By G.R. Koonce

Passive Crossover Linear Phase Speakers, Part 2

The author continues his in-depth study of using a passive crossover for linear-phase speakers.

I decided I wanted to try a linear-phase system. I intended to use a three-way with passive CO. This pretty much limited me to the first-order CO approach. I tried to develop a system with three drivers, but the results were poor, and I fortunately did not build such a system.

DECISIONS

As developed previously, the solution is a coaxial driver or a symmetrical array. Not aware of a tri-axial driver, I determined that the only viable answer was the symmetrical five-driver array—woofer over midrange over tweeter over midrange over woofer (WMTMW). George Augspurger informed me that the phase-linear monitors for studio work used arrays of five drivers in the WMTMW configuration. That decided it—I would build with the WMTMW approach.

I also knew that the acoustic origins would need to be aligned, meaning a curved or stepped front panel. Not knowing how to build a curved front panel or how to model the system with the drivers mounted at an angle, I chose a stepped front panel. To match the front panel, it would be nice to either curve or step the sides of the enclosure, but then I couldn't figure out how to apply the grille cloth. Thus I decided to go with straight sides on the enclosure and try to fight any diffraction/echo problems with damping material on the front panel.

Because the first-order CO requires such wide overlap in the woofer and midrange response, I figured a 6½″ woofer was the largest I could use. This meant the bass would be restricted. The remedy was to cross over to a subwoofer with an electronic CO. Thus the system would not be phase-linear over the full audio band, just from a couple hundred hertz up. The intent was to keep the frequency of crossing over to the subwoofer below 100Hz.

I developed a design with the three drivers having the responses that were shown back in Fig. 10. Fortunately, the tweeter is 4Ω and has the needed 6dB sensitivity advantage over the midrange driver. The woofer, with a slightly higher sensitivity than the midrange, could be used to compensate diffraction spreading loss at low frequency.

Figure 24 depicts the modeled performance of this system. The low-frequency rise is the diffraction-spreading-loss compensation. From about 200Hz up, the system is essentially linear phase on the tweeter axis. The polar magnitude response does not look bad, with few angles showing any higher magnitude than on the tweeter axis.

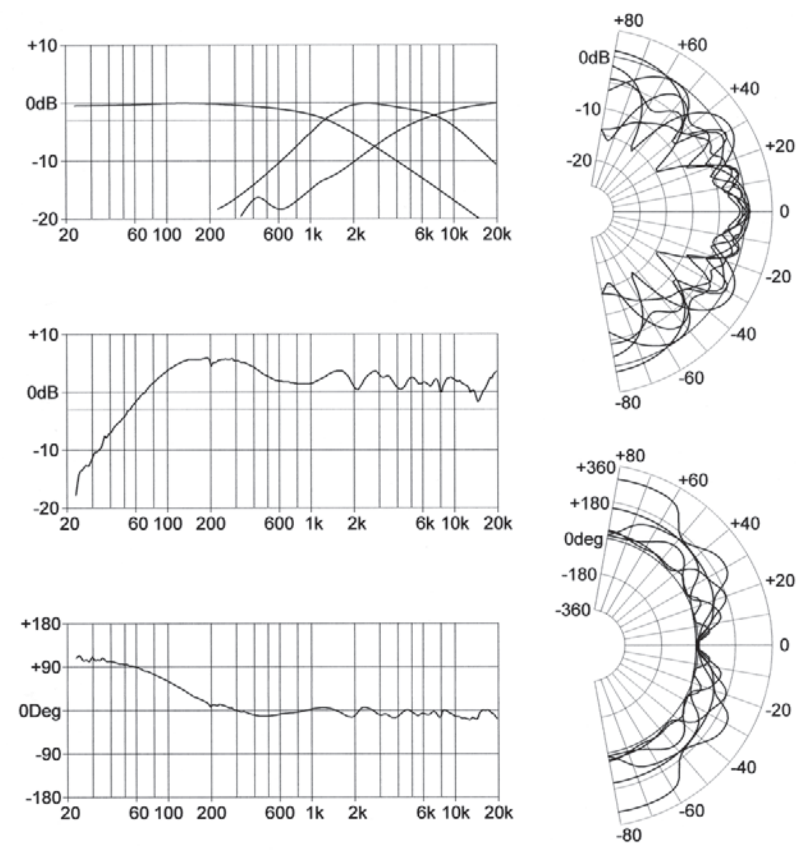

FIGURE 24: Modeled performance of three-way WMTMW system.

The system was designed to focus at a distance of 114″, which matches my listening position in the garage. This focus, along with the driver acoustic origin differences, determined the steps needed in the front panel. The driver CTC spacing was set at what I thought I could build keeping the angled steps reasonable.

Photo 1 is a front and back view of the basic enclosure showing the front panel steps. The angles between flush-mounted drivers are in the range of 20° to 24° to minimize any effects on the driver responses. The back of the chamber holding the tweeter is open and all driver wiring exits through this area.

The woofers and midranges are each in their own closed box (CB). The midrange CB is inside the woofer CB with its own removable back. The small midrange CBs have high-density fiberglass on the sides and back and are fully stuffed with polyester fiber. The woofer CBs have thick normal fiberglass on the sides, and I stuffed the volume behind the midrange CBs with slightly compressed fiberglass insulation. All chambers are stiffened via hardwood dowels that are damped with duct seal (dumdum).

Photo 2 shows the finished right-hand system for listening. The 8″ subwoofer covers the range 25 to 90Hz. Construction of this subwoofer using a TBSpeakers (Tang-Band) driver and flared port is covered in reference #11. The breadboard first-order CO (**Fig. 25**) sits on top of the subwoofer. Note that a zobel is used on all drivers and the series R-L-C network is included to limit the tweeter impedance rise at its resonance.

You can see in **Photo 2** that the front panel is covered with ½″ thick normal fiberglass insulation. The sidewalls in the midrange/tweeter region also have high-density fiberglass layers cut at about a 45° angle below the ½″ fiberglass layer. I had hoped this would be sufficient to limit enclosure edge diffraction problems with the stepped front panel. (Testing later indicated it may not be sufficient.)

I mounted the WMTMW columns on a sloped pedestal to keep them upright and to put a seated listener on the tweeter vertical axis. The two speakers face straightforward so you listen at an angle off the horizontal axis that I included in the design.

As discussed, both the woofers and midranges are in highly damped CB enclosures. The woofer Qtc measures just above 0.5 and the midrange Qtc in the 0.78 range. The midranges are thus flat down to about 100Hz, but would not be used to the lower limit of their range. My ability to test large enclosures is rather limited because of the size and congestion of my back room.

Avoiding echoes by quasi-anechoic testing, **Fig. 26** depicts the measured system response from 1kHz up. The systems are clearly as close to linear phase as the driver responses will allow. The wiggles in the tweeter response show I have more work to do in damping diffraction/echoes around the tweeter. This is the condition of the systems at the time of the listening sessions because I tested after the weather drove me out of the garage. I thought the strings were slightly strident, but I was using SACDs cut from old analog master tapes, so you never know whether the cause is your speakers or the recording. After testing, I suspect the speakers.

LISTENING TO A LINEAR-PHASE SYSTEM

Listening to the systems was a good experience. I liked them very much (naturally!). They formed a specific image that stayed behind the enclosures. The major attribute was the clarity and speed of transients, whether with a single instrument or an orchestra. I originally attributed this to the linear-phase characteristic.

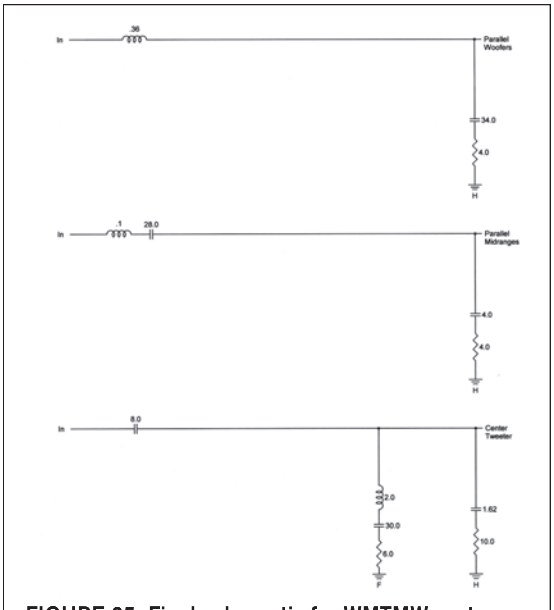

FIGURE 25: Final schematic for WMTMW system.

George Augspurger told me that the linear-phase studio monitors sounded good, but he believed the reason was the careful component matching by the manufacturer rather than the linear-phase characteristic. To test this conjecture, I decided to listen to the systems with the linear-phase property destroyed. The first-order CO sums to nearly the same response with the midrange drivers normal polarity (phase linear) or with the midrange polarity inverted (not phase linear) (**Fig. 27**). To my surprise, and to that of other listeners who participated, the sound hardly changed. The systems were no longer phase linear, but were still fast and clean.

I then modeled and tried a second-order CO that matched the magnitude response of the original first-order CO as closely as I could (**Fig. 28**). This CO configuration requires the midranges to be wired with inverted polarity. The polar plots display a lot more nulls and phase reversals than with the first-order CO. Whether it is the strange polar plots or the components I used to implement the CO, the second-order CO did not sound quite as good as either version of the first-order CO. The sound was a little muted or congested mostly in the bass region.

Finally, I modeled and tried a third-order CO with all drivers positive polarity (**Fig. 29**). The sound of this CO was very good, and on some selections I thought it better than the first-order CO. Again, the systems were fast and clean without the phase linearity.

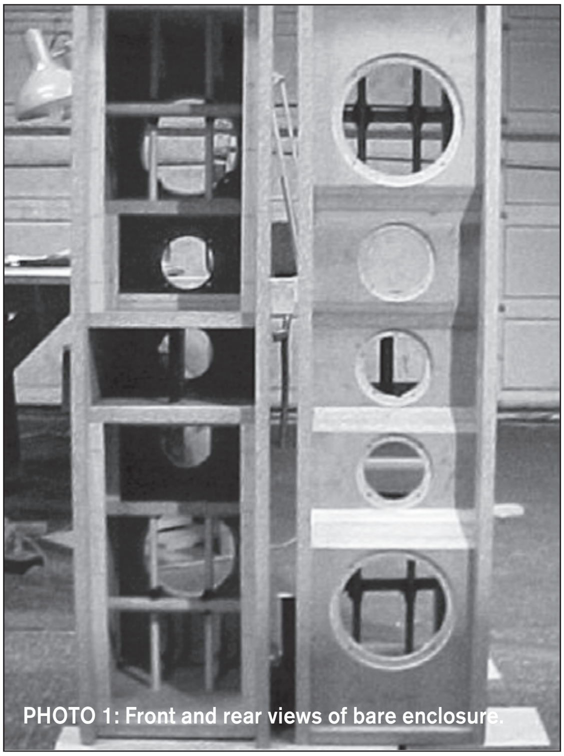
PHOTO 1: Front and rear views of bare enclosure.


PHOTO 2: Finished speaker with subwoofer and breadboard crossover.

DOES LINEAR PHASE MATTER?

My short answer is no. As long as you keep the phase change rate within reason, limiting the delay dispersion, the sound should be fine. However, the techniques you need to build a linear-phase system are worthwhile and should be used. I review these techniques later.

Colin[12, 13] and others have investigated the audibility of "delay dispersion," i.e., the fact that different frequencies are delayed different amounts of time. For the midrange/tweeter region, he believes up to about 1ms is tolerable. It is a complex topic, about which you should read in the original articles.

The point is that for a good-sounding system with quick, clear transients, you need to keep the phase shift at a minimum, not necessarily going for linear phase. Generally, a first-order CO with all drivers the same polarity is fine in terms of delay dispersion. Once you go to higher-order COs, the acceptability of the dispersion depends on the CO frequency and other variables. Crawford[14] investigates correction networks for CO delay dispersion.

While I found the effect of the various COs was subtle on listening to music, the same was not true when listening to a square wave. The square wave has a very "edgy" sound, and the first-order CO with all drivers the same polarity retained this sound better than the other COs. As Colin discusses in his articles, there may be certain musical instruments that display sonic change at lower values of delay dispersion.

The following factors are pretty much forced on you in building a linear-phase passive-crossover system and are generally good for all systems.

1. The symmetrical driver array is an important tool for any system. Colin[13] points out that the symmetry keeps the acoustic origin position of the system stable over frequency, removing an effect he believes is audible. To me, the main advantage is that it minimizes any lobing problem with a multi-driver system.

   To see just how powerful it is, I modeled the Yamanaka second-order fill driver CO used with a WMTMW array of ideal drivers (**Fig. 30**). The lobing problem so prominent with this three-driver system (Fig. 11) is greatly reduced. I then tried the Yamanaka

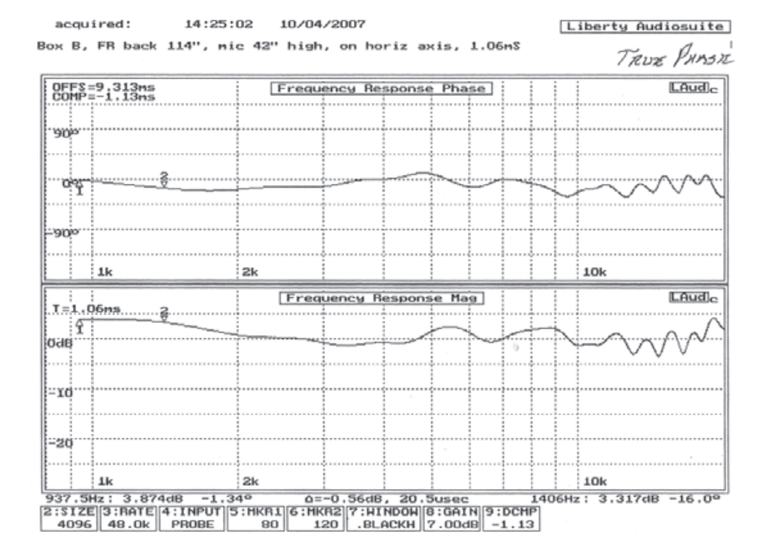

FIGURE 26: Measured performance of three-way WMTMW system.

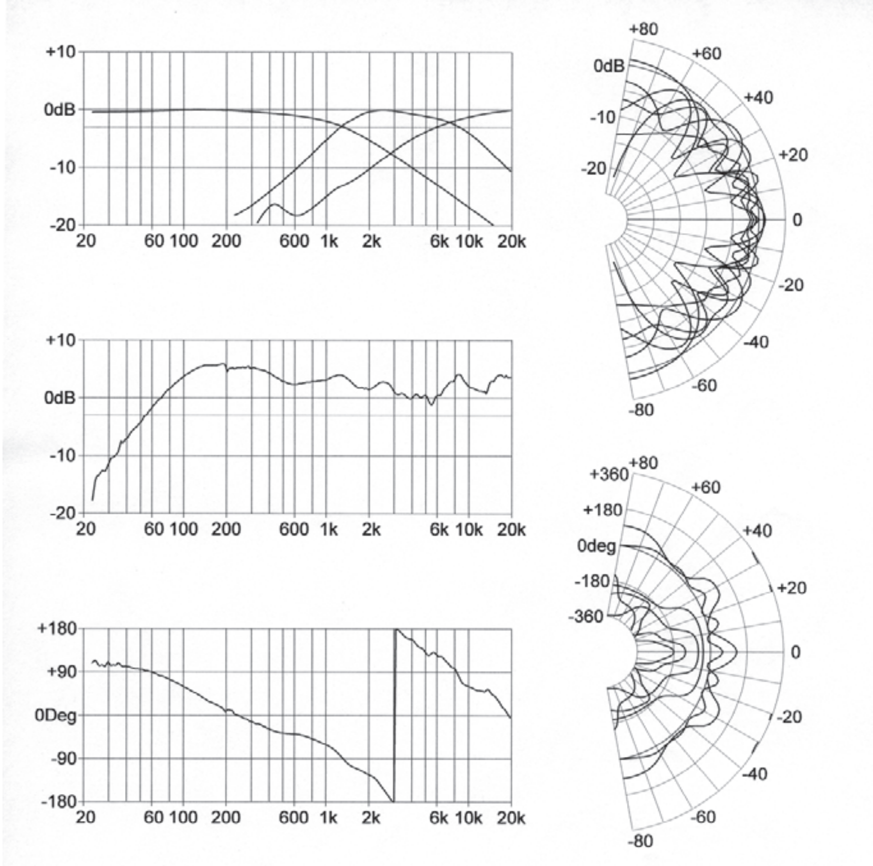

FIGURE 27: Modeled performance of WMTMW system with midrange polarity inverted.

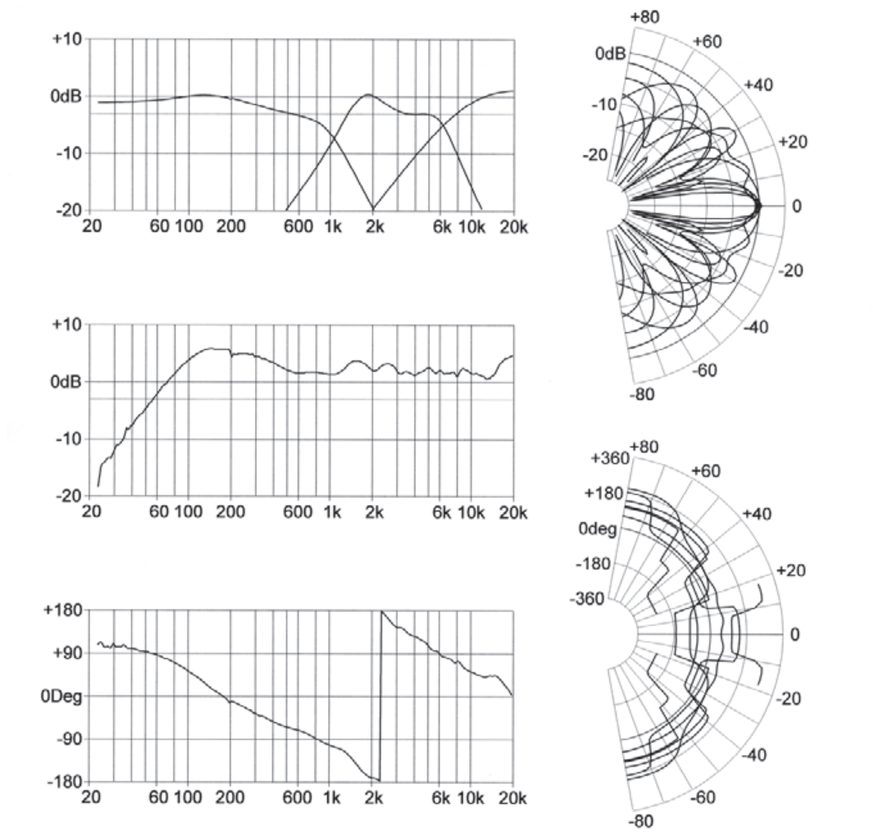

FIGURE 28: Modeled performance of WMTMW system with second-order crossover.

second-order CO on my five-driver columns (**Fig. 31**). I needed to change the front panel steps but I did not try to optimize the magnitude response, and still it looks like an acceptable system. The symmetrical array approach is very powerful, and you should certainly consider it if you plan to try any of the fill driver approaches. I'm of the mind that if you have a five-driver array, then build a three-way system!

One item to keep in mind is that a symmetrical array system will generally display low input impedance. I built my five-driver system with nominal 8Ω woofers and midranges and a 4Ω tweeter. With all the zobels and crossover, the input impedance was 3Ω from about 200Hz on up. I have never had much luck hooking up drivers in different enclosures in series, but if you can make that work, it would remove the requirement for the tweeter to have a 6dB higher sensitivity and yield a higher system input impedance, but require much larger inductors.

2. Aligning the acoustic origins of the

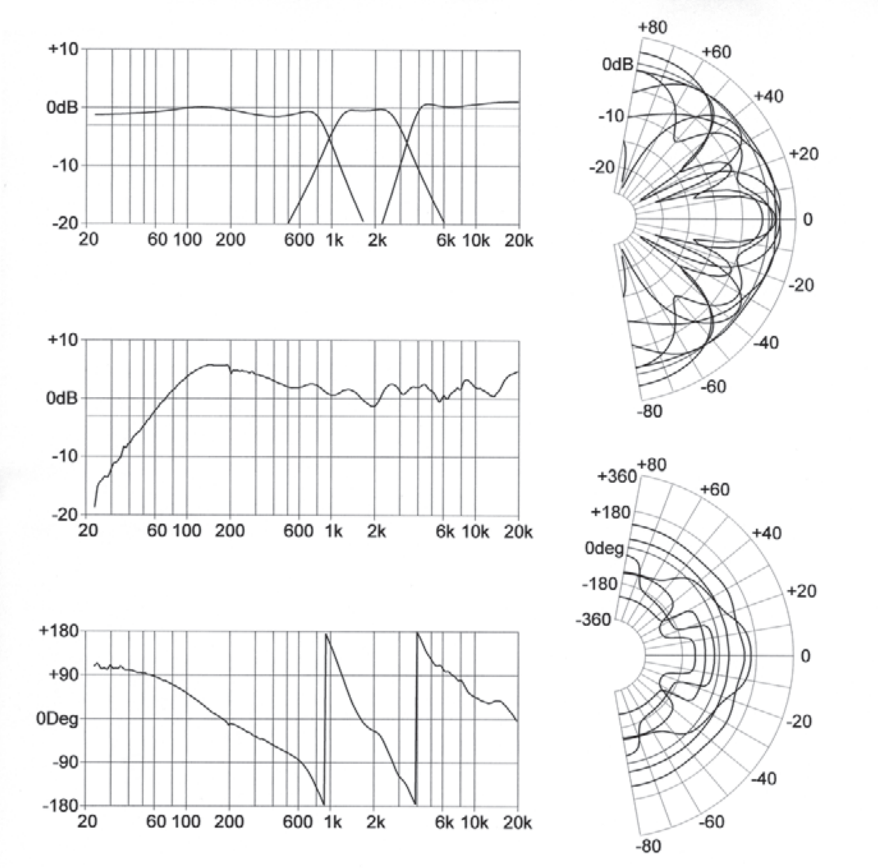

FIGURE 29: Modeled performance of WMTMW system with third-order crossover.

drivers is very important in obtaining linear phase, and I believe it may be useful for all systems. I hate that thought because such systems are so difficult to build. Also, any steps in the front panel cause diffraction/echo problems such as I am still fighting. If you are using only a driver pair, then acoustic origin alignment may be possible by simply tipping the front panel. This means you are listening to the drivers on an angle that will reduce the upper frequency limit on the woofer and show some rolloff in the tweeter response.

When you go over two drivers, you need to consider a curved or stepped front panel or mounting some of the larger drivers at an angle to move their acoustic origin forward. This angle mounting would, again, place a lower frequency limit on a driver and make system modeling more difficult. If it were not for the edge diffraction problem, I would simply build each driver in its own small enclosure so I could simply stack them up and slide them back and forth for acoustic origin alignment.

3. To build a linear-phase system dictated wide overlapping response ranges for the drivers. This, in turn, required physically small woofers. Such small drivers are inherently quicker than big drivers and are thus beneficial to transient response. In this day of subwoofers it probably makes sense to use smaller woofers and cross over to a subwoofer at some frequency below 100Hz.

SUMMARY

Passive CO approaches for building linear-phase systems are rather limited in number. This article examines the approaches I could locate. Most of them do not yield practical systems unless they are used with coaxial drivers or a symmetrical array of drivers. Building such a system also requires positioning the acoustic origins of the drivers, which makes construction rather difficult.

This work has supported those who believe that linear phase is not a requirement for a good-sounding system. It would appear that what is required is minimizing the system phase shift variation, i.e., the time dispersion.

The techniques needed to build a good linear-phase system, however, appear to hold merit for any system. The symmetrical array, acoustic origin positioning, and use of smaller, fast drivers can aid any system.

If you really wish to build a linear-phase system, I recommend an active CO and digital technology in which time delay can be implemented to make construction easier. Even with an active CO, you should not ignore any potential lobing problems.

ACKNOWLEDGMENT

I would like to thank George Augspurger for his numerous and useful comments throughout this odyssey into linear-phase systems. *aX*

REFERENCES

11. G.R. Koonce and R. O. Wright, "Vented 8″ Driver Subwoofer," *aX* 5/04, p. 18 and 6/04, p. 44.

12. Dennis Colin, "Waveform Phase Distortion," *SB* 1/97, p. 18.

13. Dennis Colin, "Frequency Delay Dispersion," *aX* 11/07, p. 16.

14. Dick Crawford, "The Phase Redeemer," *SB* 5/97, p. 34.

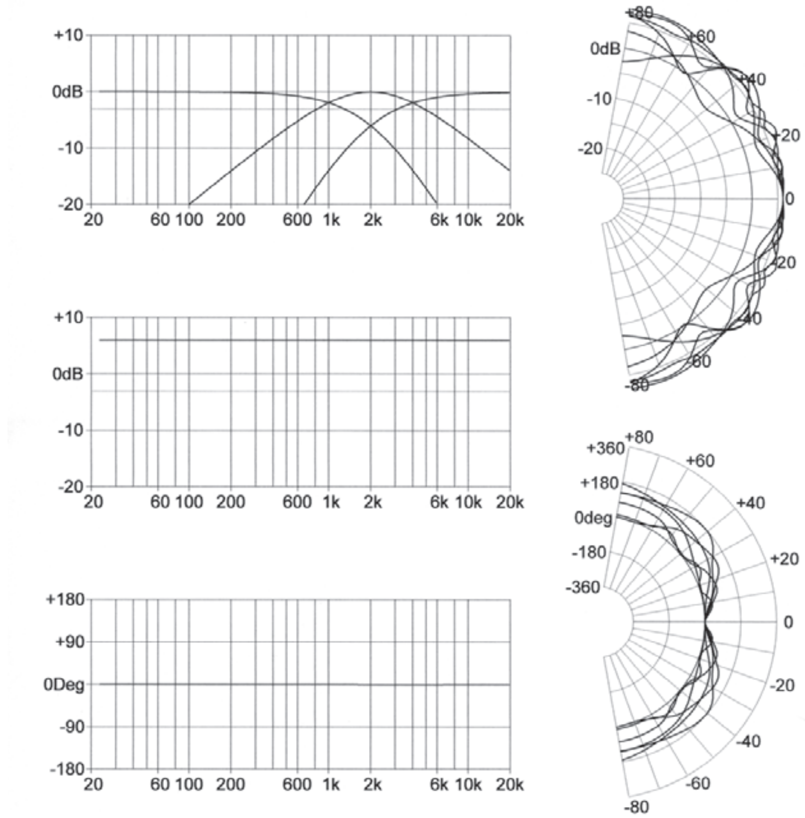

FIGURE 30: Ideal-driver WMTMW system with Yamanaka second-order fill-speaker crossover.

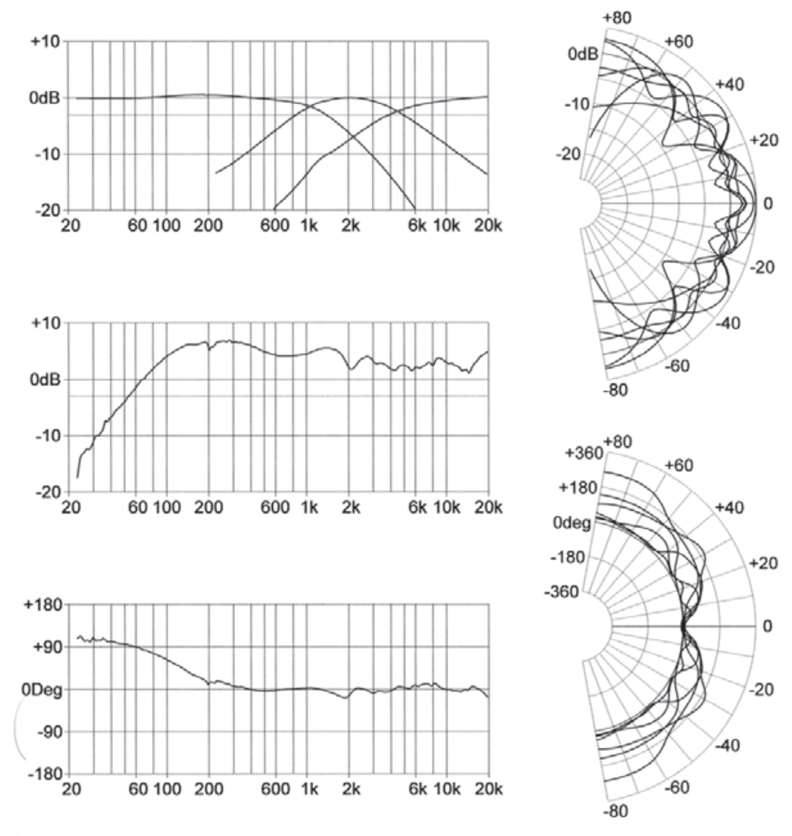

FIGURE 31: Real-driver WMTMW system with Yamanaka second-order fill-speaker crossover.