High-Pass Filtering in Two-Way Systems
A White Paper from Linea Research

Paul Williams May. 2004

Overview

In this paper, we look at how the positioning of a high-pass filter impacts the performance of a two-way crossover system, and draw conclusions about correct positioning.

The Need for High-Pass

Although most professional audio components are very capable of reproducing frequencies down to very low values, sometimes including DC, system designers rarely allow their systems to make use of this, and purposely put a lower limit on the range of frequencies that the system will be allowed to pass by using high-pass filter. This is because, whereas the efficiency of human hearing reduces as frequencies fall below a few tens of Hertz, the demands on the system increase. These subsonic signals are rarely useful, and are often generated accidentally. The power contained in common audio signals usually increases as frequency decreases, which means the power handling demands of amplifiers and loudspeakers must increase as the lower-limit of frequency reduces. Unnecessary downward extension of the frequency range will therefore increase system cost if clipping distortion or driver damage are to be avoided. Furthermore, in some situations, driver excursion can continue increasing as frequencies decrease into subsonic areas, which can lead to permanent driver damage. The solution is to curtail the lower frequency limit using a system high-pass filter. It is recognised that this constrains the audio signal to a known quantity, and ensures that the signal range will be within the capabilities of a system that is designed for a given situation without wasted cost.

Crossover Filters

The requirements of band-splitting the audio signal for a two-way system are numerous, but two of the aims are often:

1. To provide filtering on each band such that the acoustically summed output will be of constant magnitude with respect to frequency.
2. To retain a constant phase difference (ideally 0 degrees) between the band outputs across the crossover region to prevent beam tilting as frequencies traverse the crossover region.

Such properties are provided by proper implementation of the Linkwitz-Riley filter type, for example. A low-pass/high-pass Linkwitz-Riley filter pair will indeed sum to a completely flat magnitude response, and will maintain precisely zero degrees phase difference between the two filter outputs, across all frequencies.

Figure 1 shows the magnitude response of a two-way Linkwitz-Riley filter pair with a crossover frequency of 100Hz, together with the summed response.

Figure 2 shows the phase response of each filter. Note that they are identical.

Fig.1 - 4th Order Linkwitz-Riley

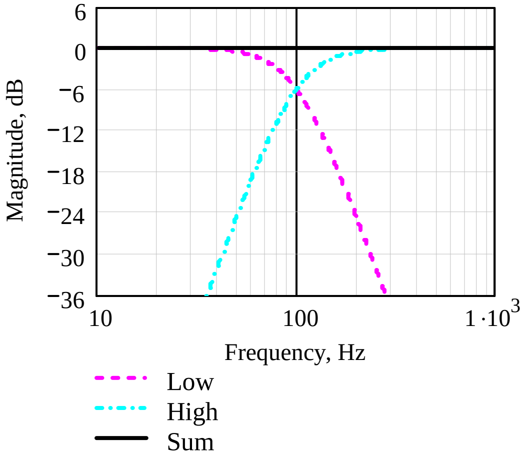


Fig.2 - 4th Order Linkwitz-Riley

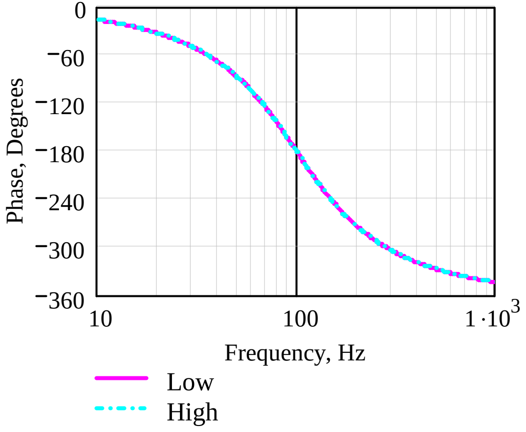
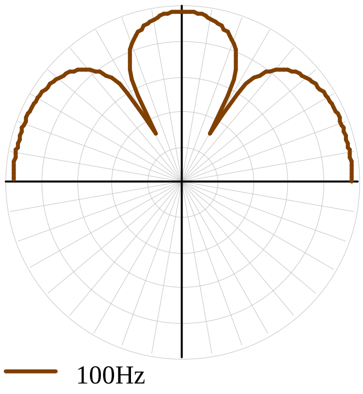


Figure 3 shows the polar response of the system - that is the magnitude response at different observation angles.

This is plotted at the crossover frequency with driver separation equal to the wavelength of the crossover frequency. The scale lines are at 10 degree and 10dB intervals. It does not take individual driver directionality into account. Note that the main lobe is exactly on-axis, and is entirely symmetrical. It is important to ensure that no phase shifts are allowed to impinge on any one band since this will impair the accuracy of summing, and will tilt the beam emanating from the loudspeaker system. Such tilting will cause colouration of the signal, and this colouration will depend on the listening position.

Fig.3 - 4th Order Linkwitz-Riley



Using Crossover Filters for System High-Pass

In active crossover devices, it is quite common for each band to comprise both a high-pass and a low-pass crossover filter, the low-pass of the Low band and the high-pass of the High band being used together to form the crossover point for this two-way system. In this configuration, the high-pass of the Low band and the low-pass of the High band would normally be unused, and would be bypassed. It is also often the case that the high-pass crossover filter on the Low band is used as a system high-pass filter. Since the High band already has a high-pass function due to it's crossover filter, this would seem to be a good solution to the requirement for a system high-pass filter. However, it can easily be shown that this high-pass filtering on only the Low band causes phase shifting of the Low band, which will cause phase anomalies between the bands.

Adding a Fourth-order 30Hz Butterworth High-Pass filter just to the Low band causes a phase shift on that band, resulting in the two bands being out of phase, as shown in Figure 4. The system no longer complies with the Linkwitz-Riley requirements. Figure 5 shows the resulting anomaly on the summed magnitude response, and Figure 6 shows that the phase shift has tipped the main lobe of the beam off-axis at the crossover frequency, causing colouration that will depend on the listening position. Both of these anomalies will become worse the closer the High-pass frequency is to the crossover frequency.

Fig.4 - With High-Pass filter

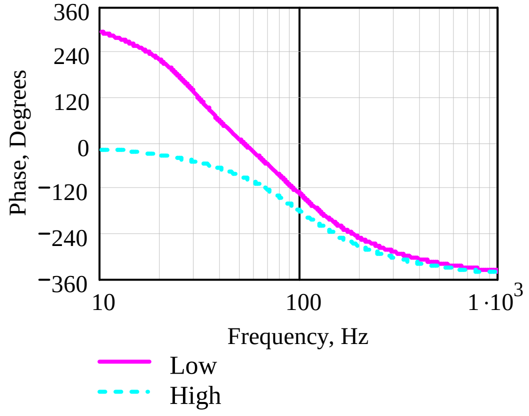


Fig.5 - With High-Pass filter

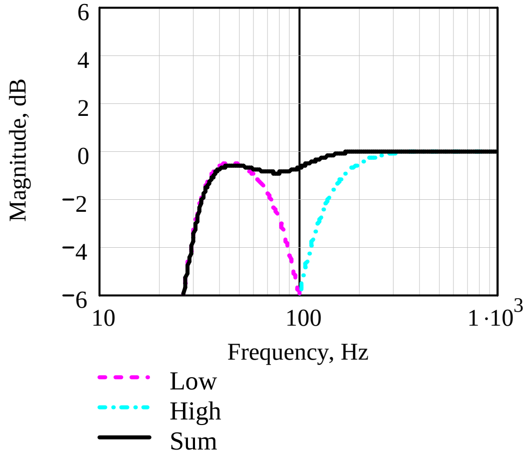
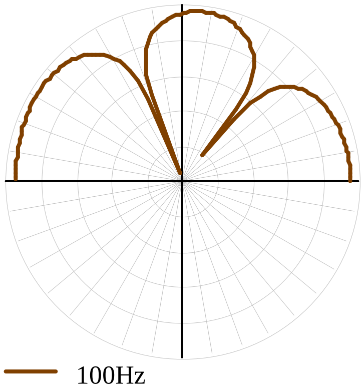


Fig.6 - With High-Pass filter



Compensation Using Delays

System designers may unwittingly compensate for this anomaly when band delays are adjusted. The high-pass filter, which introduces towards 360 degrees of phase lead at very low frequencies, still causes a phase lead as much as 45 degrees at the crossover frequency.

If we increase the phase lag by adding a small delay of 1.3 milliseconds, we can correct the phase shift at the crossover point, and thus bring the two bands in-phase again. On the face of it, this seems quite reasonable, and we can indeed see in Figure 7 that this does correct the polar pattern, and puts the main lobe back on-axis. However, if we look at Figure 8 we can see that the summation, whilst now correct at the crossover point, is not quite correct either side.

Fig.7 - With Delay Compensation

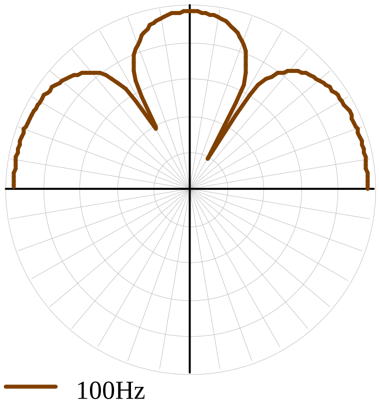
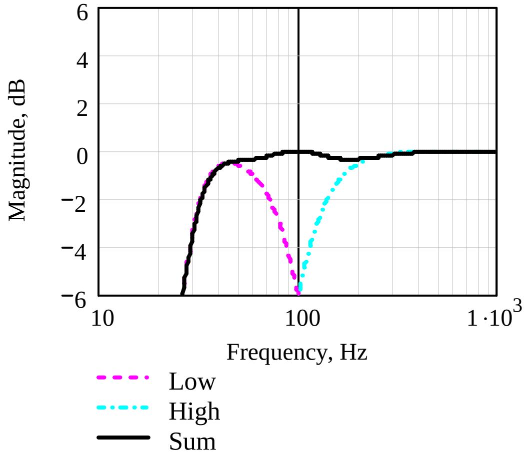
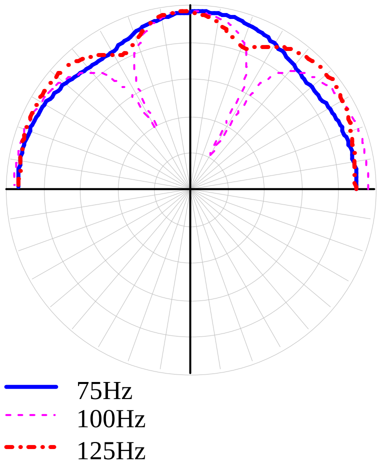


Fig.8 - With Delay Compensation



Furthermore, Figure 9 shows that the polar patter wanders off axis slightly either side of the crossover point.

Fig.9 - With Delay Compensation



A Better Solution

A more complete solution is of course to place the High-Pass filter in the input path so that both bands are phase shifted identically, and will thus continue to meet the Linkwitz-Riley requirements perfectly. Figure 11 shows that with the High-Pass filter on the Input, the bands sum perfectly.

Figure 12 confirms that the polar response remains rock-steady on-axis throughout the crossover region.

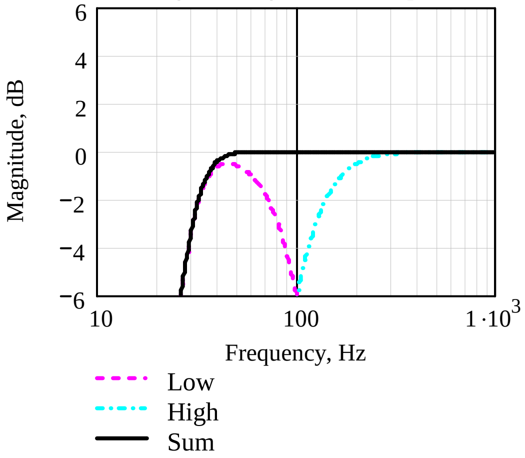


Fig.11 - High-Pass on Input

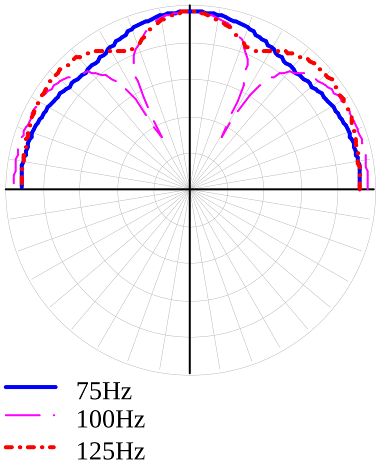


Fig.12 - High-Pass on Input

Parameter Conversion - A Problem

A problem arises if it is required to take the parameters arrived at for a Loudspeaker system controller which uses Low band system high-pass filtering, and apply these to a controller which uses the more correct Input high-pass filtering, since the former will most likely have an incorrect delay setting on the Low band. Figure 13 shows that loudspeaker controller parameters intended for a controller without input high-pass filtering cause a summing anomaly if the delay setting on the Low band is not corrected. Figure 14 also shows that this system throws the polar main lobe off-axis.

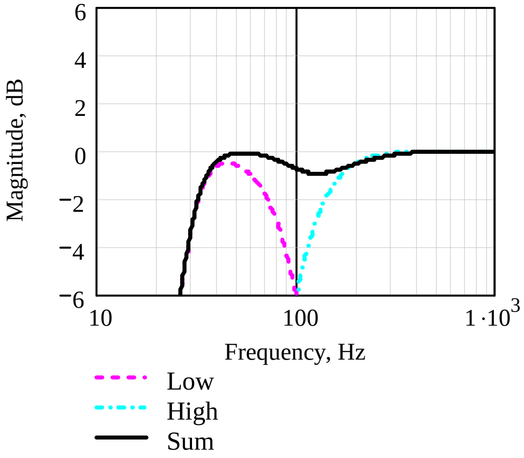


Fig.13 - Incorrect delay setting

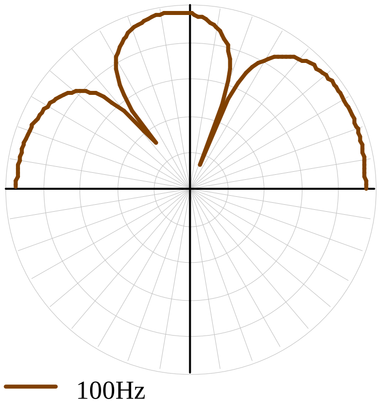


Fig.14 - Incorrect Delay Setting

Summary

We have shown that there is only one correct place to do system high-pass filtering, and that is where there is full-range signal, most conveniently done in the input path of the loudspeaker system controller. Using a spare crossover high-pass filter on the Low band will, with some added delay, produce approximately correct, but imperfect results. Care should be exercised if converting parameters from a system employing Low band high-pass filtering to a system using the more correct Input high-pass filtering.

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