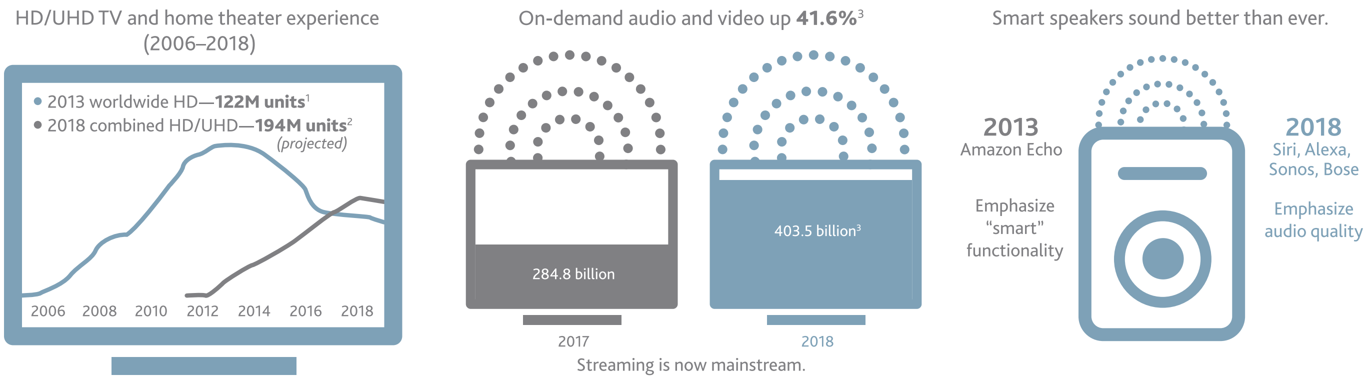
EASTMAN

How material selection can improve audio performance

Innovative audio devices are overdue for innovative housing materials.

Audio products are integrated into our lifestyles in ways that were unimagined 10 to 15 years ago. New applications and growing consumer demand (Figure 1) have sparked technological innovation as well as increased demand for higher audio quality.

Figure 1. Market overview and key trends



NOTE: In July 2018, 90% of households had HDTV sets.[1]
NOTE: Streaming now accounts for more than 50% of audio consumption.[4]

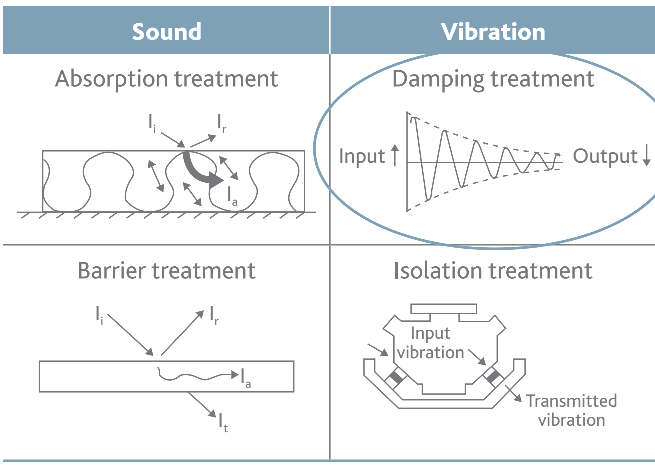
As home theater entertainment systems, audio streaming, and a variety of smart speaker devices have become more common, audio performance plays an ever-greater role in customer satisfaction. One simple example of this trend is the smart speaker and similar AI devices. When the first-generation Amazon Echo was introduced in late 2014, the emphasis was on the "smart" aspect of smart speakers. In subsequent years—and product generations—there has been increased focus on sound performance.

Innovations in audio performance have largely come from developing advanced transducers and other components. At the same time, advancements in materials used for audio enclosures have been much slower, resulting in vibration, distortion, and degradation of audio performance.

The goal: reduce unwanted resonance in audio enclosures

Rather than attempting an all-encompassing investigation of noise reduction, the goal of this white paper is to focus on the impact of viscoelastic response in device housings and how materials with inherent vibration damping properties can reduce distortion and improve audio performance in speakers.

Noise reduction process



*Performance of all treatments is **frequency** dependent; performance of a damper is **temperature** dependent also.*

In the following pages, Eastman describes a methodology for testing candidate materials in the frequency ranges relevant to audio applications. We also present a case study involving a molded in-ear monitor (earbud) application that measured cumulative spectral decay (CSD) and total harmonic distortion (THD) to demonstrate the role of housing material on resonance, distortion, and listener experience.

The value of a material change

Manufacturers continue to look for innovative ways to improve their audio products—and develop devices with better sound. A housing material that provides superior vibration damping properties without significant redesign can be a cost-effective solution for improving customer satisfaction and increasing market share.

Evaluating vibrational damping properties

Damping refers to the ability of a material or system to dissipate energy (e.g., vibration to heat). The vibration damping properties of Eastman materials have been demonstrated at a wide range of frequencies in previous works.[5,6] For this white paper, Eastman applied the same techniques to compare acoustic performance of competitive materials in frequency ranges relevant to consumer audio applications.

Recent tests evaluated damping loss factor (DLF) for Eastman Tritan™ copolyester, Eastman Trēva™ engineering bioplastics, polycarbonate (PC), and acrylonitrile butadiene styrene (ABS) resins under controlled conditions, geometries, and temperatures.

Methodology

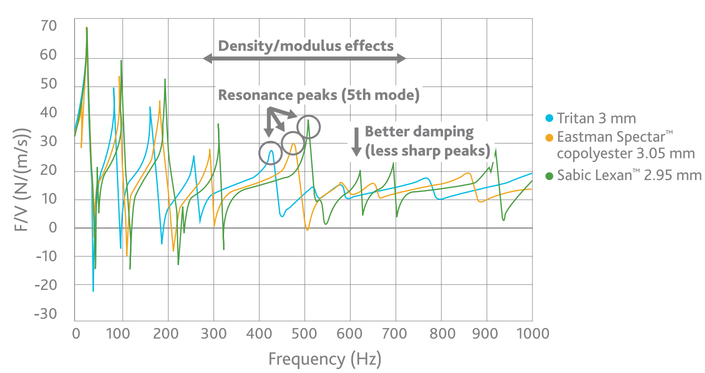
- Collaborating with Kolona and Saha Engineers, a center point impedance (CPI) method was used to compare how the vibration damping properties of test materials can affect acoustic performance—based on a working SAE standard (SAE J3130).
- All tests were conducted at room temperature.
- CPI testing employed a frequency generator, accelerometer, impedance head, and data collection software.
- The frequency generator created vibration at the center of rectangular test bars. The magnitude of this input was measured via the impedance head.
- An accelerometer measured the motion of the bar as the input vibration traveled through the part.
- DLF, often expressed as tan(δ), was determined from vibrational response at discrete resonance modes. (Only longitudinal modes were measured.)
- Frequency vs force/velocity was plotted as the frequency response function (FRF).

What frequency response function tells us

FRF, as measured by CPI, allows us to compare the vibrational damping capabilities of different materials in a similar geometry by analyzing their resonance modes.

Figure 2 shows the frequency response curves for four candidate materials. Pronounced modal resonance peaks indicate less damping value for the PC and ABS materials compared to Tritan copolyester and Trēva cellulosics.

Figure 2. FRF example



Graphics courtesy of Kolona and Saha Engineers, the collaborator on all center point impedance testing.

A closer look at modal resonance

To quantify the level of damping, we calculate the DLF for each resonance peak (see Figure 3). The peak width is determined 3 dB below the maximum (Δf_n) and divided by the resonance frequency (f_n) which gives the DLF (ηc) at that discrete resonance. Mathematically, the loss factor is stated:

$$\tan(\delta) = \eta c = \Delta f_n / f_n$$

Figure 3a. Calculating modal resistance

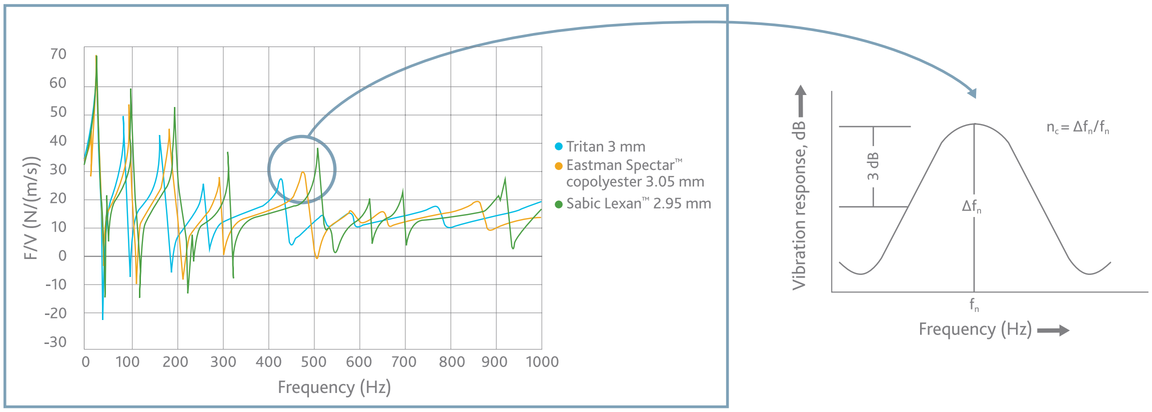
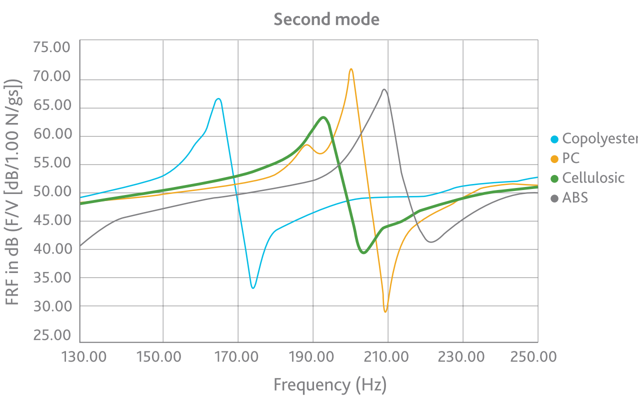


Figure 3b. Modal resonance—detail



The FRF and DLF results for the four test materials are presented in Table 1. With these calculated values, we can make direct comparisons between different materials as long as they are molded with the same geometry.

Table 1. FRF and DLF—Results summary

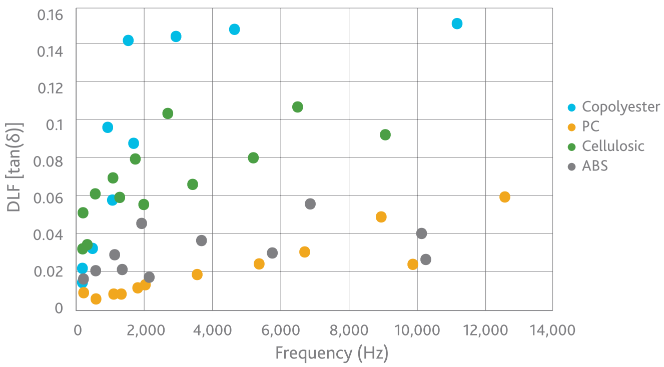
	Mode 2		Mode 3		Mode 4		Mode 5		Mode 6	
	Frequency	DLF	Frequency	DLF	Frequency	DLF	Frequency	DLF	Frequency	DLF
Copolyester	167	0.021	466	0.033	911	0.101	1469	0.149	—	—
PC	202	0.007	566	0.007	1109	0.009	1831	0.035	2723	0.019
Cellulosic	194	0.033	547	0.061	1075	0.070	1729	0.080	—	—
ABS	210	0.017	591	0.021	1160	0.029	1915	0.047	2850	0.106

NOTE: By the 6th mode, the vibration energy has been substantially damped by Tritan and Trēva materials and it is not possible to accurately resolve a resonance peak.

Comparing damping loss factor over extended frequencies

For a broader perspective, additional tests were conducted to calculate DLF for frequencies from 100 to 14,000 Hz.

Figure 4. Center point impedance data

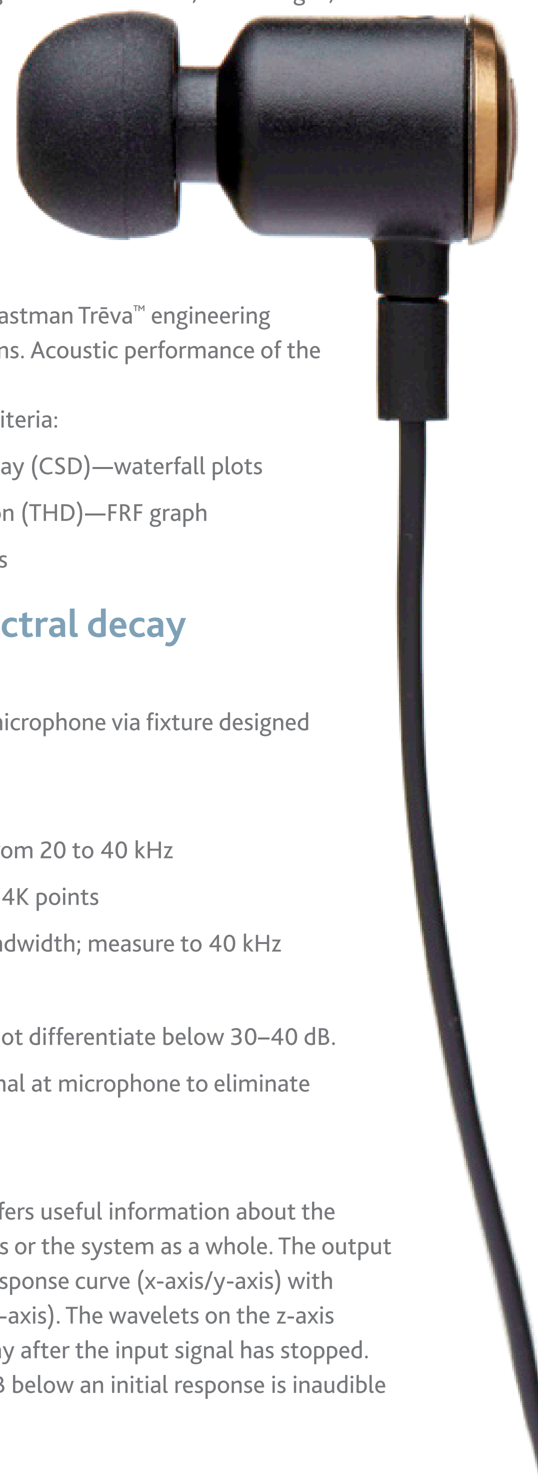


Result summary

- Damping loss factor, as determined from frequency response function, can help determine the vibrational damping capabilities of different materials.
- Eastman copolyester and cellulosic demonstrate improved damping properties compared to PC and ABS over a wide range of frequencies, indicating the potential for superior performance in audio applications requiring reduced resonance, less distortion, and improved acoustical performance.
- Damping loss factors represented in Figures 2 and 3 are consistent with comparisons at higher frequencies that are not relevant for audio applications (Figure 4).

Evaluating performance in a fully molded device

Eastman collaborated with an external partner to evaluate the audio performance of polymers when fully molded and assembled in test housings. The collaborator, DW Designs, evaluated test housings of Periodic Audio Be (beryllium) in-ear monitors (IEM).



Housings were molded in Periodic Audio's incumbent PC material as well as Eastman Tritan™ copolyester and Eastman Trēva™ engineering bioplastic (cellulosic) resins. Acoustic performance of the devices was evaluated on three criteria:

- Cumulative spectral decay (CSD)—waterfall plots
- Total harmonic distortion (THD)—FRF graph
- Subjective listening tests

Cumulative spectral decay

CSD methodology

- IEM was connected to microphone via fixture designed to mimic ear canal.
- Input is FM slide (chirp).
  - Provides a pure tone from 20 to 40 kHz
  - Allows generation of 64K points
- Sample with 48 kHz bandwidth; measure to 40 kHz
- Set to 50 dB range
  - Human hearing does not differentiate below 30–40 dB.
- Run at 110 dB SPL nominal at microphone to eliminate noise floor

CSD results

The CSD waterfall plot offers useful information about the performance of the drivers or the system as a whole. The output is basically a frequency response curve (x-axis/y-axis) with an added time element (z-axis). The wavelets on the z-axis show how the cycles decay after the input signal has stopped. Anything that is 20–30 dB below an initial response is inaudible to the human ear.

Figure 5a. Polycarbonate

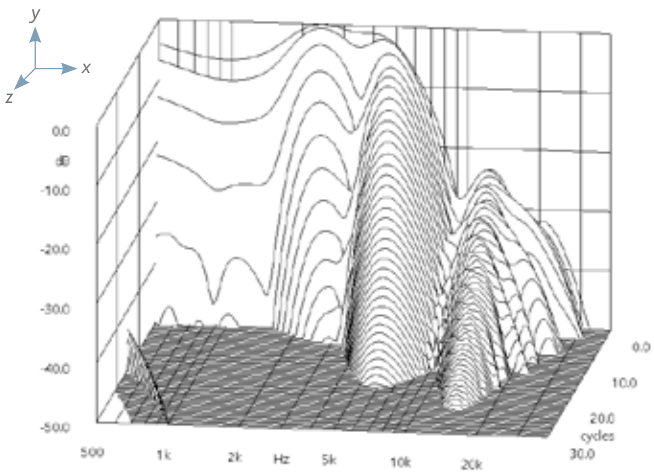


Figure 5b. Copolyester

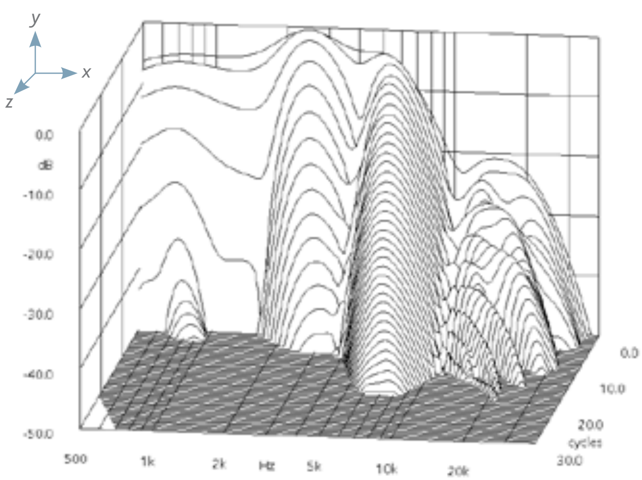
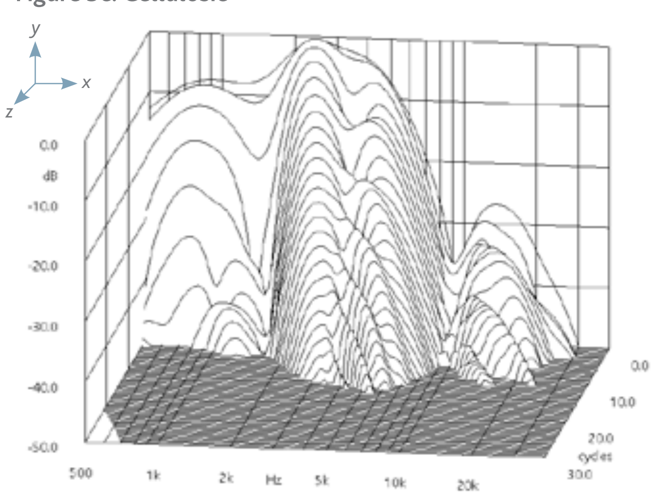


Figure 5c. Cellulosic



Analyses

PC CONTENT

- At 6 kHz, PC housing experienced ~20 cycles of resonance, which died out relatively quickly.
- At 14 kHz, it again experienced ~20 cycles, which decayed less quickly.

TRITAN CONTENT

- Initial transducer response is more energetic than the PC test.
- Ridge at 6 kHz is similar to PC.
- Ridge at 14 kHz is nearly eliminated—decay is very rapid.
- Improved overall response compared with PC

TRĒVA CONTENT

- Ridge at 6 kHz decays noticeably faster.
- Ridge at 14 kHz is almost nonexistent.
- Acoustically, Trēva is a very dead material.

In summary, both Tritan and Trēva provide less of their own audio signature to interfere with the consumer's audio experience.

Total harmonic distortion

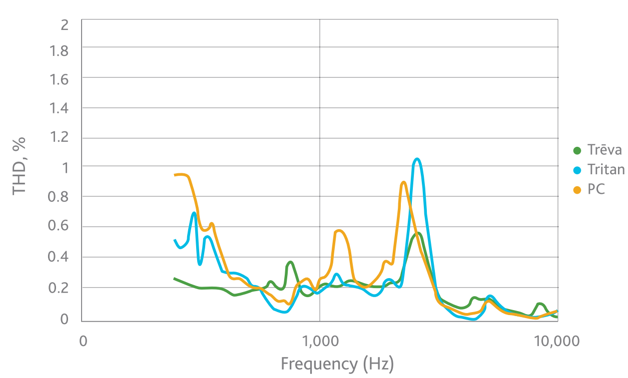
THD methodology

- THD sweeps were run for each IEM at 100 dB SPL nominal.

THD results plotted

- Lower THD values indicate that the audio signal is not perturbed or altered.
- CONTEXT: The Periodic Audio Be model with incumbent PC has been rated the "lowest THD IEM on the market" by third-party tests (less than 1% THD at 1 mW).

Figure 6. THD @ 100 dB SPL, IEM



Graphics and images courtesy of Periodic Audio.

Analyses

- PC shows the most pronounced peaks for resonance.
- Tritan shows fewer peaks, although there is one large primary resonance at 2500 Hz.
- Trēva performed best, with the lowest overall level of measured THD.

Case study summary

- Eastman polymers (Tritan and Trēva) both have superior damping characteristics relative to PC.
- THD improvements with Tritan and Trēva were measurable.
- Tritan demonstrated better top-end extension with better damping than PC.
- Trēva is acoustically a very dead material for audio applications.

Subjective listener testing

Test results presented on the previous pages established that differences in audio performance of enclosure materials can be measured. But can they be heard?

Eastman conducted subjective listener testing to determine whether changing enclosure material can provide a discernable benefit for audio engineers, designers, and consumers.

Methodology

- Panel—Three listeners with audio expertise and familiarity with the Periodic Audio Be IEM
- Source—SONOS® Connect, optical out
- D/A—Channel Islands Audio VDA
- 2 D/A converter
- Amplifier—Channel Islands Audio VHP
- 2 headphone amp
- Playlist—15 demo tracks were selected from a variety of music styles, chosen to highlight potential issues with the Be model IEM (source: Tidal.com HiFi).

Listener feedback

Comments from the panel of expert listeners provided many interesting comments, including:

- Sibilance is reduced
- More space
- Toned down resonance
- More full and overwhelming
- "Buzzy-ness" is reduced
- More even amplitude
- Changes are subtle but audible and consistent

Listener panel summary

All these improved listener experiences can be related to reduced distortion and improved decay on the waterfall plots of the enclosures made with Eastman Tritan™ copolyester and Eastman Trēva™ engineering bioplastics.

Looking ahead to improved acoustic performance

Innovative applications and greater IoT integration will continue to raise the bar for audio performance. Engineers and designers will be tasked with improving the integrity of voice input as well as audio output.

The challenge of reevaluating designs provides manufacturers an ideal opportunity to consider how different materials can

improve device performance—and strength in the marketplace. Eastman is already working with acoustic engineers, material scientists, mechanical engineers, and other acoustic innovators to improve their products. Here are a few of the areas where improved vibrational damping can add value:

- Enhancing audio performance in devices
- Reducing resonance of cabinets/enclosures that can contribute to a listener's audio experience
- Improving active noise cancellation
- Preventing feedback and feedforward systems from going unstable by reducing resonance and interference contributed by housing
- Reducing load on digital signal processing (DSP)
- Reducing computational load by removing resonances—for longer battery life
- Reducing computing power of PCB—to mitigate cost
- Increasing efficiency of speaker/microphone systems by reducing echo
- Allowing higher SPL of speaker systems incorporating microphones by reducing echo and reverberation

Combining sound performance with reliability

Eastman **TRITAN**™
copolyester

- Proven in wearables as well as portable and stationary devices
- Excellent impact strength and flex fatigue resistance
- Excellent chemical resistance (including body oils, hygienic cleaners, and cosmetics)
- Design flexibility—excellent secondary operations

Eastman **TRĒVA**™
engineering bioplastic

- Cellulose-based thermoplastic
- Reduced environmental impact
- Excellent chemical resistance
- Excellent flow characteristics—ideal for complicated or thin-walled designs

For more information, visit **www.eastman.com/Consumer-Electronics**.

Sources

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