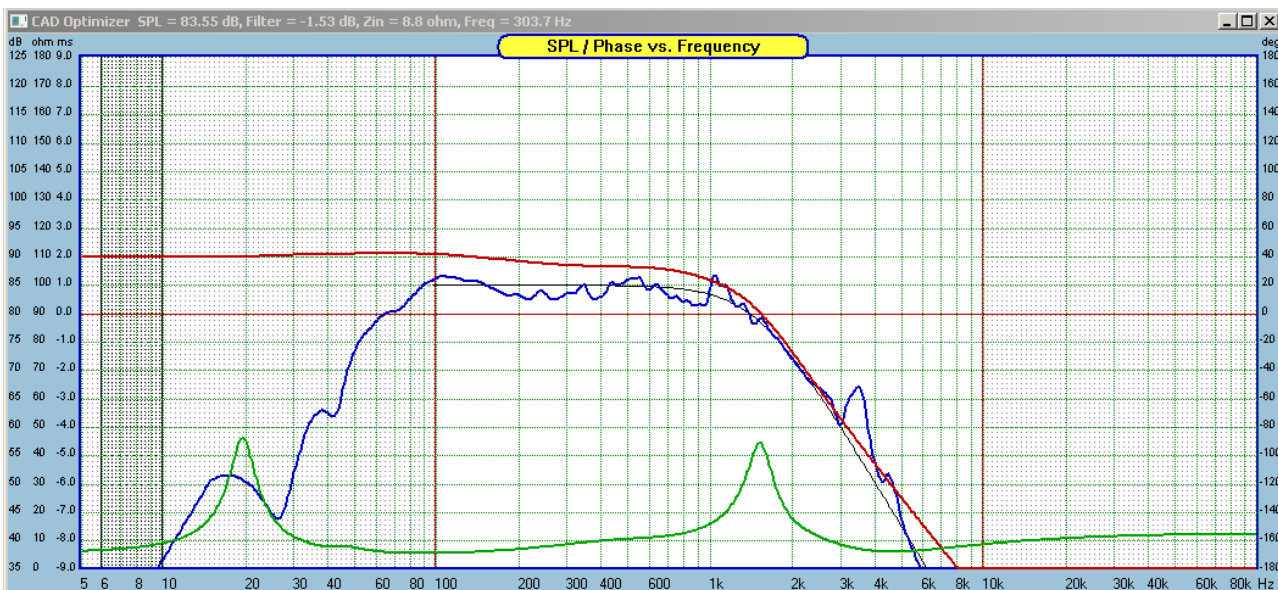
Zin [ohm] Constrained: 4.0 Apply

Ampl: 100.0 Zin: 0.00

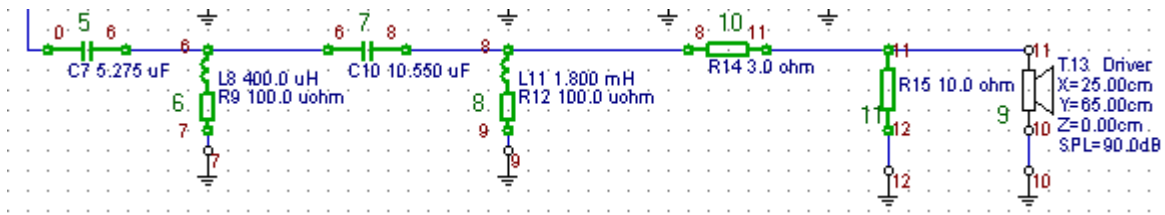
Zin [ohm] Conjugate: 6.0 Apply

Cmp = 4, Error = 658.0, ZinErr = 173.34, Trial = 138  
Zmin = 4.0, Zin = 5.80, Ztar = 6.0 [ohm]

Optimized Woofer Filter SPL curve (brown).



## Optimizing Acoustic Response of the Tweeter



**Optimization Parameters – 6 components: C7, L8, C10, L11 + L-Pad R14, R15**

**CAD Optimization Control**

**Targets Optimization Nodes**

Reference Configuration: H-P Passive, +12dB/oc | Reference Type: Bullock selected

H-P Passive, +18dB/oc | Butterworth selected

H-P Passive, +24dB/oc | Linkwitz selected

3. Reference Filter Cut-Off: High-Pass F3dB: 1500 Hz | Low-Pass F3dB: 1500 Hz | Qo Target: 0.333

4. Optimize Within This Frequency Range: From: 300.0 Hz To: 20000.0 Hz

5. BUT Exclude This Frequency Range: From: 6.0 Hz To: 10.0 Hz

6. Additional Reference Curve Shape Control: From: 0.0 Hz To: 0.0 Hz | Roll-off: 0.0 dB/dec | Attenuation: -5.0 dB

Show Target | Clear | Print

**CAD Optimization Control**

**Targets Optimization Nodes**

Doubleclick to Highlight ==> Optimize These Items

L8 = 0.660767 mH | C7 = 6.028124 uF

R9 = 0.000100 ohm | L8 = 0.660767 mH

C10 = 14.36615 uF | C10 = 14.36615 uF

L11 = 98.76871 mH | L11 = 98.76871 mH

R12 = 0.000100 ohm | R12 = 0.000100 ohm

T13 Driver | T13 Driver

R14 = 7.923940 ohm | R14 = 7.923940 ohm

R15 = 7.787771 ohm | R15 = 7.787771 ohm

Optimize | Abort | Lock ALL | New Val | Old Val | Accept New Values | Print | Clear

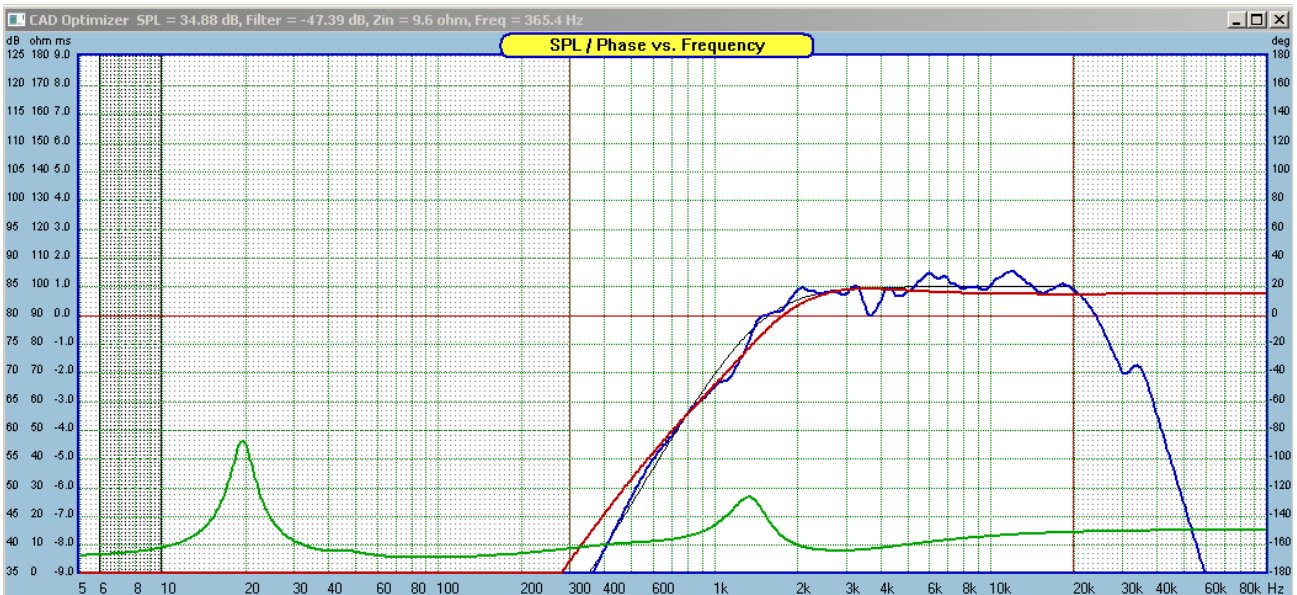
Step = 25 %

Zin [ohm] Constrained: 4.0 | Zin [ohm] Conjugate: 6.0

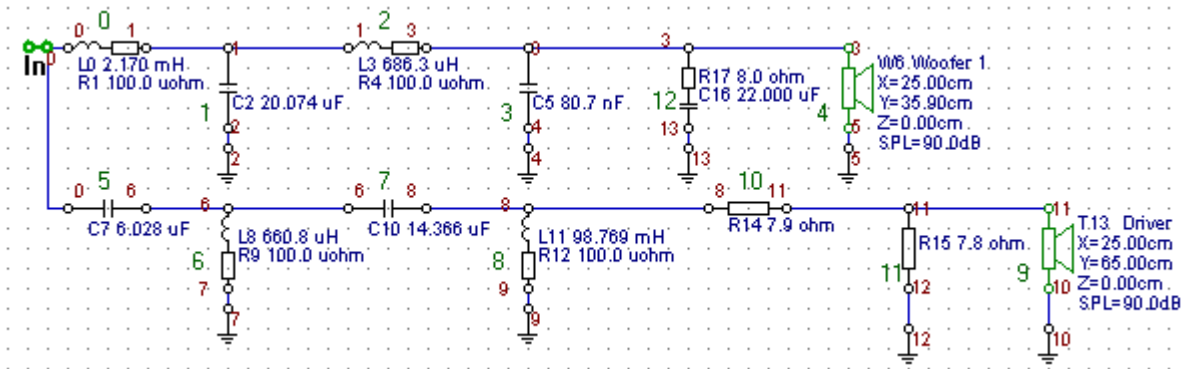
Cmp = 6, Error = 370.5, ZinErr = 398.38, Trial = 150

Zmin = 4.0, Zin = 7.98, Ztar = 6.0 [ohm]

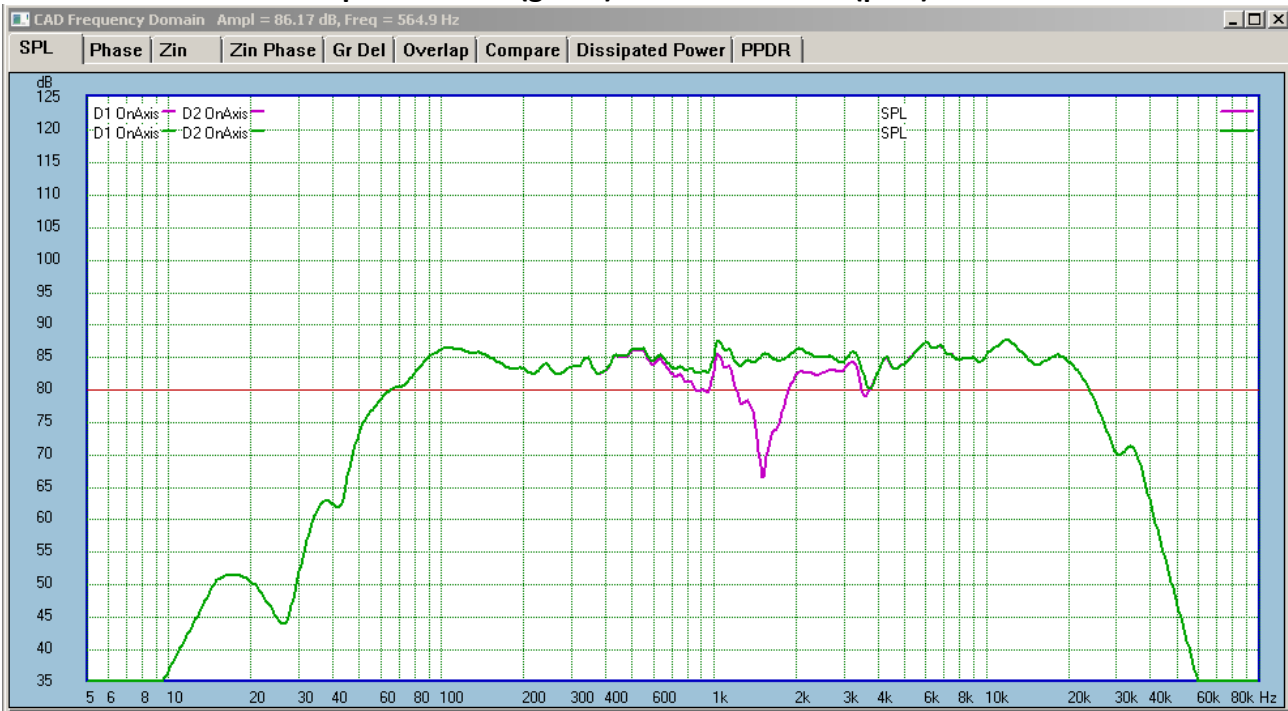
**Optimized Tweeter Filter SPL curve (brown).**



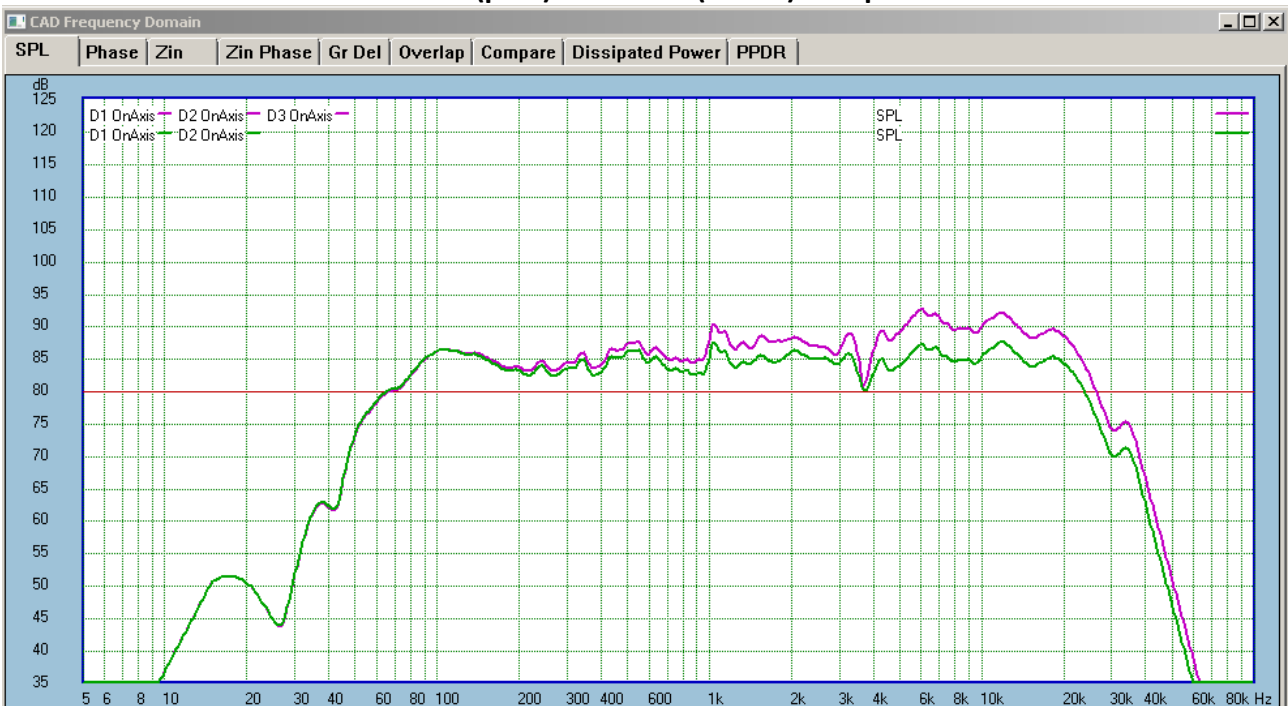
## Complete Optimized Values



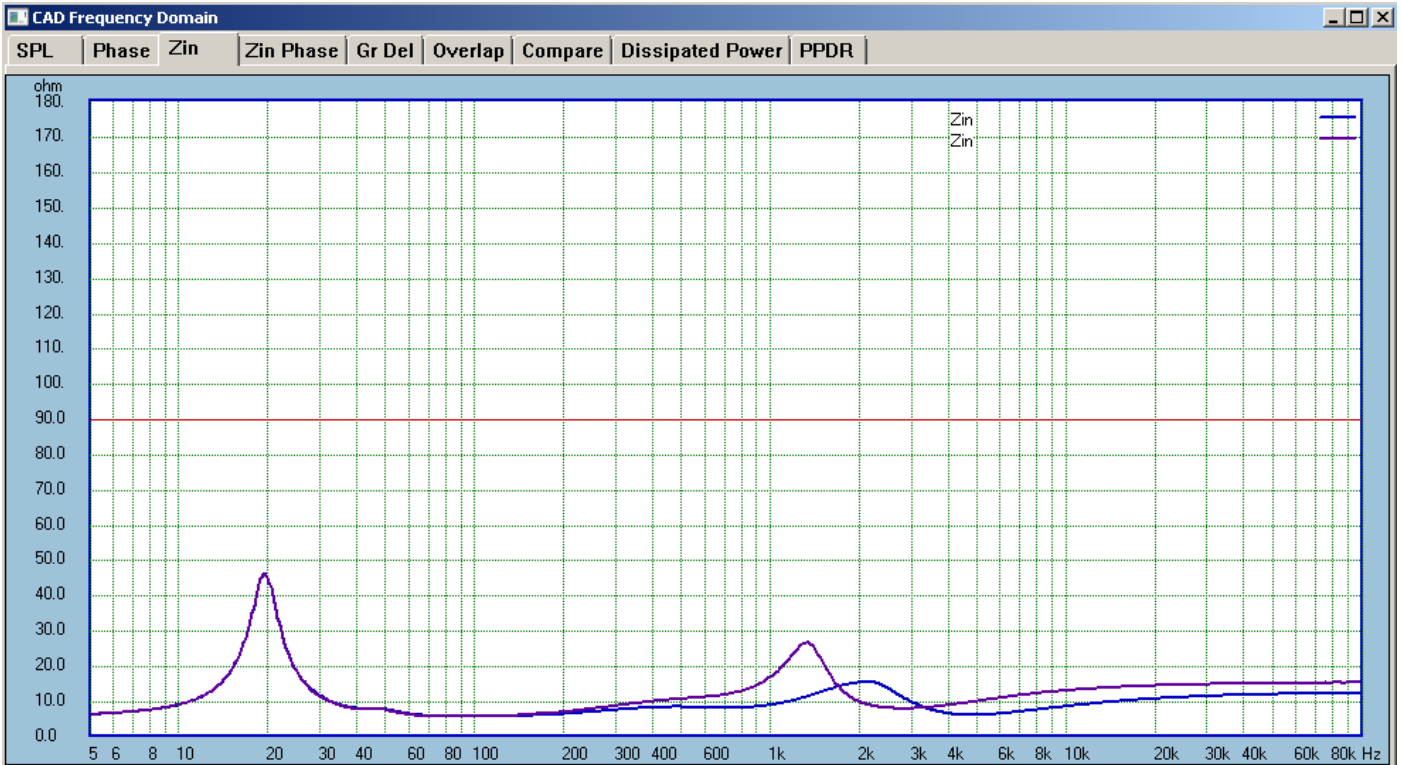
### Optimized SPL (green) and Reverse Null (pink)



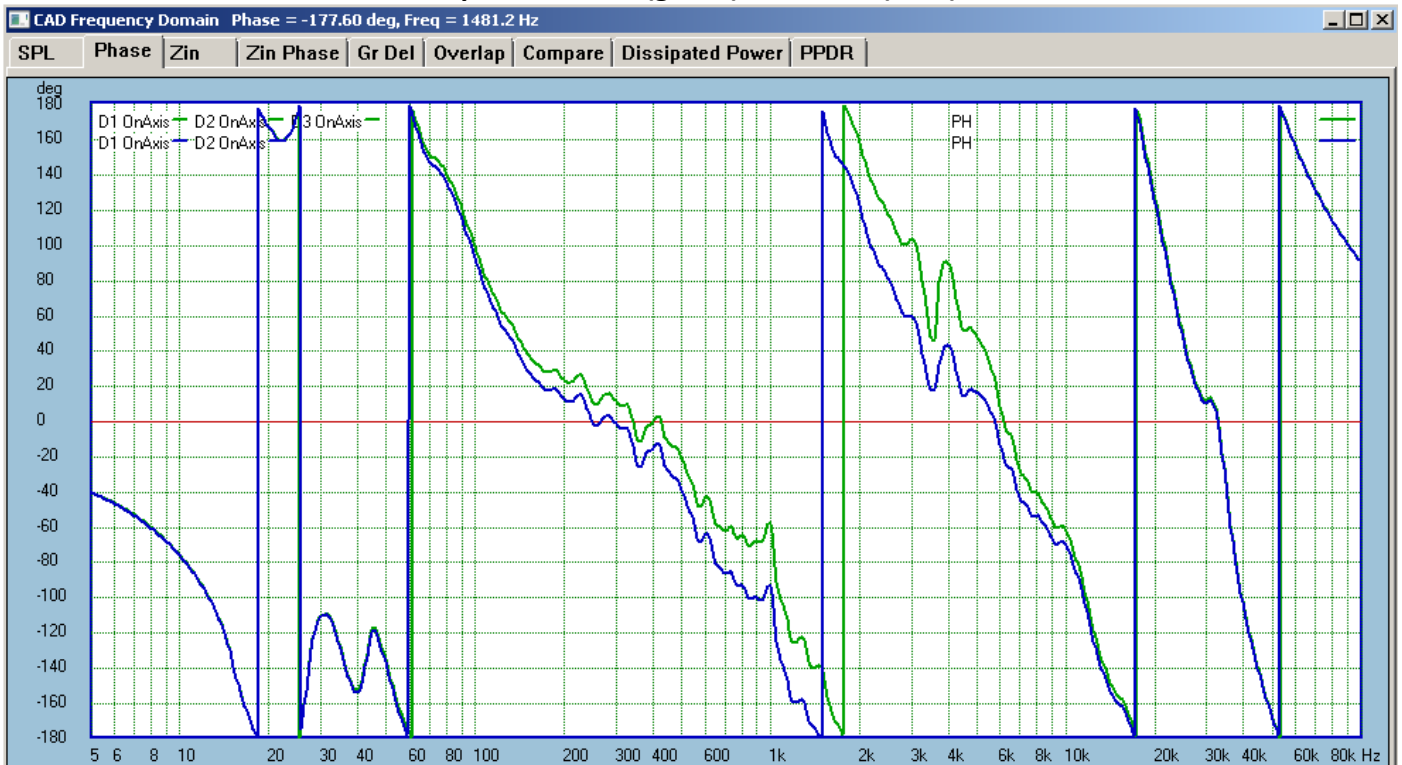
### Before (pink) And After (Green) Comparison



## Zin Before (violet) and After (blue)

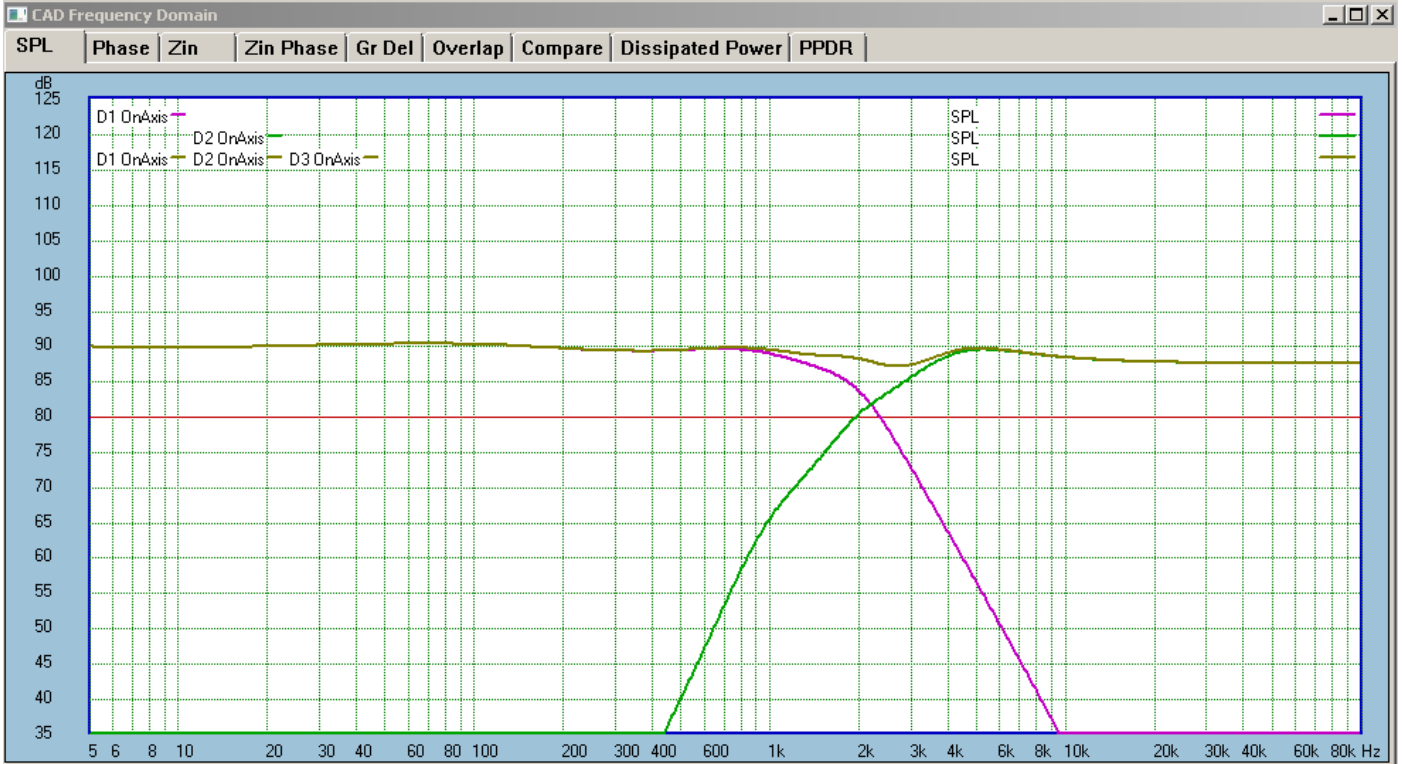


## Phase Response Before (green) and After (blue)



It is observable, that after the optimization, the Input Impedance (Zin) curve is flatter and the System Phase response transitions at 1500Hz – which is what is expected. Frequency response is now flat, the reverse null is sharp and almost -20dB deep.

## Original Crossover



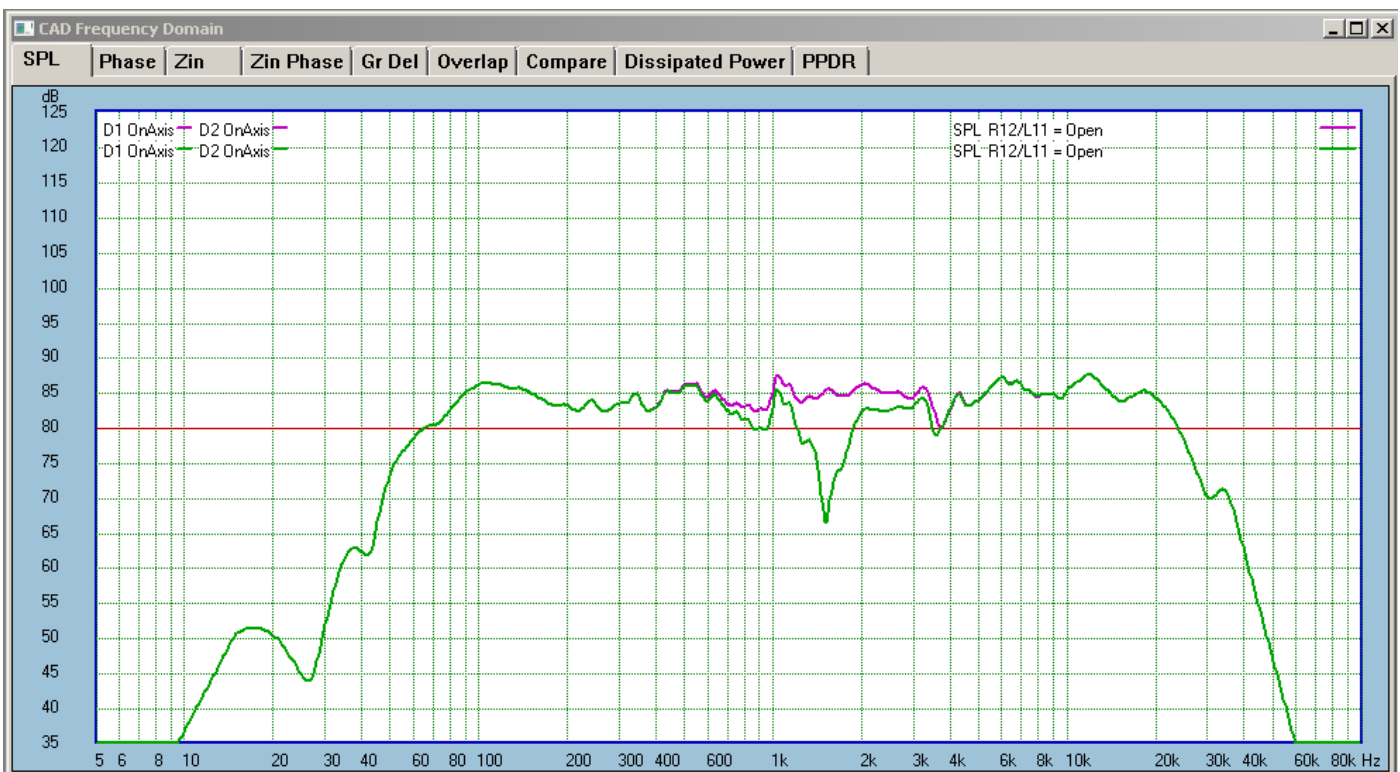
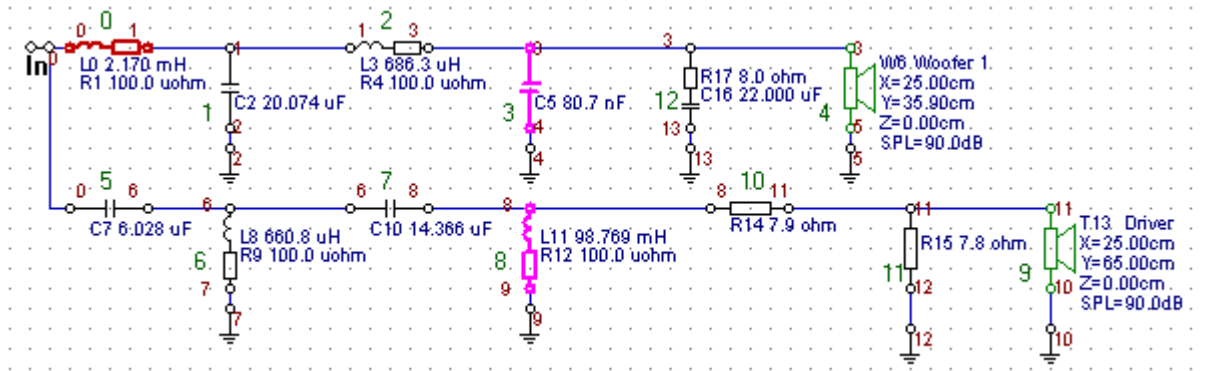
## Optimized crossover



## Optimizer Has Re-designed the Crossover.

**C5 = 80.7nF (very small) is NOT NEEDED.** When set to Open Circuit, it does not have any influence on the crossover operation.

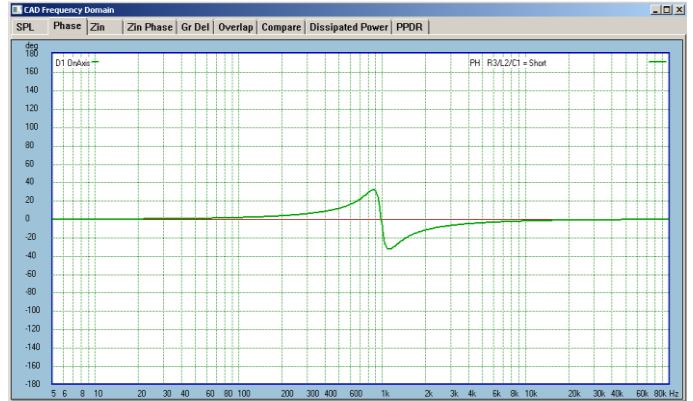
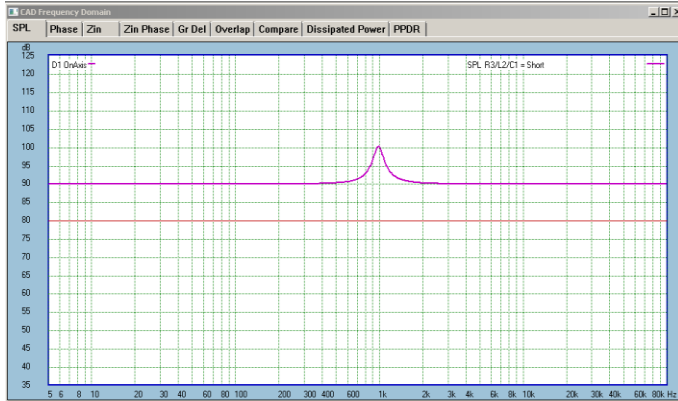
**L11 = 98.8mH (very large) is NOT NEEDED.** When set to Open Circuit, it does not have any influence on the crossover operation.





## Compensating Amplitude Peak

Frequency response has a +10dB amplitude peak – see figures below.



### Amplitude Peak Equaliser

**Design Parameters**

Re  ohm

Ao  dB

Fl  Hz

Fh  Hz

Al,h  dB

Tank Rp = 17.2982 ohm

Tank Lp = 0.33204 mH

Tank Cp = 77.9010 uF

Calculate Done

Example Print

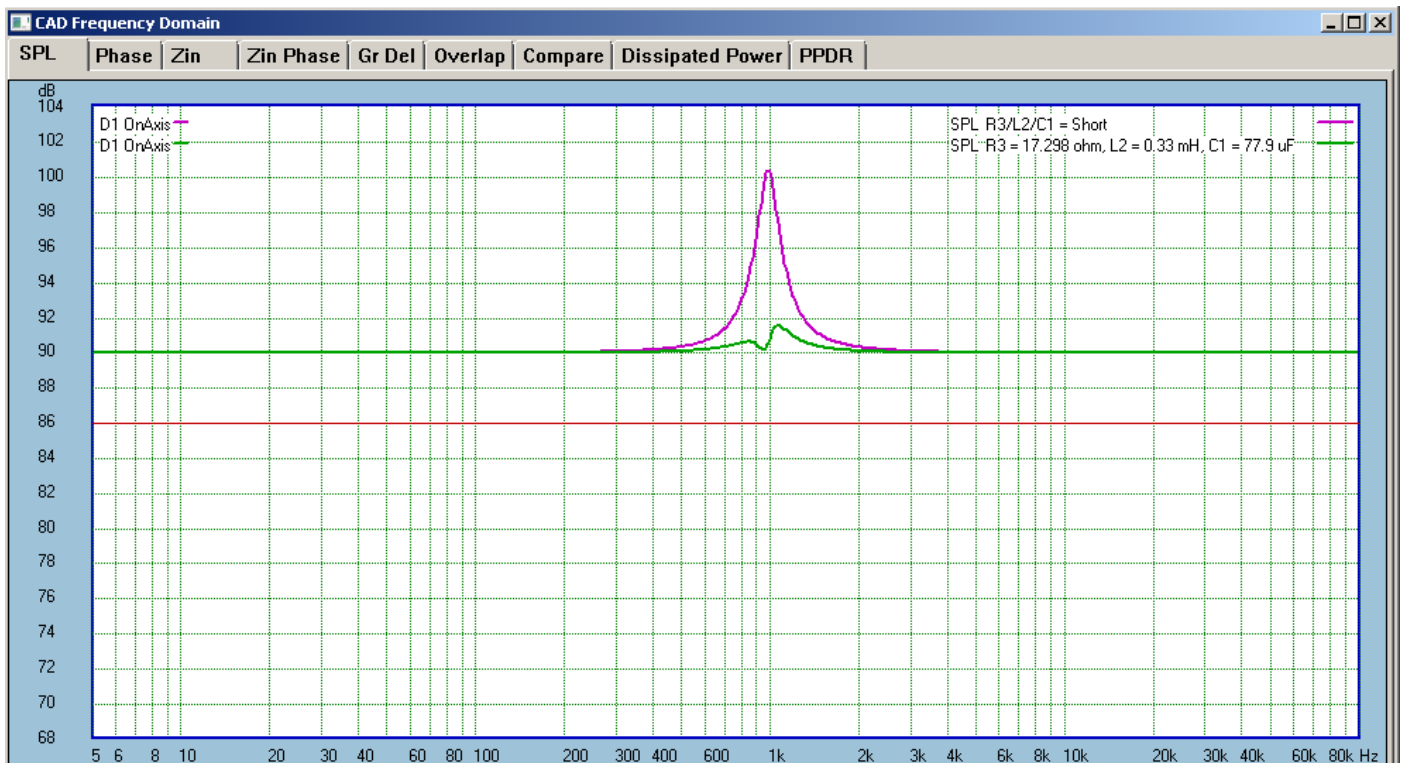
Re=Load resistance

Amplitude [dB]

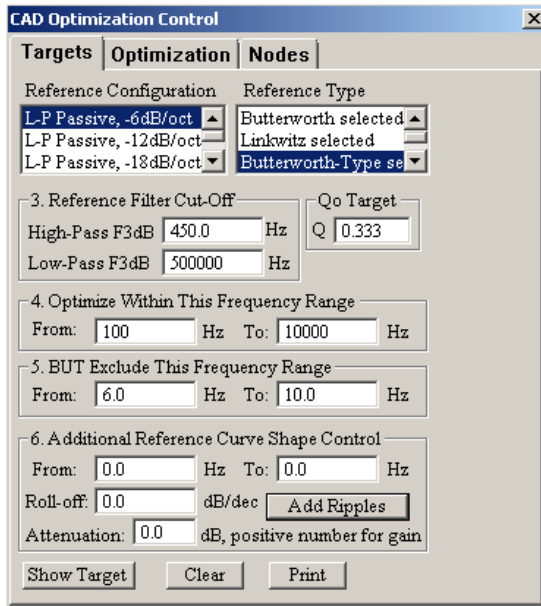
Frequency [Hz]

Ao=Bump height at Fo  
 Al=Bump height at Fl  
 Ah=Bump height at Fh  
 $F_o = \sqrt{F_l \times F_h}$   
 Al = Ah

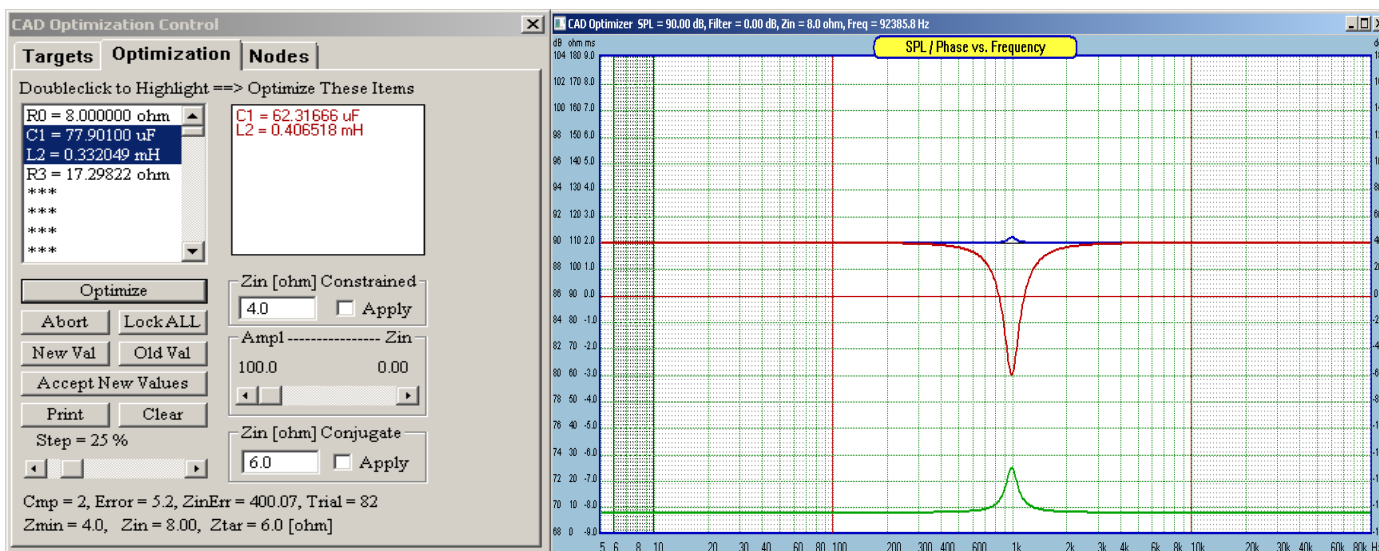
Amplitude Peak Equalizer generated component values as shown above. The peak is greatly reduced, but not eliminated.



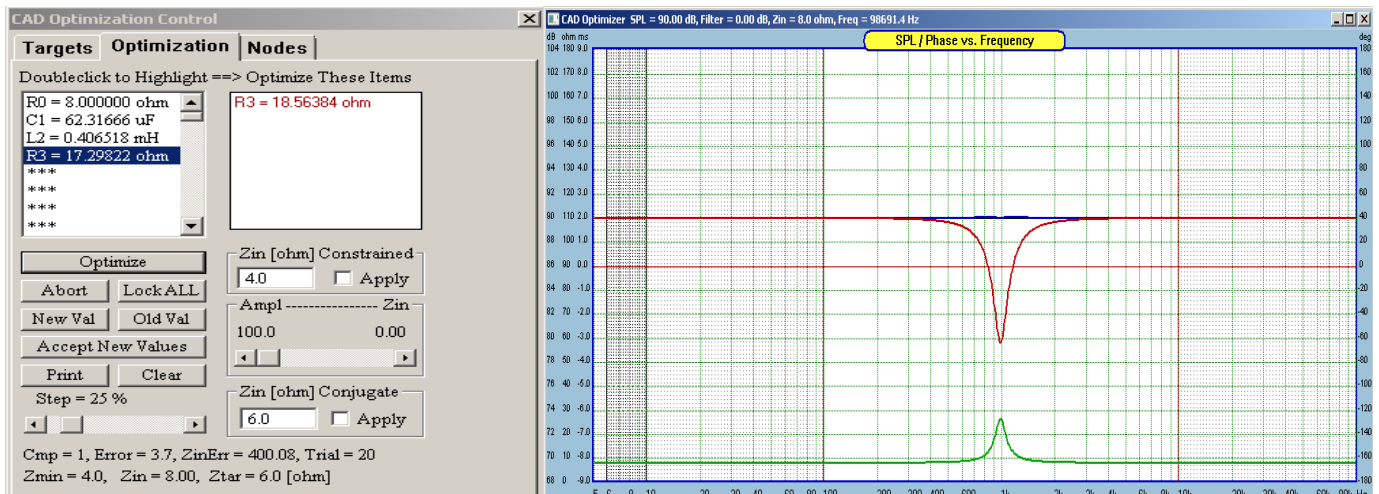
Now, the optimizer is engaged. Optimization Parameters are as follows:



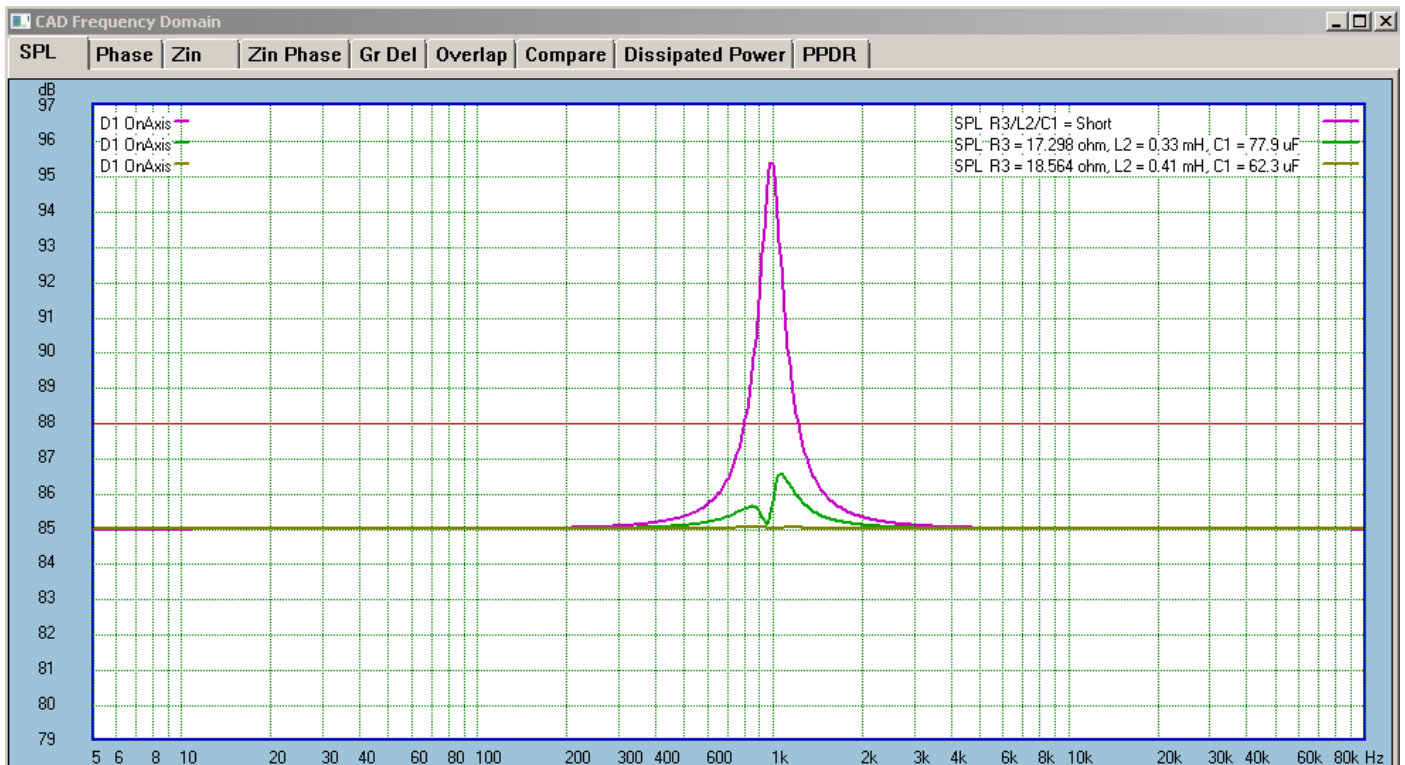
Optimization was performed in two stages. Stage 1 – C1 + L2 resulting in SPL curve improvement (blue) as shown below.



Stage 2 – R3 resulting in SPL curve improvement (blue) as shown below.



Further down are the comparison results between the values calculated by the Amplitude Peak Equalizer (green), and values optimized by two-stage optimization process (olive). Original SPL curve is pink. Please note, that the vertical resolution dB scale was set to 1dB. Otherwise, in 5dB scale, the optimized curve was a flat line.



## Conclusions

1. Loudspeaker system has been designed and optimized without single manual tweak of any component.
2. Optimizer handled up to 6 components at a time, even though it is not recommended to exceed 3 components.
3. All of the parametric performance curves exhibit good characteristics after optimization.
4. Optimized SPL curves for individual filters do not follow 4th order LR filters, but the acoustic responses from the drivers do. This was the design goal.
5. Optimizer has also eliminated two components from the crossover circuit.
6. Local SPL irregularities (10dB peak, for example) are also handled very well by the optimizer, using two-stage process.