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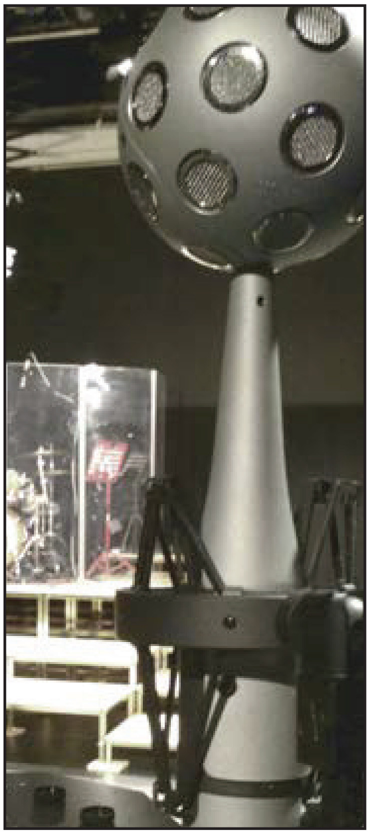

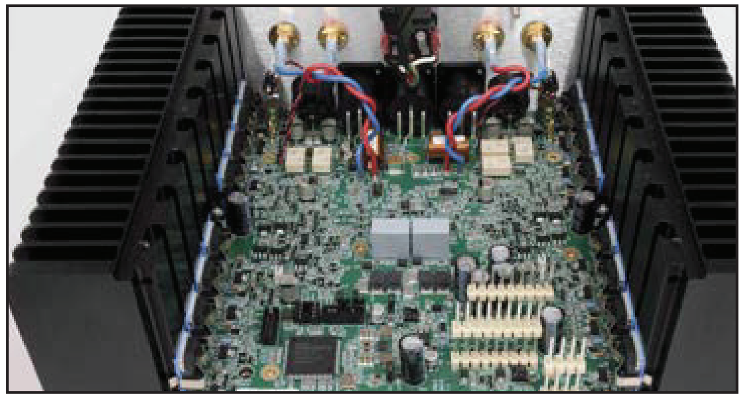

Features

ax You Can DIY!

True Bass Rides Again (Part 1)

Reproducing That Original Sound

Photo 1: The Dayton Audio Ultimax 12″ driver's front view is shown.

I am one of those audio DIYers who longs for reproduced bass that remains true to the original sound. This article is the first in a two-part series that describes my efforts to recreate the true bass sound I once achieved in a former home.

By
Thomas Perazella
(United States)

All my life I have been intrigued by reproduced bass that was true to the original sound. Unfortunately, that is a rare commodity. Most attempts to reproduce true bass are hobbled by several factors including lack of sufficient linear volume displacement from the speakers employed. While living in the Chicago, IL, suburbs in the mid-1990s, I decided to build a subwoofer that could competently reproduce anything I could throw at it. That resulted in a project that ultimately used eight 12″ woofers having high linear volume displacement in two cement-filled housings, mounted in the wall of a 450-ft^3 closet. That closet acted as an infinite baffle enclosure. The project was the subject of an article I wrote for *Speaker Builder* magazine, called "True Bass."

After many years of enjoying this quality of bass reproduction, I was faced with a dilemma. We were moving out of the Chicago area. What should I do with the speakers? Looking at the work it would require to remove them, patch the wall, and move them to the new location gave me pause for thought. When we found our new house, it was apparent that I could not repeat the in-wall scheme I had used. Therefore, the speakers remained with the house when it was sold.

Shortly after moving into the new house, I started to design a bass section for my speakers. Not being able to use the through-wall approach, I decided on two sealed boxes that would each have one driver. The original room in Chicago was 21′ long × 16′ deep with a vaulted ceiling. It was open along one long dimension to a lower-floor family room. Since the new room into which the system would be placed was considerably smaller at 13′ × 17′ with an 8′ ceiling, I felt that I could get by with less volume displacement.

Searching the drivers available at the time, I was impressed with the Dayton DVC 15 from Parts Express, which had an X_{MAX} of 15 mm and a high sensitivity of 90 dB/W. It was cost effective and became the driver of choice. With that high sensitivity, I felt I could power each driver with a 300-W plate amp. I chose the Keiga KG-5230 available from Madisound. I then proceeded to build two sealed boxes using 0.75″ MDF. The outside dimensions were approximately 24″H × 24″W × 18″D, yielding an internal volume of about 5 ft^3. For aesthetic purposes, I wanted to rear mount the drivers so I made the rear panel removable. Those subwoofers worked well with most material, but occasionally when reproducing very demanding pieces such as an 18-Hz organ pedal note at high volumes, the drivers ran out of linear displacement and high distortion resulted. It was a minor problem so I lived with that setup for about 10 years.

Time to Go for the Brass Ring

Not being known as someone who can leave well enough alone, I finally decided to change the bass section to achieve the truly effortless bass that I had in Chicago. I knew the answer would be to increase the total linear volume displacement of the drivers, while maintaining the sealed-box approach. I have always favored a sealed box for two reasons. The transient response of a sealed box is better than from a ported, passive radiator, or another enclosure that uses the driver's rear wave for additional output. A sealed box also maintains better control of the driver below resonance, enabling more output with lower distortion in that region. I could either expand my existing subs or go with a totally new approach.

Appealing New Drivers

Recently, I resurrected an old set of speakers that utilized Heil Air Motion tweeters. While doing so, I became aware of some exciting new drivers. Since I was using the same enclosures that utilized a 12″ driver, I concentrated on the new 12″ Ultimax driver from Parts Express.

The results were so good that I thought they might be the answer to achieving the bass I had from my old system. I would be able to use enclosures of smaller size for the same output.

At the same time, Parts Express introduced an updated Titanic driver with improved performance. I decided to add that driver to the mix. As part of any subwoofer discussion, it is important to remember "Hofmann's Iron Law." Josef Anton Hofmann was the "H" in KLH. He postulated that when designing boxed woofers, there are three parameters that cannot all be had at the same time. They are low-bass reproduction, small size, and high sensitivity. You can pick any two but the third will suffer. For example, you can have low bass and small size, but the sensitivity will be low. You can have low bass and high sensitivity, but you will need a large box. In designing this system, I examined three drivers that all had traits requiring different compromises.

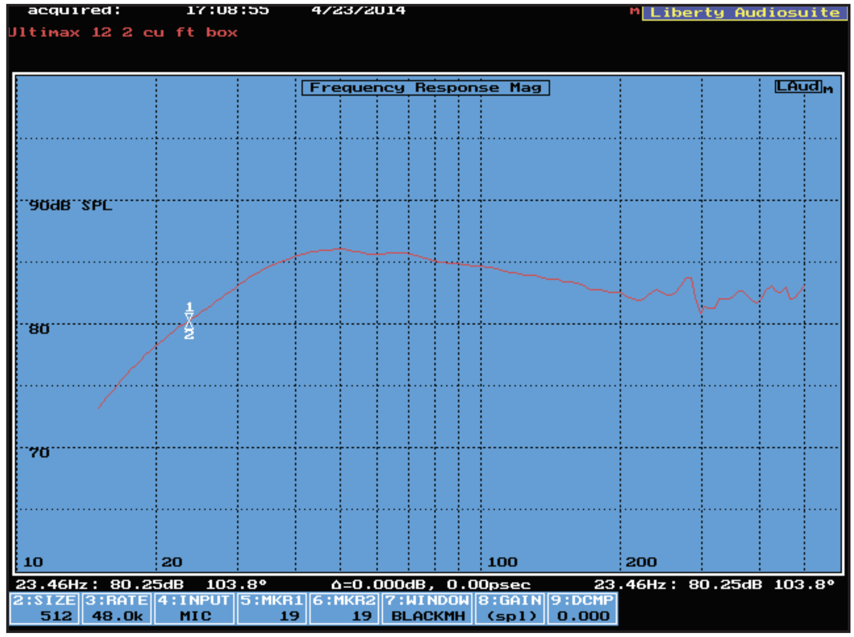

Figure 1: The Dayton Audio Ultimax 12″ driver's frequency response is measured using a 2-ft^3 enclosure.

Comparing Drivers

When comparing drivers, one of your first considerations should be whether you are going to use any kind of EQ. A totally passive implementation of a subwoofer is possible, but it will limit your options. For example, the smaller the box volume for a given driver, the higher the resonant frequency or F_B and the higher the Q_B will be. This could result in less low output and a bump at resonance for a less than optimum volume. EQ when coupled with more linear power can mitigate those problems.

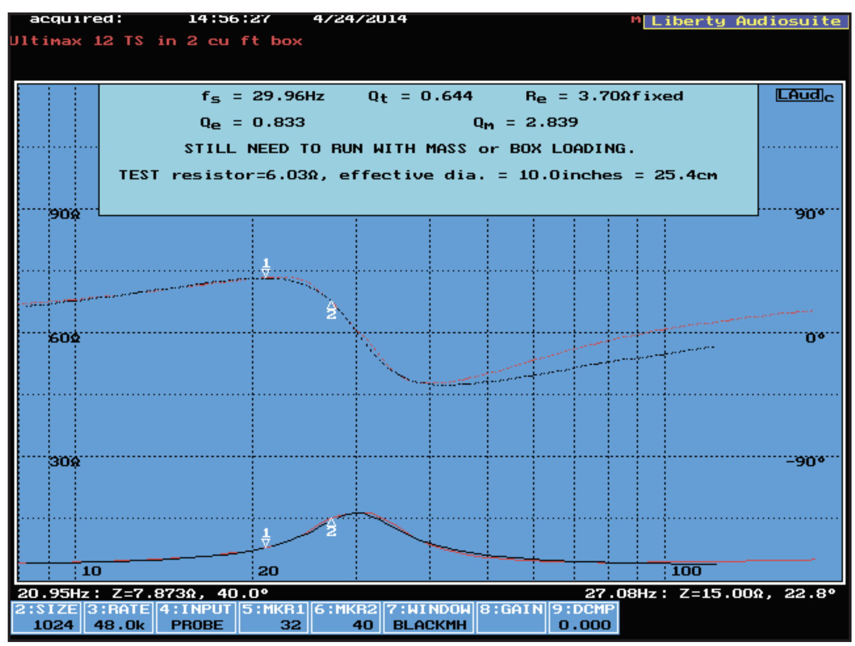

Figure 2: This shows the Dayton Audio Ultimax 12″ driver's Thiele-Small (T-S) parameters.

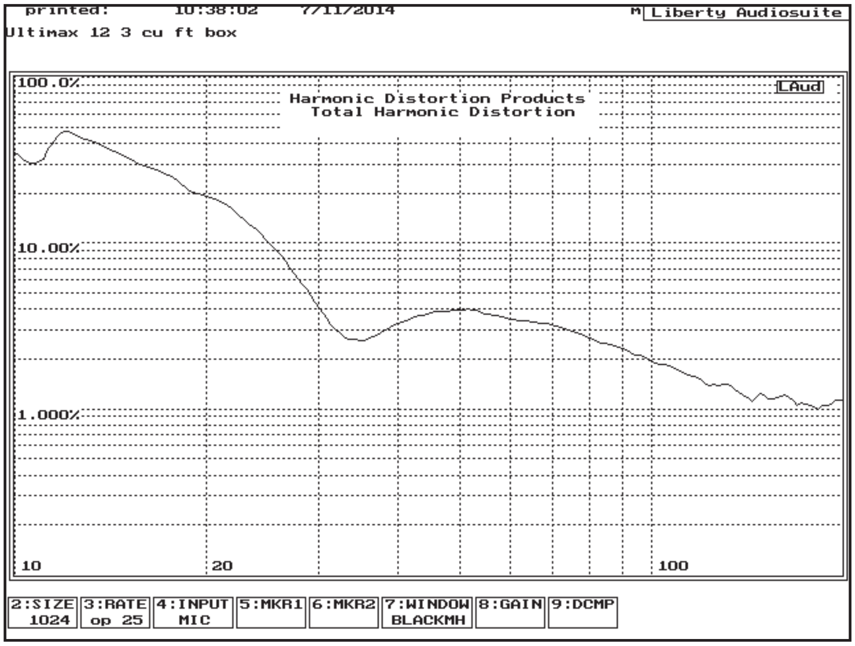

Figure 3: Dayton Audio Ultimax 12" driver's total harmonic distortion (THD) is measured at 100 dB at 1 m.

About the Author

Thomas Perazella is a retired IT director. He is a member of the Audio Engineering Society, the Boston Audio Society, and the DC Audio DIY group. He has authored several articles in professional audio journals.

Photo 2: Here is the Dayton Audio Titanic MK4 12" driver's front view.

Remember that regardless of which route is taken, the ultimate limit on clean low bass will be the combination of linear volume displacement of the driver(s) and possibly the amount of low distortion power available if sensitivity is low.

Simply stated, a driver's amount of linear volume output is the product of the linear excursion of that driver times it's radiating area. You can actually calculate the volume displacement in liters much as is done with automobile engines. The cone's area is equivalent to the piston's area in an engine and the linear excursion of the driver motor and suspension is equivalent to the engine stroke. All else being equal, the larger the displacement of an auto engine, the more work it can do. With a dynamic driver, the more linear the volume displacement, the more low distortion work the driver can do. Also as with an automobile engine, the more pistons or drivers you have, the more linear work you can do.

X_{MAX}

A dynamic driver is really a linear electric motor. Unlike a rotary electric motor where linear force can be applied in a constant direction of rotation as long as power is applied, a linear motor has a finite range of linear motion in one direction. At some point, one or both of the motor's two major elements will become nonlinear. Those elements are force factor or motor strength Bl and suspension stiffness K_{MS}. One of the best descriptions of dynamic driver nonlinearities can be found in a paper by Wolfgang Klippel available on his website (www.klippel.de).

Many modern drivers exhibit higher linearity due to enhancements in design and materials. But due to the fundamental design of a linear motor, excursion is still finite. Even with a very linear driver, once the excursion exceeds the range where the force factor falls off or suspension stiffness increases by more than 50% of original values, the distortion dramatically rises.

The parameter that describes a driver's useful linear excursion is the term X_{MAX}. It refers to the excursion in one direction where the motor strength and suspension stiffness are both within 50% of the original values. In one direction, it may be one parameter that sets the limit. In the other direction, it may be the other. Whichever direction fails the 50% test first sets the overall X_{MAX}. For example, if a driver is limited in one direction by motor strength to 12 mm and suspension stiffness in the other direction to 10 mm, the X_{MAX} should be specified as 10 mm. I say should because often drivers are specified for excursion as a total of both directions and sometimes as "total" excursion up to the point where the driver simply cannot go any further and is producing distortions that are truly huge and downright obnoxious. There are cases where X_{MAX} is not even specified, making it impossible to predict the driver's quality and usefulness.

Common Limits on Bass Quality

Probably the two most commonly experienced limits on good bass reproduction are the drivers' lack of linear displacement capability and low sensitivity. At very low frequencies, the displacement limits are most problematic. At higher frequencies, sensitivity can become the biggest problem. Why is this so?

One of the rules for bass reproduction is that for every octave decrease in reproduced frequency, you must have four times the volume displacement to maintain the same sound pressure level (SPL). To put that in perspective, if you had a particular driver that had just sufficient volume displacement to yield a 90 dB SPL at 80 Hz, you would need four of those drivers to produce 90 dB at 40 Hz and 16 drivers for the same SPL at 20 Hz.

It should be apparent why good low bass is so difficult to achieve if you are using small drivers. With a small radiating area, a small driver must have lots of linear excursion to try to move volumes of air. Even though there are some modern small drivers with surprising amounts of linear excursion, they just cannot move far enough to make up for their small cone areas. Another downside of long excursion drivers is that the cone's effective area decreases when larger surrounds are utilized to achieve larger excursions.

Remember that if you double a driver cone's diameter, you get four times the area so you can live with a quarter the excursion for the same displacement. In any case, you must have some combination of drivers that have enough combined cone area and excursion to achieve the volume displacements needed. In most cases, at very low frequencies you generally run out of excursion before you run out of amplifier power even with low sensitivity drivers.

As frequencies go up and excursion requirements decrease, amplifier power can become a factor. I have had situations where a 1,200 W/channel amplifier clipped while trying to reproduce realistic levels on a kick drum with drivers of 84-dB sensitivity. The bad news is that most people don't commit that kind of power to a subwoofer, and even then, it is still insufficient. Multiple drivers can help but if you drive them in parallel from the same amplifier, beware of potentially damaging low impedances.

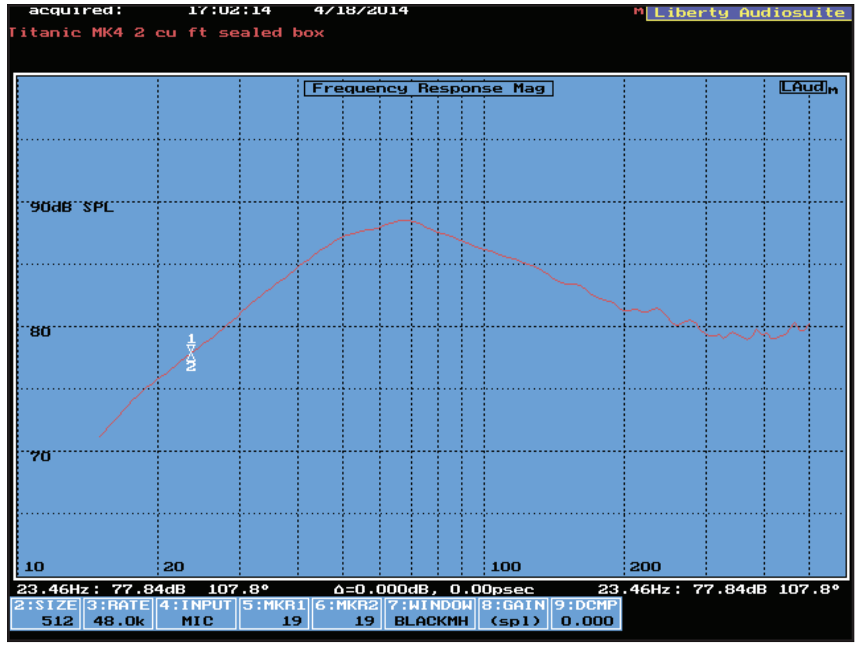

Figure 4: The Dayton Audio Titanic MK4 12" driver's frequency response is measured in a 2-ft³ enclosure.

Test Conditions

In the tests conducted below, a Crown Studio Reference amplifier was used that can produce a measured 1,200 W/channel into a 4-Ω load to minimize any amplifier limitations. All three drivers were tested for performance in their respective enclosures for frequency response, F_B, Q_B, and distortion at a 100-dB level. Measurements were close miked using an ACO Pacific 7012 microphone capsule with a 4012 preamp and a PS9200 power supply. That microphone has a flat response to below

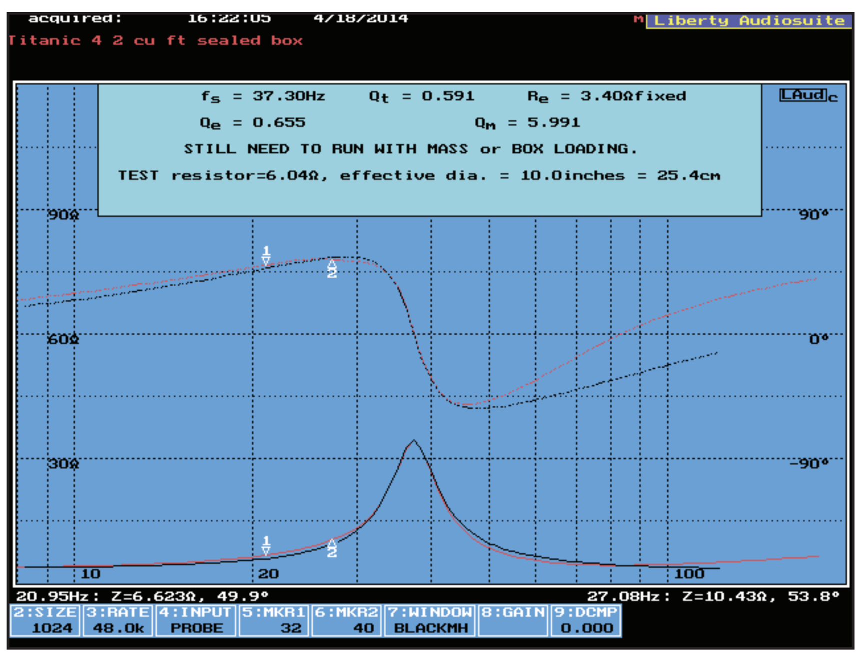

Figure 5: The Dayton Audio Titanic MK4 12" driver's T-S parameters are provided.

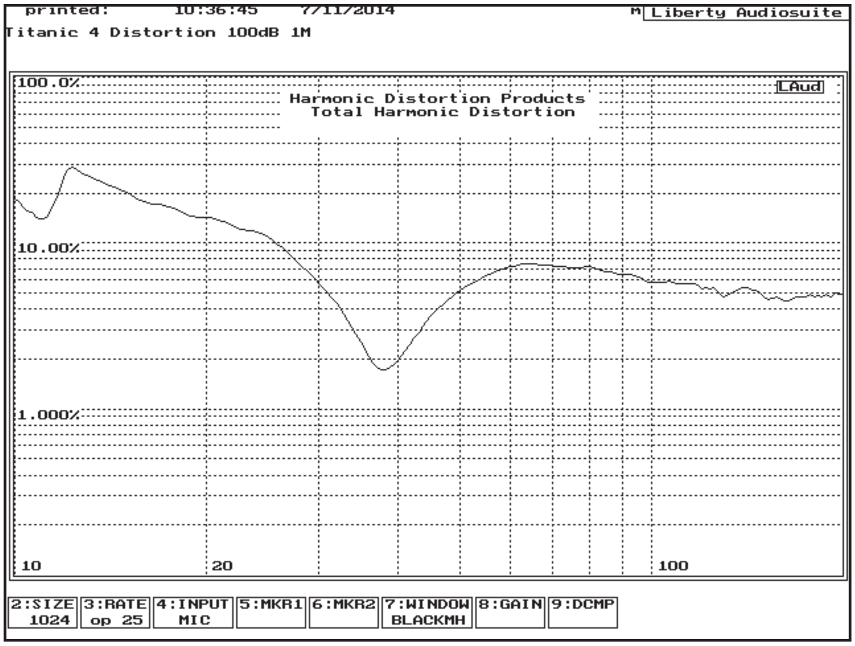

Figure 6: The Dayton Audio Titanic MK4 12″ driver's THD is measured at 100 dB at 1 m.

10 Hz. All the results are straight with no smoothing. Note that most published curves use at least 1/3 octave smoothing, making them look better.

The Factors

When deciding on a direction, you must weigh several factors including how low you want to go, how loud you want to play, the room size, the enclosure sizes, and the cost. In my case, I already had a pair of subwoofers so I had an idea of the volume displacement I needed. The decision was whether I should expand on the current subwoofers or start over. I started by testing the three drivers to assess their capabilities using Liberty Audiosuite (LAUD), the test suite from Liberty Instruments, Inc.

I used the 5-ft^3 enclosures I already had to test the 15″ DVC drivers. To test the Ultimax and Titanic drivers, I used two of the 2-ft^3 breakdown cabinets from Parts Express. This cabinet kit was designed specifically for the Ultimax 12″ and is a great way for someone without a lot of woodworking tools and experience to get started in the hobby. Note that you will still need clamps to perform the assembly. At first, it seems like the size difference between the large and small enclosures should be substantial but the dimensions were 24″ × 24″ × 18″ compared to 19″ × 16″ × 18″. That is a difference of 5″ in height and 8″ in width because the volume change is the cube of the differences in the three dimensions.

Ultimax 12″

For a dynamic driver, the Ultimax is quite interesting (see **Photo 1**). It has several features designed to give it a lot of linear excursion, which is a very large 19 mm. Instead of one spider, there are two to prevent rocking of the cone/voice coil assembly at large excursions. The "Tall-boy" rubber surrounds allow greater range of motion than conventional surrounds. Nomex honeycomb cones covered with fiberglass prevent bending under high forces. Other features minimize total distortion. The one drawback to this otherwise outstanding driver

Resources

Loudspeaker Nonlinearities-Causes, Parameters, Symptoms, www.klippel.de/uploads/media/Loudspeaker_Nonlinearities%E2%80%93Causes_Parameters_Symptoms_01.pdf.

T. Perazella, "True Bass," *Speaker Builder*, Volume 5, 1996.

———, "Tips to Resurrect a Classic Speaker or Design a New System, Part 1", *audioXpress*, November 2013.

———, "Tips to Resurrect a Classic Speaker or Design a New System, Part 2", *audioXpress*, December 2013.

———, "Tips to Resurrect a Classic Speaker or Design a New System, Part 3", *audioXpress*, January 2014.

Sources

7012 microphone capsule, a 4012 preamp, and a PS9200 power supply
ACO Pacific, Inc. | www.acopacific.com

Liberty Audiosuite (LAUD) test suite
Liberty Instruments, Inc. | www.libinst.com

Keiga plate amp
Madisound Speaker Components, Inc. | www.madisoundspeakerstore.com/keiga-amplifiers/keiga-kg5230-300-watt

Dayton Audio DVC 15
Parts Express | www.parts-express.com/dayton-audio-dvc385-88-15-dvc-series-subwoofer--295-190

12″ Ultimax subwoofer
Parts Express | www.parts-express.com/dayton-audio-um12-22-12-ultimax-dvc-subwoofer-2-ohms-per-coil--295-512

Titanic Mk 4
Parts Express | www.parts-express.com/dayton-audio-ts320d-4-12-titanic-mk-4-subwoofer-4-ohm--295-403

2-ft^3 Knockdown cabinet
Parts Express | www.parts-express.com/knock-down-mdf-20-cu-ft-subwoofer-cabinet-for-dayton-audio-12-ultimax-sub-woofer--300-7081

is low sensitivity. At 84 dB/W, it takes a lot of power to achieve the high levels of performance available from this driver. Fortunately, it can handle almost anything you can throw at it with a continuous power rating of 600 W and a maximum of 1,200 W.

Figure 1 shows this driver's frequency response. You will notice that the curve is very smooth with only a little ripple as the frequency exceeds 200 Hz, which is an area beyond normal subwoofer use.

Figure 2 shows the basic Thiele-Small (T-S) parameters. The box resonance is a very low 30 Hz and the Q is a very respectable 0.64. There are also no ripples in the impedance curve. This is great performance for a 12″ woofer in such a small box.

Figure 3 shows the distortion measurements. Actually, I was quite surprised with the low figures I got at 100 dB. Although not a high level for testing at higher frequencies, it is unusual for a speaker to do well at this level at low frequencies. Above resonance, the distortion is in the 1–3% range. The driver is well within its linear limits at this point. Below resonance, the distortion climbs in a fairly linear fashion to a peak of just under 50%, around 13 Hz. Although that may seem like a lot, it is better than average for a typical 12″ driver driven to this level and frequency. It does confirm that really low frequencies at high levels cannot

Photo 3: This is the Dayton Audio DVC 15″ driver's front view.

Driver Displacement Calculation Table										
Driver	Area	X_{MAX}	Total Linear Excursion	Individual Linear Displacement	Number of Drivers	Total Displacement	Unit Cost	Cost per Liter	Total Cost	Cost Using Existing Drivers
Original DV12 12″	610 cm²	10.5 mm	2.1 cm	1.3 ltr	8	10.2 ltr	N/A	N/A	N/A	N/A
Dayton UM12-22 Ultimax 12″	491 cm²	19 mm	3.8 cm	1.9 ltr	6	11.2 ltr	$179.90	$96.42	$1,079.40	N/A
Dayton TS320D-4 Titanic MK4 12″	498 cm²	19 mm	3.8 cm	1.9 ltr	6	11.4 ltr	$169	$89.30	$1,014	N/A
Dayton DVC385-88 DVC 15″	830 cm²	15 mm	3 cm	2.5 ltr	4	10 ltr	$132.86	$53.36	$531.44	$265.72

Table 1: I have created my own driver selection parameter table to help me decide my system's design.

be handled by a single 12″ driver no matter how capable it may be. While running this test, the fans on the Crown ran at a conspicuous level indicating the high power level being delivered to achieve the needed acoustic output.

12″ Titanic MK 4

Based on the very successful Titanic woofer series, the MK 4 represents the culmination of all the things learned in the previous versions (see **Photo 2**). These subwoofers were always known for exceptional value and high performance. But, the new 12″ goes even further with an increase to 19-mm X_{MAX}, equaling the Ultimax 12″. Add a stronger motor, power handling of 500 W average, and 1,000 W maximum, and you have a very competent driver. Another plus to this driver is a higher sensitivity of 86.6 dB/W. That means, it can produce virtually the same levels as the Ultimax with half the power. Made in the US, it has a proven track record for reliability.

Although not quite as flat as the Ultimax in the same box volume, the Titanic has a smoother response with fewer ripples (see **Figure 4**).

Analysis of the T-S parameters shown in **Figure 5** reveals a resonance of 37.3 Hz and a Q of 0.6. This box was not optimized for the Titanic but it still performed well. The cutout for the driver was also a little small to accept the large and nice rubber ring on the Titanic basket. I removed the ring, and then the driver fit with no problem. This driver really deserves a box specifically designed for it.

Figure 6 shows the Titanic's distortion figures, which were really quite low for a 12″ driver at this high level at lower frequencies. In fact, the distortion only rose to around 30% at 13 Hz and dropped below 2% around 38 Hz, besting the Ultimax by quite a bit. However, it rose to around 7% at 65 Hz, which was not as good as the Ultimax.

Dayton Audio DVC385-88 15″

This driver is a real sleeper (see **Photo 3**). It does not have all the fancy cosmetics that grab your attention when you look at it. The basket is stamped-steel painted black. The cone looks much like any other cone, although it is actually Kevlar impregnated paper. The terminals on the newer versions have improved from the early editions and are now quite substantial. Power handling is 350 W average and 700 W maximum. The sensitivity, however, rocks at 90 dB/W. To develop the same acoustical output, the Ultimax will need four times the power than this driver and the Titanic will need twice.

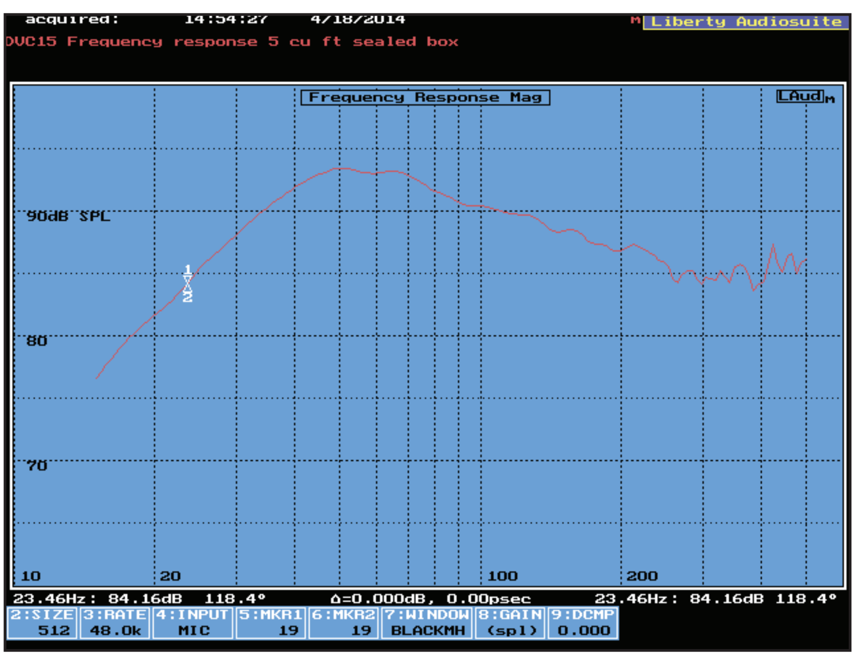

Figure 7: The Dayton Audio DVC 15″ driver's frequency response is measured using a 5-ft³ enclosure.

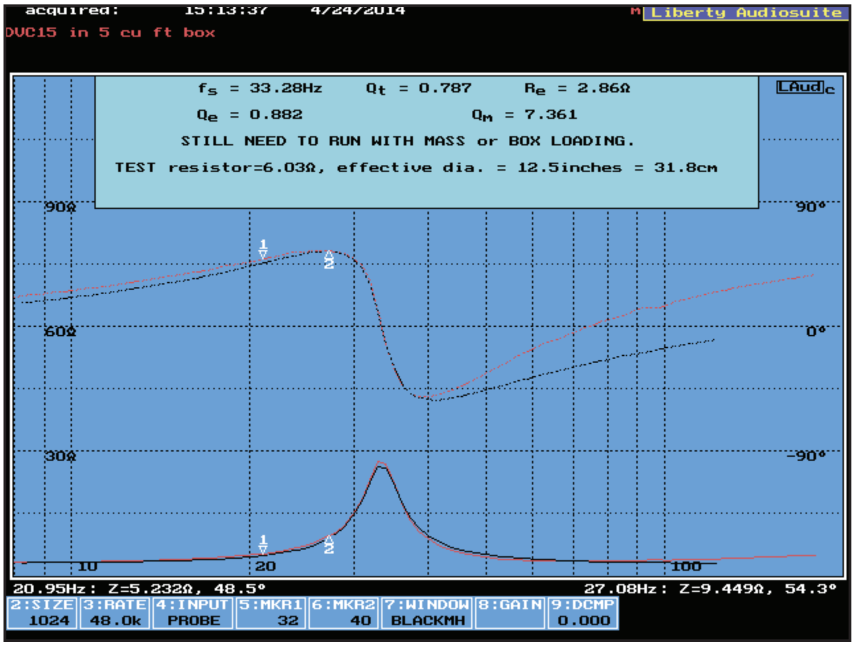

Figure 8: The Dayton Audio DVC 15″ driver's T-S parameters are provided.

Before getting into its measurements, a bit of a detour is necessary. That is because comparing this driver to the other two is in some ways the proverbial comparison of apples to oranges. For starters, it requires a much larger box. It has significantly more linear volume displacement. The cost is also lower, especially when compared on a volume per dollar basis. However, comparing them does give a better idea of the tradeoffs you make, so here goes.

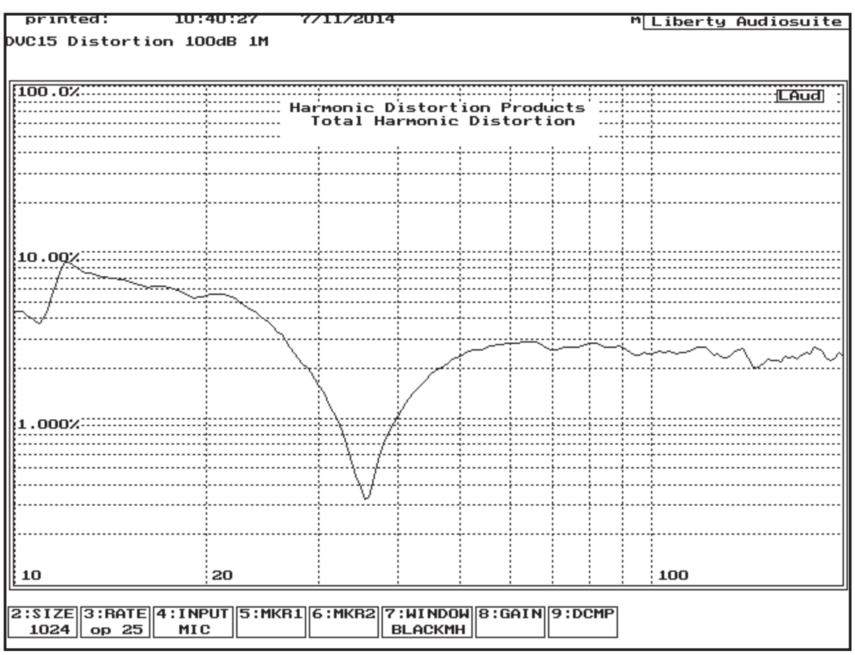

Figure 9: Dayton Audio DVC 15″ driver's THD is measured at 100 dB at 1 m.

A good way to see the differences in "decision" parameters is to create a table listing the things that will help you make the right choice. **Table 1** shows the data, which compares the physical parameters such as cone area and linear displacement to develop total linear displacement per driver. It also compares the drivers to the original driver I used in my Chicago sound system.

From this information, the total number of each driver is calculated to equal the displacement I had in the original system and also the cost to duplicate it. You will note in the last column that the use of my current subwoofers halves the cost as I already have two drivers. However, the table does not include the box or amplifier costs. If you are building your own boxes, the differences in box supplies are not that great between the larger and smaller versions. But, differences in amplifier cost to power the lower sensitivity drivers can be larger.

Table 1's first column identifies the driver. The second column gives the effective area of the cone. Remember that although large surrounds allow more excursion, they also reduce the effective area of the cone. That is why the areas of the 12″ drivers vary. X_{MAX} is given in **Table 1**'s third column. The total linear excursion in both directions is given in the fourth column. From the area and total excursion you can determine the total displacement in liters of each driver as shown in column five.

Table 1's sixth column starts getting into the meat of the subject. It determines, based on linear displacement of each driver, how many drivers would be needed to match the original system. To match the original eight, you would need six of the 12″ Ultimax drivers, six of the 12″ Titanic drivers, or four of the 15″ Daytons. The seventh column lists each driver's unit price at the time of writing. The eighth column shows the cost per liter. The ninth column is interesting because it shows the total cost for drivers if you were starting from scratch.

Table 1's 10th column shows my actual cost because I already have two of the 15″ Daytons. On a strictly cost basis, the choice is a no brainer. Expanding with the current 15″ Daytons is by far more cost effective. Even starting from scratch, using them would be roughly half the price of the other drivers so I decided to expand my system using the same 15″ drivers.

Next are the measurements. **Figure 7** shows the Dayton's frequency response. It is reasonably flat with a slight flattening around 60 Hz and a few out of pass band ripples above 200 Hz. **Figure 8** shows the T-S parameters. The resonance is a little over 33 Hz and the Q is 0.787. This is a good compromise between box size and performance.

Photo 4: For comparison, the Titanic MK4 12″ (a), the DVC 15″ (b), and the Ultimax 12″ (c) are shown side-by-side.

Figure 9 shows the distortion measurements. The distortion is very low compared to the other drivers at the lower frequencies and never exceeded 10%. You will note that once above 27 Hz, the distortion never goes above 3% and at one point drops to 0.4%. The advantage of this driver's additional linear volume displacement is very evident. For comparison purposes, all three drivers are shown in **Photo 4**.