True Bass in a Large Space

A Pro DIY Subwoofer Project from 1975 Using Electro-Voice's 30W 30" Woofer

Photo 1: Bottom and side images of the Electro-Voice 30W woofer (Photos courtesy of Canuck Audio Mart)

Today, getting true bass in a small place is quite easy and straightforward, but in 1975, it was not! After reading Thomas Perazella's DIY article, "True Bass in a Small Space" (*audioXpress*, February 2017), I thought it would be fun to write a follow-up article titled: "True Bass in a Large Space."

By
Don Keele, Jr.
(United States)

Thomas Perazella's *audioXpress* article "True Bass in a Small Space" described a $900 very-high-performance subwoofer system using a low-efficiency high-excursion 18" driver mounted in a 4 ft^3 closed box driven by a 1,200 W DSP plate amplifier, with a total weight of only 115 lbs. The system was capable of radiating several acoustic watts down to 30 Hz.

After reading that article, I was reminded of my time at Electro-Voice (EV) in the early 1970s when I designed the EV TL bass box line and specifically a very-large vented-box design called the TL303 for the EV 30W 30" driver. This article describes an equivalent solution from 1975 that provides about the same response and acoustic output, but used a high-efficiency low-excursion 30" driver mounted in a massive 76 ft^3 vented-box driven by a 60 W amplifier, with a total system weight that exceeded 800 lb!

At the time, the direct-radiator enclosure design theories of Neville Thiele and Richard Small were new and Ray Newman and I and many others at Electro-Voice were at the forefront of encouraging the industry to use the then-new Thiele-Small (T-S) driver parameters for designing vented-box (bass reflex) loudspeaker enclosures.

After reading Perazella's description of the low-efficiency high-output subwoofer system, I wondered how the vintage 1970s 76 ft^3 vented-box design with the low-excursion 60 W EV 30" driver might stack up against this latest competition. This article compares the two units using detailed simulations and analysis and comes to a somewhat surprising conclusion.

Remember that in the 1960s or early 1970s, a large amplifier was typically a 50 W to 100 W tube amplifier and the speakers of the time had very anemic excursion capabilities compared to today's drivers. Notable exceptions were Electro-Voice's 30" woofer introduced in 1959 with a large cone but still very-limited excursion and Crown's solid-state 150 W per channel DC300, which first appeared in 1967. Gerald Stanley's article is referenced in the Resources section. The 30W woofer featured a gigantic cone area but had a rather anemic excursion capability of only ±3.8 mm (±0.15")!

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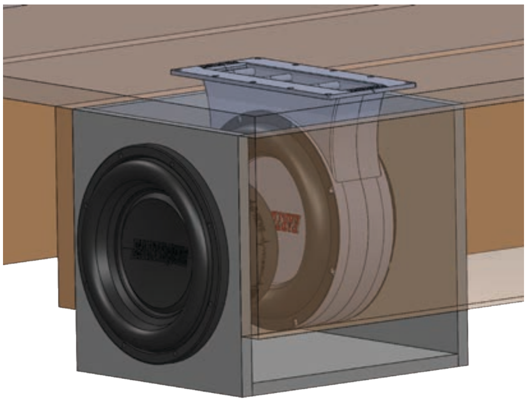

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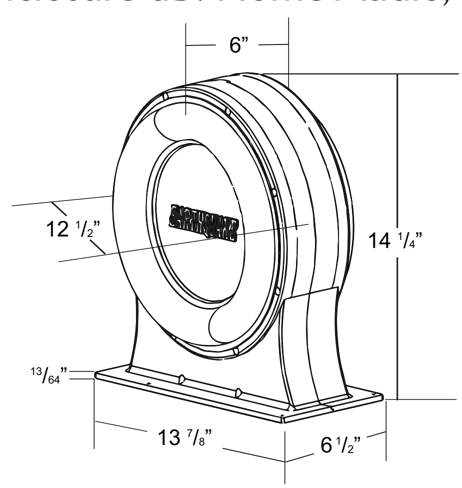

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Photo 2: The Dayton Audio 18″ Ultimax subwoofer DIY package with a MDF cabinet, a 18″ driver, and a 1,200 W DSP plate amplifier, available from Parts Express for about $900.

As we learned in the original article, Hofmann's Iron Law dictates that to generate lots of acoustic energy at low frequencies with the constraints of the 1970s, meant high efficiency, large cone area, and very-large enclosures! This is the exact opposite of the system described in the Perazella article!

The only feasible Electro-Voice driver at the time for a single-driver solution (not an array) was the EV 30W 30″ woofer (see **Photo 1**).

Question: Can a low-excursion 60 W 30″ woofer in a very-large vented box keep up with a high-excursion 1000 W 18″ woofer in a small closed box? Keep reading to find out.

The Electro-Voice 30W 30″ Woofer

Searching the Internet for "EV 30W Images" I found a number of interesting images. I also found Electro-Voice's four-page 30W engineering datasheet from 1959. On the bottom right of the first page of the datasheet, a bold statement proclaims that "Ported enclosures (bass reflex) are neither necessary nor desirable for the 30W." Ha, little did they know! (Some of the images and the complete four-page datasheet is available in the Supplementary Material section of the audioXpress website.)

The 30W has a rather anemic power rating of only 60 W (by today's standards), a 63.5 mm (2.5″) voice coil, and a ceramic magnet.

In 2017, according to the *audioXpress* article, there is a high-performance subwoofer system using a very-high-excursion 18″ driver mounted in a 4 ft^3 closed box driven by 1,200 W DSP plate amplifier. The complete DIY package is offered by Dayton Audio (Parts Express) for about $900 and includes an Ultimax 18″ driver. **Photo 2** shows an image of this kit package.

Electro-Voice TL Bass Boxes

The TL303 vented-box system for the EV 30W driver analyzed in this article is the largest system from Electro-Voice's line of TL bass boxes from the 1970s. The TL bass boxes were part of Electro-Voice's professional sound reinforcement line and were designed to be used with Electro-Voice's line

Photo 3a: This photo from 2004 shows an Electro-Voice HR9040 horn in Jim Long's home with Long on the left and Don Keele on the right. b: Long is shown beside one of his all horn-loaded systems.

of new constant-directivity sound-reinforcement high-frequency horns (models HR4020, HR6040, and HR9040) released in 1973. (A zip file containing specification sheets for these three horns is available in the Supplementary Material section of the audioXpress website.) As a side note, I wrote the verbiage for these spec sheets, plotted all the charts and graphs, and did all the measurements for these sheets. It was a lot of work, but I enjoyed it!

Photo 3 shows two pictures of Jim Long (a 45-year Electro-Voice veteran) where he has a stereo pair of HR9040 horns and folded bass-horn combinations installed for stereo listening in his living room. Amplifiers consist of a small 5 W tube amp driving the horns and a 25 W amp driving the bass horns. With this combination, he can blow your socks off! No room reflections with these babies, only direct sound! Super imaging!

The TL bass box line consists of vented-box and folded-horn designs for all of EV's "EVM" line of pro drivers including the EVM 12L, the EVM 15L, and the EVM 18B. The EV 30W 30" driver was thrown in for the TL303 sub design. Interestingly, Electro-Voice did not offer any of these enclosures as products, but only as DIY plans to support the new horns!

Outside third-party suppliers such as Charlie Wicks (The Captain of the Universe) founder of Proco Sound (www.procosound.com) started his business building TL bass boxes for the industry from these DIY Electro-Voice plans!

Vented-Box Design

With the exception of the two folded-horn boxes, I designed all the cabinets in the TL Bass Box line using the guidance of Thiele and Small. At the time, I came up with a simplified vented-box design method based on Thiele-Small theory, using simple equations that could be calculated with a simple scientific hand calculator. No computers or smart phones in those days! My original handwritten notes from February 1976 are shown in **Figure 1**.

My design method generates vented boxes with a near maximally flat B4 fourth-order Butterworth high-pass response and are based on curve fits to the graphs of Small.

The equations in my method have been replicated all over the place since 1976 without giving me any credit! I recently found an example from a recent online calculator for automotive vented bass boxes from CarStereo.com (www.carstereo.com/help/Articles.cfm?id=17) that directly implements my equations. Actually, I don't mind! My intent was to encourage people and the industry to use the then-new techniques of Thiele and Small to design better speakers! It worked!

Naming Conventions for the TL Bass Boxes

TL stands for "Transducer Low-Frequency." The following numbers in the model name stand for the low-frequency limit in Hertz followed by the

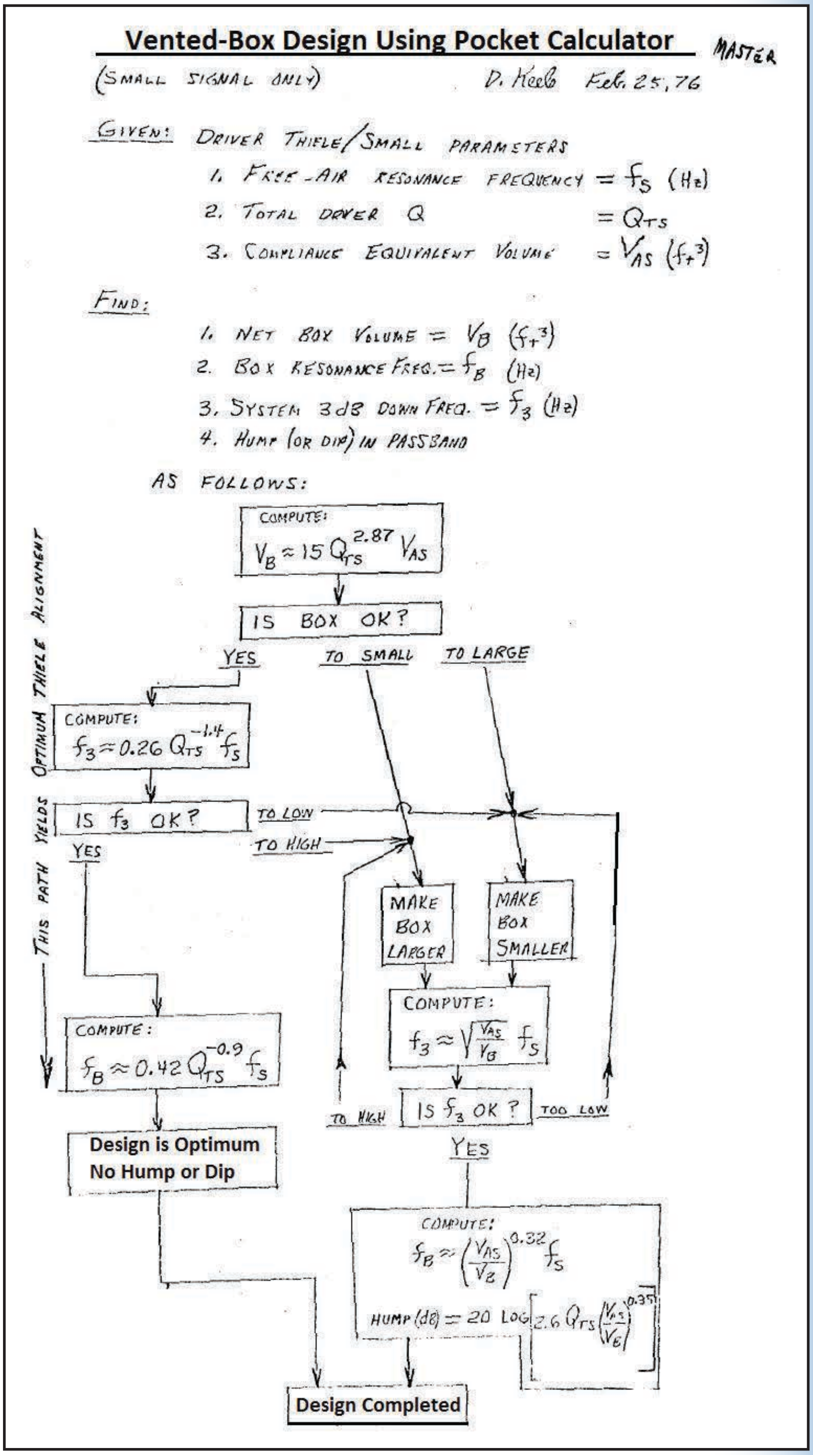

Figure 1: Don Keele's original handwritten notes from 1976 for his vented-box design method using a scientific pocket calculator. Text has been added to correct illegible sections of the image.

Photo 4: The complete line of TL bass boxes including seven direct radiators and two folded-horn boxes. The larger folded-horn box (TL4050) is not shown. The 1975 photo shows Glen Meyer inside the TL303 box and Larry Driskill standing in front.

Photo 5: The complete line of single-driver direct-radiator TL bass boxes are shown from left to right: the TL806, the TL606, the TL505, the TL405, and the TL303. These boxes housed respectively, from left to right: the EVM12L, the EVM15L, the EVM18B (two boxes) and the EV 30W 30″ driver.

Photo 6: This is a close up view of the four single-driver TL bass boxes. Note ports on the bottom of the boxes. The left three boxes are set up for the step-down mode of operation with the center port closed. The right box is set up for normal operation with all three ports open.

amount of radiated mid-band acoustic energy in watts. Thus, TL303 would stand for a speaker that can radiate 3 acoustic watts mid-band with output down to 30 Hz.

All the direct-radiator vented boxes of the TL Bass Box line could be operated in two tuning modes called: normal and step down—changing the vented-box tuning by covering up one of the ports in the box.

These modes of operation were pioneered at Electro-Voice by Ray Newman, where he discovered that a fourth-order vented-box response could be changed into a sixth-order response by lowering the box tuning by one-half octave and with the addition of a second-order high-pass filter with a Q of 2.

The normal mode represents a near maximally flat B4 fourth-order Butterworth high-pass vented-box response. The step-down mode extends the low-frequency limit down by about one-half octave by lowering the vented-box tuning frequency by one-half octave and adding an auxiliary second-order high-pass filter with a Q of 2 that provides a 6 dB lift to return the response back to flat.

Later in this article, I provide an example of a step-down alignment as it applies to the TL303 bass box. The auxiliary filter in addition to flattening the response provides much needed reduction of the vented-box's susceptibility to below-band energy content in the program material.

The step-down alignment is essentially the same as Thiele's sixth-order Class I B6 vented-box alignment number 15. For more information, you can read my 1974 paper titled: "A New Set Sixth-Order Vented-Box Loudspeaker System Alignments" (see Resources).

The TL Bass Box line included five single-driver and two four-driver array direct-radiator vented boxes plus two folded-horn boxes housing various Electro-Voice drivers (see **Photos 4–6**). The specification summaries for all the TL Bass Boxes and a complete set of builder's plans for all these systems are available in the Supplementary Material section of the audioXpress website (www. audioxpress.com).

Various views of the boxes from the TL Bass Box line are shown in **Photos 4–7**. All these photos were taken about 1974 in Electro-Voice's engineering lab in Buchanan, MI. To my knowledge, these photos are the only ones that exist of all these cabinets together in one place. Various Electro-Voice employees including me are shown in these photos.

Photo 7 shows a rather humorous photo of the massive 76 ft^3 TL303 vented system, which houses the EV 30W 30″ woofer. The box is in the "normal" tuning mode with both the top and bottom ports open. Note my right leg sticking out the bottom port, Glen Meyer's head protruding out the top port, and Bill Raventos completely inside the cabinet!

TL303 Bass Cabinet for the 30W Woofer

The TL303 vented box at 76 ft^3 was the largest enclosure of the TL Bass Box line and housed the EV 30W 30″ driver. Hey, this enclosure could be the largest ever built! The Builder's Plans for the TL303 are shown in the Supplementary Material section of the audioXpress website.

The original Builders Plans for the TL303 enclosure are dated March 1975. I was the designer, wrote the verbiage, and plotted all the graphs on the left side of the plans. The cabinet is formed by two 4′ × 8′ of sheets of 0.75″ plywood separated by 30″ and is very large and heavy!

In normal mode, the TL303 is tuned to 25 Hz with both ports open and in step-down mode is tuned to 18 Hz with the bottom port covered.

Simulations: Small- and Large-Signal

Table 1 shows the T-S driver parameters I used for my simulations. The 30W parameters differ somewhat from the parameters used for the

Photo 7: This is the large 76 ft^3 TL303 vented-box cabinet, which housed the EV 30W 30″ driver. From top to bottom is Glen Meyer, Bill Raventos, and Don Keele. A speaker engineers' dream playhouse!

Table 1: The small- and large-signal Thiele-Small driver parameters for the 30W woofer and the Dayton Audio UM18-22 woofer. These parameters were used for all my simulations.

Thiele-Small Driver Parameters					
Symbol	Description	Electro-Voice 30W 30″		Dayton Audio UM18-22 18″	
Small Signal:					
Diameter	Nominal diameter	30″		18″	
Fs	Free-air resonance frequency	16 Hz		20 Hz	
Qts	Total Q	0.27		0.53	
Vas	Compliance equivalent volume	210 ft^3	5.9 m^3	7.5ft^3	0.21 m^3
Large Signal:					
PeMax	Thermally limited maximum input power	60 W		1,000 W	
Vd	Peak displacement volume (= Sd × Xmax)	85 in^3	1,390 cm^3	165 in^3	2,700 cm^3
Xmax	Peak linear excursion	0.15″	3.8 mm	0.87″	22 mm
Sd	Effective cone area	564 in^2	3,600 cm^2	189 in^2	1,220 cm^2
Eff	Reference efficiency half-space	8.8%		0.31%	

TL303 Builder's Plans and are more up to date. The parameters for the Ultimax UM18-22 18″ woofer are those provided by Parts Express.

The program I used for the simulations I wrote myself using Igor Pro (see Source). The program is quite simple and utilizes the enclosure modeling equations of Thiele and Small. It assumes completely linear operation when the driver is operated below its excursion limit.

I have been using Igor since 1988 for all my technical papers and articles and I give it my highest recommendation! It first started out on the Apple Macintosh, and I initially ran it on my Mac 512K and later on my Mac SE for many years. Igor Pro is major competition to MatLab. My Igor box simulation program is available in the Supplementary Material on audioXpress website and will run on the free Igor Pro demo.

How to Read the Response Graphs

Figures 2–8 show the simulated small- and large-signal frequency responses of the systems I analyzed.

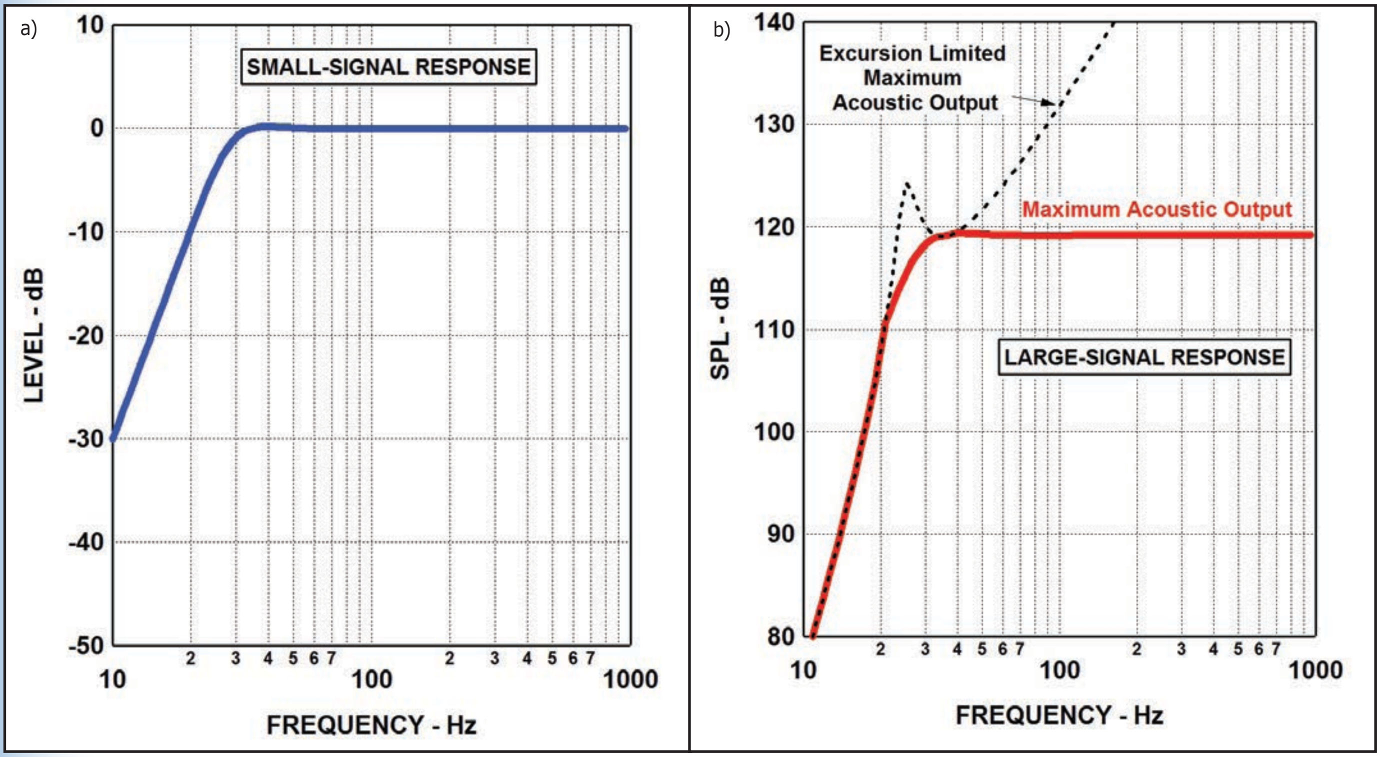

Figure 2: The small (a) and large (b) signal responses of the TL303 system in normal tuning mode. The cabinet houses the 30″ Electro-Voice 30W driver in a 76 ft^3 vented box tuned to 26 Hz. Note the ideal responses.

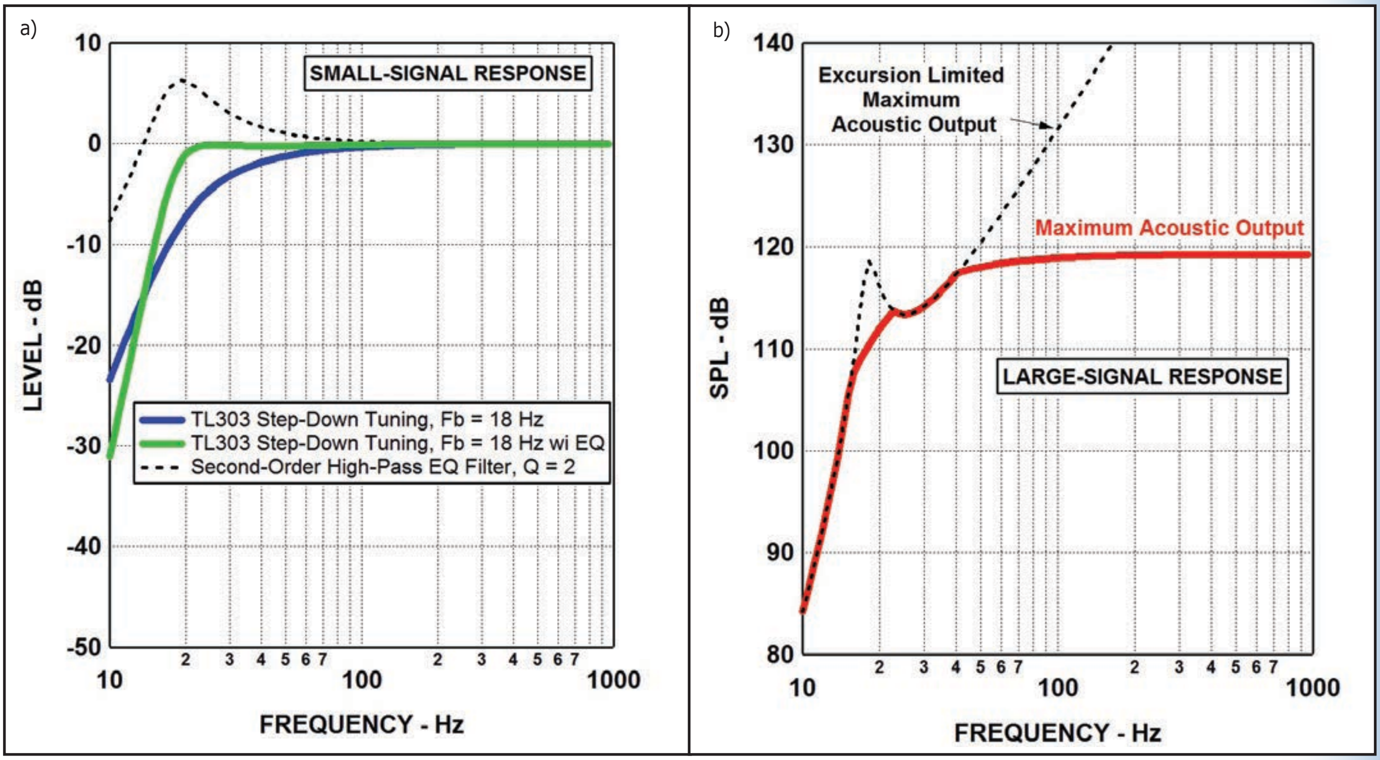

Figure 3: The small (a) and large (b) signal responses of the TL303 system in step-down mode. Figure 3a shows the response of the second-order equalizer (black dashed curve) and the equalized response (green curve).

The last two figures (Figure 7 and Figure 8) illustrate simulation comparisons of the various cabinets.

Each figure shows the small-signal response on the left graph (a) and the large-signal response on the right (b). The large-signal graph on the right (b) shows two plots: the maximum acoustic output (red curve), and the excursion-limited maximum acoustic output (black dashed curve). Both predictions are at 1 m and plotted in dB SPL.

The small-signal response of a closed box falls at 12 dB per octave below box resonance (see Figure 4a as an example), while the response of a vented box falls at 24 dB per octave below box tuning (see Figure 2a).

With today's sophisticated DSP processors, the small-signal frequency response can be equalized to have any shape or low-frequency limit desired. Hey, if you want your 3" driver system to be flat to 10 Hz, you can do that! However, it won't play very loud at low frequencies because the driver can't move enough air!

The large-signal maximum output is what defines how loud a system will play at each frequency. If you want a system to be usable to low frequencies, its maximum output must be acceptably high at all these frequencies!

The levels noted on all the large-signal graphs are the sound pressure in dB SPL at 1 m in a half-space for omni-directional radiation. This assumes that the driver is mounted in an infinite flat baffle. In this situation, one acoustic watt will generate 112 dB SPL at 1 m.

A speaker system's maximum output is limited by both the thermal and excursion limits of the driver. When you raise the input to the speaker, you will reach either the driver's thermal limit or its excursion limit, whichever occurs first.

The shape of the excursion-limited output curve is distinctly different for closed-box and vented-box systems. The closed-box output rises at 12 dB per octave over the entire range (see Figure 4b).

This is in contrast to the vented-box output that rises at 24 dB per octave below box tuning and also at 12 dB per octave above box tuning (see Figure 2b). In the region around box resonance (in this case 26 Hz), the excursion-limited output reaches a peak at box tuning and then falls somewhat and then continues rising like a closed box as if the vent were closed.

A well-designed vented box matches the thermal and excursion limits of the system at the frequency of the dip in the excursion curve. The TL303 design (see Figure 2b) meets this criterion. If a system

About the Author

Don Keele was first introduced to audio, music, and loudspeakers back in the late 1950s. Since that time, Don has worked for a number of companies in the area of loudspeaker R&D and measurement technology including Electro-Voice, Klipsch, JBL, Crown, and Harman International. For 10 years, he wrote for the now-defunct *US Audio Magazine* as a Senior Editor performing loudspeaker reviews. More recently, he worked under Floyd Toole as a member of the Harman corporate acoustics engineering group. Although technically now retired, at 76 he heads his own consulting company DBK Associates and Labs. He holds eight patents with topics including "constant-directivity" loudspeaker horns, loudspeaker arrays, and signal processing. He is a life fellow of the Audio Engineering Society (AES). His passion for the last 15 years has been to promote the use of Constant Beamwidth Transducer (CBT) loudspeaker technology in the loudspeaker industry. He has written 16 AES papers on this topic. In 2002, he received a Scientific and Engineering Academy Award for work he did on cinema constant-directivity loudspeakers. In 2016, he was presented with the AES Gold Medal Award for outstanding and significant research, design and product development, over a period of more than 45 years, of loudspeakers and loudspeaker systems providing broadband constant-coverage performance.

doesn't meet this criteria, it is over designed from either a thermal or excursion standpoint.

Correspondingly, a well-designed closed-box system matches the displacement and thermally limited maximum output curves below the closed-box corner frequency (see Figure 6b).

TL303 Normal Tuning

The small- and large-signal responses of the EV 30W in the 76 cubic foot vented box tuned to 26 Hz are shown in Figure 2. The curves exhibit near ideal vented-box responses with a 3 dB down point (f3) of about 26 Hz.

The small- and large-signal responses of the EV 30W in an 18 Hz-tuned 76 ft^3 vented box are shown in Figure 3. Here the vented-box tuning was lowered by one-half octave from 26 Hz to 18 Hz. The overall small-signal response in Figure 3a (blue) exhibits a gentle rolloff, which is equalized flat with a second-order high-pass with a Q of 2 (dashed black curve). The resultant equalized curve (green) exhibits a much lower f3 of about 18 Hz. Figure 3b shows the large-signal response of the system. Note the significant excursion limiting below 16 Hz and between 23 and 40 Hz.

BYU Bass Guitar System

The small- and large-signal responses of the EV 30W in a 28 ft^3 closed box are shown in Figure 4. This enclosure is a near optimum closed-box design! This box was used in pairs by the Brigham Young University (BYU) marching band for reproducing bass guitar (see Sidebar) and was designed by Ray Newman of Electro-Voice.

The small- and large-signal responses of the EV 30W in a 42 Hz-tuned 76 ft^3 vented box are shown in Figure 5. The small-signal response (see Figure 5a) exhibits a peak of about 4 dB at about 60 Hz.

The large-signal response of this box (see Figure 5b) only exhibits significant displacement limits below 30 Hz. The peak noted above carries over to the large-signal response (right) where it represents a healthy 4 dB increase in maximum output compared to the closed-box in a frequency range solidly in the bass guitar's range!

Ultimax Closed Box

The small- and large-signal responses of the Dayton Audio Ultimax UM18-22 18" woofer in a 4 ft^3 closed box (the system described in the *audioXpress* article of February 2017) are shown in Figure 6. This system is not excursion limited at any frequency! The system is an ideal closed-box design with the excursion-limited maximum output just grazing the thermally-limited output at low frequencies.

Simulation Comparisons

Now, compare all three systems. Figure 7 shows comparative small- and large-signal responses for three systems: The TL303 system in normal mode,

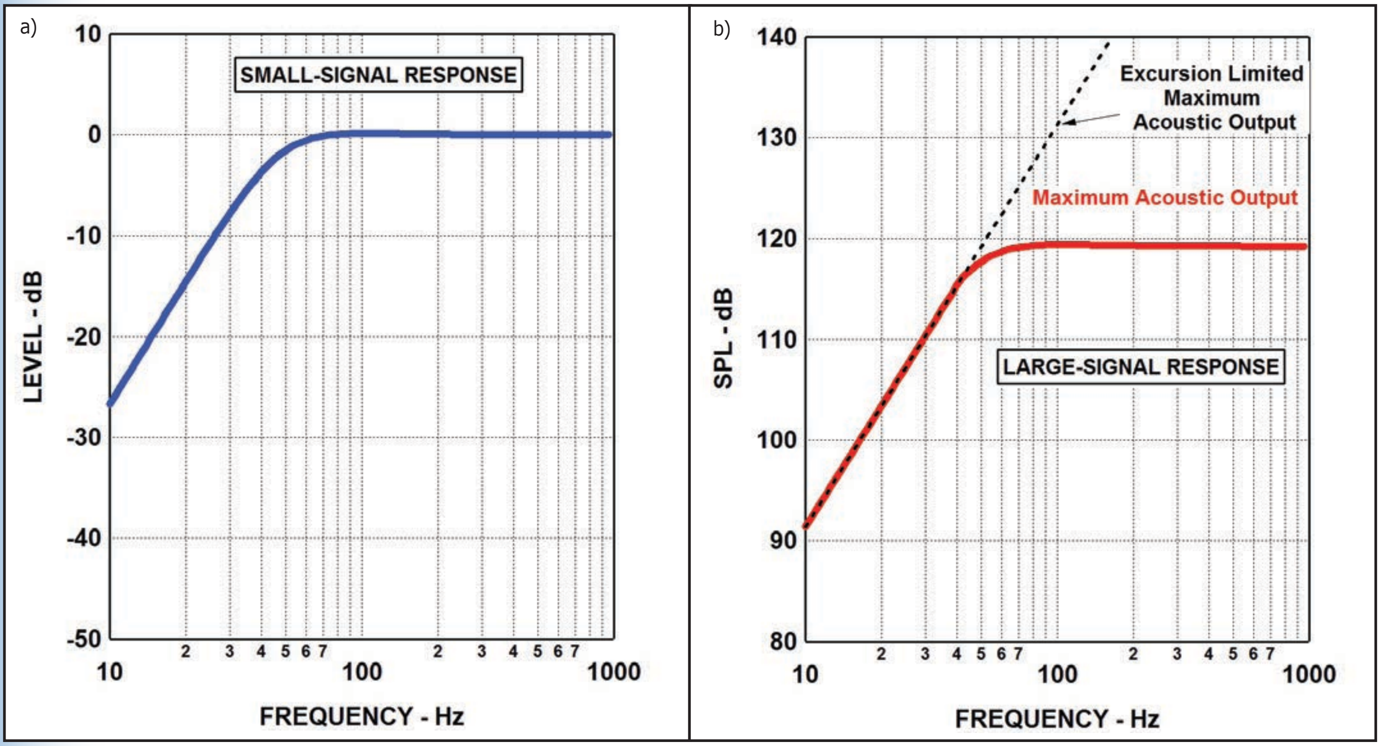

Figure 4: The small (a) and large (b) signal responses of an EV 30W driver mounted in a 28 ft^3 closed box.

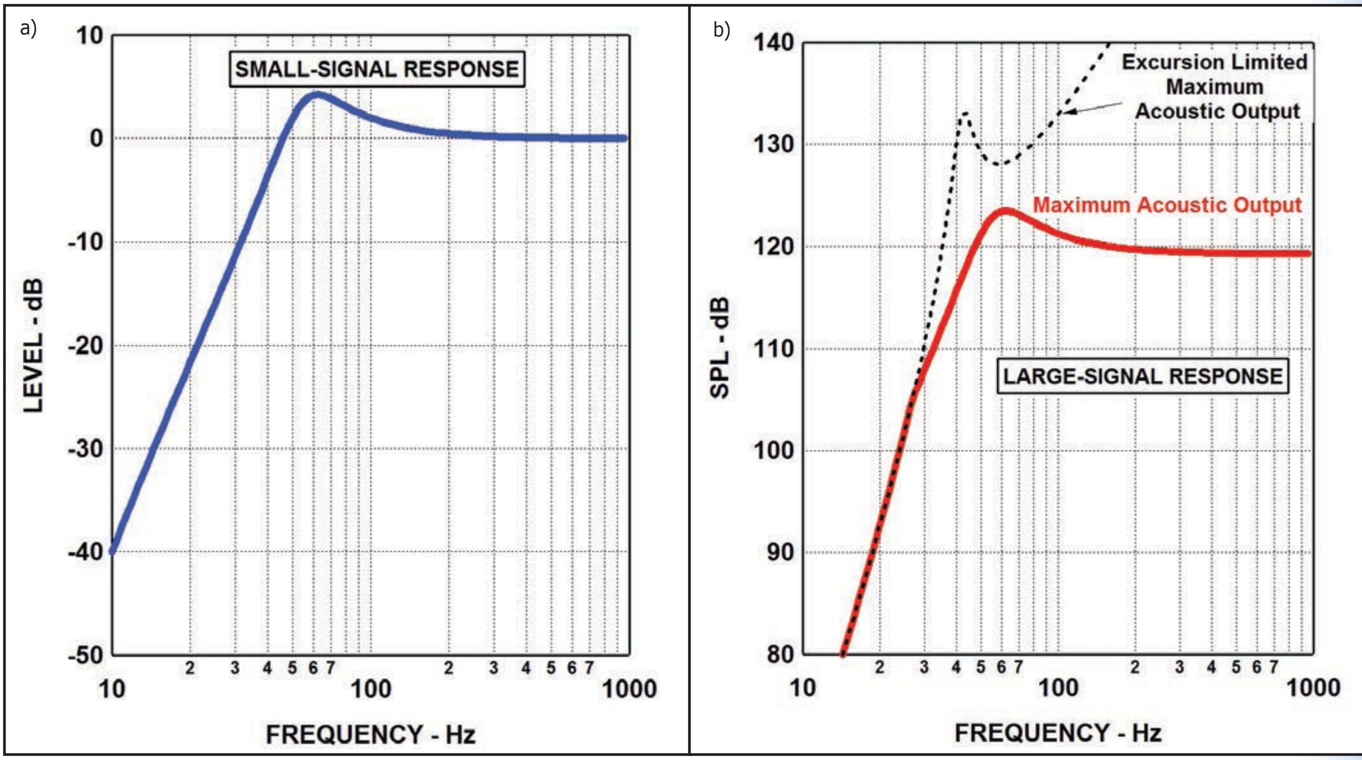

Figure 5: The small (a) and large (b) signal responses of an EV 30W driver mounted in 28 ft³ box tuned to 42 Hz.

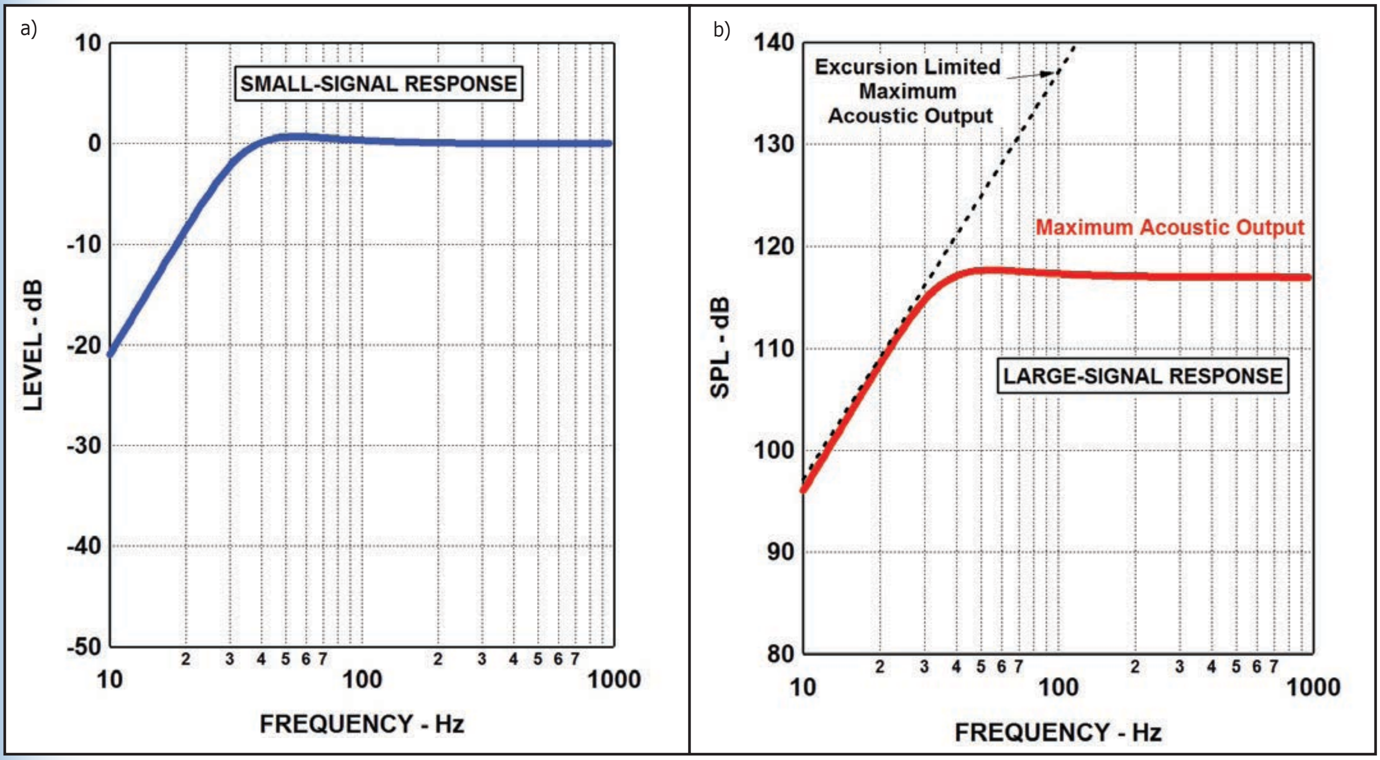

Figure 6: The small (a) and large (b) signal responses of the Dayton Audio Ultimax UM18-22 18" driver mounted in a 4 ft^3 closed box.

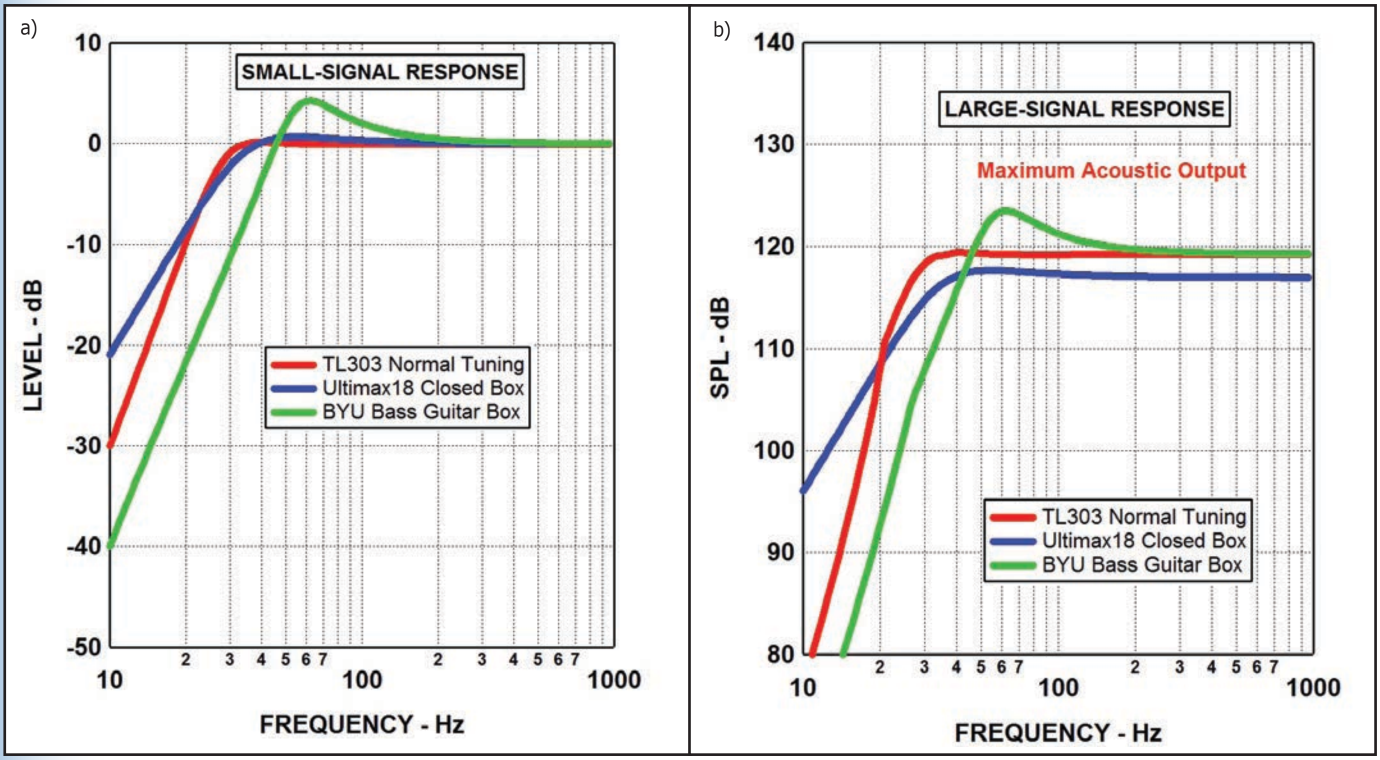

Figure 7: A comparison of the small-signal (a) and large-signal (b) responses of three systems analyzed in this article: the TL303 normal tuning (red), the Ultimax system (blue), and the BYU bass-guitar vented system (green).

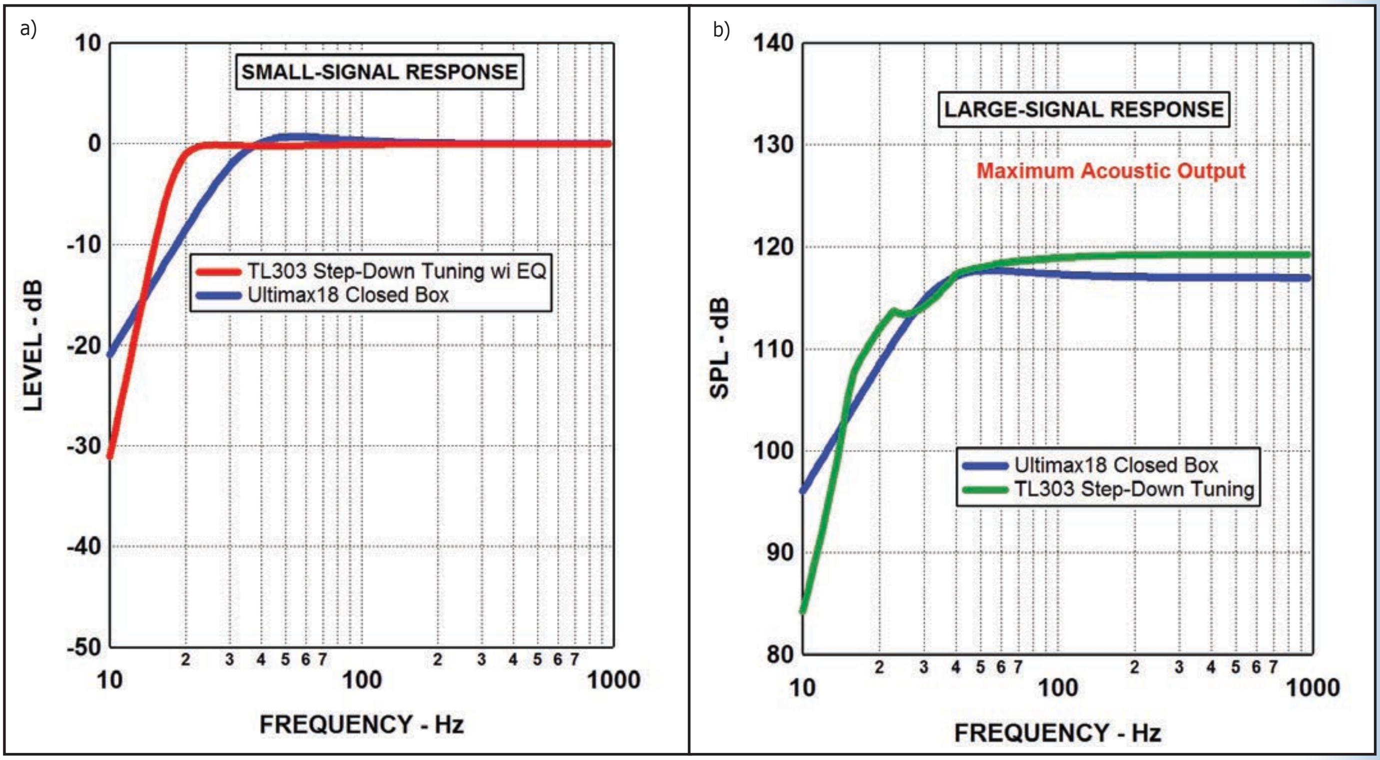

Figure 8: The small (a) and large (b) signal response comparison between the equalized TL303 system in step-down mode and the Ultimax closed-box system.

the Ultimax closed-box system, and the vented BYU Bass Guitar box.

The small-signal comparison (Figure 7a) shows the TL303 and the Ultimax system have somewhat similar responses above 22 Hz, but the TL303 rolls off much quicker at lower frequencies. The BYU system, however, exhibits a higher cutoff frequency, but with a significant peak in the response at about 60 Hz.

The large-signal responses (see Figure 7b) of the three systems have somewhat similar shapes to the small-signal responses but differ in level. The mid-band maximum levels of all the 30W systems exceed the Ultimax system by about 2.3 dB. This is not the entire story though, because the BYU vented system at 63 Hz exceeds the maximum output of the Ultimax system by a whopping 6 dB! This is ideal for a bass guitar!

Now, compare the TL303 step-down tuning with EQ and the Ultimax Closed Box. Figure 8 shows a comparison between the small- and large-signal responses of the equalized TL303 in step-down mode and the Ultimax closed-box system.

Here, the TL303 is clearly the small-signal winner with a much lower f3 of about 18 Hz compared to the f3 of the Ultimax system at about 28 Hz (see Figure 8a). However, as mentioned before this isn't the entire story because the large signal responses are what count. The TL303 maximum output (see Figure 8b) is significantly higher by about 3 dB between 16 and 22 Hz, about the same between 28 and 50 Hz, and about 2 dB above 150 Hz.

I declare the TL303 to be the winner here! It will play louder than the Ultimax system over most of the frequency range. But hey, after all is said and done, I'll pick that 4 ft^3 115 lb. Ultimax package over that enormous 76 ft^3, 585 lb. system any day! However, in 1975, you did not have the luxury of this choice!

Conclusions

In my introduction I asked: Can a low-excursion 30W 30″ woofer in a very-large vented box keep up with high-excursion 1000 W 18″ woofer in a small closed box? The answer is a resounding yes!

My simulations show that the maximum acoustic output of the large-box TL303 system in normal tuning mode exceeds the output of the small-box 18″ system by an average of about 2 to 3.5 dB above 24 Hz (see Figure 7b). In addition, the maximum output of the large-box TL303 system in step-down tuning mode (see Figure 8b) equals or exceeds the maximum output of the 18″ closed-box system at most frequencies by about by about the same margin above 15 Hz.

Furthermore, the smaller 27 ft^3 BYU bass-guitar tuned 30″ driver box (see Figure 7b) exhibited a maximum output averaging 2 to 6 dB above 45 Hz compared to the 18″ driver box.

Okay, I have shown that in the mid-1970s it was possible to design a high-performance subwoofer system that could generate several acoustic watts down to 30 Hz and below, and compete very nicely with a modern system.

BYU Marching Band 30W Bass-Guitar Box

While preparing this article, I had a vague recollection that a pair of TL303 bass boxes were used by the Brigham Young University (BYU) marching band for reproducing bass guitar at football games and for their marches in parades. (FYI: I graduated from BYU in 1972 with an MSEE degree with a minor in acoustics.)

However, my recollection was only partially correct. It was not a TL303 bass box, but a custom-built 30 W closed-box enclosure that the marching band had used, designed by Ray Newman of Electro-Voice! Its dimensions were about 4′ × 4′ × 2′ deep and had a net internal volume of about 28 ft^3.

The band would set up a pair of these systems on the football field during games along either side of the 50 yard line in the middle of the field. This was quite unique at the time because very few marching bands had bass guitar accompaniment for their band!

They said the BYU bass guitarist was very skillful in either playing ahead of or behind the band depending on where the band was on the field so they kept in time. The marching band also used these bass cabinets towed behind the band on a trailer when they marched in parades.

An interesting recollection by Ed Jones concerned the BYU band marching in Ronald Reagan's inaugural parade in 1981. They commandeered a brand new Chevy El Camino to haul the two bass boxes and drove behind the band to reproduce bass guitar. He stated that they used a 200 W Altec 1590B power amplifier that would run on 24 V and powered it with two 12 V automotive batteries!

For this article, I added an extra wrinkle. I converted the system to a vented box to increase its output and optimize the response for a bass guitar. The only logical place to tune the box is in the range of 40 to 50 Hz regardless of the resultant response shape. This is because the frequency of the open "E" string of a bass guitar is 42 Hz and as a result has minimal energy below this frequency.

I chose 42 Hz for box tuning and included this box configuration in my article's simulations. I did not consider any port implementation issues (i.e., real vent or passive radiator). I will leave that as an exercise for the reader!

However, those 1970's systems have some extremely significant major downsides: extremely-large enclosures and excessive weight. In light of this, the edge shifts dramatically to the current systems. If one allows for multiple drivers in the current systems (i.e., a dual-driver 18" system in 8 ft^3 closed box driven by a 2,400 W amplifier or equivalently two of the Ultimax systems set up side by side), the new systems would walk all over the old systems by a large margin!

I know which one I would choose!

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Resources

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*All Audio Engineering Society (AES) papers (including those listed here and more than 50 others written by Keele since 1972) are available from the Audio Engineering Society's E-Library (www.aes.org/e-lib).

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