This application note reviews crossover implementations currently available in digital loudspeaker processors. Measurements and comparisons between the crossover types are presented and discussed. It is shown that the Lake Contour linear phase crossover exceeds all existing crossover technologies in both magnitude and phase response characteristics.

1. Introduction

Sound designers have recently been provided with new tools for creating optimum crossovers for multi-way loudspeaker systems. In March 2004, Lake Technology announced Contour Controller version 2.2 software for the Lake Contour. As part of this software release, additional options of linear phase crossovers have been included. Linear phase crossover filters can provide a near perfect brick wall roll-off and an ideal phase response, offering zero phase shift throughout the entire crossover region. Previously, designers tended to choose Linkwitz-Riley filters, which provide the necessary roll-off, but incur an accompanying phase shift that tends to be less objectionable than other crossover filter options.

The most popular crossover is the 24 dB per octave Linkwitz-Riley (L-R) filter pair. It would be desirable to have crossover filters that provide greater than 24 dB per octave transition slopes; however independent listening tests have determined that higher order filters affect the quality of sound reproduction. For example, a 48 dB per octave L-R crossover does not subjectively sound as good as a 24 dB per octave L-R crossover. This is most likely due to the large phase shift that occurs in higher order crossovers. The new Lake Contour linear phase crossovers give you the best of all worlds. You can use 24 dB linear phase crossover filters as a direct replacement of the 24 dB L-R, with improved sonic transparency due to the ideal phase response. And you can move to steeper slopes without the associated negatives of a radically twisted phase response.

2. Linkwitz-Riley Crossover Measurements

The magnitude and phase response of 24 dB and 48 dB Linkwitz-Riley crossover filters are shown below, in figures 1 and 2 respectively. The phase response is shown in the top of each figure, and the magnitude response is shown in the bottom of each figure. The red trace shows the L-R low pass filter, and the green trace shows the L-R high pass filter. The blue trace shows the electrical summation of the two filters. L-R filter pairs electrically sum to a flat line magnitude response, one of the attributes that makes L-R filters so popular. The flat summation attribute leads to an optimal multi-way loudspeaker polar response.
Figure 1 – 24 dB Linkwitz-Riley crossover pair

Figure 2 – 48 dB Linkwitz-Riley crossover pair
As you can see from the measurements above, the popular L-R filters exhibit significant phase distortion, leading to unwanted interaction between speaker components through the crossover region. In the original AES paper, Linkwitz comments on the phase distortion introduced by the L-R crossover\(^1\). His conclusion is that the 24 dB per octave version is subjectively acceptable. The desire for higher slope loudspeaker crossovers led to the development of 36 dB and 48 dB L-R crossovers, but the large phase shift (as exhibited in figure 2 above) has made higher order L-R crossovers subjectively unacceptable in most instances.

3. Lake Contour Linear Phase Crossovers

In the first release of the Contour Controller software, we offered the option of a mono 4 way linear phase crossover, with roll-offs beyond 200 dB per octave and the very desirable zero phase shift of linear phase filters\(^2\). The latest Contour Controller software offers stereo 3-way linear phase crossovers, with a roll-off optimizer to give you the maximum slope within whatever propagation delay time acceptable for your application. You can also specify specific crossover slopes, such as 24 dB or 48 dB per octave. These new options now permit you to compare the benefits of zero phase shift crossovers with traditional filters of the same slope.

Figures 3 and 4 show the 24 dB and 48 dB Lake Contour linear phase crossovers, respectively. The phase response is shown in the top of each figure, and the magnitude response is shown in the bottom of each figure. The red trace shows the linear phase low pass filter, and the green trace shows the linear phase high pass filter. The blue trace shows the electrical summation of the two filters. The linear phase filter pairs electrically sum to a flat line magnitude response, maintaining the flat summation attribute that leads to an optimal multi-way loudspeaker polar response.
Lake Contour Linear Phase Crossovers

Figure 3 – 24 dB Lake Linear Phase crossover pair

Figure 4 – 48 dB Lake Linear Phase crossover pair
As you can see from the measurements above, the Lake Contour linear phase crossovers exhibit the same magnitude response as the 24 dB and 48 dB L-R crossover pairs, but the phase response is drastically improved to the point of providing an ideal response.

Using a Lake Contour linear phase crossover, you can quickly replace an existing Linkwitz-Riley crossover without having to redesign the rest of the EQ filters used on each output of a multi-way loudspeaker preset.

One of the significant advantages of using linear phase crossovers is that different types of loudspeakers can be used together without the effects of acoustic cancellation due to different crossover center frequencies. Please see Appendix A for further details.

4. Neville Thiele Method Crossovers

Neville Thiele recently introduced a new crossover method. This new Neville Thiele Method (NTM) crossover has been implemented in a variety of commercially available digital loudspeaker processors. NTM crossover filters make ingenious use of a notch in the crossover region to increase the roll-off as compared to L-R crossovers of equivalent implementation complexity. There are two commonly available NTM filters: NTM 36 and NTM 52.

Figure 5 shows the magnitude and phase response of the NTM 36 low pass filter as compared to an L-R 24 dB low pass filter. Figure 6 shows the magnitude and phase response of the NTM 52 low pass filter as compared to an L-R 48 dB low pass filter. In both figures, the NTM is shown in blue and the L-R is shown in red.

Through the figures below, it is readily seen that the new NTM filters exhibit similar phase distortion as L-R crossover filters. The transition slope of the NTM crossover is slightly steeper than the equivalent L-R implementation, thus the phase distortion of the NTM crossover is slightly worse than the equivalent L-R implementation.
Figure 5 – NTM 36 versus L-R 24

Figure 6 – NTM 52 versus L-R 48
Figure 7 below shows a comparison between the NTM 52 (shown in blue) and the Lake Contour 48 dB linear phase crossover (shown in red).

Notice the significant difference in phase response between the NTM and linear phase low pass filters.

Moving further, let’s look at the Lake Contour’s linear phase crossover when set to brick wall slope.
The Lake Contour linear phase crossover set to brick wall slope clearly surpasses all other crossover types for steep transition slope and ideal phase response.

When the Lake Contour linear phase crossover is set to brick wall, the filter is optimized to provide the highest transition slope possible. The brick wall filter does not asymptotically settle to a constant slope like a traditionally implemented crossover, therefore the transition slope cannot be measured in the exact same way. By convention, the “steepness” of these filters is determined by calculating the slope of the brick wall filter at the -6dB down point. Depending upon the Alignment Delay specified by the user in the Contour Controller software, the transition slope of the filter can vary. In the example above, the brick wall setting provides a transition slope equivalent to a 62 dB per octave filter at the -6 dB down point, and the slope increases to provide a transition slope greater than 90 dB per octave at higher frequencies.
5. Conclusion

Commonly available crossover technologies provided by current generation digital loudspeaker processors have been reviewed. Linkwitz-Riley and NTM crossovers suffer from phase distortion that affects the ability to apply steep slope crossovers and obtain subjectively acceptable acoustic responses from multi-way loudspeaker systems. Lake Contour linear phase crossovers provide the ultimate crossover choice, due to its ideal phase response characteristic. Additionally, selection of 24 dB and 48 dB transition slopes allow for easy substitution of the Lake Contour linear phase crossover for existing multi-way loudspeaker presets. When set to a brick wall slope, the Lake Contour linear phase crossover provides a magnitude and phase response that exceeds all existing commercially available crossover technologies.

6. References


7. Appendix A

Let us take the simple array example of a primary loudspeaker system and an auxiliary loudspeaker system. Such a system is commonly in use in professional applications that require consistent coverage across an audience seating area. In most scenarios, the auxiliary loudspeaker’s enclosure dimensions, acoustic output power, coverage and required operating frequency range is different than the requirements of the primary loudspeaker system.

Using a conventional crossover network for both of these different loudspeaker systems will introduce problems. Figure 1 illustrates the problem.

The primary loudspeaker is pointed straight ahead towards the audience area. The secondary loudspeaker is pointed down towards the lower audience area. The midpoint of the transition region between the two loudspeaker systems is also shown.
Figure 2 shows the complex frequency response of the primary loudspeaker (highlighted in yellow) comprised of three simple sources gain and delay optimized measured at the midpoint of the transition region.

**Figure 2 – Main loudspeaker complex frequency response using Linkwitz-Riley crossover**

Figure 3 shows the complex frequency response of the secondary loudspeaker comprised of two simple sources gain and delay optimized measured at the midpoint of the transition region.

**Figure 3 – Auxiliary loudspeaker complex frequency using Linkwitz-Riley crossover**
Figure 4 shows the combined response of both loudspeaker systems as measured at the midpoint of the transition region.

Due to the difference in center frequencies between the crossovers in the two loudspeaker systems, there will always be cancellations within the transition region. Gain, delay, equalization and directivity can be used to reduce the problem, but the phase distortion introduced by the conventional crossover cannot be removed by these methods.

Linear phase crossovers solve this problem. The linear phase characteristic allows for a seamless transition between different loudspeaker systems. Figures 5 and 6 show the complex frequency responses of the primary and secondary loudspeaker systems gain and delay optimized, now using a linear phase crossover as measured at the midpoint of the transition region.
Figure 5 – Main loudspeaker complex frequency response using LPBW crossover

Figure 6 – Auxiliary loudspeaker complex frequency response using LPBW crossover

Figure 7 shows the combined response of both loudspeaker systems as measured at the midpoint of the transition region.
Figure 7 – Main and auxiliary loudspeaker combined complex frequency response using LPBW crossover

Using gain, delay and the LPBW, the transition region between loudspeaker systems can be optimized for a seamless transition between the loudspeaker systems.