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By Chi C. Wong

Time-Adjusted Passive Crossover Systems

This Australian study on passive crossovers is an interesting adjunct to Koonce's work published last summer.

I would like to thank G.R. Koonce for his very informative articles[1] on linear phase passive crossovers. In the past 18 months, John[2] and I have spent some time analyzing passive time-adjusted crossovers proposed by Yamanaka and Baekgaard[3]; both require a "filler" speaker. Koonce's investigation concentrates on the acoustic characteristics of loudspeaker systems with linear phase crossovers. In contrast, we study the non-ideal electrical properties of filter components and speaker impedance, using PSpice (student version 9.1) to evaluate the worst-case conditions of various time-adjusted crossovers. This study appears to stand as a supplement to Koonce's excellent articles.

We use formulas by Yamanaka and Baekgaard to determine crossover components, which are accurate to three digits, and allow them to have tolerance. We assume that speakers are matched with zobel and/or notch networks such that the impedance is 8Ω and resistive. Again, we allow a tolerance to be added to individual speakers.

As a comparison, we also include a first-order system, using worst-case and sensitivity analysis to evaluate the performance of the different designs in both the time domain and frequency domain. In frequency analysis we use the phase of the summed output as the output variable. In time-domain analysis the magnitude is the output variable.

We use the following conditions/assumptions:

- Nominal crossover component values are calculated to the third significant figure with all speakers made equivalent to an 8Ω resistor.
- Component tolerance and speaker tolerance are assigned to be +1% or +10%.
- Crossover frequency is fixed at 2kHz in all cases.
- Acoustic properties of speakers are ideal; for example, all speakers have the same acoustic center, and each acts like a perfect point source.
- In frequency-domain analysis both the magnitude and phase responses are considered. The worst case is derived when the phase plot produces the biggest discrepancy from the nominal.
- In time-domain analysis a 500Hz square wave is used as the test signal. The worst-case is derived when the magnitude produces the biggest discrepancy from the nominal.
- Component values are similar but not identical to those in reference 2.
- PSpice does not use a true optimization algorithm. However, worst-case simulation results should show that the *actual* worst-case, if different, could only be worse.

RESULTS

Figures 1A–1C show the (worst-case) frequency response (Bode plots) of the second-order Yamanaka system with various component tolerances. In an ideal world the magnitude plot is a horizontal line of 0dB and the phase plot is another

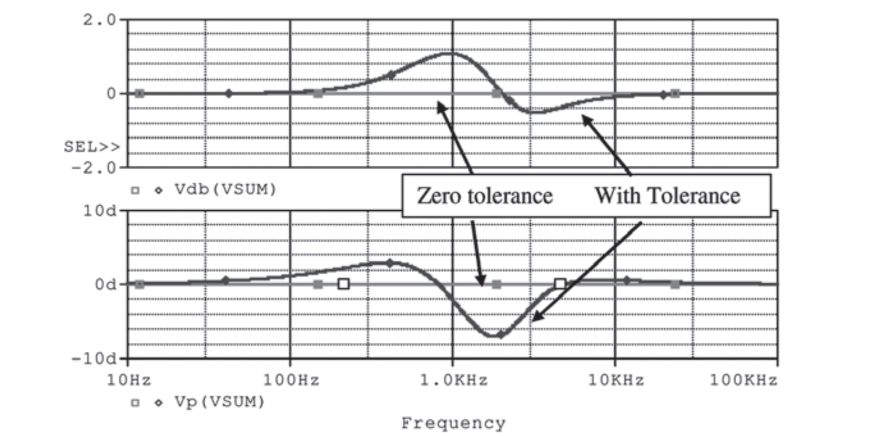

FIGURE 1A: Frequency response of the Yamanaka system with component tolerance: 1%, speaker tolerance: 10%. Upper plot is the magnitude plot and lower plot is the phase plot.

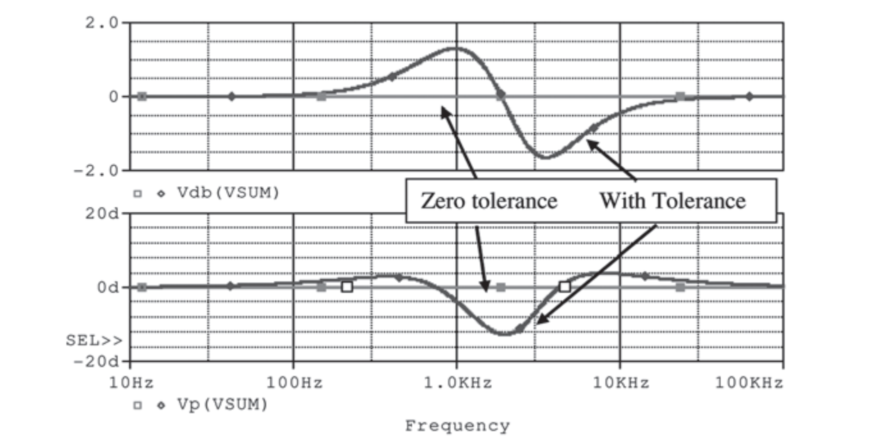

FIGURE 1B: Frequency response of the Yamanaka system with component tolerance: 10%, speaker tolerance: 1%. Upper plot is the magnitude plot and lower plot is the phase plot.

horizontal line with 0°. **Figure 2** shows the response from a first-order system. **Figure 3** shows the results from a third-order Baekgaard system. All are affected by component tolerance with the third-order Baekgaard system being the worst.

Another set of worst-case results can be generated when the magnitude response dips instead of peaks. **Figures 4A** and **4B** show the (worst-case) time response of the Yamanaka system with two different tolerance settings. In an ideal case the original 1V 500Hz square wave can be reproduced. **Figure 5** shows the relatively poor time-response from the Baekgaard system. For the second-order system, component and speaker tolerance must be kept within 10% if frequency response abnormities are kept within ±2dB and ±20°.

CONCLUSION

From the above samples and John's work[2], I can conclude that

- Speaker units must be tamed to be a constant resistance, probably within 10% tolerance or better.
- Crossover components must be selected (almost) exactly according to the designed values and with the best tolerance. The importance of tolerance increases with system order.
- The third-order Baekgaard system is around two times worse than the second-order Yamanaka system with the same component/speaker tolerance.
- The second-order Yamanaka system is close to the first-order system with component/speaker tolerance of 10% if the former has 1% crossover components.
- The first-order system is not immune to component and speaker tolerance. It is more tolerant. However, the shadow sloping of the filters is not good for most speakers.
- The third-order Baekgaard system demands very tight component tolerance

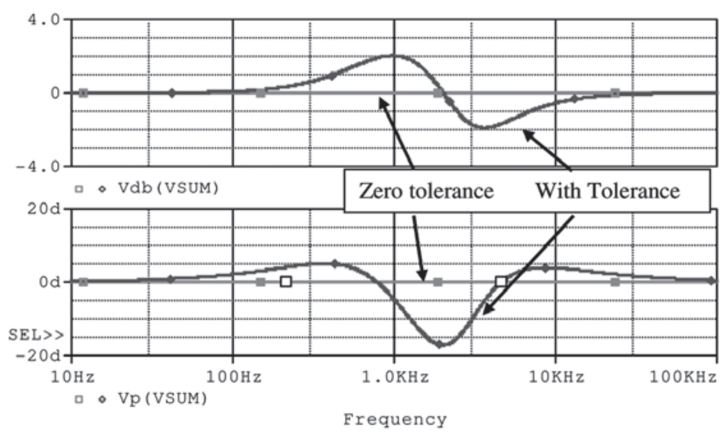

FIGURE 1C: Frequency response of the Yamanaka system with component tolerance: 10%, speaker tolerance: 10%. Upper plot is the magnitude plot and lower plot is the phase plot.

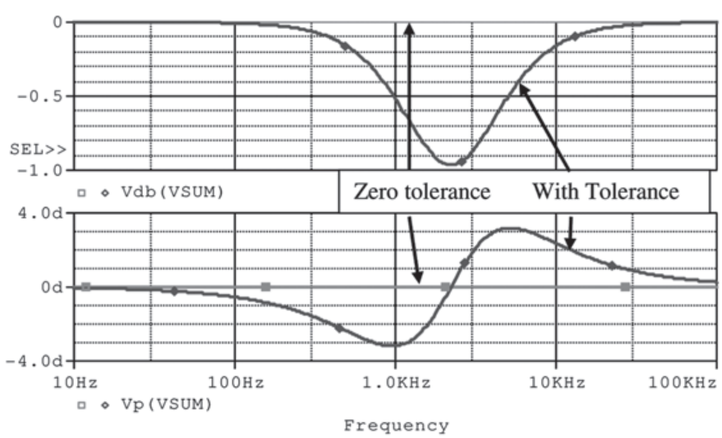

FIGURE 2: Frequency response of the first-order system with component tolerance: 10%, speaker tolerance: 10%. Upper plot is the magnitude plot and lower plot is the phase plot.

and does not appear to be practical.
- The second-order Yamanaka system seems to be the only viable solution. (This conclusion is quite different from Koonce's listening experience.)

The performance of a complete speaker system is undoubtedly affected by non-ideal acoustic and electrical conditions, so it appears that a perfectly time-adjusted passive loudspeaker system is unlikely to be practical in the real world. Perhaps an active system, and possibly with the aid of digital techniques[4], is the only way to move closer toward this objective. *aX*

REFERENCES

1. G. R. Koonce, "Passive Crossover Linear Phase Speakers," Part 1 and Part 2, *aX* 6/08 and *aX* 7/08.

2. John O'Connor, "*Time Aligned* [sic] *Crossovers for Audio*", M.Eng., Minor Thesis, RMIT University, 2008. (Unpublished)

3. Steve Stokes, "A Unique Crossover Design with Waveform Fidelity," *aX* 1/07.

4. Iain McNeill, "Crossover Approaches," *aX* 10/08.

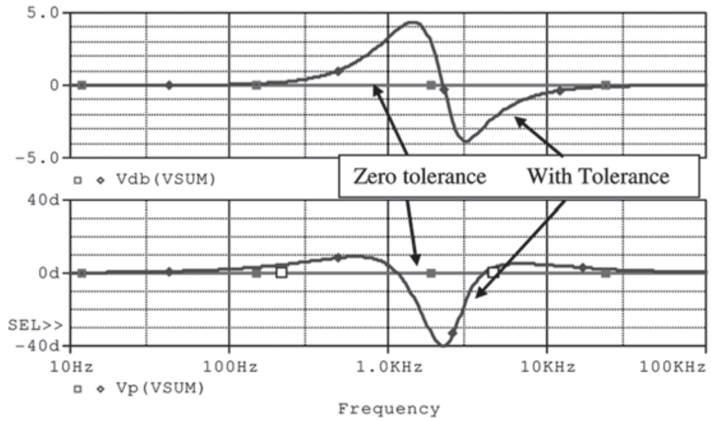

FIGURE 3: Frequency response of the Baekgaard system with component tolerance: 10%, speaker tolerance: 10%. Upper plot is the magnitude plot and lower plot is the phase plot.

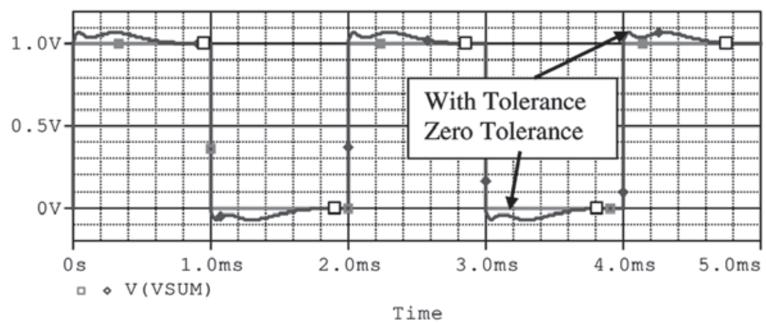

FIGURE 4A: Time response of the Yamanaka system with component tolerance: 1%, speaker tolerance: 10%.

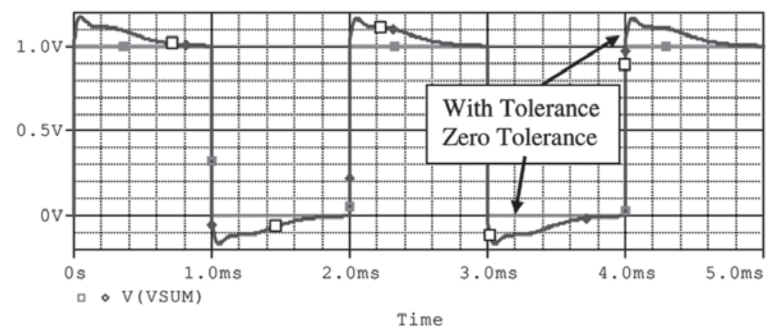

FIGURE 4B: Time response of the Yamanaka system with component tolerance: 10%, speaker tolerance: 10%.

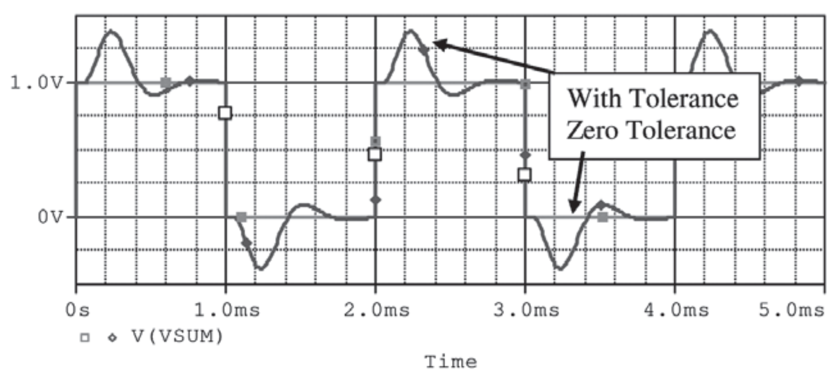

FIGURE 5: Time response of the Baekgaard system with component tolerance: 10%, speaker tolerance: 10%.