Cones-a-Flapping

A 3-way Minimally Baffled Dipole Loudspeaker
Charlie Laub, Designer/Builder

ABBREVIATIONS USED IN THIS DOCUMENT:

FR = frequency response
PR = power response
DI = directivity index

DESIGN CONCEPT :

Cones-a-Flapping is an evolution of my previous dipole loudspeaker projects that employ the principle of minimal baffle size. This states that the baffle width around a driver must not exceed 2 times the radiator diameter. Following this principle helps the loudspeaker to maintain constant directivity across the audio band.

LOUDSPEAKER DESIGN :

Prior efforts were 4-way designs that used sealed subwoofers to handle frequencies below approximately 80 Hz. In the current design, the subwoofers have been eliminated and the woofer band has been improved in terms of output capability and low frequency extension. The woofers (SB Acoustics WO24P-8) have relatively low distortion for their class. Four woofers placed in a 20x20 inch panel act as a single larger driver, with two reversed to reduce even order distortion. A 3.3 mH inductor is used both to flatten the **FR** and to reduce motor-generated third order distortion products. By connecting all four drivers in parallel the voltage sensitivity is maximized and both the total impedance and the value of the inductor required is minimized. The inductor value was chosen so that its impedance is rising as the driver impedance is falling back to Fmin above the fundamental resonance, with the sum remaining above 4 Ohms. The series inductance tilts the response down by 6dB/octave beginning at 70 Hz to cancel out the rising dipole response. To take advantage of boundary gain, the woofer panel is placed on the floor. These design choices allow the woofer section to have a relatively high voltage sensitivity and frequency extension into the mid 30s, with F3=36 Hz.

Similar to previous projects, the midrange (SB Acoustics MW19TX-8) and tweeter (Aurum Cantus AST25120) are used “nude”. These drivers are suspended within a non-resonant wire cage that straddles the woofer panel and is acoustically transparent. The suspension mechanically decouples the midrange and tweeter and minimizes the acoustic obstacle that these drivers present within the listening space. The low-distortion midrange uses a concave Textreme cone, which improves breakup and pushes the frequency at which the driver becomes directive upwards. The driver is operated from 300 Hz to 2k Hz (2.75 octaves), which is a wide bandwidth for a nude dipole and nicely complements the bandwidth of the tweeter. The mounting flange of the tweeter is removed to minimize the baffle area, leaving only the smaller motor and diaphragm sections.

MEASUREMENTS :

Quasi-anechoic measurements were conducted on the tweeter and midrange at 0.5 m distance. A measurement was made on the woofer panel at 3 m distance with the microphone at an elevation equal to the tweeter height (1.1 m). The measurement data of both the tweeter and midrange was extrapolated to a distance of 3m (where the woofer panel measurement was made) by reducing the SPL level by 15.5 dB and adding delay of 7.4 msec.

CROSSOVER DEVELOPMENT :

The crossover was developed from the measurement data using a suite of in-house crossover modeling tools with the goal of implementing the filters using IIR DSP. Full details of the filters are provided at the end of this document. The crossover design process begins by flattening and smoothing the driver responses, then adjusting gains and applying the crossover filters. The goal is to obtain as flat an on-axis response as possible. Crossover points of 300 Hz and 2.0k Hz were used. Both crossovers employ a type of steep filter with stopband notches that I developed. It produces low group delay and passband ripple of only 0.15 dB. For further information on the crossover please see the description near the end of this document. After the design process had been completed in the modeler, the system **FR** was re-measured and a few final adjustments were made to the crossover filters.

TONAL BALANCE AND VOICING OF A DIPOLE LOUDSPEAKER:

Often, a loudspeaker with a dipole radiation pattern and a flat on-axis **FR** is perceived simultaneously both as bass anemic and too bright. Why? A conventional "boxed" loudspeaker with a near flat **FR** has a **DI** that increases from 0 dB at low frequencies to 10 dB or more at high frequencies. In contrast, a loudspeaker with a dipole radiation pattern and a flat **FR** has a constant **DI** value of about 4.75 dB.

Because the **PR** can be approximated by the inverse of the **DI** curve, the dipole pattern will deliver 4 to 5 dB less acoustic power at low frequencies (anemic bass) and 4 to 5 dB more acoustic power at high frequencies (brightness) when both systems have flat on-axis **FR**. In addition, a dipole cannot pressurize the room and will not benefit from room gain at very low frequencies. For these reasons, a dipole must be voiced in such a way as to offset these differences in **PR** even though this will also change the dipole's on-axis **FR**.

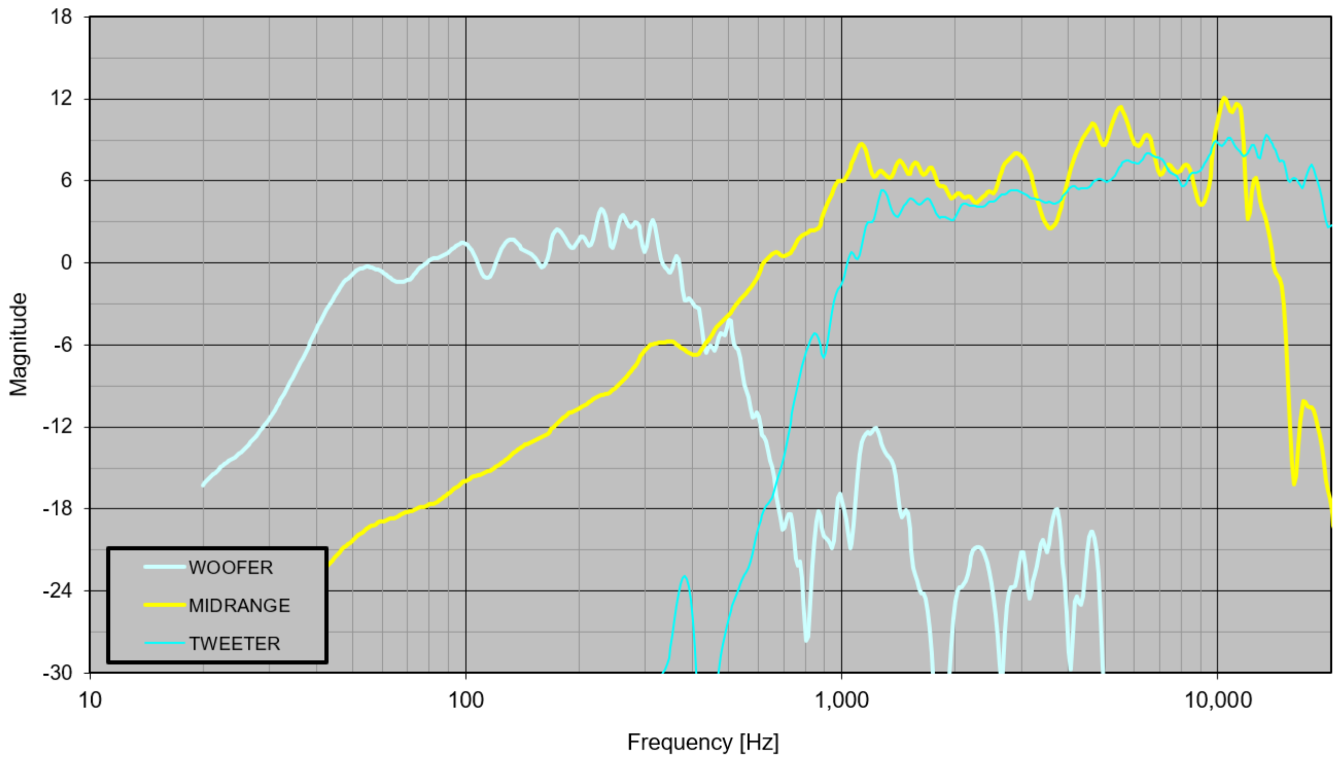
A survey of Klippel reports available online (see: https://www.erinsaudiocorner.com) gave rise to a first order approximation of the **DI** that trends upwards at 3 dB/decade across the audio band. The **PR** model is the inverse of that curve and trends down at 3 dB/decade. Initially the voicing EQ is set equal to this **PR** curve.

Voicing was conducted while listening to various types of music over a period of many weeks and adjusting the EQ curve to improve the overall tonal balance. The final EQ curve spans 8 dB and is plotted alongside the -3dB / decade **PR** trend line. In addition, the final voicing EQ was found to be nearly identical to listener preferred steady-state responses reported in 2013 by S.E. Olive. The in-room steady state response is similar to the loudspeaker **PR**, so this is an interesting but not surprising correlation. The voicing EQ was implemented with additional filters placed upstream from the crossover.

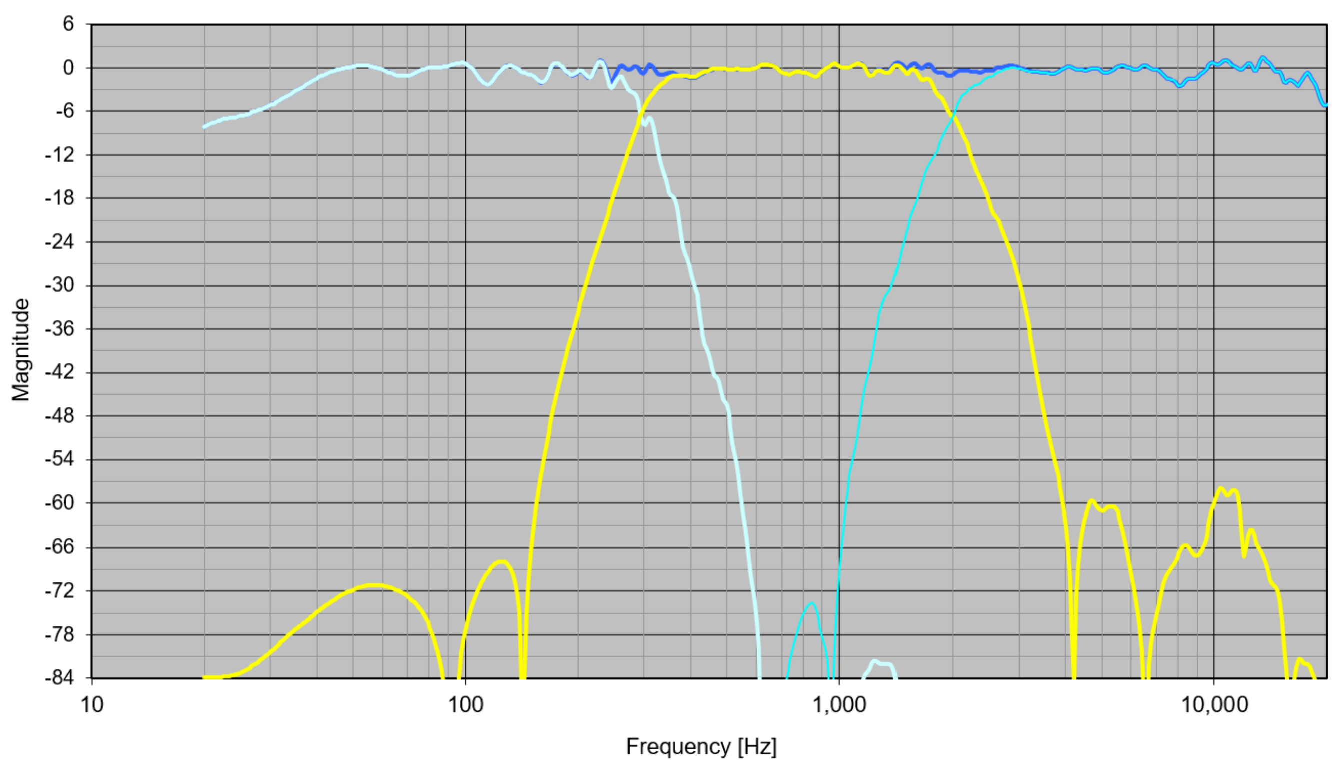
AUDIO EQUIPMENT AND PLAYBACK CHAIN :

The audio source is a laptop computer running Ubuntu Linux. Audio from apps is routed through PulseAudio, where the format is converted to 24-bit, 96k Hz (resampling when necessary). Routing and DSP processing is performed with software I wrote that invokes elements of the Gstreamer multimedia processing platform. Audio is output via ALSA to a Topping DM7 multichannel DAC. The tweeters and midranges are powered by an amplifier that uses Hypex nCORE NC502MP modules, and a Crown DCi 2|1250 drives the woofer panels.

Raw Driver Responses :



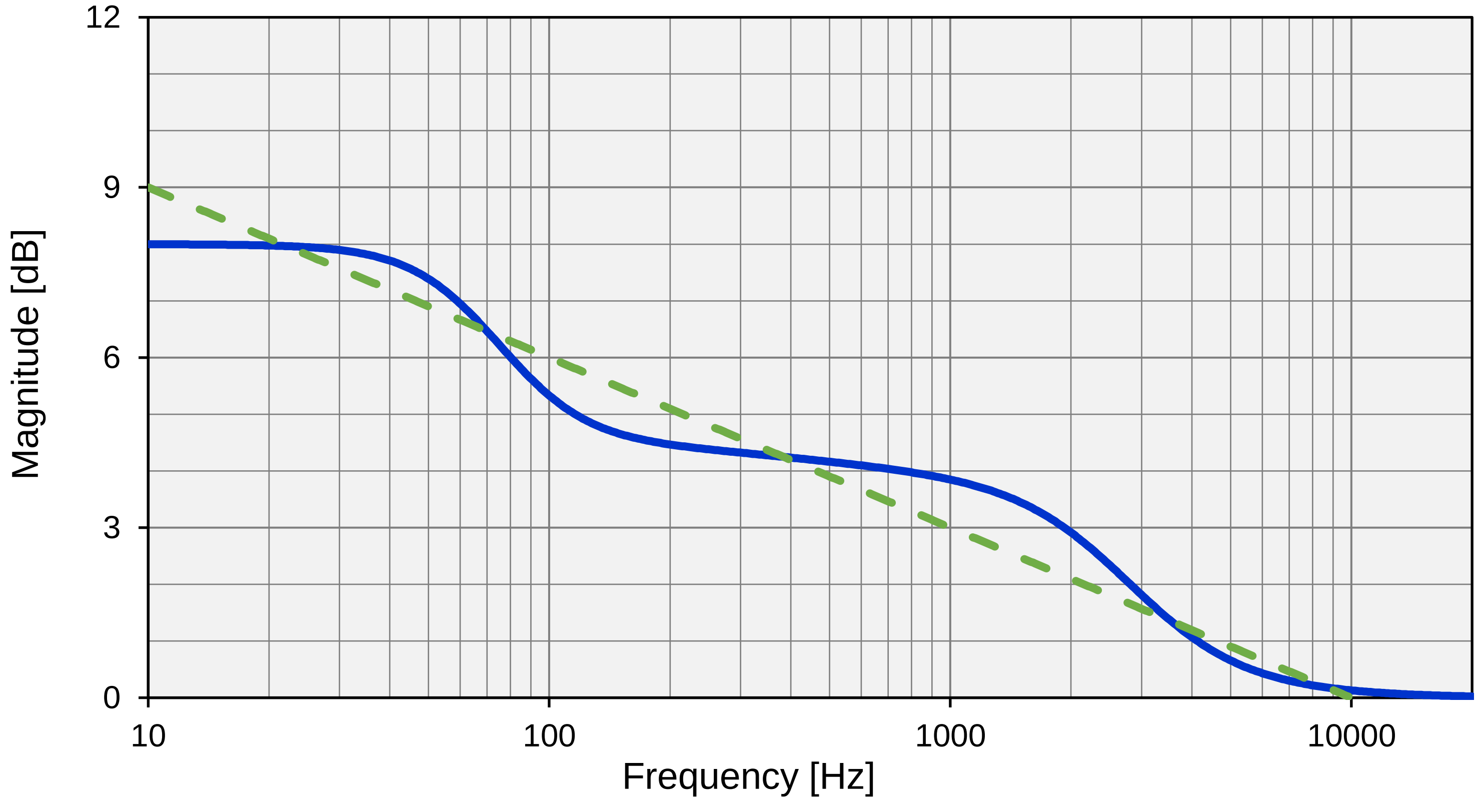
System Response before applying Voicing EQ :



Voicing EQ :

Dashed green line = -3dB per decade trend line

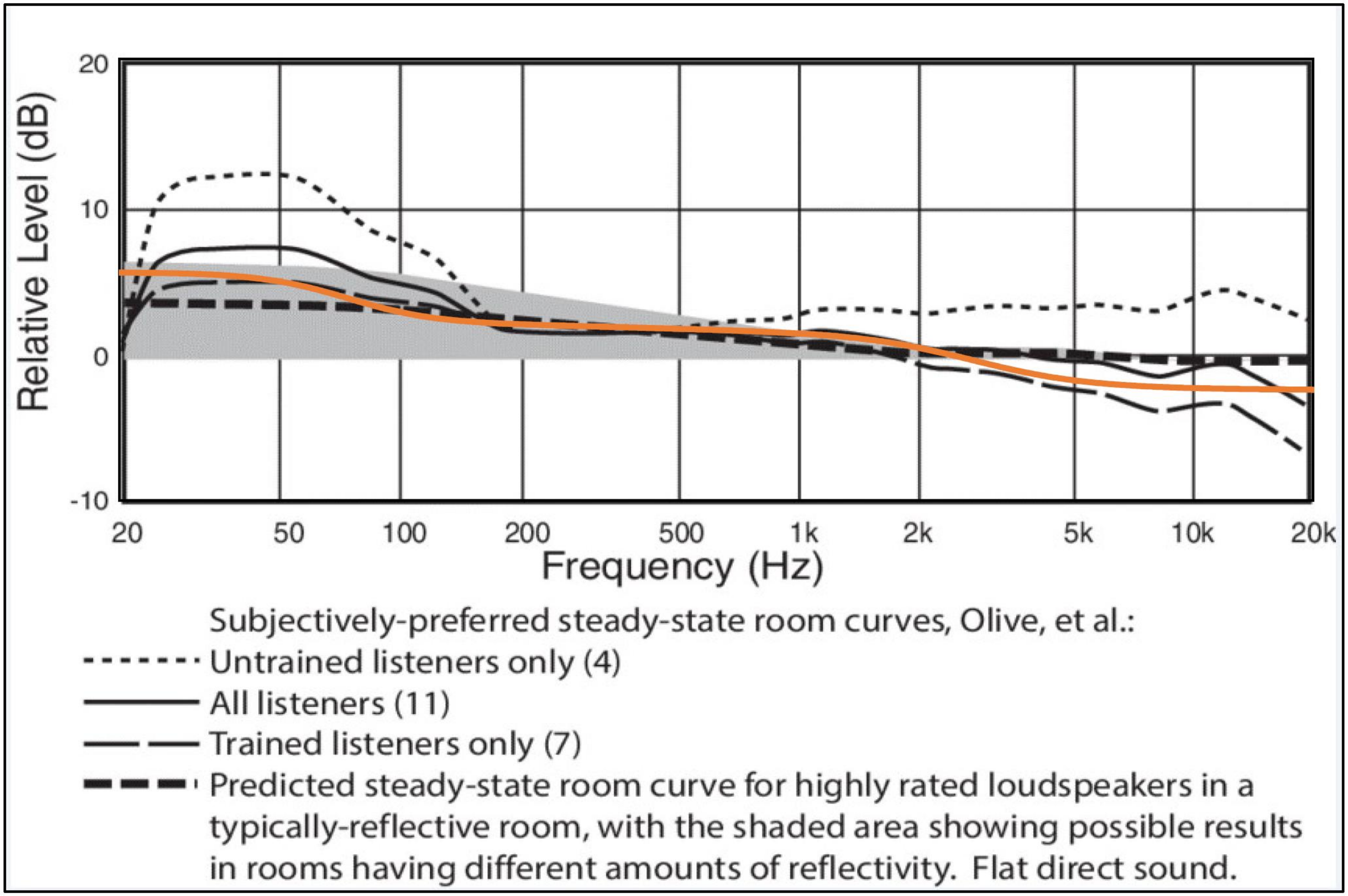
Blue line = voicing EQ applied to the Cones-a-Flapping loudspeaker



Comparing the voicing EQ curve (below, in orange) to Listener Preferred Steady-State Responses as reported by Olive [1].

1. S.E. Olive, T. Welti, E. McMullin, “Listener Preferences for In-Room Loudspeaker and Headphone Target Responses,” presented at the 135th Convention of the Audio Engineering Society (2013 Oct.), convention paper 8994.

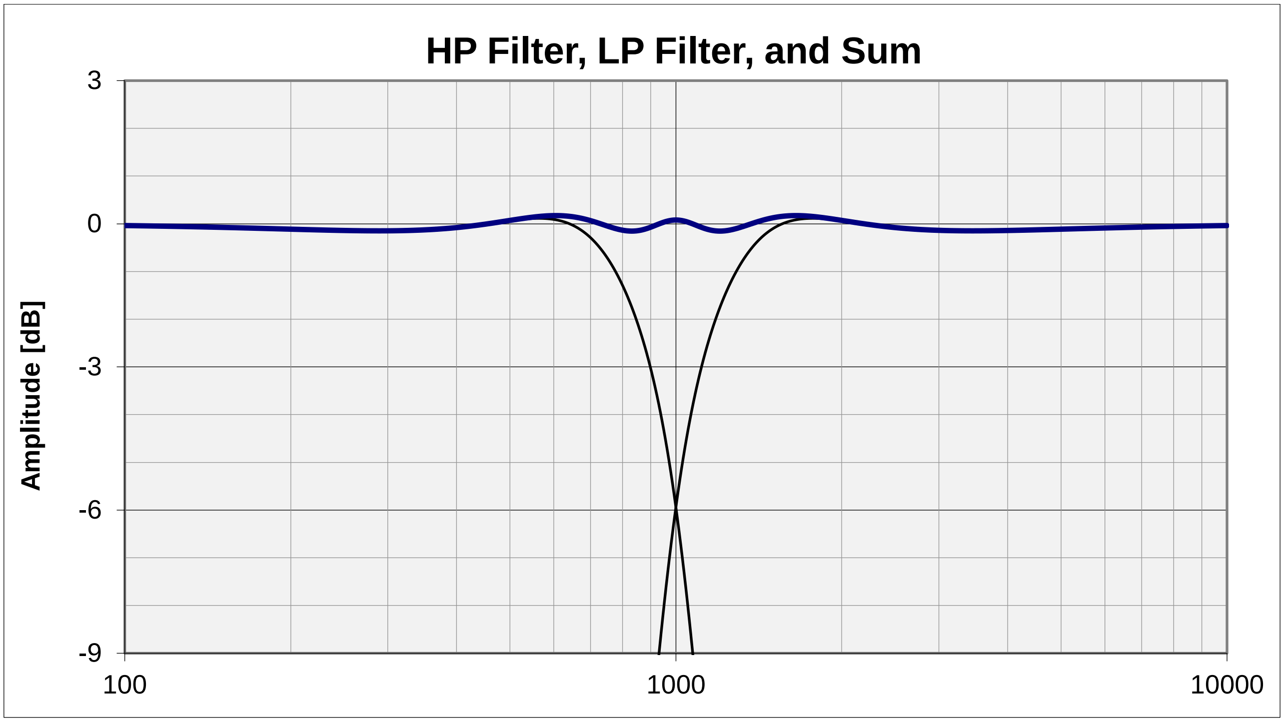
NOTE: Figure below adapted from Figure 14 of F. Toole, “The Measurement and Calibration of Sound Reproducing Systems”, JAES vol. 63 Issue 7/8 pp. 512-541; July 2015. Available online at: https://www.aes.org/tmpFiles/elib/20230726/17839.pdf

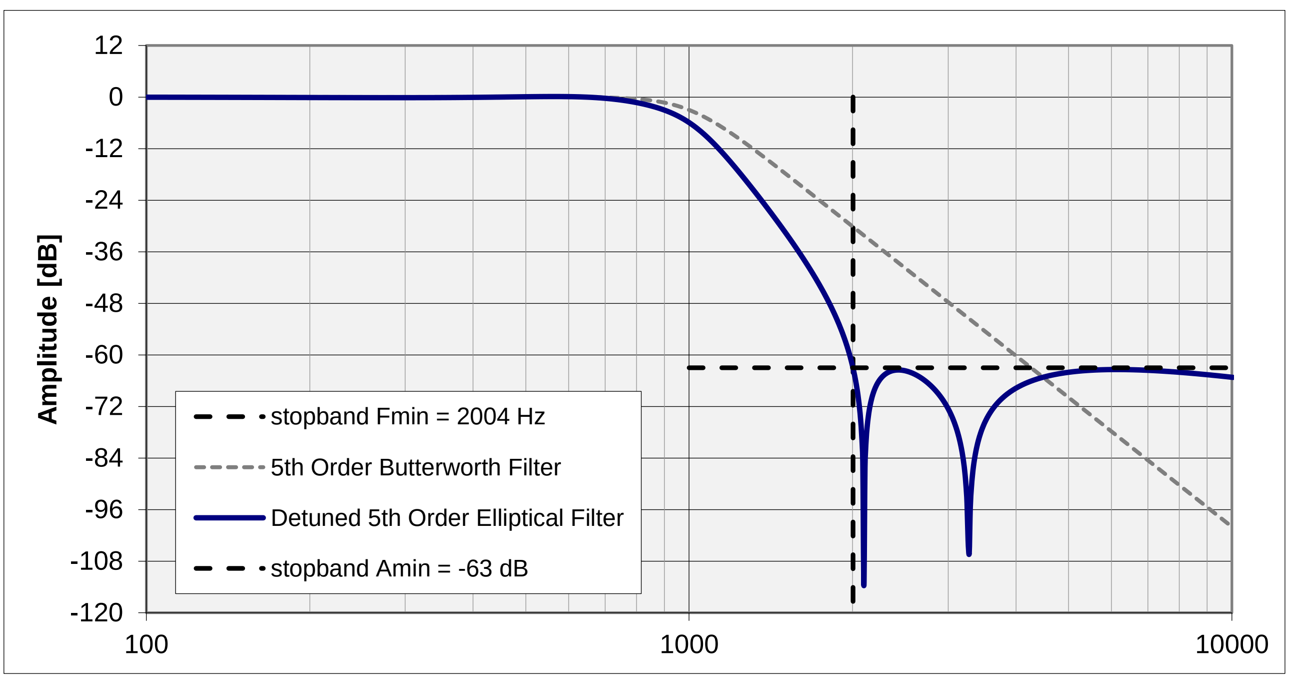


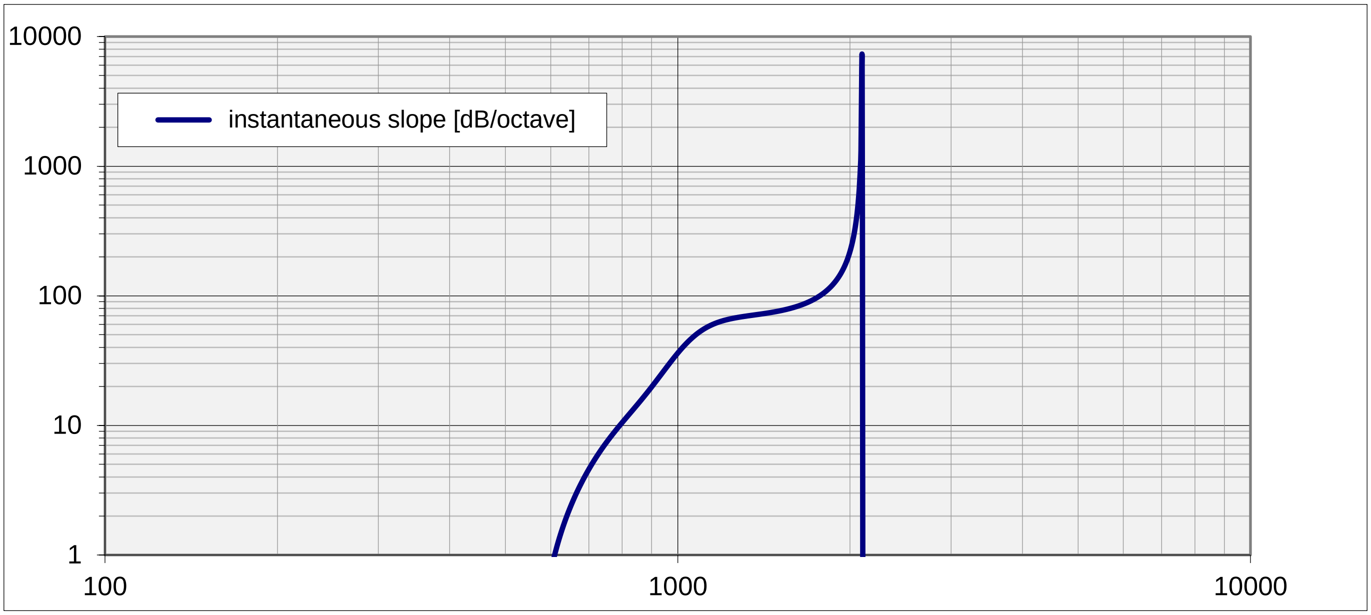
5th ORDER CROSSOVER FILTER INFO:

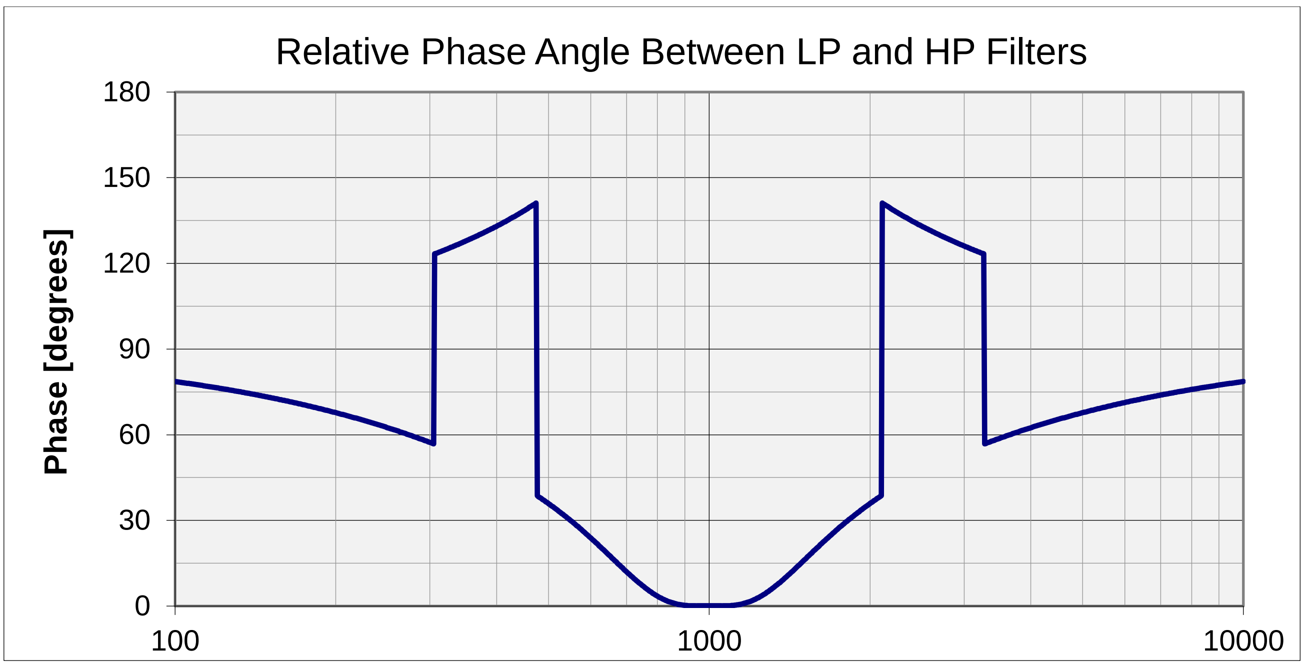
The crossover filters used in Cones-a-Flapping are described below. These 5th order filters include zeros in the stopband and are derived from an elliptic filter via optimization. The highpass and Lowpass responses are in-phase at the crossover frequency due to additional phase rotation from the stopband notches. The instantaneous slope in the transition band is 36 dB/octave at Fc and passes 100 dB/octave at a frequency of only 1.8 Fc. The stopband region begins at 2.0 Fc where attenuation meets or exceeds 63 dB. This is one example of a series of filters I have designed that share some of the characteristics of notched crossovers previously developed by Hardman, Modaferri, and Thiele.

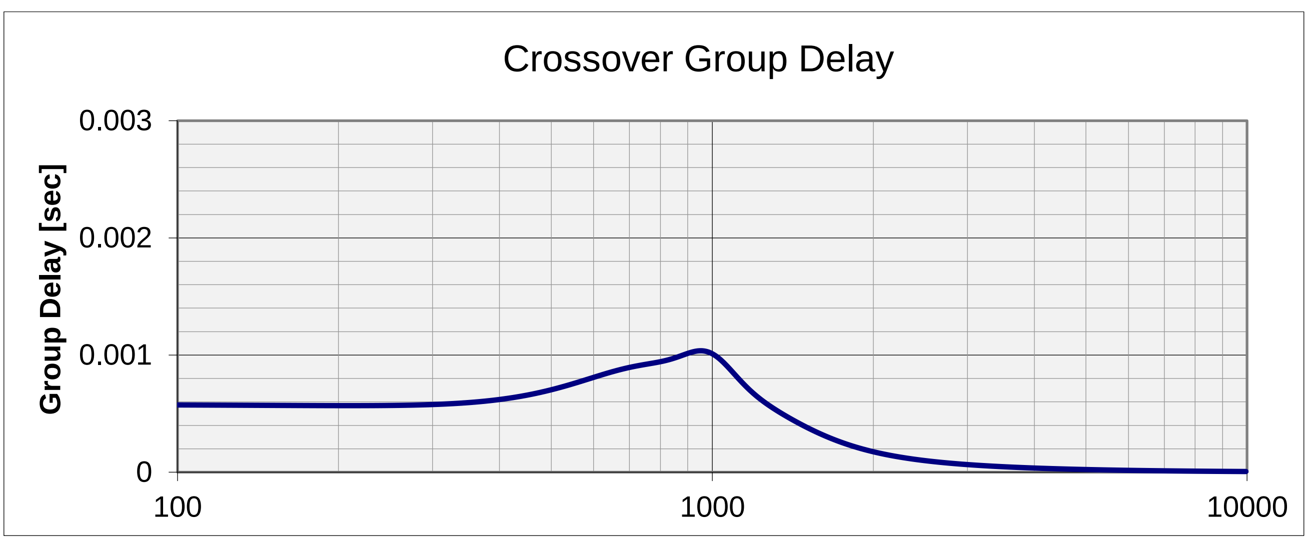
The following figures are plotted versus frequency for a crossover frequency of 1k Hz.






10000
1000
100
10
1
instantaneous slope [dB/octave]
100
1000
10000


Relative Phase Angle Between LP and HP Filters
Phase [degrees]
180
150
120
90
60
30
0
100
1000
10000


Crossover Group Delay
Group Delay [sec]
0.003
0.002
0.001
0
100
1000
10000

CROSSOVER and VOICING EQ FILTERS:

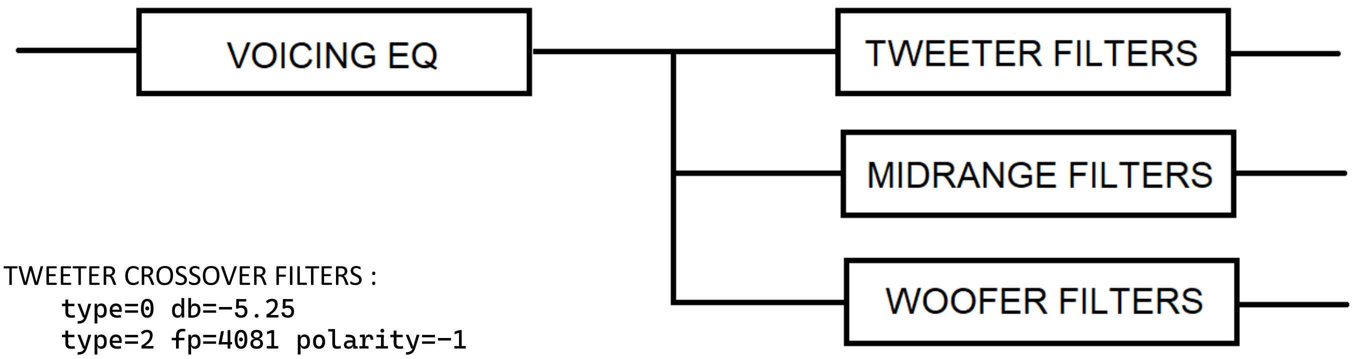
For each band listed below, use the key at right to identify the filter from the filter type in the list of filters.

1st ORDER FILTERS:
0 = gain block
1 = 1st order Lowpass
2 = 1st order Highpass
3 = 1st order Allpass
4 = 1st order low shelf
5 = 1st order high shelf

2nd ORDER FILTERS:

21 = 2nd order Lowpass
22 = 2nd order Highpass
23 = 2nd order Allpass
24 = 2nd order low shelf
25 = 2nd order high shelf
26 = parametric EQ
27 = notch filter
28 = biquadratic filter

DSP SIGNAL FLOW :



TWEETER CROSSOVER FILTERS :
```
type=0 db=-5.25
type=2 fp=4081 polarity=-1
type=27 fp=1950 qp=2.15 fz=857
type=27 fp=2620 qp=1.16 fz=550
type=26 db=-1 fp=2960 qp=2
type=25 db=-3 fp=5000 qp=1
```

MIDRANGE CROSSOVER FILTERS :
```
type=0 db=-5.75
type=28 fp=875 qp=0.8 fz=1050 qz=1
type=24 db=15 fp=325 qp=0.5
type=23 fp=10000 qp=0.56
type=26 db=-2.5 fp=1120 qp=6
type=2 fp=612 polarity=-1
type=27 fp=293 qp=2.15 fz=143
type=27 fp=392 qp=1.16 fz=91.61
type=1 fp=980
type=27 db=-12.44 fp=2051 qp=2.15 fz=3779
type=27 db=-25.3 fp=1527 qp=1.1 fz=5894
type=23 fp=1000 qp=0.7
type=26 db=3.5 fp=415 qp=2
```

WOOFER CROSSOVER FILTERS :
```
type=0 db=-7.5
type=1 fp=147
type=27 db=-12.44 fp=308 qp=2.15 fz=630
type=27 db=-25.3 fp=229 qp=1.15 fz=982
type=28 fp=30 qp=0.6 fz=60 qz=0.5
type=26 db=-2.5 fp=50 qp=2
```

VOICING EQ FILTERS:
```
type=24 db=3.5 fp=75 qp=0.7
type=5 db=-0.25 fp=300
type=5 db=-0.25 fp=600
type=25 db=-4.0 fp=2800 qp=0.6
```