Test Bench

Home Audio Drivers from Dayton Audio, SB Acoustics, and Wavecor

By Vance Dickason

All three transducers submitted for this month's Test Bench are intended for home audio applications. From Dayton Audio, I received the ES140Ti-8 5.5" midwoofer, which is another model from its new Esoteric line. From SB Acoustics, I received the SB65WBAC25-4, a new 2.5" full-range device. And, Wavecor sent the TW030WA12, a new 30-mm cloth waveguide loaded tweeter.

The ES140Ti-8

The first driver I tested was the 5.5" ES140Ti-8. It is the companion model to the Dayton Audio Esoteric 7" ES180Ti-8 midwoofer, which was featured in *Voice Coil's* December 2014 issue. Features for the ES-140Ti are similar to the ES-180Ti and include a well-configured proprietary six-spoke cast-aluminum frame with narrow 9-mm wide spokes to minimize reflections back into the cone (see **Photo 1**).

The area below the suspended spider mounting shelf is almost completely open, resulting in effective cooling of the motor and voice coil. For the cone assembly, Dayton Audio chose a rather stiff flat-profile woven glass fiber cone with a 2.75" diameter convex woven glass fiber dust cap. Compliance is provided by a nitrile-butadiene rubber (NBR) surround, nicely designed with a shallow discontinuity where it attaches to the cone edge. Remaining compliance comes from a 4.5" diameter elevated black cloth spider.

The Dayton Audio ES140Ti-8's motor design is well thought out and incorporates dual copper shorting rings (Faraday shields) and a neodymium ring magnet. Finite Element Analysis (FEA) designed, the neodymium magnet motor uses a 3" (76-mm) diameter voice coil wound with rectangular copper-coated aluminum wire (CCAW) on a titanium former (hence the ES140Ti designation). Motor parts include a polished chrome return cup for the neodymium ring magnet that incorporates a 35-mm diameter rear vent (with an open-cell foam dust cover) for additional cooling. Last, the voice coil is terminated to a pair of gold-plated terminals. In terms of physical appearance, this is a very good-looking driver.

Photo 1: The ES140Ti-8 is a 5.5" midwoofer from Dayton Audio's new Esoteric line.

I used the LinearX LMS analyzer and VIBox to create voltage and admittance (current) curves with the driver clamped to a rigid test fixture in free air at 0.3, 1, 3, 6, and 10 V. Unlike a majority of 5.25" to 5.5" diameter woofers, 10-V curves are usually too nonlinear for LEAP to get a reasonable curve fit. However, that was not the case for the ES140Ti-8. I was able to use all the curves including the 10-V curves. As has become the protocol for Test Bench testing, I no longer use a single added mass measurement to determine V_{AS}. I use the actual measured cone assembly mass (Mmd) supplied by the driver manufacturer, which was 16.5 grams for the Dayton 5.5" woofer.

Next, I post processed the 10 550-point stepped sine wave sweeps for each ES140Ti sample and divided the voltage curves by the current curves (admittance) to derive impedance curves, phase added by the LMS calculation method. I imported them, along with the accompanying voltage curves, to the LEAP 5 Enclosure Shop software.

Since most Thiele-Small (T-S) data provided by the majority of OEM manufacturers is generated using the standard model or the LEAP 4 TSL model, I used 1-V free-air curves to additionally create a LEAP 4 TSL parameter set. I selected the complete data set, the LTD model's multiple voltage impedance curves, and the TSL model's 1-V impedance curve in the LEAP 5's transducer derivation menu and created the parameters for the computer box simulations. **Figure 1** shows the 1-V free-air impedance curve. **Table 1** compares the LEAP 5 LTD, TSL, and factory published parameters for both Dayton Audio ES140Ti-8 samples.

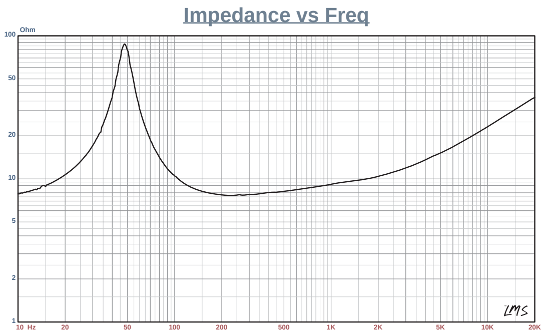

Figure 1: Dayton Audio ES140Ti-8 midwoofer 1-V free-air impedance plot

LEAP parameter calculation results for the ES140Ti-8 were, as with the ES180Ti last month, very close to the published factory data. Following my normal protocol for Test Bench testing, I used the LEAP LTD parameters for Sample 1 to set up computer enclosure simulations. I programmed two computer box simulations in LEAP 5—a Butterworth-type sealed enclosure with a 278 in^3 volume with 50% fiberglass fill material and a vented QB3 with a 503 in^3 volume tuned to 44 Hz with 15% fiberglass damping material.

	TSL Model		LTD Model		Factory
	Sample 1	Sample 2	Sample 1	Sample 2	
F_S	50 Hz	47.7 Hz	47 Hz	45.6 Hz	49 Hz
R_{EVC} (series)	6.23	6.46	6.23	6.46	6.25
Sd	95 cm^2	95 cm^2	95 cm^2	95 cm^2	98.5 cm^2
Q_{MS}	6.62	6.10	7.11	6.57	6.64
Q_{ES}	0.48	0.48	0.47	0.48	0.45
Q_{TS}	0.44	0.44	0.44	0.45	0.4
V_{AS}	7.9 ltr	8.4 ltr	8.7 ltr	9.2 ltr	8.1 ltr
SPL 2.83 V	84.8 dB	84.7 dB	84.7 dB	84.4 dB	84.5 dB
X_{MAX}	5 mm	5 mm	5 mm	5 mm	5 mm

Table 1: Dayton Audio ES140Ti-8 woofer comparison data

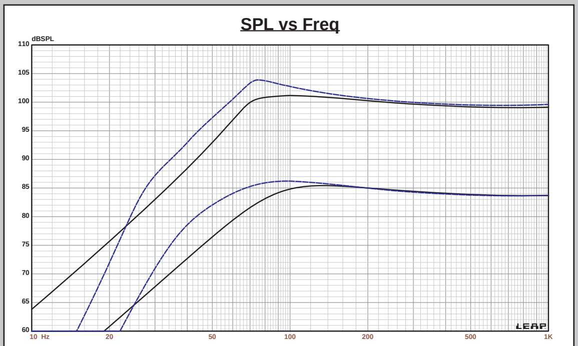

Figure 2: Dayton Audio ES140Ti-8 computer box simulations (black solid = vented at 2.83 V, blue dash = sealed at 2.83 V, black solid = vented at 19.5 V, and blue dash = sealed at 21 V)

Figure 2 shows the ES140Ti-8's results in the vented and sealed boxes at 2.83 V and at a voltage level sufficiently high enough to increase cone excursion to 5.75 mm (X_{MAX} + 15%). This produced a F3 frequency of 74 Hz (F6 = 60.2 Hz) with a Q_{TC} = 0.68 for the Butterworth sealed enclosure and –3 dB = 55 Hz (F6 = 43.8 Hz) for the vented QB3 alignment.

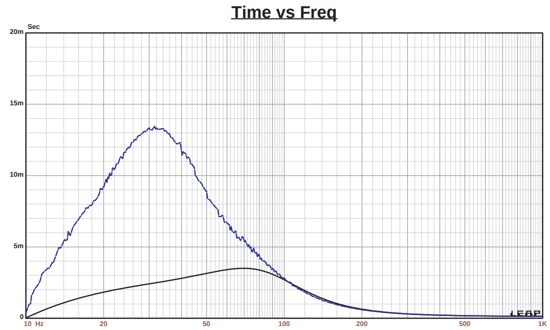

Figure 3: Group delay curves for the 2.83-V curves in Figure 2

Figure 4: Cone excursion curves for the 19.5/21-V curves in Figure 2

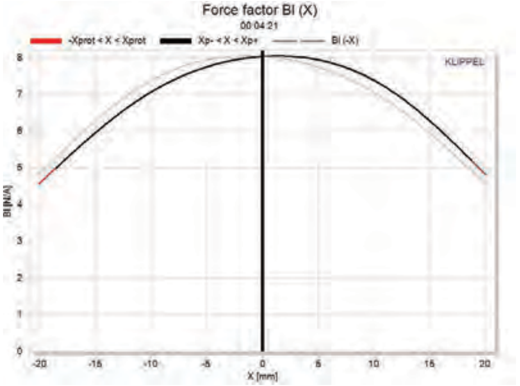

Figure 5: Klippel analyzer Bl(X) curve for the Dayton Audio ES140Ti-8

Increasing the voltage input to the simulations until the maximum linear cone excursion was reached resulted in 101 dB at 19.5 V for the closed-box enclosure simulation and 104 dB for a 21-V input level for the larger vented box. **Figure 3** shows the 2.83-V group delay curves. **Figure 4** shows the 19.5/21-V excursion curves. Because the vented box example reached 11 mm of excursion at about 25 Hz (twice the X_{MAX} number), adding a steep 24 dB/octave high-pass active filter located about 25 to 30 Hz would prevent over excursion and distortion for vented box example by a substantial margin.

Klippel analysis for the ES140Ti-8 produced the Bl(X), K_{MS}(X), and Bl and K_{MS} symmetry range plots shown in **Figures 5–8**. (Our analyzer is provided courtesy of Klippel GmbH. Pat Turnmire, of Redrock Acoustics, performs the tests. This data is extremely valuable for transducer engineering, so if you don't own a Klippel analyzer and want analysis done on a particular project, visit www.redrockacoustics.com.)

The ES140Ti-8's Bl(X) curve is very symmetrical and has a rather broad Bl curve for a 5.5" woofer (see **Figure 5**). The Bl symmetry plot shows a fairly constant coil-out offset that reaches about 1.2 mm at the driver's physical X_{MAX} position, which is trivial and probably within production tolerance (see **Figure 6**). **Figure 7** and **Figure 8** show the ES140Ti-8's K_{MS}(X) and K_{MS} symmetry range curves. The K_{MS}(X) curve is definitely not as symmetrical in both directions as the Bl curve, but it shows a decreasing coil-out offset that gets to about 0.62 mm at the physical X_{MAX} position, which is also relatively minor.

The ES140Ti-8's displacement limiting numbers were XBl at 82% (Bl = 12.4 mm) and for XC at 75%, C_{MS} minimum was 11.9 mm, which means the compliance is the most limiting factor for prescribed

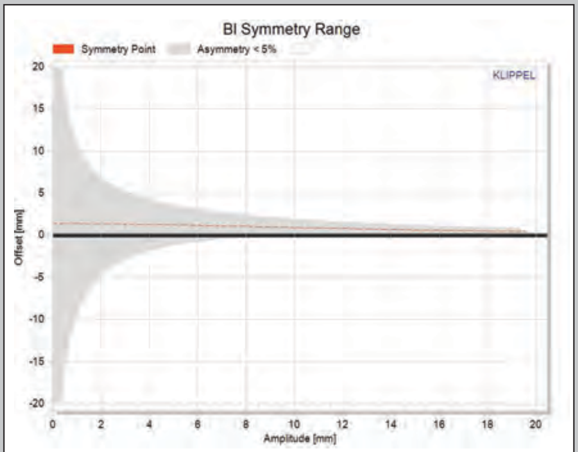

Figure 6: Klippel analyzer Bl symmetry range curve for the Dayton Audio ES140Ti-8

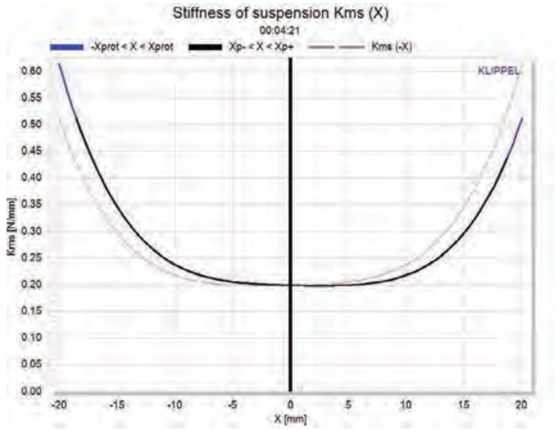

Figure 7: Klippel analyzer mechanical stiffness of suspension K_{MS}(X) curve for the ES140Ti-8

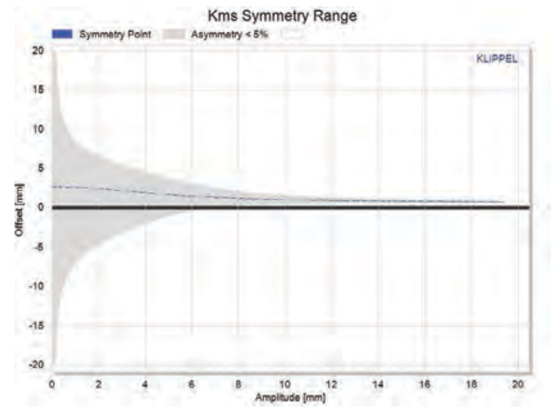

Figure 8: Klippel analyzer K_{MS} symmetry range curve for the Dayton Audio ES140Ti-8

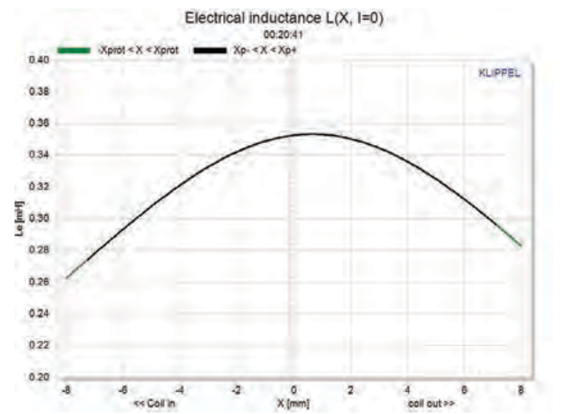

Figure 9: Klippel analyzer L(X) curve for the Dayton Audio ES140Ti-8

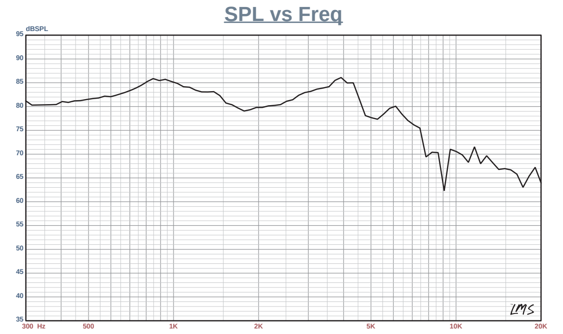

Figure 10: Dayton Audio ES140Ti-8 on-axis frequency response

distortion level of 10%. However, both numbers were significantly greater than this driver's physical X_{MAX}.

Figure 9 shows the ES140Ti-8's inductance curves Le(X). Inductance will typically increase in the rear direction from the zero rest position as the voice coil covers more pole area. However, this does not occur because of the effective multiple copper inductive shorting rings. The result is a minor inductance swing with an inductive variation of 0.03 to 0.05 mH from the resting position to the in and out X_{MAX} positions, which is good performance in any driver.

Following the Klippel testing, I mounted the ES140Ti-8 woofer in an enclosure with a 15" × 8" baffle filled with damping material (foam). Then, I used the LinearX LMS analyzer set to a 100-point gated sine wave sweep to measure the device under test (DUT) on and off axis from a 300-Hz-to-40-kHz frequency response at 2.83 V/1 m.

Figure 10 shows the ES140Ti-8's on-axis response indicating a smoothly rising response to about 900 Hz, dropping about 6 dB to 2 kHz, and rising again to about 4 kHz, where it begins its low-pass roll-off. **Figure 11** displays the on- and off-axis frequency response at 0°, 15°, 30°, and 45°. The –3 dB frequency at 30° off axis relative to the on-axis sound pressure level (SPL) is about 2.8 kHz, suggesting a crossover between 2 to 3 kHz should be appropriate. **Figure 12** provides the ES140Ti-8's two-sample SPL comparisons, showing a 0.5-to-1-dB match throughout the operating range up to 4 kHz.

For the remaining tests, I used the Listen SoundCheck software, SoundConnext analyzer, and SCM microphone (courtesy of Listen) to measure distortion and generate time-frequency plots. For the distortion measurement, I mounted the ES140Ti-8 in free air and used the noise stimulus to set the SPL to 94 dB at 1 m (12.6 V). Then, I measured the distortion with the Listen microphone

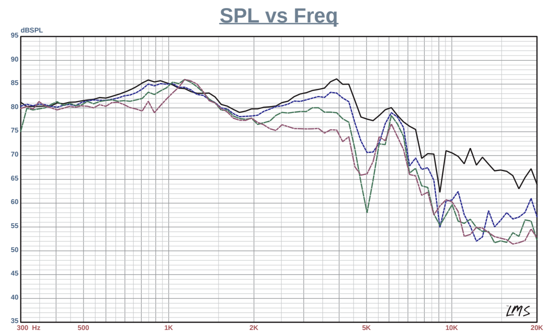

Figure 11: Dayton Audio ES140Ti-8 on- and off-axis frequency response (black solid = 0°, blue dot = 15°, green dash = 30°, purple dash dot = 45°)

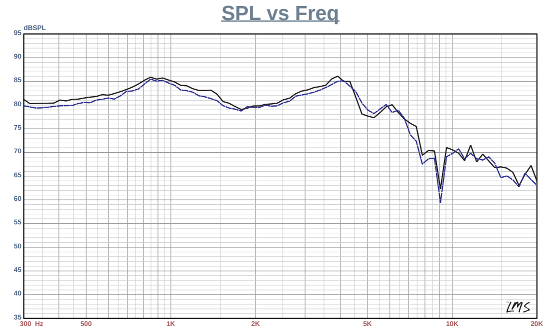

Figure 12: Dayton Audio ES140Ti-8 midwoofer two-sample SPL comparison

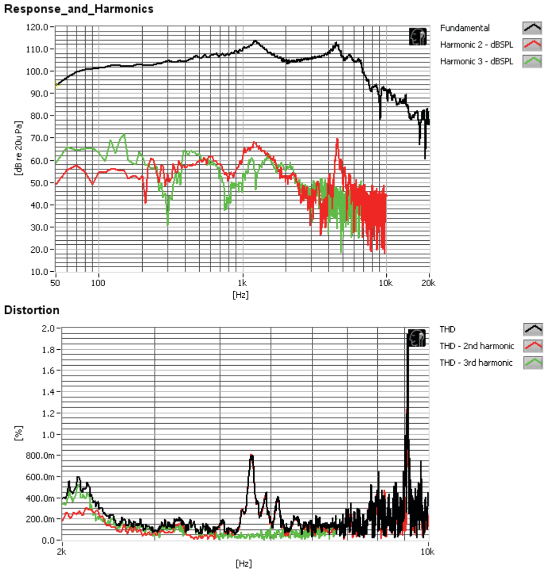

Figure 13: Dayton Audio ES140Ti-8 SoundCheck distortion plot

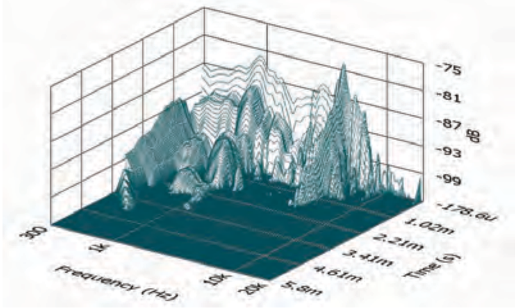

Figure 14: Dayton Audio ES140Ti-8 woofer SoundCheck CSD waterfall plot

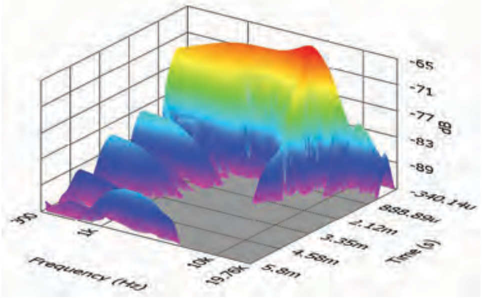

Figure 15: Dayton Audio ES140Ti-8 midwoofer SoundCheck Wigner-Ville plot

placed 10 cm from the dust cap.

Figure 13 shows the distortion curves. I then used SoundCheck to get a 2.83-V/1-m impulse response and imported the data into Listen's SoundMap Time/Frequency software. **Figure 14** shows the resulting cumulative spectral decay (CSD) waterfall plot. **Figure 15** shows the Wigner-Ville (for its better low-frequency performance) plot. For more information, visit www.daytonaudio.com.

The SB65WBAC25-4

Unquestionably, the 2" to 2.5" diameter full-range drivers are one of the most used transducers in consumer electronics. They are finding broad use in soundbars, pedestal soundbars (soundbars that contain down firing subwoofers that double as TV stands), docking stations (these are starting to go away), and desktop speakers such as the Sonos products, and portable Bluetooth speakers (e.g., Jambox, Beats, Samsung, Bose, and a million others). Indonesian-based SB Acoustics sent me its entry into this crowded field of play, the new SB65WBAC25-4 (see **Photo 2**).

Photo 2: The SB65WBAC25-4 is a 2.5" full-range driver.

The SB65WBAC25-4 is a 2.5" diameter full-range driver built on a proprietary injection-molded polymer frame that is fully vented below the spider mounting shelf for enhanced cooling. The cone assembly consists of a "dented" aluminum cone. The "dents" were added to improve stiffness, with a 30-mm diameter plastic dust cap, suspended with a NBR surround and a flat cloth spider (damper). For a 2.5" woofer, the SB65WBAC25-4 has a rather large 25.4-mm diameter voice coil wound with round copper wire on a non-conducting vented former, terminated on opposite sides of the cone to solderable gold-plated terminals. Driving the cone assembly is a neodymium motor using a neodymium ring magnet rather than a slug, and a milled return cup.

I used the LinearX LMS analyzer and VIBox to create both voltage and admittance (current) curves with the driver clamped to a rigid test fixture in free air at 0.3, 1, 3, and 6 V. I discarded the 6-V curves as being too nonlinear for LEAP 5 to get a good curve fit. As has become the protocol for Test Bench testing, I no longer use a single added mass measurement. Instead, I use actual measured mass, and the manufacturer's measured Mmd data (2.45 grams). Next, I post processed the six 550-point stepped sine wave sweeps for each of the SB65WBAC25-4 samples and divided the voltage curves by the current curves (admittance) to produce the impedance curves, phase generated by the LMS

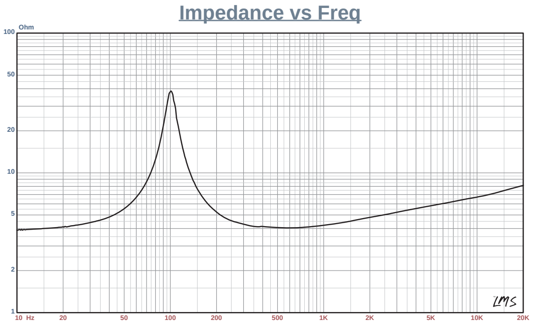

Figure 16: SB Acoustics SB65WBAC25-4 1-V free-air impedance plot

	TSL Model		LTD Model		Factory
	Sample 1	Sample 2	Sample 1	Sample 2	
F_S	101.2 Hz	100.4 Hz	103.1 Hz	102.1 Hz	115 Hz
R_{EVC} (series)	3.72	3.71	3.72	3.71	3.6
Sd (cm2)	19.6	19.6	19.6	19.6	20
Q_{MS}	6.92	6.81	6.54	5.88	6
Q_{ES}	0.71	0.73	0.88	0.85	0.77
Q_{TS}	0.54	0.55	0.52	0.54	0.43
V_{AS}	0.54 ltr	0.55 ltr	0.52 ltr	0.54 ltr	0.43 ltr
SPL 2.83 V	80.9 dB	80.7 dB	80 dB	801.1 dB	83.5 dB
X_{MAX}	2.65 mm	2.65 mm	2.65 mm	2.65 mm	2.65 mm

Table 2: SB Acoustics SB65WBAC25-4 full-range driver comparison data

calculation method. I imported them, along with the accompanying voltage curves, to the LEAP 5 Enclosure Shop software. Since most T-S data provided by OEM manufacturers is produced using either a standard method or the LEAP 4 TSL model, I used 1-V free-air curves to additionally create a LEAP 4 TSL model. I selected the complete data set, the LTD model's multiple voltage impedance curves, and the TSL model's 1-V impedance curve in LEAP 5's transducer derivation menu. Then, I created the parameters for the computer box simulations. **Figure 16** shows the 1-V free-air impedance curve. **Table 2** compares the LEAP 5 LTD, the TSL data, and the factory parameters for both of the SB65WBAC25-4 samples.

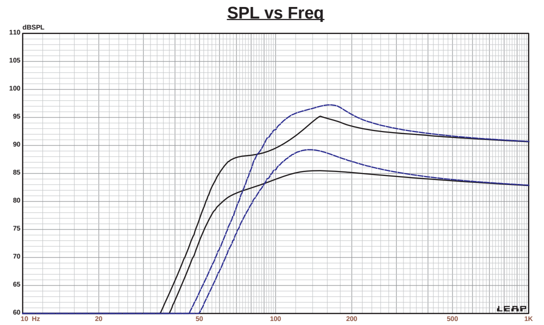

Figure 17: SB Acoustics SB65WBAC25-4 computer box simulations (black solid = vented at 2.83 V, blue dash = sealed at 8 V, black solid = vented at 8 V, and blue dash = sealed at 21 V)

LEAP TSL parameter calculation results for the SB65WBAC25-4 were reasonably close to the factory data. However, the Q_{TS} for the LTD multi-voltage parameters exhibited a somewhat higher number. Next, I followed my usual protocol and used the LEAP LTD parameters for Sample 1 to set up computer enclosure simulations. I programmed two vented enclosure simulations into LEAP—an 89-in^3 Chebychev/Butterworth-type vented alignment tuned to 65 Hz (with 15% damping material) and a 63-in^3 vented enhanced Q Butterworth alignment (with 15% damping material in the box) tuned to 103 Hz.

Figure 17 shows the SB65WBAC25-4's results in the two vented box simulations at 2.83 V and at a

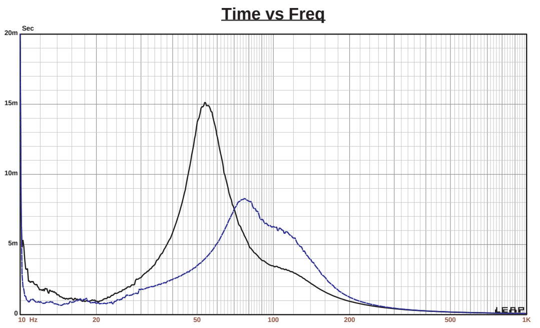

Figure 18: Group delay curves for the 2.83-V curves in Figure 17

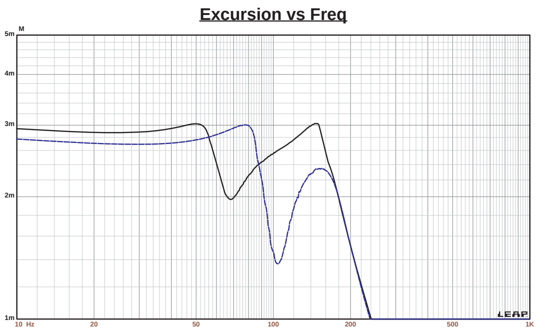

Figure 19: Cone excursion curves for the 8-V curves in Figure 17

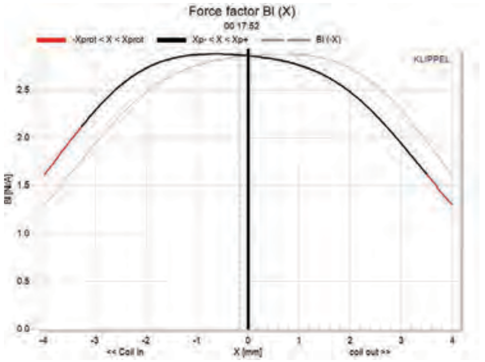

Figure 20: Klippel analyzer Bl(X) curve for the SB Acoustics SB65WBAC25-4

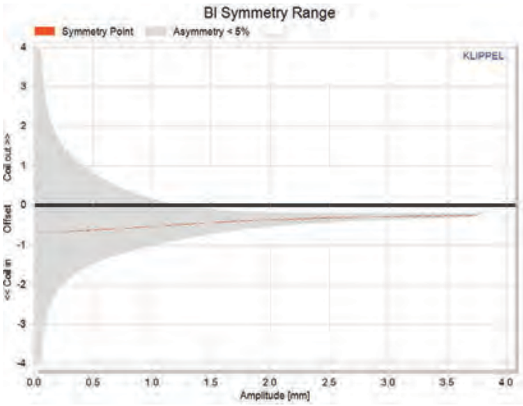

Figure 21: Klippel analyzer Bl symmetry range curve for the SB Acoustics SB65WBAC25-4

voltage level sufficiently high enough to increase cone excursion to 3 mm (X_{MAX} + 15%). This produced a F3 frequency of 80.7 Hz (F6 = 60 Hz) for the 89-in^3 Chebychev/Butterworth enclosure and –3 dB = 102 Hz for the 63-in^3 enhanced Q Butterworth vented simulation. Increasing the voltage input to the simulations until reaching the maximum linear cone excursion resulted in 95 dB at 18 V for the Chebychev/Butterworth enclosure simulation and 97 dB with an 8-V input level for the enhanced Q Butterworth vented enclosure. **Figure 18** shows 2.83-V group delay curves. **Figure 19** shows the 8-V excursion curves.

The SB65WBAC25-4's Klippel analysis produced the Bl(X), K_{MS}(X), and Bl and K_{MS} symmetry range plots shown in **Figures 20–23**. **Figure 20** shows the SB65WBAC25-4's Bl(X) curve is relatively broad and fairly symmetrical with some "tilt" to the curve, but not bad for a short X_{MAX} 2.5" diameter driver. **Figure 21** shows the Bl symmetry plot with a minor coil-in (rearward) offset at the rest position that decreases to 0.29 mm at the driver's physical 2.65-mm X_{MAX}.

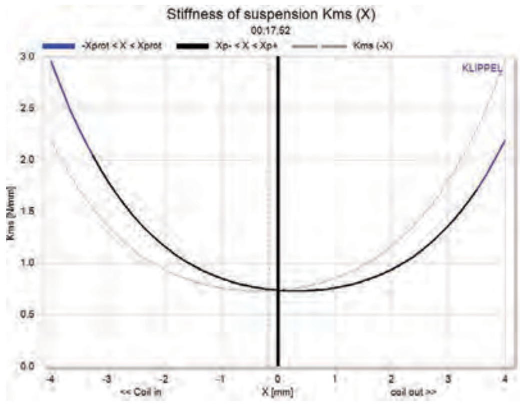

Figure 22: Klippel analyzer mechanical stiffness of suspension K_{MS}(X) curve for the SB Acoustics SB65WBAC25-4

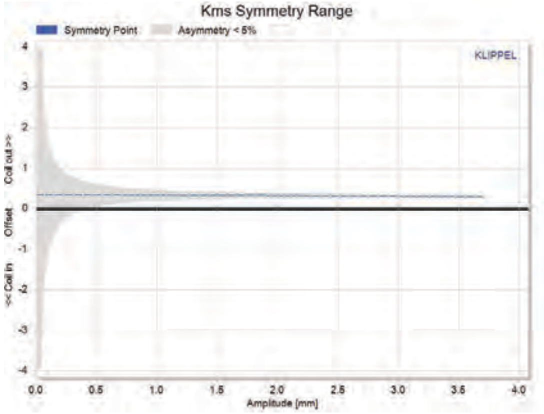

Figure 23: Klippel analyzer K_{MS} symmetry range curve for the SB Acoustics SB65WBAC25-4

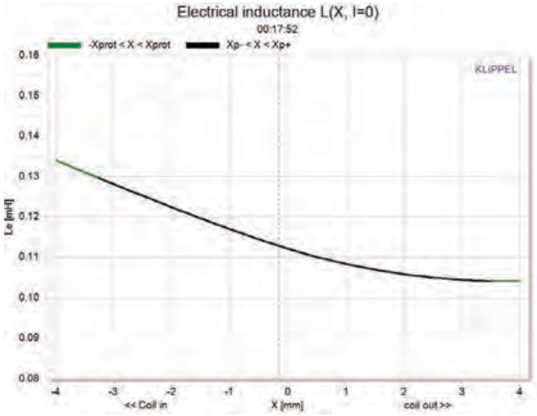

Figure 24: Klippel analyzer L(X) curve for the SB Acoustics SB65WBAC25-4

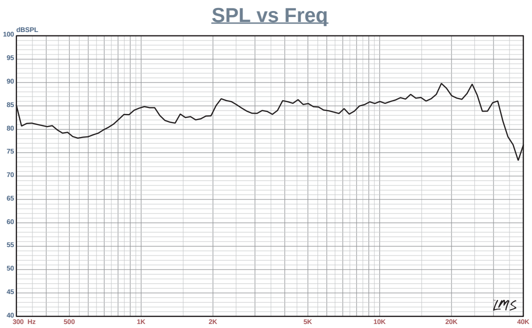

Figure 25: SB Acoustics SB65WBAC25-4 on-axis frequency response

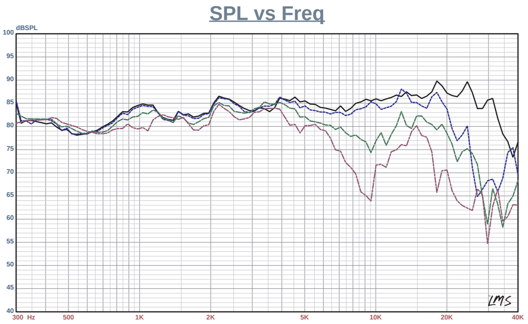

Figure 26: SB Acoustics SB65WBAC25-4 on- and off-axis frequency response (black solid = 0°, blue dot = 15°, green dash = 30°, purple dash dot = 45°)

Figure 22 and **Figure 23** show the $K_{MS}(X)$ and K_{MS} symmetry range curves. The $K_{MS}(X)$ curve is also moderately symmetrical and has a very minor forward (coil-out) offset at the rest position, staying mostly constant to about 0.36 mm at the physical X_{MAX} position. The SB65WBAC25-4's displacement limiting numbers were XBl at 82% (Bl is 2.9 mm) and for XC at 75%, C_{MS} minimum was 2.6 mm, which means that compliance is the most limiting factor for a prescribed distortion level of 10%.

Figure 24 shows the SB65WBAC25-4's inductance curve Le(X). Inductance will typically increase in the rear direction from the zero rest position as the voice coil covers more pole area, which is what happens. However, the SB65WBAC25-4's inductance variation is only 0.014 to 0.007 mH from the in and out X_{MAX} positions, which is very good.

Next, I mounted the SB65WBAC25-4 in an enclosure that had a 9"× 4" baffle filled with damping material (foam). Then, I used the LinearX LMS analyzer set to a 100-point gated sine wave sweep and measured the transducer on and off axis from a 300-Hz-to-40-kHz frequency response at 2.83 V/1 m.

Figure 25 shows the SB65WBAC25-4's on-axis response, indicating a smoothly rising response all the way out to 30 kHz. The big mistake I think a lot of designers make is not to equalize the upper rise. If you don't, it makes the speaker sound thin and really lacking bottom end. The trade-off, of course, is that the device's apparent loudness decreases. One way to overcome that issue in these small two-driver Bluetooth devices—ones that have the woofers mounted close together with no possibility of any stereo phantom center—is to drive them in parallel as a mono source, thus increasing the product efficiency by 3 dB.

Figure 26 displays the on- and off-axis frequency response at 0°, 15°, 30°, and 45°. The roll-off at 30° off axis is almost as good as a 25–30 dome tweeter, so I would expect this driver's full-range fidelity to be quite good. **Figure 27** shows the SB65WBAC25-4's two-sample SPL comparison, which is a close match to within less than 0.5 to 1 dB throughout the operating range.

For the remaining tests, I used the Listen SoundCheck AmpConnect analyzer with the Listen 0.25" SCM microphone and power supply to measure distortion and generate time-frequency plots. For the distortion measurement, I rigidly mounted the SB65WBAC25-4 in free air and used a noise stimulus to set the SPL to 94 dB at 1 m (7.2 V). Then, I measured the distortion with the microphone placed 10 cm from the dust cap. **Figure 28** shows the distortion curves. I then used SoundCheck to get a 2.83-V/1-m impulse response and imported the data into Listen's SoundMap Time/Frequency software. **Figure 29** shows the resulting CSD waterfall plot. **Figure 30** shows the Wigner-Ville plot. While the intended application for this SB65WBAC25-4 is TV, multimedia, and lifestyle speakers I suggest it would make a great driver for line-source applications. For more information, visit www.sbacoustics.com.

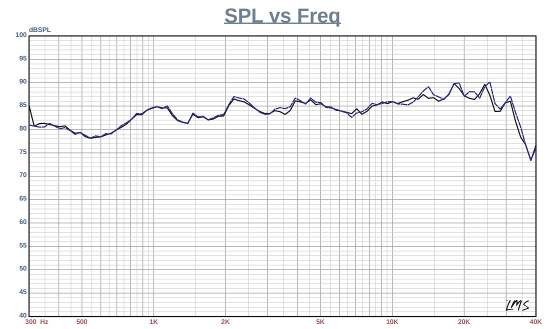

Figure 27: SB Acoustics SB65WBAC25-4 two-sample SPL comparison

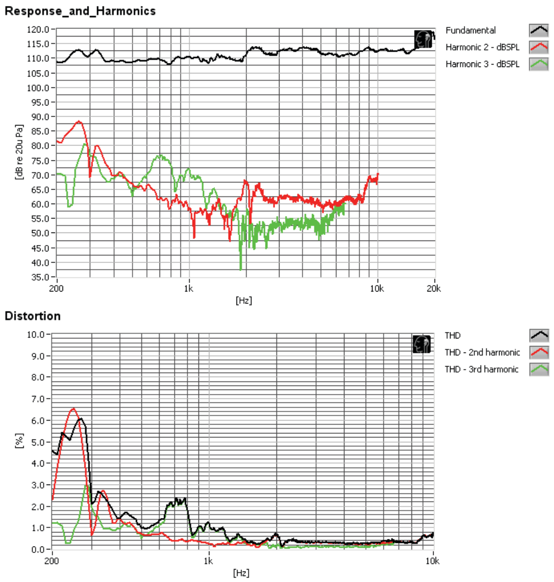

Figure 28: SB Acoustics SB65WBAC25-4 SoundCheck distortion plot

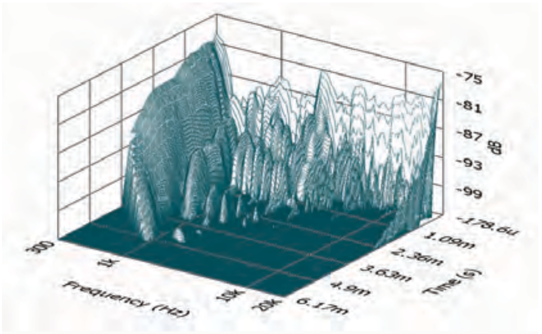

Figure 29: SB Acoustics SB65WBAC25-4 woofer SoundCheck CSD waterfall plot

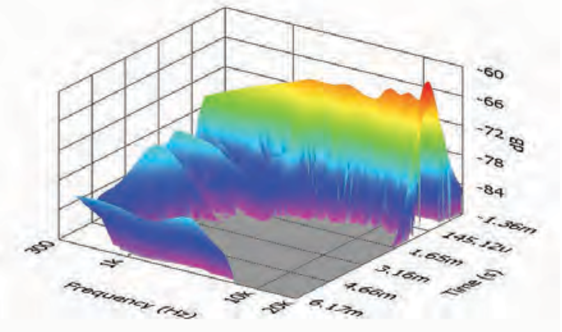

Figure 30: SB Acoustics SB65WBAC25-4 SoundCheck Wigner-Ville plot