Celestion Axi2050 2" Compression Driver on K-402 Horn And Subjective 3-D Printed Phase Plug Extension Effects

This report documents the integration of the Celestion Axi2050 2" compression driver on a Klipsch K-402 horn and includes acoustic and electrical measurements of their resulting combination. I am aware of no other ***in-production*** horns that can fully take advantage of this driver's very broad-band performance than the K-402 horn. Even the largest SEOS 30 horn isn't big enough to take advantage of the extended low end of this new Celestion Axi2050 driver.

Additionally, subjective performance of the throat-mounted “phase plug extension” that is an apparent replica of the Klipsch version used in the second-gen Jubilee is included for reference.

The Celestion Axi2050 compression driver is a relatively new 2”-throat driver and is the one is used in the second-gen Jubilee (“Heritage”). An exploded view of its assembly is shown below (figure 1):

Figure 1 Exploded view of the Celestion Axi2050 2" compression driver

The Axi2050 has a very large diameter “axi-periodic” ring radiator diaphragm (figure 2) that uses advanced design techniques to avoid the problems of other dome-type titanium diaphragm 2" throat drivers, including its complex-formed ring radiator diaphragm that avoids the issues of non-axial dome diaphragm motion (chattering or break-up modes) seen in other titanium and aluminum diaphragm dome diaphragm drivers.

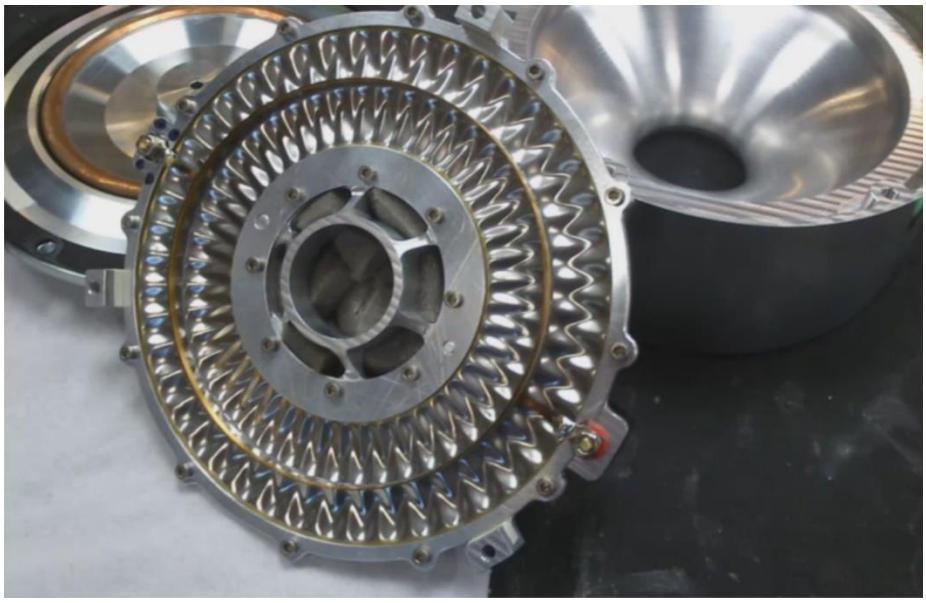

Figure 2 Celestion Axi2050 "axiperiodic-formed" titanium diaphragm

The three-part phase plug of this driver conducts the acoustic power generated by the diaphragm into two distinct acoustic channels that meet at the exit or throat of the driver. The purpose of compression driver phase plugs is to prevent destructive interference of sound energy from across the diaphragm's moving areas (clamped at its inner and outer diameters) that creates its acoustic output. When one considers that a full wavelength of sound at 20 kHz is only 5/8" (1.7 cm), and 5/16" (.85 cm) to have interfering sound waves cancelling each other at 180 degrees of phase from each other, it is easy to see the purpose of compression driver phase plugs to avoid destructive interference of sound energy inside the driver compression chamber.

A phantom view and a cut-away view of the driver with its extensive three-part phase plug is shown in figure 3, below:

Figure 3 Celestion Axi2050 phantom/cut-away views showing extensive 3-piece phase plug design

The K-402-HF horn assembly with driver, as is used in the first-gen Jubilee design with K-69-A driver attached is shown below in figure 4:

Figure 4 KT-402-HF assembly used in the first-gen Jubilee

Mounting the Axi2050 driver onto the Klipsch K-402 horn is straightforward using its 4-stud/nut connection (figure 5):

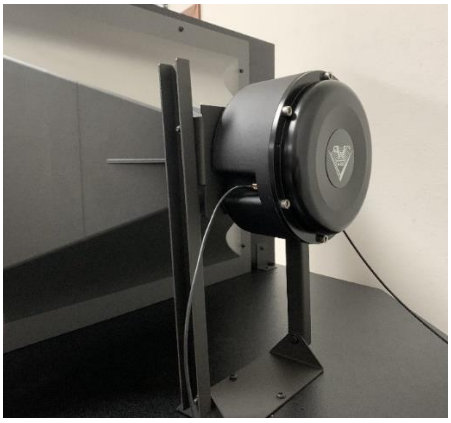

Figure 5 Celestion Axi2050 driver mounted on K-402 horn

The first-gen Jubilee has a smaller footprint and lighter weight than the second-gen Jubilee, and can be easily upgraded visually from a black Duratex finish to a veneered center-panel of the bass bin (figure 6, below):

Figure 6 A first-gen Klipsch Jubilee with veneered panel bass bin

Note that the author instead places acoustic absorption material across the center section of the bass bins in order to reduce nearfield acoustic reflections which audibly improve the performance of the first-gen Jubilee's sound stage, both laterally and vertically, so center panel veneer is not desirable to have.

Integrating the Axi2050 driver into the first-gen Jubilee

The amplitude (SPL) plot of the SPL response of a Celestion Axi2050 on a K-402 horn on top of a Jubilee bass bin is shown (figure 7, below) of the raw uncorrected response of both drivers. This particular raw-response plot is used to help determine the best crossover frequency:

Figure 7 Raw SPL Responses of the first-gen Jubilee bass bin and the Axi2050 on a K-402 horn

The suggested crossover frequency between the bass bin and the K-402 from the above plot is about 225 Hz, although raising this frequency to ~300-350 Hz will ensure slightly lower harmonic distortion at highest SPL operation (well over 105 dB at 1m).

Figure 8 Phase response of first gen Jubilee bass bin and Celestion Axi2050 on K-402 horn

The phase plot of figure 8, above, shows the large overlap between the two horns/drivers, which indicates the design flexibility of where the crossover point can be located. From looking at the phase plot alone, a viable crossover frequency can be ~ 190 Hz (where the Axi2050 on a K-402 horn really begins to lose on-axis SPL response) all the way up to about 800-900 Hz, where the Jubilee bass bin

begins to lose on-axis SPL response. That's as wide a response overlap band that I've seen, and indicates greater flexibility in choosing a crossover frequency.

Horn-loaded bass bins using a "W" section that have a truncated mouths, i.e., a flat baffle between the two horn mouths side-by-side, like the first-gen and second Jubilees, the original Klipschorn, as well as the Belle Klipsch, etc., introduce polar narrowing issues above the frequency where the separation distance of the two horn mouths is more than 1/3 to 1/4 wavelength at the upper crossover frequency for the bass bins (about 225 Hz). This is controlled by the width of the center front baffle and the width of each “W” section horn mouth (illustrated below in figure 9 of another “W” section bass horn design with and without truncated horn mouths, showing the added footprint area required for a non-truncated horn mouth design):

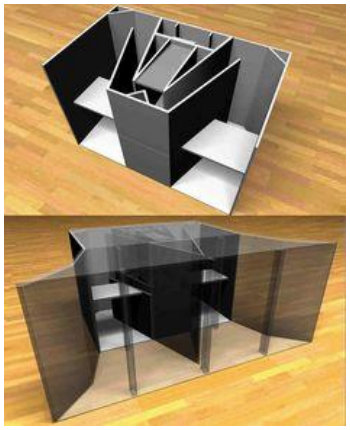

Figure 9 "W" section bass bin with and without truncated horn mouth (Levan horn)

Crossing over at a lower frequency than 400-600 Hz has the advantage of avoiding the narrowing of the bass bin polars that occurs in both the two Jubilee bass bins (first-gen and second-gen). The polar coverage of the K-402 and the bass bin at crossover are nominally 90-100 degrees, as shown by the blue trace in figure 10, starting above 221 Hz as shown. This figure plots the anechoically measured -6 dB horizontal coverage relative to the on-axis SPL value:

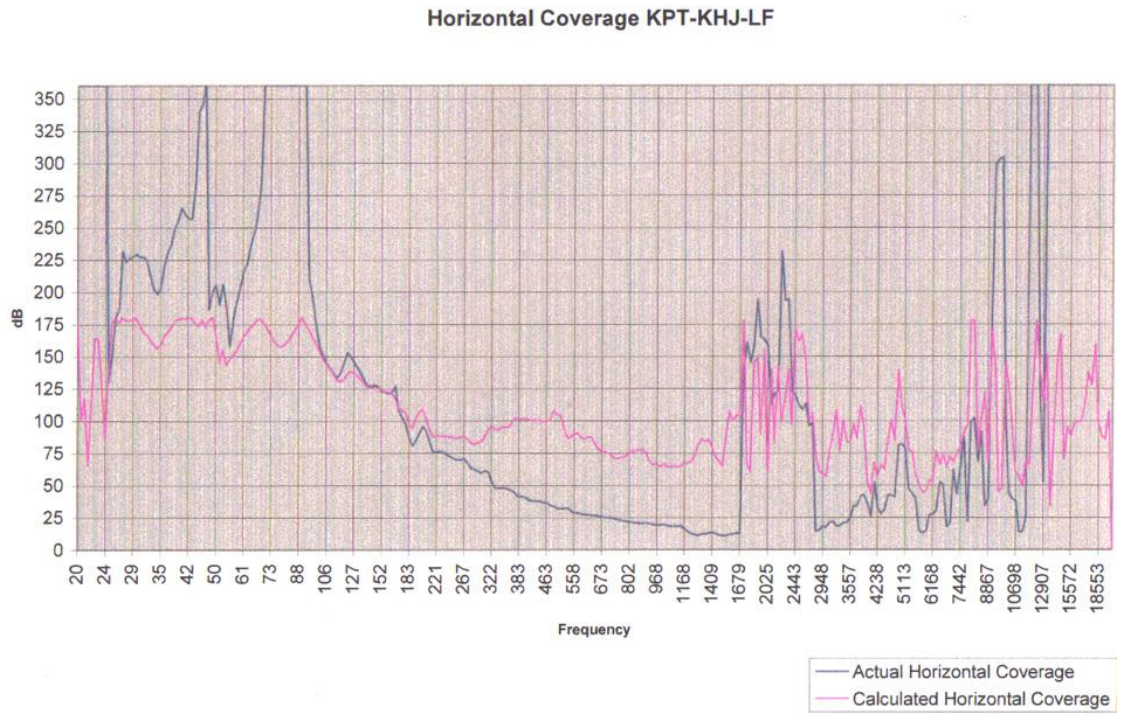

Figure 10 Horizontal coverage angles of the first-gen Jubilee Bass bin

The Axi2050 can cross about an octave below other 2" compression drivers due to its large axiperiodic diaphragm and extensive three-part phase-plug design, and can avoid the polar narrowing problems of the "W" section bass bins in the 200-500 Hz band by crossing at a lower frequency. Figure 11, below, shows the -6 dB horizontal coverage of the K-402 horn:

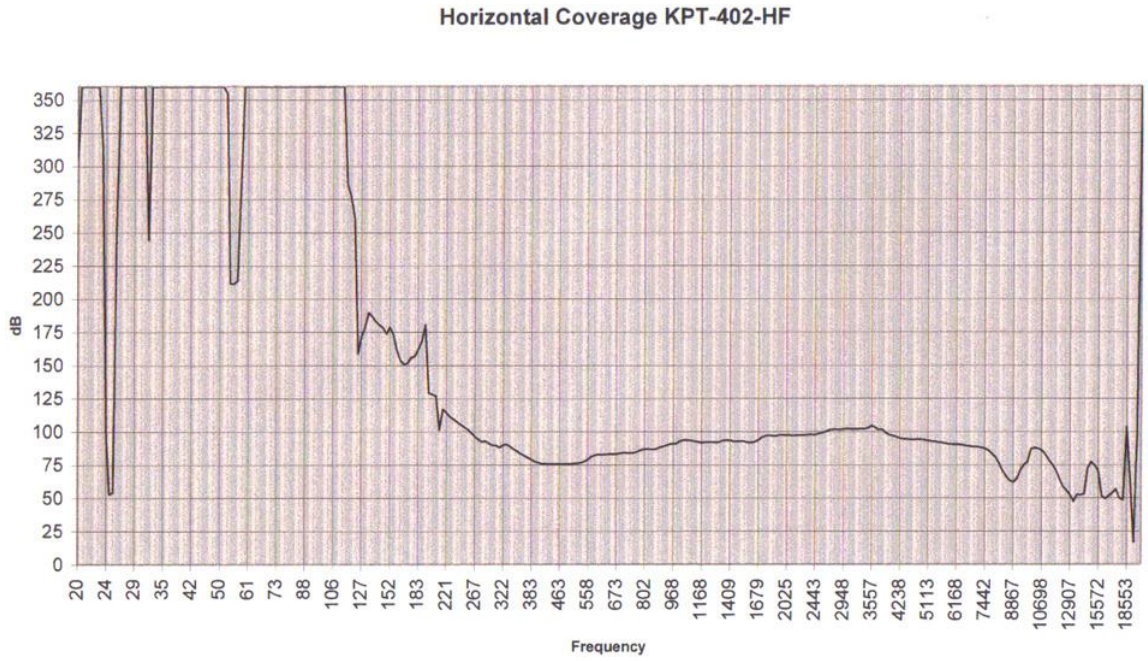

Figure 11 Anechoically measured K-402 HF horn horizontal coverage (-6 dB)

The Axi2050 compression driver raw SPL (amplitude) on-axis is compared to a TAD TD-4002 beryllium dome compression driver in figure 12, which shows their respective raw response on a K-402 horn for illustrative purposes. The acoustic sensitivity of the TAD TD-4002 driver is higher and a bit flatter, indicating higher overall acoustic efficiency of the TAD driver (the two raw amplitude response curves on-axis of fig. 9 are not shown at the same input gains, but rather shown in terms of their relative shapes). But the Axi2050 driver requires so little input power, its lower sensitivity is not a factor when bi-amping using DSP crossovers. The relative amplitude response plot shown in Figure 12 is a qualitative factor only.

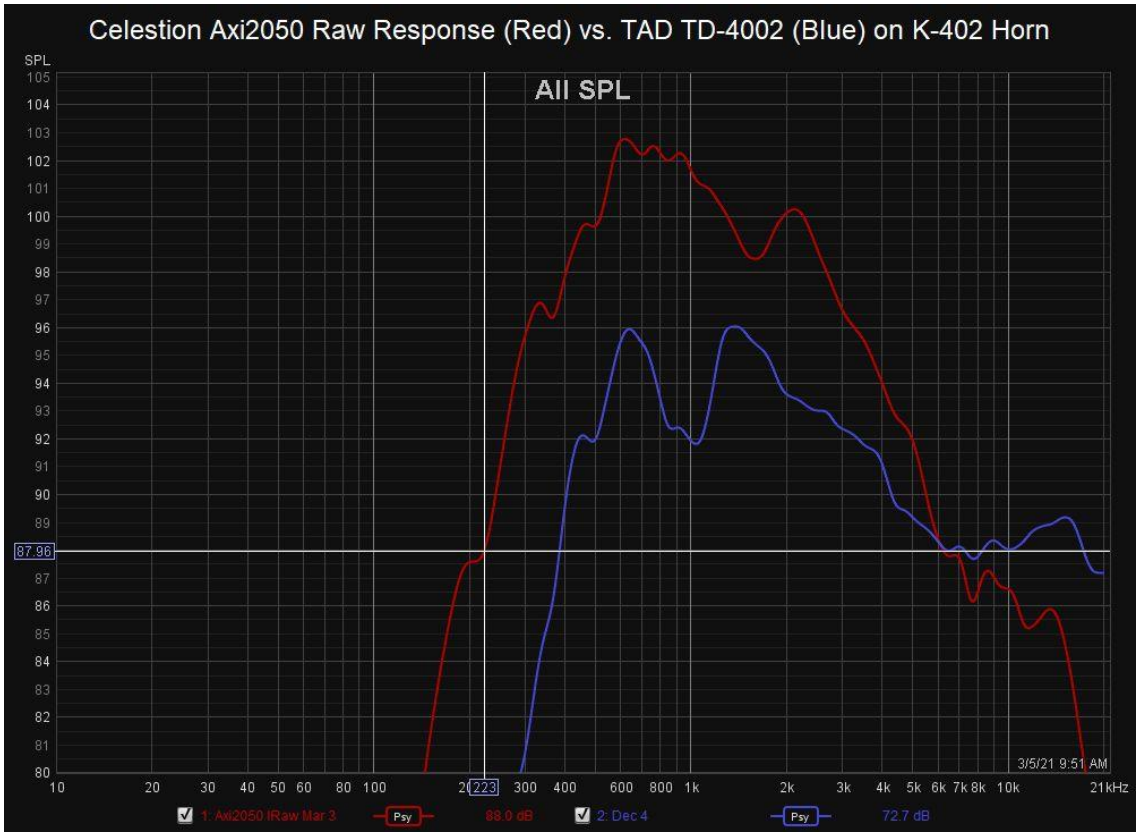

Figure 12 Relative raw SPL responses of the TAD TD-4002 and Celestion Axi2050 on K-402 horn

Figure 13 shows is the corresponding raw phase response of the two drivers on a K-402 horn:

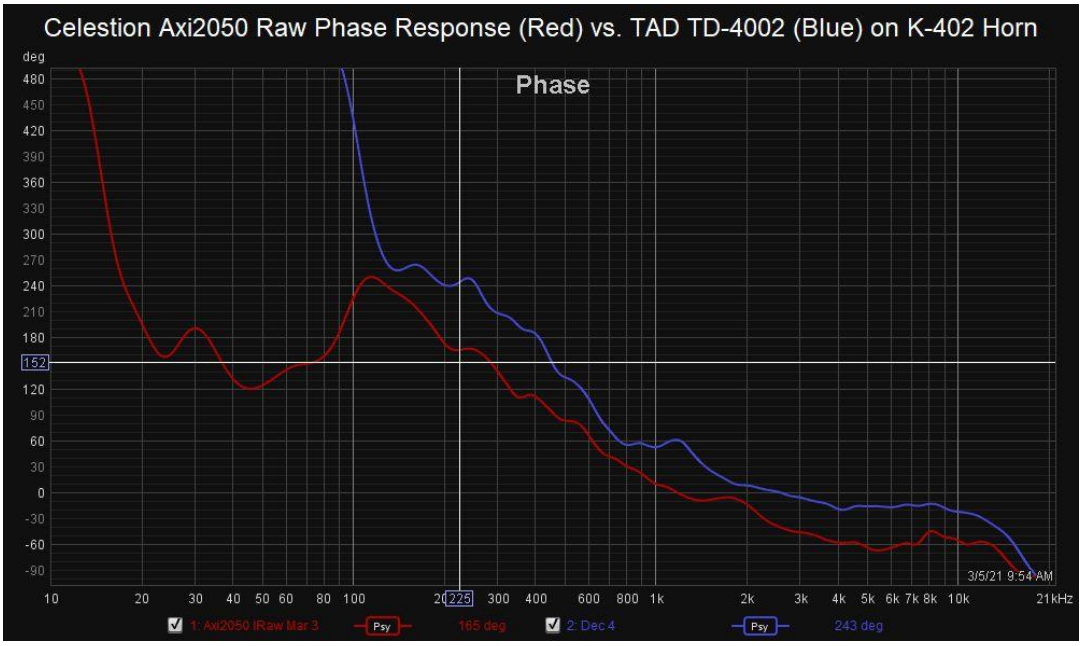

Figure 13 Comparison of TAD TD-4002 and Celestion Axi2050 phase responses on K-402 horn

The relative step responses re shown in figure 14, below:

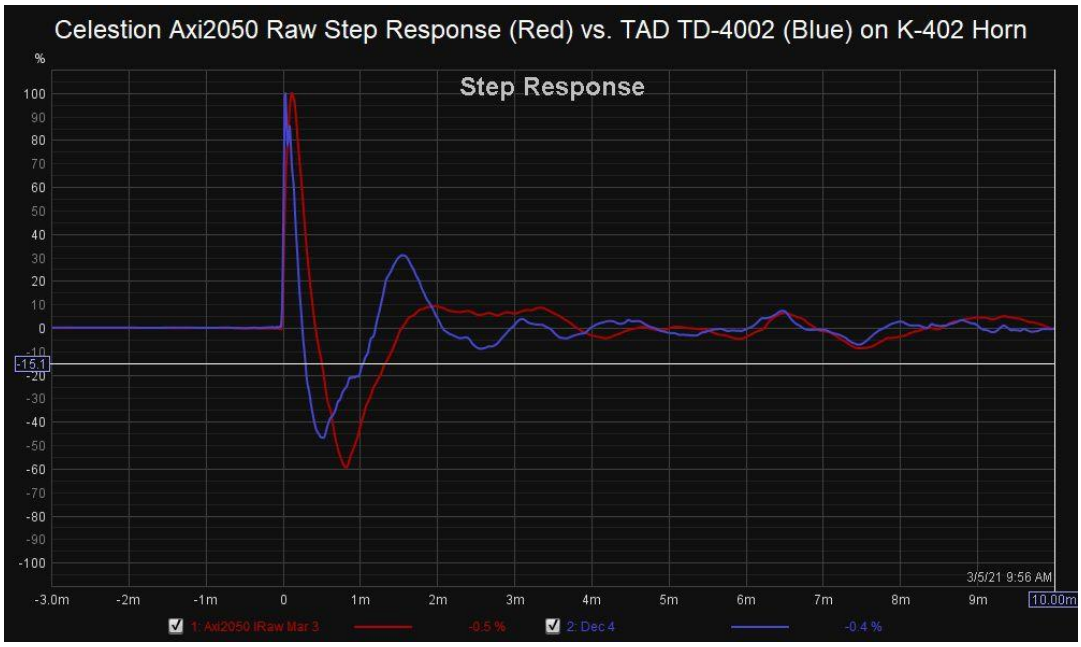

Figure 14 Comparison of TAD TD-4002 and Celestion Axi2050 step responses

The moving mass of the Axi2050 is apparently higher than the TAD TD-4002, but the improved low-end response and the lower cost of the Axi2050 are offsetting factors.

The plot below shows the "predicted SPL" responses--the response based on initial flattening of the two drivers' responses using DSP crossover PEQs without extra effort to extend their responses on either end of the spectrum (high or low) based on the REW EQ facility's initial responses. Figure 15 shows the relative response of each driver in as close to an "apples vs. apples" fashion as is possible.

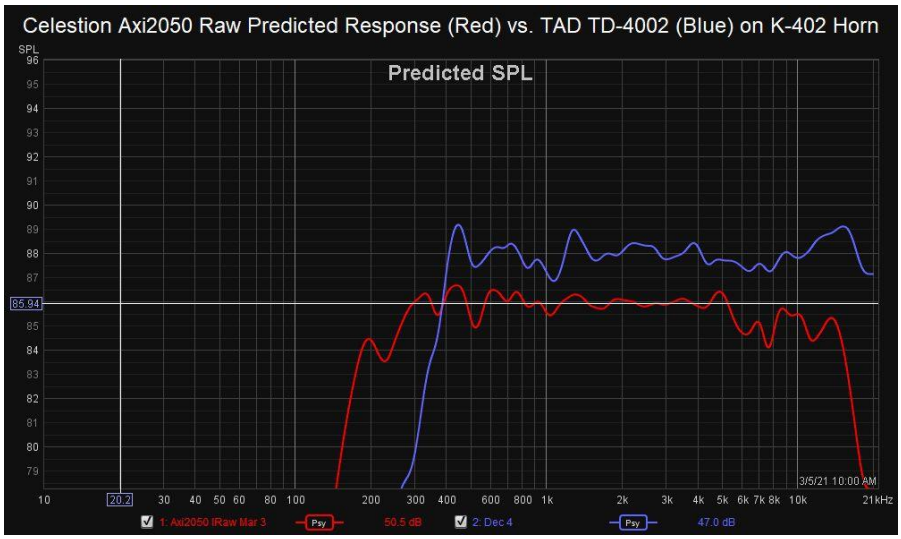

Figure 15 Natural bandwidths of TAD TD-4002 and Axi2050 drivers on K-402 horn

There are no significant harmonic distortion differences between the TAD TD-4002 and Axi2050 drivers across their respective passbands. First the TAD driver on a full-up Jubilee with bass bin at 93 dB (at one metre microphone distance, crossed at ~525 Hz), shown below in figure 16:

Figure 16 TAD TD-4002 harmonic distortion at 93 dB (1m) on K-402 horn

Then the same harmonic distortion levels at 93 dB for the Axi2050 with Jubilee bass bin (crossed at 225 Hz), figure 17, below:

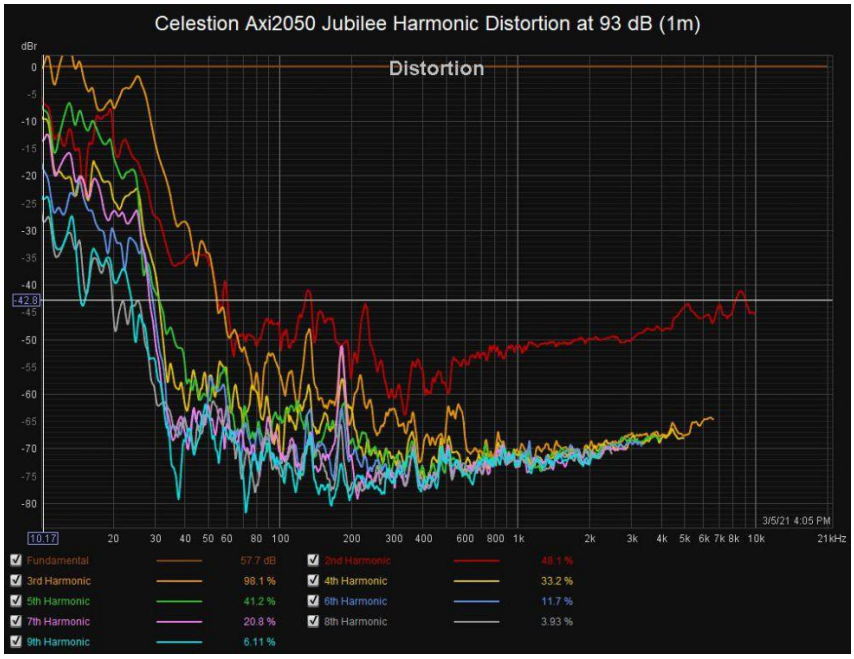

Figure 17 Celestion Axi2050 harmonic distortion at 93 dB (1m) on K-402 horn

Electrical input impedance of the Axi2050 as measured by *DATS V2* in free air is shown in figure 18:

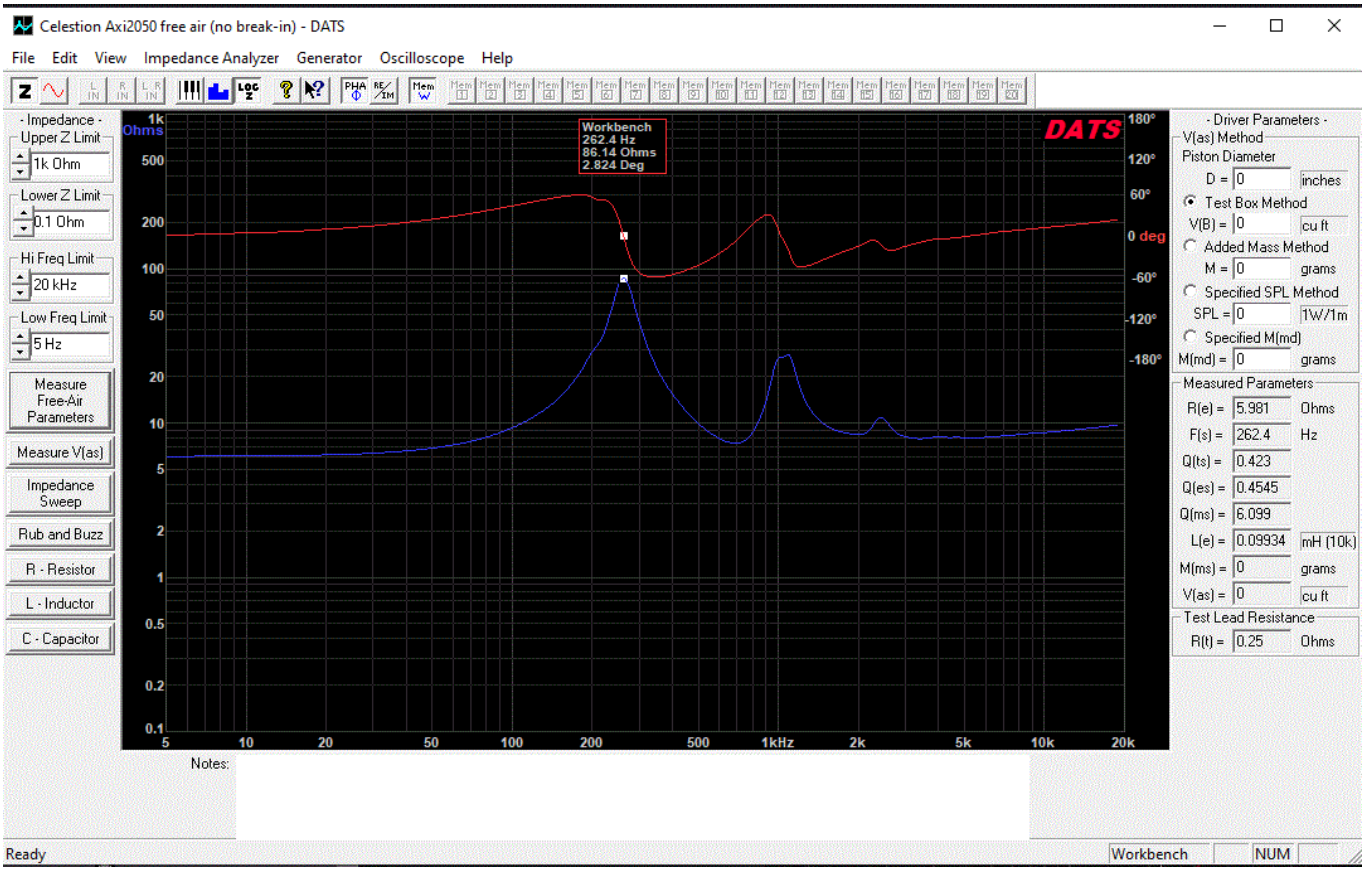

Figure 18 Celestion Axi2050 free air electrical impedance (DATS V2)

Finally, the Xilica DSP crossover settings that were used for the Axi2050 channel are shown (figure 19):

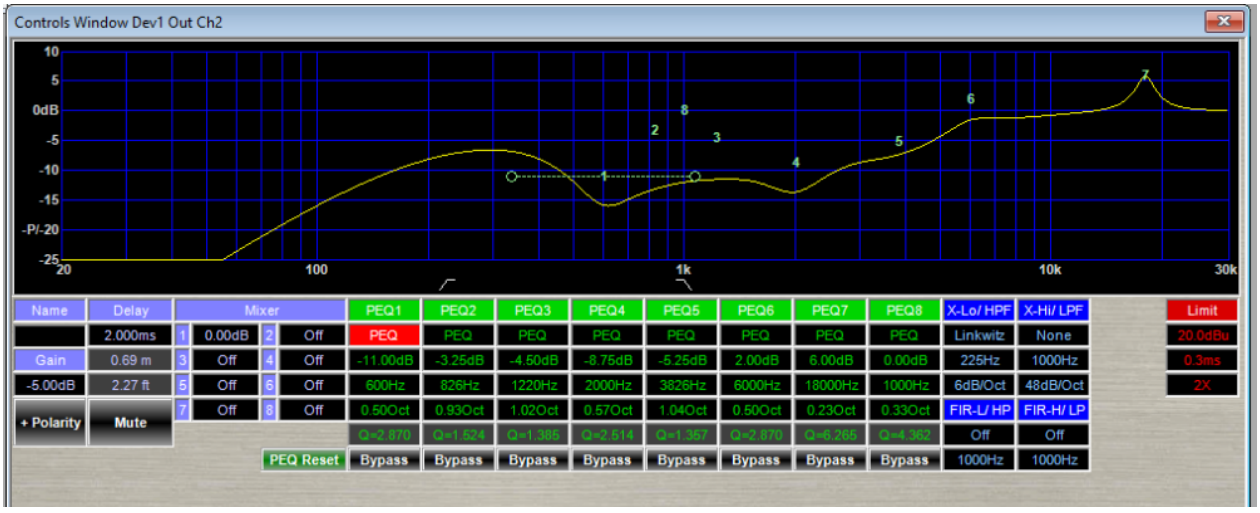

Figure 19 XConsole view of Celestion Axi2050/K-402 DSP settings used for PEQs, channel delay and gain, and high pass filter

Listening Impressions:

The Axi2050 is pretty much a match for the TAD TD-4002 with the understanding that there is a *very* small apparent difference in "sparkle" or "air" on the very top end. It is so small that I doubt anyone could pick it out on a blind-blind A-B comparison test, unless the test music used was very specific to show the differences. The two drivers are apparently fully interchangeable in terms of their resulting sound quality after being very carefully dialed in. Even playing the TAD TD-4002 on the left channel and the Axi2050 on the right channel for a couple of days can provide no observations about left-right sound quality/balance other than the sparkle comment I made above--subject to sighted bias.

The difference in crossing the K-402/Axi2050 an octave lower than the K-402/TAD TD-4002 is not generally audible, although I have lowered the K-402 on top of the Jubilee bass bins in both cases to minimize the vertical separation issues between the two horns. It seems to me that the Axi2050 on the right, crossed an octave lower than the TAD TD-4002 on the left, makes a very, very subtle difference, and only if moving well outside of the listening position(s) laterally. The right channel (Axi2050) may sound a little fuller in the lower midrange (225-500 Hz) which is difficult to pick out, but I would expect this might become more audible over time if listened to extensively. I can't make a judgment presently, but the idea (in my mind's eye) of crossing an octave lower is one that I would welcome--it's just that I'm not sure that I can really hear it presently.

Apparently, this driver can't really be beat in terms of sound quality, equal to the sound quality of the TAD TD-4002s, and having an extra octave of low-end response that the K-402 horn can easily take advantage of.

Subjective Impressions of the 3-D Printed In-Throat Phase Plug Extension

Figure 20 A Klipsch-produced throat-mounted phase plug extension

I measured no need to change the EQ on the loudspeaker channels (see figure 20, above) after installing the phase plug extensions. After evaluating the subjective effects of the add-on phase plug extension (3-D print file is available), there are subtle and not so subtle effects. While sitting at the stereo "sweet spot", i.e., on-axis between the two K-402 horns aimed directly at

one listening spot in the room, their effects can be detected as a very subtle increase in the ambience of the higher frequencies, notably in decay trails. The sound improvement can be described as more realistic sound quality than the Axi2050 on a K-402 without the phase plug extension (here reporting on its effects using a TAD TD-4002 Be-dome driver).

The big difference in performance is when moving around the room, sitting off-axis. In these cases, the they actually solve the issue of changing timbre at extreme high frequencies while moving about the room, particularly when standing up from a sitting position. Wherever listening to the loudspeakers, the timbre is the same across the width of the room and in height when moving toward the loudspeaker while standing.

As far as why Klipsch is calling this device a "phase plug extension", this is likely related to the matching of the annular rings of the throat lens to the termination of the Axi2050 phase plug, as shown below in figure 21:

Figure 21 Axi2050 throat view showing the driver's three annular channel phase plug termination

Figure 22, below, shows the Klipsch-produced phase plug extension mounted to the throat of the K-402 horn, between the K-402 mounting stand bolting surface and the mouth of the K-402 horn itself.

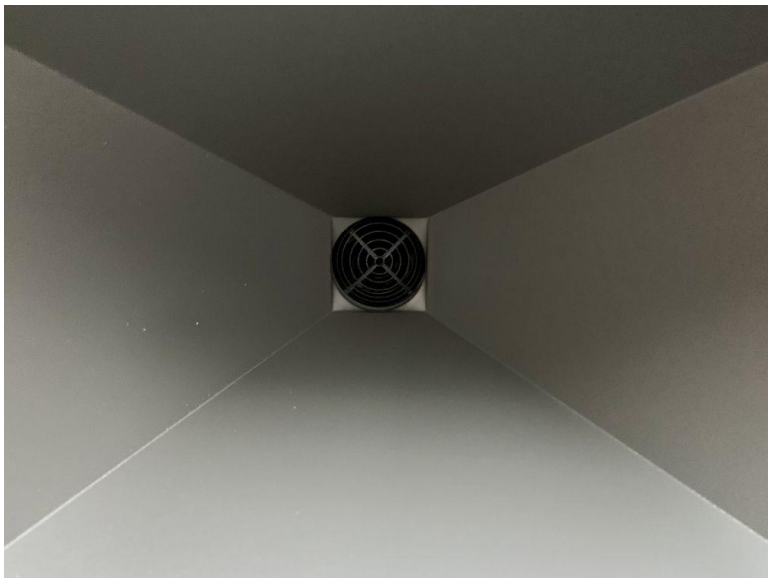

Figure 22 Klipsch Phase Plug Extension on K-402 horn

The design of the throat lens corresponds to those rings of the Axi2050 driver throat exit plane and doesn't apparently correct the phase of the wavefronts leaving the compression driver, but only affects polar coverage for frequencies whose corresponding half wavelength is less than 2" (i.e., frequencies above 6.8 kHz). Since the device functions the same using a TAD TD-4002 driver (with its long 1.5→2 inch “snout”), the phase plug extension appears to actually be a throat-mounted diverging acoustic lens. The effectiveness of this lens begins to break down above the point at which the annular lens rings are again separated by 1/2 wavelength of sound (about 14-15 kHz).

This device seems to recover some of the top-end sparkle of the Axi2050 driver relative to other 2” compression drivers, but it is fairly subtle acoustically. The loudspeakers need to be extremely carefully dialed in to hear the difference, including having sufficient EQ on the top octave of the Axi2050 driver (or any 2" compression driver, for that matter) to achieve flat on-axis response above 10 kHz.

When using a "W" section dual mouth folded horn bass bin like the Jubilee bass bins, using the Axi2050 addresses the one Achilles heel of the Jubilee: its lower midrange crossover apparent center movement from the centerline of the K-402 to the centerline of the bass bin, which comes at a point that's in the middle of the vocal range (400-600 Hz) in the first-gen Jubilee.

Moving the K-402 horn lower to move its centerline closer to the centerline of the bass bin mouths can reduce this issue, and while this is a significant improvement in that area, it doesn't actually solve the issue. But crossing over an octave lower (about 300 Hz) is another way to significantly lessen this issue and the related issue of the truncated bass bin horn mouths that do not rejoin in the middle like the La Scala bass bin does. Crossing an octave lower puts the two bass bin mouths within 1/3 wavelength of each other, thus eliminating the source of the bass bin polar lobing in the horizontal axis at or near its high frequency crossover frequency.

Chris Askew (original: 5 March 2021, revised 23 Mar. 2023)