SOUND AND VIBRATION NEWS

WAVES

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UNIVERSAL MAN

NOTHING RUNS LIKE A DEERE

MICROSOFT HAS THE QUIETEST PLACE IN THE WORLD

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Brüel & Kjær

BEYOND MEASURE

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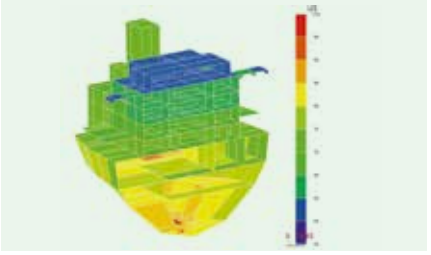

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FRONT COVER IMAGE
Expert profile Trevor Cox. Photo courtesy of Chris Foster Photography

Brüel & Kjær
BEYOND MEASURE

LETTER FROM OUR PRESIDENT

SOLUTIONS TO DIVERSE CHALLENGES

Welcome to this latest issue of Waves. This year, we are celebrating our MSC Application Research Centre (ARC) in Michigan, which has been helping customers with all sorts of sound and vibration challenges for the past decade. You can get an overview of the ARC's state-of-the-art testing capabilities and read some of the broad range of projects handled there.

In fact, our customers increasingly contact us needing more than our equipment and solutions; they need help to resolve their challenges. With our recent acquisition of Detroit-based sound and vibration consultancy Sound Answers, we have extended our ability to provide engineering services to industries including automotive, aerospace, telecom, audio and many more.

This issue highlights some of the varied companies and people that we already work together with. You can read how we have been helping fine-tune a system to improve the French shooting team's accuracy ahead of the 2016 Olympics. Flicking through a few pages, you can see how John Deere has been using our software to coordinate engine reliability tests around the globe.

We also have an interview with the multi-talented expert Trevor Cox: Professor, BBC presenter and all-round explorer of the sonic world. Over in Spain, we have been mapping the noise of moving high-speed trains with CAF, to increase the viability of this transport of the future. And a team at Singapore's Nanyang Technological University has been using our equipment to develop a class-D amplifier to dramatically improve sound quality in audio devices.

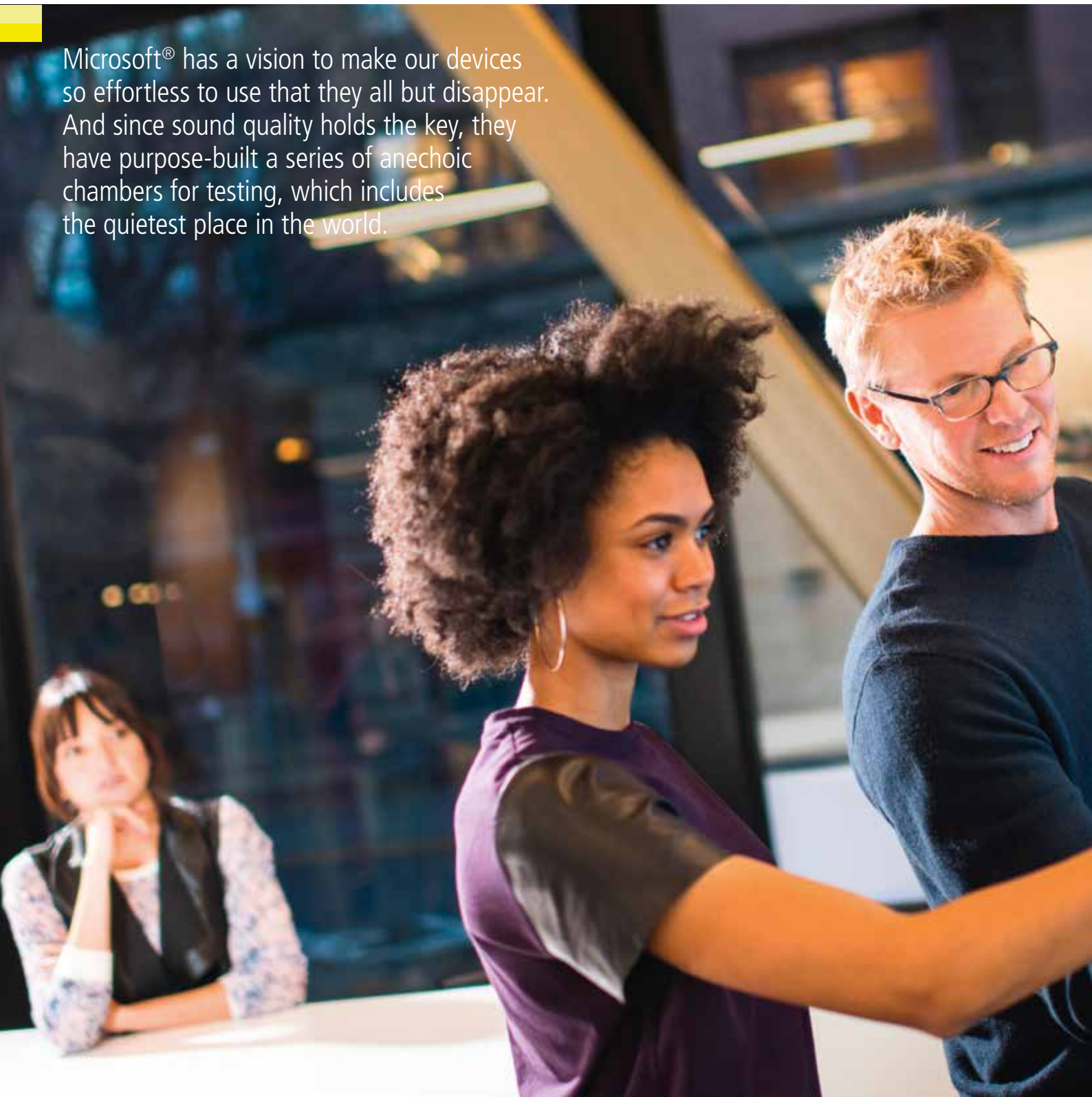
Through such diverse sound and vibration activities we are all inspired to develop and discover, to find ways of improving our environment and creating a better quality of life for us all.

We hope you enjoy reading this issue.

SØREN HOLST
PRESIDENT

THE QUIETEST PLACE IN THE WORLD

Microsoft® has a vision to make our devices so effortless to use that they all but disappear. And since sound quality holds the key, they have purpose-built a series of anechoic chambers for testing, which includes the quietest place in the world.



For conferencing with Surface Hub to be effortless, it needs quality sound reception and transmission – throughout the room and beyond it

If there's one thing the digital age has made clear to us all, it is that our experience with products is everything. Gone are the days of studying instruction manuals; as each new iteration of our cherished devices reaches our hands, we expect a leap in their intuitiveness. And at the same time, we expect them be more pleasing: faster, more capable, quieter.

For Microsoft, leading this progression requires top sound quality in everything we hear and whenever we speak. When you hold a Surface™ tablet in your hands, every 'bong' that informs you a window has opened affects your perception of the device. While videoconferencing with colleagues through a Surface Hub screen, you expect clear voice transmission – wherever you are in the room. And when using Microsoft's speech interface Cortana®, she must respond accurately to your voice commands.

NATURALLY COMMANDING

Natural language interfaces are a major part of Microsoft's vision for the future. The company's world-leading brains are hard at work on human/machine interfaces that feel so natural and effortless that they essentially disappear. "The most natural human communication mode is speech and language – all over the world," says Hundraj Gopal, Principal Human Factors Engineer at Microsoft. "We are finally at an inflection point. We are on the verge of using spoken language as a real and valuable communication interface with technology." ▶

> "GOOD VOICE RECOGNITION STARTS WITH GOOD ACOUSTIC DESIGN. OUR ANECHOIC CHAMBERS AND TEST EQUIPMENT ALLOW US TO RELIABLY CHARACTERIZE OUR MICROPHONE AND SPEAKERS."
>
> LESALLE MUNROE
> SENIOR ENGINEER, SURFACE DEVICES
> MICROSOFT

THE QUIETEST PLACE **IN THE WORLD**

Bringing the world together requires a dedication to achieving sound quality in the devices we use

Beyond machines understanding us, we humans also need to understand each other effortlessly if technology is to become an 'invisible' assistant. So in phones and large screen devices alike, Microsoft uses multiple microphones to hone in on our voices with location algorithms. By then separating our voices from the background noise, they can clarify the signal we need – so we don't strain our ears to hear or raise our voices to be heard.

A SOUND FOUNDATION

Beneath such clever programming however, the quality of any audio interface ultimately comes down to its hardware. As LeSalle Munroe, Senior Engineer, Surface Devices says: "Good voice recognition starts with good acoustic design. Our anechoic chambers and test equipment allow us to reliably characterize our microphone and speakers to give us the best chance of meeting our voice recognition goals."

For all hardware devices, LeSalle and his colleagues characterize microphones and speakers precisely. "In general, we test components alone, and then components in the whole system, focusing on raw acoustics like frequency response, total harmonic distortion (THD), rub and buzz, dynamic range, acoustic seal, sensitivity and noise floor," he says. "Then we do full system qualification with added processing."

The last step is to test voice recognition and sound quality. "This can take up more than 50% of the time, because it is

HoloLens 3D headsets rely on voice commands to make using them as natural as possible

> "WE ARE ON THE VERGE OF USING SPOKEN LANGUAGE AS A REAL AND VALUABLE COMMUNICATION INTERFACE WITH TECHNOLOGY."
>
> HUNDRAJ GOPAL
> PRINCIPAL HUMAN FACTORS ENGINEER
> MICROSOFT

a very iterative process," says LeSalle. "We investigate the relevant aspects of audio engineering technologies, and map them to human perception, acceptance and annoyance, in order to increase user satisfaction."

QUIET CONFIDENCE

Much of Microsoft's hardware testing takes place in Building 87, on Microsoft's Redmond Campus. Inside, Cortana gets blasted with precise speech from a Head and Torso Simulator (HATS) or mouth simulator, which she must understand and respond to – whatever the background noise they add. The researchers also test the ability of beamforming algorithms to locate a speaker's voice – again in quantified background noise. 3D spatialization technologies are tested on HATS to see how effective they are at conveying the audio cues we need to immerse us in authentic sound fields – particularly for the HoloLens augmented reality headset. They also measure sounds such as keyboard and trackpad clicks, to find the most pleasing sounds for a device to confirm our interactions with it.

Whatever the test, a controlled acoustic environment is critical. Microsoft has several anechoic chambers in Building 87, but with their quietest one, they have gone beyond merely controlled. With a background noise level of –20.6 dB(A) SPL, its noise floor is closer to the absolute lowest sound possible than other anechoic chambers. It even took the Guinness World Record in 2015.

One of the core reasons behind the huge effort to make this record-breaking chamber was to test components like humming displays, singing capacitors, rattling components and structural vibrations. "Being able to capture and characterize printed circuit board noise is a huge challenge for us," says LeSalle. Although such noise levels are often tiny and well below the levels that our ears can detect, they can add up in non-linear ways to make a total noise that is audible, annoying, and interferes with voice recognition. ▶

MICROSOFT'S BUILDING 87

The world's quietest room is just one chamber within Building 87. This cutting-edge complex of hardware labs houses research into acoustics, human engineering factors such as ergonomics, and the 'Lab of the Future', where some of the world's leading experts in fields as diverse as psychoacoustics, industrial design and history come together to find new approaches to human/machine interfaces.

Few had seen inside Building 87 before late 2015, but following the acoustic world record, Microsoft has made the whole complex accessible through an interactive tour and videos.

THE QUIETEST PLACE
IN THE WORLD

THE WORLD'S QUIETEST PLACE

Microsoft's record-holding chamber was specified by a large team in Microsoft, and built by acoustic chamber specialists Eckel Industries Inc. The team paid careful attention in excruciating detail to ventilation systems, sprinkler systems, lighting, vibration control, instrumentation panels, cabling, and electrical noises.

Brüel & Kjær and BlackHawk Technology Inc. measured the noise floor of Microsoft's quietest anechoic chamber at –20.6 dB(A) SPL. The quietest level of noise theorized by mathematicians is Brownian motion – the movement of particles in a gas or liquid – at –23 dB(A).

The measurement method was specified by Guinness, and used a two-microphone coherent power measurement technique with two Type 4955 low-noise microphones. The acousticians measured the same overall dB(A) multiple times.

Scan here to see the Guinness World Record attempt

GOOD WORKMEN DON'T BLAME THEIR TOOLS

"We always want to have the best tools available for the job," continues LeSalle. "Our other anechoic chambers are very good, no doubt. However, we wanted to build one with even better audio capabilities, so we could measure lower levels of sound, a higher purity of sound measurements, and increase the validity and reliability of our measurements – so we can quantify the audio performance of our products at a finer and greater level of detail. The chamber and the Brüel & Kjær microphones and preamps we use allow us to achieve the repeatability we want."

It's probably no surprise that Microsoft's engineers are perfectionists. And according to Gopal, it is a pre-requisite. "Top products require a long-term commitment to excellence: top-notch experts from several disciplines and high-quality equipment," he says. With this recipe for success, Microsoft can be sure the sound performance in their devices is built on the purest data. With precise knowledge of their individual components and systems, and the sharpest algorithms and codecs, they are melting the machine/human divide.

But the record-breaking lab is about more than the finest, most reliable measurements today. It's a stone-built commitment to developing top quality hardware in the future. Because when Microsoft's researchers are innovating how we will interact with new devices, there's no roadmap to follow. They must imagine and then build their visions on the best foundations possible. And whatever amazing leaps that requires, Microsoft wants the best tools to hand, ready to realize the future we all want to see and hear.

> "TOP PRODUCTS REQUIRE A LONG-TERM COMMITMENT TO EXCELLENCE: TOP-NOTCH EXPERTS FROM SEVERAL DISCIPLINES AND HIGH-QUALITY EQUIPMENT."
>
> HUNDRAJ GOPAL
> PRINCIPAL HUMAN FACTORS ENGINEER
> MICROSOFT

THE SCREAMING VOID: AN HOUR IN AN ANECHOIC CHAMBER

As you walk into an anechoic chamber, you enter a strange new world: spiky, soft walls enclose every surface of the room. And when you look down, the floor is just a see-through mesh. Bouncing on the criss-crossed wires, the atmosphere seems to thicken around you – closing in more than the densest fog.

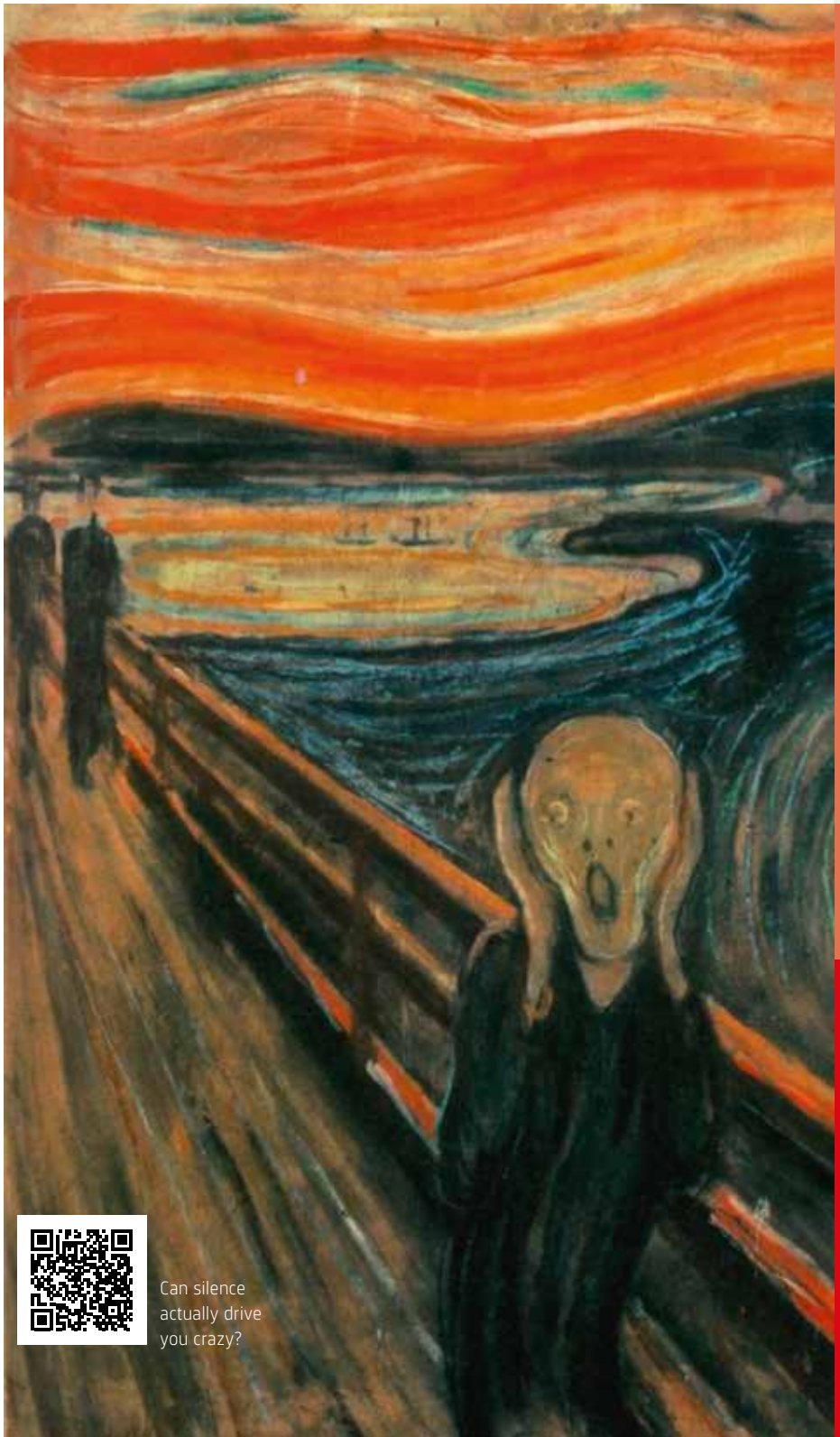
Many myths surround these surreal and fascinating spaces. Some people claim that the longest anyone has spent in an anechoic chamber is forty-five minutes. They say any longer would drive you insane.

EFFECTS ON THE HUMAN BODY

Being in extreme silence has an interesting effect. With no sound to distract you, your body becomes the sound field. If you spend some time in an anechoic chamber you will hear:

- Your stomach rumbling and gurgling loudly
- Your throat swallowing
- The hissing from your breathing lungs
- A low-pitched hum from your ears – louder than the effects of tinnitus
- Your heart beating loudly – you may even become so aware of your heart that you feel your chest moving from the heartbeats

Not a pleasant experience, and some people can only endure a few minutes of this strange silence! However, the record certainly stands at more than forty-five minutes. David Muller from Veritasium made a video investigation where he was able to spend a full hour in an anechoic chamber – and claimed he could have stayed in there for hours.



Can silence actually drive you crazy?

PRONE TO EXCELLENCE:

SAVVY ENGINEERING STUDENT AIMS FOR ACCURACY

Photo courtesy of Harold Gérenton

French engineering student Raphaël Chevalier has developed a device that helps Olympic prone shooters improve their accuracy by up to 24%.

Prone position is the most basic and stable of all rifle shooting positions. Trained shooters often master the prone position first, as it is the one position where all common shooting factors can be isolated and addressed.

The 50-metre rifle prone shooting event, also called '60 shots', has been part of the Olympic Games since 1908. In this event, competitors shoot from a distance of 50 metres with a .22 long rifle carbine at a target 15 centimetres in diameter. The goal is to shoot all 60 shots as accurately as possible within the 50-minute time limit.

LIKE MINDS, NICHE SCIENCE

Raphaël Chevalier is an engineering student specializing in Materials and Structures at SIGMA Clermont in Clermont-Ferrand, France. An active sports shooter since he was 17, Raphaël is passionate about the science behind the shot, specifically vibration. That's why he changed his focus from visual and audio techniques to structural vibration.

In 2013, Raphaël met Olympic shooter Rémi Moreno Flores. Rémi is a PhD in Sports Science specializing in carbine shooting performance. With so much in common, the two became friends and Rémi introduced Raphaël to the rest of the Olympic team.

Photo courtesy of Raphaël Chevalier

Engineering student Raphaël Chevalier demonstrates shooting in prone position.

THE SCIENCE BEHIND THE SHOT

Rifle shooting is a precise science where the combination of barrel and ammunition affects the bullet's accuracy. This is mainly due to the gun's 'kick', also known as recoil, as the bullet fires: transverse vibrations result from recoil forces in the rifle imparting on the back of the barrel. These vibrations cause a variation in shot accuracy.

Raphaël soon got the idea to develop a system and corresponding technique for analyzing and predicting how rifles perform with certain ammunition. He explains, "Traditionally shooters experiment with endless combinations of ammunition and barrel in an attempt to minimize the effect of the vibration. It's a lot of trial and error and it's very time-consuming. You can even be eliminated from a competition if you are using the wrong ammunition. I got the idea to measure the vibration of the rifle to help minimize the trial and error process. With my system, the Olympic team can fine-tune their gear during training in order to improve their performance during competition." ►

> "IT'S SO EXCITING TO BE A PART OF THE OLYMPIC TRAINING PROCESS – AND REALLY GRATIFYING TO SEE WHAT IMPACT MY RESEARCH AND MY TOOLS ARE HAVING ON THE SHOOTERS' RESULTS."
>
> RAPHAËL CHEVALIER, ENGINEERING STUDENT, SIGMA CLERMONT

PRONE TO EXCELLENCE: SAVVY ENGINEERING STUDENT AIMS FOR ACCURACY

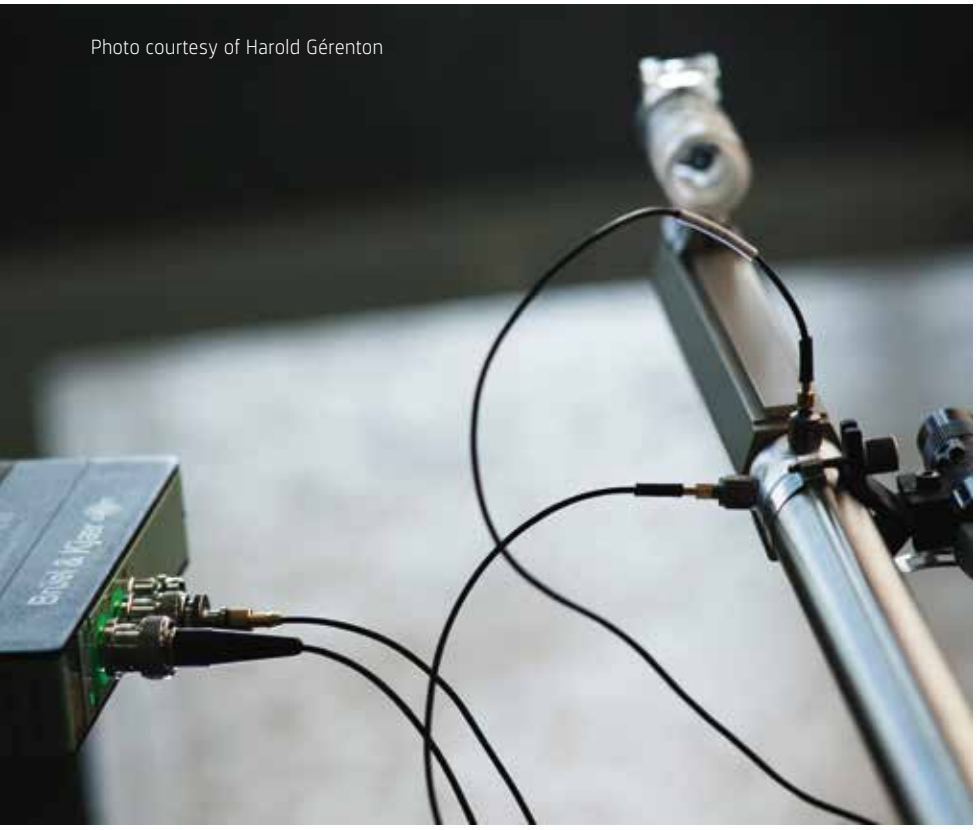


Photo courtesy of Harold Gérenton

Raphaël and Henri's data measurement and analysis system: A .22 long rifle carbine with two accelerometers connected to data acquisition and recording equipment.

ENTER BRÜEL & KJÆR

Once Raphaël had his methodology in place, he needed some help testing the system, gathering data and analyzing the results, so he contacted Brüel & Kjær. "When I explained my research project to them, they responded enthusiastically," says Raphaël. "They sent Henri Gérenton, who is an application engineer, to meet with us at INSEP (France's National Institute of Sport and Physical Education) and do a half-day measurement session."

"I was very impressed with the level of research this young group was conducting," says Henri. "We had Raphaël and Rémi, two clearly very clever and passionate people, along with other international-level shooters and their national trainer, Éric Viller. As a group, they had very keen expertise in this niche domain, and they were conducting top-level research with a good methodology. It was exciting to be a part of it."

THE DATA MAKES A DIFFERENCE

To capture the data they needed, Henri and Raphaël placed two accelerometers – one vertically and one horizontally – at the extremity of the gun barrel, and they recorded time signals of the shots in order to reconstruct the motion of the muzzle and the muzzle jump (the tendency of the front end of the firearm to rise up after firing).

Henri and Raphaël recorded signals using Brüel & Kjær LAN-XI data acquisition hardware and PULSE™ Time Data Recorder software. They made as many recordings as possible in order to increase their statistics, and they changed parameters, such as the gun barrel, the ammunition, the gun itself and the specification of the gun barrel, in a systematic way to achieve a more nuanced view of their results.

AIMING HIGH WITH THE RESULTS

"Thanks to the measurements done by Brüel & Kjær, we have been able to determine the relative impact of some of the parameters on vibration and confirm the efficacy of different types of rifles and gear," explains Raphaël. "That means we were able to calibrate my system for optimizing the barrel-to-ammunition match that will improve shooters' gear accuracy during training."

Raphaël also gathered data for developing a tool for measuring muzzle jump. This tool can help shooters and their coaches better analyze their shots during competitions. Although in experimental stages, the system is already being used to fine-tune rifles for shooters training to qualify for the 2016 Olympic Games.

"It's so exciting to be a part of the Olympic training process – and really gratifying to see what impact my research and tools are having on the shooters' results. At the last training session I attended, the trainers saw a 24% improvement in accuracy thanks to my tools. I can't wait to see the results of the Olympics this summer." ■

CAN YOU PLAY THE ASPHALTOPHONE?

When you drive over lumps and bumps on the road, the sounds rumble up into your car. But you might be surprised to learn just how much road makers can control theses sounds.

The phenomena of encoding music and tones into road surfaces was originally discovered in the 1950s – using parallel corrugations in the tarmac. But it was not until 1995 that Danish artists Steen Krarup Jensen and Jakob Freud-Magnus invented the 'Asphaltophone'.

Today, 'musical roads', 'singing roads' and 'melody roads' can be found all over the world.

TEST YOUR MENTAL MUSIC MUSCLES!
If the distance between the corrugations on a musical road is 16 cm:

1. What tone do you get if you drive a constant speed of 100 km/h (62 mph)?
2. How fast would you have to drive to hear the tone 'C_4'?

(Assume the concert pitch was tuned at 440Hz.)

Find the answers on page 27.

The Asphaltophone in the making
Photo courtesy of Jesper Holdgaard

WHO SAYS WHAT?

"SLOW BUT STEADY WINS THE RACE."

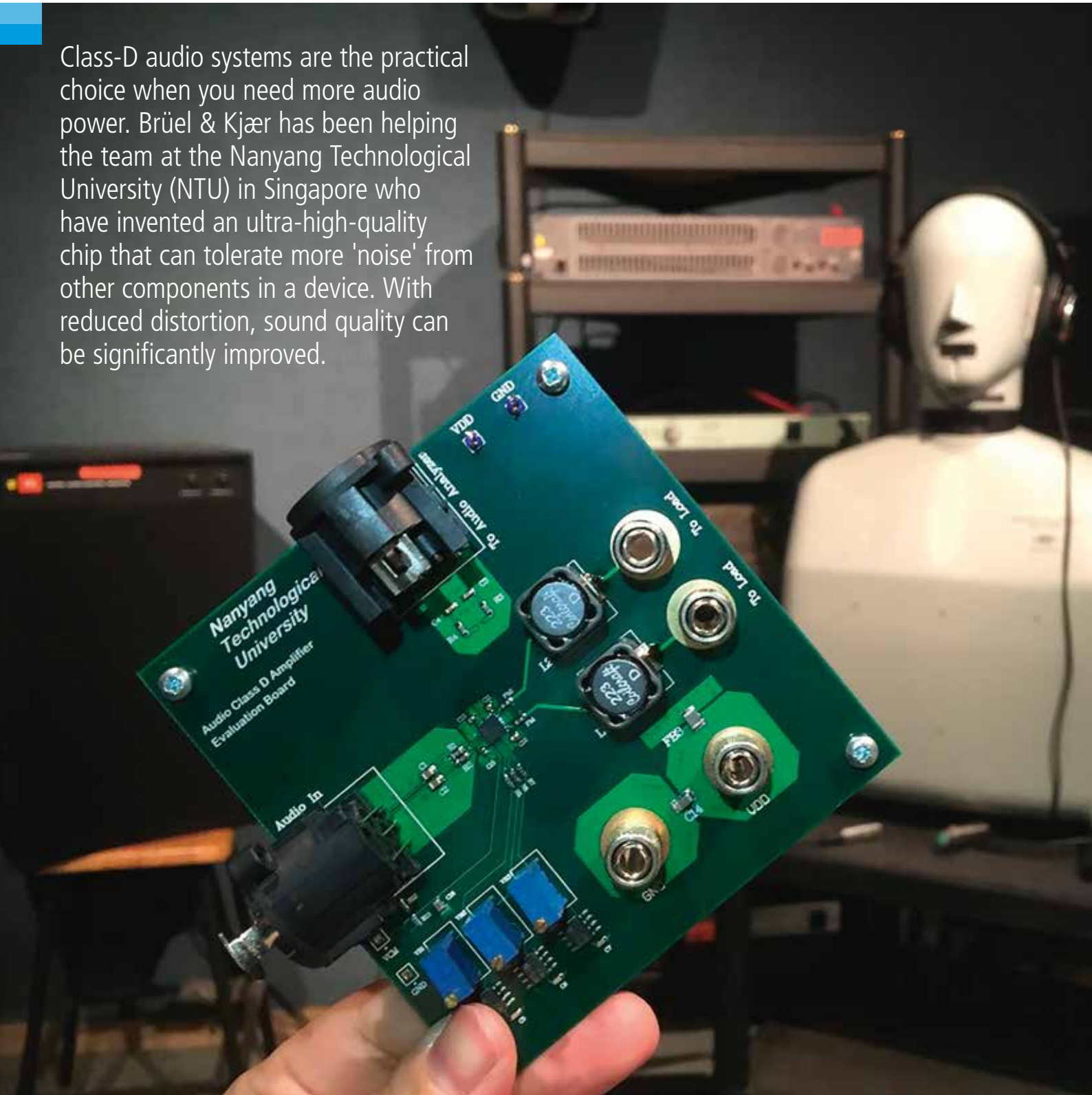
AESOP
(C. 620 – 564 BCE)

Aesop was an Ancient Greek fabulist or storyteller credited with a number of fables now collectively known as Aesop's Fables.

As a manufacturer of high-speed trains, CAF does not believe that 'slow' wins any race. But driving at a 'steady' – although high – speed is definitely a top priority for them. Learn more about how CAF uses beamforming technology to reduce noise – and thereby gain speed on pages 24.

CLASS-D TECHNOLOGY: ENHANCING SOUND QUALITY

Class-D audio systems are the practical choice when you need more audio power. Brüel & Kjær has been helping the team at the Nanyang Technological University (NTU) in Singapore who have invented an ultra-high-quality chip that can tolerate more 'noise' from other components in a device. With reduced distortion, sound quality can be significantly improved.



Today, audio is about more than dynamic range or Total Harmonic Distortion (THD). It's also about power: more of it for less. The team from the Division of Electrical and Electronics Engineering, part of NTU, are researching ultra-low-power, ultra-high-efficiency Class-D amplifiers (CDAs).

Ge Tong, a senior research scientist at NTU, began working with Brüel & Kjær 10 years ago when she was pursuing her PhD. "The project I was doing then was to design an active noise cancellation earphone (which was nascent at that time)," explains Ge Tong. "I used the Brüel & Kjær Head and Torso Simulator and also the PULSE system – and I am still using them now for my Class-D amplifier project and some other projects."

Increasingly, devices need high-quality sound without sacrificing power efficiencies. For the majority of people, smartphones have become the main listening device, so audio quality is getting more attention from phone manufacturers. In view of the high power-efficiency requirement, it is not surprising that virtually all smart mobile devices today use a CDA as the driver to the primary loudspeaker.

However, Class-D audio applications require a wide breadth of design knowledge and technique. An ideal Class-D amplifying stage has no distortion and no noise generation in the audible band and provides close to 100% efficiency. However, in practice, CDAs have imperfections that generate distortion and noise.

A NEW CDA DESIGN

To still obtain high power efficiency, without resorting to a high switching frequency, the team at NTU proposed a novel CDA design. This new design embodies an input-modulated carrier generator and a phase-error-free, pulse-width modulation (PWM) modulator. ▶

> "WHEN WE FIRST STARTED USING THE HEAD AND TORSO SIMULATOR AND PULSE SYSTEM TO MEASURE OUR CDA, A BRÜEL & KJÆR ENGINEER CAME TO HELP SET UP THE SYSTEM AND TEACH US HOW TO USE IT. WE HAVE BEEN USING IT EVER SINCE."
>
> GE TONG
> SENIOR RESEARCH SCIENTIST AT NTU

CDAS: THE CHALLENGES

- The key parameters to qualify and quantify the performance of CDAs include:
  - THD + N – measuring non-linearity and noise
  - Power Supply Rejection Ratio (PSRR) – measuring immunity to supply noise
  - Output noise – measuring noise level
- CDAs are largely deficient in fidelity and noise immunity. For example, only very few CDAs feature THD + N < 0.01% and a PSRR > 90 dB, and none feature PSRR > 100 dB
- A high switching frequency (FSW), for example FSW > 500 kHz, and/or complex multiple feedback loops can improve these parameters but can also incur undesirable compromises from:
  - Increasing the power dissipation – hence compromising the power efficiency
  - Increasing the electromagnetic interference – also reducing power efficiency and making the CDA not fully integrated if additional external components are required ■

CLASS-D TECHNOLOGY: ENHANCING SOUND QUALITY

The prototype CDA features:

- A low Total Harmonic Distortion + Noise (THD + N) of 0.0027%
- The highest Power Supply Rejection Ratio (PSRR) to date, PSRR = 101 dB at 217 Hz
- A relatively low switching frequency, FSW ≈ 320 kHz at nominal operating conditions

TESTING THE DESIGN

Measuring CDA performance is relatively simple using an audio analyzer. Ge Tong and the NTU team measured THD + N and PSRR using a PULSE system that was seamlessly connected to a Head and Torso Simulator (HATS), which "listens" to the sound from a headset driven by a CDA, and measures the acoustical audio signal. Ge Tong explains: "This was essentially an integrated circuit design project. The development process started with the schematic design and simulation, followed by layout, parasitic extraction and post-layout simulations. If the post-layout simulations meet the design specifications, we can send the design for fabrication. Finally, the design is tested and verified. The whole process takes about one year."

TOO GOOD TO BE TRUE?

"The most challenging step in this project was probably to convince ourselves that it was in fact doable," says Ge Tong. The design specifications are very stringent – far superior to anything that has been done before. On first appraisal, it might be thought that the specifications are too good to be realistic. The NTU team spent a lot of time rederiving the noise and non-linearity mechanisms and checking that their theoretical analyses were correct.

After a number of discussions and checks, everyone in the team was convinced that the design specifications could be achieved and the actual execution of the project went very smoothly, ultimately resulting in the team designing the first-ever 'ultra-high-quality' Class-D amplifier.

UNPRECEDENTED AUDIO PERFORMANCE

The result of this project is unprecedented performance from the CDA. The pinhead-sized chip encompassing the novel CDA design ultimately means that the audio from smartphones will sound like it is coming from high-end stereos, and wireless headphone users will be able to enjoy a longer battery life. Future applications of the chip include audio amplifiers, car audio systems, and televisions.

The team at NTU is continuing to improve the design and they aim to establish it as the industry gold standard for CDAs. Ge Tong concludes, "We hope to commercialize our CDAs in the near future. Several major IC design companies have expressed an interest in our design and our discussions with them are ongoing."

HEAD AND TORSO SIMULATOR (HATS)

Brüel & Kjær's Head and Torso Simulator is a manikin with mirrored external "ears" that ensures uniform and reliable binaural sound quality measurements. The calibrated ear simulators are optimized to measure all devices placed close to the ear, for example, hearing aids, hearing protectors, and headphones, as well as telephones and headsets.

INTEGRATED CIRCUIT (IC) DESIGN

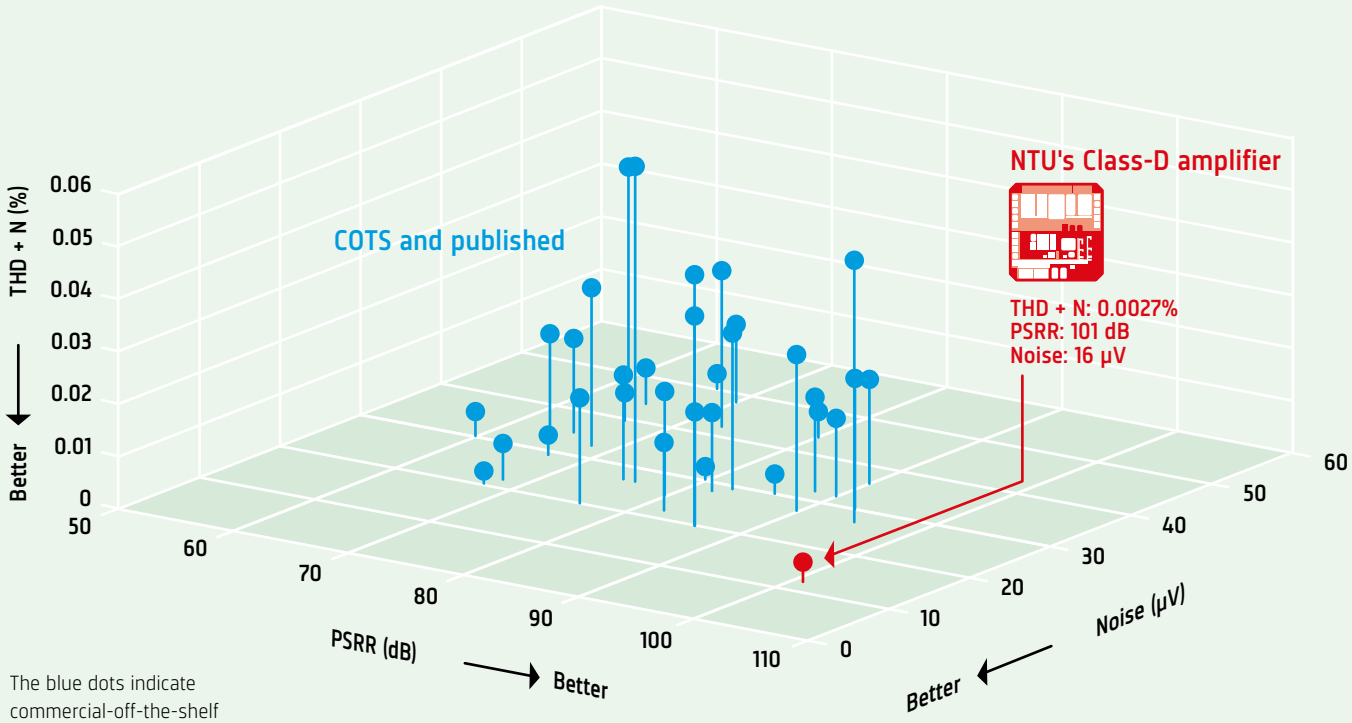
IC design involves the particular logic and techniques required to design ICs. In an IC, the multiple individual components (for example, transistors, diodes, resistors, capacitors, and the conductive pathways that connect all the components) are embedded directly into a single piece of silicon crystal.

- Simulation – pre-layout simulation is done to develop design constraints
- Post-layout simulation – simulation using the completed IC layout to verify compliance with the design constraints
- Parasitic effects – the unavoidable and usually unwanted capacitance that exists between the parts of an IC simply because of their proximity to each other
- Parasitic extraction – involves calculating the parasitic effects in the devices and interconnects of an IC

CDAS CAN BE CLASSIFIED INTO THREE CATEGORIES:

- High quality: THD + N < 0.02%, PSRR > 80 dB, and output noise < 40 μV
- Very-high quality: THD + N < 0.01%, PSRR > 90 dB, and output noise < 30 μV
- Ultra-high-quality: THD + N < 0.005%, PSRR > 100 dB, and output noise < 20 μV

PERFORMANCE BREAKING THROUGH – THE WORLD'S FIRST-EVER ULTRA-HIGH-QUALITY CLASS-D AMPLIFIER



The blue dots indicate commercial-off-the-shelf (COTS) and published CDAs and the red dot indicates the new CDA – illustrating the significant advantages of the new design

DR GE TONG

Dr Ge Tong is a multi-disciplinary engineer with research encompassing ultra-low-power, ultra-high-efficiency analogue circuits and signal processing, and printed/organic electronics on flexible substrates for biomedical and IoT applications.

She has published ~40 research papers in top peer-reviewed journals and conference proceedings and filed 18 patents. She currently leads a research team of six researchers, and is the Co-principal Investigator of a research grant amounting to S$600k from Singapore-MIT Alliance for Research and Technology. She is an Associate Editor of the IEEE Transaction on Circuits and Systems-II.

NOTHING RUNS LIKE A DEERE

To ensure the wheels can give a tight turning radius, tractor engines must be as tall and narrow as possible, which restricts the location of engine-mounted components

AVOIDING NATURAL RESONANT FREQUENCIES

When a singer shatters a wine glass using acoustic energy, they hit the special note that coincides with the glass' natural resonant frequency – the frequency that makes it vibrate with large amplitudes. Components mounted on an engine face the same effect from vibrational energy.

John Deere® has five core engine types, but since each application has specific configurations, there are over 20,000 unique variations.

Whether harvesting forests, digging foundations, or propelling ships, people depend on John Deere's engines to get things done. But since each application places unique stresses on the engine-mounted components, the NVH team must anticipate thousands of variables to meet the demands of the real world.

When a John Deere engine comes into the world, there are many possible lives that await it. It might become the heart of an American tractor that ploughs huge fields in Texas at a steady pace and rarely sees a road. But if that engine powers a European construction machine, it could have a very different experience. It will face intense periods of high loads as it digs holes in the ground, followed by variable levels of speed and effort as the machine moves on hard metal tracks.

Such types of use, or 'duty cycles' affect the reliability of the whole machine, and especially of the engine-mounted components. This is because, for a given engine speed and load, each engine produces vibrations in a certain pattern. Some frequencies are more damaging than others, so fatigue problems can arise from repeated excitation at those specific frequencies. It is up to the design team to avoid these.

> "WE BUILD EACH ENGINE PROGRAM FOR THE APPLICATION. IT MAKES OUR JOB MORE DIFFICULT, BUT THIS WAY EVERY CUSTOMER GETS EXACTLY WHAT THEY NEED."
>
> KRISTIE IVERSON, SENIOR NVH ANALYSIS ENGINEER, JOHN DEERE

TENS OF THOUSANDS OF DUTY CYCLES

For John Deere's diverse machinery range, there are just five main engine types. But there are hundreds of possible configurations of components and engine mountings. Multiply this by hundreds of different duty cycles for every unique application, and the number of unique vibration patterns reaches five figures.

Kristie Iverson, Senior NVH Analysis Engineer, explains: "While most companies buy an engine off the shelf and are forced to make it work with their machines, we build each engine program for the application. It makes our job more difficult, but this way every customer gets exactly what they need."

To avoid the damaging frequencies in so many possible circumstances, prediction is essential. At John Deere's Product Engineering Facility in Waterloo, Iowa, designers create new components using CAE programs. Kristie Iverson takes these design files and analyses them to understand how they will respond to vibrational forces from the engine combustion. She simulates the harshest duty cycles, to give a comfortable 'buffer' of durability that the customer won't exceed. ▶

NOTHING RUNS
LIKE A DEERE

ITERATIVE SYNERGY

"If the analysis reveals excessive vibration, I can suggest to the design group that changes are needed, such as a component needs more stiffness, or a different material. And we work together in an iterative process like that, until they come up with a design that is within our historic bounds for acceptance criteria," says Kristie.

Prototype testing is essential too, to reduce design risks by checking for any durability issues in the real world of mud, workmen and random events. On John Deere's own test farms, vehicles are exhaustively tested, and only at the end of a gruelling programme are new designs ready for market.

> "I COULD BE AS CONFIDENT LOOKING AT DATA COLLECTED IN FRANCE AS IF I HAD COLLECTED THE DATA MYSELF. THAT'S A VERY GOOD FEELING."
>
> KRISTIE IVERSON, SENIOR NVH ANALYSIS ENGINEER, JOHN DEERE

KNOWLEDGE CAPITAL

John Deere's history of accurate data is the knowledge 'capital' they have accumulated: over 30 years of documented NVH reports – thousands of reports and terabytes of data. This knowledge capital allows continual design evolution by providing the basis of every new CAE and NVH model, and by helping to set the acceptance criteria for the vibration levels a component can tolerate reliably.

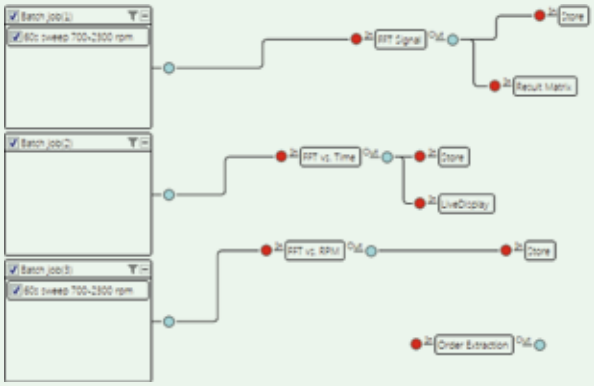
In one case, John Deere's European NVH team noticed interesting behaviour in a physical prototype during a specific application. "We also noticed this issue in our US-based engine model, and we wanted to correlate and see exactly why that was," says Kristie.

REPEATABLE GLOBAL TESTING

Conducting comparable testing across two continents is challenging, as there are so many variables that people can select, such as software settings and test approaches. As Kristie says, "They all needed to compare apples to apples with lots of measurement points. So it was a challenging test."

By using PULSE Reflex, it was easy to share and standardize test approaches. The NVH group in the US created an analysis chain including various analysis types, and sent it out to other NVH engineers who could simply drop the analysis chain into their copy of PULSE Reflex.

PULSE REFLEX PROCESS CHAIN



John Deere's NVH analysts can share the same analysis chains, displays, and axes, ensuring they all follow a standard procedure, wherever they are in the world

"After testing, the global NVH people can just stick their data on the internal network, and I can run it through my project in no time," says Kristie. "Then all my displays and all my axes are set up the same. We're looking at the same thing, so I could be as confident looking at data collected in France as if I had collected the data myself. That's a very good feeling. Having the confidence that I can tell my manager the very next day that the test done in France is better or worse than the one we tried in the US is invaluable."

With several analyses to perform on different measurements from multiple runs, all with many channels, Kristie often uses the batch processing functionality in PULSE Reflex. "This case was a large survey – 5 runs, each with 48 channels – and the output should be 2D spectra and colour maps. I was able to process it in an afternoon. That would have taken me a long time to do one by one," she says.

REVIEWING TESTS IN MODELS

After a long field-test like this, it's not always clear what causes an issue in a prototype. Correlating the test data with the CAE design model allows Kristie to review tests at leisure, to gain useful insights that provide a clear engineering direction. ▶

NOTHING RUNS
LIKE A DEERE

A forestry machine may use a transversely mounted engine due to operator visibility concerns, which changes the vibration behaviour of the engine

The time spent at certain loads under certain conditions – the duty cycle – is unique to each machine, bringing unique vibration and temperature profiles for the engine-mounted components

"I can narrow down to a specific component and model the whole duty cycle to see if indeed that condition produces high stress which might cause a failure," says Kristie. "We might not be able to instrument with strain gauges or accelerometers in the exact failure location on a real machine, but I can create an analytical gauge anywhere in the model. Being able to match what I see on a test machine gives me a specific target to reduce the stress by X amount, so that the predicted life is acceptable."

Information like this is easy for the CAE design group to use. "We have a good relationship," she says. "What makes PULSE Reflex really nice is that it doesn't matter where that data came from – from test or analysis. I post-process it the same way, and we can compare the results because they are the same."

At the same time, the feedback from each real-life test continually improves the accuracy of John Deere's CAE and NVH models themselves. This is essential for Kristie's confidence in her predictions, which are ultimately what the machines' reliability depends on.

NVH INTEGRATED INTO CAE

With such tight integration of testing and modelling, John Deere has increased the amount of design iterations that are feasible, so they can test more ideas, and at the same time analyse more precisely. This ensures their customers get top engine reliability, whatever their specific application or configuration – among thousands of possibilities. And all without over-engineering components, creating unnecessary complexity, or specifying shorter service intervals. With ever-more effective integration of testing into CAE, they move confidently into a future of analysis-led design.

> "I CAN NARROW DOWN TO A SPECIFIC COMPONENT AND MODEL THE WHOLE DUTY CYCLE TO SEE IF THAT CONDITION PRODUCES HIGH STRESS, WHICH MIGHT CAUSE A FAILURE."
>
> KRISTIE IVERSON, SENIOR NVH ANALYSIS ENGINEER, JOHN DEERE

THE LONGEST ECHO

"MY INITIAL REACTION WAS DISBELIEF."

PROFESSOR TREVOR COX, ACOUSTIC ENGINEER

In 2014, acoustics expert Trevor Cox crawled through a narrow pipe into a subterranean oil tank in Inchindown, Scotland. One gunshot and 75 seconds later, he had set a new world record for the longest echo in a man-made structure.

FACTS AND FIGURES

- The Inchindown bombproof fuel oil tank was built over 80 years ago for the Royal Navy
- The oil tank measures twice the length of a football pitch
- The total reverberation time is 112 seconds
- The world record reverberation time is 75 seconds*

The previous world record for a man-made structure was 15 seconds, which was also held by a structure in Scotland – the Hamilton Mausoleum in South Lanarkshire.

You can learn more about Trevor Cox's dedication to amazing sound phenomena in our expert profile article on pages 34–37.

*According to the International Standards Organization (ISO), the definition of rever-beration time is the time that a sound takes to decay until it is 60 dB below the level of the initial impulse sound.

Hear the record-holding gunshot in the underground chamber

Listen to Trevor Cox playing his saxophone with the world's longest echo

ON THE RIGHT

High-speed train manufacturer, CAF, rely on world-class beamforming technology to reduce the noise generated by their trains – helping to make high-speed trains a more viable option for travellers and operators alike.

Because of its relatively low levels of CO_2 emissions, train travel is considered one of the most environmentally friendly methods of transportation. In fact, according to the Green Jobs Initiative, part of the United Nations Environment Programme (UNEP), the railway is one of the key sectors in the goal to achieve sustained social and economic growth, compatible with climate stabilization.

High-speed trains are one of the most eco-friendly ways to travel thanks to their extremely high capacity and efficiency.

High-speed trains also offer comfort and safety to travellers and a great opportunity to railway operators looking for competitive services to add to their portfolio.

THE HIGH-SPEED CHALLENGE

The one drawback of high-speed trains is that they are extremely loud. Construcciones y Auxiliar de Ferrocarriles (CAF) is a global leader in the manufacture and supply of high-tech rolling stock based in Beasain, Spain. They developed the OARIS solution, a family of high-speed trains capable of reaching 350 km/h.

"WE WERE ABLE TO REDUCE THE EXTERIOR NOISE BY 3 TO 5 DB(A). WE ARE CONFIDENT THAT NO OTHER NOISE MEASUREMENT SYSTEM COULD HAVE HELPED US ACHIEVE THIS."

ISAAC GUTIÉRREZ,
R & D ENGINEER AT CAF

TRACK

Isaac Gutiérrez, R & D Engineer at CAF, explains, "The European Technical Specifications for Interoperability (TSI) has set maximum pass-by noise levels for high-speed trains. This is to ensure that people who live in the pass-by communities are not burdened by ridiculously high noise levels. Because of these requirements, high-speed trains are not allowed to run at night. We are constantly working to reduce the rolling and aerodynamic noise generated by the train, to help operators extend the daily operative time and make the service more viable."

THE ART OF THE NOISE MAP

CAF creates noise maps that help them identify and focus on the train's various noise sources. The rolling noise is the noise produced by the wheels, rail and sleepers and is generated by the wheel-rail contact. The aerodynamic noise is the noise generated by air passing over the train's exterior shapes and irregularities, such as the front nose, the first bogie, the inter-coach gangways and the pantograph.

"Aerodynamic noise is the most important noise contributor to the overall pass-by noise level and is the most challenging to measure and understand. We were looking for the most accurate way to do this, in order to make relevant adjustments to our train design and meet the European TSI requirements," says Isaac.

BEAMING IT IN

Mario Menendez, Isaac's Brüel & Kjær counterpart, said CAF's challenge was quite clear. "The acoustic dynamic range of a high-speed train passing by is massive.

In just a few seconds you go from almost complete silence to extremely high noise levels. Measuring this noise requires a wide dynamic range acquisition system capable of recording both low and high noise levels with the same precision and at a very high sampling rate. Our beamforming technology can do this."

"We had been working with Brüel & Kjær for 20 years and we were aware of their beamforming technology," says Isaac, "but we had never applied it before. When Mario suggested we use it, we decided it was the best option, as we trusted the equipment and Mario and his team."

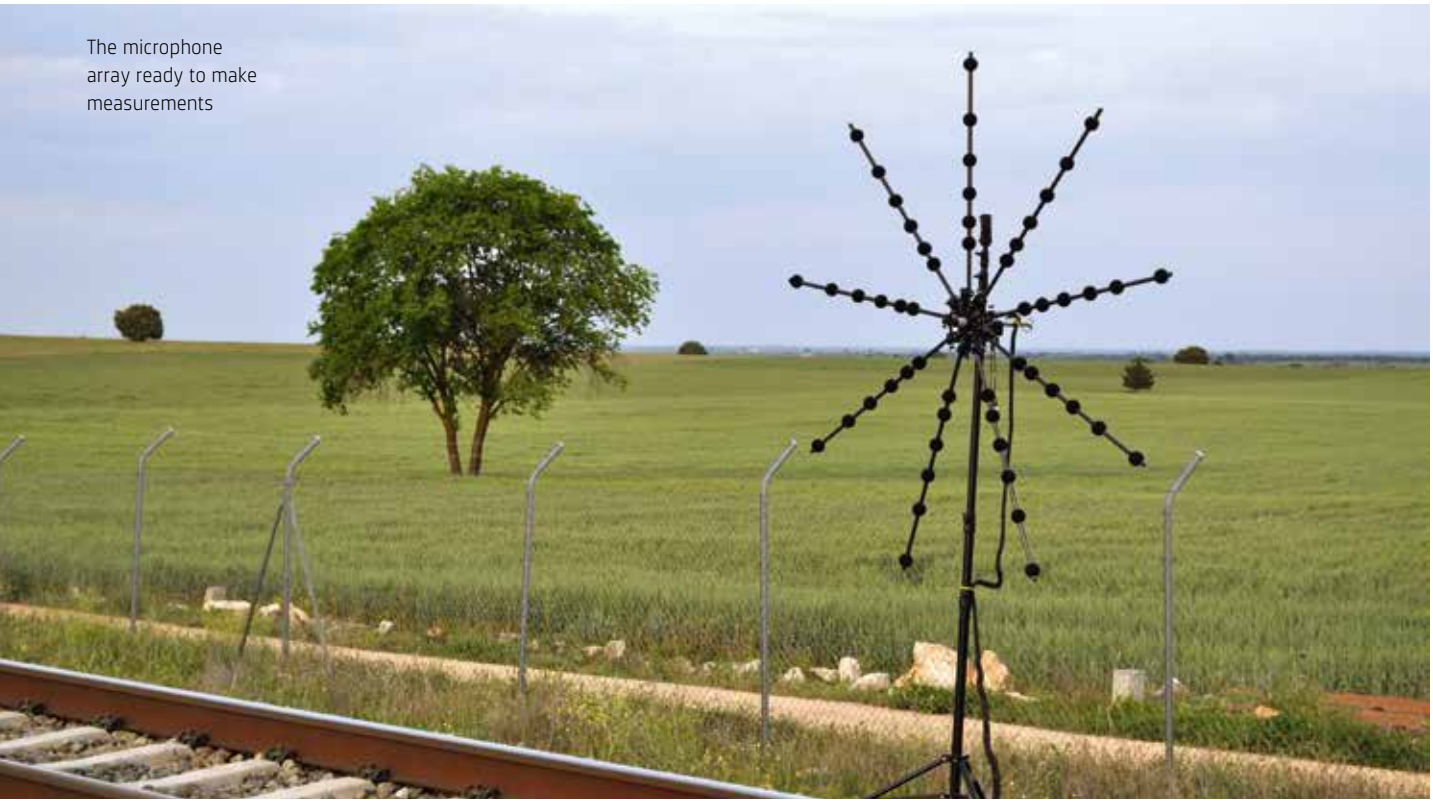
LET THE MEASURING BEGIN

Isaac and Mario set up their beamforming system at pass-by sites across the Spanish countryside,with the on-site support of Vincent Raisseix, a Brüel & Kjær Application Engineer. "Our Rail Vehicle Moving Source Beamforming System is based on the PULSE™ platform," Mario explains. "The system follows a linear movement parallel to the planar microphone array and enables speed-position calculation from a pulse speed signal or photocells."

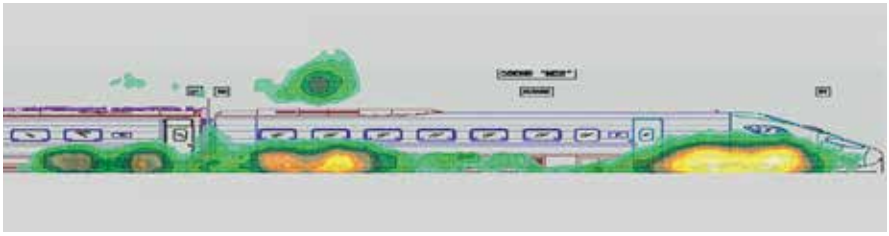
The microphone array has nine arms – each with six microphones fitted with windscreens to minimize the effect of air turbulence on the train pass. The signals from all 54 microphones are fed to a multichannel PULSE LAN-XI system that simultaneously records the raw signals at a sample of more than 65 kHz per channel. "This high sample rate allows you to make any type of signal processing or hear any microphone signal in very high quality," says Mario. ▶

ON THE RIGHT TRACK

The Oaris high-speed train from CAF



The microphone array ready to make measurements



Example of a noise map produced with the help of a Brüel & Kjær Rail Vehicle Moving Source Beamforming System

PRECISE PLANNING AND PREPARATION

Although the equipment and methodology were top-class, the project was not without challenges. "These types of pass-by tests need to be done at night when the high-speed railway has no traffic," says Isaac. "Yet the instrumentation needs to be deployed, calibrated and tested during the day when the railway is active. As you can imagine, this presents some serious safety challenges and requirements that need to be met."

"You also have the challenge of limited time and budget," adds Mario. "All measurements and recordings need to be right the first time – there is no room for overloads, system failures, or missing or defective items." To ensure these challenges were met, CAF and Brüel & Kjær carefully planned the project and all instruments were tested in advance.

THE RESULTS: A QUIETER RIDE

The project resulted in noise maps

CAF engineer Isaac Gutiérrez with the OARIS high-speed train

indicating sound pressure, pressure contribution density and sound intensity for the whole and individual parts of the train. "From studying the noise maps, we have determined that we, for example, could modify the shape of the cars to change the direction of the air passing between the cars. By making this modification, we were able to reduce the exterior noise by 3 to 5 dB(A). We are confident that no other noise measurement system could have helped us achieve this." This is exactly the data CAF needs to be highly competitive in the high-speed train manufacturing game. "If we can achieve quieter high-speed trains, the trains can run at night, making them a more viable option for travellers and a more profitable service for operators," Isaac explains. "This is why high-speed noise reduction has become a strategic area for CAF – and why our collaboration with Brüel & Kjær is so important to us."

ASPHALTOPHONE! QUIZ ANSWER

We hope you noticed our little quiz about encoding music and tones into road surfaces. If not, please go back to page 13 and test your mental music muscles before you read on.

QUIZ ANSWERS

When you drive 100 km/h, which is equal to 27.8 m/s, you will pass 173.6 corrugations per second, which will radiate a fundamental frequency of 173.6 Hz, corresponding to an F tone in the third octave. Therefore:

1. When you drive down the described road at 100 km/h (62 mph), you will hear the tone 'F_3'.

2. To hear the tone 'C_4' you would have to drive 151 km/h (94 mph).

MAKING A MUSICAL HIGHWAY

Footage from YouTube

ALL QUIET ON BOARD

A 34,000 DWT bulk carrier, provided by the Hakodate Dock Co., Ltd

Noise is a significant issue for anyone working on ships. Even moderate noise and vibration can affect comfort and lead to a drop in performance. Professor Hideyuki Shuri, an authority on ship noise, has been working for many years to overcome the challenges.

It is important to regulate noise levels on ships. The goal of the International Maritime Organization (IMO) noise level code on board ships, which became mandatory for new ships in July 2014, is to protect mariners against hearing loss, improve comfort levels and make aware the need to communicate with colleagues and hear alarms. The level and duration of noise and the length of sailing time

have a significant influence and are taken into account when calculating the noise limits according to the regulations. The IMO code recognizes the need to establish different noise level limits for machinery spaces, control rooms, workshops, and accommodation areas on ships; you don't want sailors to have to wear hearing protection while sitting in a dining room, recreation room or sleeping compartment.

SOURCES OF NOISE

Mariners are affected by a variety of mechanical, aerodynamic and hydro-acoustic noise. The main sources of ship noise are the main propulsion engines and the generators. In addition, auxiliary engines, pumps, turbochargers, compressors, fans, piping, and heating and air conditioning systems all generate noise, as do propellers, thrusters and exhaust systems.

EXPERTISE IN SHIP NOISE AND VIBRATION

Professor Shuri, who currently works at Tokai University in Japan, has more than 34 years of experience working for two shipbuilding companies: Hitachi Zosen Corporation and the Universal Shipbuilding Corporation. His roles have included senior researcher and laboratory chief, developing noise prediction programmes for ships and offshore structures, and studying noise control technologies.

SHIPBUILDING RESPONSIBILITIES

It is difficult to limit ship noise because the vibration from the sources propagate through the steel structure, which has very little damping and, for example, the structure near residential cabins can radiate sound.

The IMO noise level code for ships includes:

- A format for noise survey reports (mandatory)
- Guidance on the inclusion of noise issues in safety management systems (recommended)
- Suggested methods of attenuating noise (recommended)
- A simplified procedure for determining noise exposure (recommended)

All shipowners have to meet the new noise regulations for new ships with a gross tonnage of 1,600 and over. If the noise level exceeds the regulations, shipbuilders can't deliver the ships. Usually the noise level limits of cabins and working spaces are described in the ship construction contract between shipbuilders and owners. ▶

PROFESSOR HIDEYUKI SHURI

Professor Hideyuki Shuri's work includes developing noise prediction programmes for ships:

- April 1974 to August 2002: Worked for the Hitachi Zosen Corporation
- September 2002 to March 2008: Worked for the Universal Shipbuilding Corporation
- April 2008 – present: Professor at the Department of Navigation and Ocean Engineering, School of Marine Science and Technology, Tokai University, Japan

"SINCE I JOINED THE SHIPBUILDING INDUSTRY IN 1974, I HAVE USED BRÜEL & KJÆR EQUIPMENT TO MEASURE AND ANALYSE NOISE AND VIBRATION. WHEN I STARTED, I USED THE BRÜEL & KJÆR 2203 SOUND LEVEL METER TO MEASURE NOISE LEVELS ON SHIPS."

PROFESSOR SHURI

ALL QUIET
ON BOARD

Measuring the noise level of a diesel generator set

Measuring the vibration acceleration level of a diesel generator set

Measuring the vibration acceleration level on a cabin wall

CONTINUOUS NOISE EXPOSURE CALCULATION

Daily noise exposure level ($L_{ex,24h}$) represents the equivalent noise exposure level for a period of 24 hours.

$$L_{ex,24h}=L_{Aeq,T} + 10 \log (T/T_0)$$

where:
T is the effective duration on board
T_0 is the reference duration 24 h.

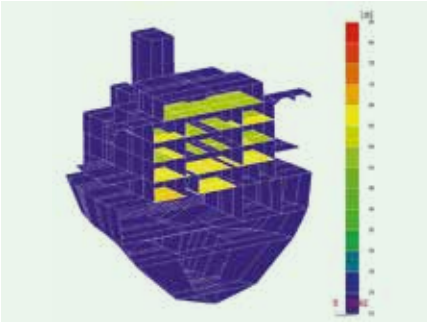
The total equivalent continuous A-weighted sound pressure level ($L_{Aeq,T}$), is calculated using the different noise levels (L_{Aeq,T_i}) and associated time periods with the following equation:

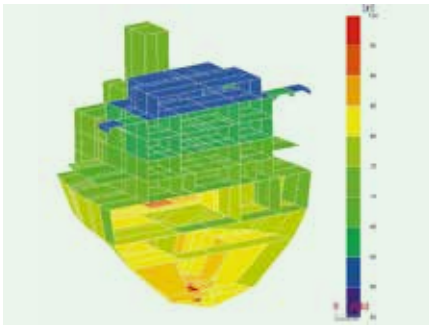
$$L_{Aeq,T} = 10 \log \left[\frac{1}{T} \sum_{i=1}^{n} (T_i \times 10^{0,1 L_{Aeq,T_i}}) \right]$$

Where L_{Aeq,T_i} is the equivalent continuous A-weighted sound pressure level, in decimals, averaged over time interval T_i;

$$T = \left[\sum_{i=1}^{n} T_i \right]$$

$L_{ex,24h} = L_{Aeq,24h}$ when seafarers are on board for a period of 24 hours.





The vibration acceleration levels of a ship's structure (right) and the noise levels in cabins (left), calculated by a noise prediction programme

To comply with the noise level limits, shipbuilders:

- Estimate ship noise during the early design stage
- Implement noise control measures to reduce noise levels, if necessary
- Conduct noise control treatments during the building process
- Measure noise levels during sea trials

Finally, shipbuilders and shipowners confirm that the measurements satisfy the noise level limits. The noise limits are designed so that within each day or 24-hour period the equivalent continuous noise exposure for a seafarer does not exceed 80 dB.

To understand the current situation, the noise levels of 39 existing ships (mostly bulk carriers and oil tankers) were measured during sea trials. For ships of 150,000 GT, the average noise level in cabins or hospitals was around 55 dB and for ships of 5,000 GT, the average noise level was greater than 65 dB. These results indicate that noise levels in cabins are generally greater for smaller ships and that it is necessary to reduce the noise levels more than 5 dB in order to satisfy the noise level limits of the IMO noise code.

TACKLING NOISE

If the results from the sea trials do not satisfy the noise limits, shipbuilders carry out additional measurements to find the noise sources and the transmission route from the source to the receiving rooms.

After analysing noise and vibration acceleration data, shipbuilders can investigate which is more dominant: structure-borne sound or airborne sound in the receiving room. Then shipbuilders have to decide on cost-effective noise-control measures. For example, to minimize accommodation noise levels it could be necessary to reduce structure-borne noise by isolating exhaust systems and certain pipe work and duct work from casings, bulkheads, etc.

MEASURING BOTH NOISE AND VIBRATION LEVELS

The IMO noise level code stipulates how to measure noise levels on ships, detailing the requirements for measuring equipment, operational conditions during sea trials, and the measurement procedures.

"The Brüel & Kjær 2250 is popular among ship manufacturers as it measures both noise and vibration acceleration levels and this is very useful in order to investigate noise control measures," explains Professor Shuri. "The 2250 can also carry out transmission loss measurements of a cabin construction and provide the absorption coefficient measurements in a cabin, which are necessary measurements when investigating noise control."

TWO PROJECTS FOR JAPANESE SHIPBUILDERS

Recently, Professor Shuri and Brüel & Kjær have been working together on two projects for the cooperative association of Japanese shipbuilders. The first project started in April 2011 and will finish in April 2016. "The aim of this project is to develop noise prediction programmes for shipbuilding engineers," explains Professor Shuri. "Our second project, which started in March 2015 and will also finish in April 2016, is about developing noise control technology to effectively reduce noise levels in cabins."

These projects aim to obtain a lot of accurate noise and vibration data during sea trials and to measure many acoustic properties, such as transmission loss of a cabin construction and the absorption coefficient of cabins. "This data is necessary for the development of noise prediction programmes and to verify noise control measures," says Professor Shuri. "Shipbuilding engineers have measured noise and vibration data and acoustic properties on more than 30 ships using a 2250 and have used the building acoustics measurement system. We have obtained a lot of data, relying on technical support from the engineers at Brüel & Kjær Japan," explains Professor Shuri. ▶

NOISE LEVELS (DB) FOR SHIPS OF 1,600 GT AND OVER

WORK SPACES

- Machinery spaces – 110
- Machinery control rooms – 75
- Workshops – 85
- Other work areas – 85

NAVIGATION SPACES

- Navigating bridge and chartrooms – 65
- Look-out posts, incl. navigating bridge wings and windows – 70
- Radio rooms – 60
- Radar rooms – 65

ACCOMMODATION SPACES

- Cabin and hospitals – 60 (55 for ships over 10,000 GT)
- Mess rooms – 65 (55 for ships over 10,000 GT)
- Recreation rooms – 65 (60 for ships over 10,000 GT)
- External recreation areas – 75
- Offices – 65 (60 for ships over 10,000 GT)

ALL QUIET **ON BOARD**

The setup for measuring the absorption coefficient in a cabin

DESIGNING TO REDUCE NOISE

Shipbuilders are gradually improving ship designs to reduce noise. For example, adding damping materials to steel structures and employing floating floors and high-performance insulation walls to help reduce noise levels in cabins. Advances in engine-mounting systems have also lowered noise and kept it from travelling through a ship's hull. Sound insulation is also used more effectively in ship machine spaces than in the past, to reduce the airborne sound from machines.

Engineers working for shipbuilders are increasingly using noise prediction programmes to improve ship designs, predicting cabin noise levels early in the design process. And they are also developing noise control measures in cooperation with material manufacturers to effectively reduce noise levels in cabins.

"To effectively reduce noise, engineers need precise noise predictions, which can be made early in the design process, along with the proper implementation of noise control measures and the accurate measurement of noise and vibration," says Professor Shuri. "There is a need to continuously improve noise control materials, and develop new technologies in cooperation with engineers, according to the requirements of shipbuilders."

STRICTER REGULATIONS TO COME

These projects are still ongoing but it is clear that precise noise and vibration measurements, involving both the right equipment and the right methods, are essential for the shipbuilding industry. Brüel & Kjær continue to help shipbuilders achieve greater accuracy, to better meet the noise regulations. "I believe that the requirements for reducing noise levels will increase and noise level limits will become even stricter in the future," says Professor Shuri.

Looking to the future, Professor Shuri believes that noise source identification technology is one of the most effective methods to reduce noise on ships: "To provide an effective method for engineers, I hope to develop practical usage rules for noise source identification in ship cabins during sea trials, in cooperation with engineers from Brüel & Kjær Japan," concludes Professor Shuri.

> "I BELIEVE THAT THE REQUIREMENTS FOR REDUCING NOISE LEVELS WILL INCREASE AND NOISE LEVEL LIMITS WILL BECOME EVEN STRICTER IN THE FUTURE."
>
> PROFESSOR SHURI

HAND-HELD ANALYZER TYPE 2250 IN BRIEF

- Advanced, single-channel, hand-held analyzer
- Performs high-precision, Class 1 sound measurements in environmental, occupational and industrial application areas
- Versatile, cloud-enabled modular platform
- Optional application modules include frequency analysis with 1/3-octaves, FFT, advanced logging (profiling), reverberation time and sound recording
- Field measurements are supported by an advanced companion app

A NEW WHITE PAPER FROM THE STACKS

MEASURING VIBRATION CHARACTERISTICS IN SEATING

A long commute is often stressful and tiring, so comfortable seating becomes increasingly important for drivers as well as passengers. But how do we test the overall comfort quality of seats?

A comfortable and pleasant ride is an important factor for drivers and passengers alike when they decide which vehicle to buy. Vibration induced by powertrain, ancillaries and road can dramatically affect how passengers judge the quality of the ride. The design of a comfortable seat is, therefore, paramount, as it is a means of reducing the vibration excitation affecting drivers and passengers. In order to efficiently evaluate seats in terms of vibration ride, an objective algorithm that can predict the subjective perception of seat vibration is required.

Many studies have been done to predict the subjective perception of riding vibration comfort. ISO 2631 is the most often used standard for this purpose. The relevant studies and standards are based only on the estimation of vibration energy with a frequency weighting function applied and often do not take into account the amount of temporal variation.

In collaboration with Toyota, two subjective experiments for seat vibration quality were conducted on road as well as in Brüel & Kjær's full vehicle NVH simulator. While the on-road subjective assessment provides more realistic ratings of seat vibration quality, it is not cost-effective and does not provide the subjects with the possibility of back-to-back comparisons, that is, comparing two or more different seats, one after another, within the same experimental session.

The current joint investigation proposed an algorithm called 'Vibration Roughness' correlating with overall subjective pleasantness by considering the temporal variation of vibration signals together with the overall vibration energy. Vibration Roughness explained our subjective data better than the traditional metrics using only vibration energy, and the predicted results were less affected by the sensor locations and directions.

SEE MORE
Read the full white paper at

www.bksv.com/whitepapers

EXPERT PROFILE

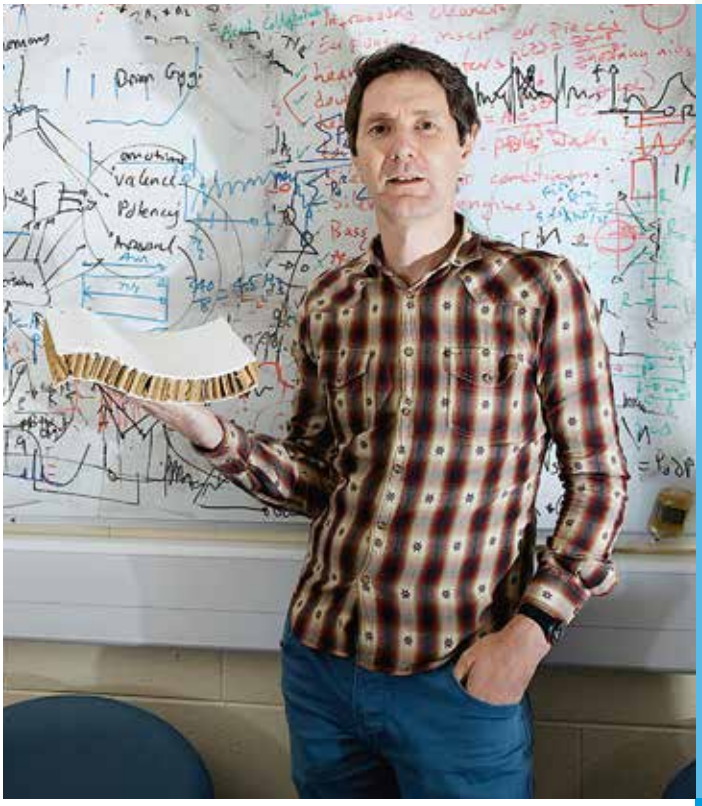
UNIVERSAL MAN

PROFESSOR TREVOR COX
BSC, PHD, FIOA (HON)

Location:	University of Salford, UK
Position:	Professor of Acoustic Engineering, author and freelance radio presenter
Expert:	Architectural acoustics, perception and digital signal processing (DSP)
Mission:	Improving acoustics, engaging the public
1989:	BSc Physics, University of Birmingham
1992:	PhD Acoustics, University of Salford
1993:	Lecturer, London South Bank University
1995:	Lecturer, University of Salford
2006-11:	EPSRC Senior Media Fellow
2010-12:	President, Institute of Acoustics

> "I FIND INSPIRATION ALL AROUND ME, BECAUSE I'M VERY CURIOUS ABOUT HOW THE WORLD WORKS."
>
> TREVOR COX

He writes academic books, carries out scientific research, presents TV documentaries, makes radio appearances, writes science books and presents science shows reaching 15,000 schoolchildren. Add to this a full time position as Professor of Acoustic Engineering at the University of Salford and you have the multi-faceted, 49-year-old, Bristol-born, Trevor Cox.



Why do you do what you do?

What makes acoustics especially interesting to me is that it combines both physics and psychology. The ultimate judgement as to whether an acoustic engineering project has worked is usually made by a human (for example, a member of the public) listening to the results. Understanding the human mind is one of the most exciting areas of research at the moment.

What initially drew you to acoustics?

I played music throughout my childhood, and combining my interests in music with my expertise in physics seemed the perfect combination for my PhD studies.

What are the challenges and rewards of your work?

In general, people in acoustics have to work hard to get sound to be given sufficient priority. Modern human beings are very focused on sight and this bias permeates academia and industry. I'm always fighting to ensure sound isn't completely overlooked.

Teaching students is the most challenging and rewarding part of my job. There will always be students who struggle at some point during a course, and so it is a constant challenge to try to come up with new ways of putting across complex concepts to help their learning. However, it is very rewarding, and I particularly like hearing about what our graduates are doing. Salford has been running acoustics courses since the 1970s, so we have graduates across the world in many different industries. One of the nice things about social media, is nowadays you get to hear about what they're doing.

Is there a turning point or defining moment in your work?

My first area of research was in the design of room acoustic diffusers for studios and performance spaces. I spent my PhD understanding how they worked. I then realized I could use numerical optimization to allow designs of any shape. This was a key development, because it enabled diffusers to match the visual requirements of architects, and has led to my designs being used worldwide. As an engineer, seeing your research being exploited is immensely satisfying.

You're a professor of acoustics who regularly appears in print, onstage, online, on radio and television – from the New Scientist to The Royal Albert Hall to YouTube and the BBC. How do you reconcile the academic with the public persona?

If you meet me face-to-face you'll find I'm a typical introverted engineer, a typical Englishman almost poleaxed by the fear of causing embarrassment, but one who is also very good at pretending to be outgoing! I've never tried to cultivate a public persona. Friends have commented that it is funny reading my popular science book 'Sonic Wonderland', because it feels like I'm having a conversation with them. ▶

UNIVERSAL
MAN

What are the best and worst decisions you have ever made?
My best decision was to never discuss my worst decisions in public.

Trevor Cox playing the saxophone in the oil storage tank in Scotland where he recorded the world's 'longest echo'

You seem very comfortable with social media – how has this changed the way you approach your work?
I see Twitter as a publicity game that I have to play. Although that sounds negative, there are some real positives, like when people tweet to say they've enjoyed a radio programme. It can also be a useful research tool for asking questions.

Any personal ambitions unattained?
It would be nice to present a TV documentary. But it's hard to get a sound documentary on TV that isn't about music, because commissioners always think audio is better suited to radio. Failing that, I'd like to get a returning programme commissioned on BBC radio. I'm making a pilot for such a series this spring.

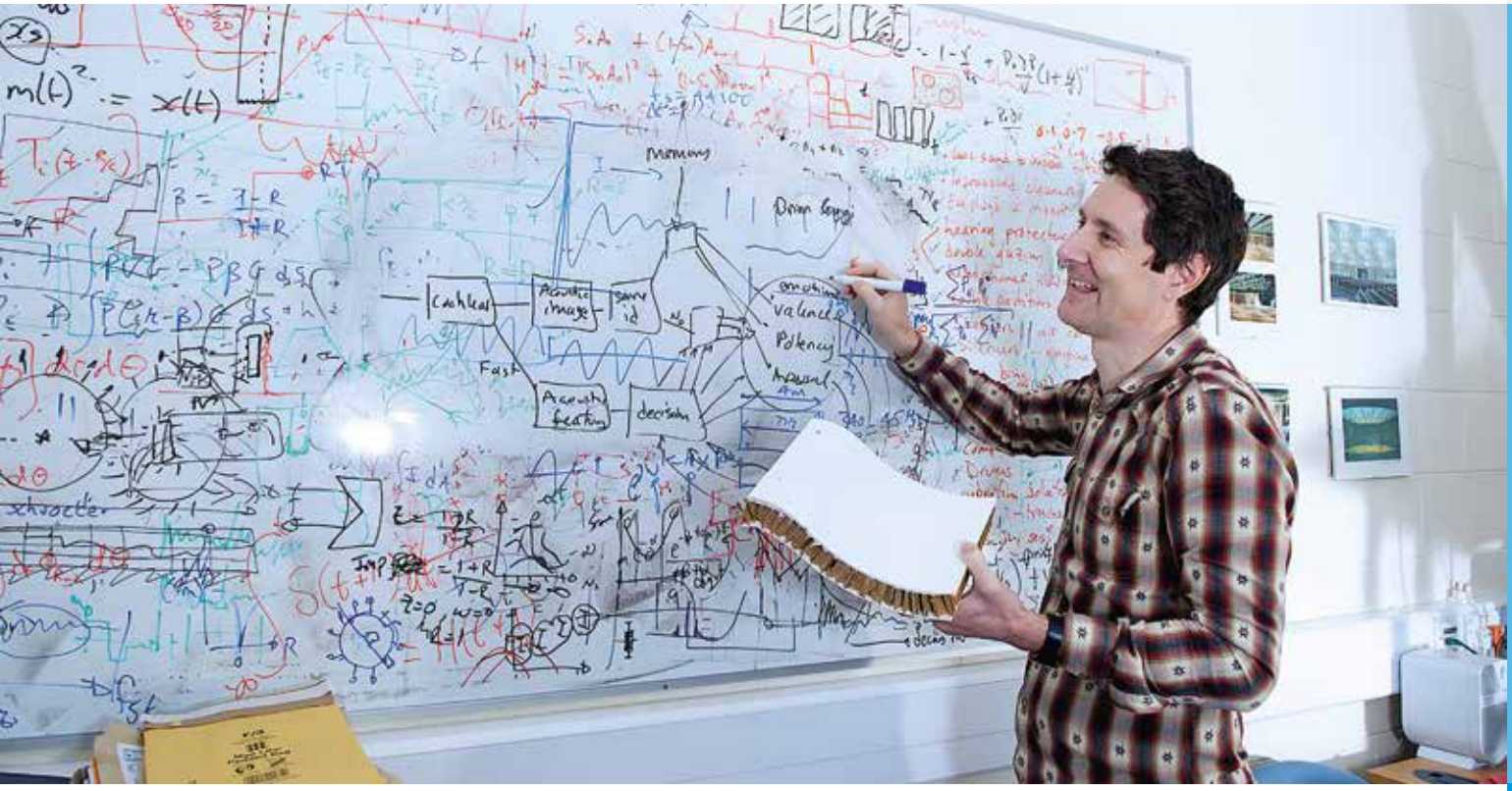
Many acousticians have an incredible understanding of and true talent for music, many of them proficient in playing a number of musical instruments. Are acousticians frustrated musicians?
There's a big difference between being a professional and amateur musician. Being an amateur you can concentrate on enjoying it – very different to being a professional. I think if I were a professional musician, the joy would go out of playing.

Your projects seem to range from serious to quirky – making music from vegetables, acoustic analysis of the world's 'longest echo' and the science of scary screams to name but a few. What was your favourite project?
Hunting the sonic wonders of the world was very special because it took me around the globe to hear so many different sounds in so many strange places: a military oil tank in Scotland with the world's 'longest echo', booming sand dunes in the Mojave Desert and an organ made out of cave formations to name just three examples.

Any unexpected outcomes to any of them?
I was pretty sure that the military oil tank in Scotland would break the world record, but I was surprised by how much more reverberant it was than the previous world record holder – it added a whole minute to the record. The tank was constructed to be bomb-proof, leading to a place where a loud low note on a saxophone lasts a couple of minutes before dying away to silence.

What's your latest project?
I'm just about to start writing a new popular science book called 'Speech Odyssey'.

TREVOR COX USED THE INTERNET TO DISCOVER THE WORST SOUND IN THE WORLD



Trevor Cox writing on the white board in his office. The object in his hand is a diffuser sample. Diffusers are used to treat sound aberrations in rooms such as echoes

Talking about his popular science book 'Sonic Wonderland' at Café Scientifique, Manchester just a couple of days after breaking his shoulder

Where is acoustic research heading?

Much of my research nowadays is focused on audio because of the growth in the number of devices we all carry around with us that use sound, such as mobile phones, and the capability of modern computing to allow the sound to be manipulated. I'm just starting work on a big data project called 'Making Sense of Sound', working with colleagues at Salford and Surrey University. It is looking at how to take the vast amounts of audio data being generated (for example, uploaded online) and trying to develop tools to allow computers to make sense of it.

What is your favourite sound?

The sound of my children playing and chatting away to themselves when they were younger. Now they're eighteen, and don't do it anymore!

TEN YEARS WITH THE ARC

This year, the MSC Application Research Center (ARC) lab, located just outside Detroit, Michigan, celebrates its 10-year anniversary. For the past decade, this unique noise and vibration solution facility has been providing state-of-the-art NVH testing capabilities for a broad range of projects.

KNOWLEDGE AND EXPERIENCE IN ONE LOCATION

Noise and vibration testing is a crucial challenge for many companies, whether they have a large engineering staff or they are a small company being asked to do this for the first time. It can be a perfect solution to take advantage of Brüel & Kjær engineering services at the ARC, because it has product development labs, engineering simulation facilities and state-of-the-art testing hardware all in one place. In addition to all the latest types of test equipment, applications and solutions, this rare one-stop facility has the expertise of dedicated Brüel & Kjær staff on hand to help gain insights and find effective engineering strategies.

REVERBERATION CHAMBER

The hemi-anechoic chambers are intended for measurements where you want to be sure that the sound is not reflected and measured more than once. The opposite of this is the reverberation chamber, where you want sound to reflect as much as possible. In the reverberation chamber, the goal is to have a uniform sound field at any given point in the room. This is useful for transmission loss tests and also for sound power tests. Sound power is a measure of the acoustic energy being radiated by a test subject. These tests are usually controlled by standards that dictate the number and positions of microphones to be used and are specific to the application.

TYPES OF TESTS

- Transmission loss testing
- Sound power testing

TYPICAL TEST OBJECTS INCLUDE:

- Household appliances (for example, dishwashers and vacuum cleaners)
- Other consumer products (for example, power generators and concrete saws)

CASE STUDY

For a home-appliance company, engineers used the sound power measurement technique to test numerous appliances, such as dishwashers, vacuum cleaners and washing machines. It has also been used for testing other consumer products, for example power generators and concrete saws.

BY: **ERIC FRANK**
Operations Manager
Global Engineering Services
Brüel & Kjær
North America

FULL ANECHOIC CHAMBER

Similar to the structural hemi-anechoic chamber (SHAC), the purpose of the full anechoic chamber (FAC) is also to avoid any reflections for very precise measurements. The FAC is smaller in volume and the sound absorbent cones used on the walls in the SHAC and the acoustic hemi-anechoic chamber (AHAC) are also used on the floor, for further reduction in reverberation. There is a port in one of the walls adjacent to the reverberation chamber, which can be used to mount samples for transmission loss testing. Since the ambient noise level in the FAC is much lower than in the other chambers, it is a good resource for test subjects that produce very little sound.

TYPES OF TESTS

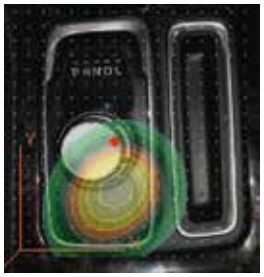
- General troubleshooting
- ISO or OEM standardized tests for automotive suppliers
- Transmission loss testing

TYPICAL TEST OBJECTS INCLUDE:

- Very quiet products, such as computer components
- Individual automotive parts, such as transmission shifters
- Medical instruments

CASE STUDY

An automotive supplier who was experiencing a problem with the shifter knob that they provide for luxury vehicles, used the FAC and its low ambient noise level to help solve the issue. Their part includes a mechanism that allows the driver to shift out of Park. The sound level of this was very quiet (less than 40 dBA), but still unacceptable in a high-cost sedan. A Brüel & Kjær beamforming array was used to identify the spot that radiated the most noise. This information allowed our team to disassemble the part to understand why that area was transmitting so much noise and to develop some countermeasures to improve their product. Ultimately, the noise was reduced by almost 9 dBA. This difference may not have been detectable in a standard test chamber with a higher level of ambient noise.



TEN YEARS WITH
THE ARC

STRUCTURAL HEMI-ANECHOIC CHAMBER

The structural hemi-anechoic chamber (SHAC) is the most commonly-used test chamber at the ARC because of its broad dimensions and versatile accommodation. It is equipped with a large steel bedplate floor with T-slots that make it very convenient for structural component testing. It also has a 10-ton overhead crane mounted near the ceiling for handling large materials or even for full-vehicle body separation and lifting. This chamber also has exhaust extraction capability and a CO_2 monitoring system, so a vehicle's engine can be operated without concern. It is located near the building's utilities, so it is convenient for products that require compressed air, 110 or 220-volt electricity or water.

TYPES OF TESTS:

- Structural component testing
- Modal testing
- Sound power testing

TYPICAL TEST OBJECTS INCLUDE:

- Consumer products, such as dishwashers, refrigerators or food-waste disposers
- Vehicle components from exhaust systems to electric parking brakes
- Large materials and full vehicles

CASE STUDY

Many of the SHAC's capabilities were used by Hyundai, a provider of commercial vehicles in the Korean market. The ultimate goal was to work with a CAE firm to redesign the truck's acoustic package based on Statistical Energy Analysis (SEA). This project included a Source Path Contribution (SPC) analysis to understand the airborne and structure-borne properties of the system. This meant that the team needed to disconnect the cab mounts from the frame and use air bags and the compressed air in the room to isolate the two structures. The overhead crane was used to support the free-floating passenger cab. Because of the room's acoustic treatment, the team was able to reassemble the truck and leave it in the same test chamber to perform the airborne sensitivity measurements by using a volume velocity source.

THE SOUND AND VIBRATION CONSULTANCY 'SOUND ANSWERS' HAS BEEN ACQUIRED BY BRÜEL & KJÆR, AND THE TALENTED WORKFORCE IS BECOMING THE CORE OF BRÜEL & KJÆR'S ENGINEERING SERVICES AT THE ARC.

ACOUSTIC HEMI-ANECHOIC CHAMBER

The acoustic hemi-anechoic chamber (AHAC) is also commonly used as a general-purpose test cell, but it has its own unique features. While it has the same physical dimensions and similar acoustic properties as the SHAC, it is intended to be used in transmission loss tests.

The AHAC is adjacent to two reverberation chambers – one below the test cell, the other to its side. The fundamental theory behind transmission loss testing is to mount a test article between two opposing acoustic conditions – one that is uniformly loud (reverberant), and another that is uniformly quiet and free from echoes (anechoic). A test article is normally mounted in a wooden buck, which is thoroughly sealed around its edges. Sound (close to 120 dBA) is blasted at the test article from within the reverberation chamber. A beamforming array or sound intensity probe is used on the quiet side of the test part to understand location and frequency content of any weak spots. The reverberation chambers, both above and below the AHAC, allow a part to be mounted just as it would be in real life, allowing accurate representation of its in-service attenuation performance.

TYPES OF TESTS:

- Transmission loss testing

TYPICAL TEST OBJECTS INCLUDE:

- Large panels – such as a vehicle's floor plan
- Sealant products of various compositions

CASE STUDY

Transmission loss testing is used with ISO Standards to qualify sealant products of various compositions. For example, in one project, each sample was mounted in the middle of a metal channel, which was built into a test panel between the two chambers. With such a small area, a single microphone could be used in place of an array to measure the transmission loss of each sample and the sealant products could be ranked, showing which performed the best in a specific frequency range.

TEN YEARS WITH
THE ARC

4-WHEEL-DRIVE CHASSIS DYNAMOMETER

While the SHAC has exhaust extraction, which allows staff to test a running engine in a vehicle, this is rarely enough information to resolve a complex issue. In normal road driving, a vehicle's powertrain behaves very differently, which changes the sound and vibration characteristics dramatically. This is where the 4-wheel-drive chassis dynamometer comes in. It provides a repeatable way to test a vehicle's powertrain and drivetrain under load, allowing engineers to test a vehicle under extremely controlled conditions that simulate driving it on the road. It is also pretty nice, for example, to be able to test a vehicle during Michigan's winter without worrying about snow!

Engineers can control the temperature and humidity of the room while the dynamometer is in operation to ensure the powertrain experiences test conditions are as faithful as possible. And to replicate the effects of a rough road in a repeatable way, an alternative 'road shell' can be added to the dynamometer's rollers.

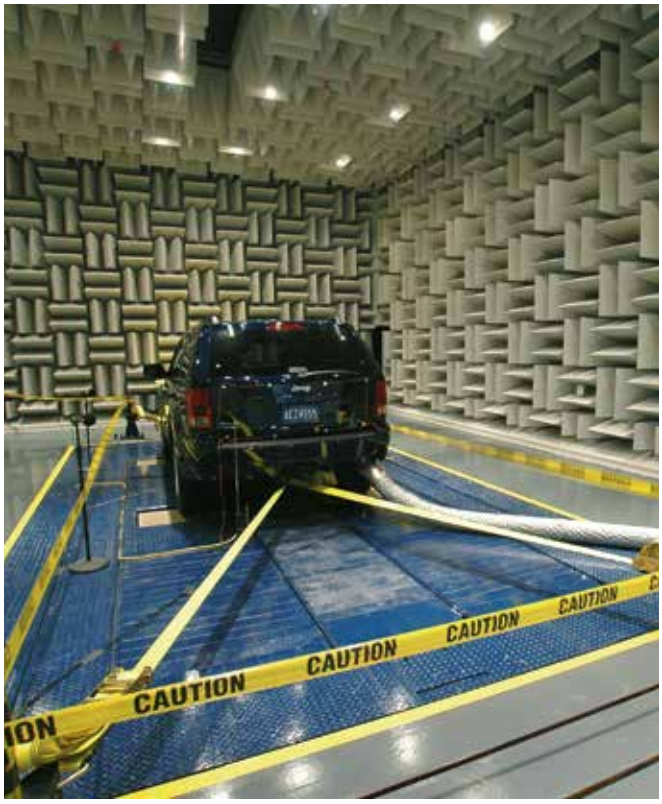
The rear axle of the dynamometer can be easily moved to accommodate the wheelbase of many vehicles. The machine's front and rear motors are each capable of providing or absorbing up to 300 horsepower. This means that the vehicle can be driven normally while the dyno is used to absorb the torque from the wheels or that the dyno can be used to spin the tyres and drivetrain of the vehicle. The torque from the motors allows engineers to control the vehicle in many configurations to problem-solve sound and vibration issues.

TYPES OF TESTS

- Vehicles' powertrain and drivetrain under load
- Automotive benchmark tests

TYPICAL TEST OBJECTS INCLUDE:

- All types of vehicles – from small sports sedans to flat-bed commercial trucks



CASE STUDY

Automotive OEMs often use the chassis dynamometer to outsource the logistic coordination and thorough testing of many cars from the same class. For example, Brüel & Kjær engineers worked with an exhaust manufacturer to test a Ford Focus, Volkswagen Jetta, Nissan Sentra, and five other similar cars in just a few days. This compares favourably to testing with normal road driving, which can take several weeks and which also contains considerable undesirable variability during each test. By using the chassis dynamometer, customers can be confident that differences found in the data are due to the car itself – not weather, road conditions or noise from other traffic.

JUST NOT IN THE MOOD

Brüel & Kjær received an unusual request from a Danish film-producer, who was working on a documentary on spiders. His production team were in the process of trying to record the mating dance of steatoda bipunctata spiders, also known as false widow spiders.

They had already filmed the male spider rubbing his lower body against his upper body in order to attract the attention of the female, but had severe problems trying to record 'macro'-sound with their equipment. The sound energy was simply too low for a TV production microphone.

The team explored the phenomenon in an anechoic chamber, which for this purpose, was equipped with high-sensitivity microphone Type 4955 and our new PULSE LAN-XI Type 3161 with a direct monitoring output connected to an active speaker in the control room.

Three female and four male spiders took part, but none of the males seemed to be in the mood for romance. After an expectant few hours our patience ran out. We gave the spiders a fly in the hope that we could at least get some sound recording done. Seconds later, the footsteps of the seven spiders could be heard alongside the intense sound of a fly in its death throes. The battle lasted a few minutes and then all was silent again. The spiders' appetite for food was obviously greater than that for love. Time for an afternoon snack …

Hear the impressive recording of spider footsteps

The struggling fly who lost the fight

ENGINEERING SERVICES EXPAND WITH SOUND ANSWERS ACQUISITION

As sound and vibration solutions have become more complex, companies sometimes need more than a simple understanding of how to make measurements; they need help to solve their challenges. To strengthen the engineering services that Brüel & Kjær can offer, Detroit-based sound and vibration consultancy, Sound Answers, has now become part of Brüel & Kjær.

The engineering team from Sound Answers brings on board new insights and domain knowledge gained while solving problems for diverse customers in the automotive and aerospace industries, and with off-highway and consumer products. Sound Answers and Brüel & Kjær were strategic partners for nine years, during which time the two companies established a long track record of joint projects and a tight relationship.

With this acquisition, Brüel & Kjær has extended its capability to provide sound and vibration troubleshooting and product development services. As Brüel & Kjær's Vice President of Global Sales & Services, Alan Humphrey says, "This is an exciting time for Brüel & Kjær. We've always recognized the high value that our relationship with Sound Answers has added to our business in the US. Now we have the opportunity to make that impact globally. We look forward to working with our new colleagues."

SOUND ANSWERS
PART OF BRÜEL & KJÆR

Measure exhaust noise with Noise Patrol

Correctly measuring the exhaust noise of motorcycles, cars and trucks is a challenge for police, whose measurements must comply with ISO standards, EU directives, and local country legislation.

To make the job easier, the new Noise Patrol Type 3665 measures the sound and detects the engine's speed at the same time. The system is built around a Type 2250-L sound level meter and an iPod®, and helpfully guides the user through the procedure necessary to meet the relevant standard.

For vehicles where it is not possible to detect the RPM from the sound alone, the system can also incorporate RPM by connecting to the vehicle's OBDII connector. For motorcycles and all-terrain vehicles, an optional inductor probe is available.

Get your real-time noise emissions on your iPhone

Subscribers to the noise monitoring service Noise Sentinel can now view environmental data on the go. A new mobile app called Noise Sentinel Stakeholder allows authorized users to access real-time or historical noise data from wherever they are. Companies in noisy industries like construction can also use it to more easily share their noise levels with the public, management, partners, and external authorities – by encouraging them to download a simple app. The app brings to any mobile iOS device the same functions that stake-holders currently use via their PC.

Download on the App Store

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Calibration guarantees your measurements are accurate, and ensures your peace of mind. But administering calibration wastes testing time, while accidentally neglecting it risks invalid data.

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CUSTOMER NEWS

ISS ASTRONAUTS CHECK THEIR ACOUSTIC EXPOSURE

Orbiting the Earth on the International Space Station (ISS) places unique stresses on astronauts, one of which is noise. Fortunately, the spacemen can monitor their acoustic conditions using a Brüel & Kjær Type 2260 sound level meter that is allowed to reside on the ISS – after receiving special flight approval some years ago.

But with few acoustic experts in space, the astronauts must learn how to use the instrument here on Earth. This meant that the European Astronaut Centre (EAC) needed another sound level meter to train on, with exactly the same user interface.

Despite the instrument being discontinued some years ago, Brüel & Kjær was able to send its very last Type 2260 on one final mission. The instrument has now been donated to the EAC, making a fitting end to its high-flying career.

Grundfos pinpoints tiny pump noise sources

Grundfos needs to be sure its pumps are quiet enough for both domestic use and industrial demands. During development, their engineers need to understand any noise sources, which also helps indicate any potential reliability issues.

To locate the most difficult-to-find noise sources during product development, Grundfos sought a new system, so they set up a demonstration challenge to decide which one. Grundfos engineers rigged a pump with two tiny sound sources, which Brüel & Kjær's array technology was able to quickly identify and visualize, at various frequencies and levels.

Grundfos new system will enable their engineers to identify noise sources from a range of distances, thanks to the array's unique geometry.

Mumbai Airport's NoiseDesk takes off

Mumbai's Chhatrapati Shivaji International Airport (CSIA Mumbai) is India's second busiest, handling approximately 36 million passengers and 700,000 tonnes of cargo a year.

CSIA Mumbai has initiated a noise abatement programme to comply with the International Civil Aviation Organization's (ICAO) 'balanced approach' to reducing aircraft noise impact on communities. To do it, the airport needed a comprehensive noise monitoring system that could eliminate background city noise and integrate data from different noise terminals to report noise levels through a single portal.

CSIA Mumbai chose the NoiseDesk subscription service to monitor noise and track flights 24/7 because of its simplicity and automation, which has enabled the airport to quickly implement a noise abatement programme with minimal staff. When a loud event occurs or a complaint is received, NoiseDesk automatically identifies which aircraft is likely to be responsible.

"With a more accurate understanding of our noise impact, we can plan changes that increase community comfort," said Mr Shailendra Joshi of CSIA Mumbai DGM Environment & Sustainability.

Dassault Aviation's Falcon 8X in noise certification tests

The newest business jet from the French manufacturer will provide comfortable long-range flights to discerning clientele, but first it must achieve flight noise certification.

Dassault Aviation has tested the Falcon 8X, gathering noise data for the effective perceived noise levels (EPNLs) for each of the flight conditions: approach, flyover and sideline. The European Aviation Safety Agency (EASA) will now make the official calculations using the data.

The Brüel & Kjær system used by Dassault Aviation uses three GPS-synchronized data acquisition stations that are distributed around the test area. They communicate via Wi-Fi, and are controlled from a central monitoring station that interfaces to flight-track data and layered weather data.

Faurecia revs up exhaust system test capabilities

Emissions control expert Faurecia works in three main areas – weight reduction, pollutant emissions control and energy recovery – to ensure its products meet the most stringent environmental standards and address the public's growing concern over dangerous emissions.

To ensure their exhaust systems can endure a lifetime close to the road, Faurecia's research and development test centre in Bavans has invested in a new shaker system from Brüel & Kjær. With the new system, Faurecia has increased its testing capacity, allowing thorough testing in a shorter time frame.

FIVE QUESTIONS FOR ZHIGANG CHU

At 37, Zhigang Chu is not only a Chief Engineer of Technical Support Team with Brüel & Kjær China but also an Associate Professor at Chongqing University. He is passionate about Huaiyang cuisine, in particular braised carp, crab meatballs and crab yolk buns. Without hesitation, he cites December 9, 2009 – the day his now six-year-old son was born – as the best day of his life.

MOTTO:
"乐于感恩"
"BE GRATEFUL, ALWAYS"

What attracted you to Brüel & Kjær?
I first got to know Brüel & Kjær when I was doing my Bachelor project at university. I used a really old-looking modal exciter for modal analysis. My supervisor asked me if I knew how old it was. It turned out that the exciter was five years older than myself – but it worked like a dream.

What drives you in your work?
Interest and the sense of accomplishment.

What are you passionate about?
Academic research, Mahjong and playing cards (Dou Dizhu).

What irritates you most about your own personality?
Impulsiveness. People are welcome to say that I'm not good enough, but I will argue with anyone saying that Brüel & Kjær or Chongqing University is not good enough!

If you could have two super powers, what would they be and why?
One – to understand all technologies and theories at a glance so that I could solve all technical challenges and wouldn't need to study any more. The second – to make my students and customers understand and accept whatever I tell them as soon as I tell them.

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