Using Eastman plastics to reduce unwanted resonance in audio enclosures

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EASTMAN

Keeping pace with market trends

Eastman

World headquarters—Kingsport, Tennessee, U.S.A.

- 14,500 dedicated employees
- 50 manufacturing sites in 100 countries
- $9.5 billion annual sales

Industry-leading polymers in many categories

Consumer electronics—polymer and applications expertise

Dedicated to environmental stewardship, social responsibility, and economic growth

Market overview and key trends

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- Audio products have been an integral part of people's lives for a long time.
- In the last decade and a half, several global trends have lead to product innovation and a changing competitive landscape.

HD TVs

Mid-2000s: Adoption of HDTVs and drive towards creating home theater experiences leads to emergence of **sound bars** and home-theater-in-a-box products

Streaming services

Late 2000s: Emerging and wide adoption of music streaming and subscription services creates opportunities for high quality **connected speakers.**

PANDORA Spotify

AI

2015: Emergence of AI assistants like Siri and Alexa leads to skyrocketing adoption rates of **smart speakers**

Siri

Vibrational damping and noise reduction

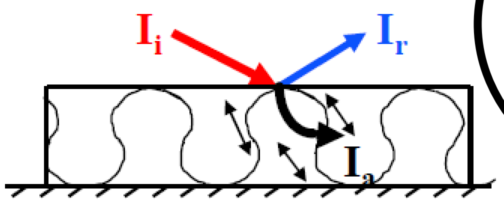
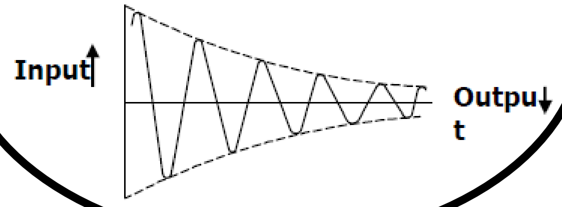
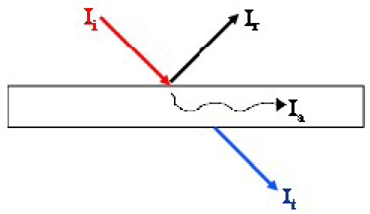
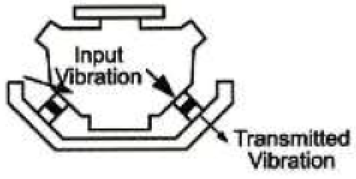
Outline

- Fundamental acoustical damping differences
  - Test: Center point impedance
  - Response: Damping loss factor

- Case study: In-ear monitors (ear buds)
  - Waterfall plots (cumulative spectral decay)
  - Total harmonic distortion
  - Expert listener panel

- Materials
  - **Eastman Tritan™ copolyester**
  - **Eastman Trēva™ engineering bioplastic** (cellulosic)
  - PC
  - ABS

Noise reduction process

Sound &	Vibration
Absorption treatment 	**Damping treatment** 
Barrier treatment 	**Isolation treatment** 

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

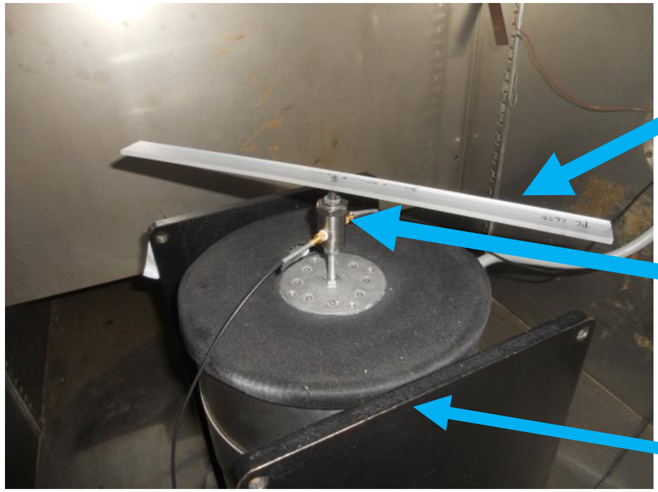
Courtesy of K&S Engineers

Vibrational damping properties

Center point impedance

Methodology

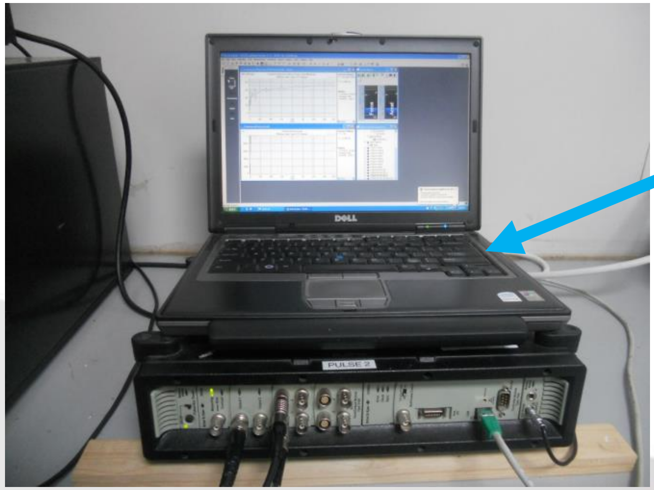
- A rectangular part is vibrated at a range of frequencies.
  - Assumed as a vibrating beam to simplify calculations
  - Takes into account longitudinal modes of vibration only
- An accelerometer and impedance head in contact with the part measure the force and velocity of the vibration as it travels through the part.
- Frequency versus force/velocity of response is plotted as frequency response function.
  - **Damping loss factor is determined from response at discrete resonance modes.**



Sample

Impedance head/ accelerometer

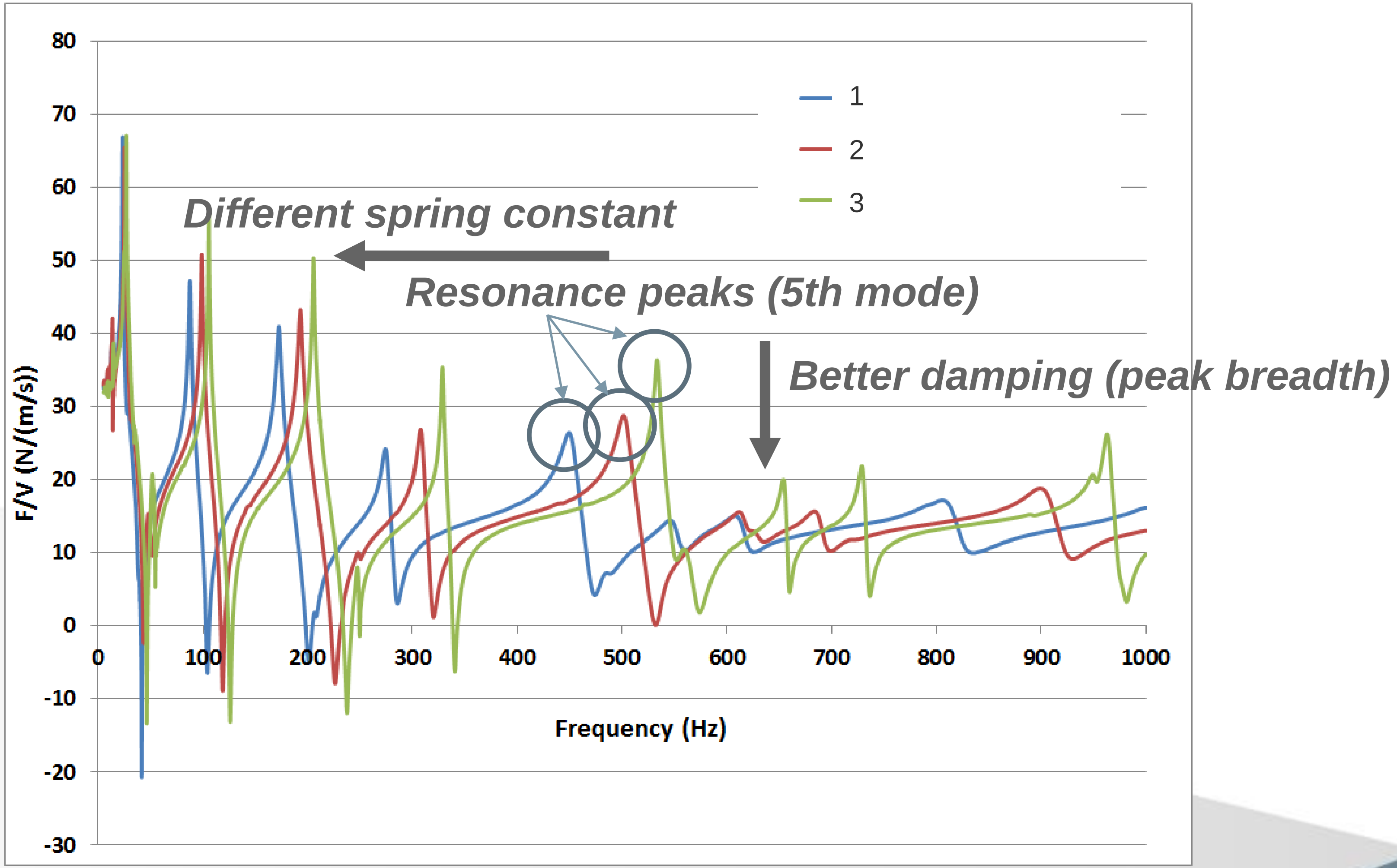
Frequency generator



Data acquisition software

Courtesy of K&S Engineers

Frequency response function—example



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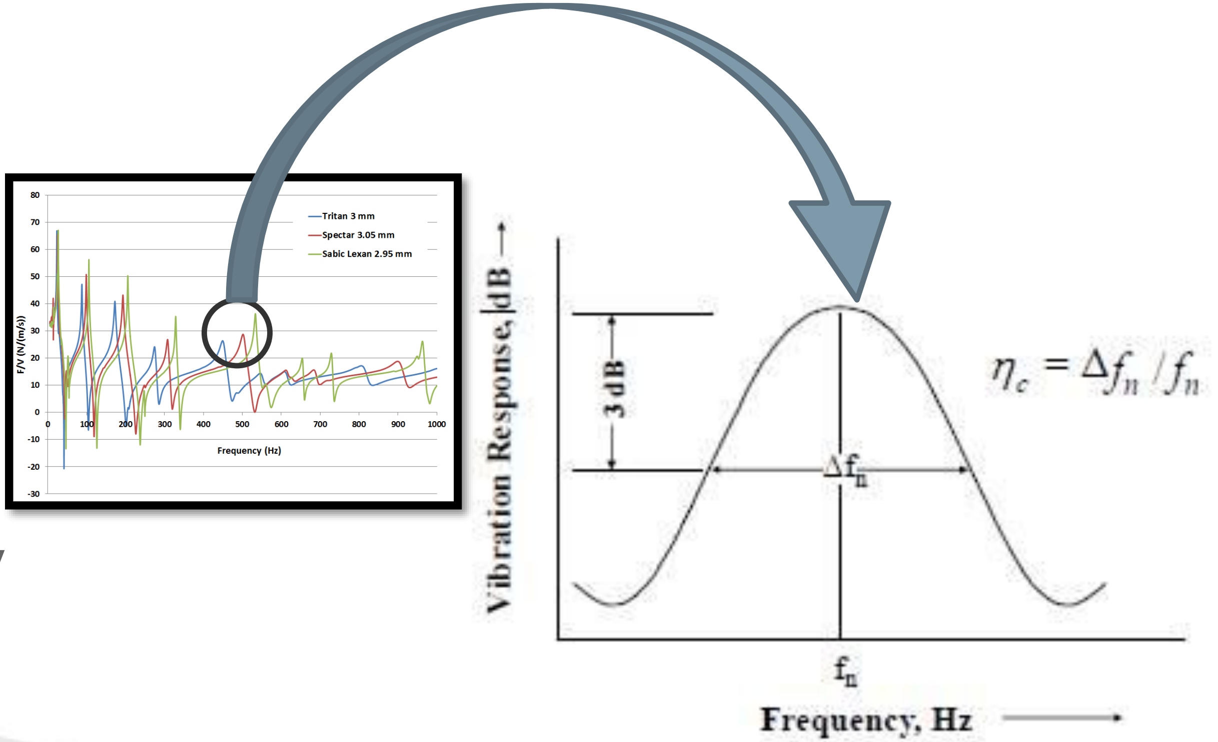
Damping loss factor (tan[δ]) and quality factor

- The damping loss factor tells us **how well a material damps vibrational energy at resonance.**
  - The greater the tan(δ) at a given resonance mode, the better the damping.

- Damping loss factor is calculated at discrete resonance modes for the vibrating beam.
  - Mathematically, the loss factor is given by

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

- This value can be compared only for similar geometries.
  - Cylinders, spheres, etc., would all have different modal vibrations

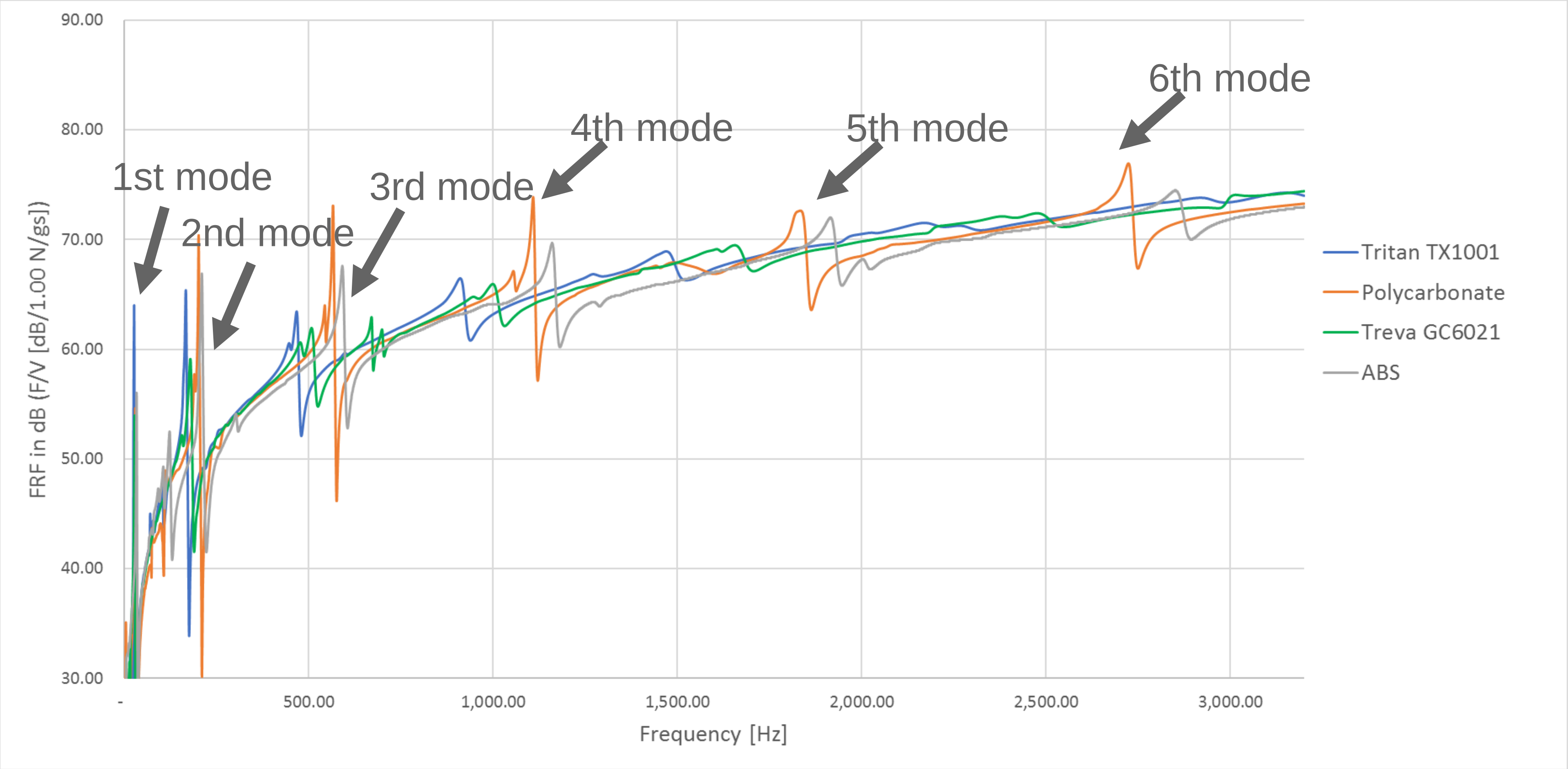


Frequency response curves

- To demonstrate material differences, we will go stepwise through the frequency response function of four materials.
  - **Copolyester, cellulosic**, polycarbonate, ABS
  - Bars tested: 300 x 20 x 3 mm
  - Testing carried out at room temperature

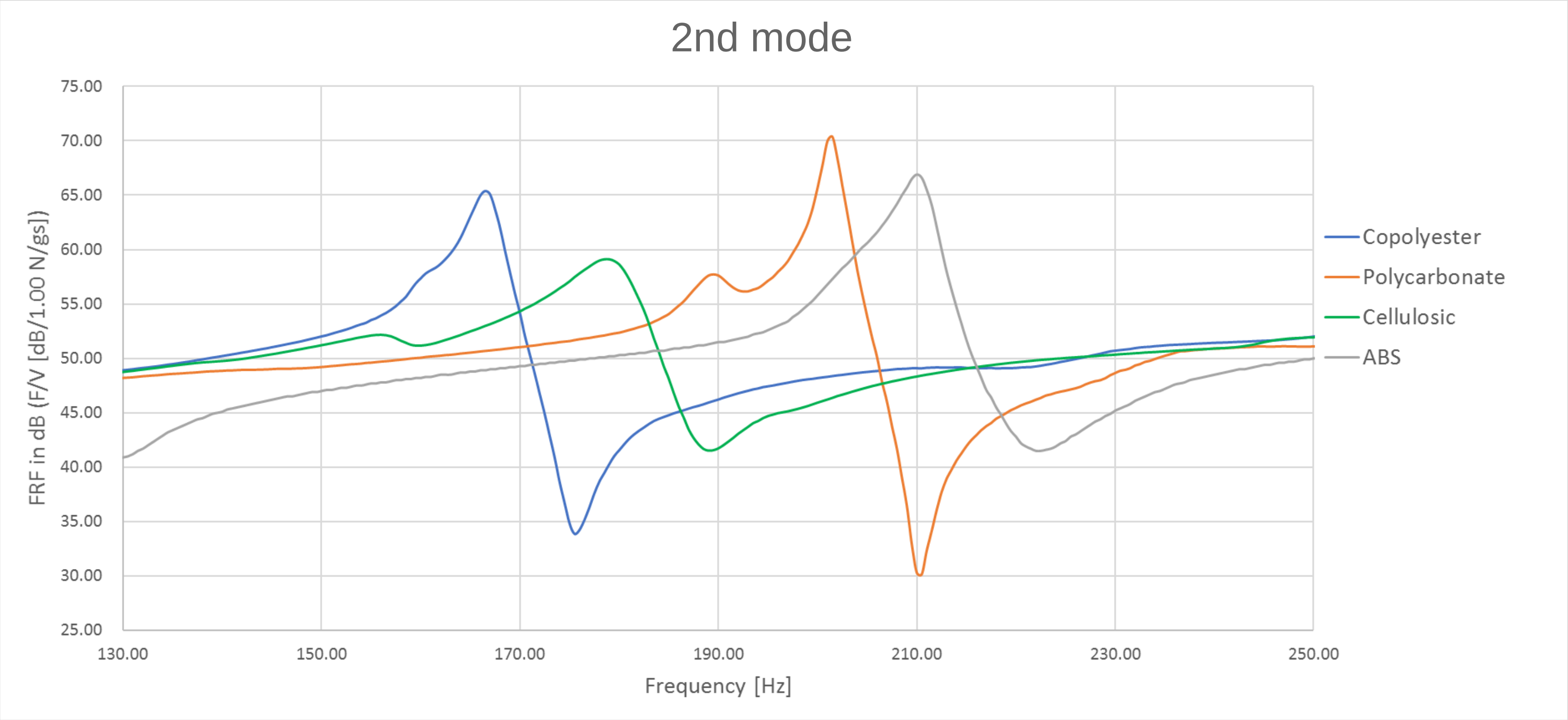
- We analyze the modal response of the material using center point impedance testing and review the **damping loss factor** (tan δ) at discrete frequencies.

FRF example (300 x 20 x 3 mm bar)

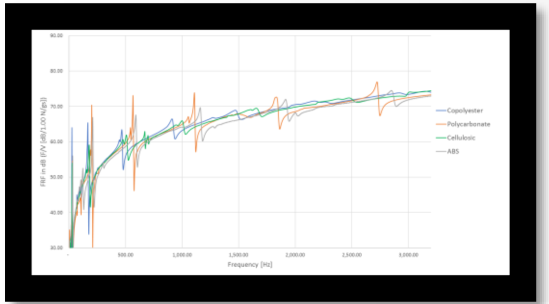


Courtesy of K&S Engineers

Modal resonance—detail



	Mode 2	
Material	**Frequency**	**tan(δ)**
Copolyester	166.5	0.021
Polycarbonate	201.5	0.007
Cellulosic	179	0.045
ABS	210	0.017



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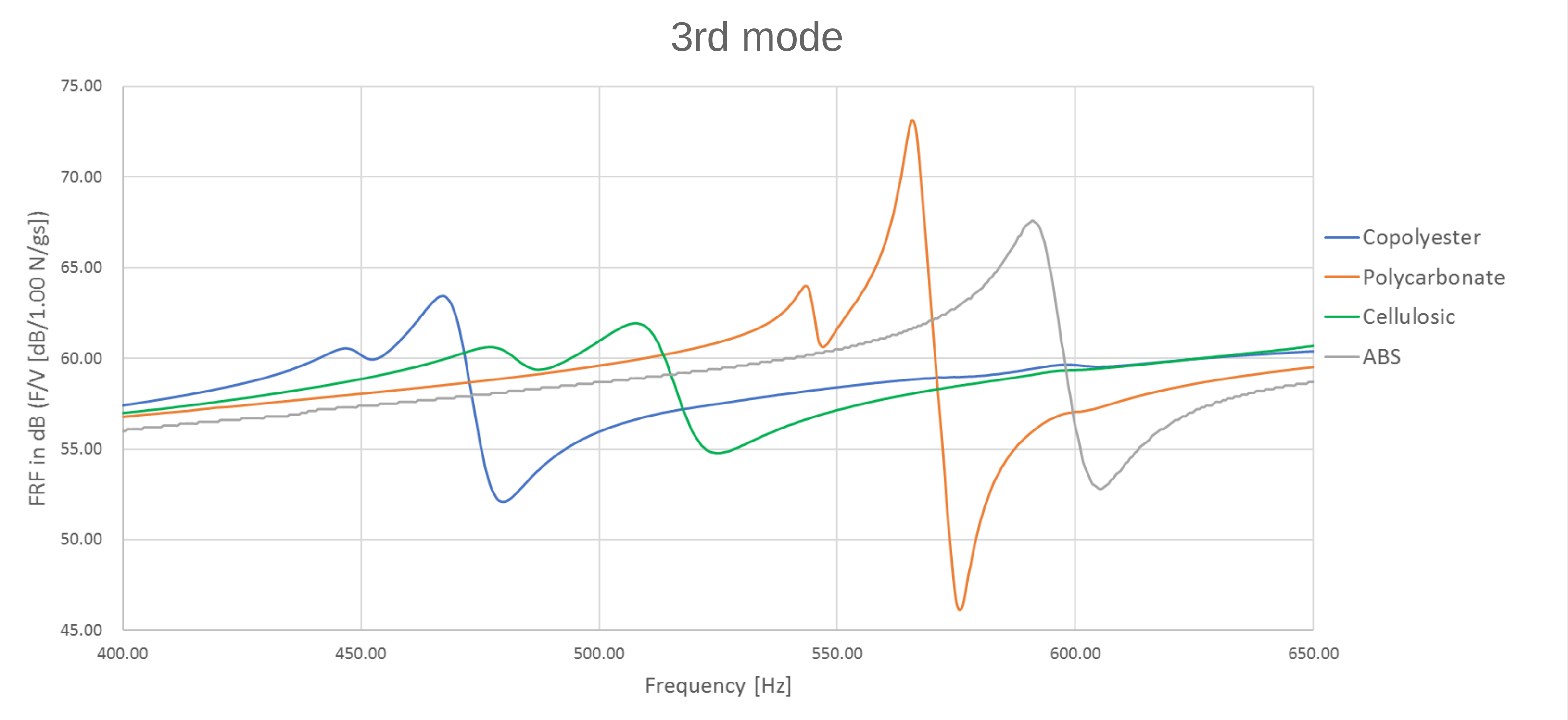
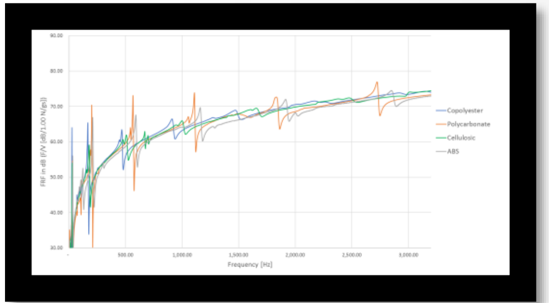
Modal resonance—detail



	Mode 3	
Material	**Frequency**	**tan(δ)**
Copolyester	466	0.033
Polycarbonate	566	0.007
Cellulosic	507	0.133
ABS	591	0.021



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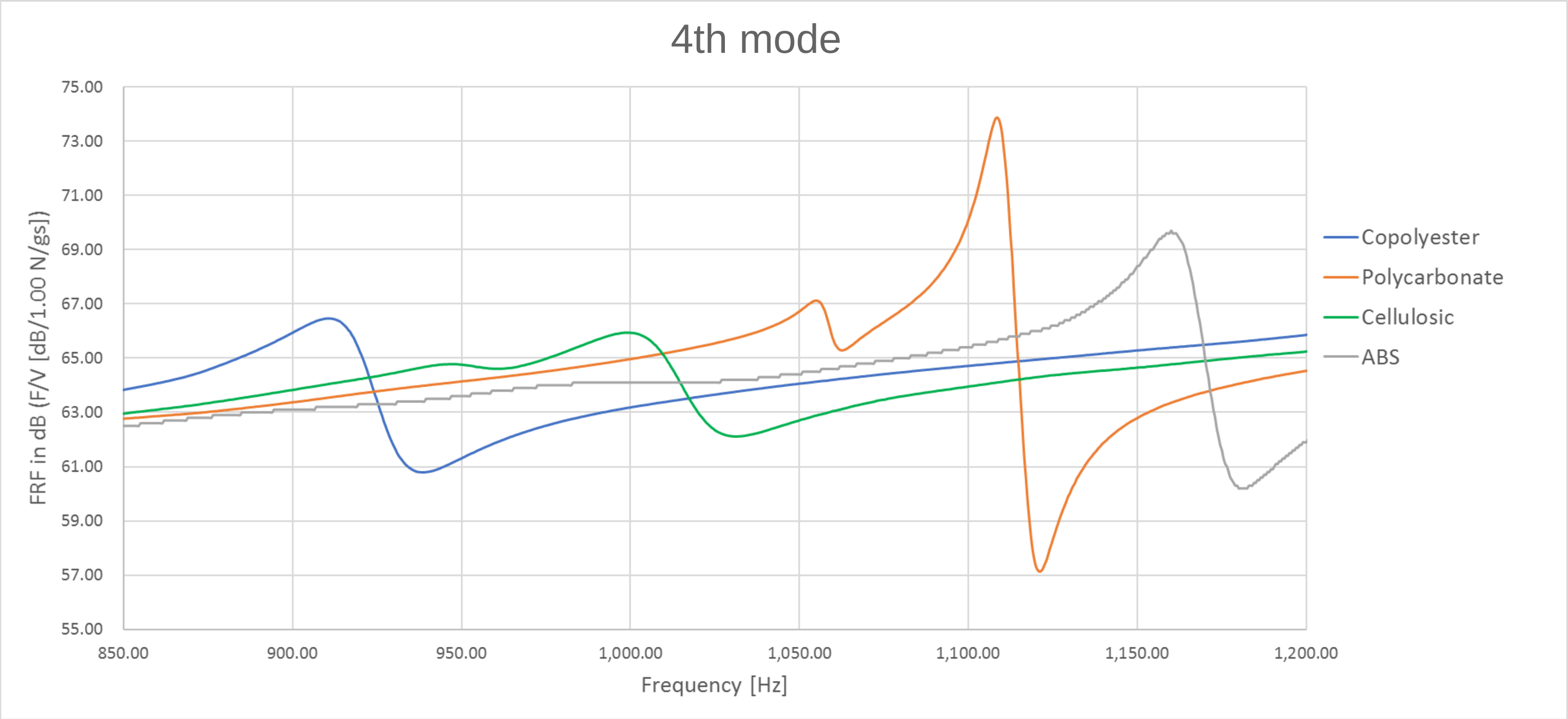
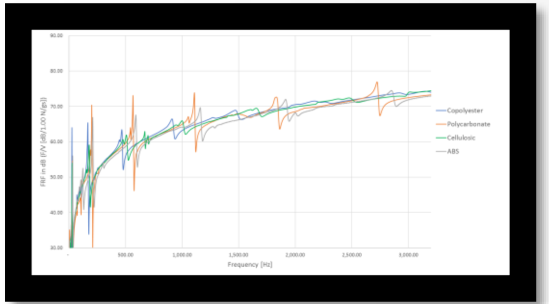
Modal resonance—detail

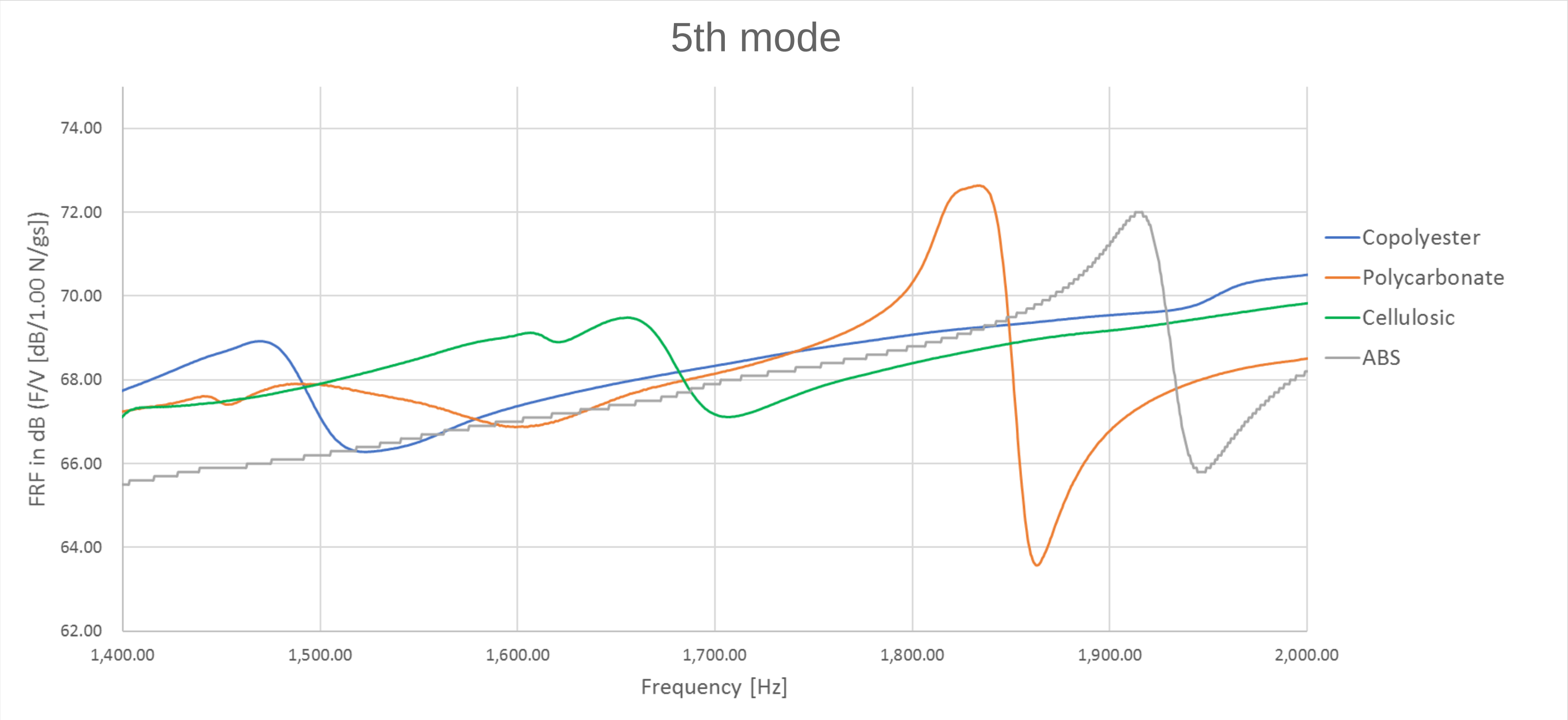


	Mode 4	
Material	**Frequency**	**tan(δ)**
Copolyester	910.5	0.101
Polycarbonate	1109	0.009
Cellulosic	1000	0.173
ABS	1160	0.029

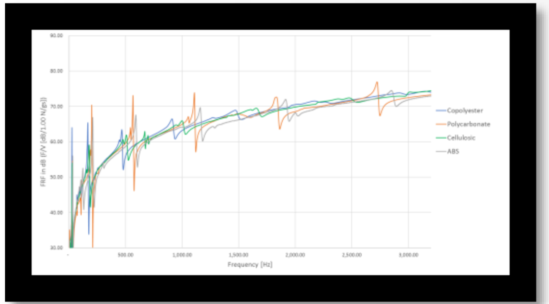


Courtesy of K&S Engineers

Modal resonance—detail

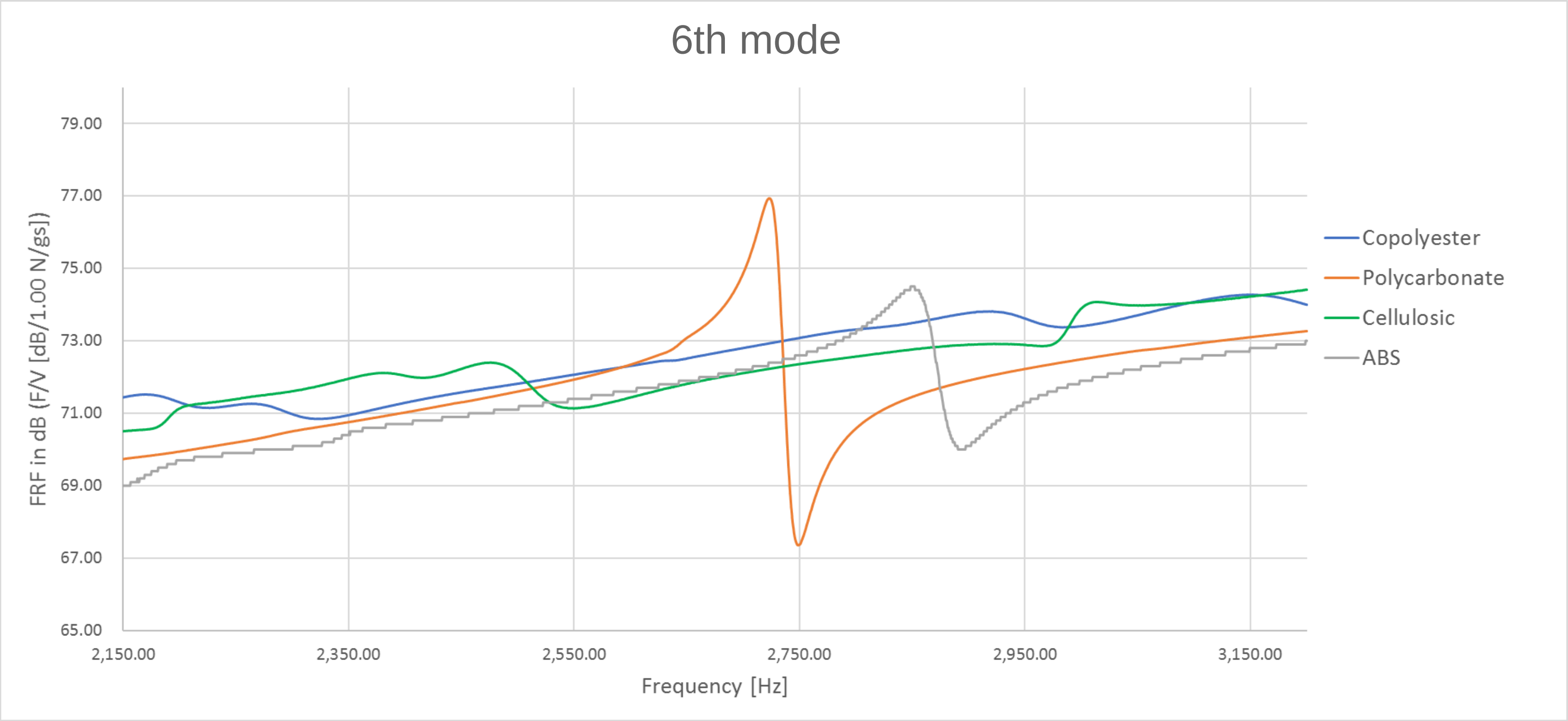


	Mode 5	
Material	**Frequency**	**tan(δ)**
Copolyester	1468.5	0.149
Polycarbonate	1831	0.035
Cellulosic	1655	0.213
ABS	1915	0.047

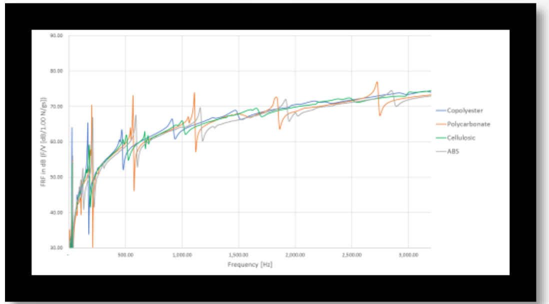


Courtesy of K&S Engineers

Modal Resonance—detail



	Mode 6	
Material	**Frequency**	**tan(δ)**
Copolyester	-	-
Polycarbonate	2723	0.019
Cellulosic	-	-
ABS	2850	0.106



Courtesy of K&S Engineers

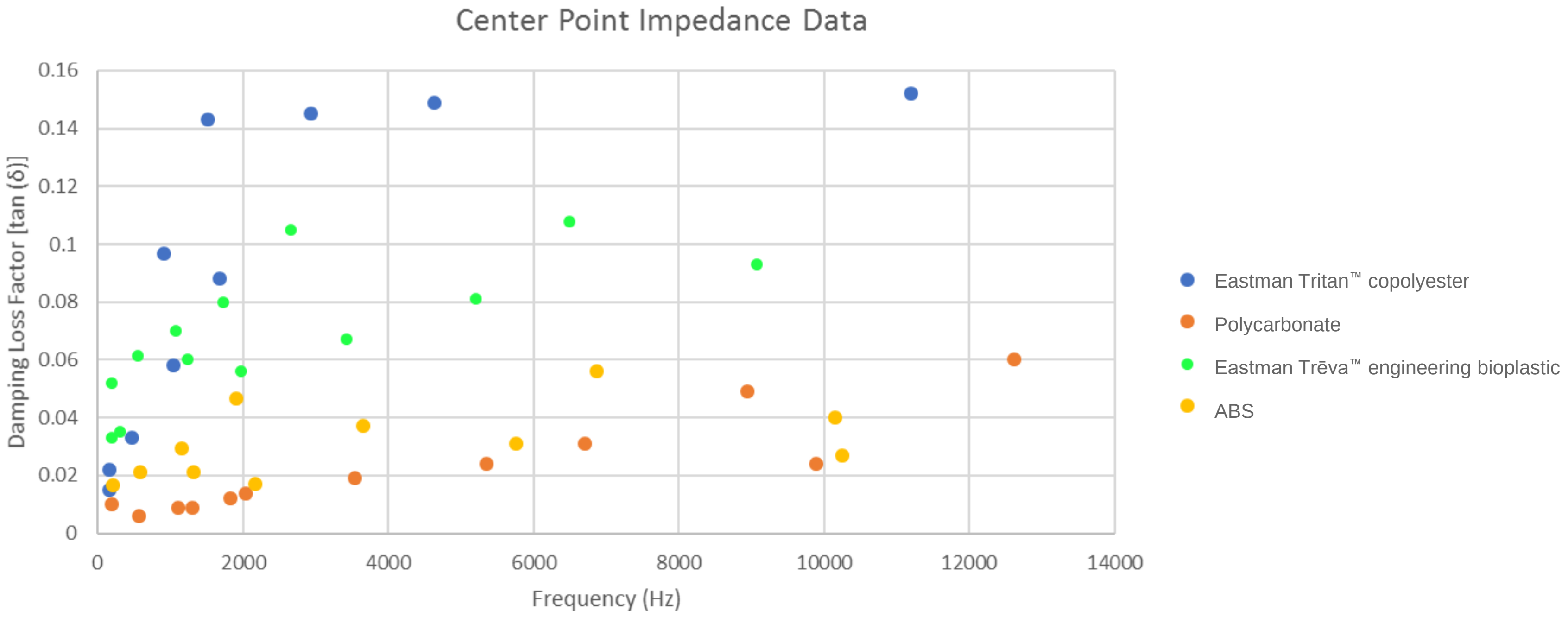
Damping loss factor—composite data

- The process illustrated in previous slides was repeated for several samples.
  - At least three geometries were tested for each material.

- The resulting data spans 100–12,000 Hz to incorporate damping loss factor relevant to audio applications.

Damping loss factor—results

Composite data



Courtesy of K&S Engineers

Summary—vibrational damping performance

- Center point impedance testing can be used to determine damping loss factor at discrete resonance modes to compare materials of similar geometry.

- Frequency response functions can help to demonstrate quantitative and qualitative differences in how different materials damp vibrational energy.

- Copolyester and cellulosic demonstrate **improved damping properties and sound quality 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.**

Audio part testing
(ear buds/in-ear monitors)

Periodic Audio® in-ear monitor (IEM) evaluation

- Eastman collaborated with an external partner (Periodic Audio®) to mold beryllium model in-ear monitor housings with . . .
  - Polycarbonate (Chi Mei, incumbent)
  - Copolyester (Eastman Tritan™ copolyester)
  - Cellulosic polymer
(Eastman Trēva™ engineering bioplastics)
- Acoustic performance of device measured for each material
  - Cumulative spectral decay (acoustic waterfall plot)
  - Total harmonic distortion
  - Subjective listening tests

Courtesy of Periodic Audio

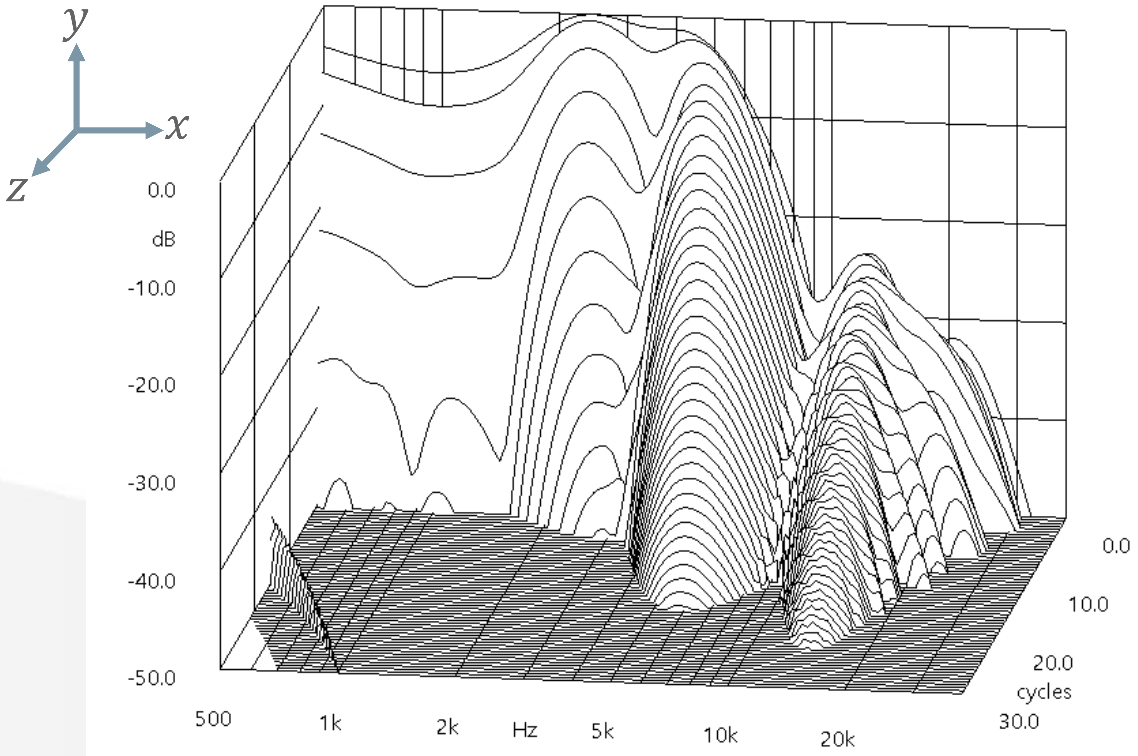
Cumulative spectral decay

Methodology

- In-ear monitor connected via fixture to microphone
  - Specialized fixture acoustic volume is designed to mimic ear canal (20 mm wide)
- FM slide (chirp) is input
  - A pure tone from 20 Hz to 40 kHz
  - Allows generation of 64K points
- Sample with 48 kHz bandwidth; measure to 40 kHz
  - Require 2x frequency generation to accurately measure response in desired region
- Microphone set to 50 dB range
  - Human hearing does not differentiate below 30–40 dB drop.
- Run at 110 dB SPL nominal at microphone to eliminate noise floor
  - Reduces/eliminates ambient noise

The audio waterfall plot

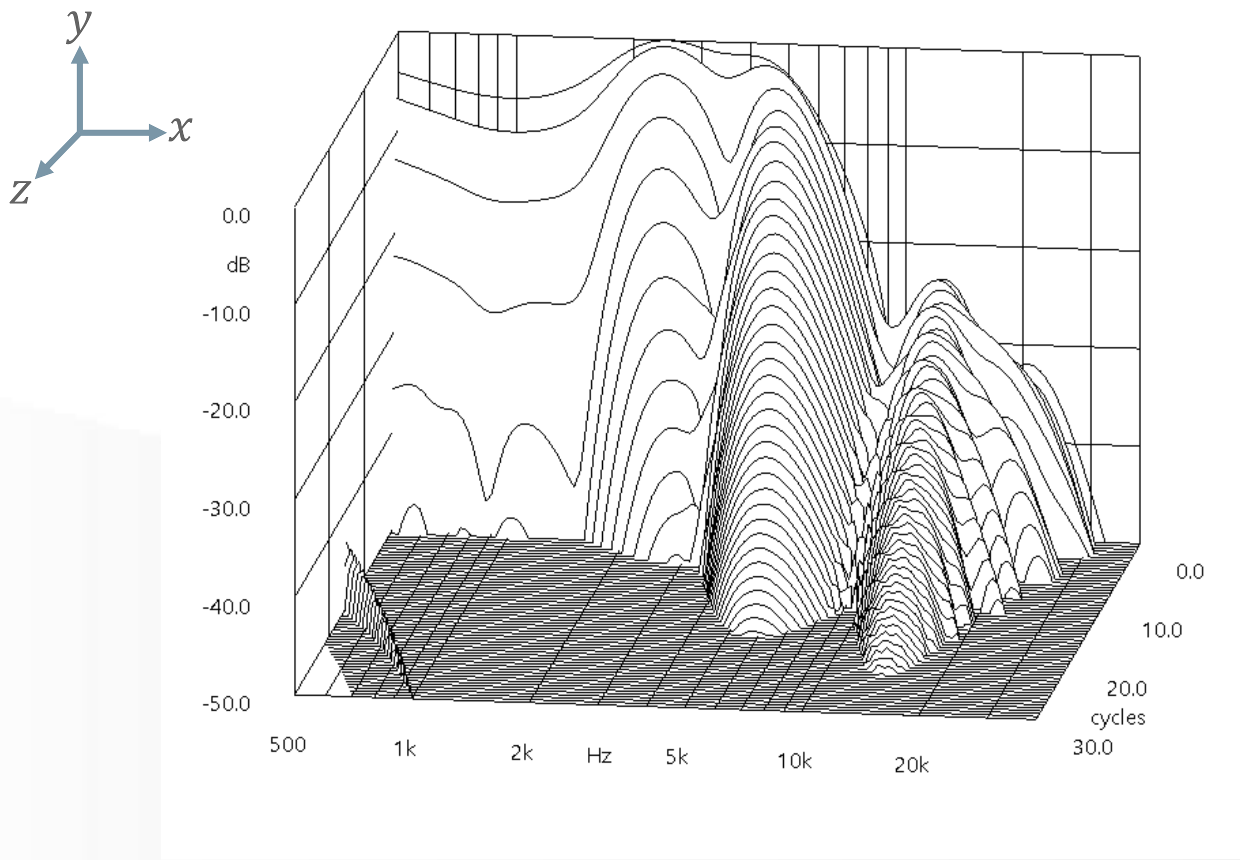
Typical CSD results



Courtesy of Periodic Audio

Audio waterfall plot

CSD results—polycarbonate

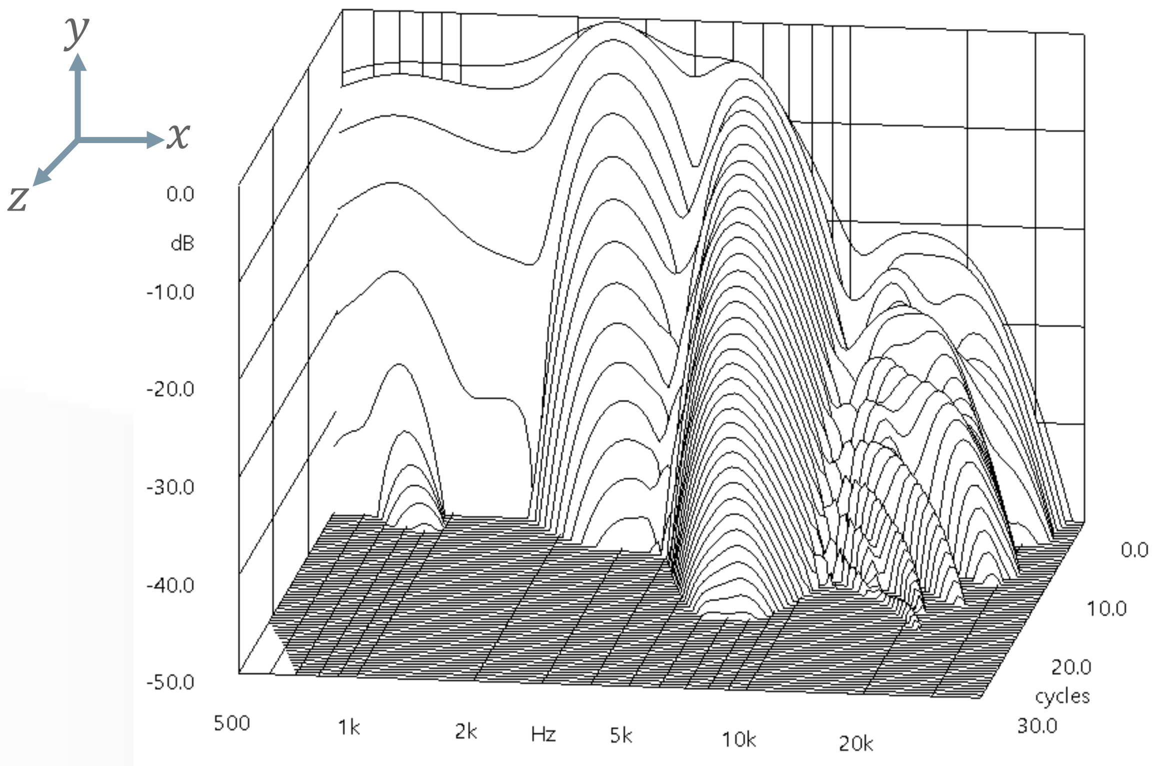


- Typical response; clean
- Not much beyond 20 cycles of resonance above 5 kHz
- Dies out relatively smoothly
- Ridges at 6 kHz and ~14 kHz (nearly 20 cycles of resonance)

Courtesy of Periodic Audio

Audio waterfall plot

CSD results—copolyester

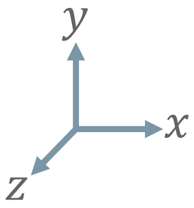


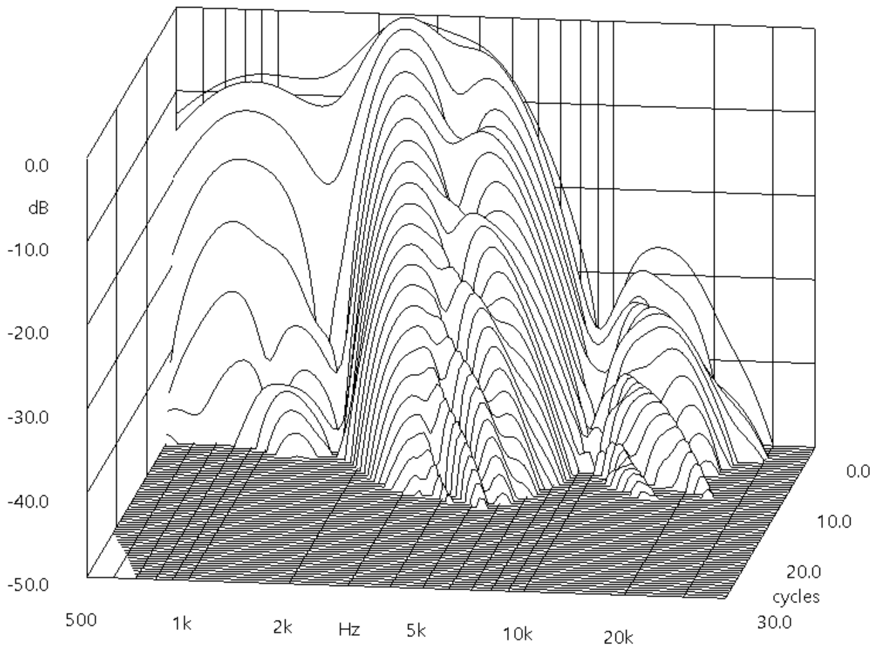
- Improved response
- Ridge at 6 kHz is similar (primary transducer resonance)
- Ridge at 14 kHz is eliminated
- Even with higher energy input, copolyester still decays it faster than the PC

Courtesy of Periodic Audio

Audio waterfall plot

CSD results—cellulosics

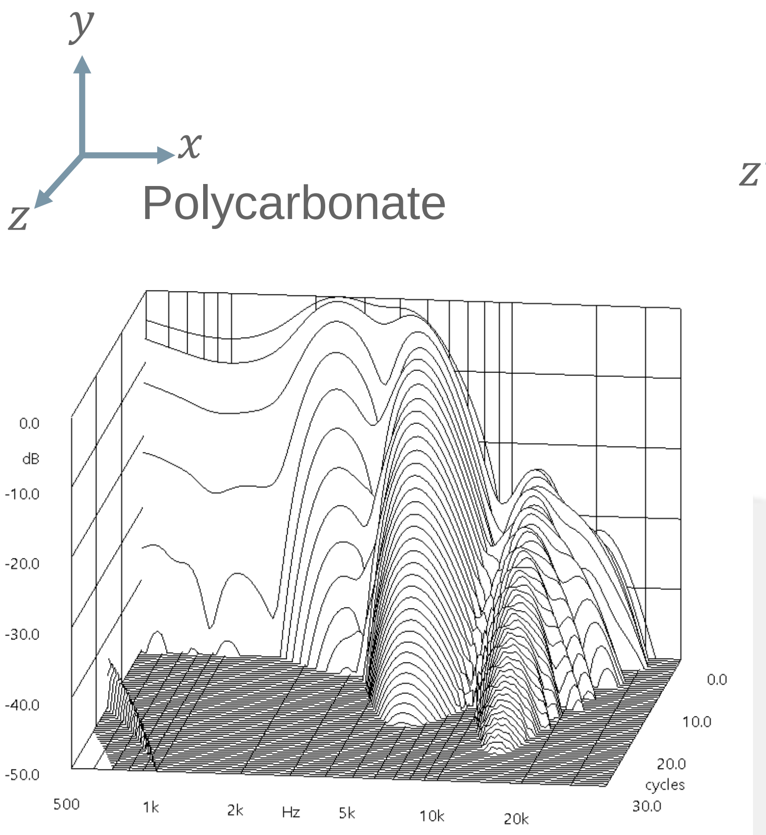


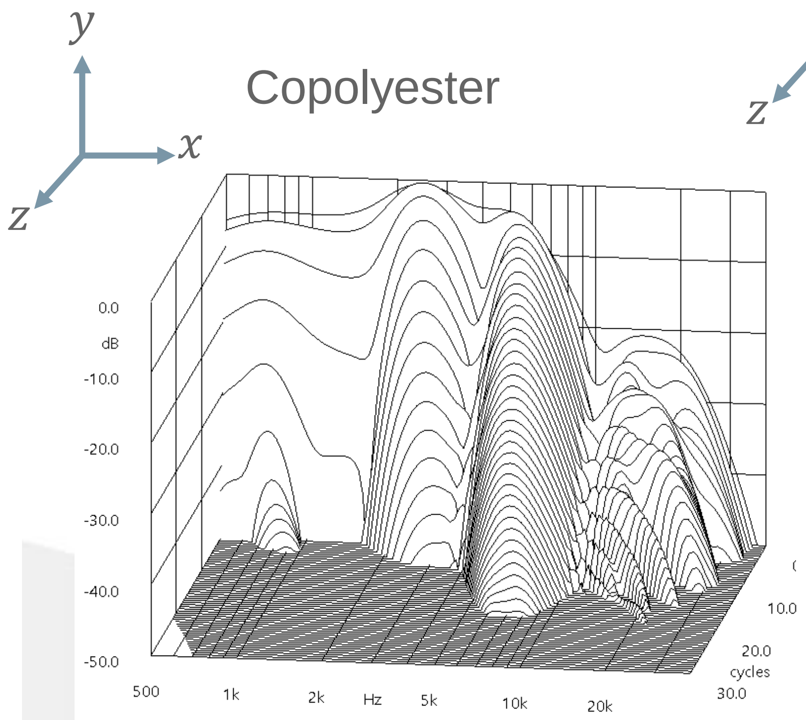


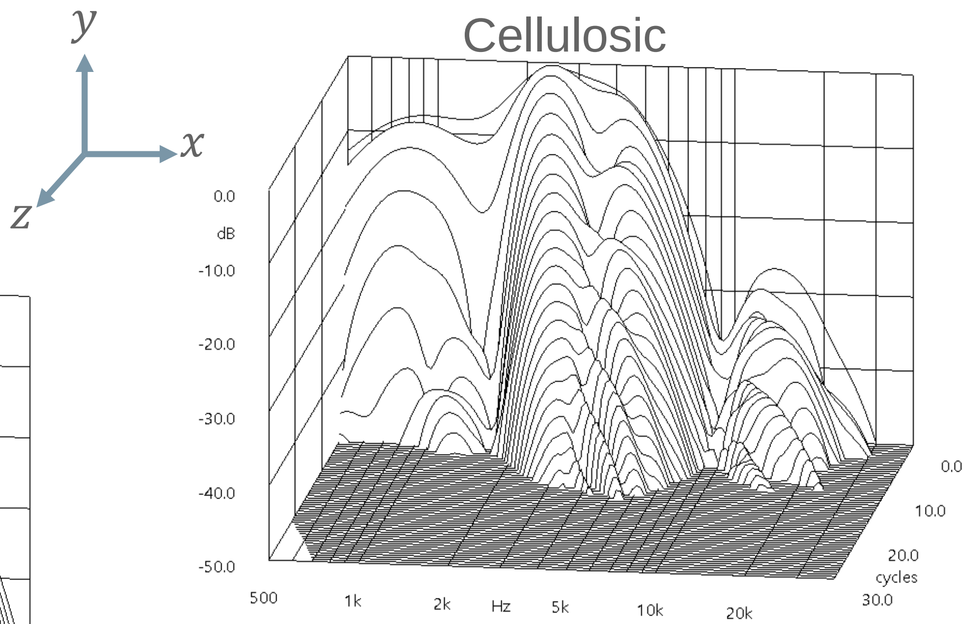
- Very clean response
- No pronounced ridge at 6 kHz; nothing at 14 kHz
- All energy dies very quickly above 8 kHz
- Acoustically, a very dead material

Courtesy of Periodic Audio

Waterfall plot—summary







Courtesy of Periodic Audio

Total harmonic distortion

Methodology

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- Distortion happens when an audio signal is distorted from its original state. We call distortion any form of alteration that you bring to an audio signal, regardless of the type or source.

- THD sweeps were run for each IEM at 100 dB SPL nominal.
  - This particular model has been third-party tested as the “lowest THD IEM on the market.”

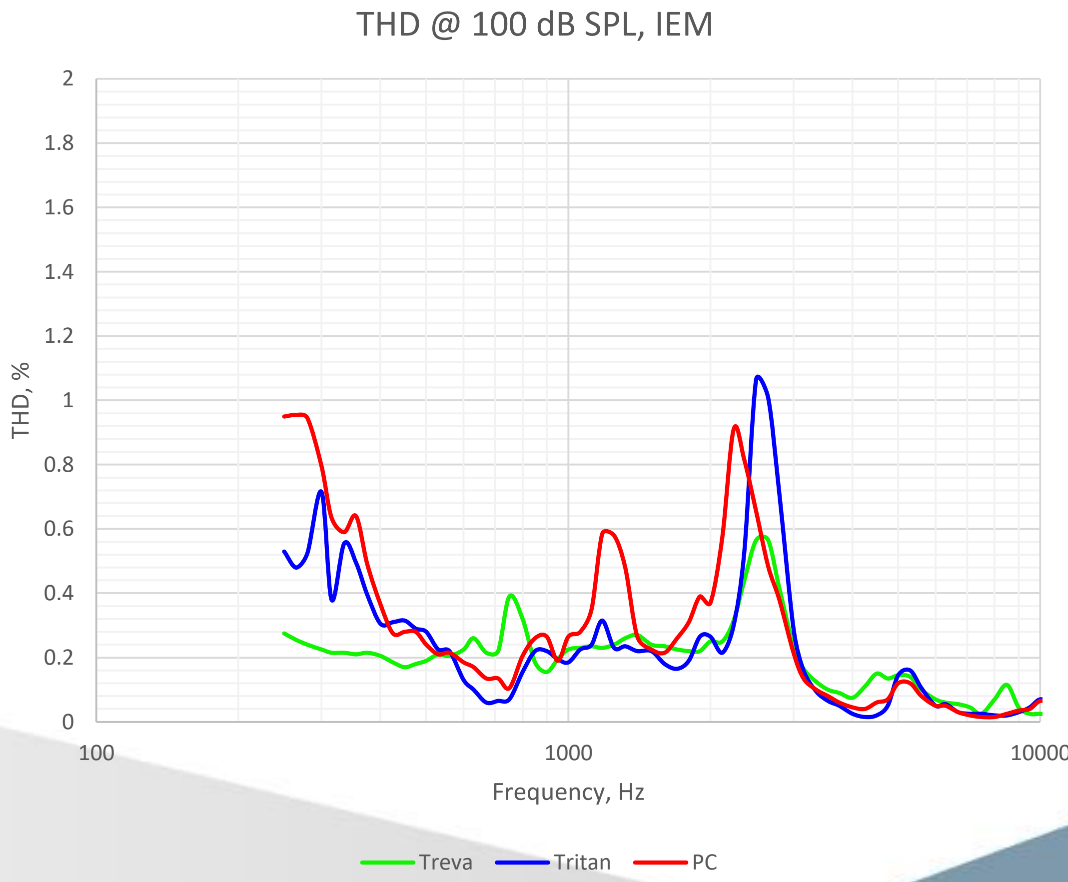
http://audiojudgement.com/total-harmonic-distortion-tutorial-thd/

Courtesy of Periodic Audio

Total harmonic distortion

Results

- PC shows the most peaks for resonance.
- Eastman Tritan™ copolyester is better (although it does have a large primary resonance at 2500 Hz).
- Eastman Trēva™ engineering bioplastic (cellulosic) was the best with the lowest overall level of measured THD.



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Expert listener feedback

- Stock demo track list used (Tidal.com HiFi source):
  - Steely Dan’s “Black Cow”
  - Von Grey’s “Phengophobia”
  - Sarah Jarosz’s “Peace”
  - Dave Grusin’s “Fascinating Rhythm”
  - Two Steps From Hell’s “All is Hell That Ends Well”
  - Keb’ Mo’s “Every Morning”
  - Nirvana’s “Where Did You Sleep Last Night (MTV Unplugged)”
  - Massive Attack’s “Angel”
  - Alison Krauss’s “Let Me Touch You For A While”
  - Johnny Cash’s “Wayfaring Stranger”
  - Holly Cole Trio’s “I Can See Clearly Now”
  - Alanis Morissette’s “The Prayer Cycle”
  - Lake Street Dive’s “I Want You Back”
  - Paul Simon’s “Gone At Last”
  - Cowboy Junkies’ “Walking After Midnight”
- Three listeners, all very familiar with the Periodic Audio IEMs
- Source is a SONOS® Connect, optical out
- D/A is the Channel Islands Audio VDA·2 D/A Converter
- Amplifier is the Channel Islands Audio VHP·2 Headphone Amp

Courtesy of Periodic Audio

Expert listener feedback

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- “Some ***sibilance*** in Holly Cole’s voice ***is reduced***; a bit ***more “space”*** around chorale in ‘The Prayer Cycle’ with copolyester”
- “Cellulosic seems to ***tone down the overly resonant drums*** in ‘I Want You Back’ and bring out more ambience in ‘Walking After Midnight.’ Johnny Cash’s voice is less buzzy—not sure if that is good or bad.”
- **“Changes are subtle, but audible and consistent.”**
- “I think I can feel Keb’ Mo’s foot tapping better with copolyester.”
- “Wow—Massive Attack is even ***more ‘full’ and overwhelming*** with pulsing bass in the cellulosic.”
- ***“‘Buzzyness’*** in Alanis’s voice ***is gone*** with cellulosic.”
- “Walking bass on Paul Simon seems ***more even*** in amplitude with both cellulosic and copolyester.”

Courtesy of Periodic Audio

Summary—IEM case study

- Copolyester and cellulosic both have superior damping characteristics relative to polycarbonate.
- THD improvement with cellulosic and copolyester is measurable.
- Copolyester has something good going on, with better top-end extension yet better damping than polycarbonate.
- Cellulosic is, acoustically, a very dead material for audio applications.
- Consumers who seem to be able to hear fine details a bit better generally prefer the acoustic performance of cellulosic and copolyester.

Courtesy of Periodic Audio

Hypotheses for audio product improvement: We need you!

- Enhance audio performance in devices
  - Reduce resonance of cabinets/enclosures that can contribute to a listener’s audio experience.
- Improve active noise cancellation
  - Prevent feedback and feed-forward systems from going unstable by reducing resonance and interference contributed by housing.
- Reduce load on digital signal processing (DSP)
  - Reduce computational load by removing resonances, leading to longer battery life.
  - Reduce computing power of PCB to mitigate cost.
- Increase efficiency of speaker/microphone systems by reducing echo
  - Allow higher SPL of speaker systems incorporating microphones by reducing echo and reverberation.

Looking (and listening) ahead

- New functionalities
- New applications
- New reasons to reassess enclosure materials—and consider a material change

Thank you!

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