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Last year, the annual *Loudspeaker Industry Sourcebook* (LIS) gained an entirely new dimension with a complete update of the online directory (www.loudspeakerindustrysourcebook.com), which contains even more complete listings than in previous years.

Inside LIS 2017 and the online directory, you will find updated information with all the contacts that make it an invaluable resource for the industry. In the magazine, you will also find high-quality Industry Features and Reports that provide an invaluable perspective of our industry's evolution. In cooperation with the Association of Loudspeaker Manufacturing and Acoustics (ALMA) International, most of the articles we selected for this year's edition are based on presentations that took place during ALMA's International Symposium & Expo 2017. This should provide you with an idea of the incredible value of attending this event, for which *audioXpress*, *Voice Coil*, and the *Loudspeaker Industry Sourcebook* are official media partners.

Every year, we also ask audio and speaker industry experts about their business expectations and the trends they consider most relevant. From this sampling, we can conclude that the most relevant technologies over the last 24 to 12 months, promise to create a significant impact throughout the industry. Most importantly, there are also new and significant trends just ahead.

As most of the experts highlighted, USB-C, Lightning and related audio input/output interfaces will continue to be an important area to consider, increasing opportunities for the audio industry.

Although headphones continue to be popular, the fastest growing segment of the audio industry is currently in loudspeakers, with consumers embracing the new class of portable wireless speakers, multi-room audio, and with new categories of smart- and voice-controlled speakers gaining traction and generating a new phenomena in terms of consumer audio. In 2017, we have seen how the Amazon Echo voice-controlled speaker inspired the industry for the possibility of smart speakers, creating a new category. Connected speakers—because that will be the new class, not necessarily only voice-controlled—are already the fastest growing audio product segment for 2017. Adding to those platforms, the combination of powerful DSP, microphone arrays, sensors, and the latest wireless standards and network connectivity, will create a foundation with an incredible potential to revolutionize all loudspeaker applications,

Another notable trend focuses on different approaches in speaker design and in transducers, inspiring new designs in applications. In 2017, loudspeaker manufacturers are rethinking the conventional and challenging what's been possible.

Finally, as reflected in ALMA International's theme for 2018, "The Revolution of the Audio Signal Chain," the signal path from source to speaker will continue to evolve, from a variety of discrete components to converged and integrated, embedded, networked, and increasingly "intelligent" solutions, ultimately determining the quality of audio. The theme for AISE 2018 will focus on this convergence and how this will impact transducer design, the integrated speaker, and overall loudspeaker performance.

We hope you enjoy the annual edition of the *Loudspeaker Industry Sourcebook*! —*The Loudspeaker Industry Sourcebook* Staff

Audio Finds Its Voice

People are spending more money on recorded music and audio technology is developing fast, bringing many opportunities for speaker manufacturers

By
Jack Wetherill
(Futuresource Consulting)

Worldwide consumer spending on recorded music is on the rise, up 8% in 2016 to $20 billion and the outlook is one of further growth, driven primarily by the uptake of music streaming services. About 129 million consumers were paying for streamed music by the end of 2016 and many others are content to stream for free (83 million on Spotify alone). Over half of smartphone owners use their phone as a music source and by the turn of the decade, Futuresource Consulting believes that the worldwide base of smartphone owners will have grown by a further third to 4.8 billion people.

Against this rosy economic background, music listening has become a personal experience, often enjoyed on headphones and while on the move. As a result, the headphones market has experienced consistent growth in units and revenues for more than a decade (see **Figure 1**). Futuresource data shows that 2016 turned in record growth of 19%

HEADPHONES AND WIRELESS SPEAKERS ARE KEY GROWTH AREAS

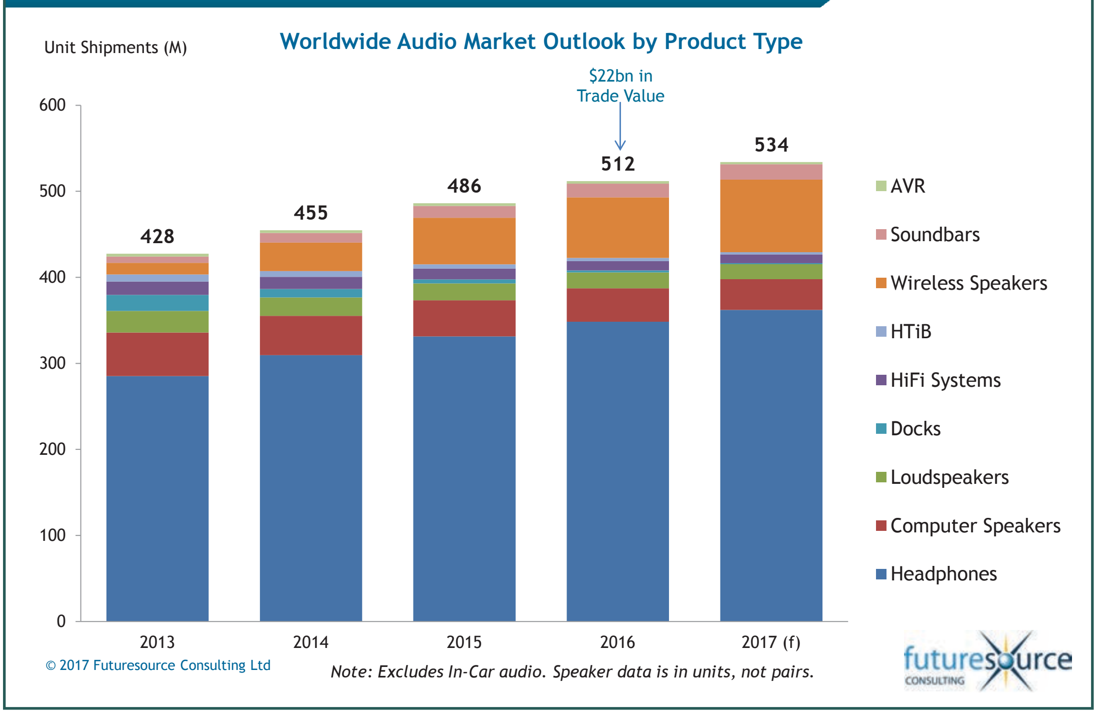

Figure 1: For the headphones market, Futuresource data shows that 2016 turned in record growth of 19% in value to generate trade revenues of $8 billion, shipments growing 6% to 349 million units.

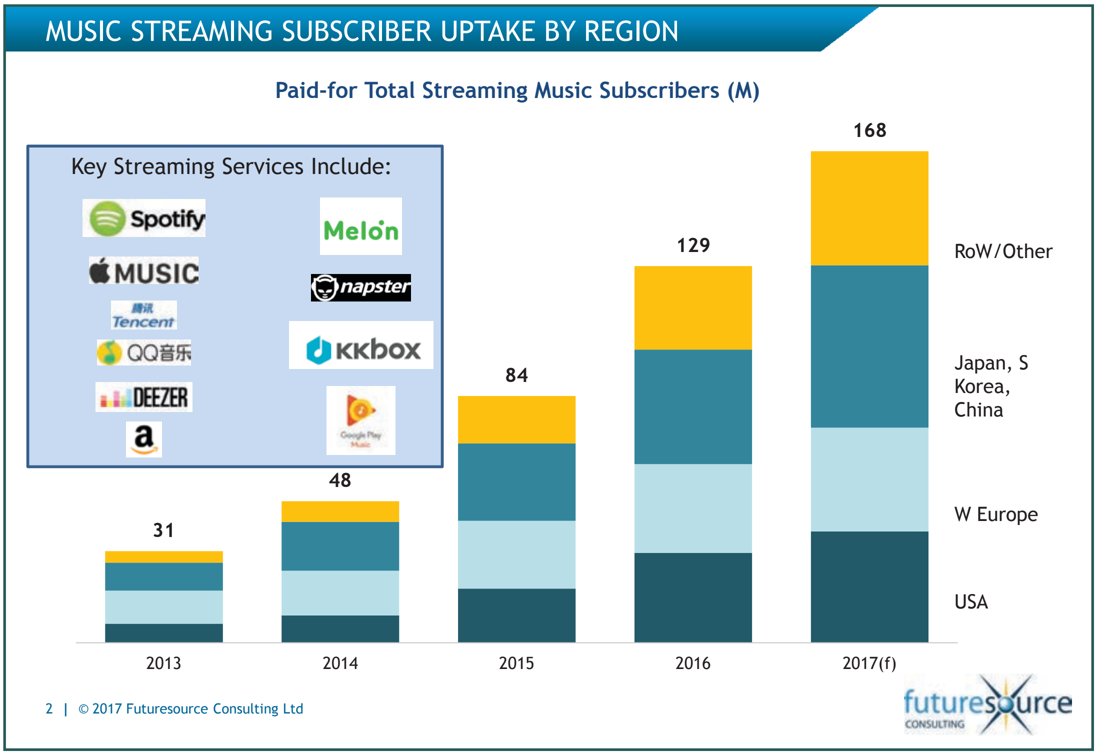

Figure 2: As a result of the success of streaming music, demand for wireless speakers continues its upward trajectory, exceeding 70 million units with trade revenues growing 36% to approach $6 billion.

in value to generate trade revenues of $8 billion, shipments growing 6% to 349 million units. The average price per pair of headphones was $38.50 in 2016, an increase of 14% in just one year. Over time, headphones have incorporated many additional features although the stand-out feature is wireless connectivity. Wireless models recorded 57% unit growth in 2016. The bulk of headphones continue to sell at price points less than $25, although the share of this segment has fallen from 73% in 2012 to 56% in 2016, signifying a shift in consumer spending to better quality models with more features.

Fashion and lifestyle play an important part of the pricing strategy for many brands in this market, celebrity endorsements additionally create more value to some brands, while premium headphones vendors rely on their reputation and brand heritage.

Wireless Speakers

Headphones makers are not the only beneficiary of this growth in music spending and the shift to streaming (see **Figure 2**). Demand for wireless speakers continues its upward trajectory, growing up 30% in 2016 to exceed 70 million units with trade revenues growing 36% to approach $6 billion. Initially, demand was the result of the desire to play out primarily from the smartphone and audio brands (e.g., Bose, JBL, and Sonos) have capitalized upon this.

During 2016, Voice Personal Assistant (VPA) speakers became the focus of much attention due to the success of Amazon Echo and the debut of Google Home speakers. Futuresource expects voice control to change how we interact with our electronics—from controlling our in-car and in-home entertainment, to white goods and

Photo 1: Voice Personal Assistant (VPA) speakers are turning Amazon and Google into significant audio hardware brands.

Photo 2: Immersive sound is driving the high-end audio market and finding its way into a broader range of devices.

smartphones. Wireless speakers seem well placed to benefit from the ease of control that voice interface brings and to become a major control hub for consumers to interface with their smart home devices and the Internet in general.

Amazon and Google are rolling out VPA speakers to further their service reach into consumers' homes rather than sell hardware, but in the process they have tremendously boosted sales of Wi-Fi speakers and become major audio hardware brands in their own right (see **Photo 1**). Traditional audio speaker brands are all assessing how to respond to the challenge posed by voice control, knowing they do not have the funds to develop their own voice assistant technology. As a result, partnerships are forming and Amazon is enjoying the early successes, signing up brands such as Bose, Harman, Sonos, and those on the Play-Fi platform to adopt Alexa in future products. These are early days for voice control and with five main contenders in the English language VPA race—Apple (Siri), Amazon (Alexa), Microsoft (Cortana), Google (Google Assistant), and Samsung (Bixby)—there is a lot of ground to fight for, with no clear winner in sight.

Google and Amazon wireless speakers (including Dot) sold 8.4 million units in 2016, forming 56% of the Wi-Fi market, supporters of which were seeking a killer application after the desire for multi-room playback appeared to be stalling.

Despite the attention grabbing VPA Wi-Fi speakers, Bluetooth-only devices still form 80% of the wireless speaker market, with consumers appreciating their relative simplicity and lower price points, especially in emerging markets. Bluetooth quality and features are good enough for most consumers and the next release of Bluetooth specs promises further enhancements, which should reinforce their popularity.

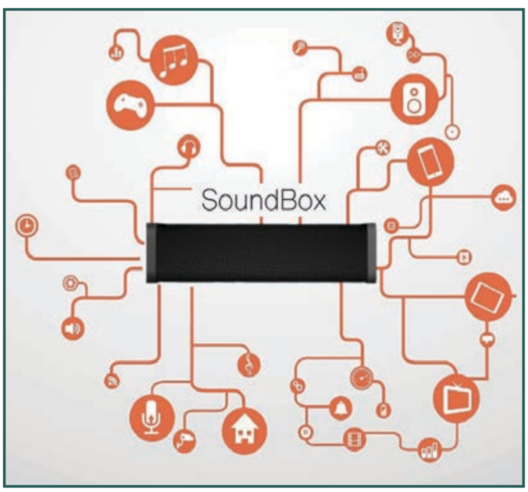

Photo 3: Netgem's Soundbox is a new configuration of set-top box and soundbar.

Traditional Loudspeakers

Beyond wireless speakers, areas of growth for standalone speakers are harder to identify. Traditional bookshelf and floorstanding speakers continue to fall out of favor (down 5% in 2016), largely the casualty of consumers migrating from packaged to digital music and unaware of how to bring their analog hi-fi onto their network despite the availability of digital bridges and Google Chromecast audio dongles.

Loudspeaker manufacturers are working in an age where mainstream consumers crave simplicity and are increasingly loath to devote space in their homes to speakers, wires, and component devices. Sales of dedicated home-theater speakers declined by an estimated 9% in 2016 against the background of a falling A/V receiver market. Home-theater-in-a-box (HTiB) systems cannibalized this market in the first decade of this century, but HTiB is now giving way to soundbars. HTiB at their height sold 10 million units per year (usually with six speakers) but now sell below 3 million in 2017. Soundbars have been a success story based on simplicity, with the majority of the soundbars sold by TV brands leveraging the fact that their flat-screen sets do not generally provide good sound. Soundbar shipments rose 15% to reach 16 million unit in 2016, up by 17% in trade value to generate revenues in the region of $2.8 billion. However, some Western European markets are experiencing a slowdown in sales, partially impacted by a stagnant TV market and a general maturity in demand for the segment. These factors leave question marks over where the next opportunity is for loudspeakers in the home-theater context. Consumers are now being offered flexible options involving wireless speakers (e.g., Samsung's 360 speakers), although the likelihood is that this will result in fewer speakers being sold.

Consumer desire for concealment is helping fuel demand for in-wall and in-ceiling speakers. Increasingly sophisticated options provide almost total invisibility and good quality sound. Demand is growing by 5% per year, riding on the wave of the growth in custom install, especially in the US, where house building is again on the rise. High-end models are also being deployed for top of the range home-theater installations, where 4K pass-through and more immersive sound, most notably from Dolby Atmos, but also DTS:X and Auro are encouraging system upgrades (see **Photo 2**).

Sound Processing Technologies

These companies are also pitching their sound processing technologies as solutions to upgrade sound in other devices (e.g., smartphones, tablets, and PCs). Lenovo and LeEco devices with Dolby Audio were shown at CES 2017 and Atmos is now supported by Windows 10.

Device makers work in a highly competitive environment and good sound remains a way of standing out from the crowd. Pay-TV companies are also recognizing this and experimenting with new configurations of devices such as Netgem's Soundbox which combines the features of a set-top box into a soundbar (see **Photo 3**), and SK Telecom's Surround STB, where a pair of speakers features integrated set-top box technology as an offer to high-end subscribers.

Cars are increasingly viewed as the next frontier for premium entertainment thanks to developments in connectivity and the expectation that owners will be able to spend more time enjoying entertainment as their driving responsibilities recede thanks to autonomous driving systems. In-car entertainment hardware is a $26 billion global business and speaker demand will benefit from developments in this sector, which Futuresource believes is set for annual growth of 5% per year in value.

Company Mergers

Against this growing demand for wireless, for discreet devices and premium sound in portable devices and in-car the industry has seen a number of mergers and acquisitions over the past year. EVA's acquisition of Bowers and Wilkins emphasizes the link increasingly made between audio and smart home. Relationships with the custom install channel are becoming more important as high street retail recedes, something Sound United no doubt bore in mind when buying D & M Holdings, a deal which brings together the Polk, Definitive, Boston Acoustics, Enon, Marantz, and Heos brands.

Tessera's investment in DTS is a reminder that audio technology can be allied with imaging and networking technologies to provide products that will meet demand for smart audio devices that function as part of the broader smart home. Tessera—now rebranded Xperi—also sees DTS as a means to further its in-car ambitions.

The biggest deal of all was Samsung's $8 billion takeover of Harman, the key motivation for which was access to connected car solutions, which accounted for 65% of Harman's sales last year. Only two years ago, Harman had acquired Bang & Olufsen's Automotive car audio business. But Samsung also harbors ambitions in professional and consumer audio and the deal sees brands such as JBL, Revel, and Soundcraft come under Samsung ownership.

Loudspeaker manufacturers are operating in a rapidly changing landscape. Consumers increasingly crave simple, discreet products that provide good sound and perform a range of tasks. The growth in wireless speakers will be further fuelled by VPA features, more sophisticated sound will be incorporated into everyday devices (e.g., smartphones and PCs) and the in-car opportunity will be substantial. ***LIS***

About the Author

Jack Wetherill is Senior Market Analyst, Consumer Electronics at Futuresource Consulting. With more than 15 years of research and consulting experience, Wetherill leads Futuresource Consulting's Home Consumer Electronics team. He joined Futuresource in 1999 after several years working in Library and Information Management. During his time at Futuresource, Wetherill has been closely involved in the tracking and forecasting of the global market for Home A/V products. He currently drives Futuresource Consulting's continuous reporting into TV, Home Audio & Video Hardware, Smart Home, and Appliances and is a regular speaker at conferences.

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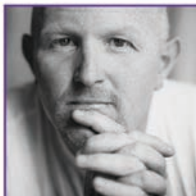

Quality Audio Can Exist

Key is the Signal Path

By
Dan Foley
President, Association of Loudspeaker Manufacturing & Acoustics (ALMA) International

ALMA International's goal for 2018 is to promote the importance of sound engineers having a deeper understanding of every aspect of the audio signal path and its impact on audio quality.

The opportunity for the average consumer to experience higher-quality audio in 2017 has never been better. Despite previous assertions that the days of high-quality audio were long gone, those being the "good old days" of turntables, separate preamps, power amps, and so forth, audio products that produce high-quality sound are very much in demand.

The sound systems that come standard in vehicles selling for less than $20,000 can rival those of luxury cars from a decade ago. Headphones costing $300 or more are now the norm. Focal, renowned for its audiophile loudspeakers and high-end studio monitors, released two headphone models in 2016, its first ones ever. Despite selling prices in the four-figures, Focal had a several-month backlog shortly after these headphones were introduced.

Audio Signal Paths Have Changed

What is in the past has to do with the audio signal path. For the vast majority of audio products, the audio signal no longer passes through discreet components, such as an equalizer, preamplifier, and power amplifier before it reaches the loudspeaker. Modern audio products have converged these discreet analog components and added digital hardware and signal-processing algorithms. Turntables no longer just convert the undulations in a record groove to a low-level voltage. Integral USB technology enables the music listener to rip vinyl directly to a digital format as it integrates the cartridge PLUS phono preamp, analog-to-digital converter, USB chip set and possibly on-board DSP, into a converged product. Modern powered headphones, at a minimum, incorporate amplifiers that are typically a Class-D design. Noise-cancelling headphones are that much more complicated with integral microphones, DSP and Wi-Fi and/or Bluetooth technology. Sound bars typically include all of these features plus many loudspeaker transducers packaged in a single enclosure so as to achieve a surround-sound experience with no physical surround speakers.

With today's complex products, there are many more parts of the signal path where sound quality can be diminished prior to reaching the plus and minus terminals of a transducer's voice coil. When this does occur, the consumer will often blame the loudspeaker when the root cause has nothing to do with acoustic/electroacoustic aspects of the products' design.

The Impact

How does this convergence impact the loudspeaker industry, especially for loudspeaker transducer designers? The impact is that loudspeaker designers must be cognizant of how the various parts of the audio signal path, in particular any digital portion, will affect the audio sound quality emanating from his or her design. The following is an example of how the loudspeaker could be falsely blamed for poor sound quality when the root-cause has nothing to do with the transducer.

A few years back, I was attending a Bluetooth Unplugfest where unreleased Bluetooth products are tested to ensure they "play nice" with other Bluetooth products in regard to discovery, pairing, and streaming audio with no (major) quality degradation.

I was testing a second-generation product that was implementing a new Bluetooth voice codec that enabled speech to be sampled at 16 kHz instead of 8 kHz. By extending the speech frequency response by one octave (up to 8 kHz vs. 4 kHz), the person listening to the conversation on this product will hear speech that sounds more natural. I successfully paired this product with the audio analyzer I was using and confirmed the Bluetooth audio sampling rate was indeed at 16 kHz.

I streamed some speech files and viewed the response from its amplifier output on a live FFT trace (this product was designed to use external loudspeakers). I immediately noticed that there was little energy above 4 kHz even though these speech files contained considerable energy above 4 kHz, especially the sibilance portions (e.g., "S" sounds). I then ran a frequency response sweep from 20 Hz to 8 kHz and saw that above 4 kHz, the response rapidly dropped off.

The engineer with whom I was interacting was involved with only the Bluetooth-protocol aspects of the design and did not know what was happening in regard to the audio signal processing. He immediately contacted his audio DSP colleague back at his company. This engineer looked at his DSP code and discovered that the original anti-aliasing filter designed to work with the older 8 kHz sampling-rate codec had never been changed to reflect the 16 kHz sampling rate being used with the more modern Bluetooth voice codec. This negated one of the important aspects of this second-generation product—namely a more natural-sounding conversation when used as a speakerphone.

The typical end-customer would have no idea that the anti-aliasing filter had been set incorrectly and most likely would blame the loudspeaker because "it does not sound good." How often have you heard that customer comment and that's all the information you have to help you find the root-cause of the poor sound quality?

AISE 2018

The theme for the ALMA International Symposium & Expo (AISE) 2018 is "The Revolution of the Signal Chain" and the example I provided is one of many where audio engineers, not just transducer engineers, need to have a deeper understanding of every aspect of audio signal path and its corresponding impact on audio quality.

The transducer engineer needs to be aware of how every part of the signal chain can impact a loudspeaker's performance. But this also applies to the engineers designing amplifier chips and developing DSP algorithms. Just because some type of "cool" signal processing can be achieved in a DSP chip does not mean it's the elegant engineering solution to achieving better audio quality. Choosing the appropriate transducer in the first place and/or a better acoustic design may be the actual elegant solution. If the people making the decisions on loudspeakers are not educated as

to a particular electrodynamic transducer's limitations regarding sound reproduction, then poor choices can be, and often are, made. The transducer engineer is then left with cleaning up a mess of which he or she was never even aware.

The days of having a multi-decade career designing one part of an audio system and throwing one's design over the proverbial wall are long over. Today's engineers designing an audio system, or any of its components, needs to have at least a basic understanding of the complex interactions of each part of the entire audio signal path. This requires a willingness to learn about technologies for which one may have been formally trained.

Attending meetings organized by professional technical organizations is a great way to learn about emerging technologies as well as expanding one's network of technical contacts. For those of you associated with a company that utilizes many engineering disciplines, do not hesitate to approach your colleagues who have expertise in areas other than your own. In my three-plus decades involved in the technical side of audio, whenever I approached another engineer with a sincere willingness to learn more about his or her world, he or she was always very happy to further educate me. In return, I often was able to provide them some "golden nuggets" of knowledge applicable to their work. What initially started as a teacher/student relationship often became friendships that have lasted many years and been strengthened by our mutual passion for the audio industry. ***LIS***

About the Author

Dan Foley has been in the audio test and measurement industry for more than 35 years and has a broad background in analog and digital audio test, acoustics, electro-acoustics, telecom audio, as well as vibration measurement and analysis. He was recently elected President of the Association of Loudspeaker Manufacturing & Acoustics (ALMA) International, is a member of Audio Engineering Society (AES) and the Institute for Electronics and Electrical Engineers (IEEE), and has many close ties to the audio industry, having worked for the likes of Bose, Listen, and Brüel & Kjær. Foley has developed and taught seminars regarding digital signal processing techniques used in acoustic, vibration and audio test, and measurement applications. He currently serves on the IEEE Transmission Access & Optical Systems Committee as well as standards committees of AES. Foley is also an Adjunct Faculty Member at Worcester Polytechnic Institute where he is developing a curriculum in audio product design engineering.

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ABOUT ALMA INTERNATIONAL

The Association of Loudspeaker Manufacturing and Acoustics (ALMA) International is a not-for-profit trade association. ALMA is the only international trade association dedicated to improving the design and manufacture of loudspeakers. ALMA's membership is comprised of loudspeaker designers and manufacturers as well as suppliers of test and measurement equipment and other products, consultants, and other service providers to the loudspeaker industry. Individuals, academic institutions, and educators participating in the loudspeaker industry are encouraged to join. ALMA enjoys and welcomes a global membership. The organization was founded in 1961 as "The American Loudspeaker Manufacturers Association" In 2001, ALMA changed its name to "Association of Loudspeaker Manufacturing and Acoustics International" to reflect a global reach and to embrace a more diverse membership.

Mission Statement:
"ALMA is The Source of standards, news, networking, and education for technical and business professionals in the acoustics, audio, and loudspeaker industry."
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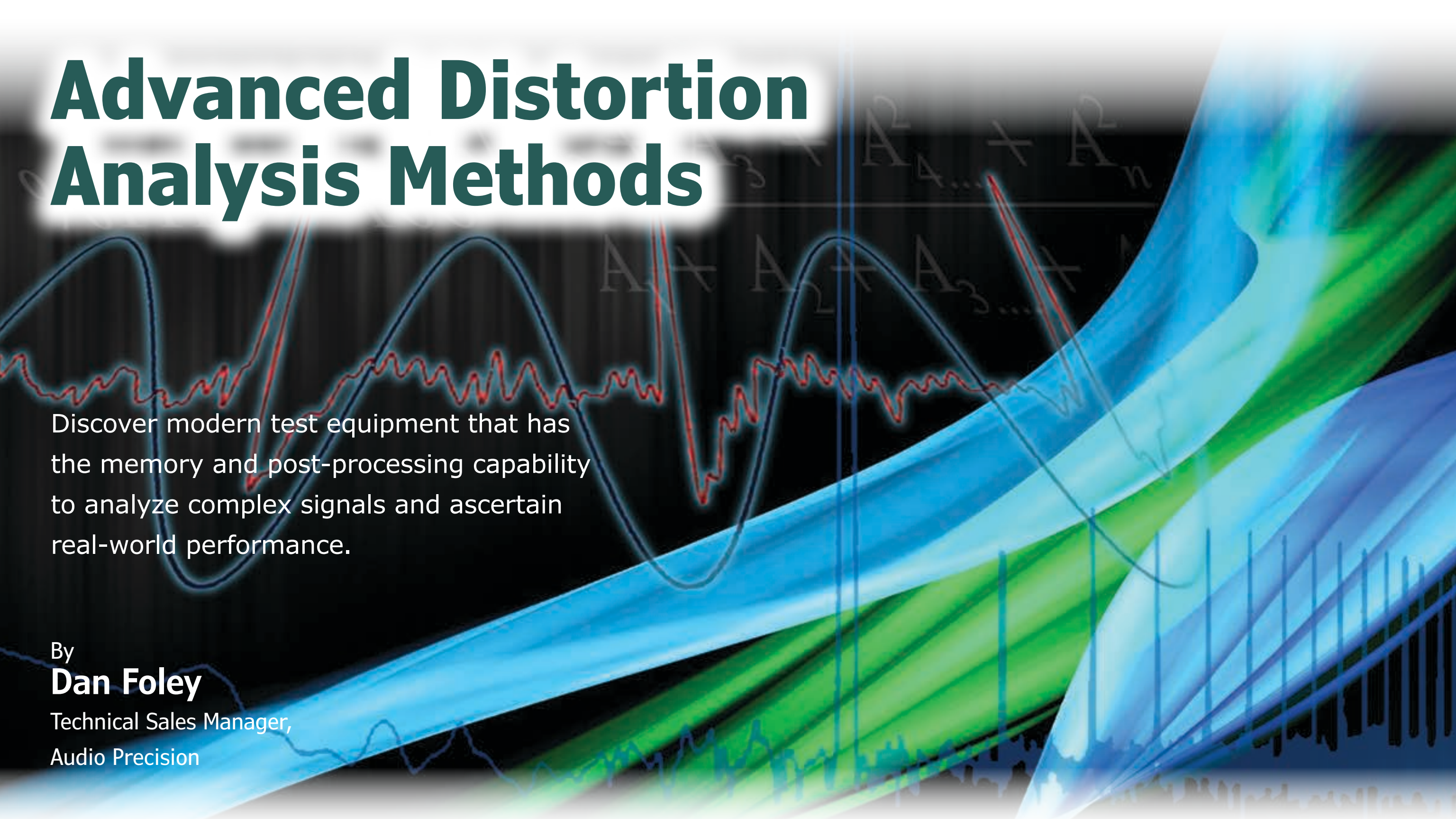


Advanced Distortion Analysis Methods

Discover modern test equipment that has the memory and post-processing capability to analyze complex signals and ascertain real-world performance.

By
Dan Foley
Technical Sales Manager,
Audio Precision

Since the advent of the sine wave oscillator until present, sinusoids and sinusoid-based excitation signals (e.g. two-tone and multi-tone) have been the primary stimuli used to characterize distortion. With single-tone excitation, the primary distortion measurement is either total harmonic distortion (THD) or total harmonic distortion plus noise (THD+N). The latter is almost exclusively used for characterizing electronic devices. THD and THD+N are often times the only distortion measurement presented in product datasheets and associated marketing material. In addition, engineering decisions are often made based solely on these measurements.

Determining THD

THD is determined via two methods. The THD value generated from **Equation 1** only has the energy of the Fundamental (A_1) in the denominator.

$$\%THD = 100\frac{\sqrt{A_2^2 + A_3^2 + A_{4....}^2 + A_n^2}}{A_1} \qquad [1]$$

In **Equation 2**, the THD value can be slightly lower compared to the THD calculated using **Equation 1**, because the denominator includes the energy of the fundamental plus the harmonics.

$$\%THD = 100\frac{\sqrt{A_2^2 + A_3^2 + A_{4....}^2 + A_n^2}}{A_1 + A_2 + A_{3....} + A_n} \qquad [2]$$

While these measurements indicate how accurately the device under test (DUT) reproduces a sine wave from a signal generator, these metrics have two major drawbacks:

1. THD and THD+N do not indicate the level of high-order harmonics, which are more audible than lower-order harmonics.
2. A sine wave has a crest factor of only 3 dB, which is at last 10 dB lower than speech and/or music. Such a low crest factor may not excite non-linear behavior that otherwise would be present using a signal that has a much larger crest factor.

In regards to THD+N, the measurement is comprised of harmonic energy and noise energy. A THD+N value does not give any indication as to whether or not the distortion is dominated by harmonics or noise or if both are equivalent in total energy.

Since the THD value is typically dominated by the second and third harmonics, these low-order harmonics are often masked psychoacoustically by the fundamental. Thus, a THD value can be in the

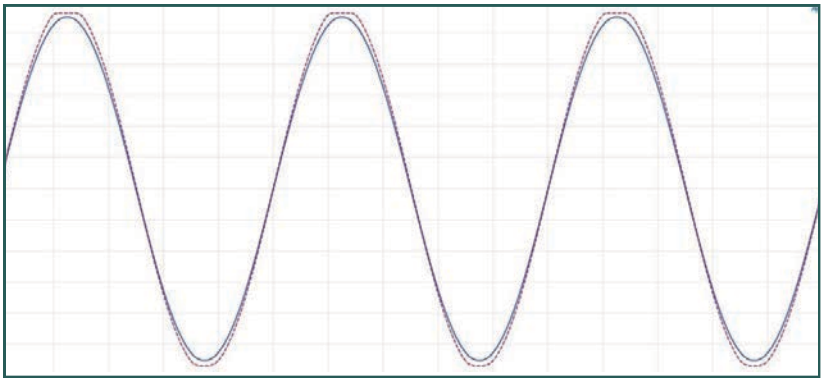


Figure 1: The clipped 1 kHz sine wave (dashed line) is compared to "clean" sine wave (solid line).

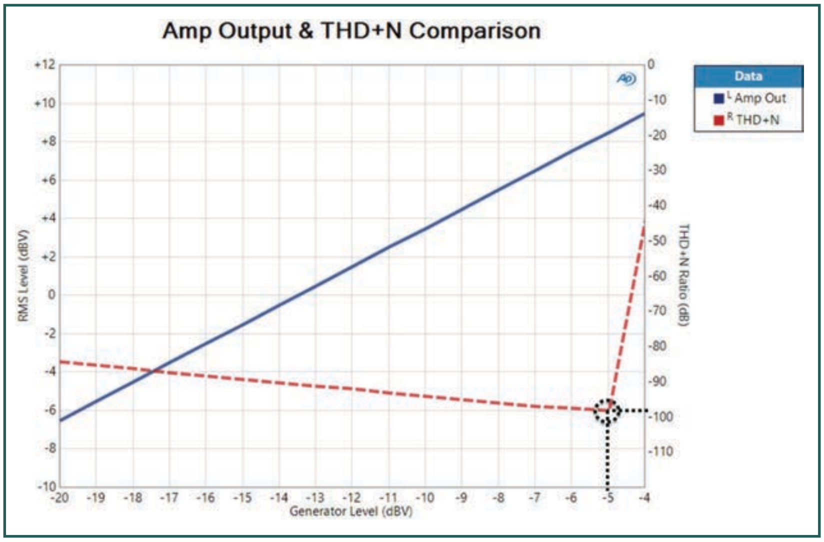


Figure 2: The 1 kHz stepped-level input is measured from -20 dBV to -4 dBV in 0.5 dB steps.

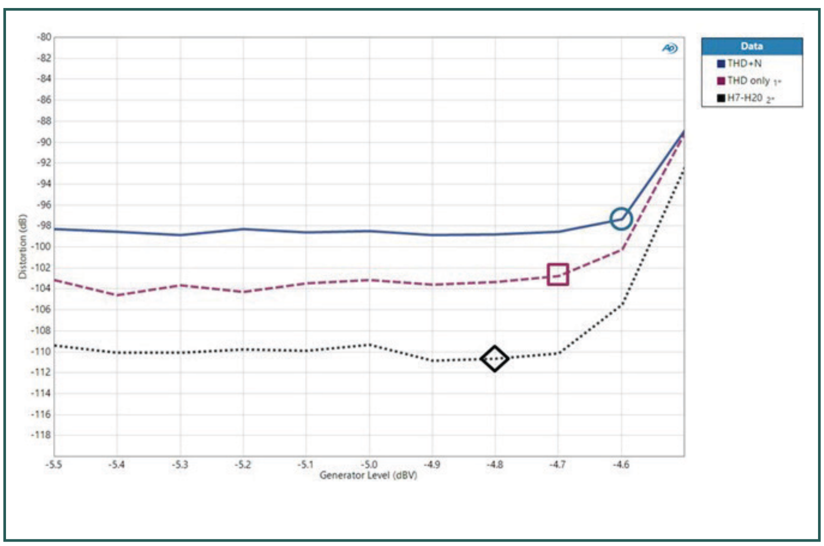


Figure 3: Here we compare the THD+N, THD, and the power sum of H7-H20.

10% to 20% range but the sine wave still sounds "clean" (i.e., undistorted). However, harmonics at and above the 10th harmonic can range from 60 dB to 80 dB below the fundamental and be audible.[1] This is equivalent to 0.1% and 0.01% THD, respectively, assuming that only these high-order harmonics are present in the measurement.

Measurement Principles

The following measurement examples are for electronic devices but these measurement principles apply to acoustic transducers and finished loudspeakers as well.

The device under test (DUT) is the headphone output of a small two-channel mixer with the volume control at full gain (13.5 dB). The classic way to measure linearity is to keep increasing the level of a single tone, typically 1 kHz, until the sine wave shows a flattening of either the positive or negative peak or both (see **Figure 1**). The THD of the clipped sine wave (dashed line) is approximately 1% (-40 dB). For this article, the author wanted to study what happens to the number and levels of higher-order harmonics when small increases in THD or THD+N distortion was observed.

In **Figure 2**, there are two data traces presented—the DUT Input/Output (solid line) and its corresponding THD+N (dashed line). The DUT input is a 1 kHz sine wave stepped-level sweep from -20 dBV to -4 dBV in 1 dB steps. The THD+N is dominated by noise since the THD+N level is decreasing as the input level increases. Once the DUT input reaches -5 dBV, there is a noticeable sharp increase in the distortion

Figure 3 compares the THD+N (solid line) to THD (dashed line) and then the power sum of the seventh through the 20th harmonics (dotted line). Note that the THD is 6 to 7 dB lower than the THD+N until the input level reaches -4.6 dBV. At inputs levels below -4.6 dBV, the electronic noise dominates. Only above -4.6 dBV does the THD curve starts to rise. At this input level, harmonics of the 1 kHz test tone are now being generated. However, such a low level of harmonic distortion would not be visible by just viewing an oscilloscope trace. Only Fast Fourier Transform (FFT) analysis can provide more detailed information as to what is happening with the harmonic energy, in particular higher-order harmonics. **Figure 4** shows the corresponding oscillocope and FFT traces with the DUT input level at -4.6 dBV.

These three different ways to view distortion, THD+N, THD-only, and high-order harmonics only lead to different conclusions regarding DUT performance—namely that the input level where distortion begins to increase can be -4.8 dBV, -4.7dBV or -4.6 dBV. One may initially think that a difference of only 0.2 dB, especially when overall distortion (and noise) levels are close to 0.001% (-100 dB), will be minimal. However studying the harmonic content at these three different levels via FFT analysis shows dramatic changes in high-order harmonic energy.

The FFT trace (see **Figure 5**) shows the level difference in H2–H20. The blue trace represents an input level of -4.7 dBV and the lighter red trace is a -4.6 dBV input. With only a 0.1 dB increase, high-order harmonics are now 10 dB or more above the DUT noise floor.

When the input level is increased by 0.2 dB, the increase in high-order harmonic energy from the seventh to 20th harmonics increases between 10 dB to 20 dB.

Table 1 is a summary of the overall distortion levels. Even at an input of level of -4.5 dBV, the distortion is still considered "low" (about -90 dB or 0.003%) for an inexpensive consumer electronic product. However, the FFT traces show that significant high-order distortion is present. If the -4.5 dBV FFT spectrum shown in **Figure 6** was that of a loudspeaker driver, the presence of these high-order harmonics would be indicative of rub and buzz.

Can the dramatic change in high-order harmonic energy be discernable in the time domain? When only viewing the drive signal (1 kHz sine wave), the answer is no. **Figure 7** shows DUT output and the sine waves are indistinguishable other than a small change in the peak levels due to the DUT amplifying the input signal by 13.5 dB.

The test equipment used to perform these measurements, the Audio Precision APx family of audio analyzers, can display the residual distortion waveform. In **Figure 8**, the 1 kHz sine output and the corresponding residual distortion waveform (red trace) is displayed when the input level is -4.7 dBV. Because the actual level of this distortion signal is in the microvolts range, the waveform has visually been amplified by 80 dB (factor of 10,000). The residual waveform looks "noisy" because the only harmonics present are the 2nd and 3rd and these are -110 dB relative to the output signal.

By increasing the DUT input to -4.6 dBV (see **Figure 9**), changes to the residual distortion waveform become more noticeable. There are a few more prominent spikes but it is still looking more like noise than a periodic signal. Once again, it is only through FFT analysis, that the increase in the high-order harmonics can be measured. A caveat is that the measurement equipment needs

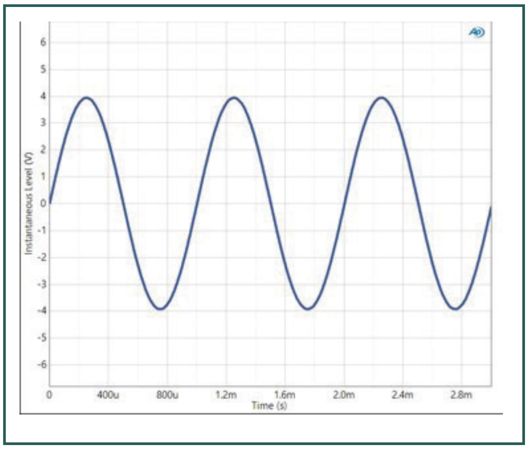


Figure 4: The DUT input level of -4.6 dBV is measured at 1 kHz. The high-order harmonics are -110 dB to -125 dB below the Fundamental.

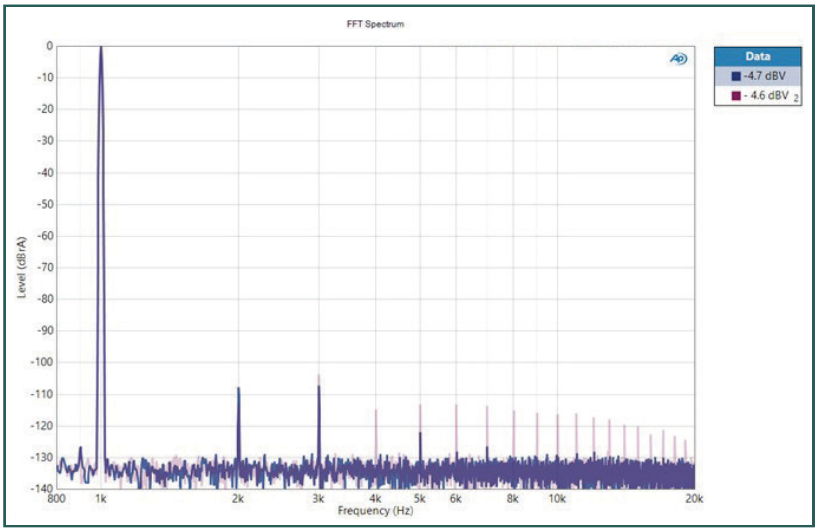


Figure 5: This is the difference in harmonic content when input level increases by only 0.1 dB.

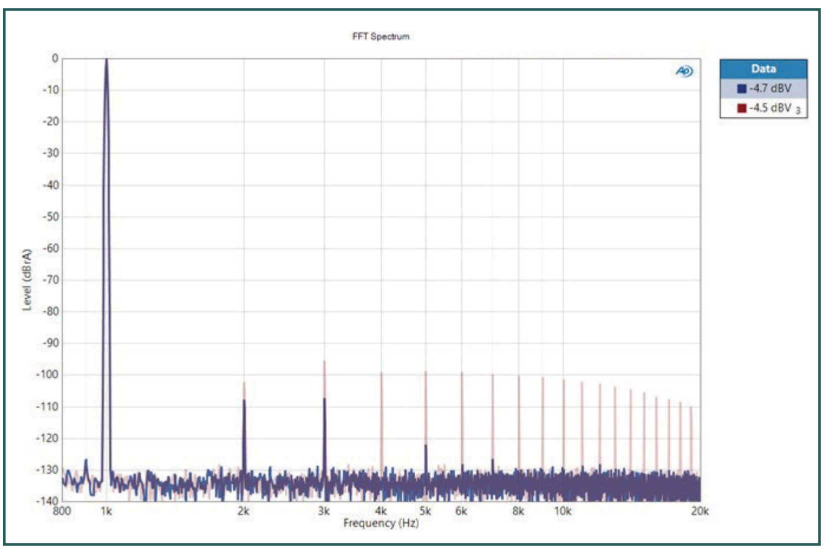


Figure 6: Increasing the input level by +0.2 dB results in 20 to 30 dB more high-order harmonic energy.

Excitation Level @ 1 kHz	THD+N (20 kHz BW)	THD (20 kHz BW)	High-order Distortion (H7- H20)
-5.0 dBV	0.00114% (-98.3 dB)	0.00057% (-104.9 dB)	0.00032% (-110 dB)
-4.7 dBV	0.00111% (-99.1 dB)	0.00063% (-104.3 dB)	0.00032% (-110 dB)
-4.6 dBV	0.00135% (-97.4 dB)	0.00096% (-100.7 dB)	0.0005% (-106 dB)
-4.5 dBV	0.00413% (-87.6 dB)	0.00406% (-87.8 dB)	0.0023% (-92.5 dB)

Table 1: Distortion levels of two-channel mixer are shown at various input voltages.

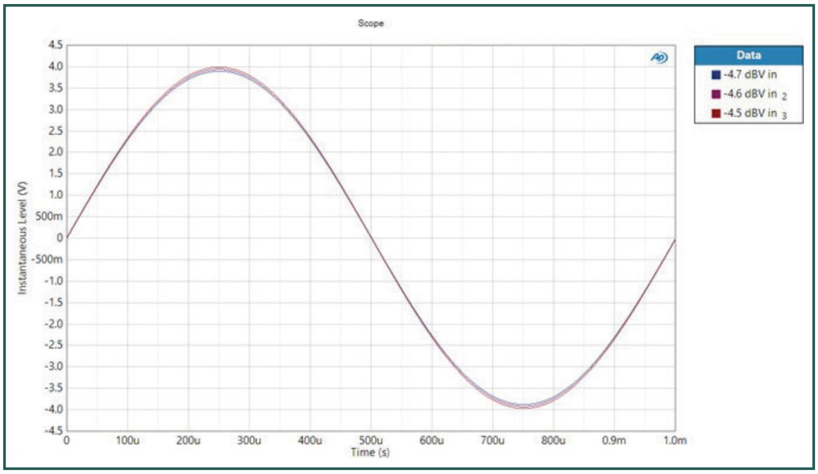


Figure 7: The DUT output with 1 kHz input level ranges from -4.7 dBV to -4.5 dBV.

to have sufficiently low input noise so that these very low-level signals can be measured using FFT methods. Once the input increases to -4.5 dBV (see **Figure 10**), the residual distortion waveform no longer resembles a noisy waveform. There are prominent spikes that coincide with when the output signal reaches its maximum negative voltage level of -4.0 V.

Upon more detailed analysis, the negative-going waveform begins to compress once the voltage level is at -4 V_{peak}. However, the positive peak is not compressed. In **Figure 11**, the solid line is the DUT output when the input is -4.5 dBV and the dashed line is for an input level of -4.1 dBV. At this higher input level, the THD+N is 0.38% (-48 dB). These measurements reveal that the power supply cannot reproduce levels in excess of 4 V_{peak} without compressing the negative portion of the waveform. This results in significant distortion, in particular with high-order harmonics.

So what happens when a music signal is used instead of a sine wave? Will the same compression characteristics be measurable? To see if this is the case, the author obtained a recording of a classical piano piece recorded at 192 kHz/24-bit resolution. The piece of music was edited using Audacity to select a small section of the piece where one simple chord is being played on the piano with no other instruments present. The duration of this chord is approximately one second. The corresponding time trace (wav file view) of this chord is shown in **Figure 12**. Even though this is a simple signal from a musical perspective, it is very complex in regard to sharp changes in amplitude. This trace is displayed where the Y-axis represents the digital level of the wav file so 100 mD represents a digital level of -20 dBFS.

This wav file was played into the DUT at RMS levels that ranged from -5.0 dBV to -3.0 dBV in 0.5 dB steps. A 7 ms portion of the response waveform was analyzed because it was in this portion of the waveform where the negative voltage level from the DUT output would equal or slightly exceed -4.0 V_{peak}. Looking at the oscillocope traces, the difference between input levels of -5.0 dBV, -4.5 dBV, and -4.0 dBV is quite subtle. At -4.0 dBV input, there is a slight compression of the negative portion of the music signal (see **Figure 13**).

The APx software that controls the APx audio analyzer hardware offers post-processing functions, enabling one trace to be compared to another. This capability makes this compression much more

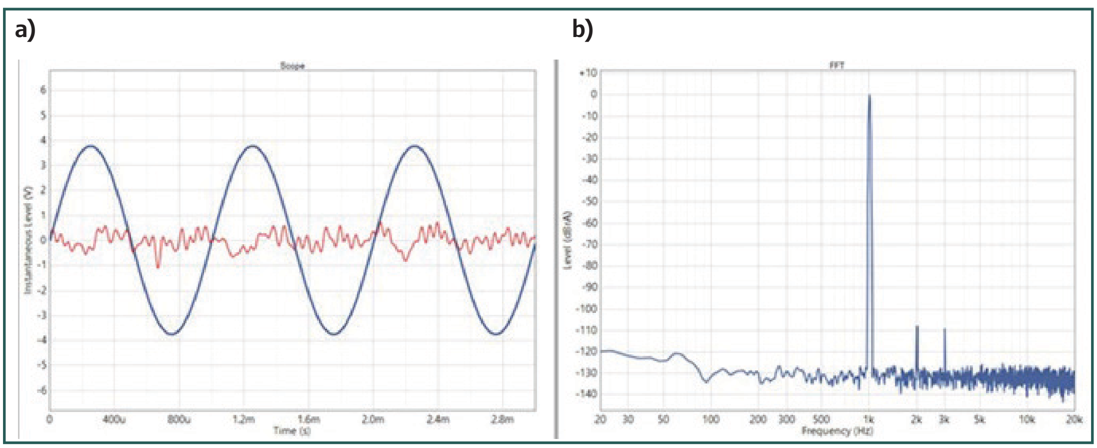


Figure 8: The -4.7 dB, 1 kHz excitation signal is shown with superimposed residual distortion (a) and the corresponding FFT (b).

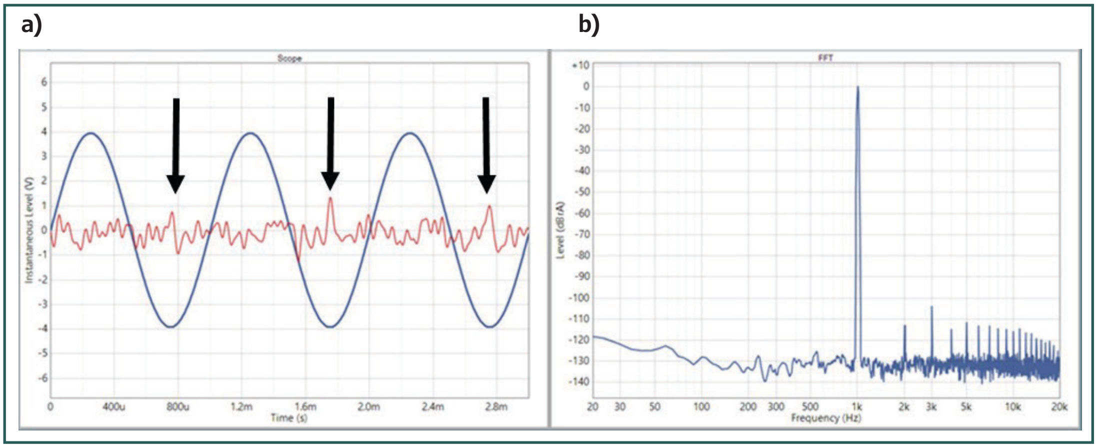


Figure 9: Increase of only 0.1 dB results in additional high-order harmonics, see the superimposed residual distortion (a) and the corresponding FFT (b).

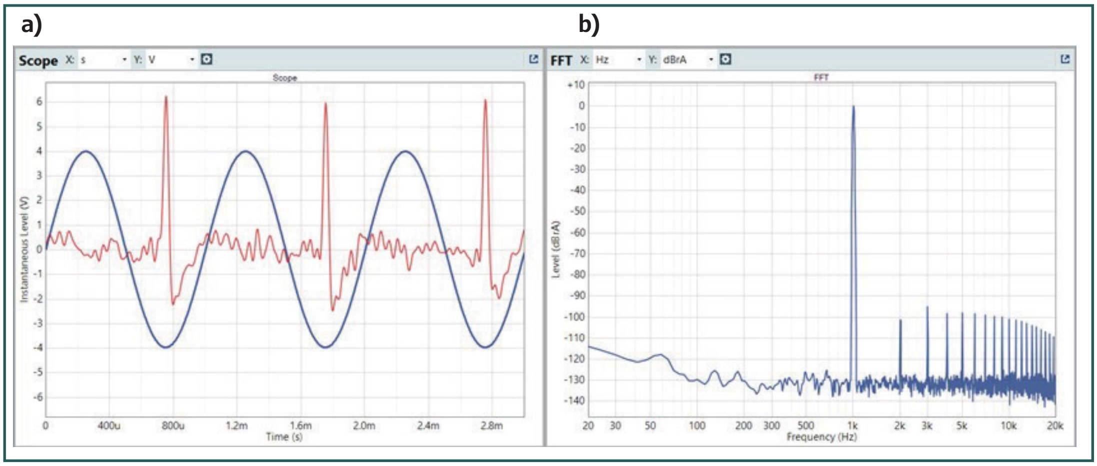


Figure 10: The +0.2 dB level increase results in prominent spike of residual distortion waveform (a) and large high-order distortion (b).

apparent. In **Figure 14**, the blue curve compares the DUT output of the -5.0 dBV and -4.5 dBV inputs. The red curve compares the output of the -4.5 dBV and -4.0 dBV inputs.

The time duration where this compression occurs is very short – less than 150 μs. Whether or not such a short duration of compression creates an unwanted audible distortion still needs to be tested. Please note that the waveform shown in **Figure 14** is a difference curve and not the actual music waveform playing from the DUT. What this shows is that when the input level is -4.0 dBV, the time that the negative-going portion of the music signal is compressed is 145 μs longer than when the input level is -4.5 dBV.

Audio Reproduction

The main purpose of audio reproduction equipment is to reproduce the source-music waveform as accurately as possible given design and cost constraints. Any aspect of the design that does modify these complex waveforms should be modified, within budget and time constraints, to minimize these types of distortions. Although listening tests still need to be performed on this particular DUT, analysis of this sort may provide the design engineer more objective information that can map to subjective assessment of audio quality (e.g., "tight sounding" vs. "muddy").

Given that FFT analysis is ubiquitous and inexpensive compared to years past, can this type

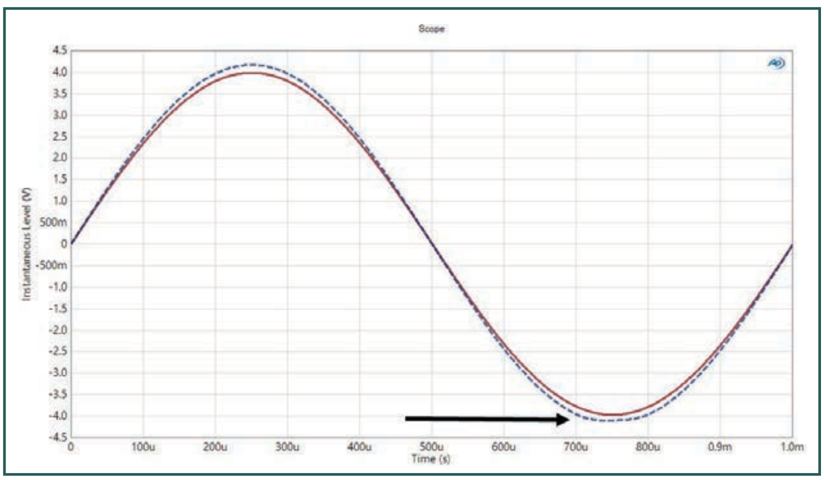


Figure 11: Slight compression of the maximum negative level results in significant distortion increase. Solid line sine wave THD+N = -88 dB and dashed line sine wave is -48 dB (100× greater).

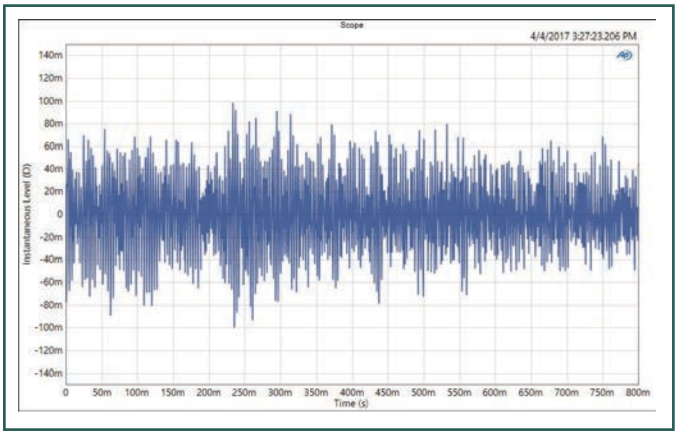


Figure 12: This is the music waveform of simple piano chord sampled at 192 kHz.

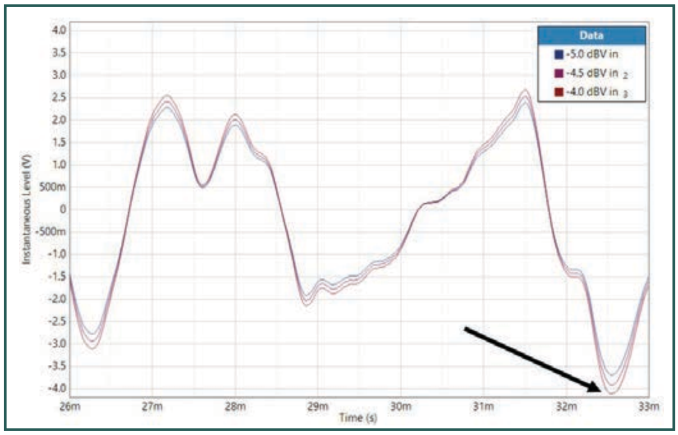


Figure 13: A detailed view of 7 ms portion of piano chord is depicted at three different input levels.

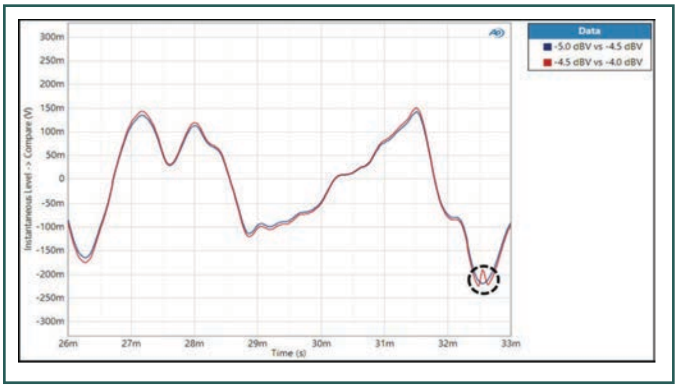


Figure 14: Comparing the music waveform, compression of the negative-going portion of waveform is evident input level of -4 dBV.

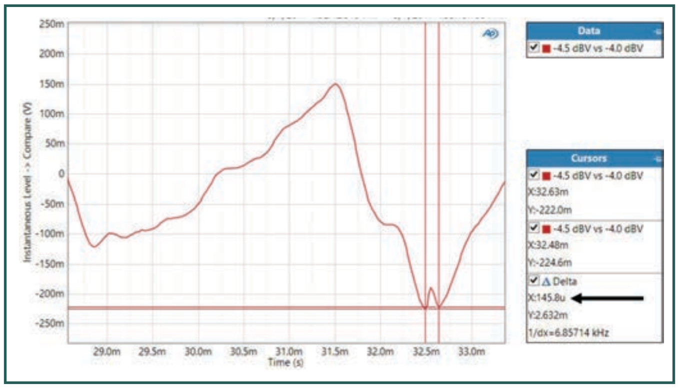


Figure 15: The time the waveform is compressed is short (145.8 μs), but this still may be long enough to alter sonic characteristics of transient portion of musical waveform.

About the Author

Dan Foley has been in the audio test and measurement industry for more than 35 years and has a broad background in analog and digital audio test, acoustics, electro-acoustics, telecom audio, as well as vibration measurement and analysis. He is a member of Audio Engineering Society (AES) and the Institute for Electronics and Electrical Engineers (IEEE), and has many close ties to the audio industry, having worked for the likes of Bose, Listen, and Brüel & Kjær. Foley has developed and taught seminars regarding digital signal processing techniques used in acoustic, vibration and audio test, and measurement applications. He currently serves on the IEEE Transmission Access & Optical Systems Committee as well as standards committees of AES. Foley is also an Adjunct Faculty Member at Worcester Polytechnic Institute where he is developing a curriculum in audio product design engineering. Dan is a published author of ASME and AES and has an engineering degree from the University of Hartford, West Hartford, CT.

Reference

[1] S. Temme, “Audio Distortion Measurements,” Application Note, Brüel & Kjær Sound & Vibration Measurement A/S, www.bksv.com/media/doc/BO0385.pdf.

of compression be measured in the frequency domain? **Figure 15** shows FFT traces of a few hundred milliseconds of the piano waveform. The solid blue line is a DUT input level of -5.0 dBV and the dashed red line is at -3.0 dBV. The 1 kHz sinewave distortion level at the -3.0 dBV input level is close to 0.5% which is quite excessive for electronics. **Figure 16** also shows a comparison (ratio) of these two traces. Since the level difference is 2 dB, this is why the difference is basically a flat line from 200 Hz to 6 kHz. The only difference between these two FFT traces is above 3 kHz and this variation is only a few hundredths of a decibel.

The fact that the difference is negligible is most likely due to the compression occurring for a short time. The music waveform is at its maximum negative level for a very short time (146 μs) and the effects of this short-time (e.g., transient) compression is “hidden” due to FFT analysis requiring that a block of data must be analyzed to view the corresponding spectrum. This block analysis will “smear” the energy of the transient making it much more difficult to analyze these very short-term events. This is one drawback of using spectrograms and Short-term Fourier Transform (STFT) to analyze DUT transient behavior, especially when using complex test signals like music.

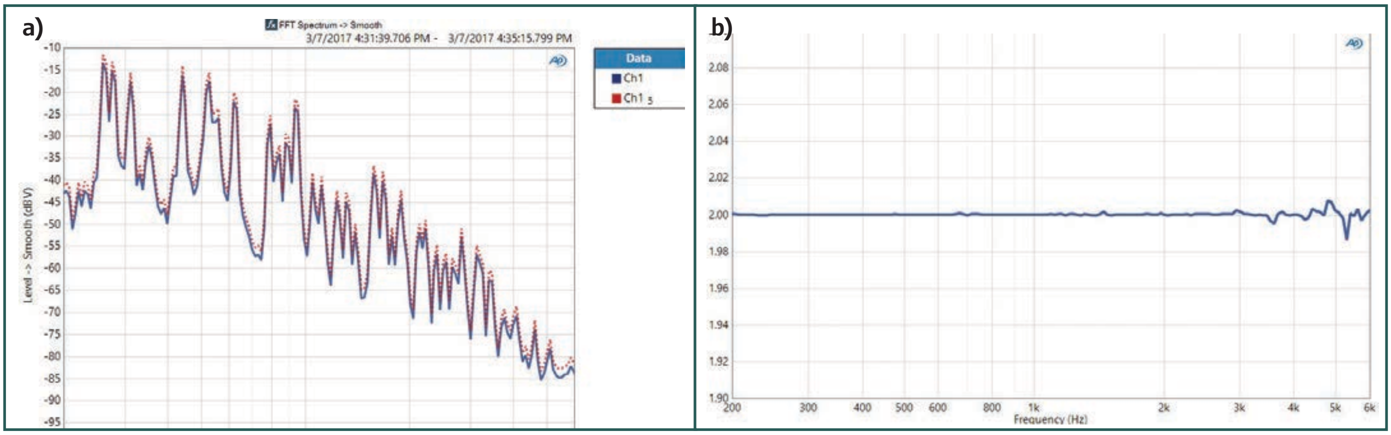


Figure 16: (a)Here we compare the frequency spectrum of transient portion of piano chord at -5 dBV (THD at -105 dB) and -3 dBV (THD at -34 dB). (b) Despite huge difference in THD, changes in frequency characteristics of transient portion of piano chord are negligible.

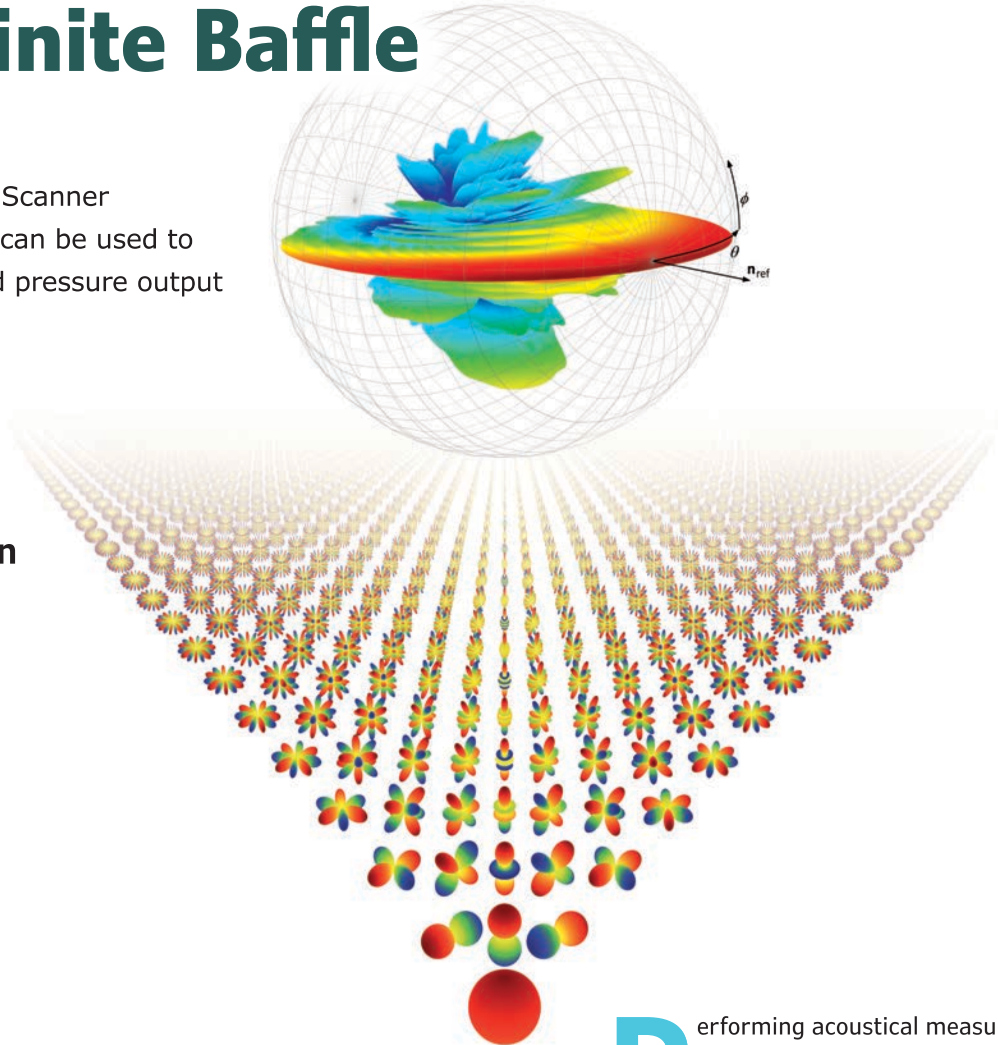
Conclusion

For decades, distortion measurements have typically been a single number that represents either THD or THD+N. Engineering decisions made from only these measurements can lead to false conclusions regarding how a product, or component such as an amplifier circuit or loudspeaker driver, will actually behave when reproducing music. Measurement of THD and THD+N should be complemented with detailed FFT analysis, especially at those input levels that result in slight changes to an overall THD or THD+N value.

The presence, or lack of, high-order harmonics due to small changes of input level can provide valuable information regarding compression characteristics. When feasible, augment classic measurements based on sinusoidal stimuli with actual music signals. Today's modern audio test equipment has the memory and post-processing capability to play these complex signals and analyze the response in the frequency and time domain to better ascertain real-world performance. ***LIS***

The Infinite Baffle

The Klippel Near Field Scanner measurement system can be used to measure the 3D sound pressure output of audio devices.



By
Christian Bellmann
R&D Engineer, Klippel GmbH

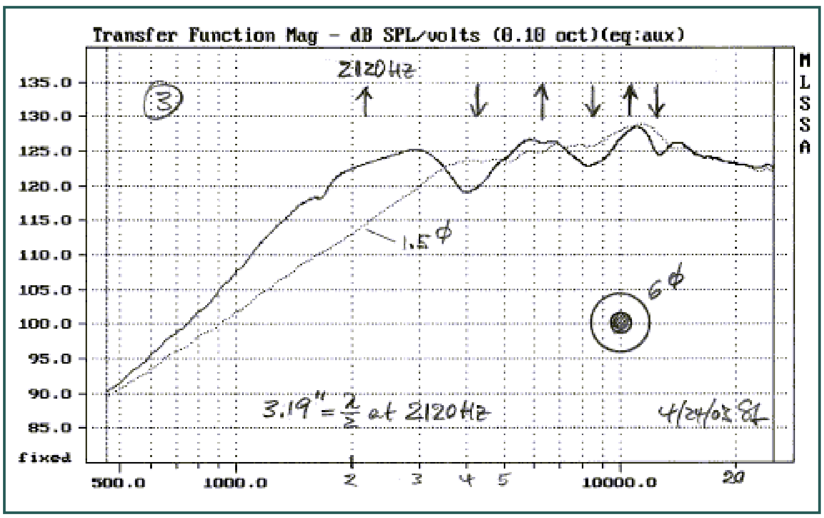


Figure 1: The test measures the diffraction effects of a 1.5″ driver mounted in a 6″ circular baffle. (Image courtesy of Linkwitz Lab, www.linkwitzlab.com)

Performing acoustical measurements of transducers, the speaker is usually mounted in a baffle, which avoids the acoustical shortcut between front and rear side and enables a measurement without the influence of a loudspeaker cabinet (compression effects, box resonances, and diffractions). Ideally, the loudspeaker should be mounted (e.g., in the floor of a half space anechoic chamber). In practical usage, the dimensions of the baffle are usually limited (e.g., 1350 mm × 1650 mm —IEC norm baffle), which brings up new problems that effect measurement results. For the very low frequencies, the baffle is too small compared to the wave length, which causes an acoustical shortcut. Diffractions from the baffle edges disturb the measurement as well.

Diffraction Effects

How much can diffractions disturb the measurement results? To show these effects, Siegfried Linkwitz has published a test series with a 1.5″ driver mounted in baffles of different shapes and sizes. In this test, circular baffles show the most distinct diffraction in the measurement, because this causes reflections from every point at the edge to arrive at the same time and affect the same frequencies. The consequences are very distinct peaks and dips (up to ±5 dB) at multiples of the baffle size (see **Figure 1**).

Using a rectangular baffle and placing the transducer out of the center, as it is recommended by the IEC norm baffle, reduces but does not eliminate the diffraction effects.

Thus, for on-axis measurements in a good anechoic chamber, the standard baffle is an option. There are several possibilities to improve the measurement setup. For example, applying some acoustical damping on the rear side can reduce the influence of the acoustical shortcut.

3D Directivity Data

How is 3D directivity data acquired? Measuring 3D radiation data becomes slightly more complex. To acquire the 3D data, an automatic measurement system is needed. A common solution is mounting the loudspeaker in the floor of a half anechoic chamber and measuring different angles by using a microphone array. Especially for phase measurement, the microphones need to be accurately positioned and the tolerance between the microphones needs to be calibrated (see **Photo 1**).

More problems appear when measuring in a norm baffle. The influence of the baffle makes accurate off-axis measurements nearly impossible. So how can the influence of the limited baffle dimensions be minimized? And is it possible to measure the full 3D radiation with a limited baffle? To answer these questions, we will explore an alternative measurement technique.

Spherical Wave Expansion

A very powerful approach that is well proven for the directivity measurement in full space is the spherical wave expansion. The Klippel Near Field Scanner (NFS) measurement system uses this method to determine the 3D sound pressure output of an audio device (see **Photo 2**).

Based on a measurement in the near field of the devices, the system solves the wave equation for the particular device using special solutions: Hankel functions for the energy transfer from near into far field and spherical harmonics for the angular radiation characteristics.

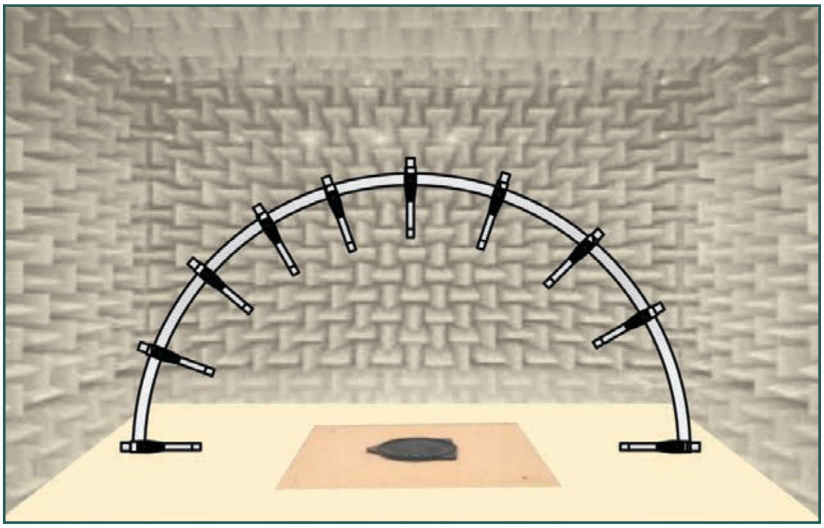


Photo 1: Directivity is measured using a microphone array.

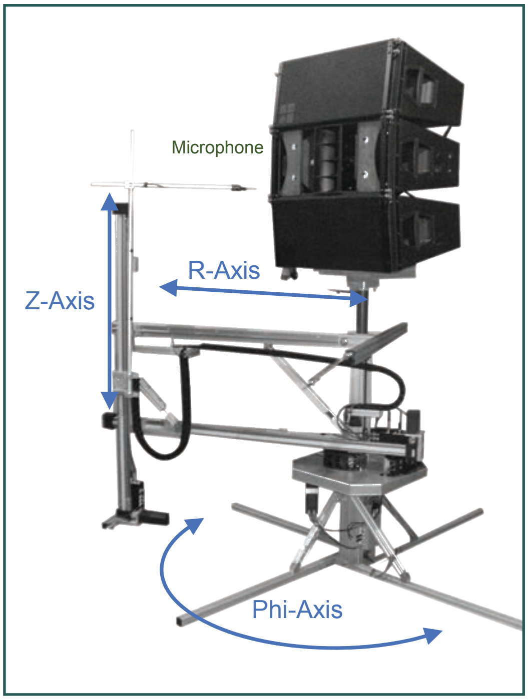


Photo 2: This device is Klippel's 3D Near Field Scanner (NFS).

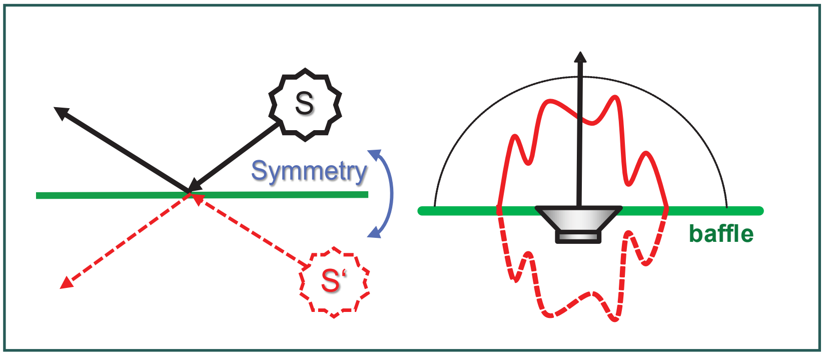


Figure 2: This is a symmetry condition half space measurement.

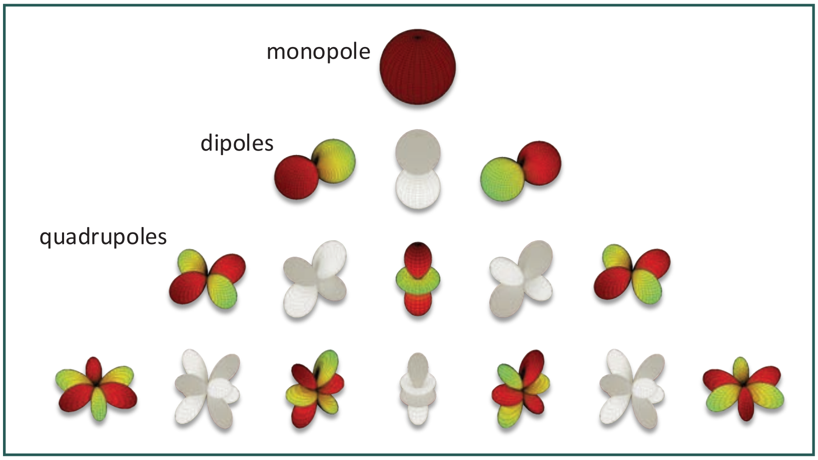
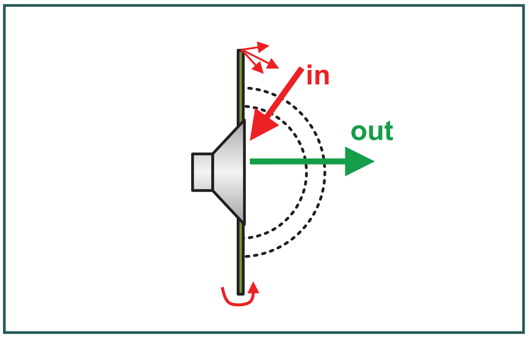


Figure 3: Baffle symmetry requires a subset for spherical harmonics.

Figure 4: Scanning on two layers enables additional phase information to be used to separate the direct sound from incoming waves.



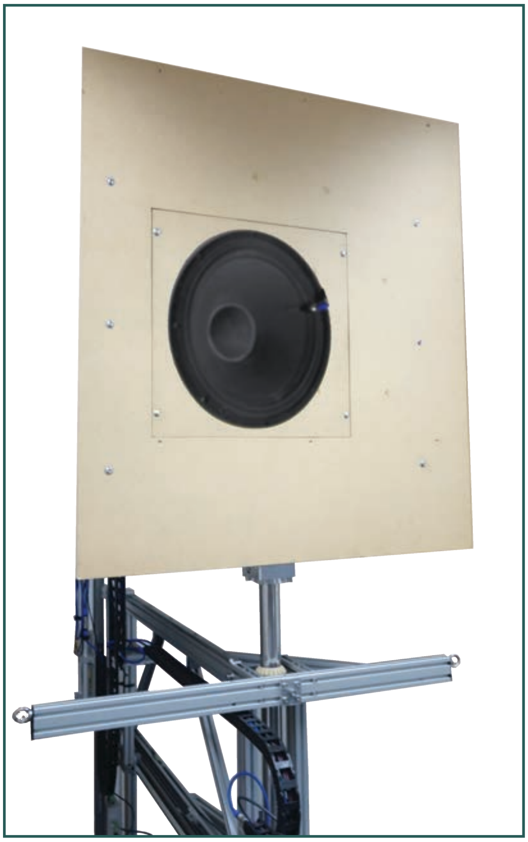


Photo 3: For the measurement setup, we placed a 1 m ×1.3 m wooden baffle in the center of the Near Field Scanner.

In addition, the influence of a bad measurement room can be eliminated using field separation techniques. In the end, the measurement system provides the sound pressure output at any point in 3D space.

To use the spherical wave expansion for a transducer mounted in a baffle, first, let's have a short look at the general modeling of loudspeaker S in half space. The reflection on the plane can be modeled by a mirrored sound source S, which is similar to a symmetrical sound field (see **Figure 2**).

This symmetry can easily be applied to the spherical wave expansion by using only a subset of basic functions that fulfills the symmetry condition (see **Figure 3**). In addition, by scanning on two layers, the additional phase information can be used to separate the direct sound from incoming waves (see **Figure 4**). That means, the method can compensate the room (reflections, modes) as well as the influence of the baffle (e.g., diffractions, acoustical shortcut).

Thus, the measurement can be performed in a normal room (non-anechoic), providing perfect half space, free field radiation data. Also, the shape and size baffle is not as important anymore. If the baffle is larger than the measurement surface, its effects can be compensated.

Testing a 18" Woofer

One of the most critical measurement objects is a large 18" woofer. Especially for this device under test (DUT), the traditional method was running into problems. The most anechoic room has room modes below 100 Hz, and a normalized IEC baffle is too small, so acoustic shortcut cancels out the low frequencies.

About the Author

Christian Bellmann was born in Freiberg, Germany, in 1987. He studied mechatronics in Dresden University of Technology with the focus on control engineering, power electronics, and electrical drives. In 2013, he received a Diploma degree for his thesis "Separation of Direct Sound and Room Reflections Using Holographic Methods," which was supervised by Dresden Technical University and the Klippel GmbH in Dresden. After his graduation, Bellmann joined the Klippel GmbH where he is currently engaged in the research and development of loudspeaker measurement systems with focus on acoustical holography.

For the measurement, we placed a 1 m × 1.3 m wooden baffle in the center of the Near Field Scanner (see **Photo 3**). The measurement points are an equal area spaced on two hemispheres with 30 cm and 35 cm radii in front of the driver. During the measurement process, we moved the microphone around the speaker while the baffle stays at a fixed position.

For the results, look at the sound pressure in 0.3 m on axis clearly shows how the field separation detects the direct sound (see **Figure 5**).

The narrow room resonances at 60 Hz and 160 Hz were removed, and the influence of the acoustic short at low frequencies was compensated as well. This cancellation caused the measured sound pressure in the near field to be 3 dB below the actual forward radiated sound pressure level (SPL) of the driver.

As a last step, we extrapolated the far field characteristics 10 m from the transducer from the near field data, giving a complete picture of the radiation behavior of the loudspeaker (see **Figure 6**).

As shown in **Figure 7**, the loudspeaker is almost omnidirectional for low frequencies and starts beaming at about 600 Hz. At approximately 1.5 kHz, the driver has its first break-up.

Conclusion

It is beneficial to use the spherical wave expansion for half space measurements. In combination with the field separation, the measurement can be performed in a normal room and the effects of a non-infinite baffle (acoustical shortcut, diffractions) can be eliminated. This provides more accurate measurement data of the sound pressure output at any point in 3D space. ***LIS***

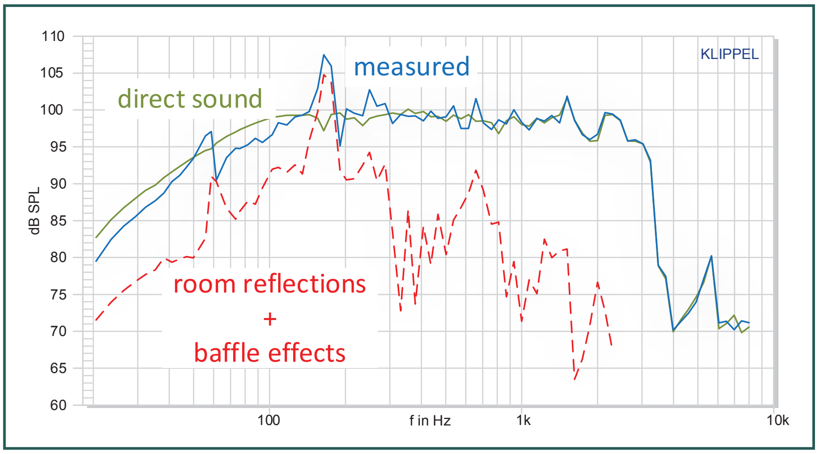


Figure 5: Here is the near field sound pressure level in 0.3 m on axis.

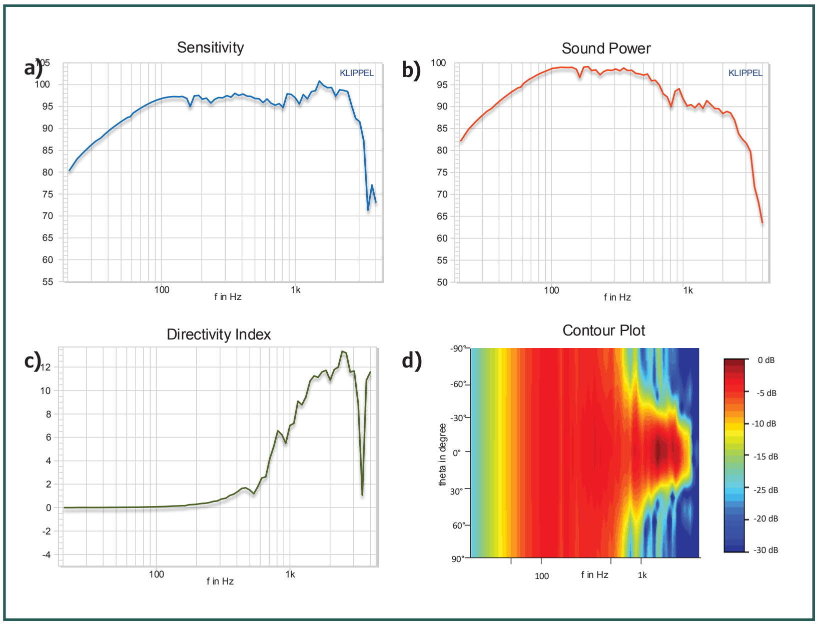


Figure 6: we extrapolated the far field characteristics 10 m from the transducer from the near field data. The complete data provides the sensitivity (a), sound power (b), directivity (c), and the contour (d).

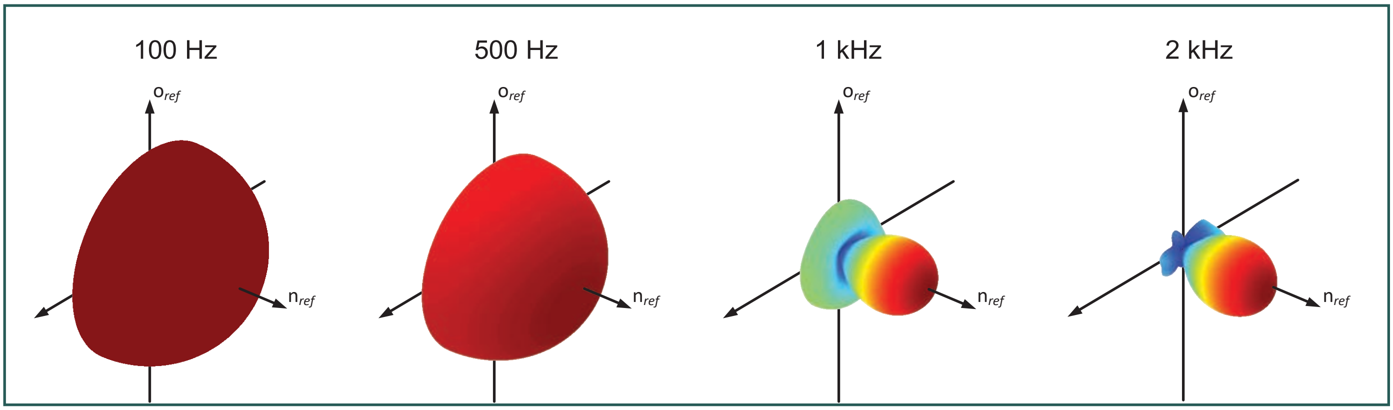


Figure 7: The loudspeaker is almost omnidirectional for low frequencies and starts beaming at about 600 Hz.

Chasing the Elusive "Good Sound" Meter for Loudspeakers

By
Tim Gladwin
Harman International

In 1977, Henning Moller produced an Application Note for Brüel & Kjær Sound & Vibration Measurement A/S titled "Multidimensional Audio." Moller defined "good sound" as a global concept resulting from the integration of local parameters in both subjective and objective domains.

In each domain he identified approximately 38 parameters or dimensions to be considered for the determination of "good sound." Moller described a virtual instrument, the "Good Sound Meter," which (if it existed) could measure the characteristics of an audio system. Twelve years later, Tomasz Letowski stated the problem succinctly: "Although the concept of sound quality is widely used, the term itself is not clear and does not have a precise meaning."

There have been many articles since about "which loudspeaker measurements matter." The list includes a great two-part article written by Joe D'Apollito in 2008. However, Moller's application note, subsequent Journal of Audio Engineering Society (JAES) papers, and most of all, his diagram, have enduring relevance.

Some aspects of good sound in loudspeakers have been studied in great depth. The relationship between the frequency and the directivity response to subjective listener preference has been determined to a statistically valid degree. Such studies take tremendous resources of time, money, and people. Many of the other dimensions have not been so well scrutinized, with the result that superstition and cargo cult science remain.

Let's take a look at the advancements our industry has made in working toward the "Good Sound Meter" and perhaps consider the next steps.

Sound Quality

"Sound quality is not a quantity which can be measured directly. Yet, we all believe there is a relationship between what we measure and what we hear."[1]

When Moller wrote this in 1979, he identified a plethora of objective physical attributes, both linear and non-linear. At the time, the measurement capability for many of these attributes simply did not exist. There was much speculation on what physical measurements are most subjectively important. This permitted the propagation of a variety of belief-based speaker philosophies that persist even today!

Moller's original diagram identifies 39 subjective and 37 objective "dimensions" (see **Figure 1**). Subjectively, our two ears and a brain can, in real time, discern good sound from bad. This is typical of human perception—popular analogies are our perception of beauty and in wine tasting. We simultaneously and continuously perceive, integrate, and evaluate the entire environment. Sometimes trained (or gifted) listeners can describe specific parameters with accuracy, but overall, we tend to provide only subjective descriptions. The rest of this article will focus on objective dimensions.

Objective Measurements

Objectively, our instruments can measure one, or in some cases, several parameters to high precision, but individual measurements cannot positively determine "good sound." In the wine tasting analogy, we can measure acidity, solids, sweetness, clarity, but no single measurement can confirm it is "good." Some particularly bad speaker measurements (e.g., very high distortion) can identify low fidelity sound, but we cannot truly identify good sound with one measurement. However, combinations of several objective measurements may be used to predict user preferences as shown by Sean Olive in US Patent #8,311,232, "Method for Predicting Loudspeaker Preference" (see **Figure 2**).

Of the 32 objective dimensions identified by Moller in 1977 (see **Figure 3**), how many are routinely measured today? I know of one successful company that only measures the on-axis frequency response. Other companies still claim to "voice" speakers by ear alone! Despite this there is a strong case for a scientific approach. In the last 40 years, we have seen tremendous advancements in electronics and computers and added several loudspeaker measurements including:

- Controlled Listening Tests (i.e., double blind, MUSHRA, ABX, and Speaker Shuffler), which enable us to quantify the subjective through statistics
- Additional Time-Based Measurements (i.e., step response, waterfall plots, and time of flight
- Dynamic tests (e.g., "Boink," max SPL, compression, and dynamics)
- Diverse SPL Measurements (i.e., 2Pi, 4Pi, ground plane, free field, near field scanning, contour plots, and EASE data)
- Signal Processing tests (i.e., surround processing, EQ, limiters, DSP, HRTF, Bluetooth, IACC, Atmos, and WISA)

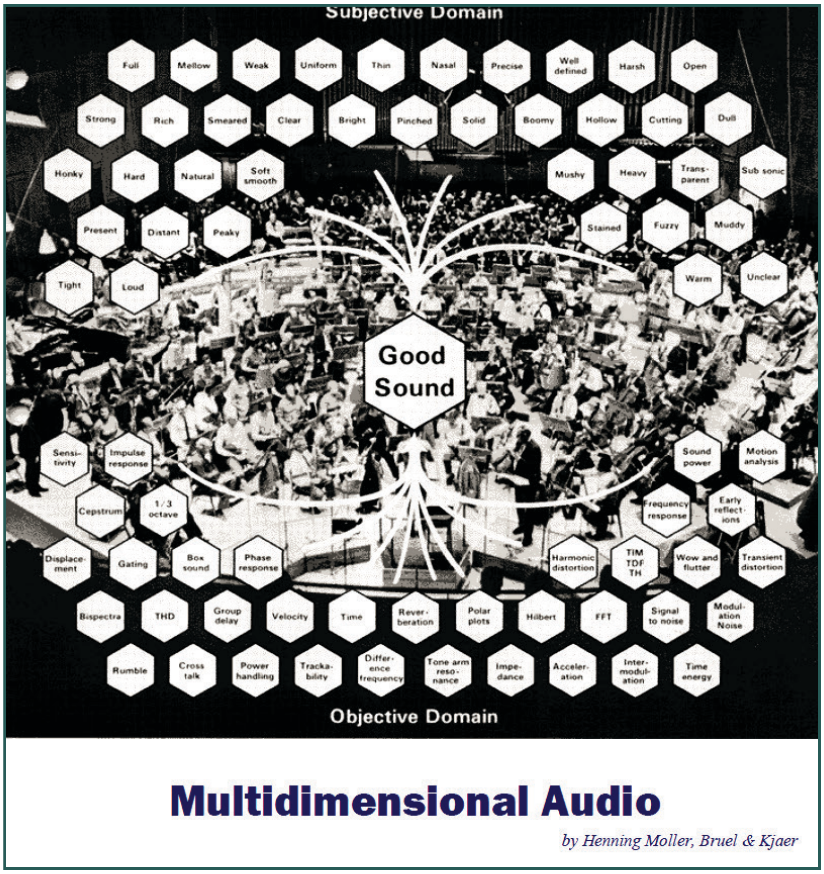
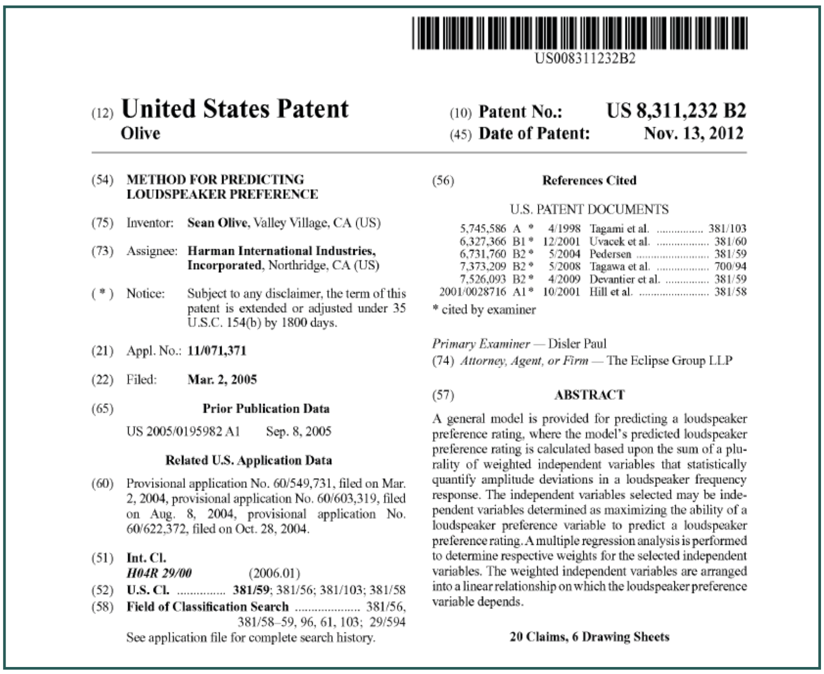


Figure 1: This is Hening Moller's "Good Sound" diagram, which has had enduring relevance for the last 40 years.



US008311232B2

(12) **United States Patent**
Olive

(10) **Patent No.:** **US 8,311,232 B2**
(45) **Date of Patent:** **Nov. 13, 2012**

(54) **METHOD FOR PREDICTING LOUDSPEAKER PREFERENCE**

(75) Inventor: **Sean Olive**, Valley Village, CA (US)

(73) Assignee: **Harman International Industries, Incorporated**, Northridge, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1800 days.

(21) Appl. No.: **11/071,371**

(22) Filed: **Mar. 2, 2005**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(51) **Int. Cl.**
H04R 29/00 (2006.01)

(52) **U.S. Cl.** **381/59**; 381/56; 381/103; 381/58

(58) **Field of Classification Search** 381/56, 381/58–59, 96, 61, 103; 29/594
See application file for complete search history.

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Primary Examiner — Disler Paul
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(57) **ABSTRACT**

A general model is provided for predicting a loudspeaker preference rating, where the model's predicted loudspeaker preference rating is calculated based upon the sum of a plurality of weighted independent variables that statistically quantify amplitude deviations in a loudspeaker frequency response. The independent variables selected may be independent variables determined as maximizing the ability of a loudspeaker preference variable to predict a loudspeaker preference rating. A multiple regression analysis is performed to determine respective weights for the selected independent variables. The weighted independent variables are arranged into a linear relationship on which the loudspeaker preference variable depends.

20 Claims, 6 Drawing Sheets

Figure 2: Sean Olive's patent describes a model to predict loudspeaker preference rating.

- Diagnostic Measurements (i.e., Rub & Buzz, laser scanning vibrometry, large signal parameters, 3D distortion, multitone distortion, DC offset, air leaks, and port noise)
- Comprehensive Tests (i.e., CTA426B, CTA2010, Spinorama, and CTA2034)
- Design Parameters (i.e., materials, size, color, and shape)

Wait, does design/appearance affect our perception of good sound? Several studies indicate that it does. Floyd Toole and Sean Olive demonstrated that appearance is a nuisance variable when determining sound quality of loudspeakers. Nuisance or not, it is a variable. Chia-Jung Tsay found in her paper "Sight over Sound" that "for novices and experts alike, visual information dominates relative to auditory information, even when sound is consciously valued as the core domain content."[2]

The ears are simply transducers—hearing/perception takes place in the brain and part of it is cognitive. What we perceive is influenced by what we see, what we know about the product, its price and its "reputation" (see **Figure 4**). Double blind tests are essential to learning about how listeners react to the sound.

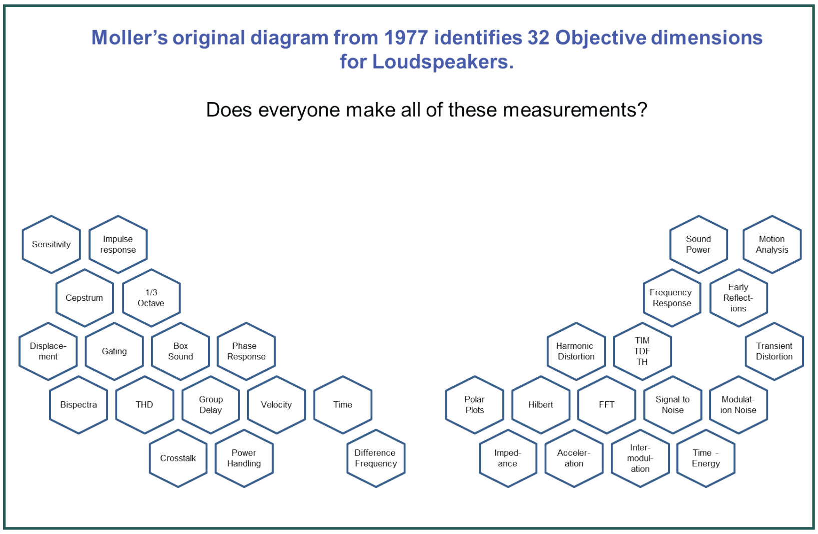

Figure 3: Henning Moller identified 32 objective dimensions for loudspeakers.

Figure 4: We listen with our eyes.

More Objective Dimensions

So, now we have 75 objective dimensions identified (see **Figure 5**). Maybe there should be more, maybe there should be less (some could be discarded or consolidated). How many are used? How many are relevant?

Let's look at three specific dimensions: Spinorama, double-blind listening tests, and the Speaker Shuffler. There have been numerous efforts to correlate the subjective and objective domains for loudspeakers.

Henrik Staffeldt at the Danish Engineering Academy published his paper on the "Correlation Between Subjective and Objective Data for Quality Loudspeakers" in 1974. But in 1965, at Canada's National Research Council, Toole began a series of controlled experiments to correlate objective anechoic measurements to subjective listener quality perception. He continued these experiments at Harman from 1991 onward, culminating with the publication of his book *Sound Reproduction* in 2008. The completely rewritten third edition of this book is due out in August 2017.

Olive joined Toole at NRC and then followed him to Harman. From more than 30 years of well-controlled and documented experiments, and hundreds of subjects from all walks of life, they have produced a formula for making a quality loudspeaker. The Spinorama test, which was incorporated into standard ANSI/CTA-2034A contains the information from which one can predict double-blind listener loudspeaker preference rankings with a statistical accuracy of 0.86 for loudspeakers with varied bass capability (see **Figure 6**). For loudspeakers of similar bandwidth, the correlation is even higher. However, even simple visual inspection of the family of curves easily identifies potentially good sounding loudspeakers: flat and smooth direct sound is essential and similarity among the remaining curves is beneficial.

Finding the Correlation

There are four key aspects to achieving the correlation between measurements and listener preference. First is the Spinorama, a series of 70 anechoic frequency response measurements as measured at 10° increments on the horizontal and vertical orbit about the speaker. This data set is reduced to five curves that characterize the speaker. The second aspect to the relationship is controlled double-blind listening tests. Neither the test operator nor the test subject can identify the speaker under test and where the nuisance variables of sensitivity, appearance, and location have been removed. The third aspect is the Speaker Shuffler, it is the device that moves each speaker into the listening location so quickly that the listener can maintain the memory of the last speaker. The Speaker Shuffler is essential to negate the variable of position in the room (see **Photo 1**). The fourth consideration is that enough tests must be conducted that the results are statistically valid.

Olive has conducted hundreds of double-blind listening tests using the Speaker Shuffler and compared the results to Spinorama curves. This type of research is expensive and tedious, but the results are very robust. If this is not the Good Sound Meter, then at least it must be an essential part of it.

IMD and THD

What about the other 72 "dimensions"? As good as it is, we know that the Spinorama isn't the entire story. Olive found that high levels of intermodulation distortion (IMD) and total harmonic distortion (THD) can affect the results.

In 1985, Toole found that subjective "sound quality" ratings closely paralleled "spatial quality" ratings. And, in 1990, Wolfgang Klippel found "the sense of spaciousness" ranked equally with frequency response.

Some of the other measurements are the basic tools we use to achieve performance and may not affect listener preference. Listeners will not hear the impedance (unless driven by a high output impedance amplifier, such as most tube amplifiers) or Theile-Small (T-S) parameters. Nor will they hear the large signal parameters directly, but they may hear more derivative aspects (e.g., distortion or resonance resulting from the design choices for those parameters).

In any true scientific endeavor, the variables must be simplified to make meaningful progress. Toole and Olive determined several nuisance variables that affected our perception of sound quality and eliminated those variables from the test method. Those variables included:

Appearance—Our judgment is affected strongly by appearance, whether it is a recognized and

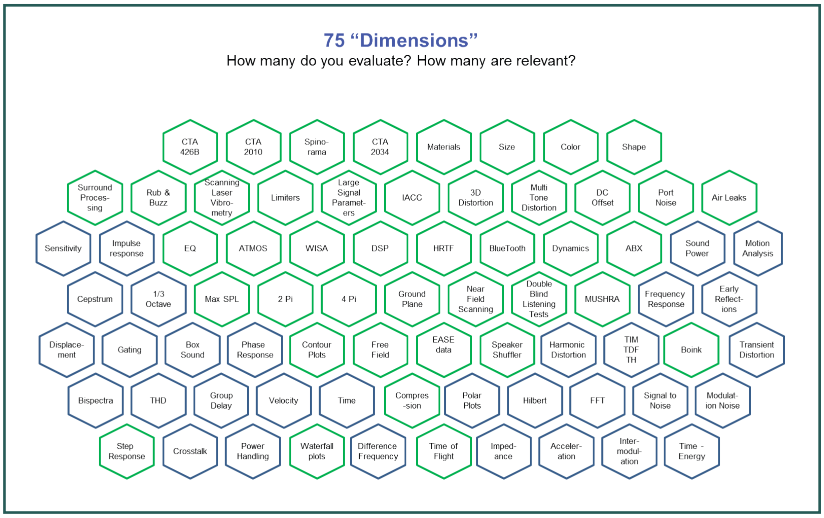

Figure 5: Even if we made all 75 measurements, how do they relate to good sound?

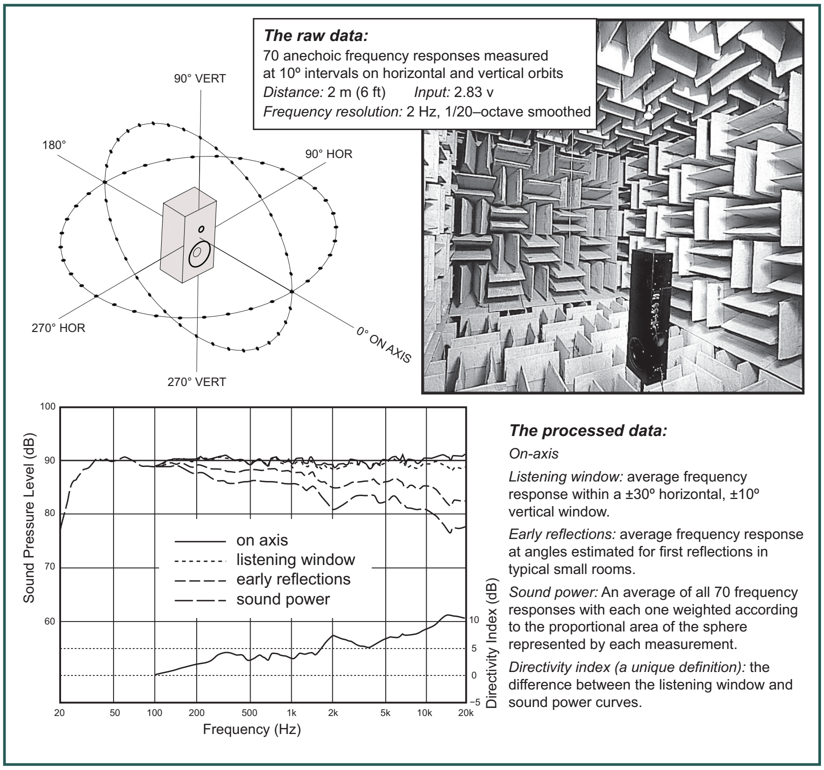

Figure 6: The Spinorama has 70 measurement points. Is the Spinorama the "Good Sound Meter"? (Image courtesy of Floyd Toole, *Sound Reproduction*, Focal Press, 2008)

Photo 1: The Speaker Shuffler moves each speaker into the listening location so quickly that the listener can maintain the memory of the last speaker.

About the Author

Tim Gladwin began working in audio in 1983 by forming an audio company to provide PA and recording services. He built two recording studios, engineered numerous live events, recorded many artists, and wrote, recorded, and produced radio shows and provided road support for several acts. In 1994, Gladwin began working for the Definitive Technology engineering team (Blue Systems, Inc.) on the BP2000 project and soon began designing transducers and loudspeakers. Tim rose to the position of Acoustic Engineering Manager at Blue Systems. In January 2010, Tim left Blue Systems to start Warkwyn Associates. At Warkwyn, Gladwin designed transducers and speaker systems for a variety of international clients. In 2012, Klippel approached Warkwyn to be its North American representative for technical support, sales, and measurement services.Tim joined Harman International as Sr. Mgr. Eng. Acoustics in March 2015 and sold Warkwyn to MISCO speakers. Gladwin now leads the engineering team responsible for Revel, JBL Synthesis, and JBL consumer luxury speakers. Gladwin is a member of the Audio Engineering Society (AES), Acoustical Society of America (ASA), American Society of Mechanical Engineers (ASME), and the Association of Loudspeaker Manufacuring and Acoustics (ALMA). He currently holds nine acoustic patents for transducer and speaker design with other acoustic patent applications pending.

respected brand, size, or color. We discriminate on appearance. This variable was countered by making the test double blind. But what if we could determine an appearance that listeners will believe sounds better?

Sensitivity—Hi-fi salespeople know that the loudest speaker will likely win the listening test. Some speaker companies maximize sensitivity, add non-linear EQ, and even add distortion to win the loudness test. Adjusting the SPL of each speaker under test to the same weighted level eliminates this variable. But in the real world, it behooves us as speaker designers to make the sensitivity competitive.

Placement—After demonstrating conclusively that placement is a major variable, especially at low frequencies in small rooms, Toole and Olive designed and built the Speaker Shuffler. All speakers under test are in exactly the same position during evaluation and the speakers can be switched within seconds. Such a facility is complex and costly; it is specific to floor and stand-mounted speakers. Wall and ceiling speakers need a second shuffler with a rotating wall section.

Additional Variables

Which of the other 72 "dimensions" need to be built into the "Good Sound Meter"? Should we tackle the nuisance variables and re-evaluate some of the other factors and distortions? How does IMD/MTD/HD/compression/max SPL affect the preference ratings? Is spatial enhancement of speakers still desirable in a multi-channel immersive sound environment? How do we evaluate it? How must a speaker look so the listener perceives that it sounds good?

This work is time consuming, tedious, and expensive if done rigorously. Few companies are willing to sponsor "science projects," much less publish the results. In my consultancy, we performed the experiments needed to develop products and generate plausible explanations, but the work was not done to a standard that could be published. My clients had no interest in that. I feel that many of us in the industry face the same situation. I joined Harman because Harman is one of the few companies committed to this research.

More Research

ANSI/CTA-2034-A could be the closest thing we have at present to the "Good Sound Meter." In 2013, the Consumer Technology Association (CTA, known as the CEA at that time) introduced the standard CTA-2034-A "Standard Method of Measurement for In-Home Loudspeakers."

CTA-2034-A is a comprehensive specification that includes the Spinorama test along with low-frequency extension, maximum useable SPL-Continuous, on-axis maximum SPL-Peak, impedance, recommended power amplifier size, the estimated in-room response, and the max recommended listening level. While the other tests have yet to benefit from the volume of scientific research that went into correlating the Spinorama to listener preference, they are based in science.

However, many of the ANSI/CTA-2034-A tests in the standard are difficult to perform or require investment in equipment upgrades. These changes do not occur overnight. Even at Harman, we have to upgrade our measurement equipment and software just to do all of the tests. At this point, there are few choices in commercial gear to perform the entire test suite and the tools are expensive. Companies using homegrown test suites will need to reprogram.

After acquiring the capability, many speaker companies might want to wait to accumulate a library of tests before publishing the data. This is a comprehensive test and it takes time to consider the data reliable. Some companies are not going to adopt it—either due to belief or financial circumstances.

Harman's Luxury Audio Group is publishing Spinorama data for new products. As we add the rest of the tests, we expect to include the full CTA-2034-A report within the year. Hopefully, other manufacturers will begin soon as well. ***LIS***

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EOL Testing of Acoustic Devices

A Truly Multidisciplinary Task

My job at NTi Audio enables me to support numerous acoustic device manufacturing places worldwide. While many things are handled individually, there are also a lot of common procedures and challenges found in almost every acoustic Quality Control (QC) environment. This article summarizes the major considerations for running a single or multiple-line acoustic QC test that is worthwhile, reliable, and reproducible.

By
Gregor Schmidle
NTi Audio

Keeping up consistent yield and quality in a high-volume acoustic device production environment requires well-designed end-of-line (EOL) manufacturing and test processes. However, there are many possible reasons for variations in measurement results. Within a single production line, variations can be caused by fluctuations in the quality of subcomponent material, changes in the manufacturing and assembly processes, as well as variance in environmental influences.

To ensure accuracy, the test system must be periodically calibrated or characterized in a system calibration. This is especially important when several production lines of the same type are operated in parallel, introducing line-to-line deviations. In many cases, these production lines are also spread across multiple facilities. When common limits are in use on different production lines, the mechanical differences between the test jigs introduce additional deviations in acoustic behavior. Further reasons for unwanted deviations are operator handling errors and wear and tear of test system components (e.g., electrical contacts). Another important topic is a recovery plan in case of an IT disaster (e.g., the loss of a hard drive).

What and How to Measure

Defining appropriate measurement parameters and functions for the EOL test lays out the groundwork for an efficient test system. There are two fundamental, yet conflicting requirements to fulfill:

- The test must be as detailed as necessary to reliably test the desired quality.
- The test must be fast enough to ensure no bottleneck in production.

Typical measurement functions (e.g., in a passive loudspeaker EOL test) are frequency response, impedance response, harmonic distortions in various configurations, sound pressure levels (SPLs) at different frequency bands, resonance frequency, Thiele-Small (T-S) parameters, speaker polarity, and Rub & Buzz measurement.

Technically, all those measurements can be executed by a single glide-sweep stimulus signal. However, in many test applications it is necessary to execute some measurement functions (e.g., frequency response, SPL, and all electrical measurements) with the nominal level of the tested device, whereas the Rub & Buzz test is typically executed at a higher level. Besides considering the measurement function, it is also necessary to set the test signal levels high enough for a proper signal-to-noise ratio (SNR) above environmental noise, but also low enough to not damage the test system operator's hearing. The latter can be diminished by suppressing the test level at higher frequencies to which the human ear is more susceptible.

For loudspeakers, the start and stop frequencies of test signals must not only cover the loudspeaker's transmission band but also adequately include the resonance frequency. If the driver's DC resistance is determined by an extrapolation of the impedance response, it is advised to set the lower frequency far enough away from the resonance. The start and stop frequency of the Rub & Buzz test signal is typically set to the loudspeaker's low-frequency range to trigger any electro-mechanical problems.

Defining Good and Bad

There are various methods and strategies to define limits when testing an acoustic device. The first major decision is whether to work with absolute limits or to use one or several reference samples. The diagram illustrates the decision process.

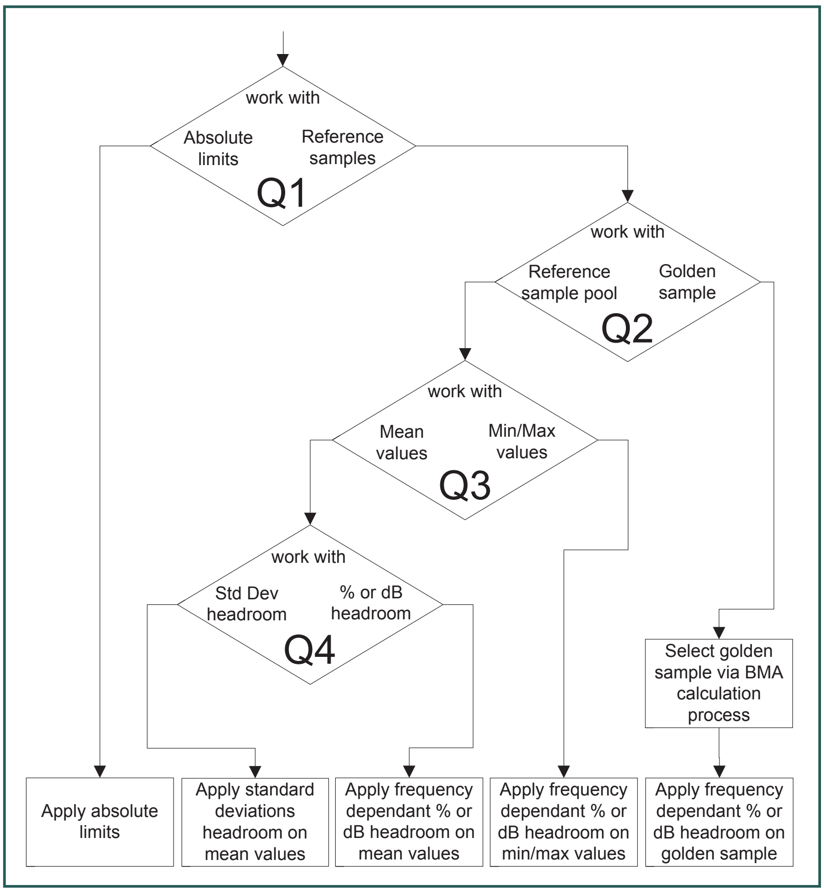
The limit finding strategy should be separately evaluated for each measurement function. Typical measurement functions suitable for the application of absolute limits are frequency and distortion response, as well as all electrical measurements such as impedance response and its derivative results. When using absolute limits for acoustic measurements, it is important to know the conditions under which the limits are valid (e.g., free field). If the conditions in the EOL test are different, the measurement result must be corrected accordingly. Reference samples are usually used when no specification is available (e.g., for Rub & Buzz).

Test Jig Considerations

The ideal test jig would be an anechoic chamber. However, in real life this is not feasible. Nonetheless, the test jig has to fulfill certain characteristics:

- Place the DUT in a defined position relative to the microphone.
- Tightly attach the DUT to the test jig.
- Create a reproducible acoustic situation.
- Avoid acoustic reflections.

A factory worker at Eighteen Sound uses NTi Audio equipment during the QC stage.



This generic limit calculation decision tree can be used to set up your decision process.

- Provide defined front and/or back cavities for the DUT.
- Shield the microphone from environment noise.
- Shield the microphone from structure-borne noise.
- Shield the operator from high sound pressure exposure.
- Allow efficient loading and unloading of the DUT (manual or automated).
- Allow reliable wiring of the DUT, with correct polarity (manual or automated).
- Allow to quickly change jig for testing different models.

Furthermore, the test jig itself should not introduce noise with resonating walls or rattling parts.

Taking all the points into consideration, the typical design is a massive, asymmetric wooden box shielded with acoustical foam in the inside. Since test jigs usually are not commercially available off the shelf, most manufacturers build their own test jigs.

While building one box is a manageable task, problems often begin when it comes to building multiple test jigs. It is recommended to accurately document all measures (e.g., length, width, distance, etc.), materials, and building processes, as even minor variations can produce measurable differences in the acoustic results.

Multiple Lines and Locations

Frequently, there are several production lines of the same type within one factory. Sometimes, the production lines are in different factories and even in different parts of the world. Yet, it is still necessary to manufacture and test the product in exactly the same way. The products shall be tested with the same test parameters, against the same limits, and, of course, deliver the same quality and yield.

Most of the components in different EOL test systems can be:

- Easily chosen to be identical (audio analyzer and accessories, cables and contacts)
- Parameterized to behave identically (audio amplifier gain and microphone sensitivity)

However, the test jigs also have to be built as identical as possible, since they directly influence acoustic behavior. Although there are mathematical corrections available, these increase the system's complexity.

When limit calculation is based on reference samples, it must be considered that the physical reference samples are only available on one site. However, the calculated limits are applied on multiple lines and sites, mostly without access to the physical reference.

Data Logging and Traceability

Almost every loudspeaker manufacturer, especially when using a quality management system, is required to be able to trace back the EOL test results of their products. For high-quality loudspeakers this might be for every single loudspeaker by using a serial number. On smaller and cost-effective devices, mostly the batch number is available. This typically allows tracing back the factory location, manufacturing date, and production line number.

For the data logging, this means that the EOL test software must be able to log several complementary data besides the measurement results, such as date and time, calendar week, project name, operator name, serial or batch number, and environmental data (e.g., temperature and humidity). Obviously, those log files can become quite large over time. Therefore, it is recommended to periodically start new log files (e.g., every week or at the start of each new production batch).

System Calibration and Maintenance

Calibration of the system ensures its accuracy. In a device calibration, the measurement results of the test device are compared against a highly accurate reference of that result and, if necessary, corrected. Device calibrations are usually performed annually by the device manufacturer. These are standards-traceable calibrations under ISO or other quality systems. Typical devices for a calibration in a loudspeaker EOL tester are the audio analyzer and the measurement microphone.

The sensitivity of a microphone can be calibrated by the system operator by using a microphone calibrator. This process can be executed as part of the system calibration. A

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system calibration is a procedure that is executed by the operator with a DUT connected to the test system. It consists of:

- Calibrating the test voltage at the DUT terminal, considering the internal or external amplifier gain setting
- Compensating for the electrical frequency response of said amplifier, thereby ensuring that the test voltage is set over the entire tested frequency band
- Calibration of the microphone sensitivity with a microphone calibrator
- Consideration of microphone to DUT distance (when calibrated for a certain SPL)

Wear and Tear on Parts

Some parts of an acoustic device EOL test system are vulnerable to wear and tear, and should be periodically checked or renewed. Parts that need to be checked include:

The electrical contacts that connect the DUT to the test system often show wear from friction, resulting in increased resistance or total loss of connection.

The measurement microphone membrane can be contaminated by dust and dirt, especially when it is facing upward. This can cause changes in microphone frequency response and sensitivity. An easy prevention is to use a dust cap and periodically exchange it.

The mechanic rest on which the DUT is positioned and fixed for the test is usually made of a soft material (e.g., foam or cork). Sometimes, an arrester system is also in use. Because they are mechanically stressed at the very same position during every unloading/loading process, those parts are in danger of wear from friction or even deformation. This can result in changes of acoustic and electrical measurement results.

When Disaster Strikes

To guarantee high availability, it is advisable to be prepared for disasters. Obviously, it is a good idea to have spare parts of all elements of a test system, especially for the ones that have a high risk of being worn out or damaged. But also, there should be documented procedures on any configuration steps that need to be taken in case of an exchange. For example, when exchanging the microphone, the sensitivity of the new microphone must be configured in the test system. This minimizes the system downtime.

To be prepared for an IT disaster (e.g., a PC or hard disk failure), a regular backup of system and project settings is recommended. This task can be automatically handled by test system software. Again, a documented procedure on how to restore the data helps to set up a new system quickly and efficiently, thus reducing downtime.

Hardware Handling

Common problems with hardware components include accidently unplugged cables, turned knobs, or toggled on/off switches. It is good practice to:

- Use amplifiers integrated into the test instrument with fixed gain.
- If an external amplifier is inevitable, use a model with fixed gain or protected volume wheels.
- Secure and stash cables.
- Protect on/off switches against accidental operation (e.g. rack with door).

Fail-Safe Workflow

The DUT must be loaded in the test jig in a clear and unambiguous way. Both the positioning and the contact process should provide haptic feedback to the operator. If the operator is required to trigger the measurement, the trigger button should be conveniently located next to the test jig, so that it can be pushed immediately after the DUT has been loaded.

Alternatively, the test system can constantly scan the contacts and automatically start the measurement once a connected loudspeaker is detected. The end of the measurement must be

Don't panic when disaster strikes. Make sure you have a plan in place.

Safeguard your system from environmental influences.

clearly displayed to the operator so that he or she can unload it immediately. When highly optimized, the next device in line can already be loaded into a second baffle, alternating with the first one that is currently being tested. This increases the throughput of the test system.

Protect Your Settings

To prevent operator errors, the test system software should have a user role management system. While a system administrator is a skilled user with no restriction, an operator is limited to have access only to the absolute necessary controls. If no configuration at all is required by the operator, interfaces such as the keyboard and the mouse can be stashed.

Troubles from Outside

Naturally, environmental influences to an EOL test should be avoided (see **Photo 3**). However, in reality this is not always possible. Therefore, it is important to be aware of the consequences those influences can have, as well as have ways to deal with them.

Temperature affects mostly the electrical parameters of an acoustic device. For a loudspeaker, this is especially the resonance frequency and its dependents. Variations of temperature can be caused by ambient temperature, but also by manufacturing processes that heat up the DUT and are executed shortly before the end-of-line test. For the latter case, before testing have a cooling phase long enough to bring the DUT to ambient temperature. It is advisable to log environmental data (e.g., temperature, humidity, and air pressure) along with the measurement data.

Manufacturing noise obviously influences the acoustic measurements. This includes air-borne as well as structure-borne noise. While some measurements are less susceptible to noise (e.g., frequency response), the most critical measurement is Rub & Buzz of loudspeakers.

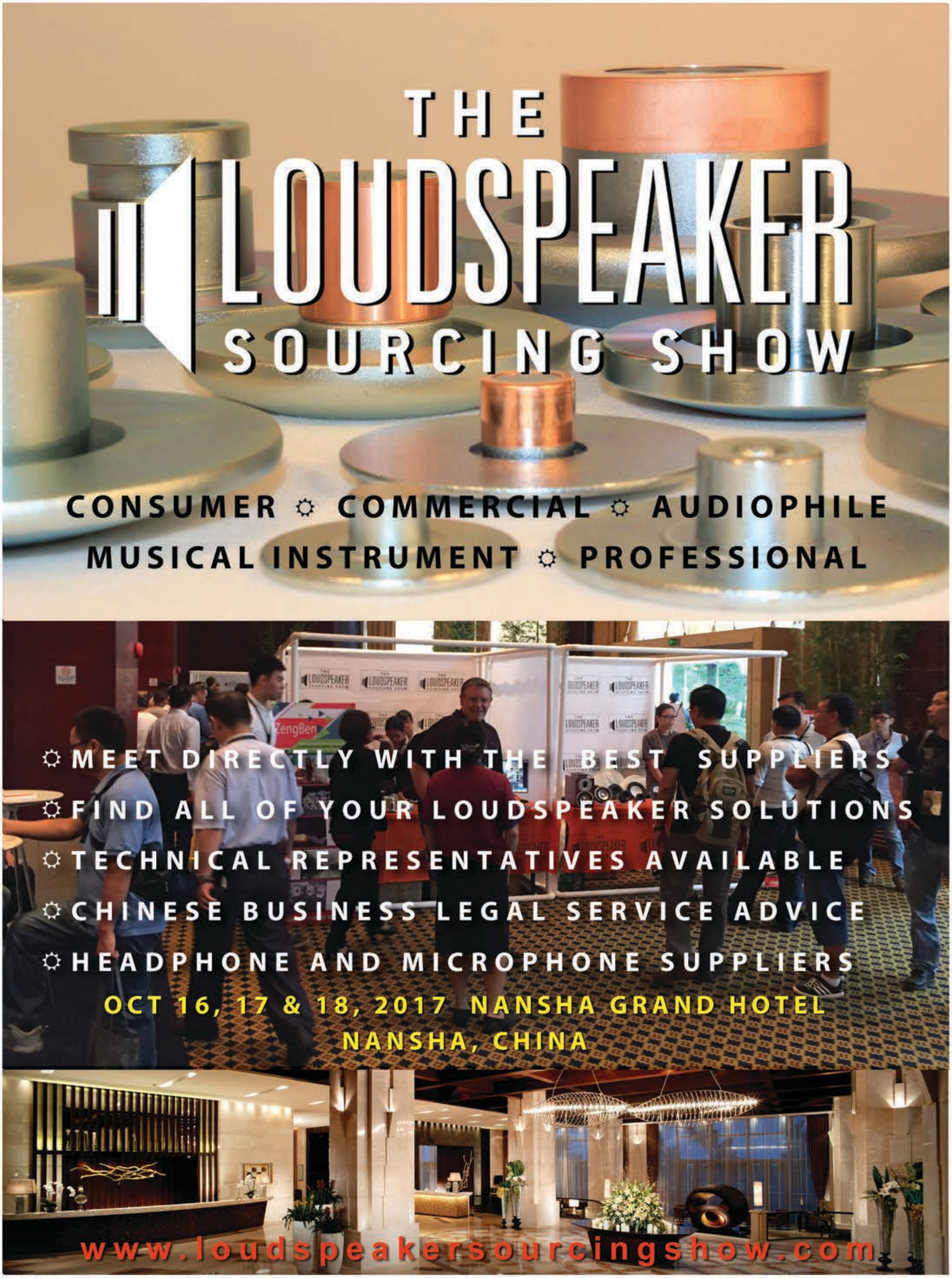
There are noise cancellation methods available in loudspeaker EOL test systems. However, this should be the last line of defense because they only deal with impulsive noise and they increase test time.

The majority of noise should ideally be physically shielded by the test jig. This is especially applicable for all constant background noise (e.g., manufacturing noise and machinery) Such shielding reduces the noise floor inside the test jig enabling you to measure Rub & Buzz effects that would otherwise be undetectable. All impulsive noise that only occurs infrequently can be handled by the noise cancellation algorithms of the EOL test system.

Electromagnetic influences are best handled by keeping audio cables short and using balanced audio (XLR cables). This is especially important for cables with low level and high impedance (e.g., microphone cables).

Wrap Up

Running a worthwhile and reliable EOL quality control for acoustic devices is by no means trivial. It requires considerations from several angles and involves multidisciplinary skills. Reproducible, reliable results can only be achieved with a combination of reliable test instruments operating within an environment that either remains constant or is properly managed. ***LIS***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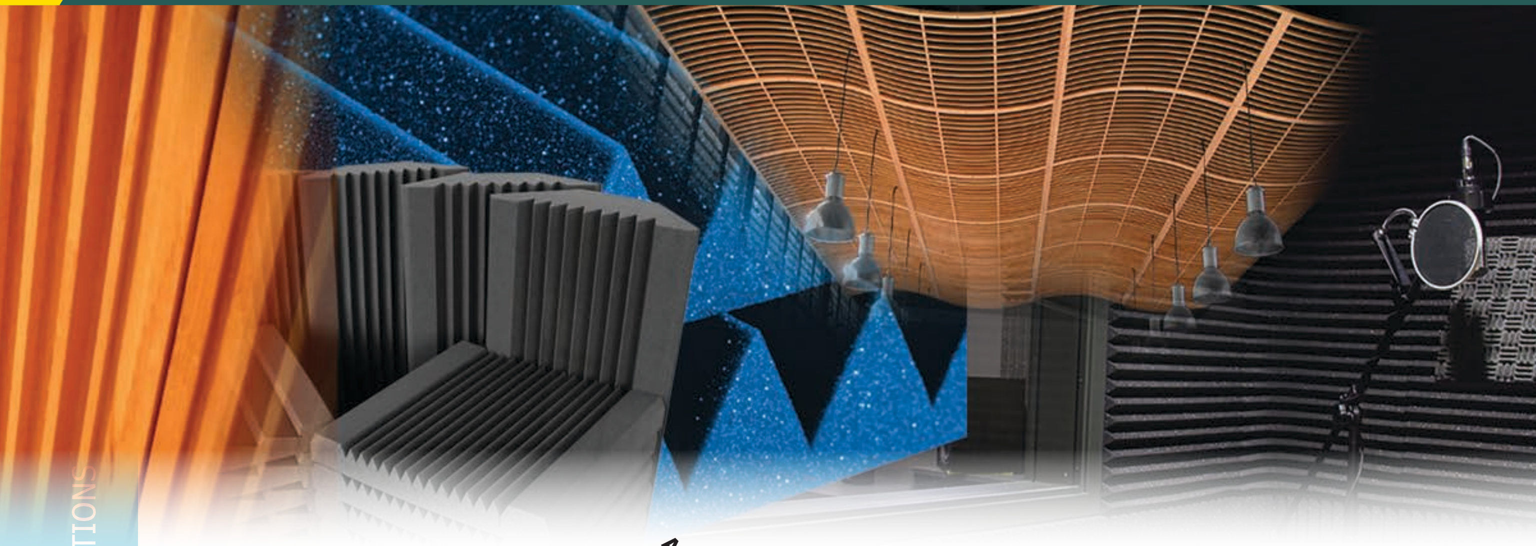
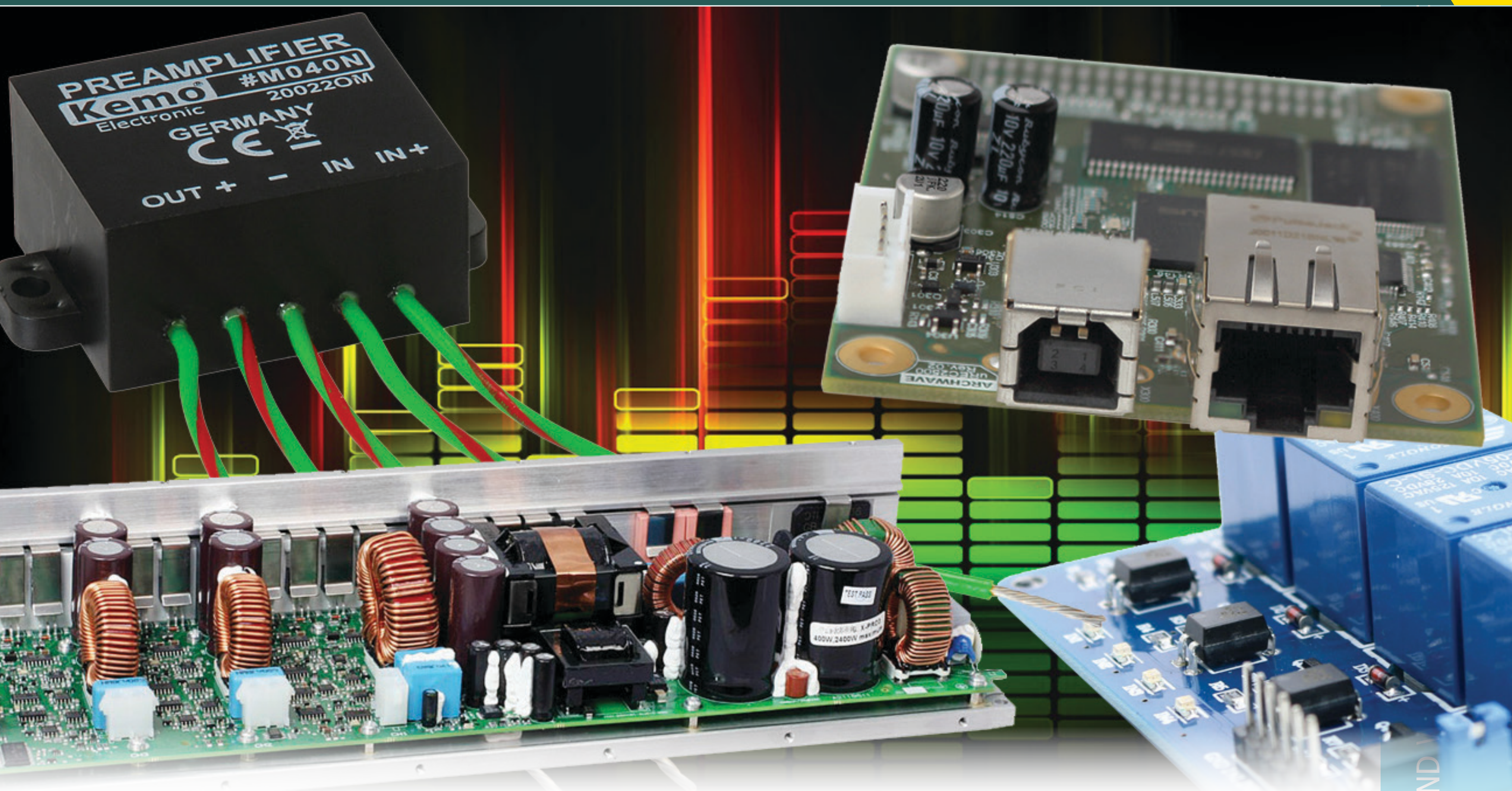


	Acoustic Consultancy Services & Design	Acoustic Doors	Acoustic Measurement	Acoustic Treatment Panels	Electroacoustical System Design	Home Theater Design	Multimedia and TV System Design	Noise Control	Sound Booths	Sound Isolation	Theater and Concert Hall Design
AUSTRALIA											
DEQX Pty., Ltd.							•				
Soundlabs Group Pty., Ltd.				•							
CANADA											
DLC Loudspeaker R&D Group	•		•	•							
Rutherford Audio			•	•		•			•		•
Solen Electronique, Inc.			•	•						•	
Stetron International, Inc.	•		•								
CHINA											
Lumi Audio (China) OEM/ODM	•		•	•		•					
Shenzhen Malata Mobile Communications, Inc.					•						
Trueanalog Strictly OEM			•		•	•				•	
DENMARK											
K & K Development			•	•							
FRANCE											
KYU Systems	•										
GERMANY											
Lautsprecher-Produktions-Gesellschaft mbH (LPG)			•								
Klippel GmbH			•	•							
Soundsgood Pro Audio Solutions	•		•	•							
HONG KONG											
Eastern Asia Technology (HK), Ltd.					•						
miniDSP			•	•							
INDIA											
GM Audio Technics, Ltd.	•		•	•							
Power Electronics & Technologies	•					•					•
IRELAND											
Crossover App			•								
ISRAEL											
Chorus Audio			•		•	•	•				

	Acoustic Consultancy Services & Design	Acoustic Doors	Acoustic Measurement	Acoustic Treatment Panels	Electroacoustical System Design	Home Theater Design	Multimedia and TV System Design	Noise Control	Sound Booths	Sound Isolation	Theater and Concert Hall Design
ITALY											
RCF, SpA	•										•
SpeakerLAB	•		•								
JAPAN											
Etani Electronics Co., Ltd.			•					•		•	
LATVIA											
Acoustic Power Lab			•	•	•	•	•				•
MEXICO											
Aletheia, AV	•									•	
NETHERLANDS											
ELTIM audio, BV				•							
Kamperman Engineering	•		•	•				•			
Sound Projects	•										
NEW ZEALAND											
Asona	•	•		•		•	•	•			•
NORWAY											
SEAS Fabrikker, AS			•								
POLAND											
Resnatura Audio			•								
PORTUGAL											
Jocavi - Acoustic Panels, Lda.				•						•	
Vicoustic	•	•	•	•	•	•	•	•	•	•	•
ROMANIA											
SC Poweraudio, SRL	•		•	•	•			•			•
SPAIN											
Brusi Acoustics	•		•								
TAIWAN											
Kingstate Electronics Corp.	•		•								
Yung International, Inc.						•	•				
THAILAND											
Clarasonic (Thailand) Co., Ltd.										•	
UKRAINE											
Mag Audio	•		•								
UNITED KINGDOM											
CE Electro-Acoustics	•										
EuroTec International, Plc.			•		•				•		
Interfacio, Ltd.					•						•
Tectonic Elements, Ltd.	•										
UNITED STATES											
AcousTex Fabrics		•		•		•					•
Acoustic Fields	•	•	•	•		•		•	•	•	•
Acoustics First Corp.	•		•	•		•		•	•	•	•

ACOUSTIC SOLUTIONS

	Acoustic Consultancy Services & Design	Acoustic Doors	Acoustic Measurement	Acoustic Treatment Panels	Electroacoustical System Design	Home Theater Design	Multimedia and TV System Design	Noise Control	Sound Booths	Sound Isolation	Theater and Concert Hall Design
Adrian Acoustics, Inc.				•							
American Bass USA	•							•		•	
AtlasIED								•		•	
Audio Precision, Inc.			•								
Audio-Optix	•			•		•				•	
B&H Photo - Video - Pro Audio				•				•		•	
Beach Dynamics	•	•	•	•				•	•	•	
Bob Young and Associates	•		•					•			
Campanella Associates & Acculab	•		•	•		•		•		•	•
Carl Tatz Design, LLC	•	•	•	•				•	•	•	
D. L. Adams Associates, Inc.	•				•		•	•		•	•
Dayton Audio	•										
DTV Installations								•			
ETS-Lindgren	•	•	•	•				•	•	•	
Excelsior Audio Design & Services					•						
Front End Audio				•				•		•	
Full Compass Systems, Ltd.		•	•	•				•			
GGEC America, Inc.			•								
HDSound	•					•					
HEAD acoustics, Inc.			•	•							
Hearing Components, Inc. (Comply Memory Foam Tips)								•		•	
HX Audio Lab	•		•	•	•			•		•	•
J&F Wood Products				•							
JP Electronics Design	•		•	•	•	•	•				
Meyer Sound				•	•						
MSC Software Corp.			•					•			
NedLab	•										
NTi Audio, Inc.			•	•							
ORCA Design And Manufacturing				•							
Parts Express			•	•				•	•	•	
PCB Piezotronics, Inc.			•					•			
Ponderosa Sound Systems	•			•	•	•	•	•		•	
PR Audio			•								
RealTraps, LLC	•			•							
Redco Audio				•							
Scantek, Inc.			•					•			
Speaker Clinic	•		•								
Spectrum Audio				•				•		•	
Studio Six Digital			•								
SVS										•	
Sweetwater.com		•		•				•		•	
THX, Ltd.						•					•
TMI Engineering	•	•	•	•	•	•	•	•	•	•	•
True Technologies, Inc.	•		•		•						
US Enclosure Co.	•	•		•				•	•	•	
Vintage King Audio				•				•		•	
Vocal Booth									•	•	
Warkwyn	•		•								
Westlake Audio, Inc.	•										
Wired 4 Sound, Inc.	•			•		•	•	•		•	•



	Amplification Modules	Digital Signal Processing	Network Connectivity	Wireless Connectivity
AUSTRALIA				
DEQX Pty., Ltd.	•	•	•	•
Soundlabs Group Pty., Ltd.	•			
BELGIUM				
Premium Sound Solutions	•	•	•	•
BRAZIL				
Advanced Audio Technologies (AAT)	•			
AMCP Electronica	•			
CANADA				
Solen Electronique, Inc.	•	•	•	•
Space-Tech Lab, Ltd.	•			
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DENMARK				
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IDEA	•			
HONG KONG				
Eastern Asia Technology (HK), Ltd.	•			•
miniDSP	•	•	•	•
INDIA				
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ITALY				
Axiomedia, SRL	•	•		•
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JAPAN				
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Bohmer Audio, AB	•	•	•	•
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	Amplification Modules	Digital Signal Processing	Network Connectivity	Wireless Connectivity
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MAG Audio	•			
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Linkplay				•
Marchand Electronics, Inc.	•			
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Space-Tech Lab, Ltd.

CHINA
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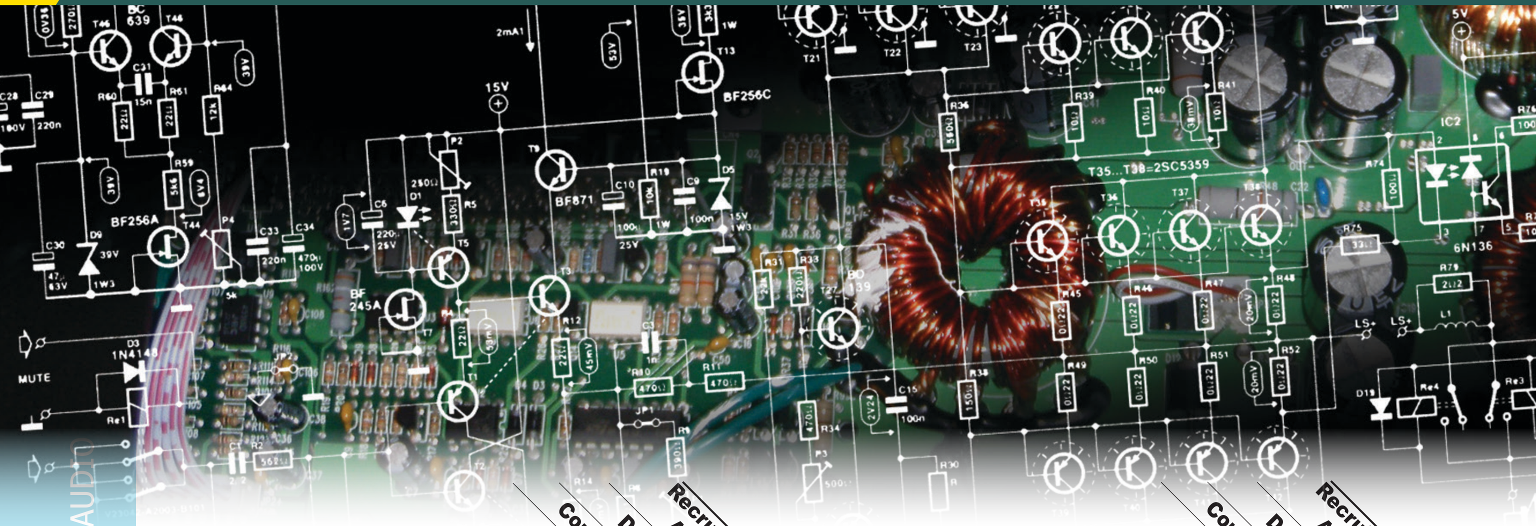
HDSound
HEAD acoustics, Inc.
HX Audio Lab
Integrated Audio Technologies
Lipinski Sound
North Reading Engineering
Pacific Audio Consulting
Prism Media Products, Inc. (Prism Sound/MASELEC/SADiE/LOUDSOFT)
Pro Sound Testing, Inc.
Studio Electric - David MacPherson
THX, Ltd.
TSG Audio

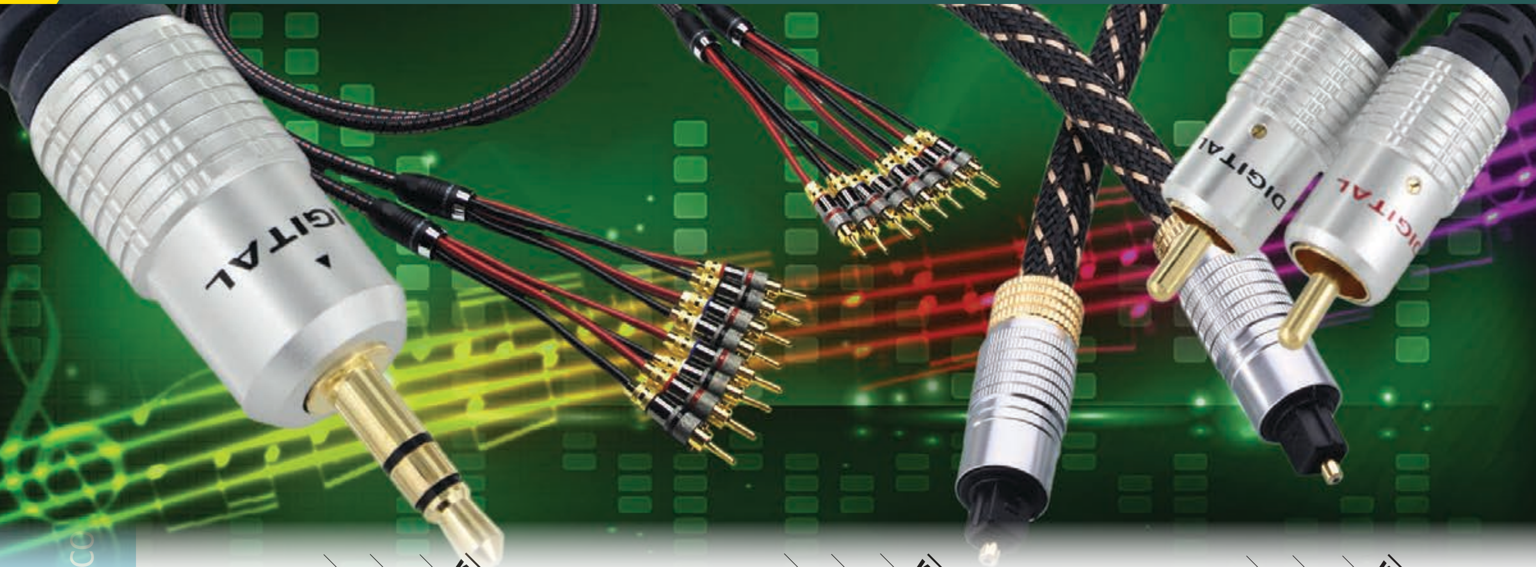


	Consultants	Designers	Recruitment Agencies
ARGENTINA			
Laufer Speaker	•	•	
AUSTRALIA			
Audinate Pty., Ltd.	•	•	
DEQX Pty., Ltd.	•	•	
Stone Sound Studio	•		
BRAZIL			
Advanced Audio Technologies (AAT)	•	•	
Edgar Prudente da Silva	•		
CANADA			
Canadian Speaker Works	•	•	
DLC Loudspeaker R&D Group	•	•	
Kravchenko-Audio	•	•	
Planet10-HiFi	•		
Solen Electronique, Inc.	•	•	
Space-Tech Lab, Ltd.	•		
Studio Reference Monitors	•	•	
CHINA			
B.W. Audio Guangzhou Co., Ltd.	•	•	
BSWA Technology Co., Ltd.	•	•	
Dongguan Yuonyunn Membrane Co.	•	•	
Fountek Electronics Co., Ltd.	•	•	
Sound Technology Development. Ltd. (Factory)	•	•	
Sun Technique Electric Co., Ltd.	•	•	
DENMARK			
LOUDSOFT, Ltd.	•	•	
FRANCE			
KYU Systems	•	•	
GERMANY			
Klippel GmbH	•	•	
Scherer Audio	•	•	
HONG KONG			
Acoustic Development International	•	•	
Ocean Star Electronics, Ltd.	•	•	
Panson Audio	•	•	
WCE Acoustics	•		
INDIA			
Power Electronics & Technologies	•	•	
ITALY			
Audiomatica, SRL	•	•	
AXP	•	•	
LATVIA			
Acoustic Power Lab	•		
NETHERLANDS			
Kamperman Engineering	•	•	
POLAND			
Resnatura Audio	•	•	
SPAIN			
Sottovoce Audio	•	•	
TAIWAN			
Yung International, Inc.			
UNITED KINGDOM			
EuroTec International, Plc.	•	•	
Hill Acoustics	•	•	
Interfacio, Ltd.			•
UNITED STATES			
Acoustic Fields	•	•	
American Bass USA	•	•	
Association of Loudspeaker Manufacturing and Acoustics (ALMA) International	•	•	
Audio Connection	•	•	
Audio Nirvana Fullrange Speakers and Vacuum	•	•	
Tube Amplifiers	•	•	
Barefoot Sound, LLC	•	•	
Beach Dynamics	•	•	
BeStar Technologies, Inc.	•	•	
Bruel & Kjaer Sound and Vibration Measurement, A/S	•		
CGN Audio Labs	•	•	

	Consultants	Designers	Recruitment Agencies
CJS Labs	•	•	
Community Professional Loudspeakers	•	•	
Danville Signal Processing, Inc.	•	•	
dB Design	•	•	
DMSI	•	•	
DTV Installations	•	•	
Earthquake Sound Corp.	•	•	
eMagineFactory, LLC	•	•	
Excelsior Audio Design & Services, LLC	•	•	
Geometric Designs LLC & Geometric Consulting	•	•	
Globe Audio Design, Inc.	•	•	
HDSound	•	•	
HEAD acoustics, Inc.	•	•	
HX Audio Lab	•	•	
Integrated Audio Technologies	•	•	
JP Electronics Design	•	•	
Linkplay	•	•	
Lowther Speakers USA	•	•	
Marchand Electronics, Inc.	•	•	
McKinney & Associations, LLC	•	•	
Menlo Scientific	•	•	
Midwest Audio Club	•	•	

	Consultants	Designers	Recruitment Agencies
NedLab	•	•	
Pacific Audio Consulting	•	•	
Planot, LLC	•	•	
Ponderosa Sound Systems	•	•	
PR Audio	•	•	
Pro Sound Testing, Inc.	•	•	
Seneschal	•	•	
Soundoctor	•	•	
Speaker Clinic	•	•	
SpeakersAndAmps.com	•	•	
Stroud Audio, Inc.	•	•	
Studio Electric - David MacPherson	•	•	
TMI Engineering	•	•	
True Technologies, Inc.	•	•	
TSG Audio	•	•	
US Enclosure Co.	•	•	
Vance Dickason Consulting	•	•	
Warkwyn	•	•	
Wired 4 Sound, Inc.	•	•	

CABLES & CONNECTORS



	Cables	Connectors	Wire Channel
AUSTRALIA			
Soundlabs Group Pty., Ltd.	•	•	
Stone Sound Studio	•	•	
BRAZIL			
Advanced Audio Technologies (AAT)	•		
CANADA			
Canadian Speaker Works	•	•	
DLC Loudspeaker R&D Group	•	•	
Rutherford Audio, Inc.	•		
Solen Electronique, Inc.	•	•	
The Canadian Loudspeaker Corp.		•	
CHINA			
BSWA Technology Co., Ltd.	•	•	•
Sound Technology Development, Ltd. (Factory)	•	•	•
Sun Technique Electric Co., Ltd.	•	•	•
DENMARK			
Estron A/S	•	•	
Jantzen Audio Denmark	•		
GERMANY			
HiFi-Tuning	•	•	
Soundsgood Pro Audio Solutions	•	•	
HONG KONG			
WCE Acoustics	•	•	
INDIA			
Power Electronics & Technologies	•	•	
IRELAND			
Crossover App	•		
ITALY			
Axiomedia, SRL	•	•	
JAPAN			
Furutech Co., Ltd.	•	•	
S'NEXT Co., Ltd.	•	•	
MEXICO			
Aletheia, AV	•		
NETHERLANDS			
ELTIM audio, BV	•	•	
POLAND			
Resnatura Audio	•	•	
RUSSIA			
Deluxe Acoustics, Ltd.	•		
SWEDEN			
Audio Pro, AB	•		
TAIWAN			
Huey Tung International Co., Ltd.	•	•	
Yung International, Inc.	•	•	•
UKRAINE			
Mag Audio	•	•	
UNITED KINGDOM			
EuroTec International, Plc.	•	•	•
Fane International, Ltd.			
Revolver Audio, Ltd.	•		
UNITED STATES			
A. Schulman, Inc.		•	
American Bass USA	•	•	
AMS Audio Enterprises, Inc.	•	•	
Audio Advisor, Inc.	•	•	
Audio Connection	•	•	•
B&H Photo - Video - Pro Audio	•	•	
Blackmore Mobile	•	•	
Carvin Audio	•	•	
Controlled Thermal Processing, Inc.	•	•	•
DTV Installations	•	•	•
Earthquake Sound Corp.	•		
Front End Audio	•	•	
Full Compass Systems, Ltd.	•	•	
G.R.A.S. Sound & Vibration	•	•	
HAVE, Inc.	•	•	•
Herman Pro AV	•	•	
JL Audio, Inc.	•	•	
Kramer Electronics	•	•	
Lamart Corp.	•	•	•
Loudspeakers Plus		•	
Madisound Speaker Components, Inc.	•		
Open Tip	•	•	
Parts Express	•	•	•
PowerPhysics, Inc.	•		
Pro Flix Sales	•	•	
Radio Design Labs (RDL)	•	•	•
Redco Audio	•	•	•
Revolution Power	•	•	
Sound Pure, LLC	•	•	
Soundoctor	•	•	
Spectrum Audio	•	•	
Stillwater Designs | KICKER	•		
Straight Wire, Inc.	•	•	•
SVS	•	•	
Sweetwater.com	•	•	
Tonian Laboratories	•		
TSG Audio	•	•	
US Speaker, LLC	•	•	
Vidsonix Design Works	•	•	
Westlake Audio, Inc.	•	•	•
Wired 4 Sound, Inc.	•	•	•
Wireworld Cable Technology	•	•	
Yandas Music	•	•	
Zu Audio	•		
zZounds Music, LLC	•	•	

	Earphones	Headphones
AUSTRALIA		
Stone Sound Studio		•
BRAZIL		
Harman of Brazil, Ltda.	•	•
CANADA		
DLC Loudspeaker R&D Group	•	•
Focal North America		•
Solen Electronique, Inc.	•	•
CHINA		
Enkor Electronics Co., Ltd.		•
Lumi Audio (China) OEM/ODM		•
Sound Technology Development, Ltd. (Factory)	•	•
HONG KONG		
Eastern Asia Technology (HK), Ltd.	•	•
WCE Acoustics	•	•
ITALY		
RCF, SpA		•
JAPAN		
Furutech Co., Ltd.	•	•
S'NEXT Co., Ltd.	•	•
SWEDEN		
Audio Pro, AB		•
TAIWAN		
Huey Tung International Co., Ltd.	•	•
Kingstate Electronics Corp.	•	•
Yung International, Inc.	•	•
UNITED STATES		
1MORE	•	•
Acoustic Development International		•
American Bass USA	•	•
American Music And Sound	•	•
Audio Advisor, Inc.	•	•
Audio Connection	•	•
AValive		•
B&H Photo - Video - Pro Audio		•
BeStar Technologies, Inc.	•	•
Blackmore Mobile		•
Bob Young and Associates	•	•
Earthquake Sound Corp.	•	•
Echobox Audio, LLC	•	•
ESS Laboratories, LLC		•
Front End Audio		•
Full Compass Systems, Ltd.	•	•
HAVE, Inc.		•
Hearing Components, Inc. (Comply Memory Foam Tips)	•	•
Materion Electrofusion		•
Open Tip	•	•
Pacific Audio Consulting	•	•
Parts Express	•	•
Peerless by Tymphany		•
PreSonus Audio Electronics, Inc.		•
Pro Flix Sales		•
Puro Sound Labs		•
RBH Sound	•	•
Revolution Power	•	
Seltech	•	•
Shure, Inc.	•	•
Sound Pure, LLC		•
Sound Sources Technology, Inc.	•	•
Spectrum Audio	•	•
Stillwater Designs | KICKER	•	•
US Enclosure Co.	•	•
Vintage King Audio		•
Yandas Music	•	•
Zu Audio		•
zZounds Music, LLC		•

	Baffles		Finished Cabinets			Sub-Assemblies										Materials	Panels	Rigging
	Ceiling Speaker Plates	In-Wall Plates	Box Arrays (PA)	Boxes	Stands	Bulk Molding Compound	Carpet	Hardwood	MDF (Fiberboard)	Other	Paper/Paper Pulp	Plastic	Plywood	Veneer	Wound Geometric Tubes			
AUSTRALIA																		
Stone Sound Studio																•	•	
BELGIUM																		
Premium Sound Solutions				•														
BRAZIL																		
Advanced Audio Technologies (AAT)				•	•													
CANADA																		
Canadian Speaker Works																•	•	•
Planet10-HiFi				•														
Solen Electronique, Inc.	•	•		•	•													
Studio Reference Monitors				•														
CHINA																		
Lumi Audio (China) OEM/ODM	•	•		•	•				•			•						
OBE Pro Audio Co., Ltd.																		•
Shenzhen Tekzone Loudspeaker Co., Ltd.																•	•	
Sound Technology Development, Ltd. (Factory)																•	•	
Sun Technique Electric Co., Ltd.																•	•	
Trueanalog Strictly OEM				•	•				•				•	•				
DENMARK																		
Kvart & Bølge, Inc.				•														
FRANCE																		
KYU Systems			•	•									•		•	•		

	Baffles		Finished Cabinets			Sub-Assemblies												
	Ceiling Speaker Plates	In-Wall Plates	Box Arrays (PA)	Boxes	Stands	Bulk Molding Compound	Carpet	Hardwood	MDF (Fiberboard)	Other	Paper/Paper Pulp	Plastic	Plywood	Veneer	Wound Geometric Tubes	Materials	Panels	Rigging
GERMANY																		
Soundsgood Pro Audio Solutions	•	•	•	•	•	•		•	•	•								
HONG KONG																		
Ocean Star Electronics, Ltd.	•	•	•	•	•		•	•	•			•	•	•	•			
INDIA																		
GM Audio Technics, Ltd.			•	•														
ITALY																		
Axiomedia, SRL				•	•		•									•		
MEXICO																		
Aletheia AV			•	•	•				•	•								
NETHERLANDS																		
ELTIM audio BV				•														
Sound Projects			•	•														•
POLAND																		
Sveda Audio				•	•													
ROMANIA																		
SC Poweraudio, SRL			•	•														
SPAIN																		
Sottovoce Audio				•	•													

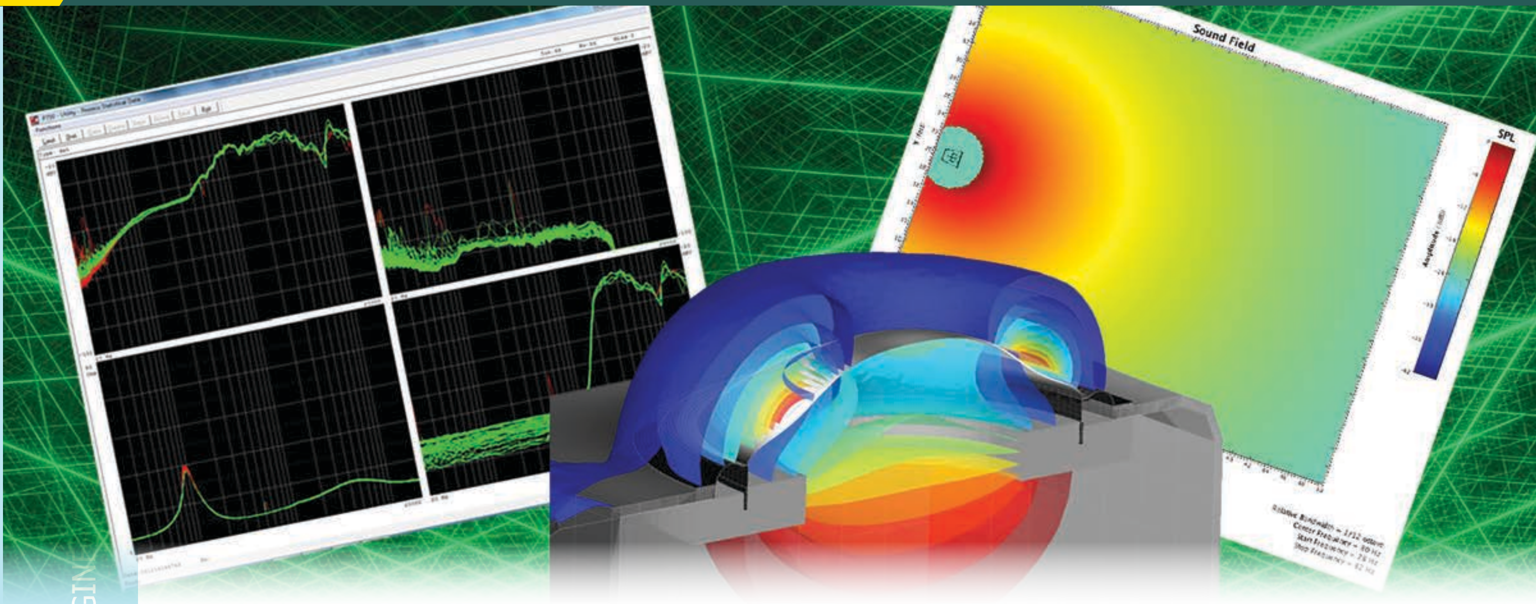
	Baffles		Finished Cabinets			Sub-Assemblies										Materials	Panels	Rigging
	Ceiling Speaker Plates	In-Wall Plates	Box Arrays (PA)	Boxes	Stands	Bulk Molding Compound	Carpet	Hardwood	MDF (Fiberboard)	Other	Paper/Paper Pulp	Plastic	Plywood	Veneer	Wound Geometric Tubes			
SWEDEN																		
Audio Pro, AB																•	•	
TAIWAN																		
Hi-Tech Sound System Co., Ltd.	•	•																
Huey Tung International Co., Ltd.	•	•	•	•	•	•	•		•			•						
Yie Feng Technology Enterprise Co.												•						
Yung International, Inc.			•	•	•				•			•		•				
UNITED KINGDOM																		
Bishopsound			•	•	•				•				•					
EuroTec International, Plc.	•		•	•								•						
PA Workshop, Ltd.				•									•			•		
UNITED STATES																		
Acry-Tech Coatings, Inc.																•		
Adrian Acoustics, Inc.	•	•	•	•	•			•	•	•			•	•				
American Bass USA	•	•	•	•	•													
AMS Audio Enterprises, Inc.	•	•		•	•													
Area 52 R&D				•					•	•			•	•				
Audio Connection								•										
Barefoot Sound, LLC				•					•									
Campanella Associates & Acculab										•								
Carvin Audio			•	•														
CGN Audio Labs			•	•						•								
Dayton Audio				•														
Eminence Speaker, LLC			•	•														
Fulcrum Acoustic, LLC				•														
Full Compass Systems, Ltd.	•	•					•										•	
GGEC America, Inc.				•			•	•	•			•	•	•				
Global Audio Source, Inc.				•	•													
Globe Plastics, Inc.	•	•		•		•				•		•						
Inlow Sound				•				•			•		•	•				
J&F Wood Products	•	•	•	•	•		•	•	•				•	•				
Levister Audio				•														
Lowell Manufacturing Co.	•	•		•														
Midwest Audio Club				•	•			•	•				•	•				
Parts Express	•	•	•	•	•		•		•					•				
Ponderosa Sound Systems			•	•	•													
Precision Sound Products, Inc.										•								
RBH Sound	•	•		•					•	•		•						
Sound Anchors					•													
Sound Sources Technology, Inc.	•	•	•	•	•		•											
SpeakersAndAmps.com			•	•														
Studio Electric - David MacPherson			•	•				•	•					•				
Tone Tubby, Inc.				•														
TSG Audio			•	•	•													
United Gasket Corp.	•	•					•				•					•		
US Enclosure Co.	•	•	•	•	•					•		•		•	•			•
US Speaker, LLC			•	•	•													
Vidsonix Design Works				•					•									
Wired 4 Sound, Inc.			•	•														•
Yandas Music				•	•													

	Enclosure Grilles	Enclosure Stuffing: Fiberglass	Enclosure Stuffing: Foam	Enclosure Stuffing: Synthetic	Enclosure Stuffing: Wool	Grille Assemblies: Fabric Suppliers	Grille Assemblies: Foam Suppliers	Grille Assemblies: Perforated Metal Suppliers	Hardware: Corners	Hardware: Handles	Hardware: Name Plates	Hardware: Fasteners & Other
AUSTRALIA												
Soundlabs Group Pty., Ltd.	•		•	•	•	•	•	•				•
Stone Sound Studio	•											
CANADA												
Canadian Speaker Works	•		•	•			•	•		•	•	•
Solen Electronique, Inc.	•	•	•	•	•	•		•				•
Tortech Sound, Inc.	•											
CHINA												
Lumi Audio (China) OEM/ODM								•				
OBE Pro Audio Co., Ltd.	•								•	•		
Shenzhen Tekzone Loudspeaker Co., Ltd.	•			•								
Sound Technology Development, Ltd. (Factory)	•	•	•	•	•	•	•	•	•	•	•	•
Sun Technique Electric Co., Ltd.	•	•	•	•	•	•	•	•	•	•	•	•
Trueanalog Strictly OEM											•	
FRANCE												
KYU Systems	•		•		•	•	•	•	•			
GERMANY												
Hubert Stüken GmbH & Co., KG								•				
HONG KONG												
Ocean Star Electronics, Ltd.	•											
INDIA												
GM Audio Technics, Ltd.			•									

	Enclosure Grilles	Enclosure Stuffing: Fiberglass	Foam	Synthetic	Wool	Grille Assemblies: Fabric Suppliers	Foam Suppliers	Perforated Metal Suppliers	Hardware: Corners	Handles	Name Plates	Fasteners & Other
ITALY												
Axiomedia, SRL						•	•		•	•	•	
NETHERLANDS												
ELTIM audio, BV				•								
SWEDEN												
Audio Pro, AB	•	•	•	•	•	•		•	•			•
TAIWAN												
Taiwan Solidex Corp.	•										•	
Yie Feng Technology Enterprise Co.	•		•				•					
UKRAINE												
Mag Audio	•											
UNITED KINGDOM												
EuroTec International, Plc.	•	•	•	•		•	•	•				
UNITED STATES												
A. Schulman, Inc.	•											
Accurate Perforating Co., Inc.	•							•				
AcousTex Fabrics	•					•						
Acry-Tech Coatings, Inc.												•
Adrian Acoustics, Inc.	•	•	•	•	•	•	•					

	Enclosure Grilles	Enclosure Stuffing: Fiberglass	Enclosure Stuffing: Foam	Enclosure Stuffing: Synthetic	Enclosure Stuffing: Wool	Grille Assemblies: Fabric Suppliers	Grille Assemblies: Foam Suppliers	Grille Assemblies: Perforated Metal Suppliers	Hardware: Corners	Hardware: Handles	Hardware: Name Plates	Hardware: Fasteners & Other
American Bass USA	•								•	•	•	•
AMS Audio Enterprises, Inc.	•					•		•				
Carvin Audio									•	•		•
Dayton Audio	•											
Full Compass Systems, Ltd.	•	•	•	•	•	•	•	•	•	•	•	•
Global Audio Source, Inc.	•											
Globe Plastics, Inc.	•								•	•		
J&F Wood Products	•	•				•						
Lowell Manufacturing Co.	•							•				
Master Bond, Inc.												
Meniscus Audio Group, Inc.			•	•								
MetalEX	•							•				
ORCA Design And Manufacturing					•							
Precision Sound Products, Inc.												•
RBH Sound	•											
SpeakerAddict	•	•	•	•	•	•		•	•	•		•
United Gasket Corp.			•	•	•	•	•					
US Enclosure Co.	•	•	•	•	•	•	•	•			•	
US Speaker, LLC									•	•	•	•
Vidsonix Design Works	•							•				

ENGINEERING SOFTWARE



	Acoustic Analysis	Box Design	Crossover Optimizer	Network Design	CAE or CAD
AUSTRALIA					
Audinate Pty., Ltd.	•	•	•	•	•
Audiosoft	•	•	•	•	
DEQX Pty., Ltd.	•		•	•	
Stone Sound Studio	•	•	•		•
BRAZIL					
Advanced Audio Technologies (AAT)		•	•	•	•
CANADA					
Canadian Speaker Works	•	•			•
DLC Loudspeaker R&D Group	•	•	•	•	
Solen Electronique, Inc.	•	•	•		
CHINA					
BSWA Technology Co., Ltd.	•				
Shenzhen Tekzone Loudspeaker Co., Ltd.	•	•	•	•	•
Sound Technology Development, Ltd. (Factory)	•	•	•	•	•
Sun Technique Electric Co., Ltd.	•	•	•	•	•
Trueanalog Strictly OEM		•			•
DENMARK					
K & K Development	•				
LOUDSOFT, Ltd.	•	•	•		
FRANCE					
KYU Systems	•		•	•	•
GERMANY					
Klippel GmbH	•				
R&D Team	•	•	•	•	
Soundsgood Pro Audio Solutions	•	•			•

	Acoustic Analysis	Box Design	Crossover Optimizer	Network Design	CAE or CAD
HONG KONG					
Ocean Star Electronics, Ltd.	•	•			•
INDIA					
GM Audio Technics, Ltd.	•				
IRELAND					
Crossover App			•		
ISRAEL					
Coby Speakers	•	•	•	•	•
ITALY					
Audiomatica, SRL	•				
SpeakerLAB	•				•
JAPAN					
Etani Electronics Co., Ltd.	•	•			•
LATVIA					
Acoustic Power Lab	•		•		
SPAIN					
Brusi Acoustics	•	•		•	
SWEDEN					
Audio Pro, AB	•	•	•	•	
Bohmer Audio, AB	•		•		•
SWITZERLAND					
Archwave				•	
TAIWAN					
Kingstate Electronics Corp.	•				•

	Acoustic Analysis	Box Design	Crossover Optimizer	Network Design	CAE or CAD
UNITED KINGDOM					
EuroTec International, Plc.					•
PACSYS, Ltd.	•				
UNITED STATES					
Bruel & Kjaer Sound and Vibration Measurement, A/S	•				
Community Professional Loudspeakers	•	•	•	•	•
Danville Signal Processing, Inc.	•		•	•	
Digmoda			•		
Geometric Designs LLC & Geometric Consulting		•	•		•
Globe Audio Design, Inc.			•		
HEAD acoustics, Inc.	•				
HX Audio Lab	•	•	•	•	
Listen, Inc.	•				
MSC Software Corp.	•		•		•
NedLab		•	•	•	
Parts Express	•	•			

	Acoustic Analysis	Box Design	Crossover Optimizer	Network Design	CAE or CAD
Prism Media Products, Inc. (Prism Sound/MASELEC/SADiE/LOUDSOFT)	•	•	•	•	
Scantek, Inc.	•				
Speaker Clinic		•	•		•
Studio Six Digital	•				
Warkwyn	•	•	•	•	•

	Car Audio	Home Audio	Marine Audio	Pro Audio
AUSTRALIA				
Stone Sound Studio	•	•		•
BELGIUM				
Premium Sound Solutions	•	•		
BRAZIL				
Advanced Audio Technologies (AAT)	•	•		
AMCP Electronica		•		
Harman of Brazil, Ltda.	•	•	•	•
CANADA				
Canadian Loudspeaker Corp.	•	•		•
Canadian Speaker Works				•
Focal North America	•	•		•
LMH Loudspeakers	•	•		•
Planet10-HiFi		•		
Solen Electronique, Inc.	•	•		•
Space-Tech Lab., Ltd.		•		
Studio Reference Monitors				•
CHINA				
Audiostar Electronics Co., Ltd.	•	•		•
B.W. Audio Guangzhou Co., Ltd.				•
Enkor Electronics Co., Ltd.		•		
Fountek Electronics Co., Ltd.	•	•		•
Lumi Audio (China) OEM/ODM		•		•
OBE Pro Audio Co., Ltd.				•
Shenzhen Tekzone Loudspeaker Co., Ltd.		•		•
Sonos Beijing Office		•		
Sound Technology Development, Ltd. (Factory)		•		•
Speakerhu Electronic Co., Ltd.	•	•		
Sun Technique Electric Co., Ltd.	•	•		•
Trueanalog Strictly OEM	•	•	•	•
Zeng Ben Industrial Corp., Ltd.	•	•		•
Zhuhai HiVi Technology Company, Ltd.	•	•		•
DENMARK				
ICEpower, A/S	•	•		•
Kvart & Bølge, Inc.		•		
Pascal, A/S				•
Scan Speak, A/S	•			
FRANCE				
Crista Technologies		•		
KYU Systems				•
Waterfall Audio		•		•
GERMANY				
Lautsprecher-Produktions-Gesellschaft mbH (LPG)	•			
Eton	•	•		
HiFi-Tuning		•		•
Scherer Audio		•		
HONG KONG				
Acoustic Development International	•	•		
Eastern Asia Technology (HK), Ltd.	•	•	•	•
miniDSP	•	•		•
Ocean Star Electronics, Ltd.		•		•
WCE Acoustics		•		
INDIA				
GM Audio Technics, Ltd.				•
Power Electronics & Technologies		•		•
INDONESIA				
SB Acoustics		•		
IRELAND				
Crossover App	•	•	•	•
ISRAEL				
Chorus Audio		•		•
Coby Speakers	•	•	•	•
Morel, Ltd.	•	•		
ITALY				
Powersoft Audio, SpA				•
JAPAN				
Etani Electronics Co., Ltd.	•	•		•
MALAYSIA				
TC Electronics Sdn. Bhd.	•	•		

	Car Audio	Home Audio	Marine Audio	Pro Audio
MEXICO				
Aletheia, AV		•		
NETHERLANDS				
ELTIM audio, BV		•		•
Sound Projects				•
NEW ZEALAND				
Theophany Loudspeakers, Ltd.		•		
NORWAY				
SEAS Fabrikker, AS		•		
POLAND				
Sveda Audio		•		•
ROMANIA				
SC Poweraudio SRL				•
RUSSIA				
Deluxe Acoustics, Ltd.		•		
Star Sound Technologies	•	•		•
SPAIN				
Sottovoce Audio		•		•
SWEDEN				
Audio Pro, AB	•	•		•
TAIWAN				
Huey Tung International Co., Ltd.	•	•		•
Hurray, Co., Ltd.	•	•		•
Kingstate Electronics Corp.	•	•		
UKRAINE				
MAG Audio				•
UNITED KINGDOM				
Compbass, Ltd.		•		•
EuroTec International, Plc.	•		•	•
Fane International, Ltd.				•
Ferguson Hill Studios, Ltd.		•		•
Precision Devices, Ltd.				•
Tectonic Elements, Ltd.	•	•		•
UNITED STATES				
Ambiance Acoustics		•		•
American Bass USA	•			
American Music And Sound	•	•	•	•
AMS Audio Enterprises, Inc.		•		•
Area 52 R&D		•		•
Audioengine		•		
Audio-Optix		•		•
B&H Photo - Video - Pro Audio		•		•
Barefoot Sound, LLC				•
Blackmore Mobile		•		•
Carvin Audio		•		
CGN Audio Labs				•
CommonSense Audio		•		•
Dayton Audio		•		
dBTechnologies				•
Digital Audio Labs				•
Digmoda		•		•
Earthquake Sound Corp.	•	•	•	•
Eminence Speaker, LLC				•
ESS Laboratories, LLC	•	•		
Fulcrum Acoustic, LLC				•
Geometric Designs, LLC & Geometric Consulting		•		
GGEC America, Inc.	•	•	•	•
Global Audio Source, Inc.	•	•		•
Globe Audio Design, Inc.		•		•
GoldenEar Technology		•		
Halford Loudspeakers		•		•
JL Audio, Inc.	•	•	•	
Levister Audio		•		
Lipinski Sound		•		•
Marchand Electronics, Inc.		•		
Meyer Sound Laboratories, Inc.		•		•
MISCO		•		•
NHT Audio, LLC		•		
ORCA Design And Manufacturing	•	•		
Parts Express	•	•		•
Pazandeh Audio Designs		•		•
Peerless by Tymphany		•		•
Performance Audio, LLC				•
Phoenix Engineering, LLC		•		
Precison Transducer Engineering (PTE)		•		•
Pro Flix Sales				•
Purist Sonics		•		•
RBH Sound		•		
Rock The Boat			•	
RSL Speaker Systems		•		
Sound & Lighting Systems				•
Sound Sources Technology, Inc.	•	•		
SpeakersAndAmps.com	•	•		•
Spectrum Audio				•
Studio Electric - David MacPherson		•		•
Tone Tubby, Inc.				•
Tonian Laboratories		•		•
TSG Audio	•	•		•
US Speaker, LLC	•	•		•
Vidsonix Design Works	•	•	•	
Weltronics Corp.		•		
Westlake Audio, Inc.		•		•
Wired 4 Sound, Inc.		•		•
Yandas Music				•
Zu Audio		•		

	Amplifiers	DSP (Digital Signal Processing)	High-Power Amplifier Modules	Marine Audio Solutions	Soundbars	Subwoofer Plate Amps	Wireless
AUSTRALIA							
DEQX Pty., Ltd.	•	•	•	•			•
Soundlabs Group Pty., Ltd.	•		•			•	•
Stone Sound Studio	•	•	•			•	•
BELGIUM							
Premium Sound Solutions	•	•	•		•		•
BRAZIL							
Advanced Audio Technologies (AAT)	•	•	•		•	•	•
Harman of Brazil, Ltda.	•	•	•	•	•	•	•
CANADA							
DLC Loudspeaker R&D Group	•	•	•		•	•	
Rutherford Audio	•		•				
Solen Electronique, Inc.	•	•	•		•	•	•
Studio Reference Monitors	•	•					
Tortech Sound, Inc.	•						
CHINA							
Enkor Electronics Co., Ltd.					•		
Fountek Electronics Co., Ltd.	•	•	•				•
Lumi Audio (China) OEM/ODM	•		•			•	•
OBE Pro Audio Co., Ltd.	•	•				•	
Shenzhen Tekzone Loudspeaker Co., Ltd.	•					•	
Sound Technology Development, Ltd. (Factory)	•		•		•	•	•
Sun Technique Electric Co., Ltd.	•	•	•	•	•	•	•
DENMARK							
ICEpower A/S	•	•	•			•	
K & K Development							
Kvart & Bølge, Inc.	•						•
Pascal A/S			•				

	Amplifiers	DSP (Digital Signal Processing)	High-Power Amplifier Modules	Marine Audio Solutions	Soundbars	Subwoofer Plate Amps	Wireless
FRANCE							
IDEA	•		•				
KYU Systems	•	•	•	•		•	
GERMANY							
Klippel GmbH		•					
Physical-Lab	•	•					
HONG KONG							
Eastern Asia Technology (HK), Ltd.	•	•	•	•	•	•	•
miniDSP	•	•				•	
WCE Acoustics							•
INDIA							
Power Electronics & Technologies	•		•			•	
ISRAEL							
Coby Speakers	•	•	•	•	•	•	•
ITALY							
Axiomedia, SRL	•	•	•			•	
Powersoft Audio, SpA	•	•	•	•			
JAPAN							
Etani Electronics Co., Ltd.	•	•	•		•	•	•
NETHERLANDS							
ELTIM audio, BV			•				
Hypex Electronics, BV	•	•	•			•	
the BEE	•	•					
SWEDEN							
Audio Pro, AB		•	•		•	•	•
Bohmer Audio, AB	•	•	•			•	•
TAIWAN							
Kingstate Electronics Corp.	•				•		•
Yung International, Inc.	•					•	•
UNITED KINGDOM							
EuroTec International, Plc.	•		•	•			
Ferguson Hill Studios, Ltd.	•	•	•				•
Kleio Audio, Ltd.	•						
Revolver Audio, Ltd.	•						
Tectonic Elements, Ltd.	•						
UNITED STATES							
Adrian Acoustics, Inc.							
AMS Audio Enterprises, Inc.	•					•	•
Area 52 R&D	•	•	•			•	
Audio Advisor, Inc.	•						
Audio-Optix	•	•			•		•
Barefoot Sound, LLC	•	•	•				

INTEGRATED AUDIO

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	Amplifiers	DSP (Digital Signal Processing)	High-Power Amplifier Modules	Marine Audio Solutions	Soundbars	Subwoofer Plate Amps	Wireless
Carvin Audio	•	•					•
CGN Audio Labs							•
CommonSense Audio	•						
Danville Signal Processing, Inc.		•	•				
Dayton Audio	•	•	•		•	•	•
Digital Audio Labs	•	•					
Digmoda	•	•	•			•	
DMSI	•	•	•				
DTV Installations, LLC	•		•		•	•	•
Earthquake Sound Corp.	•		•			•	
Etal Group AB/Anaview	•		•	•	•	•	
Fulcrum Acoustic, LLC		•					
Globe Audio Design, Inc.	•	•	•			•	
JL Audio, Inc.	•	•	•	•		•	•
Kramer Electronics	•	•	•			•	•
Linear Tube Audio	•		•				
MISCO	•	•	•		•		
ORCA Design And Manufacturing							
Parts Express	•	•	•		•	•	•
Peerless by Tymphany	•	•	•		•		•
Ponderosa Sound Systems	•						
PowerPhysics, Inc.	•	•	•			•	
Pro Flix Sales	•						
Radio Design Labs (RDL)	•		•				
RBH Sound	•					•	
SpeakerAddict	•	•	•	•		•	
SpeakersAndAmps.com	•	•	•	•		•	
Spectrum Audio	•						•
Stillwater Designs | KICKER	•	•	•	•			•
Transducer Lab., LLC							
TSG Audio	•	•	•		•	•	
US Enclosure Co.	•	•	•		•	•	•
US Speaker, LLC	•						
Vidsonix Design Works				•			
Weltronics Corp.	•	•	•				
Western Electric	•						
Wired 4 Sound, Inc.	•	•			•		•

	Adhesive Dispensers	Conveyors	Curing Ovens	Lead Out Wire Termination	Production Line Equipment	Magnetizers/Demagnetizers	Ultrasonic Assembly Equipment
AUSTRALIA							
Stone Sound Studio					•		
CANADA							
Canadian Speaker Works	•	•		•		•	
CHINA							
OBE Pro Audio Co., Ltd.	•	•	•	•	•	•	
Shenzhen Tekzone Loudspeaker Co., Ltd.	•	•			•	•	
Sound Technology Development, Ltd. (Factory)	•	•	•	•	•	•	•
Sun Technique Electric Co., Ltd.	•	•	•	•	•	•	•
DENMARK							
K & K Development					•		
LOUDSOFT, Ltd.					•		
GERMANY							
Klippel GmbH					•		
INDIA							
Lakshmi Metal Coils						•	
JAPAN							
Etani Electronics Co., Ltd.					•		
RUSSIA							
Deluxe Acoustics, Ltd.							
SWEDEN							
Audio Pro, AB					•		
SWITZERLAND							
Kisling AG	•						
Megatec AG		•		•	•	•	•
THAILAND							
Clarasonic (Thailand) Co., Ltd.	•	•	•				

	Adhesive Dispensers	Conveyors	Curing Ovens	Lead Out Wire Termination	Production Line Equipment	Magnetizers/Demagnetizers	Ultrasonic Assembly Equipment
UNITED KINGDOM							
EuroTec International, Plc.	•	•	•	•	•	•	•
Fane International, Ltd.							
Hill Acoustics					•		
UNITED STATES							
Acoustic Design, Inc.						•	
Adrian Acoustics, Inc.		•			•		
Astro Machine Works, Inc.					•		•
Bruel & Kjaer Sound and Vibration Measurement, A/S					•		
Conveyor Systems & Engineering, Inc.		•					
dBTechnologies							
Delta H Technologies, LLC			•				
Dukane Northeast Technical Center					•		•
Dymax Corp.	•						
Dynavox Electronics, Inc.						•	
Ellsworth Adhesives	•						
Fisnar	•						
Fluid Metering, Inc.	•				•		
Glenro, Inc.			•				
Global Finishing Solutions, LLC			•				
Hernon Manufacturing	•	•	•		•		
Krayden, Inc.	•						
Lewco, Inc.		•	•				
Metzgar Conveyors		•					
Nordson EFD	•						
NTi Audio, Inc.					•		
Parts Express	•						
Sealant Equipment	•						
The Eraser Co.					•		
Uni-Pak Corp.		•					
Wisconsin Oven			•				
WSF Industries, Inc.			•				

MEASUREMENT MICROPHONES

	Consumer	Field Mics	Lab Instruments	Measuring Mics	Professional
AUSTRALIA					
DEQX Pty., Ltd.				•	
CANADA					
Canadian Speaker Works				•	•
Solen Electronique, Inc.	•	•		•	
CHINA					
BSWA Technology Co., Ltd.		•	•	•	•
Lumi Audio (China) OEM/ODM	•	•		•	
Shenzhen Tekzone Loudspeaker Co., Ltd.			•		
Sound Technology Development, Ltd. (Factory)					•
Sun Technique Electric Co., Ltd.	•	•	•	•	•
DENMARK					
Jantzen Audio Denmark	•				
K & K Development				•	
FRANCE					
KYU Systems			•	•	

	Consumer	Field Mics	Lab Instruments	Measuring Mics	Professional
GERMANY					
Klippel GmbH				•	
Microtech Gefell	•	•		•	•
HONG KONG					
miniDSP				•	
WCE Acoustics	•				•
INDIA					
GM Audio Technics, Ltd.				•	
JAPAN					
Etani Electronics Co., Ltd.		•	•	•	
SWEDEN					
Audio Pro, AB			•	•	
TAIWAN					
Kingstate Electronics Corp.	•				
THAILAND					
Suzuki Kanshi (Thailand) Co., Ltd.					
UNITED KINGDOM					
EuroTec International, Plc.			•	•	•
UNITED STATES					
ACO Pacific, Inc.		•	•	•	•
Audio Precision, Inc.			•		
AValive	•				•
B&H Photo - Video - Pro Audio	•				•
Bruel & Kjaer Sound and Vibration Measurement, A/S			•	•	
Dayton Audio	•	•	•	•	•
Earthworks	•	•	•	•	•
Front End Audio, LLC	•	•	•	•	•
Full Compass Systems, Ltd.	•	•			•
G.R.A.S. Sound & Vibration	•	•	•	•	•
JLI Electronics, Inc.	•	•	•	•	•
Listen, Inc.				•	
Master Bond, Inc.					
NTi Audio, Inc.			•	•	•
Parts Express	•	•	•	•	•
PCB Piezotronics, Inc.		•	•	•	
PreSonus Audio Electronics, Inc.				•	
Scantek, Inc.		•	•	•	•
Sound Pure, LLC	•				•
Speaker Clinic				•	
Spectrum Audio	•				•
Studio Six Digital			•	•	
Sweetwater.com	•				•
Vintage King Audio	•			•	•
Wired 4 Sound, Inc.	•	•		•	•
Yandas Music	•				•
zZounds Music, LLC					•

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Red Rocks & ATTPAC, Dallas
ODM Family
41.0 dBZ
ACO Pacific, Inc.
NetSLARM™
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ALERT
ALARM
CONNECT
PS9200KIT
1/2 Inch
1 Inch
1/4 Inch
Systems
<2Hz >120kHz
<0dBA .170 dBSPL
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Right Angle Preamps
• Production Lines
• Test Chamber Walls
• Flat Plate Couplers
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RAS1
4012RAS
3025 "Extremely Random"™
WHITE/Pink, 1 kHz Noise Generator
New 6.5 days randomness, 2 outputs,
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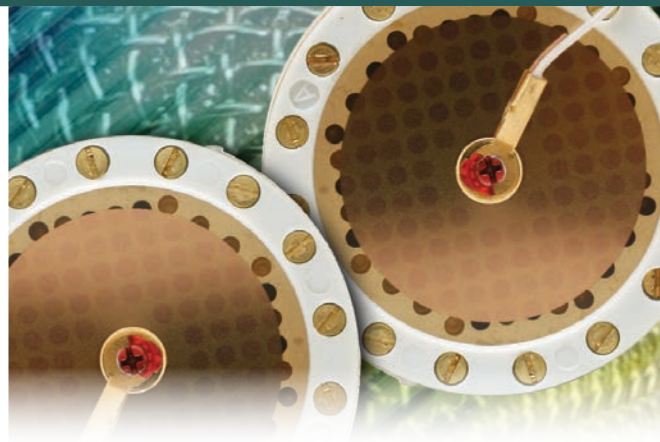

	Dynamic Capsules	ECM	LDC	MEMS	True Condenser
CANADA					
Stetron International, Inc.		•			
CHINA					
BSWA Technology Co., Ltd.		•			
Shenzhen Tekzone Loudspeaker Co., Ltd.	•				
Sound Technology Development, Ltd. (Factory)	•				
Sun Technique Electric Co., Ltd.	•	•	•	•	•
FRANCE					
KYU Systems		•		•	
GERMANY					
Microtech GEFELL	•	•	•	•	•
SWEDEN					
Audio Pro, AB	•	•			
TAIWAN					
Kingstate Electronics Corp.		•		•	
UNITED KINGDOM					
EuroTec International, Plc.	•	•			•
UNITED STATES					
ACO Pacific, Inc.		•			
AValive	•	•	•	•	•
B&H Photo - Video - Pro Audio	•	•	•	•	•
Bruel & Kjaer Sound and Vibration Measurement, A/S					•
Front End Audio, LLC	•	•	•	•	•
G.R.A.S. Sound & Vibration	•	•	•	•	
JLI Electronics, Inc.	•	•			
Microphone-Parts.com			•		•
ProFlixSales	•	•	•	•	•
Seltech		•		•	•
Shure, Inc.	•				•
Sound Pure, LLC	•	•	•	•	
Spectrum Audio	•	•	•	•	•
Sweetwater.com	•	•	•	•	•
Vintage King Audio	•	•	•	•	•
Yandas Music	•	•	•	•	

	Cell Phone	Laptop	Tablet/MID
CANADA			
DLC Loudspeaker R&D Group		•	•
Solen Electronique, Inc.	•	•	•
Stetron International, Inc.		•	•
CHINA			
M-Sound Electronics Co., Ltd.			•
Shenzhen Tekzone Loudspeaker Co., Ltd.		•	
Sound Technology Development, Ltd. (Factory)	•	•	•
Speakerhu Electronic Co., Ltd.	•	•	•
Sun Technique Electric Co., Ltd.	•	•	•
HONG KONG			
Eastern Asia Technology (HK), Ltd.		•	•
WCE Acoustics	•	•	•
TAIWAN			
Huey Tung International Co., Ltd.	•	•	•
Kingstate Electronics Corp.	•	•	•
UNITED STATES			
Adafruit Industries	•	•	•
BeStar Technologies, Inc.	•	•	•
Dayton Audio	•	•	•
GGEC America, Inc.	•	•	•
iT Parts Depot	•	•	•
Parts Express	•	•	•
Peerless by Tymphany		•	•
Seltech	•	•	•
Sound Sources Technology, Inc.	•		
The Digital PCH	•	•	•
Trade Moon	•	•	•

	Acoustic Materials	Finished Goods
AUSTRALIA		
Stone Sound Studio	•	•
BELGIUM		
Premium Sound Solutions		•
CANADA		
Canadian Loudspeaker Corp.	•	•
Canadian Speaker Works	•	•
DLC Loudspeaker R&D Group	•	•
Excelitas Canada, Inc.		•
LMH Loudspeakers		•
Planet10-HiFi		•
Solen Electronique, Inc.	•	•
Stetron International, Inc.		•
Studio Reference Monitors		•
CHINA		
Audiostar Electronics Co., Ltd.	•	
B.W. Audio Guangzhou Co., Ltd.		•
Enkor Electronics Co., Ltd.		•
Fountek Electronics Co., Ltd.		•
Lumi Audio (China) OEM/ODM		•
M-Sound Electronics Co., Ltd.		•
OBE Pro Audio Co., Ltd.	•	•
Shenzhen Tekzone Loudspeaker Co., Ltd.		•
Sonos Beijing Office		•
Sound Technology Development, Ltd. (Factory)	•	•
Speakerhu Electronic Co., Ltd.		•

	Acoustic Materials	Finished Goods
Sun Technique Electric Co., Ltd.	•	•
Trueanalog Strictly OEM		•
Zhuhai HiVi Technology Company, Ltd.		•
FRANCE		
Applications Acoustiques de Composites (AAC)		•
Audax		•
KYU Systems	•	
GERMANY		
Soundsgood Pro Audio Solutions		•
Wolf von Langa		•
HONG KONG		
Eastern Asia Technology (HK), Ltd.	•	•
Ocean Star Electronics, Ltd.		•
WCE Acoustics		•
INDIA		
GM Audio Technics, Ltd.	•	•
Power Electronics & Technologies		•
INDONESIA		
SB Acoustics	•	•
ISRAEL		
Chorus Audio		•
Coby Speakers	•	•
Morel, Ltd.		•
R H Sound Technology, Ltd.	•	

	Acoustic Materials	Finished Goods
MALAYSIA		
TC Electronics, Sdn. Bhd.		•
MEXICO		
Aletheia, AV		•
NORWAY		
SEAS Fabrikker, AS		•
ROMANIA		
SC Poweraudio, SRL		•
RUSSIA		
Star Sound Technologies		•
SWEDEN		
Audio Pro, AB	•	•
TAIWAN		
Huey Tung International Co., Ltd.	•	•
Kingstate Electronics Corp.		•
Taiwan Solidex Corp.		•
TB Speaker Co., Ltd.	•	•
Yung International, Inc.	•	•
THAILAND		
Clarasonic (Thailand) Co., Ltd.	•	•
UKRAINE		
MAG Audio		•
UNITED KINGDOM		
EuroTec International, Plc.	•	•
Fane International, Ltd.		•
Ferguson Hill Studios, Ltd.		•
Precision Devices, Ltd.		•
Revolver Audio, Ltd.		•
Tectonic Elements, Ltd.		•
Volt Loudspeakers, Ltd.		•
UNITED STATES		
A Brown		•
A. Schulman, Inc.	•	
AcousTex Fabrics		•
Adrian Acoustics, Inc.	•	•
AMS Audio Enterprises, Inc.		•
Area 52 R&D		•
Audio Connection		•
Audioengine		•
Audio-Optix	•	•
Barefoot Sound, LLC		•
Campanella Associates & Acculab		•
Digmoda		•
Dynavox Electronics, Inc.		•
Earthquake Sound Corp.		•
Eminence Speaker, LLC		•

	Acoustic Materials	Finished Goods
Fulcrum Acoustic, LLC		•
Geometric Designs, LLC & Geometric Consulting		•
GGEC America, Inc.	•	•
Hearing Components, Inc. (Comply Memory Foam Tips)	•	
J&F Wood Products	•	
JL Audio, Inc.		•
Lowell Manufacturing Co.		•
MISCO		•
Monaero Engineering, Inc.		•
MSC Software Corp.	•	
ORCA Design And Manufacturing	•	
Parts Express	•	•
Pierce Audio Products	•	•
Precision Thin Metals - Arnold Magnetic Technologies	•	
Sound Sources Technology, Inc.		•
SpeakersAndAmps.com		•
Stillwater Designs | KICKER		•
Studio Electric - David MacPherson		•
SVS		•
Tone Tubby, Inc.		•
TSG Audio		•
United Gasket Corp.	•	
US Enclosure Co.	•	•
US Speaker, LLC		•
Westlake Audio, Inc.		•

	Air Motion Transformer (AMT) Tweeters	Air Motion Transformer (AMT) Midrange	Air Motion Transformer (AMT) Woofers	Electrostatic	Compression Drivers	Full Range	Horns
AUSTRALIA							
Soundlabs Group Pty., Ltd.					•	•	•
Stone Sound Studio						•	
BELGIUM							
Premium Sound Solutions						•	
BULGARIA							
Oberton					•	•	
CANADA							
Canadian Loudspeaker Corp.					•	•	•
Canadian Speaker Works							•
DLC Loudspeaker R&D Group					•	•	•
Kravchenko-Audio						•	•
ORA Sound - Graphene Audio					•	•	
Planet10-HiFi						•	
Solen Electronique, Inc.					•	•	•
Space-Tech Lab., Ltd.				•			
Stetron International, Inc.						•	
Studio Reference Monitors					•	•	•
CHINA							
Audiostar Electronics Co., Ltd.							•
B.W. Audio Guangzhou Co., Ltd.					•		
Enkor Electronics Co., Ltd.				•			
Fountek Electronics Co., Ltd.						•	•
LAVOCE Co., Ltd.					•	•	•
M-Sound Electronics Co., Ltd.					•	•	•
OBE Pro Audio Co., Ltd.					•	•	


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hand-made
Italian loudspeakers
MADE IN ITALY
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Air Motion Transformer (AMT)	Tweeters	Midrange	Woofers	Electrostatic	Compression Drivers	Full Range	Horns
Sound Technology Development, Ltd. (Factory)					•	•	•
Speakerhu Electronic Co., Ltd.					•		
Sun Technique Electric Co., Ltd.				•	•	•	•
Wavecor, Ltd.						•	
Zhuhai HiVi Technology Co., Ltd.						•	
FRANCE							
Audax					•	•	•
KYU Systems					•	•	•
PHL Audio						•	
Waterfall Audio				•			
GERMANY							
Lautsprecher-Produktions-Gesellschaft mbH (LPG)						•	
BMS Speakers GmbH					•	•	•
Physical-Lab						•	
Wolf von Langa					•	•	
HONG KONG							
Acoustic Development International					•	•	

	AMT: Tweeters	AMT: Midrange	AMT: Woofers	Electrostatic	Compression Drivers	Full Range	Horns
Eastern Asia Technology (HK), Ltd.				•		•	
Ocean Star Electronics, Ltd.						•	
INDIA							
GM Audio Technics, Ltd.					•	•	•
INDONESIA							
SB Acoustics					•	•	
ISRAEL							
Coby Speakers				•		•	•
Morel, Ltd.						•	
ITALY							
Axiomedia, SRL					•	•	•
AXP					•	•	
B&C Speakers, SpA					•	•	•
Ciare					•	•	•
Eighteen Sound, SRL					•		•
FaitalPRO					•	•	•
Professional Audio, Snc.					•	•	•
RCF, SpA					•	•	•

	Air Motion Transformer (AMT)						
	Tweeters	Midrange	Woofers	Electrostatic	Compression Drivers	Full Range	Horns
MALAYSIA							
TC Electronics, Sdn. Bhd.				•			
NETHERLANDS							
Audio Components, BV						•	
NORWAY							
SEAS Fabrikker, AS						•	
RUSSIA							
Star Sound Technologies						•	
SPAIN							
Acustica Beyma, SL					•	•	•
SWEDEN							
Audio Pro, AB				•	•	•	
TAIWAN							
Huey Tung International Co., Ltd.				•	•	•	•
Hurray, Co., Ltd.	•					•	•
TB Speaker Co., Ltd.						•	
UKRAINE							
Mag Audio					•	•	•
UNITED KINGDOM							
Bishopsound					•	•	
Celestion					•	•	•
Compbass, Ltd.					•		
EuroTec International, Plc.				•	•	•	•
Fane International, Ltd.					•	•	•
Precision Devices, Ltd.					•	•	
Tectonic Elements, Ltd.						•	
Volt Loudspeakers, Ltd.						•	
UNITED STATES							
Acoustic Design, Inc.					•		•
American Bass USA				•	•	•	•
American Music And Sound				•			
AMS Audio Enterprises, Inc.					•	•	•
Audio Nirvana Fullrange Speakers and Vacuum Tube Amplifiers						•	
Beyma Pro Audio	•	•		•	•	•	•
CGN Audio Labs						•	
Dayton Audio					•	•	•
Dynavox Electronics, Inc.					•	•	•
Earthquake Sound Corp.					•	•	•
Eminence Speaker, LLC				•	•	•	•
ESS Laboratories, LLC				•			
GGEC America, Inc.					•	•	•
Global Audio Source, Inc.					•	•	
Loudspeakers Plus					•	•	•
Lowther Speakers USA						•	

	Air Motion Transformer (AMT)						
	Tweeters	Midrange	Woofers	Electrostatic	Compression Drivers	Full Range	Horns
Martin Sound Products (MSP), LLC					•	•	•
MISCO					•	•	
NedLab						•	
Parts Express	•	•		•	•	•	•
Peerless by Tymphany					•	•	
Sanming Sound					•		•
Seltech						•	
Simply Speakers					•		
SpeakerAddict				•	•	•	•
SpeakersAndAmps.com					•	•	•
Stillwater Designs | KICKER					•	•	
SVS						•	
Tonian Laboratories						•	
TSG Audio				•	•	•	•
Ulbrich Stainless Steels & Special Metals, Inc.					•		
US Speaker, LLC					•		•
Vidsonix Design Works						•	
Western Electric	•	•	•				
Yandas Music					•		

	Midrange Cone	Midrange Dome	Midrange Electrostatic	Midrange Planar	Midrange Ribbon	Paging Horns	Piezo	Planar	Siren/Voice Warning	Tweeters Cone	Tweeters Dome	Tweeters Electrostatic	Tweeters Ribbon	Woofers
AUSTRALIA														
Soundlabs Group Pty., Ltd.	•	•				•				•	•		•	•
Stone Sound Studio	•	•		•	•	•				•	•		•	•
BELGIUM														
Premium Sound Solutions	•	•								•	•			•
BULGARIA														
Oberton	•							•						•
CANADA														
Canadian Speaker Works														•
DLC Loudspeaker R&D Group	•	•	•	•	•		•	•		•	•	•	•	•
Kravchenko-Audio				•				•			•			•
ORA Sound - Graphene Audio	•	•		•				•		•	•			•
Planet10-HiFi														•
Solen Electronique, Inc.	•	•						•		•	•		•	•
Space-Tech Lab, Ltd.	•	•								•	•			•
Stetron International, Inc.		•									•			•
Studio Reference Monitors	•										•			•
The Canadian Loudspeaker Corp.	•										•			•
CHINA														
Audiostar Electronics Co., Ltd.														•
B.W. Audio Guangzhou Co., Ltd.														•
Enkor Electronics Co., Ltd.	•	•								•	•			•
Fountek Electronics Co., Ltd.													•	•

	Midrange Cone	Midrange Dome	Midrange Electrostatic	Midrange Planar	Midrange Ribbon	Paging Horns	Piezo	Planar	Siren/Voice Warning	Tweeters Cone	Tweeters Dome	Tweeters Electrostatic	Tweeters Ribbon	Woofers
LaVoce Co., Ltd.	•	•								•	•			•
M-Sound Electronics Co., Ltd.		•			•					•	•		•	
OBE Pro Audio Co., Ltd.														•
Shenzhen Tekzone Loudspeaker Co., Ltd.	•	•									•		•	•
Sonos Beijing Office	•	•								•	•			•
Sound Technology Development, Ltd. (Factory)	•	•				•	•			•	•			•
Speakerhu Electronic Co., Ltd.	•	•								•	•			•
Sun Technique Electric Co., Ltd.	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Wavecor, Ltd.	•	•								•	•			•
Zhuhai HiVi Technology Co., Ltd.		•								•	•		•	•
DENMARK														
Hiquphon											•			
Scan Speak, A/S	•	•								•	•	•		
FRANCE														
Audax	•	•								•	•			•

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	Midrange Cone	Midrange Dome	Midrange Electrostatic	Midrange Planar	Midrange Ribbon	Paging Horns	Piezo	Planar	Siren/Voice Warning	Tweeters Cone	Tweeters Dome	Tweeters Electrostatic	Tweeters Ribbon	Woofers
KYU Systems	•			•				•						•
PHL Audio		•									•			•
Waterfall Audio														•
GERMANY														
Lautsprecher-Produktions-Gesellschaft mbH (LPG)	•										•			•
BMS Speakers GmbH	•			•				•	•					•
Physical-Lab											•			
Wolf von Langa	•	•												•
HONG KONG														
Acoustic Development International	•	•								•	•		•	•
Eastern Asia Technology (HK), Ltd.	•	•								•	•			•
Ocean Star Electronics, Ltd.	•	•								•	•			•
WCE Acoustics									•					
INDIA														
GM Audio Technics, Ltd.	•	•								•				•

	Midrange: Cone	Midrange: Dome	Midrange: Electrostatic	Midrange: Planar	Midrange: Ribbon	Paging Horns	Piezo	Planar	Siren/Voice Warning	Tweeters: Cone	Tweeters: Dome	Tweeters: Electrostatic	Tweeters: Ribbon	Woofers
INDONESIA														
SB Acoustics	•	•					•			•	•		•	•
ISRAEL														
Coby Speakers	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Morel, Ltd.	•	•									•			•
ITALY														
Axiomedia, SRL	•	•									•		•	•
AXP	•	•								•	•			•
B&C Speakers, SpA	•										•		•	•
Ciare														•
Eighteen Sound, SRL														•
FaitalPRO	•	•								•	•			•
Professional Audio, Snc.	•	•								•	•			•
RCF SpA														•
MALAYSIA														
TC Electronics, Sdn. Bhd.	•	•								•	•			•
NETHERLANDS														
Audio Components, BV		•									•			•


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	Midrange Cone	Midrange Dome	Midrange Electrostatic	Midrange Planar	Midrange Ribbon	Paging Horns	Piezo	Planar	Siren/Voice Warning	Tweeters Cone	Tweeters Dome	Tweeters Electrostatic	Tweeters Ribbon	Woofers
NORWAY														
SEAS Fabrikker, AS	•	•									•			•
RUSSIA														
Star Sound Technologies	•	•								•	•			•
SPAIN														
Acustica Beyma, SL	•										•		•	•
SWEDEN														
Audio Pro, AB	•	•		•	•		•	•		•	•		•	•
TAIWAN														
BESTON Technology Corp.				•	•			•					•	
Huey Tung International Co., Ltd.	•	•	•				•		•	•	•	•		•
Hurray, Co., Ltd.														•
Kingstate Electronics Corp.							•		•					
Taiwan Solidex Corp.							•						•	•
TB Speaker Co., Ltd.	•	•			•					•	•		•	•
Yie Feng Technology Enterprise Co.	•													
UKRAINE														
Mag Audio	•													•

	Midrange: Cone	Midrange: Dome	Midrange: Electrostatic	Midrange: Planar	Midrange: Ribbon	Paging Horns	Piezo	Planar	Siren/Voice Warning	Tweeters: Cone	Tweeters: Dome	Tweeters: Electrostatic	Tweeters: Ribbon	Woofers
UNITED KINGDOM														
Bishopsound														•
Celestion	•								•					•
Compbass, Ltd.														•
EuroTec International, Plc.	•	•	•						•	•	•	•	•	•
Fane International, Ltd.	•									•	•			•
Precision Devices, Ltd.	•										•			•
Volt Loudspeakers, Ltd.	•	•												•
UNITED STATES														
Acoustic Design, Inc.		•												
American Bass USA	•	•	•	•	•	•		•	•	•	•	•	•	•
American Music And Sound														•
AMS Audio Enterprises, Inc.	•	•								•	•			•
Area 52 R&D	•										•			•
BeStar Technologies, Inc.							•							
Beyma Pro Audio	•	•	•	•	•	•	•			•	•	•	•	•
Carvin Audio														•
CGN Audio Labs													•	•
Dayton Audio	•	•		•	•	•		•		•	•		•	•

	Midrange Cone	Midrange Dome	Midrange Electrostatic	Midrange Planar	Midrange Ribbon	Paging Horns	Piezo	Planar	Siren/Voice Warning	Tweeters Cone	Tweeters Dome	Tweeters Electrostatic	Tweeters Ribbon	Woofers
Dynavox Electronics, Inc.	•	•			•	•	•	•	•	•	•		•	•
Earthquake Sound Corp.														•
Electro Mavin TN	•	•									•			•
Eminence Speaker, LLC	•	•	•	•	•	•	•	•	•	•	•	•	•	•
ESS Laboratories, LLC														•
Full Compass Systems, Ltd.	•	•	•							•	•	•	•	•
GGEC America, Inc.	•	•					•		•	•	•	•	•	•
Global Audio Source, Inc.										•	•			•
HDSound								•					•	•
JL Audio, Inc.	•													•
Loudspeakers Plus	•													•
Martin Sound Products (MSP), LLC	•					•								•
Meniscus Audio Group, Inc.														•
MISCO	•						•		•	•	•			•
NedLab	•	•								•	•			•
ORCA Design and Manufacturing	•				•						•		•	•
Parts Express	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Peerless by Tymphany	•	•								•	•			•
Pierce Audio Products														•

	Midrange: Cone	Midrange: Dome	Midrange: Electrostatic	Midrange: Planar	Midrange: Ribbon	Paging Horns	Piezo	Planar	Siren/Voice Warning	Tweeters: Cone	Tweeters: Dome	Tweeters: Electrostatic	Tweeters: Ribbon	Woofers
Precision Thin Metals - Arnold Magnetic Technologies		•									•			
RBH Sound	•										•			•
Sanming Sound						•			•					
Simply Speakers	•	•					•			•	•			•
SpeakerAddict	•	•	•	•	•	•	•	•	•	•	•	•	•	•
SpeakersAndAmps.com	•	•		•	•	•		•		•	•		•	•
Stillwater Designs | KICKER	•										•			•
Studio Electric - David MacPherson														•
SVS	•										•			•
Tone Tubby, Inc.	•													•
Tonian Laboratories													•	•
Transducer Lab, LLC											•			
TSG Audio	•	•	•	•	•	•	•	•	•	•	•	•	•	•
US Speaker, LLC							•							•
Vidsonix Design Works	•										•			•
Yandas Music	•	•								•	•			•

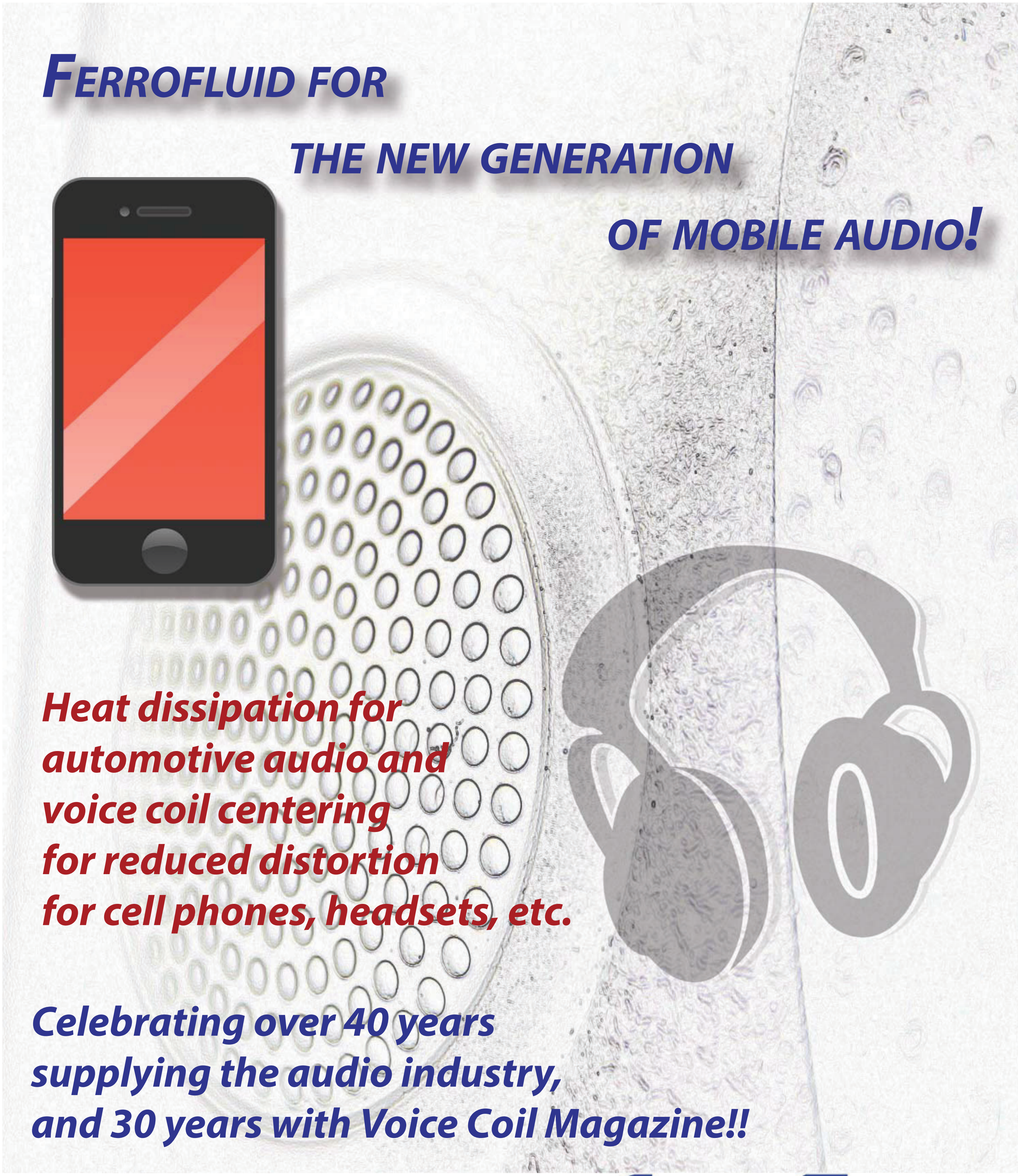
	Attenuators	Capacitors: Ceramic	Capacitors: Electrolytic Non-Polar	Capacitors: Film	Driver Protection Devices	Inductors: Air Core	Inductors: Iron Core	Plugs & Jack Dishes	Resistors	Solder	Terminal Plates	Transformers	Electronic Crossovers	Finished Passive Crossover Nets	Wire & Wiring Harnesses
AUSTRALIA															
Soundlabs Group Pty., Ltd.	•		•	•	•	•			•	•	•			•	•
Stone Sound Studio	•	•	•			•		•	•				•	•	
BRAZIL															
Advanced Audio Technologies (AAT)													•	•	
CANADA															
Canadian Loudspeaker Corp.	•	•	•	•					•		•			•	
Canadian Speaker Works	•	•	•			•	•	•	•	•				•	
DLC Loudspeaker R&D Group	•		•	•		•	•		•		•		•	•	•
Solen Electronique, Inc.	•		•	•	•	•		•	•	•	•			•	•
Space-Tech Lab, Ltd.														•	
CHINA															
Sound Technology Development, Ltd. (Factory)			•		•	•	•	•	•				•	•	•
Sun Technique Electric Co., Ltd.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
DENMARK															
Jantzen Audio Denmark			•	•		•	•		•						

	Passive Components														
	Attenuators	Capacitors: Ceramic	Capacitors: Electrolytic Non-Polar	Capacitors: Film	Driver Protection Devices	Inductors: Air Core	Inductors: Iron Core	Plugs & Jack Dishes	Resistors	Solder	Terminal Plates	Transformers	Electronic Crossover	Finished Passive Crossover Nets	Wire & Wiring Harnesses
FRANCE															
KYU Systems	•			•	•	•	•		•			•	•	•	•
INDIA															
GM Audio Technics, Ltd.													•	•	
ISRAEL															
R H Sound Technology, Ltd.	•	•	•	•	•	•	•	•	•	•	•	•		•	•
ITALY															
Axiomedia, SRL	•		•	•		•	•	•	•	•	•			•	
JAPAN															
Furutech Co., Ltd.										•					•
MEXICO															
Aletheia, AV														•	•
NETHERLANDS															
Audio Components, BV	•		•			•	•	•	•	•	•			•	
ELTIM audio, BV			•			•	•		•	•	•	•	•		•
ROMANIA															
SC Poweraudio, SRL													•	•	
SWEDEN															
Audio Pro, AB	•				•	•			•			•	•		
TAIWAN															
Bennic Components	•		•	•		•	•		•		•			•	
Huey Tung International Co., Ltd.									•			•			
Kingstate Electronics Corp.		•													
UNITED KINGDOM															
EuroTec International, Plc.					•								•	•	•
Volt Loudspeakers, Ltd.						•	•								
UNITED STATES															
AMS Audio Enterprises, Inc.	•		•	•	•	•		•	•		•	•		•	•
Arizona Capacitors				•	•				•				•	•	
AtlasIED	•											•			
Carvin Audio													•		
Danville Signal Processing, Inc.													•		
Dayton Audio			•	•				•	•				•	•	
DMSI													•		
Dynavox Electronics, Inc.			•	•		•	•		•		•	•			
Electro Mavin TN														•	
Eminence Speaker, LLC					•									•	
ESS Laboratories, LLC												•			
Full Compass Systems, Ltd.	•					•	•				•	•	•		•

	Passive Components	Capacitors				Inductors									
	Attenuators	Ceramic	Electrolytic Non-Polar	Film	Driver Protection Devices	Air Core	Iron Core	Plugs & Jack Dishes	Resistors	Solder	Terminal Plates	Transformers	Electronic Crossover	Finished Passive Crossover Nets	Wire & Wiring Harnesses
Geometric Designs, LLC & Geometric Consulting													•	•	
Global Audio Source, Inc.															•
Globe Audio Design, Inc.													•		
Hearing Components, Inc. (Comply Memory Foam Tips)	•														
Lamart Corp.										•		•			•
Lowell Manufacturing Co.												•			
Madisound Speaker Components, Inc.			•	•		•	•		•					•	
Marchand Electronics, Inc.	•												•	•	
Meniscus Audio Group, Inc.			•	•		•	•		•	•	•			•	•
NedLab														•	
ORCA Design and Manufacturing				•											
Parts Express	•	•	•	•	•	•	•	•	•	•	•	•	•		•
Redco Audio								•		•					•
Simply Speakers	•													•	
SpeakersAndAmps.com					•								•		
Spectrum Audio													•		
Studio Electric - David MacPherson														•	
UpTone Audio, LLC				•											
Vidsonix Design Works	•				•						•				•
Vintage King Audio													•		
Whitmor Wirenetics															•
Wireworld Cable Technology															•
Yandas Music													•		

SPEAKER PARTS A–E

	Adhesives & Glues					Cone Additives & Other Treatments					Cone & Suspension Components: Cones				Domes			Spiders	Surrounds		
	Acrylic Adhesives	Epoxy	Infra-Red Cure	Instant Adhesives	Water & Vinyl Based	Damping	Fire Resistance	Lacquers	Waterproofing	Wet Lock	Composite	Paper Pulp	Plastic	Metal	Aluminum/Titanium/Metal	Fabric/Mylar/Resin/Soft	Phenolic & Other Domes	Spiders	Fabric	Foam	Rubber
CANADA																					
Canadian Loudspeaker Corp.	•	•			•	•	•		•		•	•				•	•	•	•	•	
Canadian Speaker Works						•												•	•	•	•
DLC Loudspeaker R&D Group											•	•				•	•	•	•	•	•
ORA Sound - Graphene Audio		•		•												•	•				
Solen Electronique, Inc.											•	•	•								
Stetron International, Inc.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•						
CHINA																					
Audiostar Electronics Co., Ltd.																					
Dong Guan Yen Lung Electronics Co., Ltd.											•	•	•	•	•		•				
Lumi Audio (China) OEM/ODM																•	•	•	•	•	•
Sound Technology Development, Ltd. (Factory)						•		•								•		•	•	•	•
Sun Technique Electric Co., Ltd.											•		•		•	•	•	•	•	•	•
Tianyi Electronic Co., Ltd.												•				•	•	•	•	•	•
TopOne Loudspeaker Cone Co., Ltd.						•															
DENMARK																					
Jantzen Audio Denmark	•	•		•																	
Kvart & Bølge, Inc.	•	•	•	•	•	•					•	•	•	•	•						
FRANCE																					
Applications Acoustiques de Composites (AAC)					•						•	•	•	•	•	•	•	•	•	•	•
KYU Systems	•			•	•										•	•		•	•	•	•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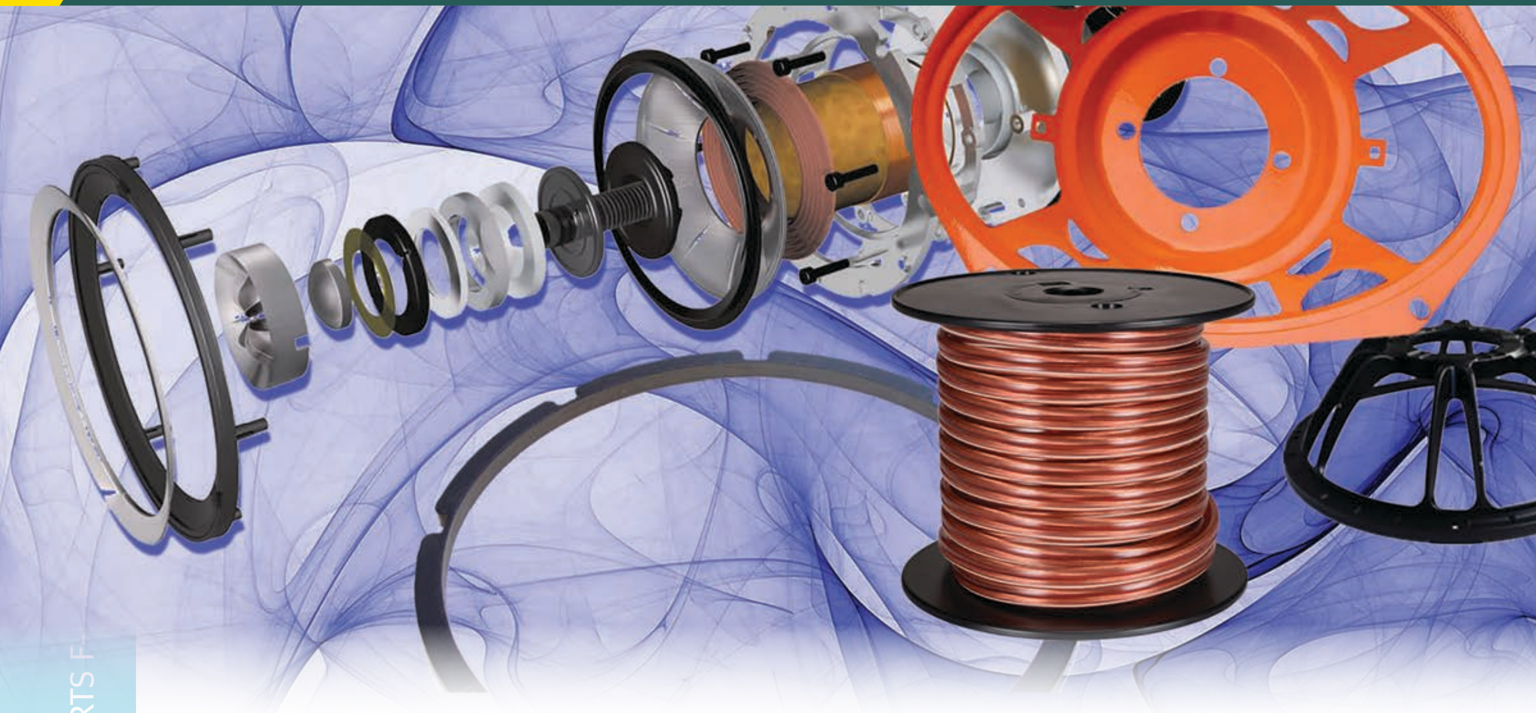
	Adhesives & Glues: Acrylic Adhesives	Epoxy	Infra-Red Cure	Instant Adhesives	Water & Vinyl Based	Cone Additives & Other Treatments: Damping	Fire Resistance	Lacquers	Waterproofing	Wet Lock	Cone & Suspension Components: Cones: Composite	Paper Pulp	Plastic	Metal	Domes: Aluminum/Titanium/Metal	Fabric/Mylar/Resin/Soft	Phenolic & Other Domes	Spiders	Surrounds: Fabric	Foam	Rubber
GERMANY																					
Dr. Kurt Mueller	•	•	•	•	•											•	•	•	•	•	•
Henkel	•	•	•	•	•																
Hubert Stüken GmbH & Co., KG											•	•	•	•	•						
Propex Fabrics GmbH & Co., KG														•	•				•		
INDIA																					
Wizard India Private, Ltd.																•	•	•	•	•	•
INDONESIA																					
SB Acoustics																•		•		•	•
ISRAEL																					
R H Sound Technology, Ltd.																•	•	•	•	•	•
ITALY																					
OEB, SRL, "Società Unipersonale"											•	•	•	•	•			•	•	•	•
Professional Audio, Snc.											•		•				•	•	•	•	•
RCF, SpA		•		•			•		•												

	Adhesives & Glues					Cone Additives & Other Treatments					Cone & Suspension Components										
											Cones				Domes			Spiders	Surrounds		
	Acrylic Adhesives	Epoxy	Infra-Red Cure	Instant Adhesives	Water & Vinyl Based	Damping	Fire Resistance	Lacquers	Waterproofing	Wet Lock	Composite	Paper Pulp	Plastic	Metal	Aluminum/Titanium/Metal	Fabric/Mylar/Resin/Soft	Phenolic & Other Domes		Fabric	Foam	Rubber
NETHERLANDS																					
ELTIM audio, BV						•	•		•												
SWEDEN																					
Audio Pro, AB				•												•	•	•	•	•	•
SWITZERLAND																					
Kisling, AG	•	•		•	•																
TAIWAN																					
Bennic Components						•					•	•	•		•						
Hi-Tech Sound System Co., Ltd.														•	•						
Huey Tung International Co., Ltd.						•										•	•	•	•	•	•
Shiuh Sheng Electronics Factory	•	•		•	•				•	•		•	•								
Sonic Electroinc Co.	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•				
THAILAND																					
Clarasonic (Thailand) Co., Ltd.											•	•	•	•	•						

	Adhesives & Glues					Cone Additives & Other Treatments					Cone & Suspension Components										
											Cones			Domes				Spiders	Surrounds		
	Acrylic Adhesives	Epoxy	Infra-Red Cure	Instant Adhesives	Water & Vinyl Based	Damping	Fire Resistance	Lacquers	Waterproofing	Wet Lock	Composite	Paper Pulp	Plastic	Metal	Aluminum/Titanium/Metal	Fabric/Mylar/Resin/Soft	Phenolic & Other Domes		Fabric	Foam	Rubber
UKRAINE																					
Mag Audio	•	•	•	•	•																
UNITED KINGDOM																					
EuroTec International, Plc.																•	•	•	•	•	•
Fane International, Ltd.					•																
Tectonic Elements, Ltd.											•	•	•	•	•						
Volt Loudspeakers, Ltd.											•	•	•								
UNITED STATES																					
Dymax Corp.											•	•	•	•	•						
Dynavox Electronics, Inc.	•	•	•	•	•											•	•	•	•	•	•
Ellsworth Adhesives						•															
Engineered Fibers Technology	•					•	•	•	•	•	•	•	•		•						
Full Compass Systems, Ltd.											•	•	•	•							
Global Audio Source, Inc.	•	•	•	•	•																
Hernon Manufacturing		•																			
J&F Wood Products						•															
Lamart Corp.											•	•	•	•	•	•					

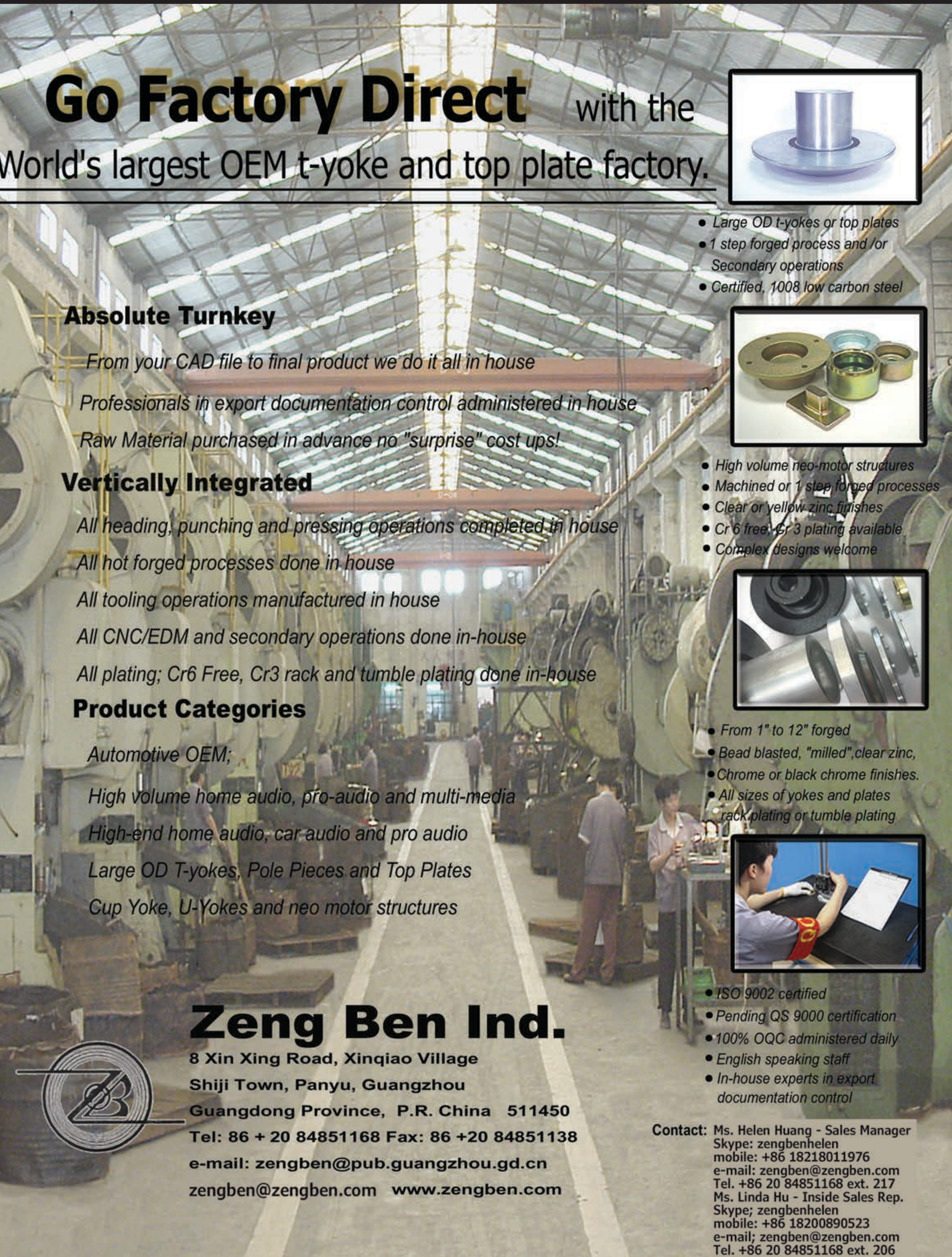
	Adhesives & Glues					Cone Additives & Other Treatments					Cone & Suspension Components: Cones				Domes			Spiders	Surrounds		
	Acrylic Adhesives	Epoxy	Infra-Red Cure	Instant Adhesives	Water & Vinyl Based	Damping	Fire Resistance	Lacquers	Waterproofing	Wet Lock	Composite	Paper Pulp	Plastic	Metal	Aluminum/Titanium/Metal	Fabric/Mylar/Resin/Soft	Phenolic & Other Domes	Spiders	Fabric	Foam	Rubber
Loudspeaker Components																•	•	•	•	•	•
Lowell Manufacturing Co.											•	•	•	•	•						
Master Bond, Inc.														•	•						
Materion Electrofusion																					
MISCO											•		•	•	•						
NedLab											•	•				•	•		•	•	•
Parts Express		•									•	•		•							
Pierce Audio Products															•			•	•	•	•
Precision Thin Metals - Arnold Magnetic Technologies											•		•	•	•						
Quick Draw & Machining, Inc.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•						
RTP Co.												•			•						
Sherwood Industries, Inc.											•	•	•	•						•	•
Simply Speakers						•				•								•	•	•	•
United Gasket Corp.						•					•								•	•	•
US Enclosure Co.									•									•			
Vidsonix Design Works													•								



	Frames & Baskets: Cast Alloy	Frames & Baskets: Frame Gaskets	Frames & Baskets: Stamped Steel: Bumped	Frames & Baskets: Stamped Steel: Damped Metal	Frames & Baskets: Stamped Steel: Double Bumped	Frames & Baskets: Range of Diameters	Lead Out Wire: Braided	Lead Out Wire: Flat Strip: Beryllium Copper	Lead Out Wire: Flat Strip: Phosphor Bronze	Lead Out Wire: Litz	Lead Out Wire: Stranded	Lead Out Wire Termination/Crimps
CANADA												
Canadian Speaker Works	•									•		•
DLC Loudspeaker R&D Group							•			•	•	
CHINA												
Lumi Audio (China) OEM/ODM	•	•	•	•	•	•						
Sound Technology Development, Ltd. (Factory)	•		•	•			•	•	•	•	•	•
Sun Technique Electric Co., Ltd.	•	•	•	•	•	•	•	•	•	•	•	•
Zhuhai HiVi Technology Co., Ltd.	•											
DENMARK												
Estron, A/S										•	•	•
FRANCE												
KYU Systems	•	•						•				
GERMANY												
Hubert Stüken GmbH & Co. KG	•	•	•	•	•	•						
Wolf von Langa	•											
HONG KONG												
Eastern Asia Technology (HK), Ltd.	•	•	•	•	•	•						
INDIA												
Wizard India Private, Ltd.	•	•										
INDONESIA												
SB Acoustics			•	•	•	•				•		

	Frames & Baskets						Lead Out Wire					
	Cast Alloy	Frame Gaskets	Stamped Steel: Bumped	Stamped Steel: Damped Metal	Stamped Steel: Double Bumped	Range of Diameters	Braided	Flat Strip: Beryllium Copper	Flat Strip: Phosphor Bronze	Litz	Stranded	Lead Out Wire Termination/Crimps
ISRAEL												
Chorus Audio	•							•	•	•		
Coby Speakers	•	•	•	•	•	•	•	•	•	•	•	•
R H Sound Technology, Ltd.							•	•		•	•	•
ITALY												
Axiomedia							•	•	•		•	
FaitalPRO	•	•									•	•
Professional Audio, Snc.	•	•	•	•	•	•	•	•	•	•	•	•
JAPAN												
Furutech Co., Ltd.											•	
P.R.CHINA												
Zhuhai HiVi Technology Co., Ltd.	•											
SWEDEN												
Audio Pro, AB	•	•	•	•	•	•	•	•		•		•
TAIWAN												
Hi-Tech Sound System Co., Ltd.		•	•									
Huey Tung International Co., Ltd.	•	•	•	•	•	•	•	•			•	
Maeden Innovation Co., Ltd.							•			•	•	•
Yie Feng Technology Enterprise Co.		•										
UNITED KINGDOM												
EuroTec International, Plc.	•	•	•	•	•	•	•	•	•			•
Precision Devices, Ltd.	•	•					•					
UNITED STATES												
A. Schulman, Inc.	•											
American Bass USA	•	•	•	•	•	•	•	•	•	•	•	•
AMS Audio Enterprises, Inc.	•	•				•						•
Dynavox Electronics, Inc.	•	•	•	•	•	•	•			•	•	
Global Audio Source, Inc.	•	•	•	•	•	•						
Globe Audio Design, Inc.	•	•	•	•	•	•						
Herman Pro AV							•	•	•	•	•	•
Materion Electrofusion								•				
NedLab	•	•										
New England Wire Technologies							•	•	•	•	•	•
North Reading Engineering	•	•	•	•	•	•	•	•	•	•	•	•
Pierce Audio Products	•	•	•		•	•						
Quick Draw & Machining, Inc.	•			•	•	•						
RDS Wire & Cable							•	•	•	•	•	•
Redco Audio											•	
Simply Speakers							•					
Standard Wire & Cable Co.							•	•	•	•	•	•
United Gasket Corp.		•										
Western Electric							•				•	
Whitmor Wirenetics							•	•	•	•	•	•
Wireworld Cable Technology											•	

	Back Plates	Magnets: Alnico	Magnets: Ferrite	Magnets: Neodymium	Magnetic Fluids	Pole Pieces	T-Yokes Top Plates	Bobbins/Formers	Collars	Magnet Wire	Polyimide Tape for Collars	Voice Coil Assemblies: Flat Wire	Voice Coil Assemblies: Round Wire	Voice Coil Assemblies: Voice Coil Stacks	Amplifiers: Amplifier for Powered Speakers	Amplifiers: Subwoofer Plate Amplifier
	Magnetic Assemblies							**Voice Coil Components**								
AUSTRALIA																
Soundlabs Group Pty., Ltd.															•	•
ELGIUM																
Premium Sound Solutions															•	•
BRAZIL																
Advanced Audio Technologies (AAT)															•	•
CANADA																
Canadian Speaker Works	•		•	•	•	•	•					•	•	•	•	•
DLC Loudspeaker R&D Group	•				•	•	•	•	•	•	•	•	•	•	•	•
Solen Electronique, Inc.			•							•					•	•
Studio Reference Monitors															•	•
Tortech Sound, Inc.															•	•
CHINA																
Audiostar Electronics Co., Ltd.								•	•	•	•	•	•	•		
Lumi Audio (China) OEM/ODM															•	•
OBE Pro Audio Co., Ltd.															•	•
One Magnet		•	•	•												
Sound Technology Development, Ltd. (Factory)	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•
Sun Technique Electric Co., Ltd.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Tianyi Electronic Co., Ltd.		•	•	•	•		•									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• Machined or 1 step forged processes
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	Magnetic Assemblies: Back Plates	Magnets: Alnico	Magnets: Ferrite	Magnets: Neodymium	Magnetic Fluids	Pole Pieces	T-Yokes Top Plates	Voice Coil Components: Bobbins/Formers	Collars	Magnet Wire	Polyimide Tape for Collars	Voice Coil Assemblies: Flat Wire	Voice Coil Assemblies: Round Wire	Voice Coil Assemblies: Voice Coil Stacks	Amplifiers: Amplifier for Powered Speakers	Amplifiers: Subwoofer Plate Amplifier
Trueanalog Strictly OEM	•					•	•									
Zeng Ben Industrial Corp., Ltd.						•	•									
Zenith Audio Electronics Co., Ltd.										•		•	•	•		
FRANCE																
KYU Systems	•			•	•	•	•	•		•		•			•	•
GERMANY																
Wolf von Langa	•					•	•	•				•	•			
HONG KONG																
Eastern Asia Technology (HK), Ltd.												•	•	•	•	•
INDIA																
Lakshmi Metal Coils													•			
Power Electronics & Technologies															•	•
Wizard India Private, Ltd.			•				•									

	Magnetic Assemblies							Voice Coil Components						Amplifiers	
		Magnets									Voice Coil Assemblies				
	Back Plates	Alnico	Ferrite	Neodymium	Magnetic Fluids	Pole Pieces	T-Yokes Top Plates	Bobbins/Formers	Collars	Magnet Wire	Polyimide Tape for Collars	Flat Wire	Round Wire	Voice Coil Stacks	Amplifier for Powered Speakers	Subwoofer Plate Amplifier
INDONESIA																
SB Acoustics	•		•	•		•	•	•				•	•	•		
ISRAEL																
Chorus Audio	•	•	•	•		•	•									
Coby Speakers	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
R H Sound Technology, Ltd.								•	•	•	•	•	•	•	•	•
ITALY																
Axiomedia, SRL			•												•	•
FaitalPRO	•		•	•			•	•					•			
OEB, SRL, "Società Unipersonale"												•	•			
Powersoft Audio															•	•
Professional Audio, Snc.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
RCF, SpA																

	Back Plates	Magnets: Alnico	Magnets: Ferrite	Magnets: Neodymium	Magnetic Fluids	Pole Pieces	T-Yokes Top Plates	Bobbins/Formers	Collars	Magnet Wire	Polyimide Tape for Collars	Voice Coil Assemblies: Flat Wire	Voice Coil Assemblies: Round Wire	Voice Coil Stacks	Amplifiers: Amplifier for Powered Speakers	Amplifiers: Subwoofer Plate Amplifier
NETHERLANDS																
Hypex Electronics, BV															●	●
POLAND																
Sveda Audio															●	●
TAIWAN																
Hi-Tech Sound System Co., Ltd.															●	●
Huey Tung International Co., Ltd.	●	●	●	●	●	●	●	●		●		●	●	●	●	●
Kingstate Electronics Corp.															●	●
THAILAND																
Suzuki Kanshi (Thailand) Co., Ltd.								●			●					
UNITED KINGDOM																
Bishopsound															●	●
EuroTec International, Plc.	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
Precision Devices, Ltd.	●		●	●	●	●	●	●		●		●	●			
Volt Loudspeakers, Ltd.													●			

UNITED STATES	Back Plates	Magnets: Alnico	Magnets: Ferrite	Magnets: Neodymium	Magnetic Fluids	Pole Pieces	T-Yokes Top Plates	Bobbins/Formers	Collars	Magnet Wire	Polyimide Tape for Collars	Voice Coil Assemblies: Flat Wire	Voice Coil Assemblies: Round Wire	Voice Coil Assemblies: Voice Coil Stacks	Amplifiers: Amplifier for Powered Speakers	Amplifiers: Subwoofer Plate Amplifier
Acoustic Design, Inc.	•					•	•					•	•	•		
American Bass USA	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
AMS Audio Enterprises, Inc.	•	•	•		•	•	•						•		•	•
Area 52 R&D	•		•	•		•	•								•	•
CommonSense Audio															•	•
Dayton Audio															•	•
DMSI															•	•
Dynavox Electronics, Inc.	•	•	•		•	•	•	•	•	•			•		•	•
Etal Group AB/Anaview															•	•
Ferrotec (USA) Corp.					•											
Global Audio Source, Inc.	•	•	•	•	•	•	•									
Globe Audio Design, Inc.	•	•	•	•	•	•	•	•	•	•	•					
HISCO - Precision Converting											•	•	•	•		
Lamart Corp.											•					
Marchand Electronics, Inc.															•	•
Materion Electrofusion								•								

	Magnetic Assemblies: Back Plates	Magnets: Alnico	Magnets: Ferrite	Magnets: Neodymium	Magnetic Fluids	Pole Pieces	T-Yokes Top Plates	Voice Coil Components: Bobbins/Formers	Collars	Magnet Wire	Polyimide Tape for Collars	Voice Coil Assemblies: Flat Wire	Voice Coil Assemblies: Round Wire	Voice Coil Stacks	Amplifiers: Amplifier for Powered Speakers	Amplifiers: Subwoofer Plate Amplifier
MISCO															•	•
NedLab								•								
Pierce Audio Products	•		•	•		•	•					•	•			
Precision Econowind								•	•	•	•	•	•	•		
Precision Thin Metals - Arnold Magnetic Technologies		•	•	•												
Radio Design Labs (RDL)															•	•
RBH Sound																
Simply Speakers					•											
Sound Sources Technology, Inc.															•	•
SpeakerAddict																
SpeakersAndAmps.com															•	•
Transducer Lab, LLC	•		•	•	•	•	•									
US Enclosure Co.															•	•
Vidsonix Design Works			•	•												
Whitmor Wirenetics										•						


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TEST EQUIPMENT

	Accelerometers	Anechoic Chambers	Audio Analyzers	Gaussmeters	LCR Bridges	MLS	Multimeters	Oscilloscopes	Resistance Bridges	Signal Generators	Sine/Square Wave Oscillators	Speaker Parts	Speaker Turntables	Spectrum Analyzers 1/3 Octave	Spectrum Analyzers FFT	Spectrum Analyzers Heterodyne	Spectrum Analyzers TDS	Stroboscopes	Test Mics	Turns Counters	Testing Cabinets
AUSTRALIA																					
DEQX Pty., Ltd.			•																		
Soundlabs Group Pty., Ltd.								•		•											
Stone Sound Studio	•		•		•		•	•			•	•	•		•			•	•		
CANADA																					
Canadian Speaker Works	•		•		•	•	•		•	•	•	•		•	•				•		
DLC Loudspeaker R&D Group	•		•		•	•	•	•	•	•	•	•		•	•	•	•		•		
Solen Electronique, Inc.			•											•	•				•		
Space-Tech Lab, Ltd.													•								
CHINA																					
BSWA Technology Co., Ltd.	•													•	•						
Shenzhen Tekzone Loudspeaker Co., Ltd.		•	•	•	•	•	•	•	•	•	•				•				•	•	•
Sound Technology Development, Ltd. (Factory)		•	•					•		•	•	•	•	•	•	•	•		•		
Sun Technique Electric Co., Ltd.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
DENMARK																					
K & K Development			•							•	•										
LOUDSOFT, Ltd.			•			•				•				•	•				•		•
FRANCE																					
KYU Systems			•		•	•							•		•				•		•
GERMANY																					
Klippel GmbH			•	•		•				•		•	•	•	•	•			•		
Physical-Lab	•	•	•																•		
Rohde & Schwarz			•				•	•						•	•	•	•			•	
Wolf von Langa												•									
ISRAEL																					
Coby Speakers	•	•	•	•	•	•	•	•	•	•	•	•	•					•	•	•	•
R H Sound Technology, Ltd.					•		•	•	•	•		•									
ITALY																					
Audiomatica, SRL	•		•		•	•	•		•	•	•			•	•		•		•		
Axiomedia, SRL					•																

	Accelerometers	Anechoic Chambers	Audio Analyzers	Gaussmeters	LCR Bridges	MLS	Multimeters	Oscilloscopes	Resistance Bridges	Signal Generators	Sine/Square Wave Oscillators	Speaker Parts	Speaker Turntables	Spectrum Analyzers: 1/3 Octave	Spectrum Analyzers: FFT	Spectrum Analyzers: Heterodyne	Spectrum Analyzers: TDS	Stroboscopes	Test Mics	Turns Counters	Testing Cabinets
SpeakerLAB			•																		
JAPAN																					
Etani Electronics Co., Ltd.		•	•			•	•			•			•	•	•				•		•
NETHERLANDS																					
Audio Components, BV			•											•	•						
SWEDEN																					
Audio Pro, AB	•		•		•									•	•		•				
Bohmer Audio, AB			•			•				•	•			•	•		•				
SWITZERLAND																					
Megatec, AG				•																	
UNITED KINGDOM																					
EuroTec International, Plc.		•	•			•	•	•		•	•	•		•	•				•		•
Hill Acoustics		•																			•
UNITED STATES																					
ACO Pacific, Inc.											•								•		
Adafruit Industries	•						•	•													
Allied Electronics, Inc.			•				•	•		•											
Audio Advisor, Inc.													•								

	Accelerometers	Anechoic Chambers	Audio Analyzers	Gaussmeters	LCR Bridges	MLS	Multimeters	Oscilloscopes	Resistance Bridges	Signal Generators	Sine/Square Wave Oscillators	Speaker Parts	Speaker Turntables	Spectrum Analyzers: 1/3 Octave	Spectrum Analyzers: FFT	Spectrum Analyzers: Heterodyne	Spectrum Analyzers: TDS	Stroboscopes	Test Mics	Turns Counters	Testing Cabinets
Audio Precision, Inc.			•																		
Beach Dynamics		•																			
Bruel & Kjaer Sound and Vibration Measurement, A/S	•	•	•							•			•	•	•	•	•		•		•
Dayton Audio			•									•							•		
ETS-Lindgren		•								•				•	•	•	•				
Fotronic Corp.	•		•		•		•	•		•				•	•	•	•	•			
G.R.A.S. Sound & Vibration																			•		•
Geometric Designs, LLC & Geometric Consulting			•																		
GL Communications, Inc.			•							•									•		
HEAD acoustics, Inc.			•																		
Herman Pro AV		•	•							•											
HX Audio Lab																					•
iT Parts Depot							•	•													
Kramer Electronics										•											
Listen, Inc.			•			•	•	•		•				•	•	•	•		•		
Marchand Electronics, Inc.			•							•	•										
Markertek Video Supply	•		•				•	•		•			•								
MCM Electronics			•		•		•	•		•	•		•	•	•	•	•				
Meniscus Audio Group, Inc.	•											•									
Meyer Sound Laboratories, Inc.			•																		

	Accelerometers	Anechoic Chambers	Audio Analyzers	Gaussmeters	LCR Bridges	MLS	Multimeters	Oscilloscopes	Resistance Bridges	Signal Generators	Sine/Square Wave Oscillators	Speaker Parts	Speaker Turntables	Spectrum Analyzers: 1/3 Octave	Spectrum Analyzers: FFT	Spectrum Analyzers: Heterodyne	Spectrum Analyzers: TDS	Stroboscopes	Test Mics	Turns Counters	Testing Cabinets
NedLab	•			•			•			•		•		•							
Neobits, Inc.					•		•	•		•								•			
NTi Audio, Inc.			•							•	•		•	•	•		•		•		
Open Tip			•				•	•		•											
Parts Express			•				•												•		
PCB Piezotronics, Inc.	•																		•		
Performance Audio, LLC			•							•									•		
Phoenix Engineering, LLC											•										
Prism Media Products, Inc. (Prism Sound/MASELEC/SADiE/LOUDSOFT)			•							•	•			•	•		•				
Radio Design Labs (RDL)			•		•				•	•	•			•	•	•	•				
Redco Audio							•			•			•								
Scantek, Inc.	•													•	•						
Smith and Larson Audio			•		•				•	•	•								•		
Soundoctor										•	•										
Studio Six Digital			•											•	•		•		•		
Techni-Tool, Inc.			•				•	•		•				•	•	•	•	•			
TEquipment					•		•	•		•											
US Enclosure Co.												•									•
Vidsonix Design Works			•																		
Vintage King Audio					•			•		•									•		
Warkwyn			•							•	•			•	•	•	•				

Benchmarking Viscoelastic Models for Loudspeakers

By
Claus Futtrup
SEAS Fabrikker, AS

At the ALMA International Symposium and Expo (AISE) 2017, Jeff Candy and I presented a paper titled "Physical Accuracy and Modeling Robustness of Motional Impedance Models." This article discusses some of the work presented in the paper and I have added some of our thoughts surrounding this topic.

One of the reasons for studying and presenting this work is to find agreement in the industry concerning the question: "How do we evaluate the various viscoelastic models and which model is best?" Here the "best" model can be the most precise model, if desired, but simplicity is also a virtue to take into account.

Other reasons include simple academic interest to understand what goes on in a loudspeaker; and to explore viscoelasticity without using a laser device, and thereby understand transducer viscoelasticity from an alternative viewpoint than what's provided by, for example, the Klippel measurement system.

Instead of a laser, we use an added-mass approach. This gives anybody the opportunity to replicate our results without (potentially expensive) laser measurement equipment, and to study and work with viscoelasticity. All that is needed are simple impedance measurement equipment and a precision scale.

The Evolution of Viscoelasticity Models

Around 1940, Harry F. Olson described the traditional model of the mechanical side of a loudspeaker transducer in terms of mass, resistance, and compliance in his book *Elements of Acoustical Engineering*. In 1978, Brian Elliott presented an Audio Engineering Society (AES) paper "Accurate Methods for Determining the Low-Frequency Parameters of Electro-Mechanical-Acoustic Transducers with BLI Excitation," with what appears to be an early realization that the loudspeaker suspension is made from elastomers and shows signs of viscoelastic hysteresis. Hence, he coins the expression "frequency-dependent damping."[1] The observation of frequency dependent damping in the audio frequency range is directly related to the presence of viscoelasticity.

In 1993, J. Grue Jensen and Morten Knudsen presented their LOG-model in the article "Low-Frequency Loudspeaker Models that Include Suspension Creep," in the *Journal of the Audio Engineering Society* (*JAES*). A simplified form of the so-called Knudsen LOG-model was adopted by Wolfgang Klippel (around 2001) and has been a kind of de facto industry standard. Recently, we have seen new alternative models appear:

- Finn Agerkvist and Tobias Ritter (2010)—the 3PC model
- Knud Thorborg, et al. (2010 and 2013)—the FDD and the SI-LOG models
- Antonin Novak (2016)—FD model

In our ALMA paper, we evaluated the four models previously mentioned, the original LOG model by Knudsen, and the classical Thiele-Small (T-S). We decided not to evaluate some models, for example the Standard Linear Solid (SLS) model, which is a classical viscoelastic material model in mechanical engineering, because it was necessary to limit the number of models for the presentation at AISE 2017.

We can see from the above timeline (1940, 1978, 1993, 2001, 2010, 2013, and 2016) that attention to viscoelasticity is increasing in our industry. Looking at the scientific papers describing the previously mentioned viscoelastic models, it seems that each model was benchmarked with different objectives and/or different quality measures.

If the industry could agree on a test method for evaluation of new models, and possibly some ways of rating the models against each other (as better or worse), some models may actually appear favorable, while others can be discarded. Common ground serves a purpose so that our industry can develop in a positive direction and prevent a jungle of viscoelastic models.

These are our motivations for generating a method to evaluate viscoelastic models and hopefully pinpoint which model is best. During such a process, it is important to keep it simple and determine suitable objective measures.

Examination of Relevant Measurement Techniques

Our AISE 2017 presentation was an intermediate step in the evaluation process, and as such, not finished work. For more information, visit www.cfuttrup.com/blogspot.html#aise2017.

The presentation gave the results of fitting, and also the technique itself. This is a method that only requires electrical impedance measurements and application of added-masses. It is required to perform a total of three measurements to extract the motional impedance Z_M. The method is novel. It has advantages when it comes to simplicity and any engineer (or DIY speaker builder) with basic measurement equipment, can do the measurements. There is no need for a laser to measure mechanical motion.

Figure 1 shows that the proposed dual-added-mass method makes it possible to precisely extract the motional impedance, Z_M. With this, the force factor (Bl) can be calculated more accurately than with a classical added-mass measurement because Bl can be determined for a range of frequencies and averaged over this range. This is based entirely on measurement data and without applying any kind of curve-fitting. The results are model-free (i.e., there is no a-priori decision on the Thiele-Small model or any of the viscoelastic models), hence we are merely looking at measurement data.

Our studies are based in the frequency domain,

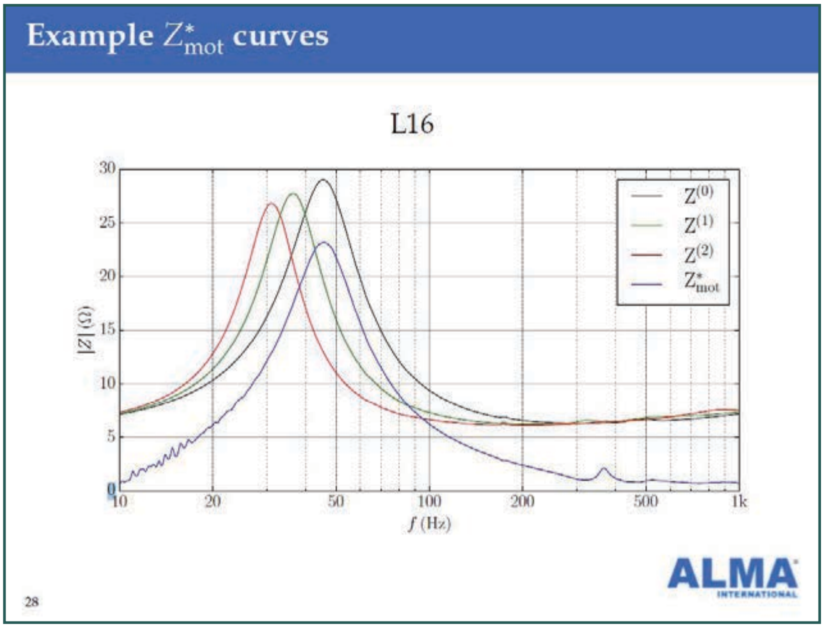

Figure 1: The proposed dual-added-mass method makes it possible to precisely extract the motional impedance, Z_M. With this, Bl can be calculated more accurately than with a classical added-mass measurement because Bl can be determined for a range of frequencies and averaged over this range. This is based entirely on measurement data and without applying any kind of curve-fitting. The results are model-free (i.e., there is no a-priori decision on the Thiele-Small model or any of the viscoelastic models), hence we are merely looking at measurement data. (Source: Slide 28 from the presentation at AISE 2017)

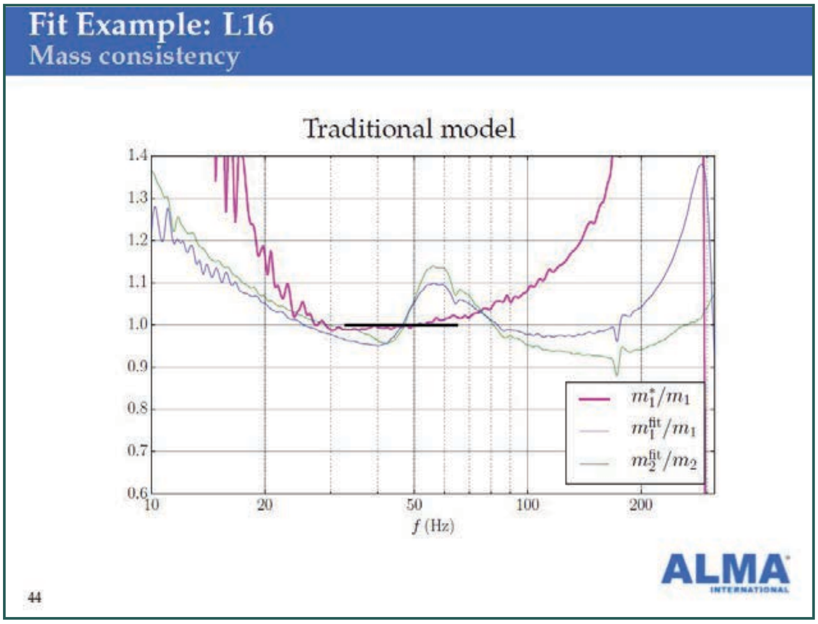

Figure 2: The proposed method also provides metrics for evaluating the quality of the measurement (diagnostics), illustrated here for the classical T-S parameter model (without viscoelasticity). The black horizontal line is the frequency range of interest, where the measurement data is of high quality (magenta curve). The graph shows that the fitted added-masses (m_1 and m_2) are not well defined in the frequency range of interest, and only at the resonance frequency (45.5 Hz) do the lines cross 1.0 (so that the fitted mass is equal to the actual measured mass). It is our conclusion from the study that it is simply not possible to properly describe a loudspeaker transducer with a classical T-S model. To obtain a stable value of the moving mass and reliably fit the motional impedance, it is necessary to apply a viscoelastic model. (Source: Slide 44 from the presentation at AISE 2017)

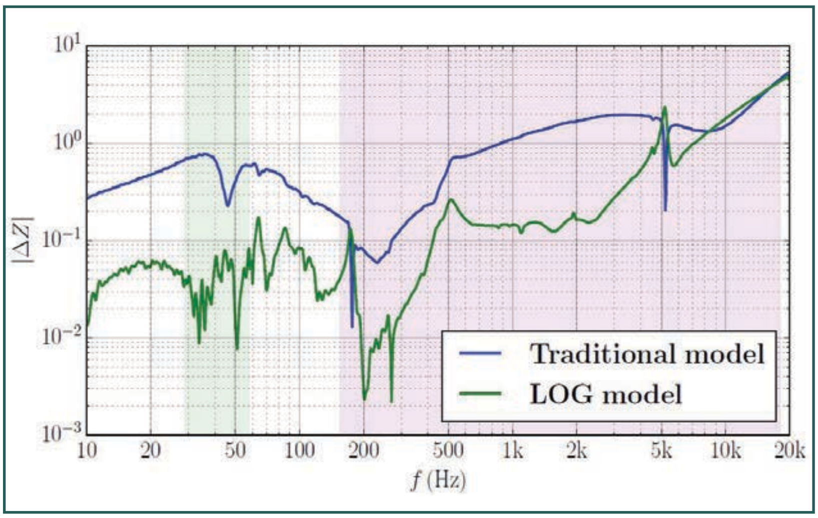

Figure 3: The fit error as applied to the L16 woofer is calculated by computing the difference in complex impedance between the model and the data, squaring the real and imaginary parts, summing the squares, then taking the square root of the total. Thus, we are plotting the error magnitude. The result shows that the LOG model gives nearly a factor of 10 reduction in error magnitude. (Source: Slides 46 and 47 from AISE 2017 presentation)

and for this method to efficiently determine the model parameters, it is required that all measurements are conducted as true steady-state measurements. In our work, we used a stepped sine signal. A pulse or Farina-sweep dynamic measurement is fast, but will not be accurate enough for getting the highest precision with the suggested technique. The equipment utilized for our experiments is a relatively inexpensive Smith & Larson Woofer Tester Pro (approximate cost is $1,000). Other equipment could also be used, provided it can apply a suitable signal and the port connected to the loudspeaker has low output impedance. In our case, this was achieved with an external power amplifier—we used a Benchmark AHB2.

Our AISE 2017 presentation only scratched the surface of how to evaluate the quality of the measurement with so-called mass consistency calculations and plot. In general, the proposed measurement technique offers significant advantages over basic T-S added-mass measurements by providing diagnostic information (see **Figure 2**).

The Fit Error

To eliminate the math and keep it short, the graph in **Figure 3** shows the fit error for the traditional T-S model compared against the LOG model. The fit error, as seen in **Figure 3**, is summed for the fit region around the resonance frequency (the green shaded area). **Table 1** shows the results from our initial study.

Drivers Under Test

The drivers under test (DUTs) were a mix of various products from SEAS Fabrikker (see **Photo 1**), currently ranging from a 10 cm full-range (FU10RB) to a 10" woofer (W26) and some were prototypes with particular properties (e.g.,low mechanical damping). For evaluation purposes, we are building a library of test data of different transducers, some of which are from other manufacturers, like the classic high-damping VIFA P17WJ00-08 (kindly provided by Scan-Speak), which was also used for the original study of the LOG Model, by Knudsen and Jensen.

Another observation in retrospect is that among the five drivers there were none with four-layer voice coils.

Key Conclusions

Our AISE 2017 paper provides details of our evaluation of the Knudsen LOG model, benchmarked against the T-S model. The T-S results (marked with grey in **Table 1**) represent a worst-case scenario, where viscoelasticity is not modeled at all. Based on a personal judgement, the authors have color-coded the results marking which results are excellent (green), good (yellow), or not so good (red), which indicates when the result is around 30% of the T-S error or worse.

What intermediate observations have we noticed and what do we read from these results? Thus far, our conclusions have determined the following:

- A two-parameter LOG model gives excellent balance of simplicity vs. accuracy
- SI-LOG and FD models may be slightly more accurate in some cases
- The 3PC model may be the most robust (more testing is required)
- All models yield frequency-dependent damping absent from the traditional model
- Added mass measurements require care and precision
- The electrical measurement system should have high signal-to-noise ratio (SNR)

Regarding simplicity, the T-S model only uses one fixed value for compliance (C_{MS}) and one fixed value for damping (R_{MS}) as linear parameters and it fails to simulate the change in impedance peak height at the resonance frequency f_S when adding mass.

The simplest extension is the Frequency Dependent Damping (FDD) model where compliance is still a static value (C_{MS}) and damping consists of two parameters (R_{MS} + an admittance value that changes with frequency, A_{MS}). This was the first iteration by Thorborg, et al. From **Table 1** it is clear that the FDD model offers an improvement, but less than the other (more advanced) models.

Average Fit Error in Ohms

Drivers	T-S	FDD	LOG	SI-LOG	3PC	FD
FU	0.089	0.025	0.026	0.016	0.026	0.025
L16	0.170	0.074	0.019	0.013	0.018	0.020
W18	0.160	0.047	0.009	0.009	0.010	0.008
L19	0.342	0.135	0.079	0.081	0.026	0.196
W26	0.216	0.046	0.033	0.031	0.032	0.032
Error Σ	0.977	0.327	0.166	0.150	0.112	0.281

Table 1: These are the results of the average fit error from our initial study. (Source: Slide 48 from the presentation at AISE 2017)

The next step up is the Knudsen LOG model where compliance and damping both change (C_{MS} becomes a straight line when plotted on a logarithmic x-axis, hence the name LOG-model) and the two are tied together with a single parameter, λ.

All other models in this investigation (the SI-LOG, the 3PC, and the FD model) add one additional parameter to the model and, therefore, they are considered three-parameter viscoelastic models. It seems clear that adding parameters to the viscoelastic model as a general rule reduces the fit error (i.e., it improves the overall quality of the fit).

The benchmark rating of the Fractional Derivatives (FD) model is significantly impaired by a bad fit to the L19 driver (a prototype driver

About the Authors

Claus Futtrup was born in Herning, Denmark, in 1971. He received his M.Sc. in mechanical engineering in 1997 from Aalborg University. His special field is material science; steel and other metals, ceramics, rubber, plastics, and composites in regard to design parameters, process engineering, and chemical and environmental issues. During his career, Futtrup has worked for several loudspeaker companies. From 1997 to 2006, he worked at Dynaudio A/S first as an R&D Engineer, designing loudspeaker boxes and later as a System Engineer for automotive. From 2006 to 2008, he was employed as a Transducer Design Engineer at Tymphany Denmark and, in 2008-2013 he was R&D Manager at Scan Speak. In 2013, he started working as Technical Sales Manager for SEAS, Norway, and in 2015 he was promoted to Chief Technical Officer. Futtrup has authored a number of Audio Engineering Society (AES) papers, most of them published in the Journal (JAES), one was presented in London in May 2011. Due to his comprehensive technical and historical knowledge about loudspeakers, he is often invited as a guest speaker at various events. In November 2015, he authored a chapter about the history of loudspeakers in the book "The Danish loudspeaker 100 year anniversary."

Jeff Candy was born in Edmonton, Canada in 1966. He received his Ph.D. in Physics from the University of California, San Diego, CA in 1994, and is currently manager of the Turbulence and Transport Group at General Atomics in San Diego. At General Atomics, he works on various topics in theoretical and computational plasma physics, with specific focus on plasma kinetic theory and turbulence. In the field of audio, he is interested in the application of methods in theoretical acoustics to practical situations. Candy is a member of the Audio Engineering Society and a fellow of the American Physical Society (APS).

Photo 1: We used these drivers in our initial study. They are listed in Table 1.

with very low mechanical damping). It requires further study to see if we can improve on this.

For Future Evaluations

There are at least two aspects to consider when it comes to modeling viscoelasticity. First, the physical accuracy of the model, and second, the modeling robustness (i.e., is the method capable of tackling small errors in the measurements or do you at least get some insight into the quality of the measurement).

Another important aspect is what should be the success criteria? For example, will it suffice to have a qualitatively good simulation of the viscoelasticity in the audio range or is it desirable to know what goes on at very low frequencies (e.g., near-DC signals), so that the exact position of the coil is known at any given time? In our qualitative evaluation, we have decided to focus on the audio range and down to about 10 Hz as the lowest point of interest.

Our work onward is initially to make further studies in the field of measuring and curve-fitting data. The results of this scientific work will be reported in a number of AES papers in the future, hopefully in 2017. Since these studies are conducted in our spare time, they progress as time permits.

Quality feedback that we received at the AISE 2017 included the desire to see a Gage R&R analysis of the method and the need to see if the calculated force factor (Bl) based on the motional impedance curve is identifiable as a flat area. These matters are to be addressed in future work.

Today, a measurement system by Klippel GmbH is readily available, which uses a laser to determine parameters. This measurement system has replaced the classical added-mass technique in companies and laboratories throughout the world. The equipment is widely used and I see no reason why the dual-added-mass method should replace this equipment. Using a laser is evidently faster and, from a user standpoint, simpler. Therefore, please consider the dual-added-mass method as an optional alternative for measuring viscoelasticity, but it is fully viable and not inferior in any way. In fact, it can be regarded as on-par with a high quality laser measurement and it is a suitable alternative for equipment manufacturers who do not offer a laser for measuring loudspeaker parameters. ***LIS***

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ORA
GRAPHENE AUDIC

GRAPHENEQ

Graphene Composites for Improved Sound Quality and Increased Efficiency in Portable Devices

ORA Sound is pioneering the use of graphene oxide composites for high-performance loudspeaker membranes. Its patented technology is poised to be the first wide-spread consumer application of graphene, leveraging the material's properties to create smaller, more efficient loudspeakers with improved sound quality.

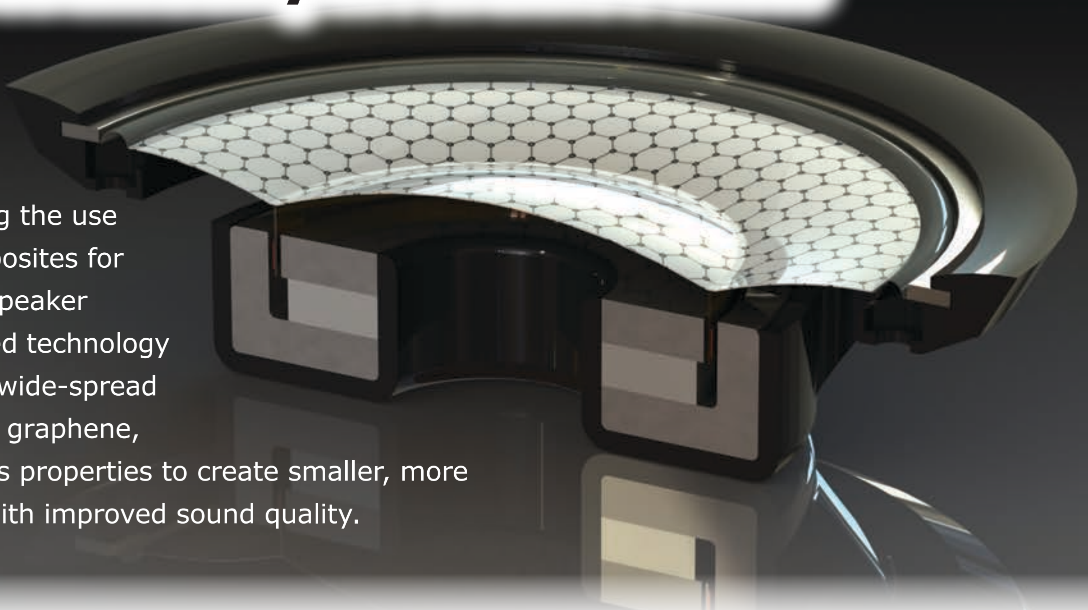


Photo 1: This is an artist's rendition of a dynamic transducer using a graphene membrane. The hexagonal, two-dimensional "honeycomb" structure of graphene makes the material extremely strong and light weight.

By
Robert-Eric Gaskell, Ph.D.
ORA Sound

ORA Sound, a Montréal-based company makes loudspeaker membranes from graphene, a newly isolated material with exceptional characteristics. The 2004 discovery of this stable, 2D material won the Nobel Prize in Physics in 2010.

Pristine graphene is a single atomic layer of carbon atoms arranged in a perfect hexagonal crystal lattice, making it very strong and stable. Measurements of the mechanical properties of graphene performed by Lee, et. al., and published in *Science* in 2008 showed the intrinsic strength of graphene to be 130,000 MPa, the strongest material ever measured—more than 25 times that of the strongest steel. The Young's Modulus, a measure of stiffness, was reported to be 1 TPa. Due to its stiffness and low density, the speed of sound in graphene is 20,000 m/s, faster than in any other known material.

The properties of graphene allow for the design of materials with precise acoustical properties that can provide significant improvements in the sensitivity, frequency response, and power handling of loudspeakers. As the consumer audio industry goes wireless, ORA Sound's new graphene loudspeaker technology is poised to offer a solution that can extend battery life while improving sound quality (see **Photo 1**).

Background

Graphene has been touted as a super-material that will change our everyday lives for the better. From transistors to solar panels to water filtration, graphene has a lot of potential. However, this new material has yet to find its way into commercial products in any significant way due, in part, to the difficulty and expense in depositing sheets of pristine graphene.

In 2013, researchers at McGill University adopted a different approach to graphene deposition for the production of graphene-based loudspeaker membranes for dynamic transducers.

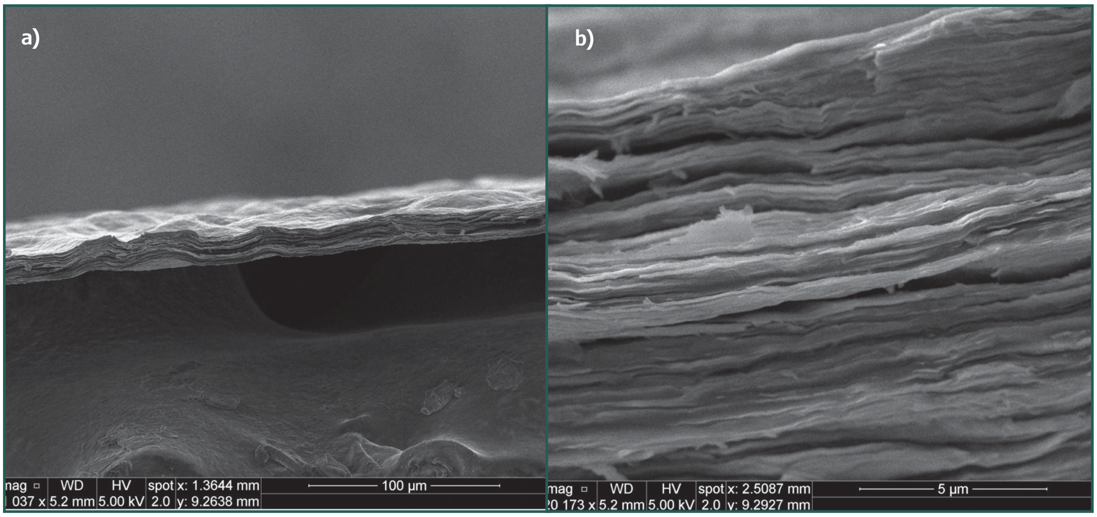


Photo 2: Scanning electron microscopy shows 100 µm scale (a) and 5 µm scale (b) of GrapheneQ revealing the laminate structure of the material. Flakes of graphene are bonded together in layers with oxygen groups and other proprietary cross-linking agents to create a tunable, light-weight, high-stiffness graphene composite over 95% graphene by weight.

The method uses flakes of graphene that have been functionalized with oxygen groups, which act to bond the flakes into a laminate material comprised of thousands of layers of graphene. The results are very stiff, very light-weight membranes that can act as drop-in replacements for current loudspeaker membrane materials to provide more output, require less power, and improve sound quality (see **Photo 2**). With raw materials costs on par with aluminum, it is possible that this can be achieved without a significant increase in cost over common membrane materials. Soon, we may begin to see graphene improve many professional and consumer products, but it is likely that the first widespread adoption of this material will be in the loudspeaker industry.

After some initial tests, the McGill team filed for a patent in 2014 and first disclosed the technology in a short paper for the Audio Engineering Society (AES) on graphene oxide (GO) in ribbon microphones. The use of graphene oxide to form loudspeaker membranes turned out to be a very robust approach. Through pre- and post-processing techniques as well as the addition of various fillers and cross-linkers, methods were developed to tune the material in terms of its Young's Modulus, density, damping, and thermal conductivity.

A prototype headphone driver came about a year after the initial patent application. In May of 2016, a Montréal-based incubator, TandemLaunch, Inc., provided seed funding for the team to develop and commercialize the technology. Marketing lead Ari Pinkas and lead researcher Dr. Kaiwen Hu joined the team to form the company, ORA Sound, branding their technology GrapheneQ for its excellent damping characteristics and low-Q resonance.

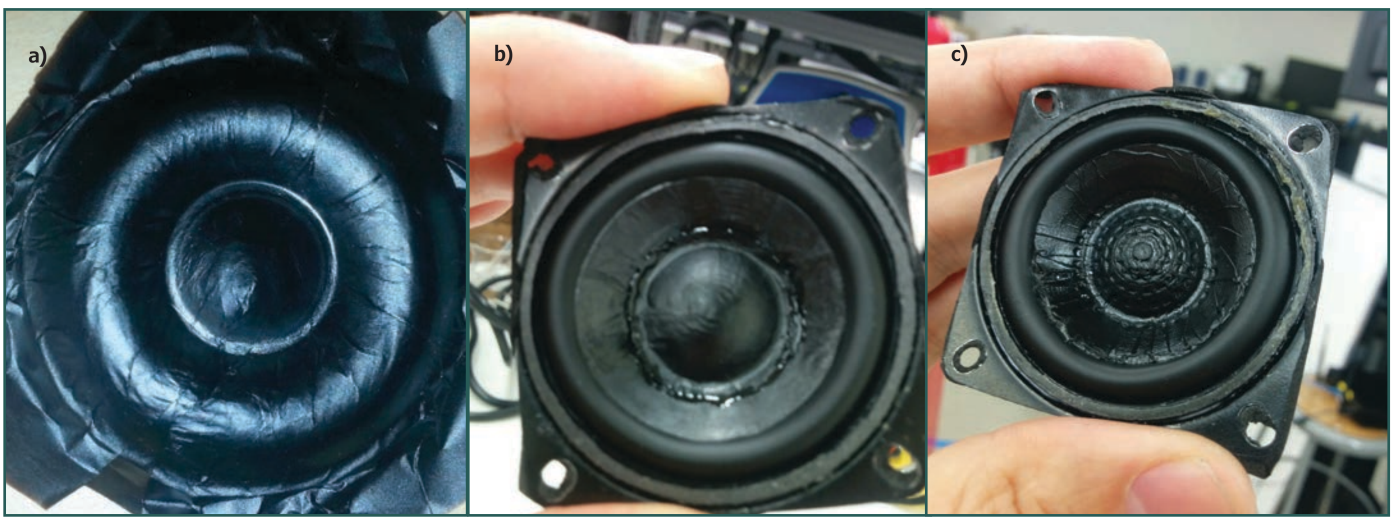


Photo 3: This is the evolution of ORA Sound's cone-forming process. The three cones are early prototypes.

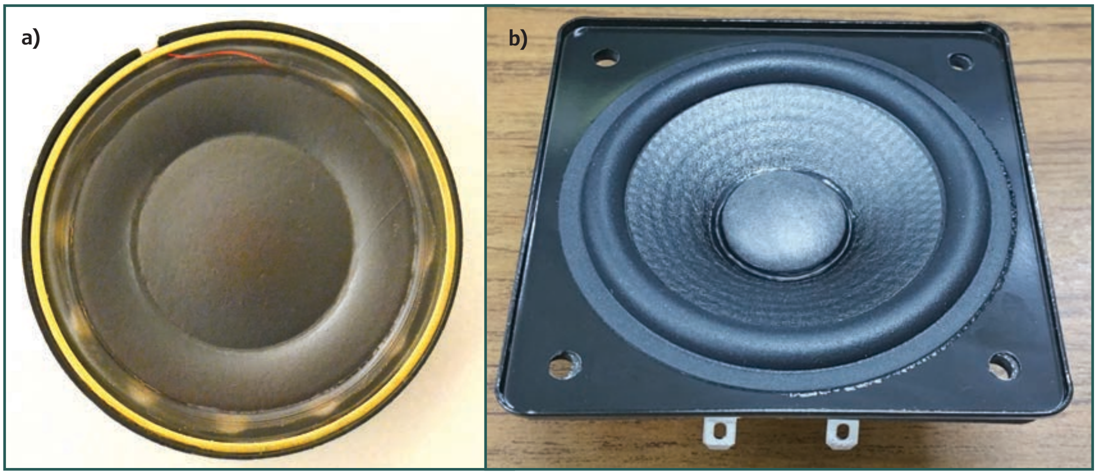


Photo 4: The headphone driver (a) is ORA Sound's current 40 mm driver design and the 3″ GrapheneQ loudspeaker (b) was used in the Warkwyn tests.

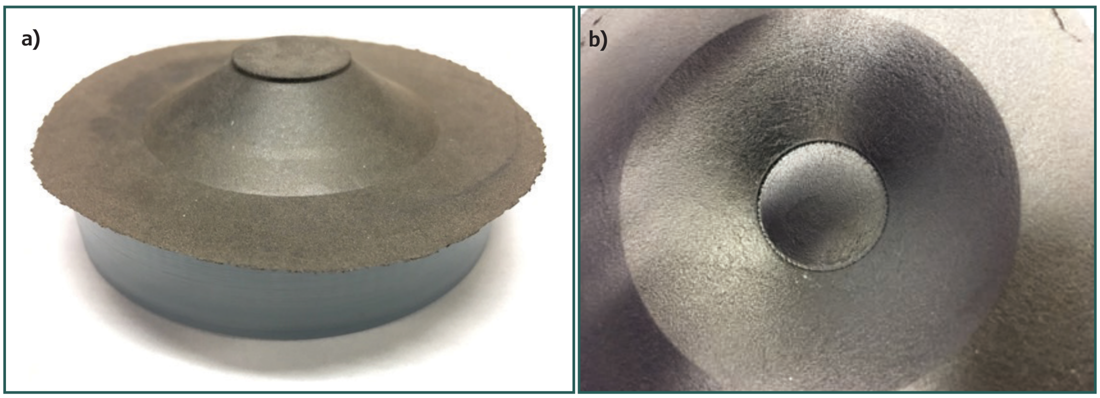


Photo 5: This is ORA Sound's most recent cone deposition. This sample still requires trimming of the excess material around the outer edge and center (a). The precise angles and shapes can be seen, particularly in the lip, for gluing to the former. The texture of the cone is a result of the texture of the mold (b).

Forming GrapheneQ Membranes

A major hurdle that needed to be overcome was the forming of GrapheneQ materials into cone and dome shapes for standard woofer and tweeter designs. Beginning with a flat sheet, graphene's stiffness does not allow it to be stretched or formed into cones, domes, or other geometries with a non-zero Gaussian curvature. Early attempts to form loudspeaker cones and dust caps led to less than perfect results. **Photo 3** shows some prototype GrapheneQ membranes with folds and wrinkles resulting from the attempt to form a 2-D membrane into a loudspeaker cone. The deposition technique has evolved to allow for the production of the 40 mm headphone driver and 3″ loudspeaker (see **Photo 4**).

The ORA Sound team developed a technique that, when combined with a patented method from Northwestern University, allows GrapheneQ to be directly formed into loudspeaker geometries. The results have been impressive in terms of the feature detail and tolerances that can be achieved with this GrapheneQ loudspeaker deposition technique.

The nano-scale of the starting material means the only limitation to forming the material is the resolution of the mold that is used in the process. The graphene flakes that form the laminate material, GrapheneQ, self-assemble parallel to the mold's surface creating an isotropic material

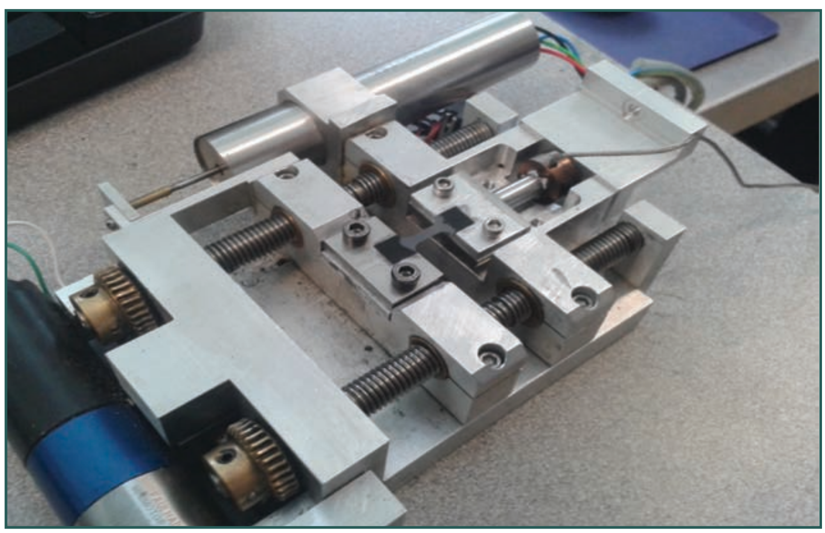


Photo 6: ORA Sound has a tensile test jig for measuring Young's Modulus.

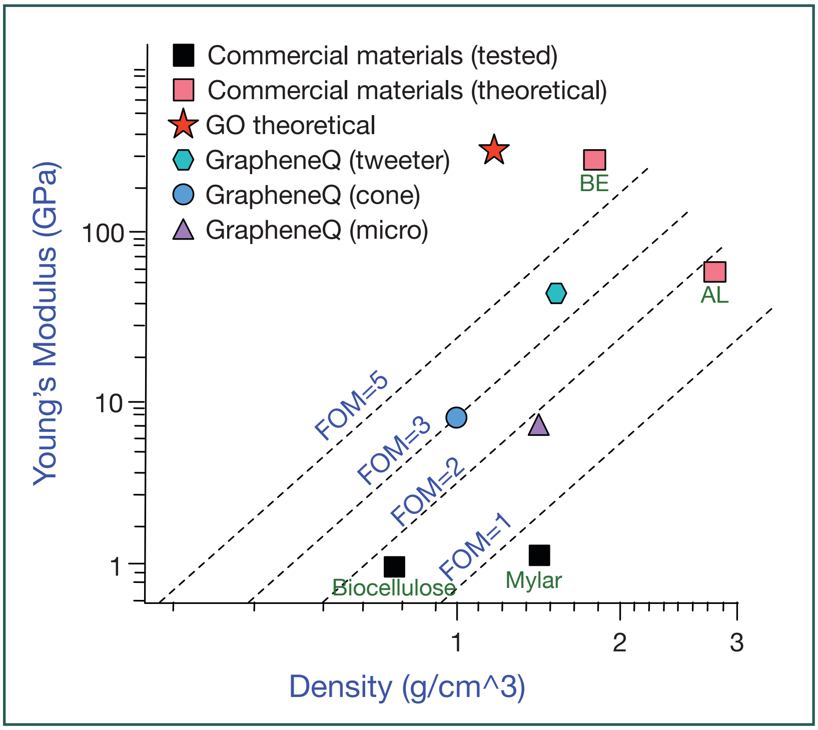


Figure 1: The chart compares Young's modulus, density, and the resultant figure of merit (FOM) for several different measured and theoretical values of various common loudspeaker membrane materials.

in the desired shape. In **Photo 5**, the texture seen in the GrapheneQ cones is due to the texture of the mold's surface—in theory, any surface finish would be achievable depending on the characteristics of the mold.

The size and thickness of GrapheneQ membranes are also widely variable. There is no theoretical limit to how large or small a membrane that can be made. The largest cone made to date has been a 3" full-range driver while the smallest has been a 2 mm balanced armature (BA) membrane. There is also a wide range of possible thicknesses. ORA Sound has made materials as thin as 10 µm and as thick as 300 µm. Thicker materials are possible, but the time to deposit a membrane goes up significantly as membrane thickness increases.

Material	E (GPa)	ρ (kg/cm3)	vS (m/s)	kT (W/mK)	$FOM = \frac{v_S}{\rho} = \sqrt{\frac{E}{\rho^3}}$
Titanium	120	4.5	5164	16	1.14
Aluminum	70	2.7	5092	240	1.89
Mylar	3	1.39	1897	0.15	1.07
Beryllium	300	1.84	12769	216	6.94
CVD Diamond	1050	3.5	17321	1800	4.95
GrapheneQ	15-130	0.600-1.800	6120-8500	≤1500 (r-GQ)	4.72-7.65

Table 1: Acoustic driver materials properties (E = Young's Modulus, ρ = Density, vS= Speed of Sound, kT = Thermal Conductivity). The figure of merit (FOM) combines the Young's Modulus and Density into a single overall metric. [* The values for GrapheneQ are based on lab results obtained through our proprietary manufacturing method. Ora Sound is continuing to tune the material properties of GrapheneQ to obtain the best balance of high stiffness, low density, and consistency in deposition. r-GQ is created through thermal reduction of GrapheneQ]

The State of the Art

ORA Sound's core technology has provided some exciting results and is getting a lot of attention from consumer audio OEMs as well as from cellphone manufacturers, hearing aid manufacturers, and many other industries that rely on loudspeakers in their products. In the year since ORA Sound was formed, its research team has made many advancements in creating new loudspeaker membrane materials but still feel that there is room for improvement.

Current efforts have focused on optimizing three variations of GrapheneQ for three specific applications. ORA Sound now has a low-density material targeted toward full-range cones, a very stiff material for tweeters, and have begun working on a material with increased thermal conductivity for microspeakers.

All of ORA Sound's material variations are tested in-house, using a tensile test jig (see **Photo 6**). Small material samples are pulled apart to provide a stress-strain curve that enables the Young's Modulus to be derived. ORA Sound evaluates the material using a figure of merit (FOM) that combines the Young's Modulus and density into a single metric, which is representative of the first bending mode of the material. This FOM enables ORA Sound engineers to predict where the first break-up mode of a loudspeaker membrane will be. The higher the FOM, the higher the frequency where a GrapheneQ membrane will begin to behave non-pistonically. Non-pistonic motion leads to distortion and frequency response irregularities that contribute to the perception of harshness and to inaccuracy in sound reproduction.

The formula used to calculate this first bending mode is highly dependent on the density (ρ) as well as the Young's Modulus (E) and is given as:

$$FOM = \sqrt{\frac{E}{\rho^3}}$$

The lower the density, the higher the FOM (see **Table 1**). A significant benefit to low density is that a loudspeaker can be made more efficient with a reduction in moving mass. A lower membrane mass also requires less external damping providing loudspeaker designers with more latitude in optimizing their designs. The current material properties of ORA Sound's various GrapheneQ materials can be seen in **Figure 1**. ORA Sound is constantly experimenting and improving the mechanical characteristics. ORA Sound's university partners have achieved a Young's modulus of 130 GPa for thin, flat sheets. This 130 GPa figure has become the target for the membranes; work is ongoing to achieve this same value in thicker, formed cones and domes.

The ability to tune GrapheneQ is one of its most interesting traits. The mechanical properties can be manipulated with slight changes to the additives, cross-linkers, and deposition techniques used on the base of graphene oxide. As a result, ORA Sound specifies a range of density, stiffness, and thermal conductivity. This is because GrapheneQ can be engineered to have specific characteristics based on the desired application. ORA Sound has defined a few good combinations of mechanical characteristics but hope to get to the point where the material's properties can be fine-tuned. These properties range from as low as 10 GPa to as much as 130 GPa with density ranging from 1.8g/cm^3 down to 0.6 g/cm^3 at a damping factor (tan delta) anywhere between 0.06 to 0.12. ORA Sound's engineers believe they can eventually produce a material that out-performs beryllium at an order of magnitude lower cost.

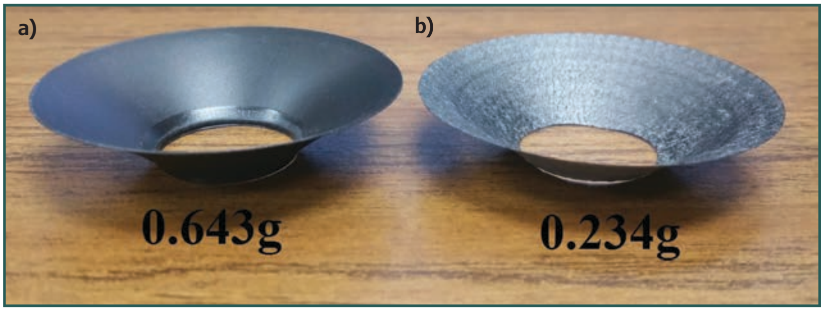


Photo 7: The mass of the 180 µm poly cone (a) weighs 0.643g and the 180 µm GrapheneQ cone (b) weighs 0.234g.

Warkwyn Tests

To test a real-world application of GrapheneQ, ORA Sound partnered with Warkwyn (a US subsidiary of MISCO). Warkwyn selected an existing 3" loudspeaker from MISCO's product line that could be made with a poly cone, a paper cone, and with a GrapheneQ cone to enable comparative testing between these materials. The loudspeaker magnet, coil, and suspension were optimized for the poly cone by design.

For a direct comparison of the effect of the cone material alone, only the cone was substituted for GrapheneQ, all other aspects of the speaker remained the same. ORA Sound selected its low-density cone material (Young's Modulus = 15 GPa,

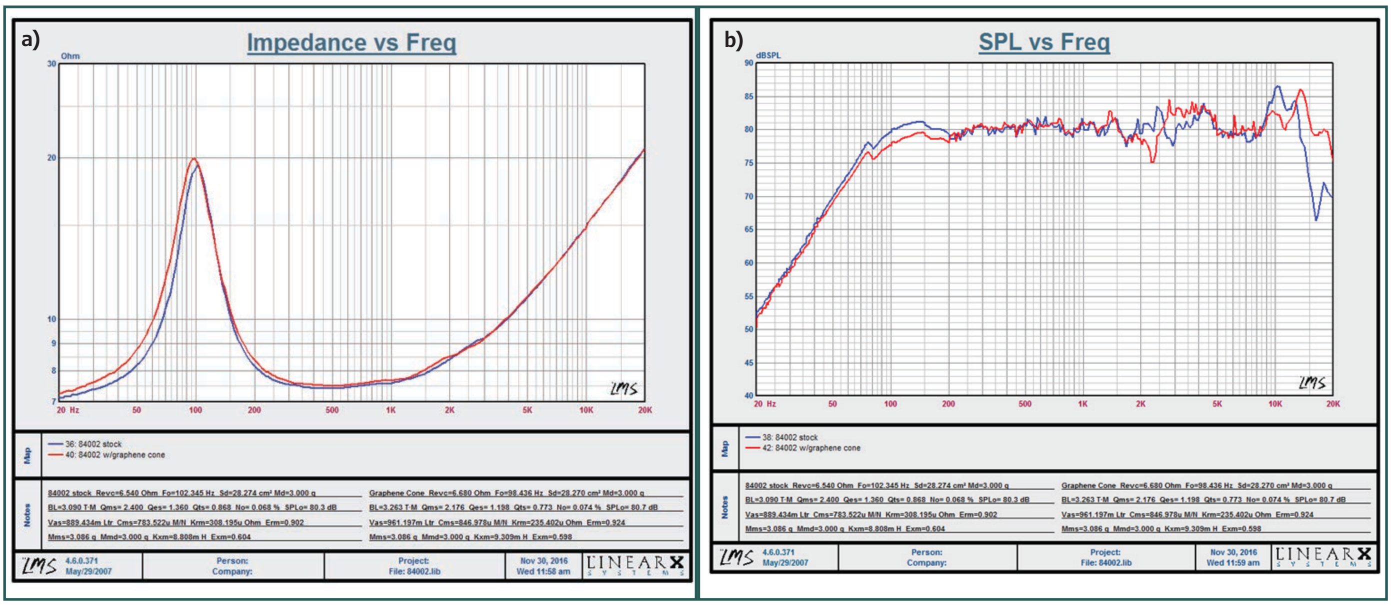


Figure 2a: This is the impedance and SPL vs. Frequency for the GrapheneQ cone (red) and poly cone (blue). b: The GrapheneQ cone has a wider-Q resonance and an extended high-frequency response. (Image courtesy of Warkwyn)

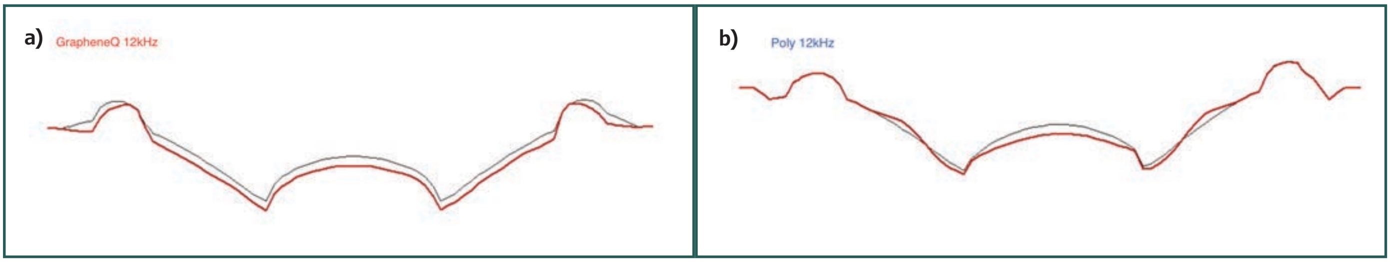


Figure 3: Laser scanning of a low-density GrapheneQ cone (a) and the standard poly cone (b) that the loudspeaker was designed for at 12 kHz. The GrapheneQ cone exhibits less breakup and begins to breakup at a higher frequency than the poly cone. (Images courtesy of Warkwyn)

Graphene Cone Speaker	Poly Cone Speaker
180 µm	180 µm
Surround only = 1.63 g	Surround only = 1.63 g
Half surround only = 0.72 g	Half surround only = 0.72 g
Graphene body only = 0.25 g	Poly body only = 0.63 g
Coil = 0.82 g	Coil = 0.82 g
Half of spider = 0.18 g	Half of spider = 0.18 g
Adhesive mass = 0.5 g (estimate)	Adhesive mass = 0.5 g (estimate)
Full cone assembly = 2 g	Full cone assembly = 2.26 g
Moving mass = 2.47 g	Moving mass = 2.85 g

Table 2: Here is a side-by-side comparison of the a graphene cone speaker and a poly code speaker.

Density = 0.8 g/cm^3) for the tests. Low-density GrapheneQ membranes were formed at the same 180 µm thickness as the equivalent poly cone (see **Photo 7**). Compared to the poly cone, the GrapheneQ cone of the same thickness was nearly one-third the mass (see **Table 2**).

The Thiele-Small (T-S) parameters for the newly made loudspeakers were measured and compared. The GrapheneQ speaker showed a 20% increase in N_o, the loudspeaker efficiency. This is less than the 70% efficiency improvement predicted by ORA Sound; however, the suspension of the MISCO loudspeaker was quite heavy relative to the diaphragm in this particular design as optimized for the poly cone (see **Figure 2**). The lower mass of the GrapheneQ membrane requires less damping and could be designed with a lighter more compliant suspension that would enable further improvements in efficiency.

Measurements of impedance between the poly and GrapheneQ cones show a slightly lower, wider-Q resonance with the GrapheneQ material. The frequency response differences between the two materials are significant in the high end with the GrapheneQ membrane extending the high-frequency response well beyond the point where the poly cone begins to drop off.

Laser scanning of the two loudspeakers was also performed. While the GrapheneQ cone did exhibit some breakup above 8 kHz, it was less than the poly cone (see **Figure 3**). The presence of some break-up was anticipated since the low-density GrapheneQ material used in the test is not the stiffest material that can be formed with ORA Sound's technology; however, the GrapheneQ cone still significantly outperformed the poly cone for which the loudspeaker had been optimized. Sonically, the differences are immediately noticeable, with several listeners describing the GrapheneQ speaker as sounding more "real" and "life-like," "more detailed," and less "like the sound was coming from a box."

What's Next?

With less than a year of development, ORA Sound has grown its graphene loudspeaker technology from a single, hand-assembled prototype to a reliable and tunable process. The company still needs to move manufacturing out of the laboratory and into the factory. ORA Sound plans to partner

About the Author

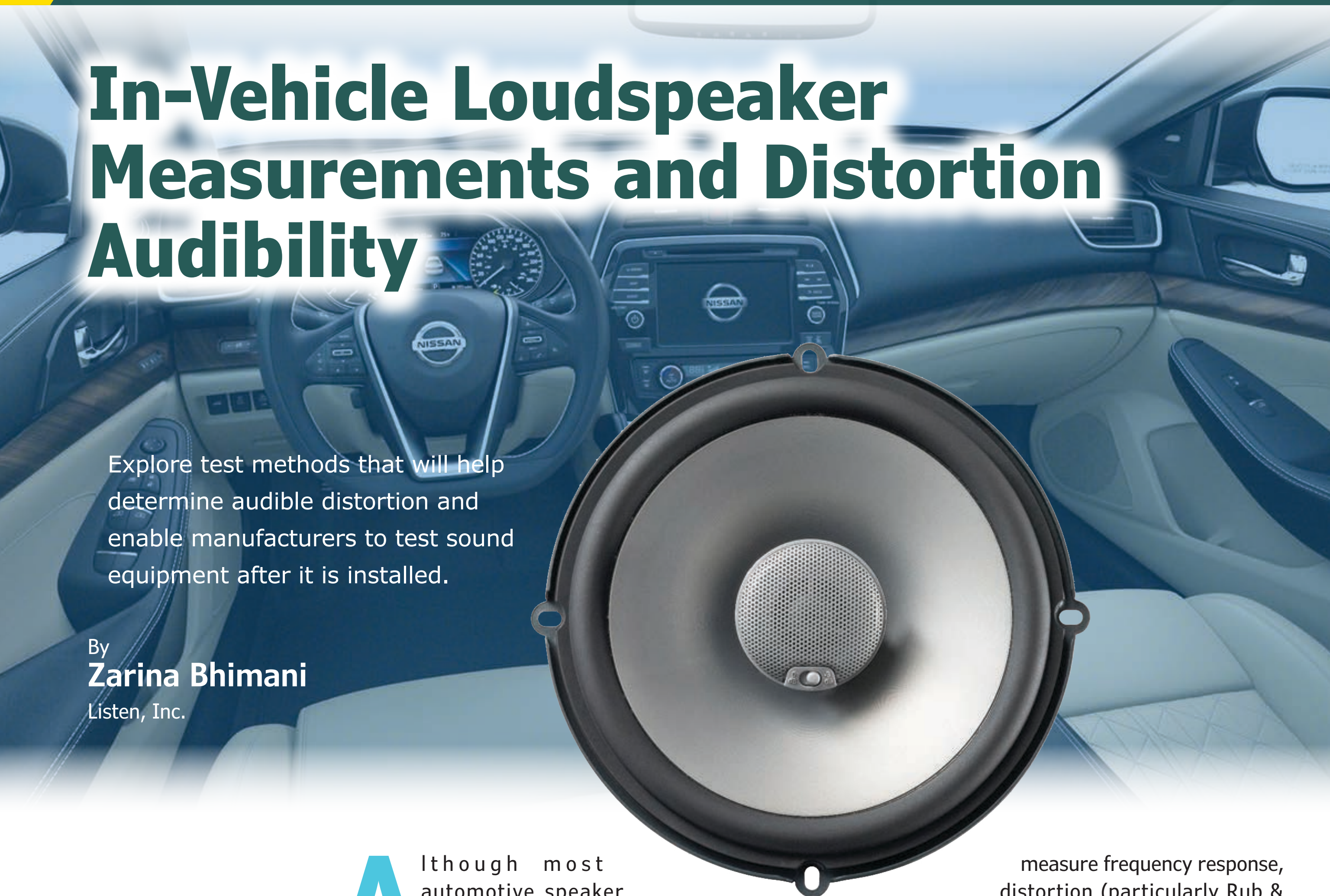
Robert-Eric Gaskell is a Canadian/American researcher, electronics designer, and Juno award-winning recording engineer. He holds a Ph.D. in Sound Recording from McGill University where he continues to teach courses in Electronics and Digital Studio Technologies. Gaskell is a co-inventor of the core technology for ORA Sound, a Montréal based start-up working to commercialize the use of Graphene in transducer membranes. He specializes in correlating objective measurements with listener perception of character and quality in audio devices. Gaskell has worked on the design and manufacture of commercially available ribbon microphones from Audio Engineering Associates (AEA) and has his own line of microphone preamplifiers with his company GKL Audio.

with a contract manufacturer that has experience and a solid reputation in the loudspeaker industry.

In the months to come, ORA Sound plans to hire a CEO that can help guide the company's transition into scalable manufacturing. ORA Sound is also planning a small run of headphones (see **Photo 8**) that will be available for pre-order in June of 2017. The purpose of this run of headphones is to help the transition into large-scale manufacturing of GrapheneQ as well as to show prospective investors the potential of this new material.

The ORA Sound headphones will be optimized for its 40 mm GrapheneQ driver, enabling listeners an opportunity to experience the sound quality that GrapheneQ can provide. Measurements of Young's Modulus and density are informative, but there is nothing more convincing than being able to hear the technology in person. In the meantime, ORA Sound continues to engage with OEMs and ODMs that are interested in testing the material and becoming early adopters of ORA Sound's GrapheneQ technology. ***LIS***

Photo 8: Coming soon! Graphene headphones by ORA Sound.



In-Vehicle Loudspeaker Measurements and Distortion Audibility

Explore test methods that will help determine audible distortion and enable manufacturers to test sound equipment after it is installed.

By
Zarina Bhimani
Listen, Inc.

Although most automotive speaker manufacturers carry out thorough end-of-line (EOL) driver testing (in many cases, 100% of product), many automotive manufacturers do not test the speakers once they are installed. It is possible for a speaker to develop a fault through damage in transit, handling, or installation. Furthermore, the simple act of installing a loudspeaker into a car can result in vibration issues caused by mounting and other components in the car.

Such issues can prove costly for automotive manufacturers. It is not uncommon for a car dealer to install a new set of speakers in a car if a customer complains about sound quality issues. It is, therefore, advisable for automotive manufacturers to invest in both incoming speaker QC and complete EOL testing of installed systems.

The test equipment for incoming QC and in-vehicle testing is similar to EOL production tests. In fact the test setup for incoming QC is practically identical to that used in driver manufacturing facilities worldwide (see **Figure 1**). This simple setup consists of an amplifier to drive the speaker, a measurement microphone, and software to measure frequency response, distortion (particularly Rub & Buzz), and polarity.

In-vehicle testing is implemented with similar equipment, but the setup differs in that the audio signal is transmitted from the measurement software via an audio interface to the auxiliary, Bluetooth, or USB input to the head unit. The test signal is played through the speakers, and the signal is picked up by a centrally positioned microphone. Care must be taken in positioning the microphone to ensure that the path from speaker to microphone is not blocked by seats or other parts of the car's interior. Usually the best position is on, or suspended above, the front seat arm rest.

A single measurement of frequency response and Rub & Buzz is usually sufficient to ensure that the audio profile measured in the car meets specifications. If there are discrepancies, each speaker can then be measured independently (including additional measurements such as polarity) to help identify the cause. Any microphones in the car (e.g., part of a voice control/telematics system) can also be tested using the same equipment and the car's own speaker to play the test signal (see **Figure 2**).

A similar test setup can be used for R&D testing (e.g., for voicing the audio system to the car). This might include speaker positioning and equalization of the system for correct tonal and spatial balance including left/right (L/R) and front/back balancing. It may also be used for microphone positioning and directivity measurements and noise cancellation performance.

Distortion Audibility and Objective Measurements

In a recent Audio Engineering Society (AES) paper called "In-Vehicle Audio System Distortion Audibility" (141st AES Convention, 2016), Steve Temme (Listen, Inc.) and Patrick Dennis (Nissan Technical Center North America) used such a system to research in-vehicle audio system distortion audibility and its correlation to objective measurements. The objective of this research was to identify the level at which in-vehicle audio distortion became audible and identify the objective test method that correlates best to human perception. Listeners evaluated three different audio tracks for distortion against defined criteria, objective measurements were made using a variety of test signals, and the correlation between the two discussed.

Listening Test

To determine the level at which distortion was audible and sound quality perception affected, binaural recordings of musical excerpts were made through the in-vehicle audio system at various volumes, adjusted to equal loudness, and played through a low-distortion reference headphone. Listeners ranked distortion audibility and perceived sound quality.

Three test tracks were selected: "Bird on a Wire" by Jennifer Warnes (female pop vocal), "Cousin Dupree" by Steely Dan (male pop vocal) and "American Boy" by Estelle with Kanye West (female/male hip hop). Each track was edited into short loops, normalized to 0 dBFS to ensure maximum gain, and transferred to a CD for in-vehicle playback.

Binaural recordings were made using a Head-and-Torso Simulator (HATS) and a BEQ II measurement front end in the driver seat of a Nissan Altima with a six-speaker audio system. The speaker arrangement consisted of two 3" speakers on top of the instrument panel (first-order crossed over at 1.2 kHz), two full-range 6.5" speakers low in the front doors, and two full-range 6" × 9" speakers in the rear parcel shelf. The head unit did not have electrical distortion limiting or compression. The recordings were made from volume step 20 to 40 (maximum) in two-step increments. This translates to a 1 dB/step change from volume step 20 to 22, a 2 dB/step change from volume step 22 to 34, and a 1 dB/step change from volume 34 to 40.

The binaural recordings were saved with direction-independent ear EQ applied, and each recording matched for overall loudness as well as

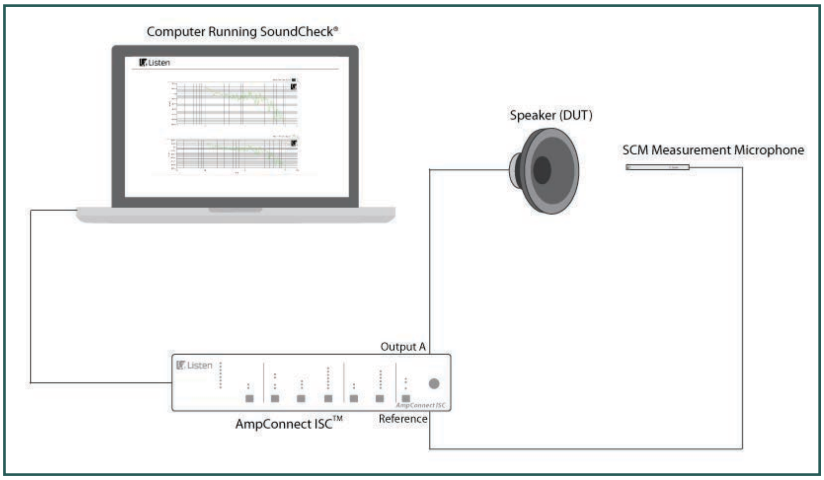


Figure 1: Here is a typical driver test setup for a production line or an incoming QC test.

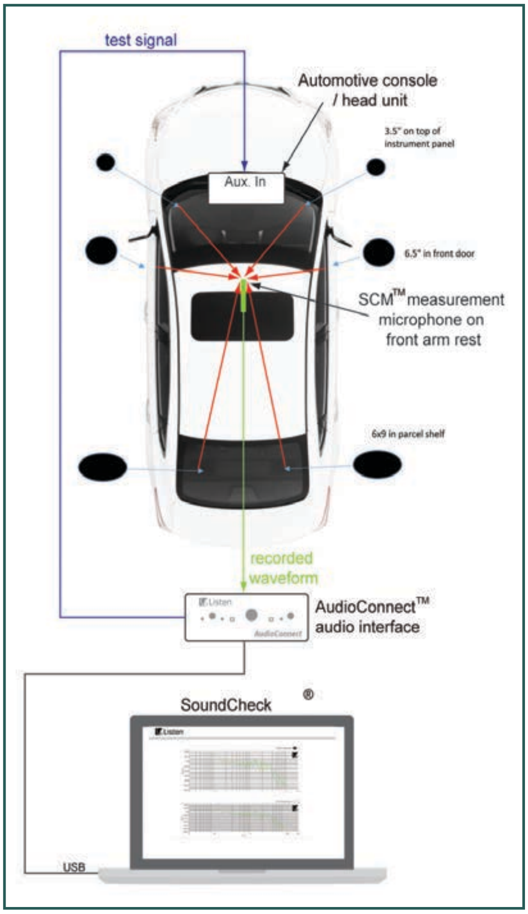


Figure 2: An in-vehicle audio measurement test setup is highly recommended.

Track	Volume Steps Used	Distortion Audibility
"Bird on a Wire"	34, 36, 38, and 40	Significant differences were found between volume 34 and 36, between 36 and 38, and between 38 and 40
"Cousin Dupree"	34, 36, 38, and 40	Significant differences were found between volume step 38 and 40 and between volume step 34 and 36. No significant difference was found between volume step 36 and 38
"American Boy"	30, 32, 34, 36, 38, and 40	Significant differences were found between volume step 30 and 32 and between volume step 32 and 34. Volume step 40, 38, and 36 had no significant difference found

Table 1: These are the results for our distortion audibility tests on three different music tracks.

spectrum in the bass region to offset the effect of dynamic loudness present in the head unit of the audio system. These adjustments removed the overall level and other frequency components, leaving only the amount of distortion as the distinguishing characteristic between recordings. The recordings were played back through a calibrated setup consisting of a programmable equalizer, headphone amplifier, and Stax SR303 headphones.

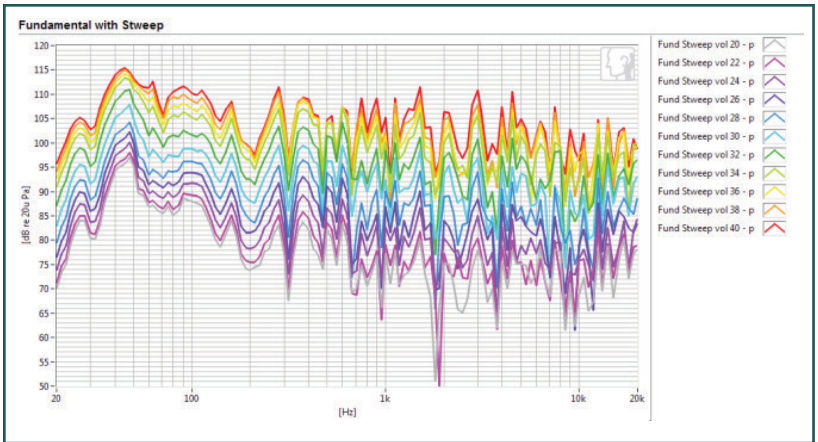


Figure 3: Fundamental vs. Volume Level (1/12th (R40) octave stepped sine sweep at 1 VRMS)

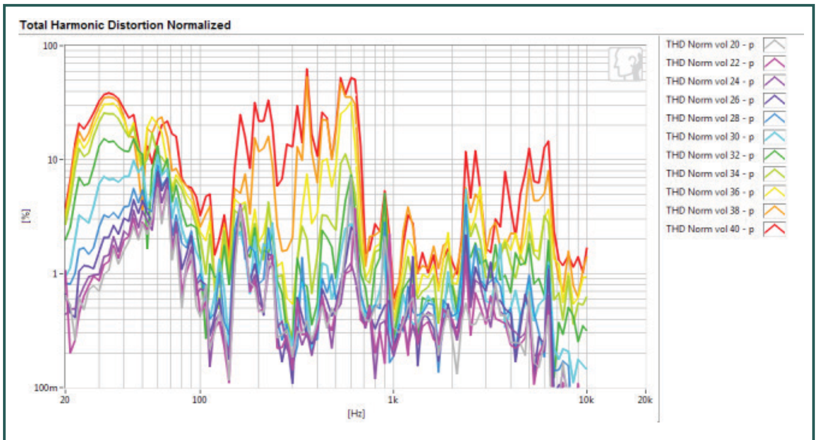


Figure 4: Total Harmonic Distortion Normalized vs. Level

The custom test GUI used a double-blind triple-stimulus with hidden reference system. Three audio tracks, the reference file, plus an additional reference, and the impaired file were simultaneously played back, with the listener able to switch between the tracks to compare distortion. The song and track presentation order were randomized. The participant identified which file had the impairment, rated the severity of the impairment on a five-point scale, and described the difference and the frequency range (bass, midrange and/or treble) in which the difference was heard. Twenty-eight listeners participated in the study.

Table 1 shows the distortion audibility results from the listening tests. Detailed statistical analysis validated these results.

Objective Distortion Measurements

A variety of objective distortion measurements were performed, using the test configuration shown in **Figure 2**. The digital test signals, created and played by the SoundCheck software, were passed through the AudioConnect audio interface for conversion to analog signals, and then amplified by the car audio head unit. A single Listen SCM3 measurement microphone—positioned on the arm rest between the driver and the passenger seats—measured the sound from the car audio system. The signal again passed through the AudioConnect (audio interface and microphone power supply) to convert the analog waveforms to a digital signal for analysis using the SoundCheck measurement software.

Objective distortion measurements were made with a variety of test signals: harmonic distortion using a swept-stepped sine; intermodulation distortion using two-tone intermodulation (one fixed and one moving tone); non-coherent distortion using pink noise; and non-coherent distortion (NCD) using the same tracks used in the listening test (see **Figures 3-10**).

The volume levels varied from about 75 dB to 110 dB SPL (see **Figure 3**). **Figure 4** shows the total harmonic distortion (THD) and frequency normalized (THD Norm) measurements at the 11 different test levels, to remove the influence of the non-flat linear response on the harmonic responses and THD curve. Not surprisingly, this shows the THD increases with level—one would expect that at some point this distortion would become clearly audible and unpleasant sounding.

High levels of THD were observed at volume 32 and above (> 95 dB), especially at volume 38 and 40, which are approaching 60% THD at more than 100 dB SPL. This was very audible and mostly due to Buzz, Squeak, and Rattle (BSR). This is clearly visible in the Perceptual Rub & Buzz graph (see **Figure 5**), which represents how the human ear perceives high-order harmonic distortion (Rub & Buzz). It was hard to tell how much of the BSR was coming from the speaker or enclosure vibrations (e.g., door panels, center console, or rear parcel shelf), as everything was vibrating at these volumes. At volume 34 and under (< 100 dB SPL), the Rub & Buzz could not be heard.

The intermodulation distortion (IMD) graph (see **Figure 6**) shows considerable IMD centered above 1 kHz, probably because four of the six loudspeakers are full range and simultaneously trying to reproduce the low and high frequencies. This would likely be less in a multi-way car audio loudspeaker system with electrical crossovers, as the two tones would be played out of separate drivers. **Figure 7** shows non-coherent distortion using pink noise. It can be seen that the distortion consistently increases with volume level above 100 Hz.

Figures 8-10 show measurements of non-coherent distortion using the three sample tracks as the test signal. The data above 10 kHz is not too meaningful, since the selected samples did not have much high frequency content. “Bird on a Wire” (see **Figure 8**) had an average SPL for volume level 30 of 94 dBC. It can be seen that the distortion increased with level at 60 Hz (around resonance) and again between 200 to 2 kHz, but was lower from 70 to 200 Hz. This is probably because the car speaker was starting to compress the signal at low frequencies and move the energy to higher frequencies as Rub & Buzz. There was a jump in distortion level at volume level 34 and above.

“Cousin Dupree” (see **Figure 9**) had an average SPL for volume level 30 of 98 dBC. This track also demonstrated an increase in distortion from 60 to 120 Hz but is fairly constant from 120 to 180 Hz. There was a jump in distortion level, especially at volume level 34 and above from 500 to 2 kHz.

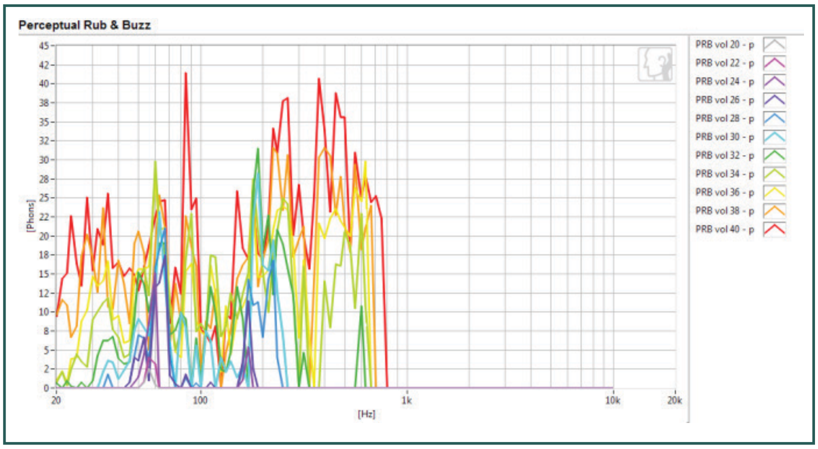


Figure 5: Perceptual Rub & Buzz vs. Level

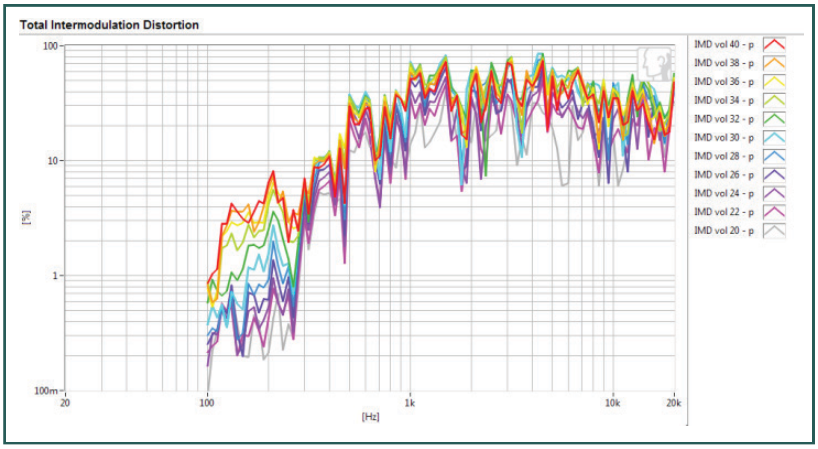


Figure 6: Total Intermodulation Distortion (IMD) vs. Level (one tone fixed at 60 Hz and 0.5 VRMS and the other swept from 100 to 20 kHz at 0.5 VRMS with 1 VRMS summed in phase)

About the Author

Zarina Bhimani has more than 20 years’ experience in technical marketing, turning the words of scientists and engineers into readable feature articles. Most of that time has been at audio companies, including stints at Ferrotec and ALMA, as well as her current 10 years at Listen, Inc. This article is based on the work of Steve Temme and Patrick Dennis. Temme is president and founder of Listen, Inc., and an audio measurement expert with more than 30 years’ experience and author of dozens of technical papers. Dennis is a principal engineer at Nissan Motor Company with more than 25 years’ experience in automotive audio systems and sound quality.

"American Boy" had an average SPL for volume level 30 of a huge 105 dBC (see **Figure 10**). This can be explained by examining the time waveform of the original song. It looks like a square wave with a very small dynamic range). The NCD distortion measurement produced similar distortion curve shapes as with the previous songs but the distortion jumps at volume level 24 and above. This is probably due to the higher recording level.

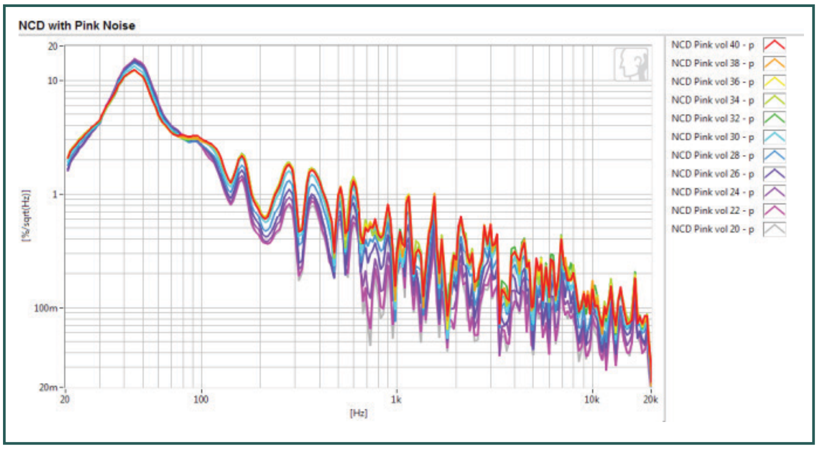


Figure 7: NCD (Pink Noise) vs. Level measured using 12th octave pink noise from 20 to 20 kHz at 0.5 VRMS (2.5 Vp).

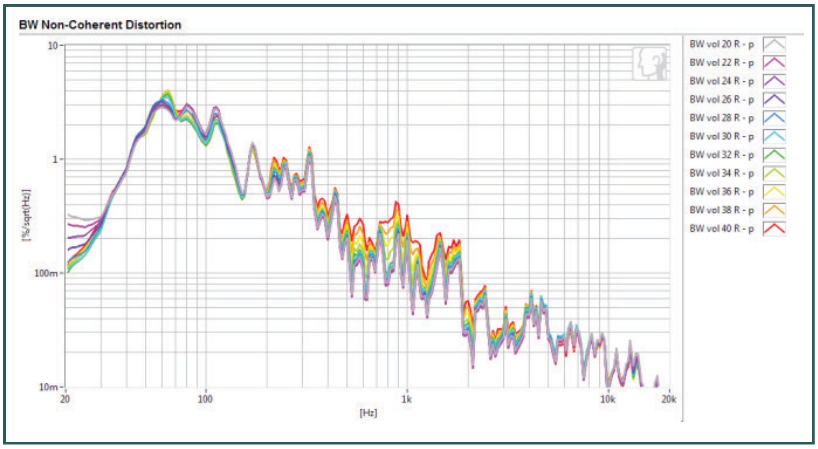


Figure 8: NCD ("Bird on a Wire" track) vs. Level

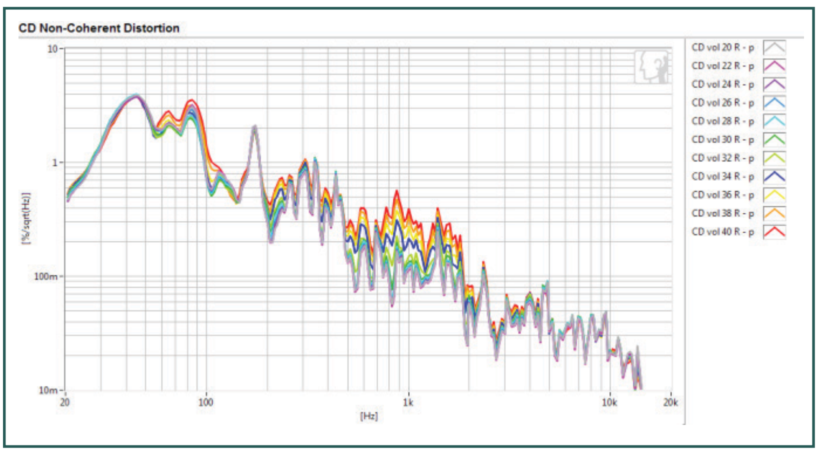


Figure 9: NCD ("Cousin Dupree" track) vs. Level.

Correlation Between Objective and Subjective Measurements

The results from the listening tests indicated listeners were able to discern audible distortion above a given threshold for different songs. For "American Boy," that threshold was quite low, from volume level 30 to 32, which corresponds to about 105 dBC. For "Cousin Dupree," the threshold was higher, volume level 32, which corresponds to 100 dBC. For "Bird on a Wire," the threshold was even higher, from volume level 36 to 38, which corresponds to about 100 dBC. Therefore, it appears that at volume levels of about 100 dBC or higher, distortion is clearly audible.

The THD measurements (see **Figure 4**) indicate that harmonic distortion, especially high harmonic distortion jumped above volume 32 (approximately 100 dB SPL). This is consistent with the subjective listening tests. It also indicates high levels of distortion throughout the entire frequency range, in particular, 20 to 80 Hz (around speaker resonance), 150 to 700 Hz, and 2 to 7 kHz. Listeners expressed that they heard most of the distortion in the bass and midrange frequencies. In summary, there appears to be a strong correlation between the amount of THD measured in the car speakers and distortion audibility.

The IMD increases at volume level 26 (see **Figure 6**). The IMD level is greatest above 1 kHz, in excess of 50%. This corresponds with listeners' comments about audible distortion in the midrange but not as well with the threshold of audible distortion, which most listeners heard at a higher threshold level.

The NCD measurements based on pink noise (see **Figure 7**) show a consistent increase with volume level above 100 Hz. The fact that distortion is not increasing as much in low frequencies indicates that it is spreading to higher frequencies. This should indicate that it will be more audible since it is far apart in frequency and will not be masked

The measurements for NCD based on music (see **Figures 8–10**) demonstrate that for "American Boy," the jump in distortion level at volume 30 corresponds well with listeners' perceived level of distortion. For "Cousin Dupree," the jump in distortion level at volume 32 also corresponds well with listeners' perceived level of distortion.

For "Bird on a Wire," the jump in distortion level at volume 36 once again corresponds well with listeners' perceived level of distortion.

In summary, NCD based on music correlates significantly better with listeners' preference ratings than THD, IMD, and NCD with pink noise measurements. It should not be surprising that this distortion metric produced the highest correlations since it used the same test signal (music) as used in the listening tests.

We suspect that even better predictions of audible distortion in music could be achieved if a psychoacoustic model was applied to take into account the masking properties of the music on audibility of distortion. This will be the topic of a future study.

Conclusions

The goal of this research project was to determine if there was a consistent distortion level vs. frequency at which distortion became audible, regardless of the music source material. If we take into account the difference in level of the music source material, this car audio system sounds noticeably distorted with most music above 100 dBC in the frequency range of 200 to 2 kHz and above 0.2% NCD.

It is likely that, at the higher volume levels, the car audio system is being pushed to its physical limits and creating lots of high order distortion or Rub & Buzz, which is quite audible and annoying. This is not surprising since the speaker cone excursion, and therefore distortion (especially odd order harmonics) is greatest at resonance.

Of the four distortion metrics measured, NCD using music as a stimulus showed the best correlation to human perception. Further tests are needed with other car audio systems and other loudspeaker systems including headphones and home speaker systems to investigate consistency with other car audio systems and other loudspeaker systems including headphones and home speaker systems to confirm that we can use the same NCD metric.

Finally, further research into adapting NCD to a perceptual model should be investigated. This may allow a common distortion metric across all sound reproduction systems to predict distortion audibility and subjective quality for human hearing. ***LIS***

Author's Note: Due to editorial space constraints, much experimental detail is omitted. For more information, download the full technical paper from www.listeninc.com/resources/published-papers.

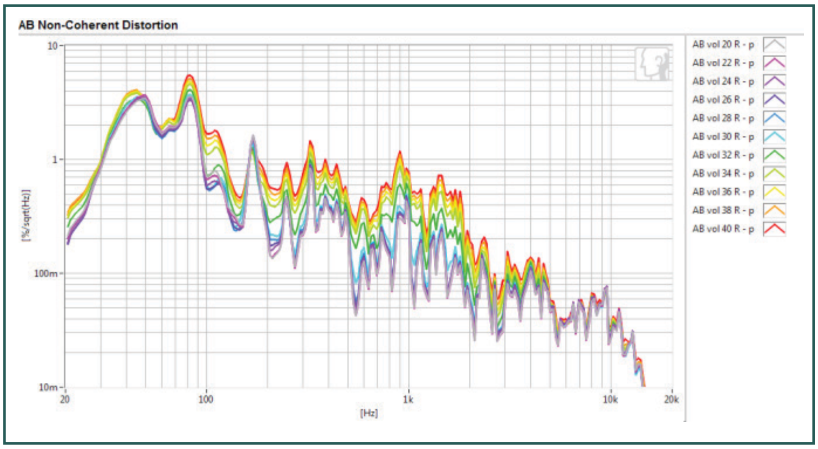
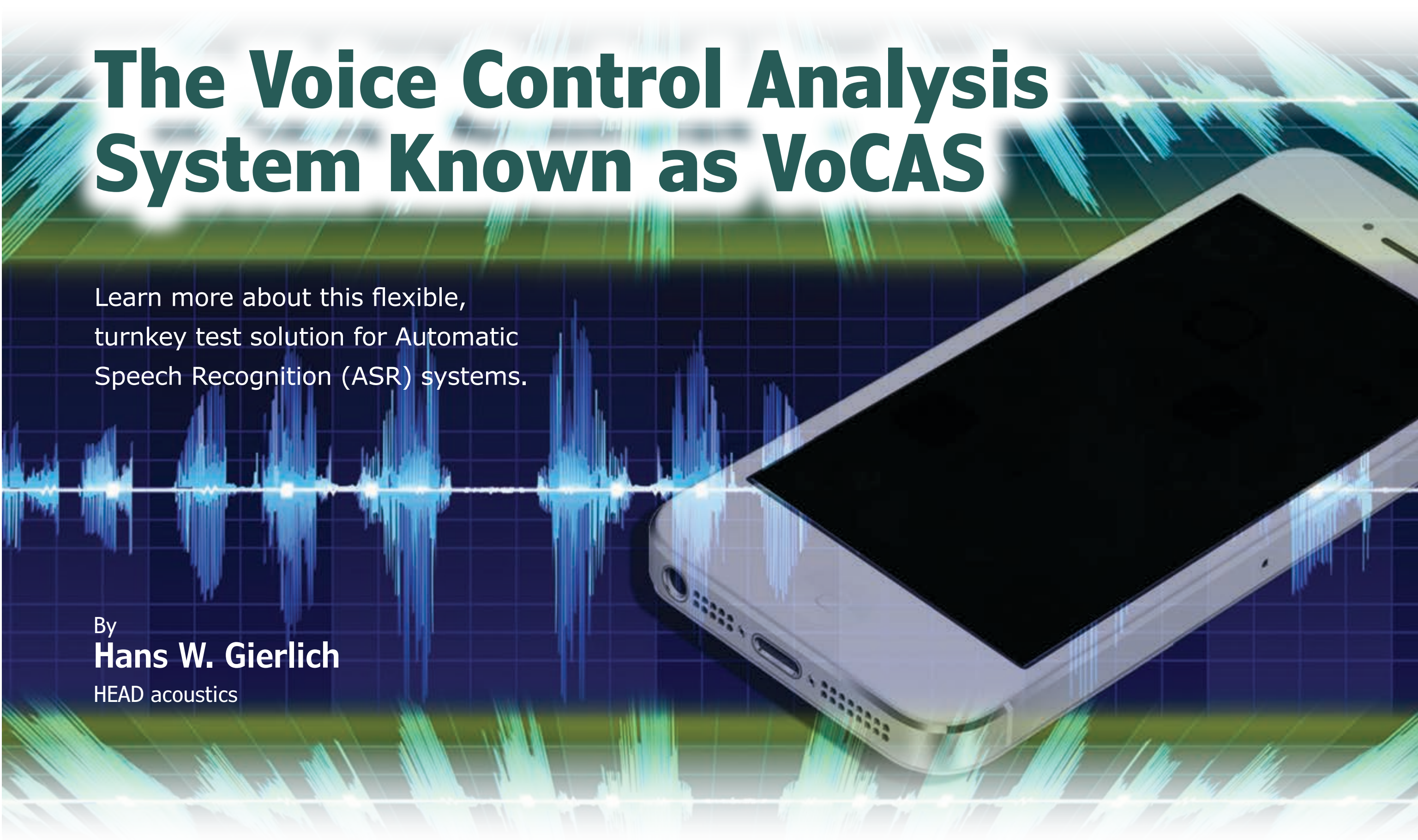


Figure 10: NCD Distortion ("American Boy" track) vs. Level. The average sound pressure level for volume level 30 was a huge 105 dBC.

The Voice Control Analysis System Known as VoCAS



Learn more about this flexible, turnkey test solution for Automatic Speech Recognition (ASR) systems.

By
Hans W. Gierlich
HEAD acoustics

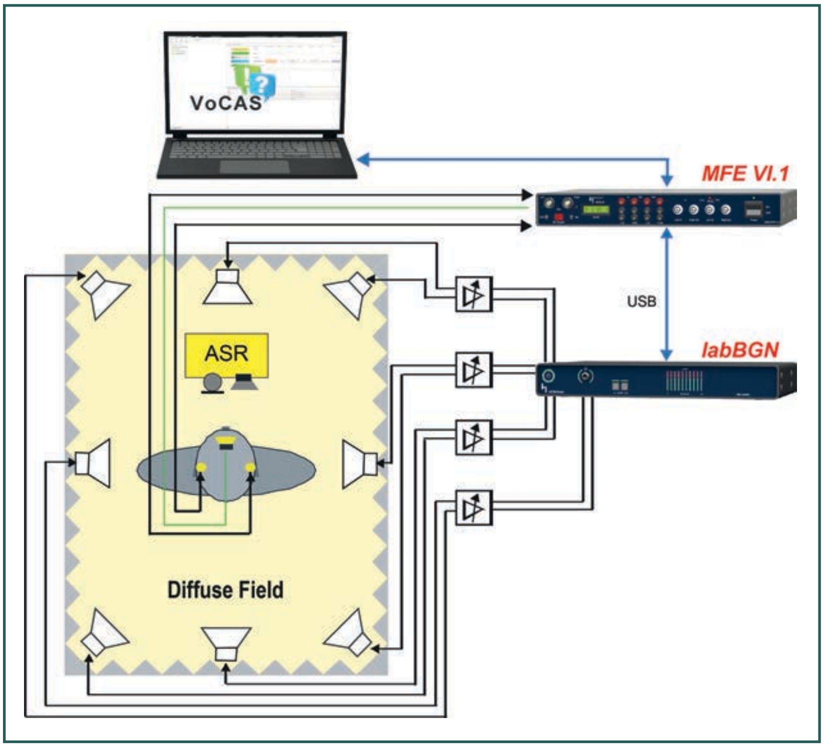


Figure 1: The test setup for ASR systems (e.g., mobile devices) includes necessary components for background noise simulation as well as playback and equalization.

Over the last few years, speech recognition technology has made significant advances. Today, the technology is being used to replace other—sometimes regarded as "old-fashioned"—input methods such as typing and texting. Large companies (e.g., Amazon, Apple, and Microsoft) invest huge amounts in research and development of their voice engines. Today, Alexa, Siri, and Cortana are digital application terms everyone knows. These are popular digital speech assistants that should improve more situations in people's every day lives.

The ability to control the playback of their favorite music via mobile, to manage the navigation in a vehicle, or to switch to another TV program with the power of one's voice are key features for customers. The use cases are almost limitless. This is also due to the fact that more companies from various fields of applications rely on Automatic Speech Recognition (ASR) systems in their products: from multi-media systems in vehicles via mobile phones, tablets and telephone hotlines to Internet of Things (IoT) devices, home automation systems, and even the banking sector, where access to the account is authenticated by means of voice biometrics.

Performance Quality of ASR Systems Varies

The quality of voice control systems is closely linked to the recognition rate or failure rate. However, using voice control systems means dealing with a variety of problems. One of the basic challenges in ASR is difference in articulation (e.g., speed, cadence, and pronunciation) among humans. A single word can be pronounced in many different ways. As a consequence, the ASR system can become confused and might misinterpret the voice command due to the variability of articulation from different talkers. Besides these human factors, the quality of the technical implementation of systems is of vital importance. The product's physical shape, the signal processing applied to clean up the signal, the microphone selection, and placement might heavily affect the overall performance and user experience.

Manufacturers of voice controlled devices have to consider several factors including the sensitivity of the built-in microphones required to deliver the best signal-to-noise ratio (SNR) for a given application. A heavily distorted microphone signal would highly degrade the entire performance of the ASR engine. Besides these variables, the position of the talker, the room, and the background noise characteristics will also affect the ASR's performance.

If background noise is present, systems have to be optimized specifically for this situation, employing dedicated signal processing to give the best possible performance in combination with the speech recognition engine used. The systems are only accepted by users if all voice commands or the keywords are completely and correctly understood by the system. If this doesn't work accurately and with low latency, consumers will not use the system and in the worst-case scenario, they might return the product.

Comprehensive Testing Solution Considers Key Factors

Currently, there are no internationally agreed standards on how to implement, test, and validate the performance of voice-controlled devices. There are also no standardized benchmarks for testing such devices. Testing requires the consideration of several factors that have an impact on the performance quality. Factors to consider include:

- How to test speech recognition systems accurately
- How to playback different voice commands in a reproducible manner

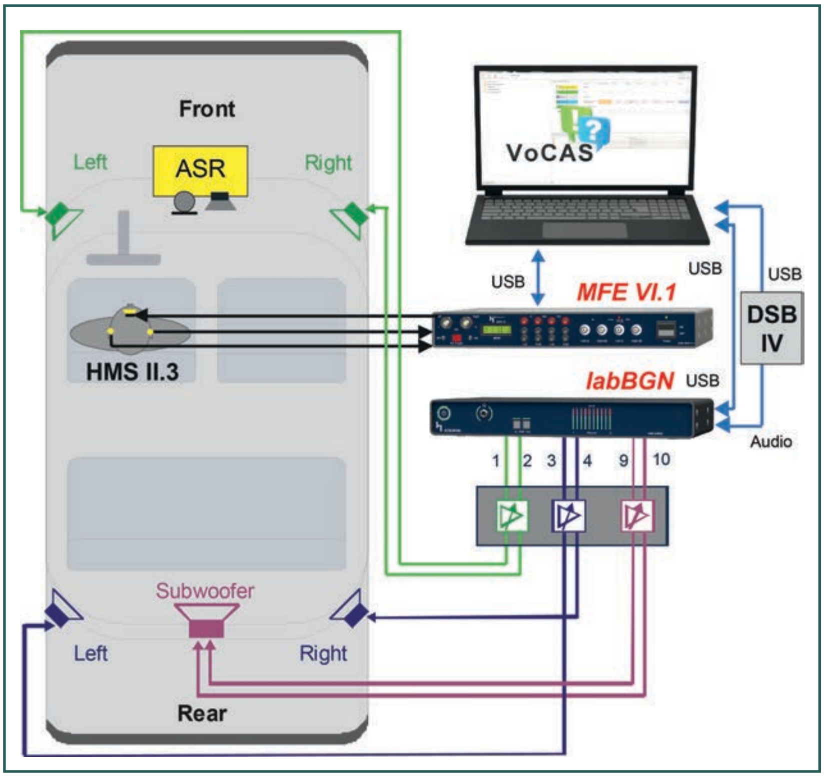
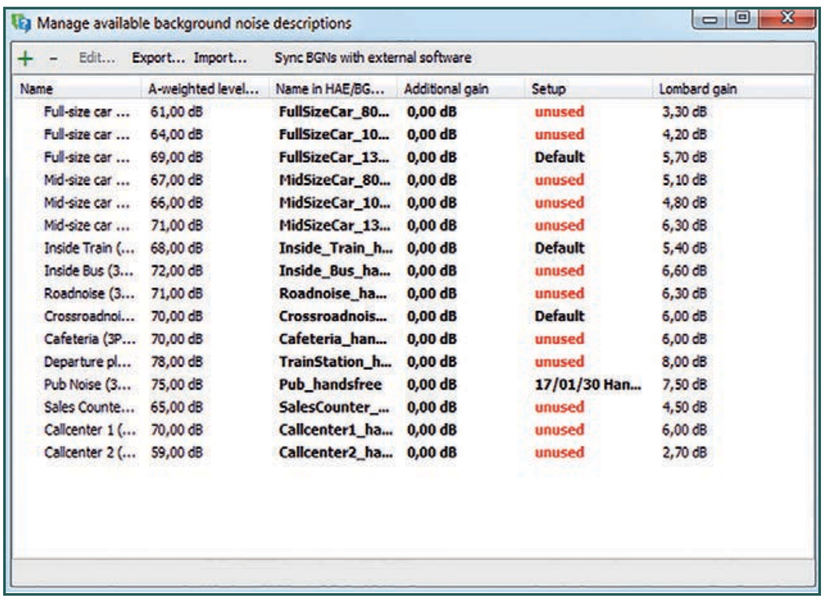


Figure 2: The test setup for ASR systems in vehicles includes necessary components for background noise simulation as well as playback and equalization.



Manage available background noise descriptions

+ - Edit... Export... Import... Sync BGNs with external software

Name	A-weighted level...	Name in HAE/BG...	Additional gain	Setup	Lombard gain
Full-size car ...	61,00 dB	FullSizeCar_80...	0,00 dB	unused	3,30 dB
Full-size car ...	64,00 dB	FullSizeCar_10...	0,00 dB	unused	4,20 dB
Full-size car ...	69,00 dB	FullSizeCar_13...	0,00 dB	Default	5,70 dB
Mid-size car ...	67,00 dB	MidSizeCar_80...	0,00 dB	unused	5,10 dB
Mid-size car ...	66,00 dB	MidSizeCar_10...	0,00 dB	unused	4,80 dB
Mid-size car ...	71,00 dB	MidSizeCar_13...	0,00 dB	unused	6,30 dB
Inside Train (...	68,00 dB	Inside_Train_h...	0,00 dB	Default	5,40 dB
Inside Bus (3...	72,00 dB	Inside_Bus_ha...	0,00 dB	unused	6,60 dB
Roadnoise (3...	71,00 dB	Roadnoise_ha...	0,00 dB	unused	6,30 dB
Crossroadnoi...	70,00 dB	Crossroadnois...	0,00 dB	Default	6,00 dB
Cafeteria (3P...	70,00 dB	Cafeteria_han...	0,00 dB	unused	6,00 dB
Departure pl...	78,00 dB	TrainStation_h...	0,00 dB	unused	8,00 dB
Pub Noise (3...	75,00 dB	Pub_handsfree	0,00 dB	17/01/30 Han...	7,50 dB
Sales Counte...	65,00 dB	SalesCounter_...	0,00 dB	unused	4,50 dB
Callcenter 1 (...	70,00 dB	Callcenter1_ha...	0,00 dB	unused	6,00 dB
Callcenter 2 (...	59,00 dB	Callcenter2_ha...	0,00 dB	unused	2,70 dB

Figure 3: As soon as a background noise simulation software from HEAD acoustics is connected, users have access to the software's realistic noise scenarios via VoCAS: from cafeteria noise to slow and fast vehicle noises and even train platform noise.

- How to consider real-life background noises in a laboratory environment
- How to generally create realistic and reproducible test conditions, which also take into account decisive factors such as room characteristics and talker positions

VoCAS, the acronym for Voice Control Analysis System, is a turnkey test solution that enables users to evaluate the quality of speech recognition systems. Depending on the ASR system to be tested,

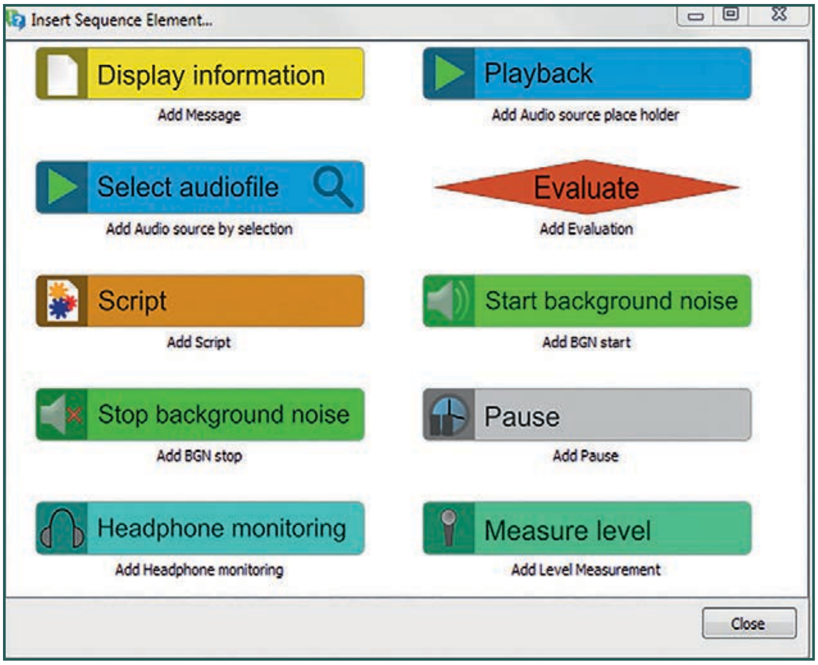


Figure 4: A test sequence consists of various sequence elements such as playback of test sets, background noises, pauses, and evaluation. The user can flexibly arrange each element, add it in any number, and individually configure it (e.g., volume, duration, etc.).

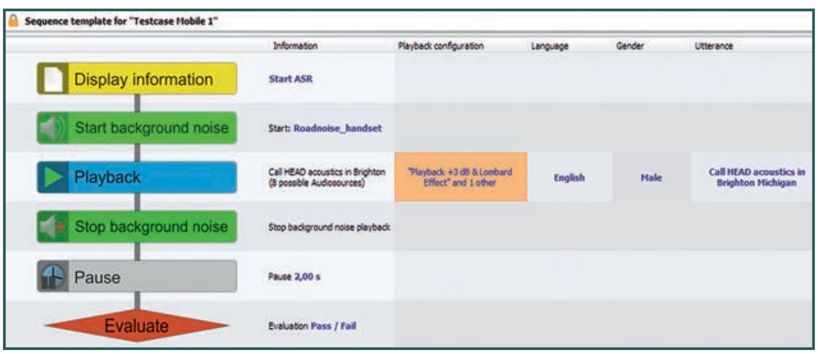


Figure 5: A possible test sequence for testing (e.g., the ASR systems in mobile phones or vehicles) enables realistic background noise to be added. The voice command is played ("Call HEAD acoustics in Brighton, Michigan"), spoken in English language by all male speakers included in the data management system, followed by a pause waiting for the reaction of the voice control system. Subsequently, an evaluation takes place as to whether the system has initiated the command or not.

an appropriate test setup in a lab is required, which consists of various hardware and software components (see **Figure 1** and **Figure 2**). Regardless of the type of ASR, every setup comprises an artificial head measurement system in combination with a specific measurement front end that enables the equalized and calibrated playback of voice recordings via the artificial head's mouth simulator. Using the ear microphones of the artificial head measurement system, it is possible to monitor any acoustical feedback of the device under test (DUT).

Background noise simulation is integrated for reproducing realistic, calibrated, und spatially correct sound scenarios. All hardware and software components can be controlled via the user interface of the evaluation software VoCAS. A key element of the software is the use of predefined test sequences to evaluate ASR systems in detail. These sequences can be freely composed by the user and can be reused at any time in the exact same manner to analyze, compare, and optimize ASR systems.

Appropriate Test Cases and Test Sequences For Evaluating Voice-Controlled Systems

Depending on the DUT and the requested test case, appropriate test sequences can be defined in VoCAS. All eligible commands for controlling a voice-control system can be evaluated, such as voice commands for vehicle navigation (e.g., "Navigate to New York airport") or voice commands for calling via mobile phone (e.g., "Call John Doe"). The automation platform enables testing under various conditions. For this purpose, a test sequence must first be defined, which consists of different elements and is sequentially processed. These elements include playback of speech commands or background noises.

VoCAS realizes realistic test conditions by taking background noises into account (see **Figure 3**). Further elements consist of level measurement of the current background noise for verification purposes, pauses for acoustical feedback of the voice-control system, or a rating dialog for the evaluation of the device under test (see **Figure 4**). All elements can be arranged via a flowchart interface, with elements added as often as required and individually adjusted (see **Figure 5**). Each test sequence is reproducible. All these key features are important aspects for manufacturers who want to reliably test their systems.

Combination of Assigned Attributes Result in Numerous Parameter Sets

When testing voice control systems, a representative set of speech samples including appropriate voice commands collected in an audio source database is required. Managing these audio files turns out to be a big issue for companies. VoCAS offers the ability to create individual audio databases by importing voice recordings, recording speech samples, and individually expanding existing databases into a data management system. Users can batch process voice recordings to adjust for Lombard level, add or remove silence, apply filters, and more by using the software's comprehensive setup options. Furthermore, voice commands can be tagged for easy retrieval during testing. For this purpose, users can define suitable attributes and values (e.g., attributes "Language," "Speaker," and "Gender").

Often there are voice recordings containing the same control command, yet differing acoustically since different languages, speakers, or dialects were used during the recordings. By means of the assigned keywords, VoCAS systematically guides the user through the desired variants and generates the corresponding measurement sequences, thus supporting the user to monitor the test progress. When defining a test sequence, all assigned attributes are selectable. The possible combinations of attributes result in numerous parameter sets. This is one of the key features of VoCAS. Thus, by easily applying different parameter sets (e.g., different speakers, languages, and background interferences) users can generate thousands of them to be run through the defined test case. The advantage for manufacturers: Their speech recognition technology is evaluated under realistic and reproducible test conditions (see **Figure 6**).

Yes, voice recognition has made significant advances over the last few years. But the conditions under which ASR is used have changed as well. Today's ASR systems are intended to be used in adverse environments. In reality, systems now need to operate under different background noise conditions, in a huge variety of rooms. The systems are increasingly used by naïve users expecting high reliability of the ASR without providing proper pronunciation, proper positioning relative to the device, or proper positioning of the devices in the room. Therefore, these systems have to be tested and optimized for a variety of use conditions. System designs have to take into account these effects and must be capable of capturing voice from various positions in the room. Voice recognition engines also have to be trained and optimized for these scenarios. And, they have to be tested accordingly. VoCAS provides all the components to efficiently test these devices under lab-type conditions. ***LIS***

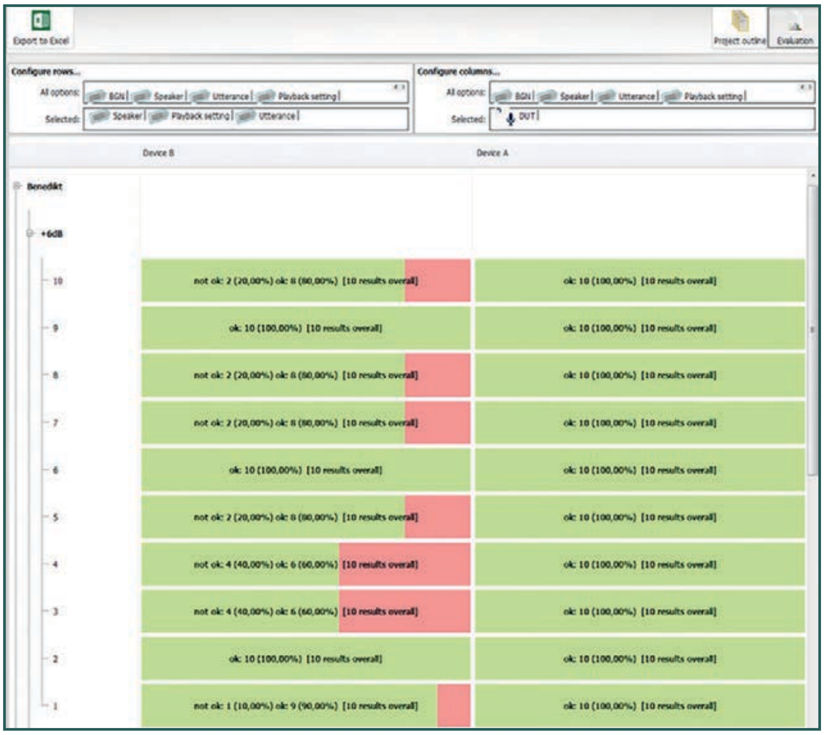


Figure 6: Straightforward display of results: The results are presented as percentage values (e.g. 60% of voice commands recognized, 40% not recognized) and color-coded for an optimal interpretation of the test results. Different voice control systems can be compared directly by placing them next to each other. All available parameters (e.g. utterance, speaker, language, background noise) can be selected for result presentation. This enables users to check which test sentence has passed or failed the test with certain attributes.

About the Author

Hans W. Gierlich started his professional career in 1983 at the Institute for Communication Engineering at RWTH, Aachen. In February 1988, he received a Ph.D. in electrical engineering. In 1989, Gierlich joined HEAD acoustics GmbH in Aachen as vice president. Since 1999, he is head of the HEAD acoustics Telecom Division and in 2014, he was appointed to the board of directors. Gierlich is mainly involved in acoustics, speech signal processing and its perceptual effects, QOS and QOE topics, measurement technology and speech transmission quality. He is active in various standardization bodies such as ITU-T, 3GPP, GCF, IEEE, TIA, CTIA, DKE, and VDA and chairman of the ETSI Technical Committee for "Speech and Multimedia Transmission Quality."

About HEAD acoustics, Telecom Division

HEAD acoustics was founded in 1986 and has been involved in noise and vibration, electro-acoustic, and voice quality testing since its inception. HEAD acoustics is based in Herzogenrath, Germany, with affiliates in France, Great Britain, Japan, South Korea, and US, as well as a worldwide network of representatives. The Telecom Division of HEAD acoustics manufactures telecom test equipment and provides consulting services in the field of speech and audio quality. Moreover, HEAD acoustics closely co-operates with DECT Forum, ETSI, ITU-T, 3GPPP, TIA, CTIA, GSMA, and other standardization bodies with regard to the development of quality standards for voice transmission and speech communication. In many partnership projects, HEAD acoustics has proven its competence and capabilities in conducting tests and optimizing communication products with respect to speech and audio quality under end-to-end as well as mouth-to-ear scenarios.

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Editor's Note: For the Questions & Answers interviews, we sent several notable industry professionals a list of questions and asked them to select the ones that they wanted to answer. The following content contains the questions they selected and their responses.

Vance Dickason

President, Vance Dickason Consulting

LIS: Which technologies, products, innovations, or trends impressed you the most in the audio industry over the past year?

DICKASON: I think the continued development of Class-D amplifiers along with the associated DSP and control GUIs is the trend that I see as most important to loudspeaker development.

LIS: Do you think test and measurement tools are adequate, or are there still tools missing that you would like to see in the market?

DICKASON: There are constant refinements in the measurement tools that are currently available. We have seen a lot of progress in measuring directivity and both linear and non-linear distortion, so this paradigm is constantly evolving. However, the body of measurement equipment has been adequate for developing loudspeakers for many years, as it's just one part of the process. At this point I really can't think of anything missing, but I probably said that same thing before Klippel analysis became a reality!

LIS: How do you see "high-resolution" audio impacting the loudspeaker development process?

DICKASON: Clarity, definition, and detail have always been a design goal in loudspeaker development no matter what the "source." Higher quality source material certainly enhances the listening experience, but doesn't really impact the speaker design process.

LIS: Did your music listening habits change in the last 12 months? Which speakers do you use more often to listen to music?

DICKASON: I seldom devote time to just listening to music, although it is playing throughout my work day. If I am devoting time to focus on music, I'm more prone to be in my recording studio playing music. All the speakers I have are either ones I designed specifically for a given manufacturer, designs from my books, the *Loudspeaker Design Cookbook* series, or ones I specifically designed for use in my recording studio. ***LIS***

Dan Digre

President, MISCO

MISCO
The Sound of Imagination

LIS: How did your current business evolve in the past 12 months? What do you foresee for the next 12 months?

DIGRE: In the past year, MISCO has continued to focus on expanding capability to meet the market needs for high quality and often unique loudspeakers and audio systems. Late in 2016, we purchased Oaktron from Mitek in order to strengthen our position in aerospace and military. During the coming 12 months, we will further reinvest in our domestic production capabilities developing high-end OEM home and pro-audio loudspeaker components. These premium products will be produced exclusively in our Minneapolis factory.

LIS: Which technologies, products, innovations, or trends impressed you the most in the audio industry over the past year?

DIGRE: We have seen improved measurement equipment from Klippel in the Near Field Scanner and also new modeling techniques for transducers and systems. On the audio product side, object-based surround sound (e.g., Dolby Atmos) has begun to gain traction in the market place.

LIS: Which technologies do you think will have a stronger impact on the audio industry in the next five years?

DIGRE: Streaming audio will continue to drive demand for the portability and ease-of-use in wireless systems solutions—speakers and headphones.

LIS: Voice recognition was the most discussed trend at recent trade shows due to the impact caused by the Amazon Echo and Alexa voice capabilities. How do you think this is going to affect the speaker market and the audio industry in general?

DIGRE: Smart speakers and self-contained interactive audio devices will become more of the music source for homes, and therefore, performance expectations will increase for these compact products.

LIS: Crowdfunding is disrupting the way new concepts and companies are launched in the market. Yet, many companies launch crowdfunding campaigns without considering the challenges. Is this an opportunity for new business or do you consider it an unwelcome phenomenon?

DIGRE: Welcome or not crowdfunding is a high-risk endeavor with low return on investment for many. Kind of like setting out to be a rock star.

LIS: Automotive and infotainment systems are another dynamic segment due to the connected car trend. How should the loudspeaker industry position itself to leverage this?

DIGRE: More efficient and lighter weight transducers are needed to keep mass low (fuel mileage) but our industry is well positioned in the automotive sector.

LIS: Digital signal processing is increasingly being used in loudspeakers and headphones. It helps surpass the physical limitations of drivers while adding extra functionalities (i.e., active noise cancelling). Where is the industry headed?

DIGRE: DSP drives the trend toward miniaturization of audio devices—making them more readily adaptable to emerging applications like wearables and IOT appliances.

LIS: How do you see "high-resolution" audio impacting the loudspeaker development process?

DIGRE: A limited but laudable movement. The audio enthusiast has always pushed the performance/quality bar higher to the benefit of the marketplace. We can say that people don't care about audio quality. Yet, decade by decade and from format to format, audio performance quality has always improved: sometimes incrementally—sometimes notably. But, we do keep getting better.

LIS: Did your music listening habits change in the last 12 months? Which speakers do you use more often to listen to music?

DIGRE: For desktop audio—I typically listen to music using our own MISCO products! ***LIS***

Jakob Agren

Head of Product Management, BU High Performance, Dirac Research AB

Dirac

LIS: How did your current business evolve in the past 12 months? What do you foresee for the next 12 months?

AGREN: Our business has grown tremendously fast in the past 12 months, in particular propelled by the increasing demand for better sound quality in mobile devices. We have increased our market share in all market segments in which we are active. We see an increasing demand for powerful yet easy-to-use room correction solutions in hi-fi, and product launches in the coming 12 months will emphasize this trend. We expect continued expansion in mobile sound optimization, an area where Dirac is already the market share leader. Moreover, our recent introduction of Dirac VR will be followed by several business announcements and related technology launches.

LIS: Which technologies, products, innovations, or trends impressed you the most in the audio industry over the past year?

AGREN: The most intriguing trend that we have seen over the past year is the surge in demand for better sound quality worldwide in all kinds of consumer devices and content types. The success of devices such as Amazon Echo is of course another interesting shift in home audio devices.

LIS: Which technologies do you think will have a stronger impact in the next five years?

AGREN: AR/VR-related technologies will impact our ways of listening to hi-fi and will also affect audio in ways that will be surprising to most of us. Speech control and technologies related to microphone arrays will strongly influence all kinds of audio devices. Speaker array technologies will be key for achieving great sound in space-constrained applications such as mobiles and tablets, etc.

LIS: Where do you believe there are larger market opportunities in terms of innovation and business growth: headphones, portable speakers, mobile audio, or virtual reality systems?

AGREN: Headphones present exciting new opportunities coupled with more advanced signal processing, microphone arrays, and sensors. Headphones will be entirely digitally controlled and equipped with various "smart" features. Virtual reality presents exciting opportunities for innovation in virtual presence systems and entertainment, but exactly how well the business will play out is anybody's guess.

LIS: Voice recognition was the most discussed trend at recent trade shows due to the impact caused by the Amazon Echo and Alexa voice capabilities. How do you think this is going to affect the speaker market and the audio industry in general?

AGREN: We believe that voice control is becoming a norm simply due to the success of Amazon Echo. It will not entirely replace other forms of control, but it will become the norm, not the exception. Consumers will expect their audio devices to be voice controlled, thus device manufacturers need to find solutions for microphone array processing and issues related to this. This further signals a need for stronger processing capacity within speakers, and of course, aggravates the demand for powered speakers. We believe that ARM-based speakers create a plethora of opportunities to stay up to date with new software requirements connected to voice, streaming, and sound-related processing. ARM-based solutions have benefits in their ease of programming as well as their processing power, compared to DSPs.

LIS: Wireless audio, streaming services are becoming more popular—both for headphones and speakers. What impact do you feel this has in speaker design and new products?

AGREN: The main promise of streaming content and wireless playback systems is the lack of huge racks of audio equipment, big intrusive speakers, cables, and last but not least, the wall full of LPs/CDs/Blue-ray discs, etc. That is, the whole playback system should be heard, not seen. As such the most successful products in this segment will probably be speakers that sound excellent, but do so in a size-defying unobtrusive package. This is a tall order, and in order to deliver, new active methods will likely have to be used.

LIS: Do you believe wireless audio, whole-home, and multi-room solutions will continue to evolve and grow over the next two years?

AGREN: Yes, almost certainly. The convenience offered is too great to resist. Companies providing these products should continue to do well.

LIS: What about home theater? Does the immersive audio experience still hold potential outside the movie theaters?

AGREN: The potential for having a fantastic immersive experience, in your own home, today is better than ever. In fact, the demos I have listened to at our customers' shops or at trade shows, far surpass the audio experience I ever got from a movie theatre. With top-performing room correction systems now appearing in products that can be afforded by a broader market, anyone who has been dreaming about his or her own high-performance home theater should have great times ahead. That said, not everyone will be willing to invest the money or the space to have this for themselves. I think that the entry-level home theater will continue to dwindle in favor of wireless audio/multi-room solutions, while the premium to high-end market may see some growth. To see a wider adoption, prices will have to come down even more and speakers need to shrink and be wireless, without sacrificing performance.

LIS: Digital signal processing is increasingly being used in loudspeakers and headphones. It helps surpass the physical limitations of drivers while adding extra functionalities (i.e., active noise cancelling). Where is the industry headed?

AGREN: Digital signal processing will be central to deliver the next generation of speaker-equipped products. It can be used to provide new features (i.e., noise cancellation), circumvent physical limitations of a driver or something in between. Examples of this is some of the small wireless speakers we see on the market today that sound much larger than should be possible in such a small package. Array-based processing will also be a major contributor to next generation products in all markets. Examples are beaming applications for teleconferencing, individual sound zones in automotive, cross-talk cancellation for smartphones and rendering of multi-channel content in headphones—the sky is the limit!

LIS: Automotive and infotainment systems are another dynamic segment due to the connected car trend. How should the loudspeaker industry position itself to leverage this?

AGREN: The connected car will have significantly more processing power available for audio than systems of old. This is required for the connectivity, but also for the features that are likely to be available in car audio in the not so distant future. Examples are individual sound zones, active noise cancellation, rear seat entertainment, audio-based driver feedback systems—the list goes on and on. The adoption of advanced signal processing also enables us to provide audio in more cost-efficient ways in terms of manufacturing of the car. Several of these technologies have already been showcased at trade shows (e.g., CES) by major automotive tier ones. Common among these technologies is the need for a large number of output channels, albeit with less bandwidth and power handling. That is, the future automotive system is likely to require many smaller speakers compared to what we see today. ***LIS***

Andrew Bellavia

Director of Market Development, Commercial Audio, Knowles Electronics

LIS: How did your current business evolve in the past 12 months? What do you foresee for the next 12 months?

BELLAVIA: Two trends emerged and are expected to continue. One is the increased adoption of balanced armature (BA) drivers in consumer earphones, in addition to their traditional base of professional musician and audiophile in-ear monitors (IEMs). This includes dynamic BA hybrids as represented by the Huawei Honor AM175 and the AKG N40, and pure BA earphones such as the sport model Run Free Pro HD by Soul Electronics.

The other trend is the growth of wire-free earphones and hearables. Maintaining a comfortable ID while packing the device with sensors, electronics, and battery leaves very little room for the driver. This is driving demand for small, high-performance balanced armatures. Examples include the Bragi Dash and Headphone, Doppler Labs Here One, Nuheara IQbuds, Alpha Skybuds, Earin, Mymanu Clik, and KANOA. Some of these are offering quite sophisticated functions such as biometric sensing, audio optimization and augmented reality (AR), and language translation. Analysts generally agree that the hearable market will explode in the next 12 months, and we agree.

LIS: Which technologies, products, innovations, or trends impressed you the most in the audio industry over the past year?

BELLAVIA: The trend toward increasing use of amplified earphones, including models using multiple drivers, creates new possibilities to enhance the user experience. These possibilities include better and more versatile crossovers, greater EQ control, loudness control, spatial effects, distortion control, status monitoring, and noise cancellation.

AR is another technology with a bright future, and audio will play an important role. Even today, there are many use cases for simultaneous machine and natural listening. We don't see characters in sci-fi movies or shows tapping on phones—instead, they interact with each other and with digital voice user assistants. Even when visual AR or virtual reality (VR) is used, the experience is greatly enhanced when natural-sounding audio is included.

LIS: Specifically with speaker design, components, drivers, and materials. What impressed you the most over the past year?

BELLAVIA: Moving coil speakers are becoming incrementally better due to materials and process improvements. Some truly innovative speakers such as carbon nanotube, using thermal means to create an acoustic wave, and MEMS still have a ways to go to match the performance of a good moving coil or balanced armature driver.

Balanced armature improvements are being driven by demands for both hearing health and hearable applications—higher output for size with increasing fidelity. In the hearing health market, it means people with increasingly severe hearing impairment can wear smaller, more comfortable hearing aids. In hearables, a smaller driver can enable more room for a larger Bluetooth antenna, higher capacity battery, or better sensor placement in the eartip.

LIS: Do you think test and measurement tools are adequate, or are there still tools missing that you would like to see on the market?

BELLAVIA: We still don't have a good way of comparing what earphones sound like above about 12 kHz because existing test couplers are not really standardized above that frequency. It is also difficult to measure inside a real ear at high frequencies. One promising improvement is the new rubber ear from G.R.A.S. Sound and Vibration, A/S with a more realistic ear canal entrance that better fits insert earphones. Some of the old standard ears are difficult for getting a proper fit.

LIS: Which technologies do you think will have a stronger impact on the audio industry in the next five years?

BELLAVIA: In the home, advanced smart-home technology with distributed audio for both voice and music, along with intelligent speech control, will enter the mainstream. Amazon and Sonos are already pursuing this route, and traditional audio companies will likely join in the Internet of Things (IoT) category.

Home-wide voice control will be a game changer as voice user assistants continue to improve and consumers sync everything from lighting, thermostats, TVs, and more into an integrated system. As a leader in high-performance audio technology, Knowles works closely with the leading IoT device manufactures to support voice control with our reliable far-field microphone systems.

Practical spatial audio will play a key role in advancing the usability of VR and AR. Up until the present time, most resources have been devoted to improving the visual experience. Yet, without coordinated audio, the experience is unreal and even disorienting. The development of 3D audio with effective head tracking will play a key role in the mainstream acceptance of visual AR are VR. For gamers, adding small microphone systems that maintain comfort, while allowing voice communication in loud environments.

Another interesting technology that shows promise is automatic equalization of sound systems to account for taste across genres, room dynamics, and individual ear response. Some work has already been done and we expect more to follow, with increasing sophistication. For example, Gracenote developed a system for automatically adjusting the EQ of car systems to match the song (e.g., more bass for rap and a level response for classical). Additionally, the startup company Nura is developing a headphone that measures an individual's hearing response and sets a custom EQ to compensate.

LIS: Where do you believe there are larger market opportunities for innovation and business growth?

BELLAVIA: The research firm IDC recently predicted more than 50% unit cumulative annual growth in VR/AR hardware through 2021. Audio will be a key component of this growth, both in combination with video and on its own. Audio AR has especially compelling use cases because, as Bragi's Nikolaj Hviid likes to point out, the ears are a parallel interface while vision is serial. That is, one can take in and simultaneously process different sounds but can only attend to what one is viewing at the moment. This is why, for example, dinner music can be used to set a mood in a way that TV screens cannot. It also means that consumers can interact quite naturally in the real world, while simultaneously taking in information from an audio virtual assistant.

LIS: Voice recognition was the most discussed trend at recent trade shows due to the impact caused by the Amazon Echo and Alexa voice capabilities. How will this affect the speaker market and the audio industry in general?

BELLAVIA: Voice recognition and digital assistants will drive demand for high-quality bidirectional audio everywhere—in cars, in homes, and in ears. Amazon's "Alexa everywhere" initiative is one indicator of this growing trend. Whether using Alexa or not, there is increasing sophistication in automotive voice recognition and control, voice-controlled thermostats, light bulbs, and other home appliances, and advanced in-ear devices providing audio feedback during sport, near real-time language translation, and more. This is creating demand for audio transducers, both speakers and microphones, optimized for these increasingly varied products. More and more companies with little audio experience are participating in this arena, placing audio solution providers in a stronger position, relative to commodity transducer vendors.

LIS: Crowdfunding is disrupting the way new concepts and companies are launched in the market. Yet, many companies launch crowdfunding campaigns without considering the challenges. Is this an opportunity for new business or an unwelcome phenomenon?

BELLAVIA: Crowdfunding is definitely creating new business for Knowles both in short and long term. Take the hearable and wire-free earphone markets. Several of the early crowdfunding entrants have already taken successful products to retail and more are on the way. As the market evolves and established players enter, not all of the startups will survive—but the designers and engineers who pioneered those products will. The expertise they gained through their crowdfunding efforts will find a home somewhere else, including at established audio companies. In this way crowdfunding has accelerated the pace of innovation in the hearable space, and therefore, new business opportunities for Knowles, now and going forward.

LIS: Sensors are bringing AV and IT together. Biometric sensors are now being used in headphones. Most wearable devices have some sort of audio integration. Is this an opportunity for the audio industry?

BELLAVIA: It is, by creating new categories of audio and hearable products with compelling use cases. Real-time biometric measurements with audio coaching during sport is just one example. Another is biofeedback devices that can monitor mood or sleep patterns, then provide feedback for relaxation training, sounds to aid sleep, and more. There is a lot of innovation in this space.

LIS: Digital signal processing is increasingly being used in loudspeakers and headphones. It helps surpass the physical limitations of drivers while adding extra functionalities (i.e., active noise cancelling). Where is the industry headed?

BELLAVIA: We see active noise cancelling (ANC) adoption growing as the performance and implementation cost decreases. It is also apparent that the popular features found in the latest connected-home speakers will migrate to the ear (e.g., with hearable devices offering in-ear digital assistants or language translation).

Hearables must enable two-way communication in all kinds of environments, positioning Knowles as the ideal partner for designers looking to achieve clear voice communication and a premium listening experience. Knowles' advanced own-voice pickup technology, employed in the Bragi Dash and Headphone, is the first example of this work.

We also assist customers who wish to add DSP tuning to their tool kit for achieving the desired sound signature in an earphone or hearable. In the future, combining a DSP inside multi-driver earphones is another area to explore for superior control over the earphone performance.

LIS: Next-generation drivers for headphones have been creating excitement in the high-end audio market. Are those designs going to evolve to more affordable consumer products?

BELLAVIA: Balanced armature (BA) drivers have a long history as the transducer of choice in hearing aids and IEMs for professional musicians and audiophiles. This history extends to general consumers through a number of BA drivers we've already introduced to the mainstream earphone market. Two recent consumer products using these BA drivers include the new Soul Electronics Run Free Pro HD wireless sport BT earphone and the Huawei Honor AM175 wired hybrid earphone.

Whether planar magnetics will get to the small sizes appropriate for earphones is still an open question. Electrostatic speakers, with their need for a higher drive voltage, still have a way to go. These drivers will probably gain more acceptance in headphones where the ability to use larger drivers and accompanying electronics is a plus.

LIS: How do you see "high-resolution" audio impacting the loudspeaker development process?

BELLAVIA: We see more demand for in-ear drivers that can support high-resolution audio (HRA) and we have fully characterized our balanced armature tweeters to meet this requirement. The AKG model N40 hybrid earphone is a recent example of an HRA product using our tweeter.

Because the measurement method is not specified in detail for earphones, Knowles has taken the lead in developing a technique to measure both drivers and complete earphones up to 40 kHz. But that doesn't prevent someone from designing a driver with a 40 kHz output that does not sound pleasing at lower frequencies. Instead, we must work to the spirit of "HRA" by developing transducers with high performance across the complete audio spectrum. ***LIS***

Michael Carnes

Founder, Exponential Audio

Exponential AUDIO

LIS: How did your current business evolve in the past 12 months? What do you foresee for the next 12 months?

CARNES: Exponential Audio added two new products targeted at the music mixing market (NIMBUS and R4). These plug-ins have been quite successful. Over the next year, we will see a renewed effort in products for post-production.

LIS: Which technologies, products, innovations, or trends impressed you the most in the audio industry this last year?

CARNES: Dante, as well as other interconnection technologies based on Ethernet. This simplifies cabling and control, while providing very high-quality audio support. It's been brewing for a while, but over the last year, many new manufacturers have entered the market.

LIS: Do you think test and measurement tools are adequate, or are there still tools missing that you would like to see on the market?

CARNES: There's always room for more (and more portable) testing devices. USB-3, USB-C, and Thunderbolt could all use quick tools to verify electrical interconnect and protocol.

LIS: Which technologies do you think will have a stronger impact on the audio industry in the next five years?

CARNES: I keep hoping for planar speakers that have high quality and affordability. I think this is the key for wider adoption of home theater with Atmos, DTS, and other immersive formats. I'd have said the same thing last year. I'll probably say it next year too.

LIS: Voice recognition was the most discussed trend at recent trade shows due to the impact caused by the Amazon Echo and Alexa voice capabilities. How do you think this is going to affect the speaker market and the audio industry in general?

CARNES: It will have legs for a while until people realize the potential security nightmares. And, it's really not much of a benefit over pushing buttons on a remote. It's more a triumph of gadgetry than anything genuinely useful.

LIS: Crowdfunding is disrupting the way new concepts and companies are launched in the market. Yet, many companies launch crowdfunding campaigns without considering the challenges. Is this an opportunity for new business or do you consider it an unwelcome phenomenon?

CARNES: It has benefits in areas where there's little private funding. This would include things such as pure water and so on. There might be some interesting possibilities in medicine as well. For commercial development, I think companies should have enough confidence to take on the risk themselves.

LIS: Sensors are bringing AV and IT together. Biometric sensors are now being used in headphones. Most wearable devices some audio integration. Is this an opportunity for the audio industry?

CARNES: Well maybe it will help for game headphones and visors. I'm personally more than happy to get some distance from technology once in a while.

LIS: Automotive and infotainment systems are another dynamic segment due to the connected car trend. How should the loudspeaker industry position itself to leverage this?

CARNES: I'm extremely skeptical about connected cars and anything having to do with the Internet of Things (IoT). There's little meaningful work in this field as regards to either security or privacy. I don't really see anything specific in the loudspeaker space other than better and cheaper.

LIS: What are your thoughts on Bluetooth 5, USB-C, Thunderbolt 3, and the evolution of those standards? Are you planning for it with regard to new product design?

CARNES: As a software maker, I don't make things for that space. But Thunderbolt devices are important for me in getting my development work done. But, I think we'll have to be prepared to scrap devices every few years.

LIS: Digital signal processing is increasingly being used in loudspeakers and headphones. It helps surpass the physical limitations of drivers while adding extra functionalities (i.e., active noise cancelling). Where is the industry headed?

CARNES: There's some great DSP in speakers and I only see this market growing. I look forward to higher sample rates in this DSP.

LIS: How do you see "high-resolution" audio impacting the loudspeaker development process?

CARNES: Slowly but relentlessly. Most of the so-called high-resolution audio currently consists of remastering older low-resolution recordings. So the benefits in that space are illusory (or imaginary). But new recordings can deliver a notably-better listening experience when supported by the reproduction chain. Of course, people will need to get off social media for a little while so they can enjoy the music.

LIS: Did your music listening habits change in the last 12 months? Which speakers do you use more often to listen to music?

CARNES: I've got a trusty set of JBL LSR monitors for my main 7.1 environment. New monitors (JBL or other) are in my future. Given that I work with immersive formats up to 22.2, these are not investments I consider lightly. ***LIS***

Zoltán Bay

Creator of the Bay Radial Speaker, BAYZ Audio

LIS: Which technologies, products, innovations, or trends impressed you the most in the audio industry over the past year?

BAY: First of all, let me thank you for this opportunity, it's a great honor. I am fascinated by the progress being made in the area of media players and streaming audio and video. As a music fan, I think the advances that have taken place recently are amazing, I can listen to streamed content even when traveling in the car. Now, I am waiting to see if CD-quality and higher resolution streaming will really make a splash. I use Spotify a lot. As far as I know, higher audio quality is in the wings there too.

LIS: Specifically on speaker design, components, drivers, and materials. What impressed you the most in a positive way over the past year?

BAY: I have seen many exciting solutions lately, just look at the appearance of beryllium in the loudspeaker industry and the new measurement procedures available.

The future promises to be very interesting and, perhaps, this interview is a part of it, the new radial tweeter I have invented may provide a new level of music reproduction quality for millions of music fans. Las year, the greatest satisfaction for me was being told that my own invention was the first in a long time with the potential to revolutionize the loudspeaker driver industry.

The resonance is very positive and I am optimistic that soon many people will be listening to the Bay Radial Speaker (BRS). My participation at the Association of Loudspeaker Manufacturing and Acoustics (ALMA) Symposium contributed greatly to my invention becoming widely known among the world's largest loudspeaker manufacturers. As I intend to sell the manufacturing licence, I couldn't have found a better place for it. At the present moment, I am negotiating with several interested parties.

LIS: Do you think test and measurement tools are adequate, or are there still tools missing that you would like to see on the market?

BAY: It would be very helpful for designers if laser scanner vibrometers became more accessible and more affordable.

LIS: Where do you believe there are larger market opportunities in terms of innovation and business growth: headphones, portable speakers, mobile audio, or virtual reality systems?

BAY: I know that the headphones market is developing extremely quickly. But, if the BRS is able to show its virtues, then maybe those who are serious about their music will also upgrade their loudspeaker system. My patent represents a radically new sonic experience and has the potential of becoming a game-changer in the loudspeaker market.

LIS: Crowdfunding is disrupting the way new concepts and companies are launched

in the market. Yet, many companies launch crowdfunding campaigns without considering the challenges. Is this an opportunity for new business or do you consider it an unwelcome phenomenon?

BAY: If you have a good idea but not enough money, you will find it very hard to implement it. It's a high-risk enterprise because if you fail, you will never get a second chance to attract investors. But if you have the guts, I think that crowdfunding can work very well in spite of this high level of risk. And a community is always a good screen, because it filters out projects it considers unworthy for funding.

Crowdfunding is, in fact, more of a challenge for established companies, because it produces new and creative market entrants. I believe that progress will be made if the market leaders see new entrants as partners and assist them. You cannot expect professional inventors (engineers) working as employees to come up with all the revolutionary new ideas.

LIS: Automotive and infotainment systems are another dynamic segment due to the connected car trend. How should the loudspeaker industry position itself to leverage this market?

BAY: Since more and more people listen to music in the car more than anywhere else, improving the quality of car hi-fi is an obvious target. But quality is hard to guarantee.

The Bay Radial Speaker would be particularly well suited to the environment of a car interior because the high frequencies come from a significantly larger surface than in traditional tweeters. Due to the energy that it radiates not being concentrated, the music becomes much more pleasant to the ears.

LIS: What about home theater? Does the immersive audio experience still hold potential outside the movie theaters?

BAY: In my opinion, multichannel does not offer any appreciable benefits for applications outside of home theater. A good high-end stereo system creates a field around the speaker that no multichannel system is able to reproduce.

LIS: Did your music listening habits change in the last 12 months? Which speakers do you use more often to listen to music?

BAY: I have gone through several speakers in recent years, but I must tell you I not only sell my patents but use them enthusiastically for my own purposes. At the risk of sounding egotistical[1], my listening tastes are best served by a system I designed myself. At the same time, I naturally concede the right of each manufacturer to cater to different needs and different tastes. There are a great many ways of influencing the sound of a sound system without changing the measured parameters.

Unfortunately, the technical specifications ubiquitous today say very little about sound quality. Let us root for Dan Foley and Audio Precision, who have been sparing no effort to change this status quo. ***LIS***

Jonathan Novick

Vice President of Sales and Marketing, Avermetrics

LIS: Do you think test and measurement tools are adequate, or are there still tools missing that you would like to see on the market?

NOVICK: I think the market is still ripe for innovations in test and measurement. Standard tests do not accurately mimic all real-world operating conditions. New techniques are always being developed and old ones get refined. However, we are a long way off from declaring that measurement technology has advanced to the point of making listening tests irrelevant.

LIS: Which technologies do you think will have a stronger impact on the audio industry in the next five years?

NOVICK: I think sensor and signal processing technologies are ripe for adoption and expansion. This will help increase the safe operating margin of devices while also combating common distortion generation. In other words, we will get even more performance from ever-smaller devices.

LIS: Where do you believe there are larger market opportunities in terms of innovation and business growth: headphones, portable speakers, mobile audio, or virtual reality systems?

NOVICK: From transistor radios to the Walkman to the iPod, the market for audio products has grown every time there were significant advancements in portability and ease of use. In the last decade, voice activation has gone from a parlor trick to a mainstream feature one now expects in phones and Bluetooth headsets. I can't think of any loudspeaker innovations though that are a direct result of the voice-activation feature. Likewise, I don't see voice-activated devices changing loudspeaker technology in products such as the Echo or Home. However, such products must contend with listening to voices from greater distances and this is pushing DSP technologies used for voice recognition.

LIS: What are your thoughts on Buetooth 5, USB-C, Thunderbolt 3, and the evolution of those standards? Are you planning for it with regard to new product design?

NOVICK: I think Bluetooth 5.0 has significant benefits that will cause consumers to replace existing Bluetooth products. I would personally like to see the use of higher quality music codecs and lower latencies that should be possible with 5.0's higher data rates. However, I think the broader market will benefit from longer battery life due to the low-energy mode and especially the ability to connect to multiple devices at once. Music appreciation is often a social activity and technologies that encourage sharing of experiences are bound to do well. Some people carry Y-cables so they can share music or video on portable players. Bluetooth 5.0 could make such sharing of content much more common.

LIS: How do you see "high-resolution" audio impacting the loudspeaker development process?

NOVICK: I am skeptical of the new push into high-resolution audio. Much of the content available in high-resolution formats was sourced from lower resolution recordings. This produces no real benefit. Consumers may perceive some benefit if they happen to buy better sounding systems to listen to their "hi-res" content. This is more likely to occur in the portable market where the playback system is just the media player and a decent pair of headphones. ***LIS***

Jade Wu

Chief Business Officer, Linkplay Technology

LIS: How did your current business evolve in the past 12 months? What do you foresee for the next 12 months?

WU: Linkplay Technology's business grew considerably with the adoption of its turnkey Wi-Fi audio platform in more than 40 speaker brands and consumer electronic devices. The patented hardware and software solution includes global streaming content integration, a complementary app, cloud services development, and multi-room, high-resolution, lossless audio capabilities. Speaker manufacturers recognized the value of partnering with us to design new products that combine these features in a cost effective, convenient way. And, development cycles are shortened considerably with new products coming to market in a few months versus the industry average of 12 to 18 months.

Another trend, Wi-Fi is replacing Bluetooth audio, which takes advantage of higher resolution quality. Last, the most disruptive technology introduced last year was Amazon's Alexa Voice Service (AVS) for third-party vendors. Linkplay capitalized on this opportunity and became the first Wi-Fi audio platform approved with AVS. Currently, five of our speaker brand customers are shipping Powered by Linkplay products with AVS, and dozens of additional speaker brand customers will be delivering products in the coming months.

LIS: Which technologies, products, innovations, or trends impressed you the most in the audio industry over the past year?

WU: The most impressive new technology is the availability of voice agents. These are a game changer for many industries with numerous Internet of Things (IoT) voice assistant products being introduced in 2016. The availability of a smart audio Wi-Fi platform integrated with personal voice assistants is now available for high-end loudspeakers, soundbars, and whole-home and portable speakers, enabling speaker manufacturers to develop new types of products. Consumers want access to music libraries, streaming music services, and the convenience of personal voice assistants.

LIS: Which technologies do you think will have a stronger impact on the audio industry in the next five years?

WU: Voice-enabled devices are creating a paradigm shift and will continue to influence the design and user experience of audio products such as speakers, receivers, and network-attached storage (NAS) devices, as well as other smart audio products. We envision audio commands being used to control devices without the use of apps or remote controls.

LIS: Voice recognition was the most

discussed trend at recent trade shows due to the impact caused by the Amazon Echo and Alexa voice capabilities. How will this affect the speaker market and the audio industry in general?

WU: It is a disruptive technology and brings enormous opportunities to the speaker market. In addition to voice assistants, new sensory technologies will be introduced for wake-up words. Also, Google and Microsoft are having an impact on the landscape with their versions of voice assistant AI speakers. We see this trend as somewhat analogous to the iPhone revolution and the introduction of Bluetooth speakers. Now the trend is the adoption of Wi-Fi speakers streaming music in high resolution with voice assistants. The audio industry will likely join forces with technology companies to create new types of speakers, apps, and other smart home products.

LIS: Wireless audio, streaming services are becoming more popular—both for headphones and speakers. What impact do you feel this has on speaker design and new products?

WU: Music streaming apps are prolific for Bluetooth and Wi-Fi speakers and have influenced speaker product design. More and more consumers want to stream audio whenever and wherever they are such as in the car, on a bus, a plane, or bike riding. And, portable speakers are offering presets to create favorite music stations.

Now streaming apps are being integrated into headsets. Products are being designed to match consumers' lifestyle and features such as voice commands. Products are being designed specifically with streaming services in mind. Form factors have changed, and we now have better performance portable devices enabled for streaming service as well as better battery and wireless capabilities.

LIS: Do you believe wireless audio, whole-home, and multi-room solutions will continue to evolve and grow over the next two years?

WU: Yes, multi-room and whole-home wireless audio solutions will continue to evolve as they are becoming a checkbox item for speaker manufacturers. And, consumers will come to expect this feature. Speaker manufacturers will choose to partner with companies like Linkplay so they can integrate this feature as well as music streaming services and voice.

LIS: How do you see "high-resolution" audio impacting the loudspeaker development process?

WU: Offering high-resolution is becoming a requirement for almost all speaker manufacturers' spec sheets, especially since consumers are choosing streaming services such as Tidal and Deezer. They want to listen to music in the highest formats available. It requires audio products to design solutions that transmit and receive the high-resolution content. This is a significant shift for brands that were accustomed to operating only in the analog domain.

LIS: Did your music listening habits change in the last 12 months? Which speakers do you use more often to listen to music?

WU: Yes, personally my music habits changed significantly. I purchased Omaker's Wow WiFi and a Bluetooth speaker Powered by Linkplay technology with Alexa Voice Service. It is fun and convenient to use. It gives me access to millions of songs, numerous Internet radio stations, and allows me to check the weather, my commute to the office, and order products and food. ***LIS***

Peter Larsen

President, LOUDSOFT, Ltd.

LIS: How did your current business evolve in the past 12 months? What do you foresee for the next 12 months?

LARSEN: Our business has increased by more than 100% during the last 12 months. This is due to higher sales of FINE Design Software and Measuring Systems such as FINE R+D. And, the new FINE DSP is quickly becoming very popular because it is ideal for optimizing/tuning of both acoustics and amplifiers in speaker systems. Several Portable PA Speakers have been successfully optimized lately.

We expect this trend to continue in the next 12 months, especially with the new 75% discount on the second software license. Instead of sharing one license, now the engineers can be much more productive with the right software on their PCs.

LIS: Which technologies, products,

innovations, or trends impressed you the most in the audio industry over the past year?

LARSEN: The virtual reality technology is impressive and will no doubt have a strong impact on the audio industry. And robots are already a dominating technology, which in principle has the potential to dominate much of our society. So, now I am wondering: When will we see a hi-fi robot on the market?

LIS: Do you think test and measurement tools are adequate, or are there still tools missing that you would like to see on the market?

LARSEN: Actually the existing LOUDSOFT measurement tools have much more potential than many realize. Measuring anechoic responses in a normal room/lab, getting SPL and impedance without switching and converting off-axis curves into polar/contour plots are among intuitive features of the latest FINE R+D.

Listening to every driver on the production line is getting too expensive when you also want to measure SPL and impedance with strict limits. The solution is using FINE QC for all measurements including the world's best Rub & Buzz test, all tested in less than 1 second.

Fast and intuitive test systems are rare on the market. Combined with high-resolution testing such products are needed. Expect to see just this from LOUDSOFT.

LIS: Which technologies do you think will have a stronger impact on the audio industry in the next five years?

LARSEN: Wireless technology such as Wi-Fi and other products are still growing in the market and probably will in the coming years.

LIS: Voice recognition was the most discussed trend at recent trade shows due to the impact caused by the Amazon Echo and Alexa voice capabilities. How do you think this is going to affect the speaker market and the audio industry in general?

LARSEN: The voice recognition technology is impressive and is really a kind of personal assistant. Whether this format will actually catch the market, depends on how people will adapt this way of communication. I would hate having my speaker talk to me.

LIS: Crowdfunding is disrupting the way new concepts and companies are launched in the market. Yet, many companies launch crowdfunding campaigns without considering the challenges. Is this an opportunity for new business or do you consider it an unwelcome phenomenon?

LARSEN: Whether crowdfunding is a good idea very much depends on the product. If the crowdfunding is about an interesting new consumer product it may be interesting for a new or developing business. However, if the product is a business-to-business item, it is hard to see how a critical mass can be obtained for creating enough funding.

LIS: What do you think about the use of sensors in audio products? Sensors are bringing AV and IT together. Biometric sensors are now being used in headphones. Most wearable devices have some sort of audio integration. Is this an opportunity for the audio industry?

LARSEN: Since the biometric sensors are so easy to integrate with other electronics like most portable audio devices, such combined products most probably will appeal to many people. Combined with wireless data transfer the potential could be very large and interesting for the audio industry.

LIS: Automotive and infotainment systems are another dynamic segment due to the connected car trend. How should the loudspeaker industry position itself to leverage this?

LARSEN: The connectivity between car and personal audio devices is getting increasingly important. The acquisition of Harman by Samsung strongly underlines this. The audio industry could benefit from offering products complying with existing standards. Future automatic cars will certainly need infotainment systems, and it is not clear how the IT/Audio/Car industries will cope with this challenge. Tesla is an interesting example of a car company very much driven by IT.

LIS: What are your thoughts on Bluetooth 5, USB-C, Thunderbolt 3, and the evolution of those standards? Are you planning for it with regard to new product design?

LARSEN: Data transfer rates are increasingly accelerated by these products. These standards must, therefore, be adopted by the industry in order to stay competitive. LOUDSOFT has already developed a new generation: FINE Hardware 2, offering much higher data transfer rates and additional channels giving unseen new features and flexibility.

LIS: Digital signal processing is increasingly being used in loudspeakers and headphones. It helps surpass the physical limitations of drivers while adding extra functionalities (i.e., active noise cancelling). Where is the industry headed?

LARSEN: DSP is a powerful technology that can be utilized well in active loudspeaker systems. For example, the FINE DSP software will design the acoustics including on/off-axis SPL of the speaker while simulating the amplifier power for each driver. Using input from FINEBox, the cone travel Xmax can be optimized at all power levels. Using DSP tools in this way will be a good help for both the designer and the user.

LIS: How do you see "high-resolution" audio impacting the loudspeaker development process?

LARSEN: High-resolution audio transducers can already be well simulated in FINECone. Using the new FINE Hardware 2 FINE R+D can sample up to 192 kHz, giving a bandwidth of close to 100 kHz.

LIS: Did your music listening habits change in the last 12 months? Which speakers do you use more often to listen to music? (name brand, model - audio chain optional)

LARSEN: I listen to my Microlab PURE 1 speakers at home using direct high-resolution streaming. At work, I listen to my Dynaudio M1 monitor speakers. I delevoped all the drivers for both these speakers. ***LIS***

Mark Valentino

Product Marketing Manager, Acoustics, PCB Piezotronics, Inc.

PCB PIEZOTRONICS INC.
MTS SYSTEMS CORPORATION

LIS: How did your current business evolve in the past 12 months? What do you foresee for the next 12 months?

VALENTINO: Increased awareness of the advantages of using test and measurement grade microphones in the design of speakers, headphones, and musical instruments has enticed PCB Piezotronics to expand our product portfolio and become a more active player in the professional audio market.

High-quality test and measurement microphones with metal diaphragms provide extremely flat and accurate signals when compared to microphones typically used on stage or microphones that use polymer diaphragms. Fidelity data is important for recording or when sound engineers are "modeling" (replicating) the sound of multiple obsolete or very expensive pieces of musical equipment. The accuracy of test and measurement microphones provides a truer representation of existing products, and an enhanced ability to understand the intrinsic sound characteristics of the pieces of equipment to be replicated. We are very excited about introducing test and measurement quality products to the professional audio industry.

LIS: Which technologies, products, innovations, or trends impressed you the most in the audio industry over the past year?

VALENTINO: There are a number of innovations and trends that have impressed me. Virtual reality, sound cancellation, modeling, and voice recognition have had the greatest impact. Gamers love the near real-life experiences that virtual reality offers. Sound quality in automobiles, planes, and within buildings and public spaces has been improved via sound cancellation products and techniques. As a professional musician, the modeling or exact replication of different instruments, speakers, or other microphones, at an affordable price is important to me. One of the most impressive technology advancements is the integration of voice recognition into everyday products and activities and the resulting improvement in the quality of life for so many people. I see these specific technologies gaining significantly more traction over the next few years.

LIS: Specifically on speaker design, components, drivers, and materials. What impressed you the most in a positive way over the past year?

VALENTINO: More and more, engineers are recognizing the need to consider sound beyond the audible range for increasing clarity and extending product life cycles. With test and measurement grade microphones that function with phantom power and have the capability to measure frequency ranges up to 100 kHz and amplitudes from 15 dBA to 164 dB with minimal distortion is changing the product design landscape.

LIS: Do you think test and measurement tools are adequate, or are there still tools missing that you would like to see on the market?

VALENTINO: The implementation of and advantages of existing test and measurement tools is now becoming better understood, and therefore, more justifiable. With these test and measurement tools, the capability to measure low noise levels, higher amplitudes with less than 1% THD, and the ability and to accurately assess higher frequencies, enables designers to improve the sound quality and life cycles of their products. As a manufacturer of test and measurement sensors, we recognize noise contributions from the entire audio chain and the advantages of having more accurate and truer representation of sound. Every component manufacturer in that chain (i.e., speaker, cable, software, and hardware) seeks better tools and continuous improvement. It's impressive to see the market move forward.

LIS: Voice recognition was the most discussed trend at recent trade shows due to the impact caused by the Amazon Echo and Alexa voice capabilities. How do you think this is going to affect the speaker market and the audio industry in general?

VALENTINO: Advances in voice recognition will greatly improve speaker sales. I envision many scenarios where voice recognition will improve the "quality of life" for the elderly or people with disabilities. Through voice recognition, you can turn on lights, ask for a favorite song to be played, call a friend, or order necessities online. This is all done without ever leaving a chair. We often hear the old adage "Garbage in, garbage out." With the accuracy of test and measurement microphones, the intelligibility of systems can quickly improve and making these products more consistent and even easier to use.

LIS: What do you think about the use of sensors in audio products? Sensors are bringing AV and IT together. Biometric sensors are now being used in headphones. Most wearable devices have

some sort of audio integration. Is this an opportunity for the audio industry?

VALENTINO: The use of high-quality sensors is a critical component that is driving this integration. Better data provided by today's sensors affect the entire lifecycle of these products, from shorter design cycles to an enhanced auditory experience in the finished product.

LIS: Automotive and infotainment systems are another dynamic segment due to the connected car trend. How should the loudspeaker industry position itself to leverage this?

VALENTINO: I see a continuing trend of noise cancellation and voice recognition within the automotive market. The use of noise cancellation for sound quality will make automotive cabins quieter and audio systems more pleasing to the ear. Voice recognition opens up a world of integration possibilities including hands-free actions like giving your vehicle driving commands or asking the vehicle about its maintenance schedule. Speaker manufacturers need to position themselves to take advantage of this through advanced interfacing.

LIS: How do you think the discussed "America first" protective policies, propelled by the current administration, will affect the audio industry? Challenge or opportunity?

VALENTINO: It is both a challenge and an opportunity. The challenge for US audio equipment manufacturers is to produce products that are less expensive without sacrificing quality. If the consumers do not see a fair price coupled with the quality they demand, they will find ways to buy non-US products. The opportunity exists for US manufacturers to grab significant market share from foreign competition. ***LIS***

Kent Peterson

Sales and Marketing Manager, Warkwyn

LIS: How did your current business evolve in the past 12 months? What do you foresee for the next 12 months?

PETERSON: We're seeing a push for more scientific data on speaker systems both large and small. As the consumer becomes more savvy, listing a simple specification such as "20-20 kHz" isn't enough anymore. This awareness extends from home audio systems through automotive systems to headphones. People want to know what they are buying and that there was some reasonable science employed during the design process—this adds value. Additionally, we're seeing a rise in the need for simulation data for acoustical modeling in the contractor space. More and more building regulations are requiring specific acoustical data for emergency evacuation and life safety communications, and if your installed device doesn't have that data available to the acoustical consultant or engineer, your product may be disqualified from a project's bid spec.

LIS: Do you think test and measurement tools are adequate, or are there still tools missing that you would like to see on the market?

PETERSON: We're seeing a rise in measurement of microspeakers, and specifically laser scanning to examine rocking modes in spiderless designs. As the personal device market stays strong and grows, measurement tools and procedures that are tailored to these markets are going to be in high demand.

LIS: Voice recognition was the most discussed trend at recent trade shows due to the impact caused by the Amazon Echo and Alexa voice capabilities. How do you think this is going to affect the speaker market and the audio industry in general?

PETERSON: It's revolutionary much in the same way that speakers flooded into homes in the 50s and 60s—of course, then it was "hi-fi"- now speakers are largely hidden or otherwise imbedded in the device. The emphasis is on clarity and intelligibility, which may force speaker manufacturers to reexamine the way speakers are built; lighter, more powerful with less distortion in a smaller package. It's also revolutionary for microphone designers; increasing sensitivity and optimizing intelligibility. Doing that in a time of heightened concern of privacy brings more software developers into league with microphone designers.

LIS: Crowdfunding is disrupting the way new concepts and companies are launched in the market. Yet, many companies launch crowdfunding campaigns without considering the challenges. Is this an opportunity for new business or do you consider it an unwelcome phenomenon?

PETERSON: We don't see it as an unwelcome phenomena. It mirrors what happened to the record industry and what seems at first unwelcome actually turns out to be liberating. Now, a talented engineer with a great idea doesn't necessarily have to futilely bang on the doors of big speaker manufacturers (like hoping for a recording contract). If the product idea is good, and the end result lives up to the hype post funding, success should be had if the engineer has a good support structure in terms of sales and marketing. As with bad music, if the business aspect of a start-up isn't solid, or the product is bogus, market forces will ultimately relegate them to history—just like the "big boys."

LIS: What about home theater? Does the immersive audio experience still hold potential outside the movie theaters?

PETERSON: Absolutely, with a twist of course. The gaming industry is really driving immersive audio. Now more than ever audio localization techniques—placement of drivers and the use of DSP to create space—are hot topics. This also challenges sound designers when writing and mixing—causing a resurgence in surround mixing in studio. We've seen some really great innovations come through our doors to accommodate this.

LIS: Digital signal processing is increasingly being used in loudspeakers and headphones. It helps surpass the physical limitations of drivers while adding extra functionalities (i.e., active noise cancelling). Where is the industry headed?

PETERSON: DSP is, of course, nothing new to speaker designers—filters, phase correction, etc. What is new is using DSP to really create a sense of space for immersive audio. People want to be in the acoustic sound field more than ever. And with the explosion of virtual reality, good localization of sound—pairing head movement with directional sound sources—is going to be the rule of the day. Not only left, right, front, and back, but creating the sense that one sound source may be further away from another and on the fly.

LIS: How do you see "high-resolution" audio impacting the loudspeaker development process?

PETERSON: We're not hearing those words too often when talking to our clients. Everyone is still striving to push the boundaries of what can be done with typical driver designs with all of their inherent inefficiencies, while making them more compact. And while "high-resolution" audio is a great catch phrase, we're not sure that will translate to the broader market. Frankly, we're happy that there is a new awareness by the general public of "better than MP3" audio quality—this is driving more boutique speaker solutions and pushing speaker designers to do more with less.

LIS: How do you think the discussed "America first" protective policies, propelled by the current administration, will affect the audio industry?

PETERSON: It's going to be a challenge but of course that drives opportunity. Much like the textiles industry, many speaker designs are produced in the US, sent abroad for manufacture, and then re-imported to the US for re-sale. If high tariffs are imposed upon import, we're going to have to find ways to cut costs on the front end of speaker design to keep consumer prices reasonable. The textiles industry was devastated by NAFTA but recovered by streamlining the process. And this is nothing new to the speaker and musical instrument industry—we've paddled these turbulent waters before and it seems there is always an opportunity to grow through new, innovative design and manufacturing techniques. ***LIS***

Mike Klasco

President, Menlo Scientific

LIS: How did your current business evolve in the past 12 months? What do you foresee for the next 12 months?

KLASCO: Menlo Scientific provides audio engineering consulting services including product definition and product development. We support selection of vendors where we match the client's requirements to the factory's technical capabilities and manufacturing scale. Our clients range from the big guys (Menlo is best known in Asia as "the small company with big clients") to innovative boutique startups.

We certainly see a lot of earphone and headphone development and everyone is expanding their Bluetooth product lineups. Over the years, the autosound aftermarket, home-theater, and whole-house audio clients have waned. But in the last year, whole-house audio product development is coming back due to the recovering economy which has rejuvenated home renovation and new home construction.

LIS: Do you think test and measurement tools are adequate, or are there still tools missing that you would like to see on the market?

KLASCO: Especially for speakers and headphones, I would like to see perceptual distortion testing, which is now used just for buzz and rub, increased in resolution. This type of test can measure not just of go/no-go testing for marginal production units but beyond that to evaluate quality of good to superb speakers and headphones—at least as one aspect of evaluation. Also for headphones, the recent work by G.R.A.S. Sound and Vibration, A/S and others on headphone couplers with wider response and less artifacts in the test data for evaluation of top-end response.

LIS: Which technologies do you think will have a stronger impact on the audio industry in the next five years? How do you think this is going to affect the speaker market and the audio industry in general?

KLASCO: Voice command was the most discussed trend at recent trade shows due to the impact caused by the Amazon Echo and Google Home smart speaker. Voice recognition has been a struggle since its inception but accuracy is close enough that the sprint to easy and consistent voice command is in sight. I mentioned that voice command products, which will lead home automation to mainstream status, and popular Sonos and similar wireless whole-house speakers will certainly all have voice command capabilities. Consistently accurate voice recognition remains elusive—especially with the radio playing, or the car window open, or communication from across the room. I suspect these voice appliances hear more than their share of foul language directed toward them!

LIS: Which technologies, products, innovations, or trends impressed you the most in the audio industry over the past year?

KLASCO: USB-C /Lightning and related audio input/output, Bluetooth 5.1 with aptX Hi-Res, True Stereo wireless earphones, near field magnetic induction (NFMI), and wireless charging.

LIS: Crowdfunding is disrupting the way new concepts and companies are launched in the market. Yet, many companies launch crowdfunding campaigns without considering the challenges. Is this an opportunity for new business or do you consider it an unwelcome phenomenon?

KLASCO: For sure there are some exciting products that got their start from crowdfunding, but there also has been many amateur efforts that crashed and burned. There is a long road from a good idea and slick video to mass production of a viable product!

LIS: What do you think about the use of sensors in audio products? Sensors are bringing AV and IT together. Biometric sensors are now being used in headphones. Most wearable devices have some sort of audio integration. Is this an opportunity for the audio industry?

KLASCO: I am writing this after the last day of the Mobile Electronics show in Hong Kong and after visiting more than a half dozen earphone factories I have to say bio-earphones for monitoring health parameters have been a sales disappointment to the industry. From an audio engineer's perspective, there is not enough room for both the sensor and earphone driver—resulting in 6 mm diameter drivers—just too small for decent bass and consistent production tolerances. Not to mention cramming in both devices means neither is position where they optimally should be.

One exciting new technology in development is the "virtual sensor," which uses the impedance of the earphone driver to "read tea leaves" for functions such as auto-shutoff when the earphone is taken out of the ear, for identifying authorized users by their earprint, as well as temperature of the ear.

LIS: Digital signal processing is increasingly being used in loudspeakers and headphones. Where is the industry headed?

KLASCO: NXP's Smart amp was game changing technology. Essentially, the equivalent of a pro sound rack-mount loudspeaker management system like the dbx DriveRack, but in a chip (with the amplifier thrown in)! All aspects of speaker operating conditions are kept in check preventing clipping and blowing out the speaker (microspeaker in the case of what is available). Today, there are a half dozen smartphone smart amplifier chips with up to few watts, but plan on higher power amplifiers coming soon. ***LIS***