2. Crossovers: Further Knowledge

Additionally to part I of the crossover papers, this paper discusses the work of crossovers any further and goes into some hefty details about alignments and phase effects.

2.1. Combining Responses

The main goal when using crossovers is to obtain a flat transfer function for the combination of low and high pass filters. To find out how signals add together is one of the most important points in crossover design. A few guidelines must be observed when combining two signals, especially when considering phase responses.

→ Combination of two independent signals: Combine as SCALAR quantities
→ Combination of two correlated signals: Combination gives +6 dB
→ Combination of two uncorrelated signals: Combine as RMS quantities

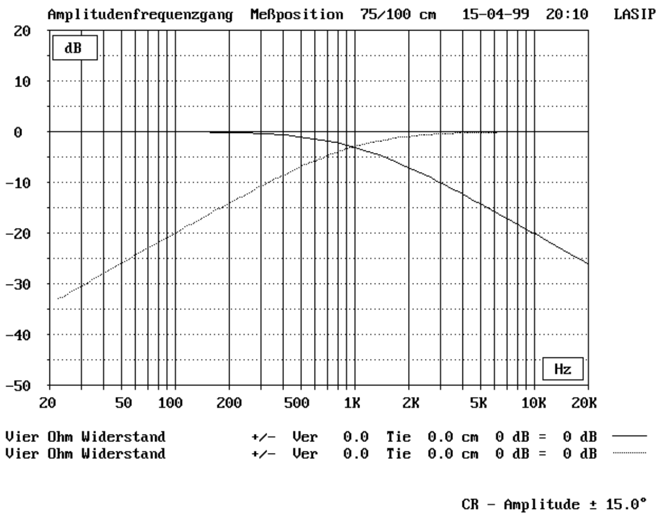
Based on the above basic summation laws we can divide the basic loudspeaker crossover networks in correlated and uncorrelated networks. It is worth noting that different filter Q's and slopes have therefore different phase characteristics, hence different filters will have different relationships between their correlated or uncorrelated counterpart.
The following table shall give an overview over the different phase characteristics and their combining characteristics:

Phase	Filter Order	Combination as:	Crossover Level:
0°	none	Correlated Signals	- 6 dB
90°	1st Order	Uncorrelated Signals	- 3 dB
180°	2nd Order	Correlated Signals*	- 6 dB
270°	3rd Order	Uncorrelated Signals	- 3 dB
360°	4th Order	Correlated Signals	- 6 dB

* Note that the signals only combine as correlated signals when the polarity of one of the filters is reversed - which then equals a 0° phase.

In addition, all even-order networks show a phase relationship which is in phase - this includes Butterworth, Bessel, Linkwitz-Riley and Chebychev, again with the note that the second order filters need to have one signal's polarity reversed to be treated as correlated signals.

This shows that certain filters require an attenuation of -3 dB at the crossover frequency, whereas others require an attenuation of -6 dB at the crossover frequency. When using the standard book formulae for crossover calculation, the result will always be either 1) the frequency at the -3 dB point or 2) the parts values at the -3 dB values. To obtain the correct frequency values to get a -6 dB attenuation as required for some filters, one must spread the given filter frequencies by a factor of about 1.3 to move the crossover point to the -6 dB attenuation. The following graphics might clear the doubts from reading the above:

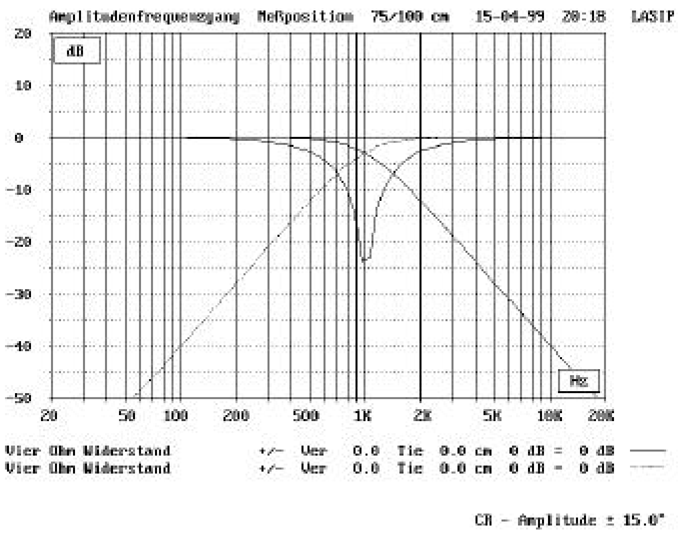


Info for fig. 1:

fc:	1000 Hz
Order:	1st
Polarity High Pass:	+
Polarity Low Pass:	+
Filter Characteristic:	Butterworth

Fig. 1 - First Order Butterworth Filter with flat overall Transfer Function

The above illustration, fig. 1., shows a first order Butterworth filter; according to the tables on the previous pages the first order filter sums as a uncorrelated filter, with the attenuation at the crossover frequency being -3 dB. As shown in the above graph, the two filter parts add up nicely to a flat summation curve - the goal has been achieved.

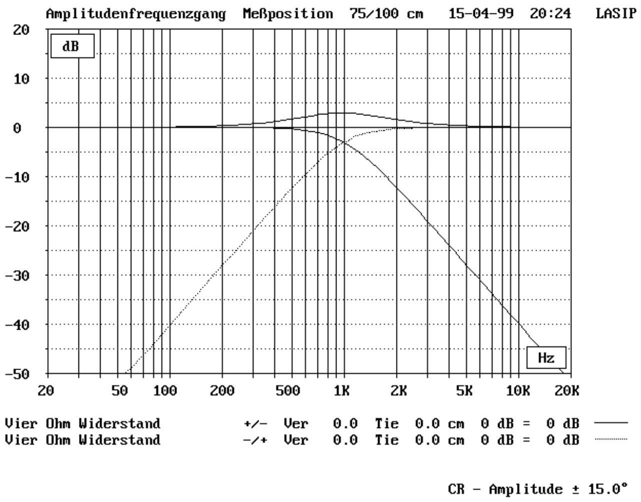


Info for fig. 2:

fc:	1000 Hz
Order:	2nd
Polarity High Pass:	+
Polarity Low Pass:	+
Filter Characteristic:	Butterworth

Fig. 2 - Second Order Butterworth Filter, Same Polarity on Both Filters

In fig. 2 one can clearly see the effects of a “misaligned” filter - first of all, the single responses are at an attenuation level of only -3dB, and furthermore, the polarity has not been changed. The result is a massive suckout at the crossover frequency due to the phase cancellations. Changing the polarity of one of the filter branches solves only a part of the problem:

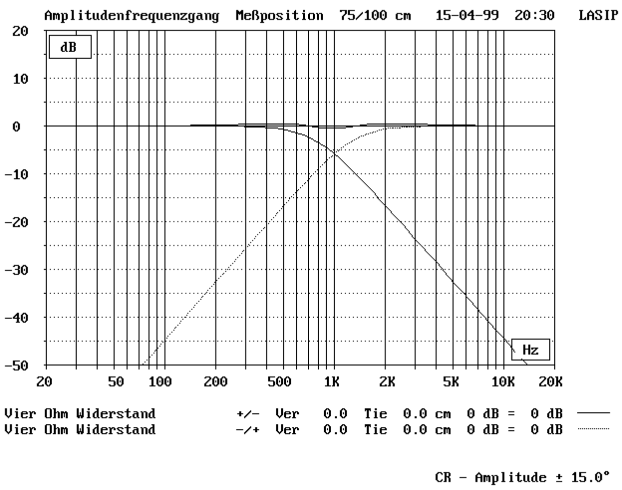


Info for fig. 3:

fc:	1000 Hz
Order:	1st
Polarity High Pass:	-
Polarity Low Pass:	+
Filter Characteristic:	Butterworth

Fig. 3 - Second Order Butterworth Filter, Polarity reversed on one Filter Branch

Fig. 3 shows already an improvement over the poor response of fig. 2. Still, the attenuation of both filter branches at crossover frequency is still -3 dB only. Using the aforementioned rule about multiplying/dividing the crossover frequency by a factor of approximately 1.3 gives then the following result:

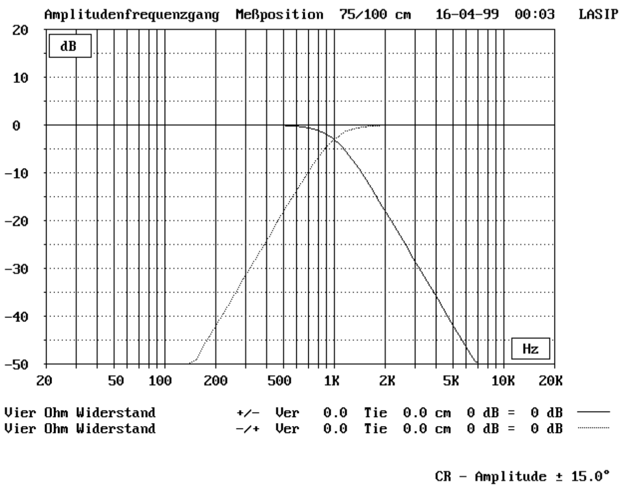


Info for fig. 4:

fc:	HP: 1300 Hz LP: 769 Hz
Order:	2nd
Polarity High Pass:	-
Polarity Low Pass:	+
Filter Characteristic:	Butterworth

Fig. 4 - Second Order Butterworth Filter, Polarity reversed, Frequency modified

The result in Fig. 4 shows exactly what we want - a flat transfer function, the respective crossover attenuations both being at -6 dB, resulting in a flat response when one of the filters' polarity is reversed. Now to the third order filter:



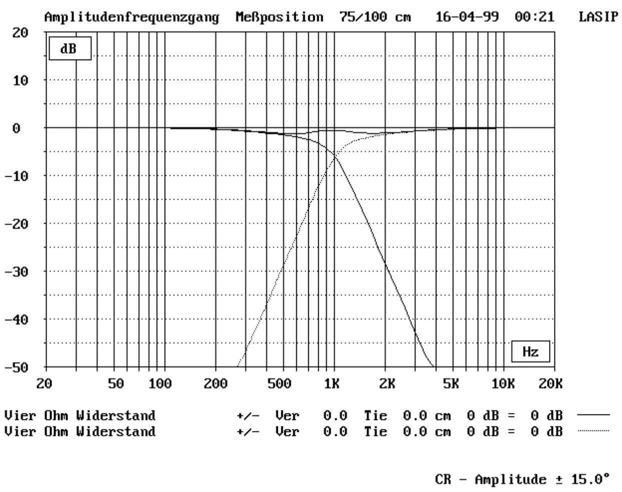
Info for fig. 5:

fc:	1000 Hz
Order:	3rd
Polarity High Pass:	-
Polarity Low Pass:	+
Filter Characteristic:	Butterworth

Fig. 5 - Third Order Btterworth Network, Reversed Polarity (Same Result with non-reversed Polarity)

Fig. 5 shows the third order Butterworth filter, where the attenuation at the crossover frequency again is at -3 dB to produce a flat summation which yields a flat transfer function. However, surprisingly, the polarity of the filter branches doesn't really matter, a fact which makes the third order filter largely independent of drive unit polarity. A handy fact…

Last but not least, the fourth-order network, shown in fig. 6 as follows:



Info for fig. 6:

fc:	HP: 1150 Hz LP: 870 Hz
Order:	4th
Polarity High Pass:	+
Polarity Low Pass:	+
Filter Characteristic:	Butterworth

Fig. 6 - Fourth Order Butterworth Filter

Looking at fig. 6 it can be seen that the response is not absolutely flat; this is due to the crossover frequency scaling. Similar as in the second order case, the actual crossover frequency must be scaled to allow for the - 6 dB attenuation at the crossover frequency. It is though very important to note that the correction factor is only about 1.15 in the case of the fourth order network.
Remember as well that there is no need to reverse the polarity of one of the filter branches; the fourth order filter has a theoretical phase shift of 360° which, fairly obvious, equals a 0° phase shift and therefore does not need any polarity changes.

So far, only the on-axis response has been considered. However, in real life, loudspeakers radiate sound not only along an axis, but into a three-dimensional space. To find out what influence the crossover design can have on this aspect, one might find it useful to proceed to paper no. 3.

Acknowledgments

1) Vance Dickason, *Loudspeaker Cookbook,* 5th ed., Audio Amateur Press

2) John Borman et al., *The Loudspeakers and Headphones Handbook*

3) Martin Colloms, *High Performance Loudspeakers*

4) Bill Waslo, *The IMP Loudspeaker Measurement System*

5) JAES Magazines

6) LASIP Loudspeaker Simulation Programm, © CONRAD Electronic, GmbH