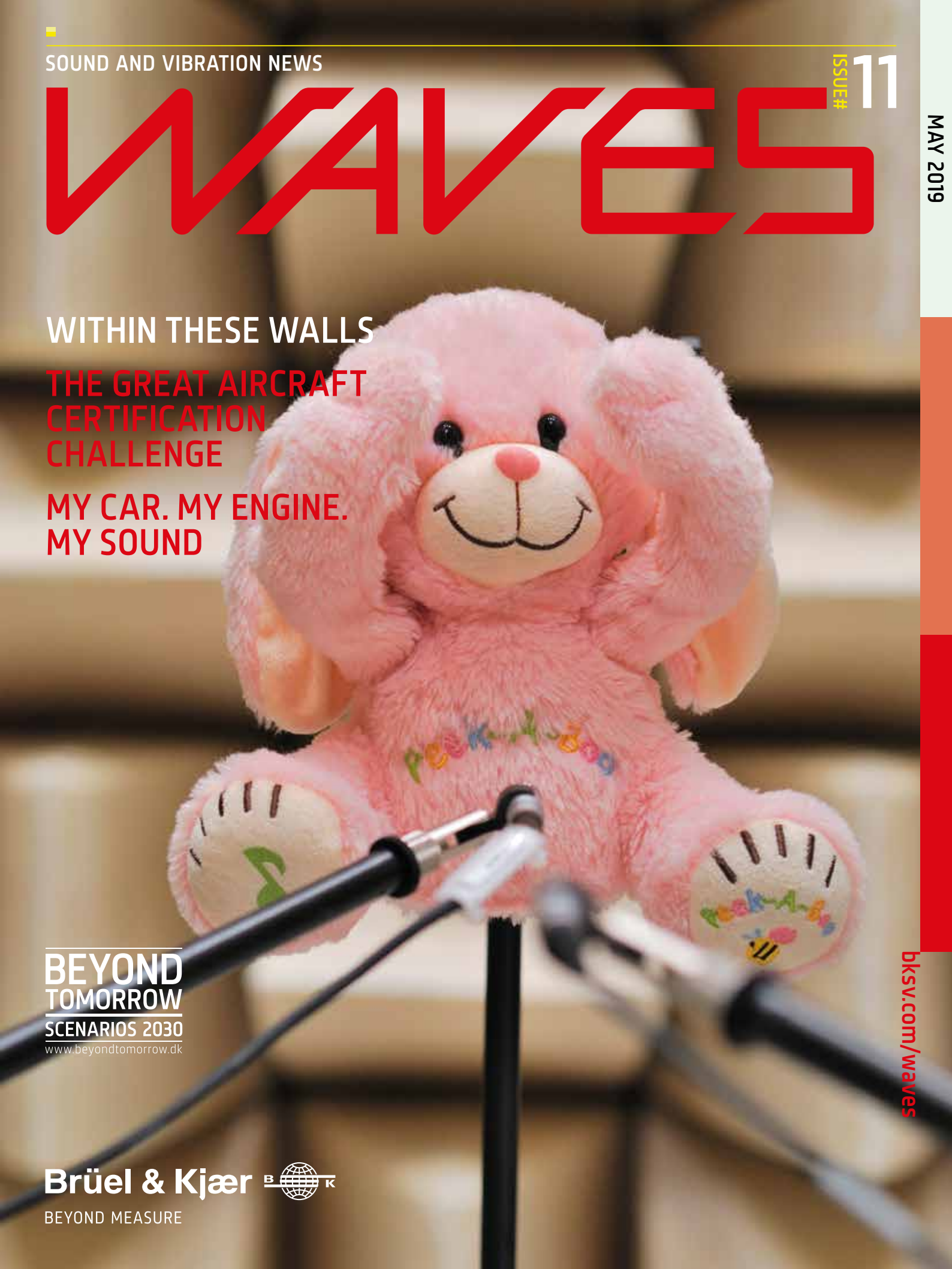
SOUND AND VIBRATION NEWS

WAVES

ISSUE# 11

MAY 2019



WITHIN THESE WALLS

THE GREAT AIRCRAFT CERTIFICATION CHALLENGE

MY CAR. MY ENGINE. MY SOUND

bksv.com/waves

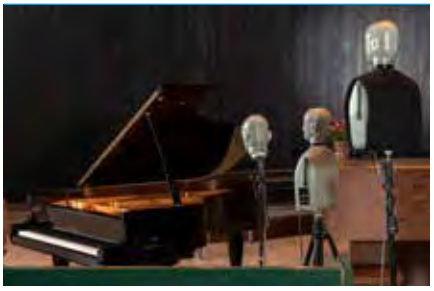
Brüel & Kjær
BEYOND MEASURE

CONTENTS

My car. My engine. My sound **4**

The greatest aircraft certification challenge **10**

Three HATS, one church and experimental music **26**



B&K 2245 – from drawing board to release **36**

EDITOR-IN-CHIEF
Henrik Ceder

COORDINATOR
Susanne Køhlert Jacobsen

WRITERS
Kim Boldt, Sheelagh Crewe, Rémi Guastavino, Bin Liu, Kristian Rymkier, Michael Whiteman

CONTRIBUTORS
Arne Bock, Bernard Ginn, Lars Kroman, Julian Simpson, Søren Jønsson

EDITORIAL OFFICE
Brüel & Kjær Sound & Vibration Measurement A/S
Skodsborgvej 307
DK-2850 Nærum
Denmark
Phone: +45 7741 2000
Fax: +45 4580 1405
Comments: waves@bksv.com
www.bksv.com/waves
Subscribe: www.bksv.com/subscribe

FRONT COVER IMAGE
Measuring toy noise at TÜV SÜD.
Photo courtesy of Sebastian Rieger

Brüel & Kjær
BEYOND MEASURE

LETTER FROM OUR PRESIDENT

STRONG FOUNDATIONS LEAD TO A GREAT FUTURE

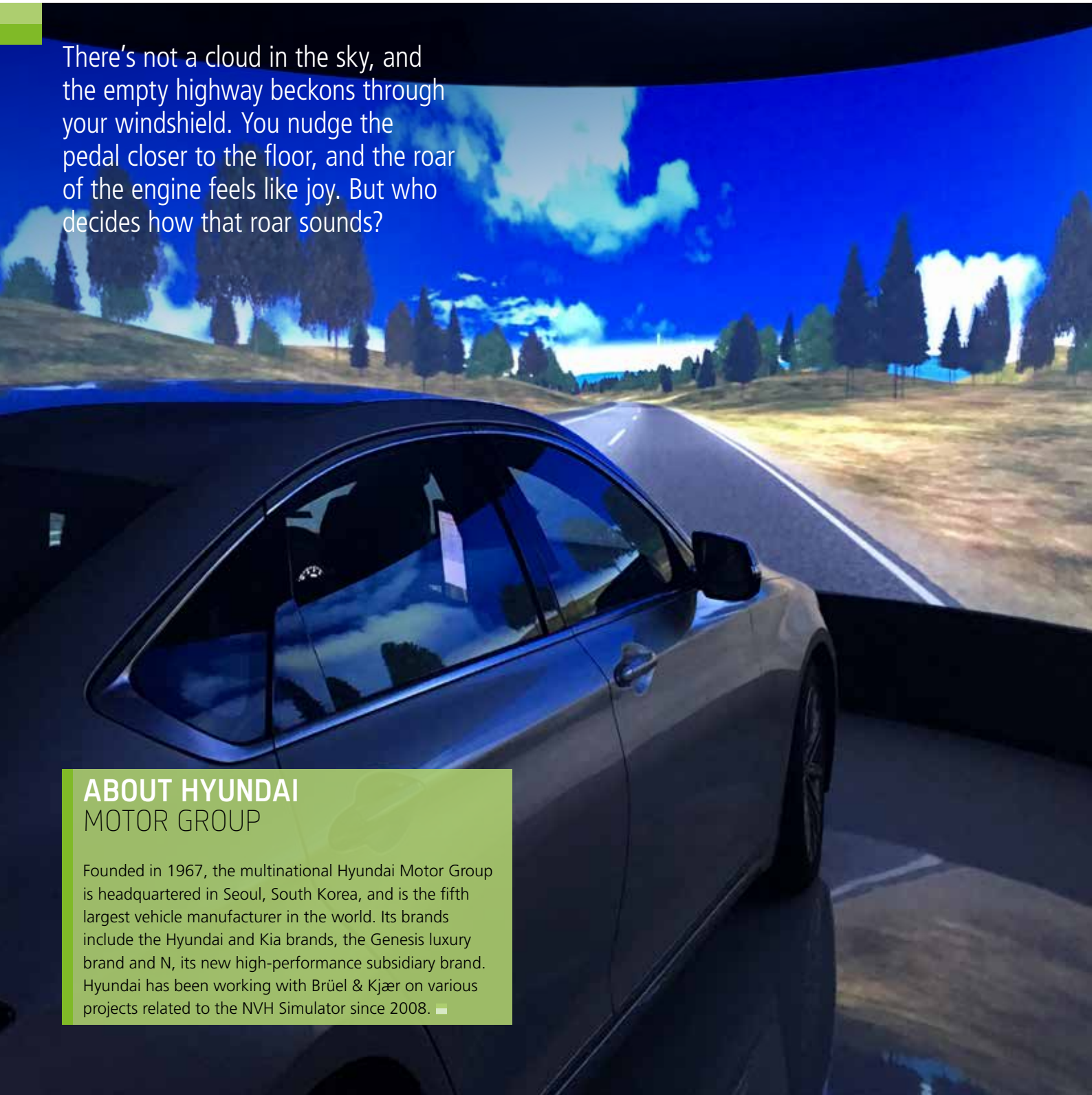
Since the last issue of Waves, Brüel & Kjær has experienced some exciting times. We've introduced a new sound level meter (SLM) with B&K 2245, merged with Hottinger Baldwin Messtechnik (HBM) to become Hottinger, Brüel & Kjær (HBK) and I am excited to have joined the team as the new president. This issue of Waves contains many articles that are representative of, not just the company's evolution, but also the ways in which we've stayed the same – a desire to ensure that our solutions provide the quality data that enable your best results.

Some articles can be retrospective, like *Historical milestones that shaped the sound level meter of today,* and remind us where the SLM began and show how far we've come. Others, such as *High-frequency HATS*, *why?* highlight new innovations for acquiring data that come ever-closer to the world we humans actually experience. And, of course, articles like *B&K 2245 – from drawing board to release*, provide a glimpse of how we consider the future and re-envision our mindset to provide a more solution-focused product.

As the new president, I would be remiss if I didn't comment on the future. The Beyond Tomorrow project resulted in a vision study that is focused on the role and methodology of product testing as we move towards 2030. The results (the views expressed by the vast majority of the industry leaders interviewed and the expert panel) indicated a single solution encompassing the entire testing gamut. With the union of Brüel & Kjær and HBM, we are progressing towards that target. And as the articles in this issue allude, this company will evolve and progress towards the testing trends and needs – but always with a firm foundation and always determined to lead the way in data quality and a solution-focused mindset.

JOE VORIH
PRESIDENT

MY CAR. MY ENGINE.



There's not a cloud in the sky, and the empty highway beckons through your windshield. You nudge the pedal closer to the floor, and the roar of the engine feels like joy. But who decides how that roar sounds?

ABOUT HYUNDAI MOTOR GROUP

Founded in 1967, the multinational Hyundai Motor Group is headquartered in Seoul, South Korea, and is the fifth largest vehicle manufacturer in the world. Its brands include the Hyundai and Kia brands, the Genesis luxury brand and N, its new high-performance subsidiary brand. Hyundai has been working with Brüel & Kjær on various projects related to the NVH Simulator since 2008.

MY SOUND

If you're driving a Hyundai, you decide how the engine sounds – with a little help from Brüel & Kjær.

Since 2015, Hyundai Motor Company (HMC) has been offering a Personalized Engine Sound System (PESS) in special vehicle models to enable customers to create different engine sounds in the same vehicle.

"PESS is the first functionality in the world that fits individual customer needs, and it provides customers with a pleasant driving experience," says Eun Soo Jo, Senior Research Engineer at HMC.

But until recently, the way Hyundai designed the Personalized Engine Sound System relied heavily on designing engine sounds in prototype vehicles driving on test tracks – a resource-intensive and sometimes unreliable process.

> "THE CHALLENGE WAS TO MAKE A TOOL THAT CAN GENUINELY INTERFACE TO THE DIFFERENT TYPES OF ASD CONTROLLERS BASED ON THE DRIVING CONDITIONS IN THE NVH SIMULATOR, SINCE EACH ASD CONTROLLER REQUIRES A SET OF DIFFERENT CONTROL SIGNALS TO BE USED."
>
> WOOKEUN SONG, PHD,
> RESEARCH ENGINEER, BRÜEL & KJÆR

DESIGNING ENGINE SOUND

For nearly a decade, many car manufacturers, including Hyundai, have used technology called Active Sound Design (ASD) to give an engine a preset target sound. An ASD controller generates the vehicle engine's sound based on various engine parameters, such as rpm, throttle and torque input. The ASD tool operates within an audio amplifier connected to the vehicle (see sidebar 'How Active Sound Design usually works'). ASD also plays a key role in the South Korean automobile giant's Personalized Engine Sound System.

"ASD allowed Hyundai's Personalized Engine Sound System to be implemented originally, but it required a lot of on-road tuning of the designed sounds," explains Wookeun Song, PhD, Research Engineer and key member of Brüel & Kjær's Innovation Lab. "Somebody needs to be driving the prototype car, and somebody else needs to be changing the settings. It's not just a one-step design process; you have to do it iteratively, which makes it very time-consuming."

Everything from different weather conditions to different road conditions have to be taken into account when tuning designed sounds. The repeatability of measurements can suffer with on-road tuning in prototype vehicles, due to changing background noise and operating conditions. And, it's not possible to conduct back-to-back comparisons between different ASD amplifiers or between different tunings. ▶

HOW ACTIVE SOUND DESIGN (ASD) USUALLY WORKS

The physical properties of a vehicle's engine and body normally determine the way it sounds inside the cabin. But ASD uses the vehicle's audio system to enable users to experience a manufacturer preset 'target' sound instead. A standard controller area network (CAN) bus unit collects real-time driving information from the vehicle, then sends that information to the ASD controller. Based on that input and the loudspeaker transfer function (that is, how a sound created at a specific point sounds inside the cabin by the loudspeakers), the controller composes a configured engine sound, which it sends through the loudspeakers.

MY **CAR.**
MY **ENGINE.**
MY **SOUND**

> "WE WANTED TO IMPLEMENT THE FUNCTIONALITIES THAT ENABLE INDIVIDUAL CUSTOMERS TO OPTIMIZE VEHICLE ENGINE SOUND BASED ON THEIR PREFERENCE USING ASD TECHNOLOGY."
>
> DR DONG CHUL PARK, RESEARCH FELLOW AT HMC (HYUNDAI MOTOR COMPANY)

What's more, demand for the prototype vehicles is huge. "The ASD designer, the door designer, the person setting up the amplifier... everyone wants to get access to this vehicle," says Wookeun.

FROM ON ROAD TO IN LAB

In addition to using ASD in vehicle prototypes, Hyundai uses a desktop noise, vibration and harshness (NVH) simulator from Brüel & Kjær to 'drive' cars in development. The NVH Simulator, however, was not part of its initial process to develop the Personalized Engine Sound System.

The NVH Simulator enables the user to evaluate, modify and design vehicle operating sounds interactively by 'driving' through a virtual scenario shown on a desktop monitor.

It uses driver controls (accelerator, gears, steering, brake) as inputs to a real-time sound model that accurately recreates the sound of a vehicle. And all the work takes place in a lab, rather than on the road.

Wouldn't it be great if the active sound design process also could be done in a desktop simulator, reducing the amount of time spent using actual prototypes.

That's what Hyundai thought, too.

OPTIMIZING THE PERSONALIZED SOUND DESIGN PROCESS

"We wanted to implement the functionalities that enable individual customers to optimize vehicle engine sound based on their preference using ASD technology," says Dr Dong Chul Park, Research Fellow at Hyundai. "We thought that the technologies related to Brüel & Kjær's NVH Simulator could enable us to develop various engine sound designs for our customers."

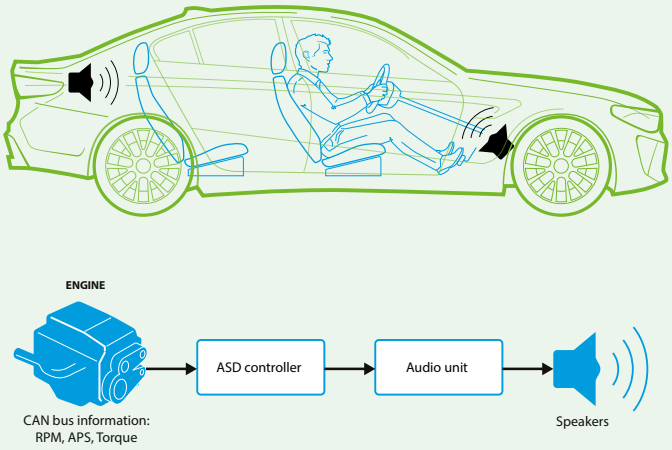
Once Hyundai explained the challenges they were experiencing, Brüel & Kjær created a plan to tackle them.

Chief among the hurdles was the fact that the NVH Simulator and the ASD controller that Hyundai was using at the time run in two different environments: the ASD controller is integrated with a vehicle's audio system, and the NVH Simulator runs in a computer. What's more, different ASD controllers from different suppliers have different parameters to be tuned, making a one-size-fits-all approach even more difficult.

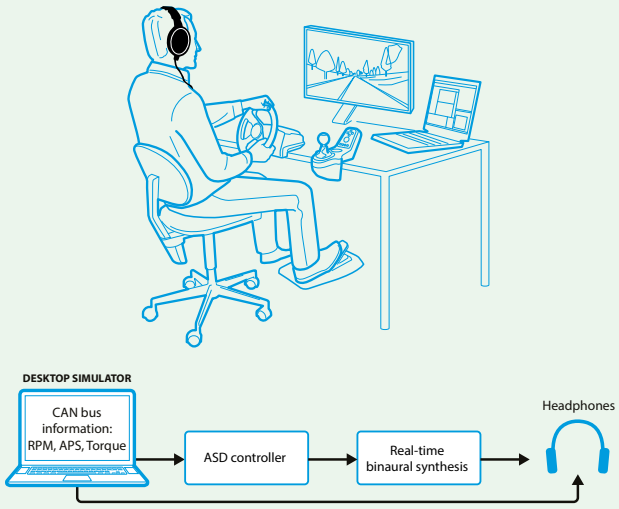
WHAT IS CAN BUS?

CAN bus is a standard controller area network that collects driving data such as rpm and torque from the vehicle.

TYPICAL ACTIVE SOUND DESIGN (ASD) SETUP



IMPROVED ASD SETUP



"The challenge was to make a tool that can genuinely interface to the different types of ASD controllers based on the driving conditions in the NVH Simulator, since each ASD controller requires a set of different control signals to be used," says Wookeun.

Together, Hyundai and Brüel & Kjær defined the specific project goals: first, to develop computer software that can combine the output of the NVH Simulator and the ASD sounds in real time – providing data compatible with the ASD controller; second, to run subjective evaluations and objective analyses for Hyundai's ASD settings – demonstrating a more optimized sound design process.

A UNIQUE SOLUTION

Wookeun and his colleagues in the Brüel & Kjær Innovation Lab met the goals in roughly one year, and Hyundai started using the new software tools for ASD in 2018. To Brüel & Kjær's knowledge, it is the first time any company has developed such a solution.

KEEPING IT PERSONAL

The Personalized Engine Sound System (PESS) concept, which Hyundai started offering in 2015, fits perfectly into the consumer trend of customizing purchases to reflect personal taste and preferences. While a typical ASD setup provides the customer with a target sound preset by the manufacturer, Hyundai's PESS can predefine different engine sounds such as dynamic, sporty and extreme, depending on the vehicle. The driver can easily select and adjust each engine sound type, volume and tone as well as the sensitivity of the accelerator using the audio-video navigation system in the dashboard.

MY **CAR.**
MY **ENGINE.**
MY **SOUND**

"PESS IS THE FIRST FUNCTIONALITY IN THE WORLD THAT FITS INDIVIDUAL CUSTOMER NEEDS, AND IT PROVIDES CUSTOMERS WITH A PLEASANT DRIVING EXPERIENCE."

EUN SOO JO, SENIOR RESEARCH ENGINEER AT HMC (HYUNDAI MOTOR COMPANY)

The NVH desktop simulator that is part of the solution does not generate CAN bus signals that can interact with Hyundai's ASD controllers. However, Brüel & Kjær made a tool for the simulator that generates appropriate CAN bus signals and unique new software connects the NVH Simulator to the ASD controller to generate the ASD sounds according to the simulator's operating conditions.

"In an on-road situation, there's a mixture of the ASD sounds from the loudspeakers and the vehicle sound on road. My goal was to simulate this by performing the binaural synthesis of ASD sounds from the loudspeakers and combining it with the binaural signal from the NVH Simulator in the laboratory situation," says Wookeun.

Hyundai can now conduct desktop ASD tuning with and without vehicle operating sound, so they can investigate the interaction between the existing vehicle sound and the ASD sound.

Since the tuning results should also match whatever type of sound is being targeted (for example, sporty or powerful), Hyundai is also now able to perform desktop listening experiments to find out which ASD tuning results in the sound closest to the target. And, they can analyse which objective parameters cause people to react negatively to a sound they're investigating.

TOGETHER FOR A BETTER FUTURE

"Brüel & Kjær's NVH Simulator and the tools they developed for this project enable us to have a faster development process. Since Hyundai Motors develops various kinds of engines and audio specifications in many countries, it's very challenging to develop all the engine sounds in a prototype vehicle. A virtual development environment was necessary," explains Dr. Park.

"Combining the NVH Simulator and ASD tuning process is a good example of a virtual environment for ASD sound design," he says.

"We see potential for NVH development and sound design based on computer-aided engineering and experimental data using these new tools," Dr. Park adds. "The tools may also be useful for the development of EV, environmentally friendly vehicles, and future mobility."

A NEW WHITE PAPER FROM THE STACKS

SOURCE CONTRIBUTION ANALYSIS FOR EXTERIOR NOISE OF A HIGH-SPEED TRAIN: EXPERIMENTS AND SIMULATIONS

SEE MORE
Read the full white paper at
www.bksv.com/whitepapers

Transport by high-speed train is becoming more widespread particularly in these climate-conscious times. How can the external noise from these moving sources be efficiently measured and assessed?

The high-speed train network is growing fast worldwide, particularly in China. Many of the lines pass close to urban areas so the external noise produced by the trains is of great interest to town planners and train manufacturers alike.

This paper presents a detailed investigation into the contributions of the various high-speed train sound sources, such as the bogie, pantograph, coach centre, etc., to the exterior noise, both experimentally and through simulations. The measurement points of pass-by noise were arranged according to the international standard ISO 3095. The noise source identification was conducted using a 78-channel wheel microphone array, and the rail vehicle moving source beamforming method was used for the source analysis. A numerical model of the exterior noise of the high-speed train was established based on the array acoustics method and the inputs come from the array measurements.

THE GREAT AIRCRAFT CERTIFICATION CHALLENGE

With certification planned for year end, the game-changing Airbus H160 is smoother, cleaner and quieter than any other helicopter. But what does it take to certify a brand-new aircraft for the skies?

ABOUT AIRBUS

Airbus is a global leader in aeronautics, space and related services. Airbus offers the most comprehensive range of passenger airliners from 100 to more than 600 seats and is a European leader providing tanker, combat, transport and mission aircraft, as well as one of the world's leading space companies. In helicopters, Airbus provides the most efficient civil and military rotorcraft solutions worldwide.

Pictures courtesy of Airbus

Last May, the Airbus H160 helicopter wrapped up its customer demos in Trenton, New Jersey. Over four days, 52 customers including 23 pilots got to experience the new aircraft. Customers said they were blown away by the power, the sophistication of the auto-pilot, the low noise level and smooth vibrations. "It's super quiet – quiet in start-up, quiet in cruise. The manoeuvrability of the aircraft…it's incredible,"* said Joe Drummelsmith of Union Holdings, a participant at the demo.

The H160 helicopter falls into the "medium" category in size and performance, targeted towards VIP transport, oil-rig crew transfers, emergency medical services and other commercial and industrial applications. It can seat up to 12 passengers and fly up to 460 nautical miles, with a VNE (never exceed speed) of 170 miles per hour. It burns 15 per cent less fuel than previous-generation engines, and thanks to innovatively shaped rotor blades, the aircraft is significantly quieter than competitive models as measured from directly below.

QUANTIFYING QUIET

The noise measurements taken from the ground are part of an aircraft's certification process (OACI Annex 16).

Before any civil aircraft can be put into service, it must be approved by authorities – European Aviation Safety Agency (EASA) in Europe and the Federal Aviation Administration (FAA) in the US. Noise certification is a measurement and calculation process in which Effective Perceived Noise Levels (EPNLs) must be generated for approach, take-off and flyover operations. The certification process is stringent and needs to be fulfilled early in the development phase to know the aircraft noise performance levels as they are important for Airbus customers, especially for Commercial Air Transport applications.

Under the responsibility of R. Corbiere, head of 'On Aircraft Integration Tests' within the Airbus Helicopters Test Centre, Airbus conducted the H160 certification tests at its testing facility at Marignane, France. Test procedures require stringent test-site selection and preparation, and regular acoustic calibration of the measurement system. This means that each test session requires a significant team, including flight crew, ground test personnel and representatives from the certifying authority, and they need to be perfectly coordinated to make sure the instrumentation records all the tests during the first run.

Airbus Acoustic Test Specialist, G. Marrou, explains: "Each test run is quite expensive with the high cost of prototype flight hours and the cost of the human resources needed to pull it off. That's why it's so important that we get accurate measurements the first time around. Additionally, it is also important for us to reduce the installation time of the complete system on the field and the data processing time."

Airbus chose to use Brüel & Kjær's commercial-off-the-shelf (COTS) Aircraft Noise Certification Test System, which complies with ICAO technical standards for the measurement of aircraft noise certification levels.

* From customer demo video:
https://www.airbus.com/helicopters/civil-helicopters/medium/h160.html

THE GREAT AIRCRAFT CERTIFICATION CHALLENGE

With this system, all the necessary tasks, including calibration processes, corrections to reference day conditions and measurement system response are incorporated, so all the phases of the noise measurement process are completely supported. Finally, the H160 acoustic certification test campaign took place in September 2017 and needed 75 flight runs to be recorded, 6½ flight hours over two days, with no technical defects on the measurement system. G. Marrou says, "Once we have all the necessary measurements from the Brüel & Kjær system, we use dedicated developed validation software to integrate the flight path of the aircraft, temperature and relative humidity in the air. With these final calculations, the official EPNLs are rendered and submitted to EASA for certification."

THE TEST SETUP

At the test facility, there are two stations: a measurement station and a test office station. The measurement station houses the Brüel & Kjær 'suitcase' that contains the measuring equipment, including the battery-powered, data-acquisition hardware and Brüel & Kjær microphones. The microphones are placed next to and 150 metres away from the suitcase. The measurement station provides Wi-Fi communication to the test office station and has a GPS antenna that enables the noise measurements to be synchronized with aircraft time and position.

The test is controlled from the test office station and real time visualization of measured levels is available during the whole test. Operators can start and stop the remote measurement system and

PREPARING FOR SERVICE ENTRY

In August 2018, EASA officially approved the acoustic certification for the H160. The first serial H160 performed its maiden flight on December 14, 2018. Certification is expected at the end of 2019 ahead of its entry into service in 2020.

upload data from the measurement station for making calculations and reports. The test station can communicate with the aircraft to obtain position data as well as with a local weather station recording weather data at a height of 10m.

The helicopter takes off and flies a predefined route. An on-board system tracks where the aircraft is. The Brüel & Kjær system on the ground records noise while the aircraft is flying.

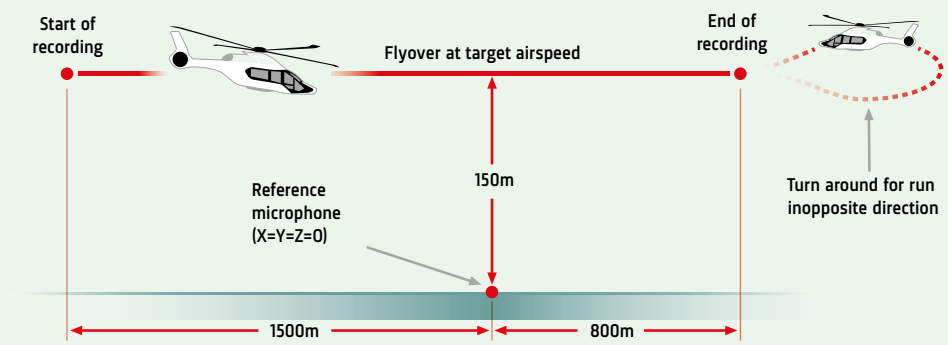
Recorded measurement data is corrected according to standards and is available immediately to be uploaded to the test office station. Finally, the field data can be made available for in-house or third-party software to make the official EPLN calculations.

IMPROVING THE R&D PROCESS

Although the official EPNLs are first ready after the certification process, instant preliminary EPNLs are provided by the Brüel & Kjær system at any time for instant validation of the test. These are very useful during the R&D process as Airbus engineers can use them to make necessary noise-level improvements throughout.

G. Marrou says, "It's extremely important to us to have access to accurate noise measurements during the R&D phase. It helps us know where we are in relation to the approved limits we need to meet and helps make our development process more efficient."

With a large need for noise certification and internal noise testing, Airbus has been a customer of Brüel & Kjær for several decades. "We like that so much high-quality equipment is available off the shelf and still customizable to our needs – and of course that it is pre-approved by the necessary authorities," says G. Marrou. "For us, there is huge value in getting the right measurements at the right time – with high reliability and continuous support."



WHAT'S THIS?

Look closely, think, and then turn to page 23 to find out if you are right.

EXPERT PROFILE

EDUCATOR AND PROBLEM SOLVER

Growing up in Stockton, a city on the San Joaquin River in California's Central Valley, Matt Allen's passion for learning led to a career in research and education. Today, he's still sharing knowledge and inspiring generations of engineers to come.

Why do you do what you do?

I want to make a difference for people and my job gives me the perfect opportunity to do just that. In my research programme, I want to create technologies that help engineers solve challenging new problems, do things that have never been done before, or understand things that they previously couldn't understand, such as non-linear vibration or rotating machinery. I like teaching because I get to interact with students when they are at a crossroads in their lives, deciding what they will be and what contribution they will make to the world. I want to inspire them to aim higher – to tackle difficult concepts, learn new things, and be good people.

What are the unique challenges you face in your work?

Trying to solve extremely difficult problems in non-linear dynamics, problems that others have worked on for years and not solved, by bringing together new methods to tackle these problems.

In his free time, Prof. Allen enjoys downhill skiing, hiking, mountain biking and he recently took up small boat sailing.

MATT ALLEN

Company and Job Title: Associate Professor, Engineering Physics Department, University of Wisconsin
Location: Madison

EDUCATION

2001 – 2005: PhD/MS in Mechanical Engineering, Georgia Institute of Technology
1994 – 1995, 1998 – 2001: BS in Mechanical Engineering: Magna Cum Laude, Brigham Young University

PREVIOUS JOBS

2005 – 2006: Postdoctoral Appointee, Sandia National Laboratories
2000 – 2001: Patterned fibre composites/New Revolution Golf, carbon fibre composite test and design engineer

What are the most challenging things about what you do?
Research is extremely difficult. We are competing with brilliant people all over the world to be the first to solve hard problems. But when we succeed it is really rewarding. For example, I began working on non-linearities due to bolted joints 10 years ago. We would try to simulate basic finite element models with bolted joints and the computations took a long time, even on a computer cluster. When the simulations were finally done, we found that the response looked a lot like that of a linear system. Now, 10 years later, we have methods that exploit the quasi-linearity of these systems to estimate the dynamic response in fractions of a second. We can now thoroughly probe these models to understand how the joints may affect a structure.

Similarly, in 2006, we began to revisit substructuring methods that had been proposed since the 1960s as a way to experimentally model substructures and combine experimental models with finite element models. We found a new way of coupling subcomponents that made them much more robust to measurement errors and allowed us to couple subcomponents even when the interface between them was continuous. This is now called the transmission simulator method and is beginning to be used by researchers all over the US and Europe.

What is your greatest achievement and why?
Perhaps the transmission simulator method mentioned above – it has had the broadest impact so far on the community. The method of "quasi-static modal analysis" (mentioned above for joints) is also becoming significant.

But the highest satisfaction comes from my interactions with students and seeing them go on to do great things. That isn't really my achievement but theirs.

Any personal ambitions?
Yes, tons! There is still so little we can do to experimentally probe and understand non-linear systems. There are some good methods, but all are limited to certain types of systems and none is all that effective for the common non-linearities that we encounter in industry. The same could be said for simulation of non-linear systems. Methods exist but they are slow (computationally expensive) and don't provide the insight that we'd like.

What are the best and worst decisions you have ever made?
Best: marrying my wife and having two children, accepting a post-doc position at Sandia and accepting a job at UW-Madison. Worst: saying yes to far too many things!

"I LIKE TEACHING BECAUSE I GET TO INTERACT WITH STUDENTS WHEN THEY ARE AT A CROSSROADS IN THEIR LIVES, DECIDING WHAT THEY WILL BE AND WHAT CONTRIBUTION THEY WILL MAKE TO THE WORLD."

MATT ALLEN
ASSOCIATE PROFESSOR, ENGINEERING PHYSICS DEPARTMENT, UNIVERSITY OF WISCONSIN

EDUCATOR AND PROBLEM SOLVER

What's your latest project?
Bolted joints (see above) and a project on non-linearities of aircraft skin panels.

Tell us a bit about your work with NASA's Loads and Dynamics technical team at the NASA Engineering & Safety Center.
I am part of an oversight team that considers all the testing and analysis that is done for the new space launch system and other programmes. We seek to assure that the best methods are being used and that work is done well, so we can assure the safety of astronauts and the success of the programme. I interact with some of the most brilliant aerospace engineers in the world and have enjoyed seeing how they think about difficult problems regarding loads and the linear and non-linear dynamics of launch vehicles.

The most recent IMAC tagline was, "It's not just modal anymore". What are the trends in tools, test methods, and simulation now and in the future?
I think that being able to address non-linearity is big. Most people don't believe that modes exist for non-linear systems, but we've found this concept to be really useful. I think that modal analysis – test, analysis, etc., continues to be a big challenge in industry. Non-linear simulation is becoming much more commonplace – we need corresponding test methods and to really understand what non-linear simulation means for a design. We can collect far more information – high spatial resolution with LDV or DIC – and we need to know how to really use this more effectively to answer important questions.

HIGH-FREQUENCY HATS, **WHY?**

A head and torso simulator (HATS) is an objective measurement instrument with built-in, human-like ear and mouth simulators that provides a realistic reproduction of the acoustic properties of an average adult human. High-frequency HATS Type 5128 is an innovative evolution of the legacy HATS Type 4128.

This article describes the unique benefits and features of the High-frequency HATS.

BY: **DR RÉMI GUASTAVINO**
Domain Specialist, Acoustics
BRÜEL & KJÆR

HIGH-FREQUENCY HATS
WHY?

LET'S START WITH THE NEW EAR SIMULATOR

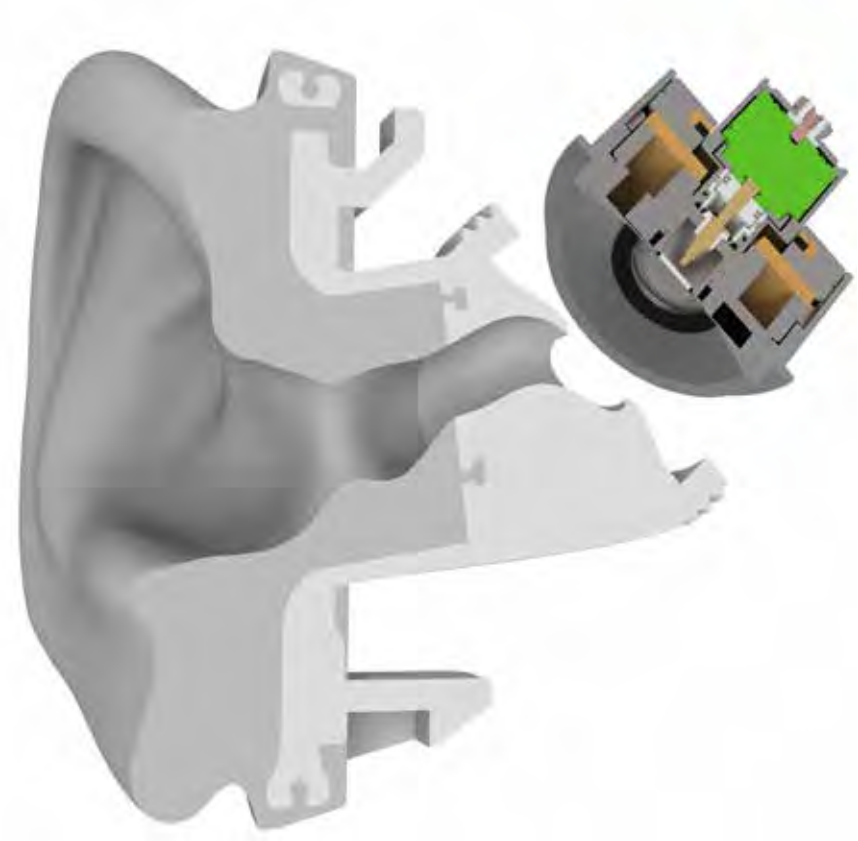
The world of communication and entertainment is evolving and consumer expectations for audio quality continue to increase. We knew that the ear simulator of Type 4128 with its cylindrical ear canal did not allow realistic mounting of in-ear devices. Neither was the legendary IEC 711 coupler designed to perform acoustic measurement over the full audio range, 20 Hz to 20 kHz.

Therefore, we decided to build a new ear simulator – starting with a human-like pinna and ear canal as well as a unique eardrum simulator that matches the impedance of an average human ear over the full audio range.

AN ANATOMICALLY CORRECT EAR

We collected the geometries of a large population of human ears using MRI scanner technology. The full ear canal geometry including the bony part adjoining the eardrum were captured. By post-processing all the data, we were able to determine an average human ear canal geometry. The new ear has an anatomically correct ear canal with an angled eardrum simulator positioned exactly at the location of the eardrum to closely match the human ear. A new design of the pinna interior structure was used to create a more robust ear capable of withstanding more wear and tear. The transition between the soft part (the silicone ear) and the hard material (the end of the ear canal where you attach the eardrum simulator) was designed to retain the transition from the soft to the bony part of the human ear canal.

We also added a soft silicone band all around the ear for better sealing of over-the-ear headphones. A new click-on system, with quick release of the ear simulator, allows for easy ear switching if needed. Finally, we designed a new mechanism to quickly attach and detach the new eardrum simulator from the ear, enabling the use of custom outer ear and ear canal geometry.



DID YOU MENTION A NEW EARDRUM SIMULATOR?

While measuring the human ear canal anatomy, we also measured the corresponding full range acoustic impedance for every single ear and were able to determine an average human acoustic impedance. To achieve optimal accuracy of the eardrum simulator response up to 20 kHz (remember that the wavelength of a 20 kHz sound wave is shorter than 2 cm) we had to use an unprecedented level of precision in the design and during the manufacturing processes. Our aim was to have an artificial eardrum that is closer to the human eardrum in size. To accommodate this, we developed a new prepolarized ¼-inch microphone with a unique, flat pressure response and a new low-noise preamplifier. A new eardrum simulator was born, matching both the frequency response and acoustic impedance targets.

WHAT ABOUT THAT MOUTH SIMULATOR?
The mouth simulator has also been redesigned. Using a custom designed loudspeaker element with an optimized geometry and a stronger magnet system, we optimized the volume of the loud-speaker cabinet. This resulted in a full-range mouth simulator (with an extended response in both the low- and high-frequency range). This also allows the mouth to be louder with an improved high-frequency roll-off. The new mouth also has a built-in amplifier, simplifying measurement setups and reducing system cost.

DID I FORGET SOMETHING?
High-frequency HATS Type 5128 was designed with a connector side panel that includes power and signal input for the mouth, and two CCLD microphone connectors (CCLD microphones allow for inexpensive BNC cables, acquisition front end and conditioning system). You do not have to go fishing for cables anymore, everything is clearly labelled and easy to reach.

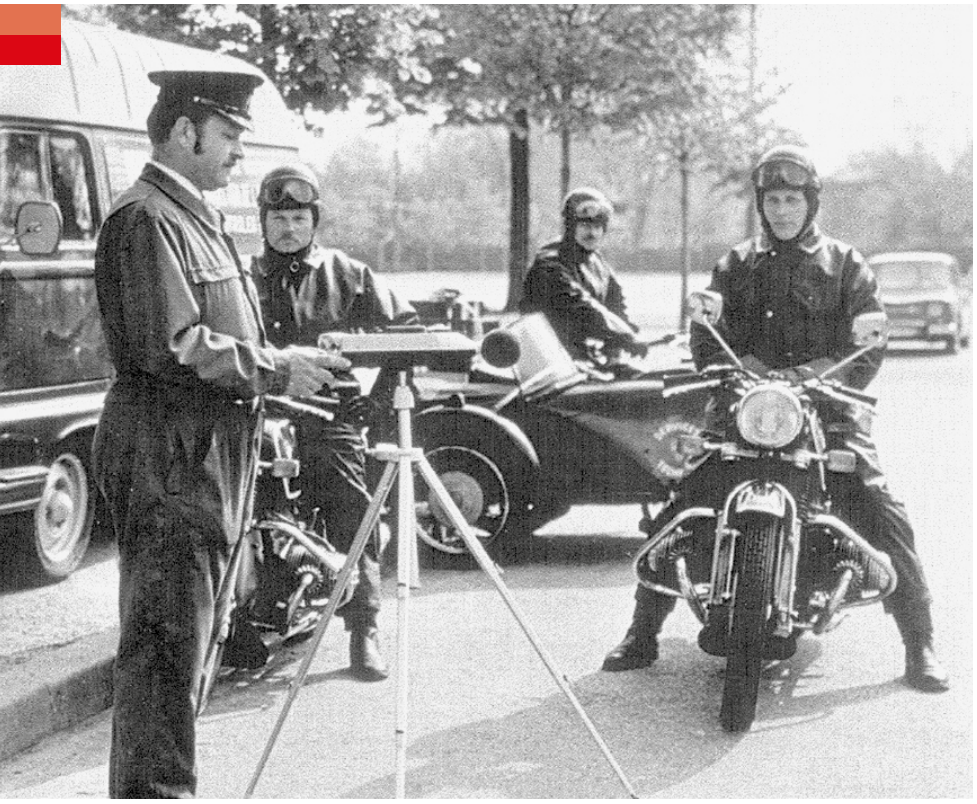
WHY DO I NEED THE NEW HATS?
Type 5128 is especially designed to be used when high-frequency content is of importance. This could be testing the audio performance of smart devices, hands free, headphones or hearing aids. Type 5128 loads the devices under test with the exact same impedance as an average human ear. This means that it measures the audio quality of a device in the same way as a human would perceive the quality. The ability to measure in the full audio band (20 Hz to 20 kHz) is a huge step in audio performance evaluation, which potentially could facilitate the retirement of the venerable IEC 711 coupler.

SPOT THE DIFFERENCE

Can you spot the five differences between these two pictures?

See the solution on page 25.

HISTORICAL MILESTONES THAT SHAPED THE SOUND LEVEL METER OF TODAY



With the relentless advance of technology, the sound level meters of today are very different creatures to those of the 60s. Let's delve into history and look at the trends that are shaping their future.

Starting in Times Square, New York, in the 1920s – a Fox Movietone News Story shows a technician from the Noise Abatement Commission making noise level measurements across the city in response to an increase in traffic. Armed with a receiver, a microphone, a phonograph and a wobbling test tone to measure "deafness produced by noise", he concludes that "the noise in Times Square deprives us of 42% of our hearing" [sic]. It would be more than 30 years until the introduction of the first sound level meter standard. With the emergence of IEC 123, published in 1961, sound level meters had to be designed according to certain criteria to be approved and accredited – the era of commercially available sound level meters had begun!

LEVEL RECORDERS AND TRANSISTORS

You have to turn the clock back 50 years to see what we would recognize as a sound level meter today. Before then, noise measurements were made using heavy equipment based on valve technology. The engineer had to transport his equipment to the site and set up input and output attenuators before starting the measurement. Once the measurement was in progress, with no internal memory, levels would be recorded on a level recorder, with the engineer marking events on the paper roll. Post-processing software was non-existent and there were no alternative ways of displaying results.

Brüel & Kjær's Precision Sound Level Meter Type 2203 launched in 1962 was, thanks to transistors, much smaller than its predecessors. Weighing in at just 5 kg with an octave filter set attached, it was arguably the first portable sound measurement device (although the level recorder did weigh another 25 kg). However, transistor technology of the day was not a precise science and not without issues. So great was the variation in resistance that transistor batches had to be sorted at the factory according to their quality before using them in production. Today, where everyday life is filled with smart miniature technology, Type 2203 doesn't seem particularly small or light, but considering the technology available at the time, it was impressive.

Sound Level Meter Type 2203 launched in 1962

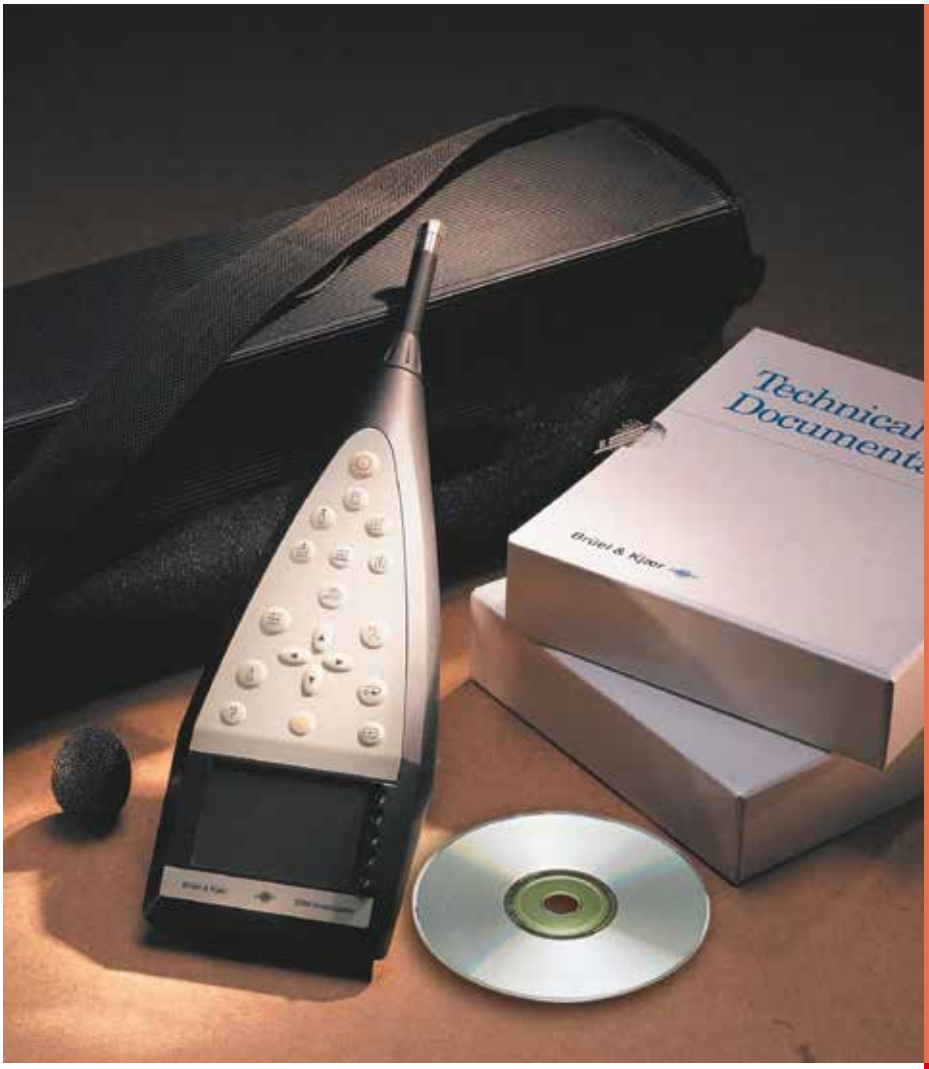
Sound
Level Meter
Type 2231

MICROPROCESSORS AND INTERNAL MEMORY

The 80s saw the end of large sound level meters. Driving this process was the emergence of microprocessors offering increased processing power due to integrated circuits that combined multiple transistors onto one chip, making parallel measurement of up to five independent parameters possible.

The first Brüel & Kjær sound level meter to integrate a microprocessor was Modular Precision Sound Level Meter Type 2231. The choice of microprocessor was the cost-effective RCA 1802 – undoubtedly a good choice as it was also used in NASA's space programmes.

Parallel to the development of microprocessors came internal memory (built-in data storage), allowing users to save their data on the sound level meter itself. This was around the time of the first electronic spreadsheets from VisiCalc, later Lotus Notes and Microsoft® Excel®. Using personal computers to make calculations was becoming more widespread.



By the late 80s and early 90s, the digital revolution was accelerating at a remarkable pace and had a huge impact on the future of sound level meters.

DIGITAL SIGNAL PROCESSING

The 90s saw the growth of digital signal processing, which, combined with greater computing power, made it possible to process more data in real time. For example, measuring a 1/3-octave spectrum on sound level meters with analogue filter sets involved measuring each frequency band individually – a very time-consuming process. With digital signal processing, real-time 1/3-octave band frequency analysis became possible, measuring all frequency bands simultaneously! As digital signal processing became widespread among sound level meter providers, more detailed analyses like FFT became possible in a hand-held platform. This new technology was adopted by Brüel & Kjær's Type 2260, released in 1994. ▶

HISTORICAL MILESTONES
THAT SHAPED THE SOUND LEVEL METER OF TODAY

Hand-held analyzer family: Type 2250-L, Type 2250 and Type 2270

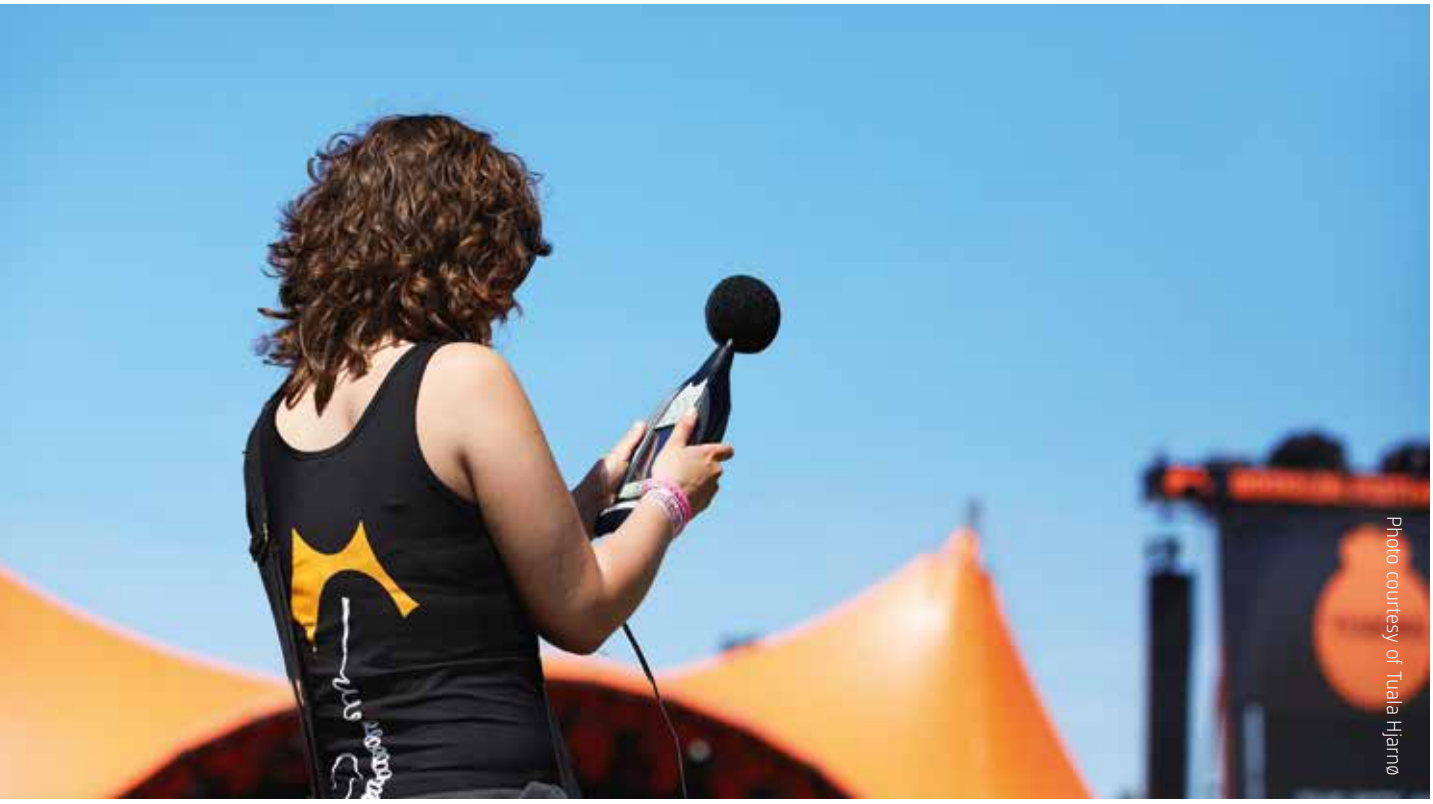


Photo courtesy of Tuala Hjarnø

CONNECTIVITY SHOWS THE WAY TO THE FUTURE

Aside from large colour displays and advanced post-processing, connectivity is a central feature of 21st century sound level meters. Released in 2004, Brüel & Kjær's Hand-held Analyzer Type 2250 shared many features with its technological cousin, the personal digital assistant (PDA). A colour and touch-sensitive display was a leap forward in usability, while USB and Ethernet interfaces offered flexible and convenient methods for connecting to a PC – be it in the same room, or on the other side of the world. Today, sound level meters Type 2250 and 2270 can even connect wirelessly to Wi-Fi networks, making remote control from a smartphone possible, along with cloud-based services for data storage and sharing.

SMART FUTURE

Today, smartphones are a constant presence in our lives. These pocket-sized devices are much more than just phones – they are wireless communication devices combining microphones, cameras, speakers, accelerometers, gyroscopes and high-resolution touch-screens, with processing power rivalling the desktop computers of just a few years ago. They connect with an ever-growing range of devices and sensors, from heart rate monitors and pedometers, to seismographs and even sound level meters like Type 2250.

It is unlikely that sound level meters will ever match the computing power and flexibility of contemporaneous smartphones, but smart devices will influence sound level meter design in the future. The display, computing and wireless technologies developed for smartphones will increasingly be integrated into sound level meters, and the use of smartphones connected to sound level meters will also increase.

We've come quite a long way since the dapper measurement technician of Times Square in 1929, jotting down numbers in a notebook and working out hearing deprivation percentages, but with the evolution of the technology keeping pace with the importance of environmental noise, who knows what the future will bring?

SPY ON THE WALL

The goodwill gesture that was a master stroke of electronic bugging.

On 4 August 1945, a group of Russian children from the Vladimir Lenin All-Union Pioneer Organization, presented Averell Harriman, US ambassador to the Soviet Union, with a wooden replica of the Great Seal of the United States. Made from sandalwood, boxwood, sequoia, elephant palm, Persian ironwood, redwood, ebony and black alder, this gesture of friendship contained a hidden listening device. The gift was hung in the office of Harriman's official residence in Moscow. Seven years later, it was discovered that the plaque was more than just a decoration and that the Soviets had been eavesdropping on Harriman and his successors the whole time, gathering crucial information about the post-war activities of the United States.

The 'Thing', as it was known, was the creation of Soviet inventor and physicist Léon Theramin, famous for inventing the musical instrument that bears his name. He designed the device while incarcerated in a secret research laboratory in a Gulag camp. Completely passive and requiring no power connection, the device was ingenious. It was designed to become active when remotely excited by radio waves of a certain frequency. Acoustic waves in the room where it was mounted caused it to vibrate and modulate the carrier radio wave. This modulation was then picked up by a separate device and converted back into audible speech allowing the Soviets to listen to conversations in the ambassador's office from 800 m away in another building. The device was found when a US radio engineer discovered the presence of the powerful carrier wave by chance, launching a search for receiving devices.

Photo: John Rooney/AP/Ritzau Scanpix

SO, WHAT IS THIS?

This is a Waltham Sonar chronometer used in WWII. The chronometer utilizes sonar waves to measure the distance between a submarine and another boat.

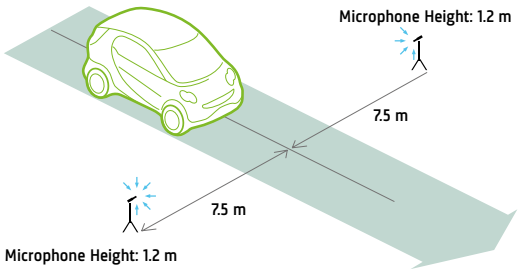
The operator starts the time measurement when the sonar wave is launched and stops it when the reflected sound is heard back. The red numbers on the dial are seconds and the black ones are yards. Sound travels approximately 1500 metres (1600 yards) per second in salt water. Therefore, a measurement of one second corresponds to a distance between the vessels of approximately 750 metres (800 yards).

See Waves issue 10 for more information on wavelengths in air and water.

MICROPHONE SELECTION GUIDE

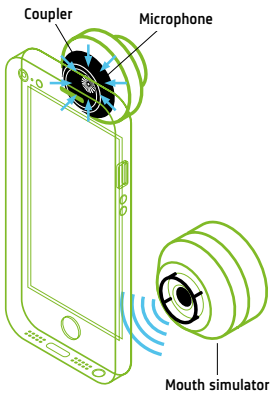
Microphone

Free-field



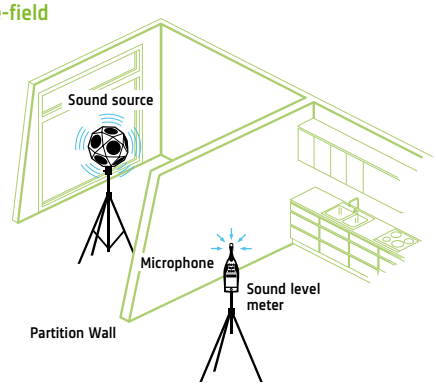
- Low noise
  - 4955 (½″ external polarization)
- General purpose
  - 4966 (½″ prepolarized)
  - 4191 (½″ external polarization)
- High frequency
  - 4954 (¼″ prepolarized)
  - 4939 (¼″ external polarization)

Pressure-field



- General purpose
  - 4953 (½″ prepolarized)
  - 4192 (½″ external polarization)
- High frequency
  - 4944 (¼″ prepolarized)
  - 4938 (¼″ external polarization)

Diffuse-field



- 4942 (½″ prepolarized)
- 4943 (½″ external polarization)

Special

- Infrasound
  - 4964 (½″ prepolarized)
  - 4193 (½″ external polarization)
- High level
  - 4941 (¼″ external polarization)
- Flush mounted
  - 4948/4949 (½″ prepolarized)
- Probe
  - 4182 (¼″ external polarization)

BY: **DR BIN LIU**
Product Manager, Transducers
BRÜEL & KJÆR

Choosing the right microphone is not an easy task and choosing an inappropriate microphone can lead to measurement errors. This easy microphone selection guide should help if you're not sure which microphone you need.

Once the frequency range and sound level range of interest is defined, the next question to ask is, "Where will I use my microphone?" For most uses, the type of sound field is the main parameter to consider. The concept of acoustic field is explained in our October 2018 issue of Waves (Issue 10, p.18, "Measurement microphones explained") and in the Brüel & Kjær microphone handbook (available for download at no cost on www.bksv.com).

- Measurements outdoors or in anechoic chambers will require a free-field microphone
- If you plan to make measurements inside, for example, within a car cabin, you will need a diffuse-field microphone (a ½-inch free-field would underestimate the sound pressure about 6 dB at 20 kHz)
- Measurements performed in small, closed couplers, for example, artificial ears used to measure headphone performance, or close to hard, reflective surfaces, require a pressure-field microphone

Are you looking for a microphone for more specialized applications? We have several models to choose from:

- Very high- and ultra-low frequency measurements require microphones specially designed for one extreme or the other, not both. Types 4964 and 4193 are prefect for ultra-low-frequency measurements, but for the very high-frequency end, a microphone like Type 4138 is needed (up to 140 kHz)
- Extremely high sound pressure levels require a robust microphone like Type 4941
- Inflow measurements may require a flush-mounted or small-footprint microphone like Type 4948/4949
- Particularly small spaces, awkward placements or harsh environments can also require specialized microphones. Type 4182 is a good start – its design provides a very high acoustic impedance probe tip (to minimize the effect on the measurement) and it can be used to measure in temperatures up to 700°C

In most cases, once you have defined the application, you can refine and choose between a:

- Prepolarized microphone (less expensive and simpler cables, easier conditioning, greater reliability in extreme humidity)
- Externally polarized microphone (often with a higher dynamic range and able to withstand higher temperatures)

Finally, remember that choosing a microphone with a larger membrane will generally lower the inherent noise and increase the sensitivity, while microphones with a smaller membrane will be able to measure higher sound pressure levels, have an extended frequency range and be less sensitive to the angle of incidence of the incoming sound wave.

SPOT THE DIFFERENCE

The sound level meter on page 19 was modified in five places.

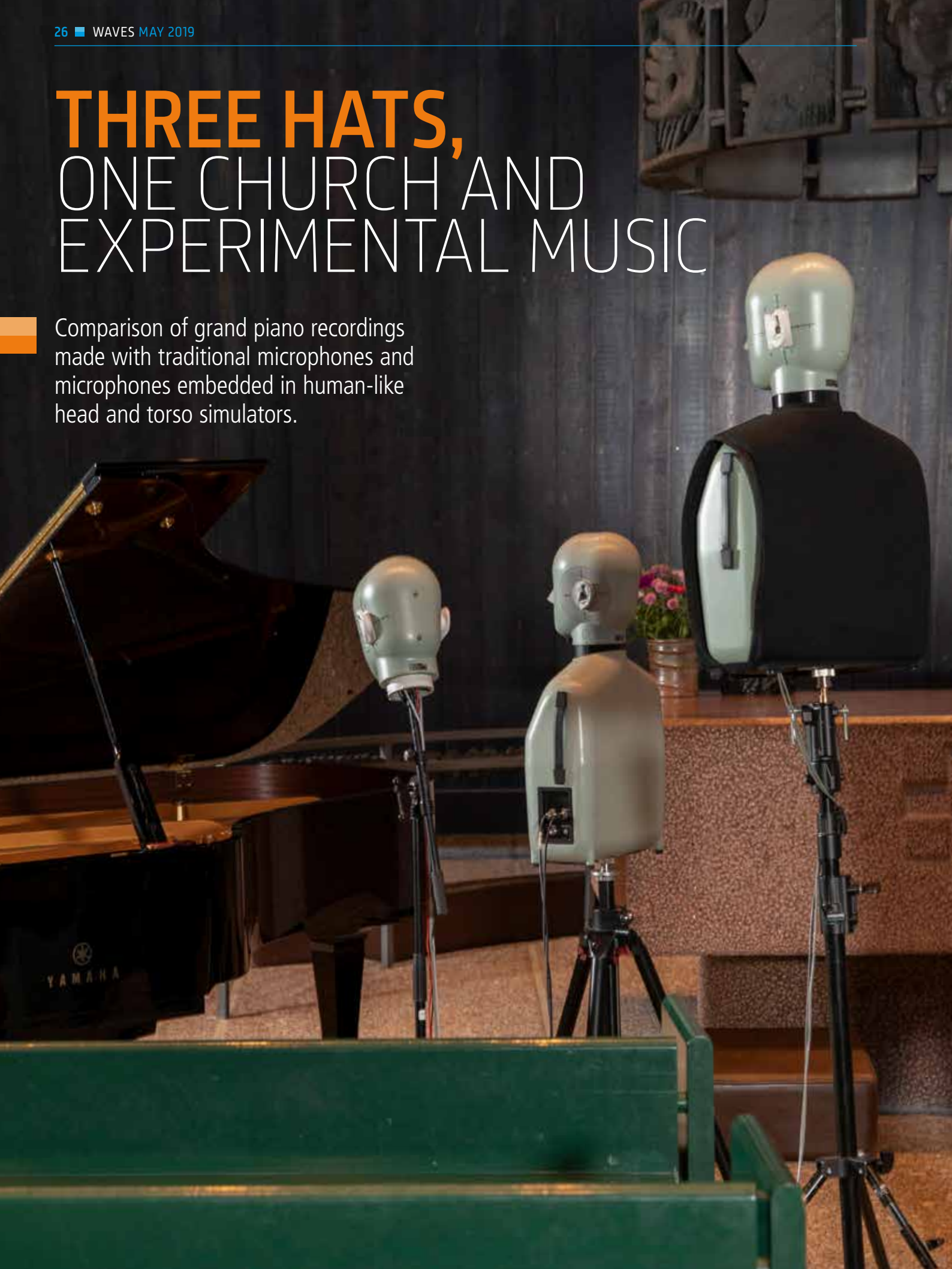
Did you get it right?

SEE MORE

www.bksv.com/2245

THREE HATS, ONE CHURCH AND EXPERIMENTAL MUSIC

Comparison of grand piano recordings made with traditional microphones and microphones embedded in human-like head and torso simulators.



BY: **KRISTIAN RYMKIER**
with contributions from
ARNE BOCK

To create new experiences in sound and new concert forms, sound engineer Arne Bock and I decided to explore the possibilities of auditory augmented reality (AR) installations via binaural recordings. We wanted to investigate how the sound quality of Brüel & Kjær head and torso simulators (HATS) is perceived compared to ordinary stereo and surround set-ups. We also wanted to experiment with binaural recording techniques in the musical domain and look at the added musical value of listening to binaural versus stereo and surround playbacks. Our interest lies in the listening experience, a subjective use of sound recordings.

The project was centred around Ellevang Church, which is in Risskov, near Aarhus in Denmark. The church was built in 1974 and was specially designed with an emphasis on good building acoustics to ensure that the preacher could be heard throughout the worship space. The result is a room providing a good, transparent sound image without too much of the reverberation typically found in churches, thus ideal for playing four original chamber music compositions using the church's new Yamaha grand piano.

We had three different HATS at our disposal for our recordings – a sound quality HATS (Type 4100) where the microphone is mounted at the entrance of the ear canal, a HATS with a cylindrical ear canal and calibrated ear simulator (Type 4128), and a high-frequency HATS with a human-like ear canal and calibrated eardrum simulator (Type 5128).

With simultaneous recordings made of the room's ambient sound and by close-miking next to the piano, we would be able to experiment with the sense of depth during the mixing phase. Our choice of HATS positioning was, therefore, totally based on the best musical result. After some experimentation, we chose to use the high-frequency HATS for the ambient sound (that is, further away from the piano and with complete balance between the direct sound of the piano and the room sound), as it was the most directional of the HATS variants and maintained a good sound focus. The other two HATS were placed around the piano to highlight the different qualities of the piano's sound, but without too much reflective content from the room.

For comparison purposes, we installed a "Williams Star" surround microphone array at its ideal height behind the high-frequency HATS and placed a stereo close-miking system over the piano strings for use later during the mixing phase. ▶

KRISTIAN RYMKIER

Composer and musician at the forefront of the Danish avant-garde

In addition to composing chamber, vocal and orchestral pieces, Kristian Rymkier also works with sound installations and digital composition with focus on 3D music, composed with a spatial awareness as a musical element, which is listened to via headphones.

- Master's degree from the Conservatoire National Supérieur de Musique et de Danse de Paris
- Bachelor's degree from The Royal Danish Music Academy
- Bachelor's in jazz saxophone from The Royal Dutch Conservatory in Den Haag

www.rymkier.com

THREE HATS,
ONE CHURCH AND
EXPERIMENTAL MUSIC

"MY MISSION IS TO CREATE CONTEMPORARY MUSIC PORTRAYING MYSELF."

KRISTIAN RYMKIER
COMPOSER AND MUSICIAN AT THE
FOREFRONT OF THE DANISH AVANT-GARDE

Finally, with the addition of surround microphones, pianist Erik Kaltoft was ready to play three music pieces entitled Nos Gypédies.

RECORDINGS

During the first day of recording we were surprised to discover on playback that there was a strong accentuation of the high frequencies, resulting in a thin sound image, and I was a little sceptical about whether any of the HATS recordings would be of any use.

The balance between low and high frequencies was very dissimilar from normal recording microphones used in standard classical music recording. The HF-bias was probably due to the respective positioning of the microphone diaphragms inside the ear canals of the three HATS.

To transfer the HATS microphone responses back toward diffuse field response, recording engineer Arne Bock spent some time programming equalizers for each HATS channel using frequency-response tables supplied by Brüel & Kjær as a guide. What a difference! The effort that went into equalizing the channels was worthwhile. The warmth returned to the replayed sound and the result gave us something really unique.

From left: Arne Bock, Erik Kaltoft and Kristian Rymkier

Arne had never doubted that the equalizers would be able to clean up the sound image, but not to the extent revealed by the results.

We then spent a day making a recording of Les Champs and making binaural recordings of the piano by HATS being moved around the room in real time.

RESULTS

We discovered that High-frequency HATS Type 5128 at the chosen ambient position gives a good sense of 3D and a super-clear sound image, including rich detail of the grand piano's sound and with precise room information. Compared to Sound Quality HATS Type 4100, Type 5128 gives very precise location information, proven by panning the HATS within the sound field and noticing the ease, or not, of small details following the same movement. With Type 5128 the details are sharper and give a deep 3D-experience, especially noticed in the reverberant information that is more precise and defined than the other HATS.

Sound Quality HATS Type 4100 produces a very open, detailed soundscape with plenty of spatial information, with maybe a slightly muddy representation of reverberant sounds.

HATS Type 4128 lies between the other two regarding depth and details; better than Type 4100, but not as intense as Type 5128.

Overall, it seems that having Type 5128 as the main receiver is the best choice, giving our recordings well-defined details and spatial information. However, when using Type 5128 in a close-miking situation it seems that the sound recorded is too focused and doesn't, for example, capture the full timbre of the piano. Type 4100 and Type 4128 appear to be better for close-miking where the level of the direct source is more dominant than the reverberant sounds.

Binaural recordings made with the sound quality HATS moving in the room provide a very fine, smooth sense of a sound source traversing the space. We will use these recordings that contain motion information as source material for new digital compositions.

By using a close-miked recording as a source, we will test whether digital binaural plugins in the mixing chain can reproduce the same quality of sound and space information as a Brüel & Kjær HATS recording at a set location. The plug-in allows us to spatially move the source in x- and y-planes, so we can virtually move it from being by the piano to the same spot where the HATS was in order to make direct comparisons. The last step will be to down-edit the recordings of the four compositions to make twin-tracks in both stereo and binaural formats. For best effect, the binaural format should be played through headphones to reproduce the music with a clear sense of 3D space – listeners should feel that their ears replace the HATS ears.

ARNE BOCK

With extensive experience in many different music styles, Danish Tonmeister and sound designer Arne Bock is one of the most sought-after sound designers in the area of sound design, live audio and recordings. He has worked with many renowned symphony orchestras such as the Royal Concertgebouw Orchestra, The Netherlands Radio Philharmonic Orchestra and the Swedish Radio Symphony Orchestra and with renowned composers such as Steve Reich and Jean-Baptiste Barrière. Arne has also programmed special solutions for surround sound in use with live amplification to provide special 3D sound experiences in concert halls.

WITHIN THESE **WALLS**

TÜV SÜD's technical acoustic experts. From left: Michael Gail, Sebastian Rieger and Thomas Heichele

It covers an astounding 8500 m², houses an interdisciplinary team of 40 engineers and technicians, has temperatures ranging from +50°C to –40°C and climate chambers big enough to accommodate a refrigerated trailer – welcome to Europe's largest independent testing laboratory, the Center of Competence for Refrigeration and Air Conditioning.

Based in the Bavarian town of Olching near Munich and operated by TÜV SÜD Industrie Service GmbH, the premises are also home to an innovative laboratory for a new in-house field of activities – technical acoustics. "TÜV SÜD's decision to bring acoustic measurements in-house instead of outsourcing them was prompted by rising demands from customers and increasingly strict test regulations," explains Andreas Klotz, Head of the Testing Laboratory for Refrigeration and Air Conditioning.

LIMITING NOISE EMISSIONS

Ventilation and extraction systems, fans in refrigeration units or vehicles, motors and pumps in machinery or refrigeration systems all produce noise that is perceived as unpleasant. To make sure that any unwanted noise from technical components is below perceptible levels, or to test whether the sounds produced are within the required tolerances, TÜV SÜD has established ideal conditions for such measurements: a 10 × 10 × 7 m semi-anechoic chamber with a volume of around 588 m³. The cavity-walled, room-in-room solution is made of precast concrete parts. The inner cube has a self-contained foundation that is separate from the rest of the building and a 60 cm thick layer of multiple elastomer panels acts as a vibration absorber, resulting in a room with an incredibly low noise level of only 5 dB(A).

"Each customer has different expectations and ideas. For us, as a technical service provider, this means that we need to re-invent ourselves daily," says Andreas Klotz. "The key to success lies in flexibility and individual customer care." To ensure this, TÜV SÜD needed a measurement system that was not only suitable for carrying out measurements on recooling systems within the scope of certification, but also met the demands of automotive suppliers for optimizing the sound of closing a glove compartment or for the approval of alarm systems.

KITTING OUT THE LAB

Opting for a Brüel & Kjær multi-channel data acquisition and analysis solution, Andreas Klotz explains why: "Brüel & Kjær is the only supplier offering package solutions that include everything from microphones to analyzer software, topped off with first-class support. Other arguments in favour of Brüel & Kjær are the quality of its products and the reputation of its brand. This technology ensures that our customers will obtain reliable and robust measurement results."

The laboratory is equipped with 16 channels of LAN-XI data acquisition hardware, where the ability of being able to use the modules in a distributed system ensures short and orderly cable runs. The power needed by the modules is supplied by Power over Ethernet (PoE) from a central switch via one network cable. The measuring room and the control station are only connected by a single network cable, a major advantage over other systems that still rely on a traditional rack-mounted system. ▶

WITHIN THESE
WALLS

Perfect soundscape with sound quality measurement

FULL DIGITIZATION

TÜV SÜD also rigorously oversaw network capability and digitization for all other measured variables recorded directly by the PULSE™ measurement software. The ambient conditions in the measurement room, for example, are read via Ethernet and supplied directly to PULSE via the GADI (Generic Auxiliary Digital Interface) driver. "The requirements related to determining electrical power parameters during acoustic measurements are one of the reasons why TÜV SÜD decided to rely on full digitization and the GADI driver. The electrical power that needs to be measured, for example, extends from the low single-digit range to several kW.

"A standard analogous 0 – 10 V signal does not allow these measurements to be realized with the necessary precision," explains technical acoustics expert Sebastian Rieger. In this case, TÜV SÜD relies on the high-precision Yokogawa power meters that are likewise actuated via the network and supply measurement data via the GADI driver to PULSE. All relevant measured data that needs to be recorded and the measured acoustic values are, therefore, all captured in one system and stored as one data set in an SQL database.

THE ROAD TO OLCHING

The acoustics laboratory has already built up a broad client base since it began its operations. Many of the acoustic measurements are performed as services for larger projects in the refrigeration and air conditioning laboratory, particularly within the scope of certification. However, an increasing number of customers in the fields of product and application testing are now also making their way to Olching.

As well as suppliers to the rail and automotive industries, manufacturers of toys, household appliances and garden tools also use the services and the infrastructure available there, which is rounded off by the provision of utilities including freshwater, wastewater and compressed air systems as well as an exhaust gas-extraction system.

THE HUMAN EAR
PART 2

Part 2 of *The human ear* examines the process of transforming sound from mechanical vibrations into neurological signals – beginning with a closer look at the cochlea.

In part 1 of *The human ear,* we used a simplified, stretched out depiction of the cochlea's inside, similar to the illustration in figure 1 to describe the interaction between the basilar membrane and the fluids in the scala vestibuli and scala tympani. The scala vestibuli and scala tympani are connected at the apex of the basilar membrane, forming a long, connected duct (Figure 1). However, this is only a simplified depiction of the cochlea, often used to focus on the interaction between fluid and basilar membrane motion.

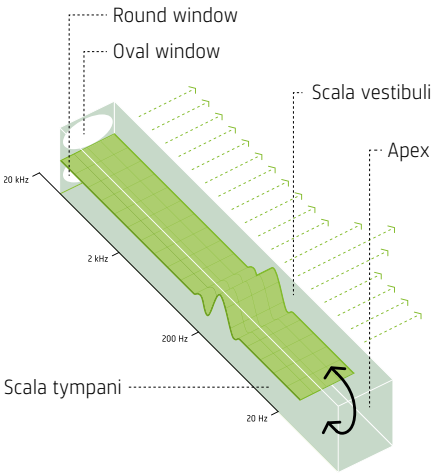
A more detailed look at the cross section of the cochlea (Figure 2) shows a third fluid-filled chamber, the scala media, running in parallel to the other two. We can also see that the scala vestibuli is not directly in contact with the basilar membrane; rather, it is separated from the scala media by Reissner's membrane.

Similarly, the basilar membrane separates the scala media from the scala tympany. The fluids in the scala vestibuli and scala tympany are called the perilymph. The fluid in the scala media is called endolymph.

Separation between these fluids is needed to maintain a high concentration of potassium ions (K+) in the endolymph. ▶

This description is based on the current understanding of the transduction process. Given the difficulty in studying the inner workings of a living cochlea, and that vital mechanisms cease to work in dead tissue, there is still much uncertainty. However, this matter is very much the subject of current research.

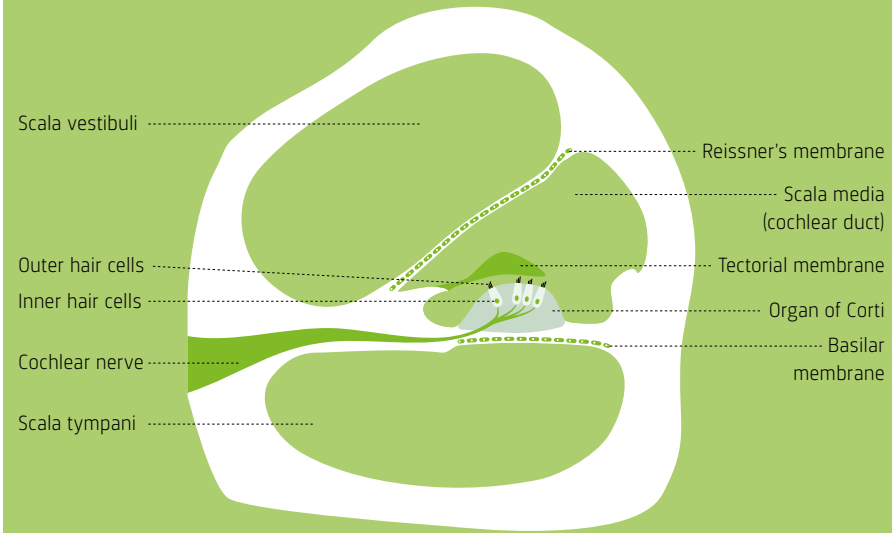
Figure 1



Schematic of the basilar membrane scaled to indicate the spatial association of frequency analysis along the membrane. The arrows symbolize transmission of pulses along the fibers of the auditory nerve, each being associated with a frequency range.

Figure 2

Schematic cross section through the cochlea. Only the components most relevant for the discussion are depicted.



THE HUMAN EAR
PART 2

BY: **MATTHIAS SCHOLZ**
User Interface Designer
PhD Applied Acoustics
Brüel & Kjær

On top of the basilar membrane, is a complex structure called the organ of Corti. This is the actual transduction organism that converts motion to electrochemical pulses, which are then sent to the brain through the auditory nerve fibres. The organ's top layer contains thousands of hair cells protruding into the endolymph. We differentiate between the inner and outer hair cells.

INNER HAIR CELLS

The inner hair cells convert mechanical motion into neurological signals (Figure 3). Think of them as tiny switches. While closed, the endolymph's K+ are prevented from entering the hair cells. However, motion of the basilar membrane and endolymph will deflect the hairs relative to each other so that the tip links open the ion-channels, causing a K+ influx. This change in concentration opens another gate allowing an influx of calcium ions Ca++, which in turn triggers the actual pulse that is sent to the central nervous system. The ions are then quickly removed from the cells to achieve the default state of a low K+ and Ca++ concentration within the hair cells.

Part 1 of this series showed that each section of the basilar membrane reacts most intensely to a particular frequency (Figure 1). Furthermore, each section is associated with a specific set of auditory nerve fibres, and the central nervous system identifies the frequency depending on the fibre delivering the impulse. In principle, a single pulse would be enough to announce a frequency, and indeed, there won't be a pulse for each wave cycle (Figure 4). Instead, the number of impulses

An inner hair cell a) while the ear is at rest, b) with hairs shifted due to motion of the fluid and basilar membrane c) after potassium ions (K+) and if calcium ions (Ca++) have entered, triggering the nerve pulse. After that, the excess of ions is removed from the cell (dotted arrows) to return the cell to its default state.

Figure 3a

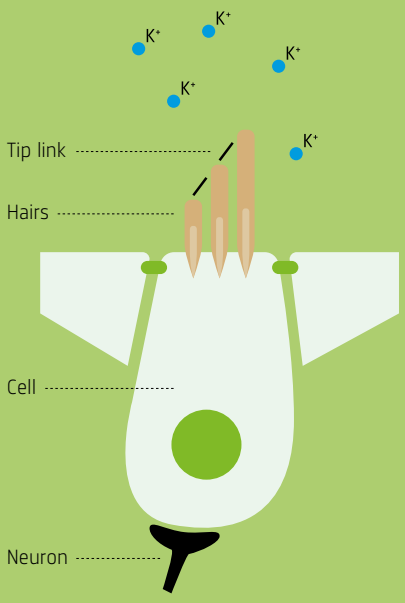


Figure 3b

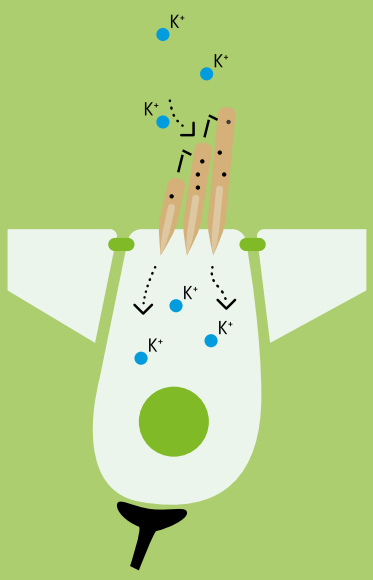
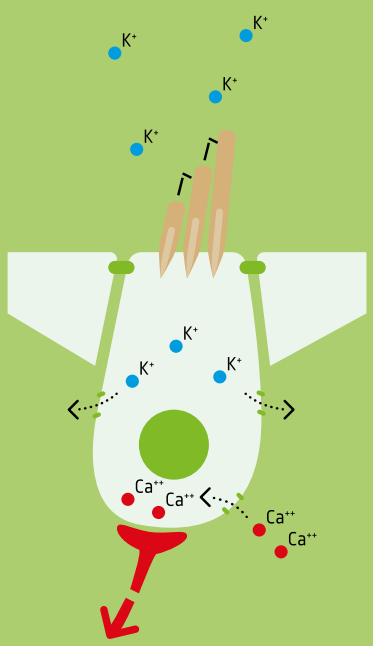


Figure 3c



fired per second depends on the intensity of the sound – the more intense the sound the more impulses triggered.

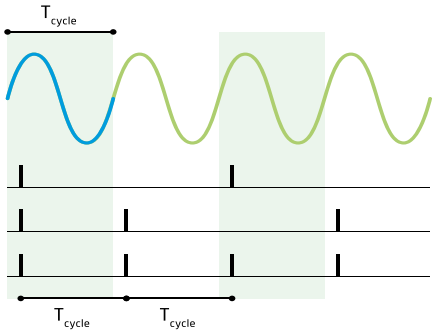
As described in Figure 4, impulses will be time-locked to the phase information in the sound waves. This phase locking is most exact at lower frequencies, becoming less accurate at higher frequencies. This allows the auditory system to compare the timing between left and right ears (see *Listening in 3D,* Waves 8). Due to head shape and the distance between the ears, signals coming from the side are registered slightly earlier by one ear. In addition to comparing the arrival time of signal bursts, the auditory system has a directional clue for continuous sounds.

OUTER HAIR CELLS

The outer hair cells do not participate in transduction. Instead, they are used to increase sensitivity. The cell walls contain a motor protein called prestin, which increases in volume when binding to an anion, in this case chloride anions (Cl–). Whenever hair-cell motion leads to a K+ influx, Cl– will be pulled from the prestin molecules, causing them to shrink in volume (Figure 5). When the K+ concentration is reduced again, the anions will reattach, and the molecules return to their expanded state. As a result, the entire cell will contract or expand, increasing the amplitude of the basilar membrane's vibrations.

This electromotility process is key to the detection of very soft sounds. Research suggests that without this active contribution of the outer hair cells, we would lose 20 - 40 dB sensitivity. Quiet sounds such as the noise of leaves and birds in a forest, a library or living room environment would be inaudible or very hard to detect without this mechanism.

Figure 4



A schematic of the phase locking for impulses. The time between two successive impulses is for a full wave cycle (or multiple of it) in a tone, such that impulses are always fired at the same phase of a wave cycle, here shortly after the onset.

HEARING PROTECTION

Why spend three pages describing electrochemical processes? To show that our inner ear is a fragile apparatus that requires care. At birth, the human ear contains approximately 3500 inner and 12000 outer hair cells. Unfortunately, they cannot regenerate, which means that destruction of these cells will result in permanent hearing loss. While age and disease can be factors, one dominant cause of hearing loss (and one that can be largely avoided) is excessive exposure to noise. Make sure to protect your ears from loud bangs and excessive noise at work and in your spare time.

Schematic operation of the outer hair cell with a) low potassium ion (K+) concentration inside the cell, the chloride anions (Cl–) being bound to the prestin molecules b) after a strong K+ influx, which pulls the Cl– from the prestin molecules

Figure 5a

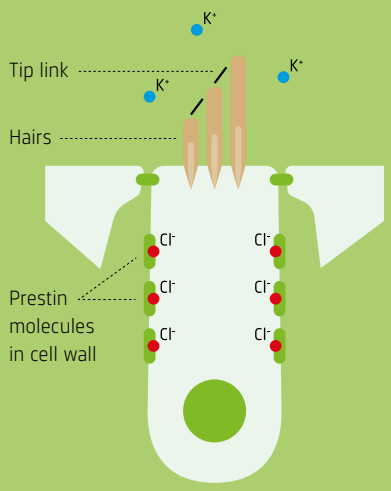
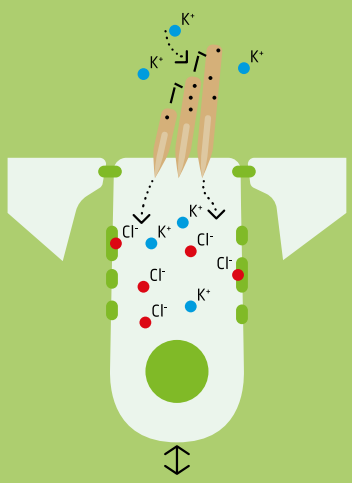


Figure 5b



B&K 2245 – FROM DRAWING BOARD TO RELEASE

BY: **MICHAEL WHITEMAN**
PRODUCT MANAGER,
HAND-HELD SOLUTIONS

From the release of the world's first transistorized and hand-held sound level meter, through the early digital and modular software-driven sound level meters to the touchscreen-driven Types 2250 and 2270 of today, Brüel & Kjær has been consistently at the forefront of sound level meter development.

Types 2250 and 2270 are extremely powerful and flexible devices. With the right software modules, they're capable of almost anything – from simple broadband sound level measurements and 1/3-octave frequency analysis to vibration measurements with real-time FFT analysis and building acoustics measurements. In the hands of experienced users, they are also easy to use.

But for users new to sound measurement, or those who only make measurements occasionally, Type 2250 can appear intimidatingly complex. Furthermore, it can be difficult for new customers to understand which software options are needed for their job. For our new entry-level sound level meter, we wanted to provide a much simpler user interface (UI) and more support in the field.

A touchscreen UI felt like a natural starting place for a user-friendly sound level meter. Type 2250 was introduced in 2004, three years before the release of the iPhone and the onset of the smartphone revolution, which has made touch interfaces ubiquitous in everyday life. But building a new sound level meter with an integrated touchscreen presented challenges.

BEST OF BOTH WORLDS

The touchscreen on Type 2250 uses a stylus. While this was typical in 2004, users today expect capacitive touchscreens they can operate with their fingers. But without a stylus to give precise input, finger-touch interfaces require large touch targets, in turn requiring large displays, ultimately resulting in a large and unwieldy sound level meter. ▶

Technology Manager Lars Kroman (left) and Michael Whiteman (right) proudly showing off the new B&K 2245 Sound Level Meter solution

B&K 2245 – FROM DRAWING BOARD TO RELEASE

Our solution with B&K 2245 is to move the touchscreen off the sound level meter and into new apps for a smartphone or tablet, allowing the best of both worlds: a compact and lightweight sound level meter, paired with a large touchscreen display. Recognizing that our customers cannot always use a smartphone, we still designed it with a user-friendly push-button-controlled UI and colour display. All measurement functions are available using the buttons, but with the apps we were able to go further.

TAILORED FOR THE TASK

Designing B&K 2245 from the ground up to be operated with apps, presented another opportunity to better serve new users. We chose to make separate apps for individual jobs-to-do. This enabled us to tailor each app to its application, reducing complexity and supporting the user. For example, the Enviro Noise Partner app includes markers, making it easy to exclude disturbances like a barking dog from environmental noise surveys. For occupational noise measurements, our Work Noise Partner app supports the user through a complete task-based noise exposure survey, from organizing measurements into tasks, making the measurements, and calculating a workday dose in the field.

Of course, there are many common features across the apps. Every app can embed photo, video, text and voice annotations directly into the measurement data, making survey documentation easy. They're also designed to be safe. Every smartphone user has at some time inadvertently brushed their phone's display, accidentally starting a phone call, or worse. To ensure that such accidental inputs don't result in lost data, we implemented safe pause and stop controls into our apps, where the user must slide the button to the opposite side of the screen. Simple but effective.

DANISH DESIGN

For B&K 2245 we wanted a sleek and modern design, but one that was also robust, easy to operate and hand-held. Of course, it needed to be acoustically optimized too. We turned to Steve McGugan, the industrial designer for Type 2250 and LAN-XI, as well as products from iconic Danish companies like B&O and Georg Jensen.

To ensure that the new sound level meter would be easy to hold and operate, we produced 3D printed mock-ups of each

iteration of Steve's designs to test the ergonomics. Where wood and clay mock-ups previously took days to produce, 3D printed mock-ups could be prepared in hours. This allowed us to explore many more variations. Just like on our previous designs, we placed the display below the buttons, so that you can have a secure grip, operate all buttons with your thumb, and be able to read the screen.

Because B&K 2245 was designed for wireless remote operation, we also wanted the user to be able to see what it's doing from a distance. With Steve, we extended the traffic-light concept from Type 2250 by integrating a light ring into the base of the sound level meter, making it easy to see the measurement state from a distance and at any angle.

NO COMPROMISE

While B&K 2245 is an entry-level sound level meter, we didn't want to compromise on its metrological performance. We want our customers to be just as confident of their results as they would be with Type 2250. We selected our new free-field microphone Type 4966, designed a completely new preamplifier, used our Dyn-X technology for analogue-to-digital conversion of the input signal. The result is a single measurement range of 16 to 141 dB(A) from noise floor to maximum level, even better than Type 2250.

Normally, a job does not end with the last measurement. Almost everybody will need to download and then analyse and report their data. To make this as hassle-free as possible, we gave B&K 2245 the ability to automatically back up its entire measurement storage to a network drive when connected to the network. And to make it even easier, we created an optional base station with Ethernet and fast charging – just place B&K 2245 into the station and walk away.

For measurement analysis and reporting, we decided to follow the same application-focused approach we took with the mobile apps, creating an associated PC app for each. Where the mobile apps are designed to support users while measuring in the field, the PC apps provide tools for analysis and reporting, again with a focus on simplicity and ease-of-use.

Only then, with a completely new hardware design, mobile and PC apps, and a range of accessories, can we say, 'job done.' Now it's your turn.

SOUNDS ABOUT RIGHT...

By Lars Kroman

A QUIET PLACE FOR SOUND

What does it mean to say it's a quiet room, and how do you measure 'too quiet'?

The anechoic chamber in building 87, with a background noise level of –20.6 dB(A) SPL, was declared the world's quietest place by Guinness World Records in 2015. Featured in Waves 5, 2016

On a Sunday afternoon, sitting peacefully, enjoying a tasty beverage, it's quiet enough to hear the distant chirping of some birds or the hum of electrical devices from other rooms. In a library reading room, perhaps footsteps padding down a carpeted aisle can be heard, or that particular frictional sliding-popping sound a finger and thumb make as they ensure that one page (not two) is being turned. In some rooms, designed to eliminate practically all external noise, it's quiet enough to hear your own heartbeat. In each case, the ambient noise drops so that the observer can no longer register it, and normally unheard sounds stand out. How do you measure that kind of quiet… especially when that quiet falls below a microphone's capabilities?

FUNCTION DRIVES REQUIREMENTS

Anechoic chambers, like the one in Microsoft's building 87 (Waves 5, 2016), isolate a room from outside noise and prevent reflected noise, eliminating ambient noise to ensure that only the target noise is measured and that the data is not corrupted by itself via reflected noise. These rooms are absorptive. They create a free-field environment, but in an enclosed space. This is the ideal environment for pinpointing noise sources that need to be mitigated.

Other rooms, like cinemas, theatres and performance halls, are designed to handle sound differently – to ensure that the audience hears a sound in a particular way. The Hahn theatre (Waves 8, 2017), built by KYD, is a primary example of ensuring that the audience hears the movies' intended effects. Through acoustic treatments, some frequencies are reinforced and others attenuated or eliminated. Ensuring that the right sound reaches the audience requires that there is no interference between the treatments and the listeners. This means that outside noise must be eliminated or mitigated.

Is there a distinction when measuring the ambient noise of the rooms? In both cases, external noise must be eliminated to ensure absolute silence, or come as close to it as possible. According to Vince Rey of Brüel & Kjær, while the purpose of the rooms is vastly different, the measurement method required to ensure their intended functions was not.

> Due to cognitive disassociation, many people become uncomfortable (to the point of distress and disorientation) in anechoic chambers because the visual and audial input do not match. While the parents of newborns may find the overwhelming silence pleasant, most people don't.

Key account managers Dave Formenti (left) and Vince Rey

Vince opined that both the Microsoft Building 87 and Hahn theatre measurement requirements were similar in the sense that the noise floor of even a low-noise microphone could not guarantee good measurements. This was obvious at Microsoft and there was a risk at the Hahn theatre. The coherent power measurement was the only solution to eliminate thermal noise from the measurements.

A QUIET PLACE
FOR SOUND

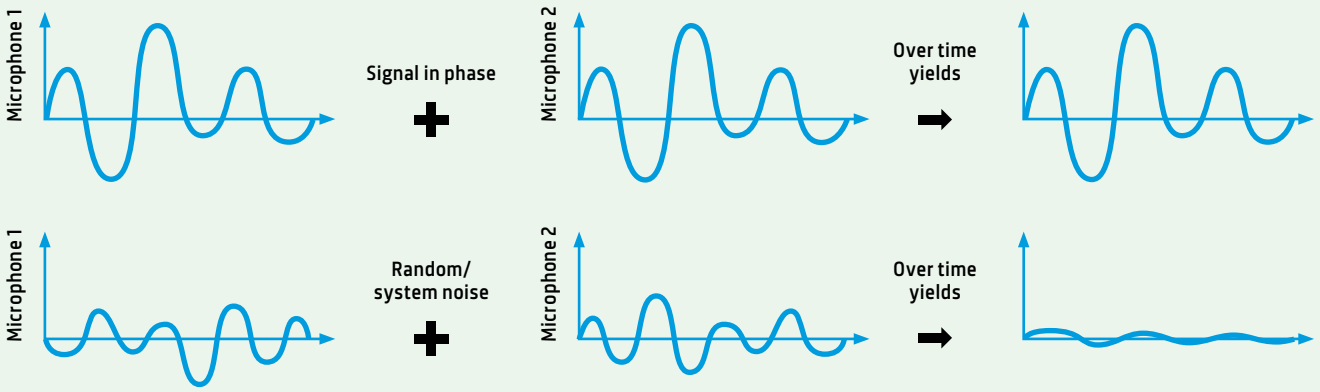
The Hahn theatre was measured at balanced noise criteria (NCB) – 6 with the HVAC on high. NCB curves are used to represent a decibel versus frequency curve for ambient noise levels in structures intended for occupancy and include noise HVAC systems. Featured in Waves 8, 2017

MEASURING BEYOND THE LIMITS

Building 87's anechoic chamber and the Hahn theatre both had the same problem: how do you measure below the limits of the microphone? The answer for both: the two-microphone coherent power method. This method uses two low-noise microphones to, essentially, subtract each other's noise from the measurement. The principle behind the coherent power method lies in taking advantage of multiple channels simultaneously measuring the exact same phenomena. If the distance between the two microphone sensing elements is small enough, they can be considered to be simultaneously exposed to the exact same pressure variation. Concurrently, the system is also exposed to its own noise (random electrical disturbance).

Coherent power integration works with complex-valued data. The integration of the part of signals that are correlated between multiple channels will see a constructive addition of signal. The part of signals that is uncorrelated will result in cancellation over time. This means that the room noise (correlated signals) will integrate over time to its true amplitude value, while the system noise (uncorrelated signals) will integrate toward zero over time.

AVERAGING, COHERENT INTEGRATION



A graphical representation of the correlation process for microphone signals. Because the microphones are so close, external noise will be functionally simultaneous and, therefore, in phase (correlated), and random/system noise will be significantly out of phase and, over time, average to zero.

The goal is to is correlate sound pressure between channels and exclude the system noise. So, if the same variation occurs at the same time for the two microphones that variation is considered pressure variation, and if a variation is not seen simultaneously for both microphones, it is considered system noise.

NVH MAKES AN APPEARANCE?

The Hahn theatre presented some particular problems. The room is not absorptive, so any noise originating inside the room, even a heartbeat or the simple act of breathing, would corrupt the measurement. Also, part of the room's isolation is a 180 kg (400 lb) door that seals tightly in its frame. There was no way to pass a wire into the room and close the door, so the measurement needed to be remotely controlled. Because the measurement needed remotely controlled time recordings, Sonoscout™, a versatile, wireless NVH tool that didn't require any additional training, was perfect for controlling the measurement. Once the data was acquired, it was remotely processed by Vince Rey (who assisted with both the building 87 and Hahn theatre measurements) for 1/3-octave coherent power analysis in PULSE™ LabShop.

THE RESULTS ARE IN

The ability of an engineer to confirm the predicted values for any design is essential. With the two-microphone coherent power method, engineers can confirm that the data is valid for target values at or below a microphone's lower limit. Both of the presented cases exceeded the microphone's limit, which was – 5 dB(A). Additionally, the tools used in the Hahn theatre measurement enabled valid data by working around specific conditions, like a massive door that must be closed. The ability to provide an accurate evaluation of a purpose-built room is necessary for ensuring valid results for that room's intended purpose: ensuring silence to ensure the right sound.

According to Andrew Steele, lead acoustic engineer for KYD, the combination of tools made setup and measurement painless. The minimal wiring needed with LAN-XI and the ability to connect wirelessly and control the measurement from another room with Sonoscout enabled him to acquire the data quickly and easily.

Two-microphone setup in the Hahn theatre

Sonoscout remotely recording time data for future processing

WHO SAID **WHAT?**

This is a familiar phrase, and one that is embraced and understood daily. In fact, the comment itself was Newton standing on the linguistic shoulders of Bernard of Chartres, a twelfth-century French neo-Platonist philosopher and scholar, who opined that "…nos esse quasi nanos gigantium humeris incidentes," which translates to "…we are like dwarves sitting on the shoulders of giants." Given his intended meaning, Bernard was likely not the first person to think this thought, and over time, the concept has evolved and been re-iterated many times since. The concept originally inferred that the moderns' limited comprehension could only see far because of the exalted wisdom of the ancients, specifically the apostles, in Bernard's case. But in more modern settings, the idea is more that successors build on what had come before and that the latest-and-greatest is better because of the foundation built by the predecessors.

This is a particularly relevant *Who Said What?,* because it embodies the spirit of the Brüel & Kjær – HBM union. The HBK concept is to build on the vision and innovations of Per Brüel, Viggo Kjær and Karl Hottinger. Building on the foundations laid by these creative minds and joining them together is a move toward a unified steady-state and sound and vibration test solution. This progress is one more step towards the likely best practices identified in the Beyond Tomorrow vision study and another way to improve data quality, acquisition, measurement and analysis in general.

"IF I HAVE SEEN FURTHER IT IS BY STANDING ON THE SHOULDERS OF GIANTS."

SIR ISAAC NEWTON
(1643 – 1727)...
OR SO MOST PEOPLE ASSUME.

HBK WILL REDEFINE THE CONCEPT OF A COMPLETE SOLUTION: BRÜEL & KJÆR AND HBM HAVE MERGED

HBK
HOTTINGER BRÜEL & KJÆR

Two global market leaders have united to combine their expertise and provide integrated solutions encompassing sensors, acquisition, preparation, evaluation and engineering services.

HBK combines the strengths of two industry leaders to provide the hardware, software and industry expertise that we need to become the solution provider predicted in the Beyond Tomorrow vision study. The consensus of the participating industry leaders and expert panel indicates that the solution of the future will be a single testing platform that incorporates the entire testing gamut. Brüel & Kjær's sound and vibration expertise and thought leadership combined with that of HBM's steady state expertise and thought leadership will be a great leap towards future testing needs and the predicted solutions of 2030.

In the course of delivering even greater value to our customers around the world, we do not only look to the future, we still live in the present, so Brüel & Kjær and HBM product lines will continue to be developed and supported with the levels of expertise and quality that has made these names so respected in their respective industries.

We would like to take this opportunity to thank all our customers and partners, and we look forward to continuing and growing our relationships with an even broader offering as HBK. Of course, all existing agreements, points of contact, procedures, partnerships, etc., will continue as is.

All questions are welcome. For more information please contact your local sales representative and check the latest news on www.bksv.com

BRÜEL & KJÆR NEWS

B&K 2245 SOUND LEVEL METER IS RELEASED

The philosophy behind Brüel & Kjær's new class 1 B&K 2245 Sound Level Meter is to instil confidence and control in professionals whose work involves noise measurement tasks.

B&K 2245 is a complete, easy-to-use solution designed to simplify noise measurement and analysis. It can be used as a stand-alone noise measurement device, or with a range of user-friendly mobile apps, each tailored to assist a specific job-to-do including environmental noise measurement, exhaust noise level testing and workplace noise. The apps provide the exact parameters and functionality needed, bringing an entirely new level of efficiency and control to noise measurements. Each device can be licenced to more than one app, so switching tasks is as easy as switching apps.

The sound level meter's robust rubberized body provides a secure grip and makes it dust and water resistant and suitable for indoor and outdoor use. In addition, the well-designed user interface makes it easy and comfortable to use.

To keep the sound level meter ready to use and protect measurement data, there is an optional smart docking station. The docking station is a high-speed charger that automatically transfers stored data to a network so that data is ready for analysis and reporting. A constantly charged and ready-to-go unit with all worry about saving or losing data removed can only boost user peace of mind.

For more detailed information on the B&K 2245 Sound Level Meter solution and the individual apps, go to www.bksv.com/2245

THE VTS IDEAS HUB

Introducing a new product, brand or service is never a straightforward process. Customer needs are identified, market research conducted, and competitor analysis achieved. However, it's often only after a customer uses the product or service that we really learn about all the advantages, flaws and their actual experience. On top of that, needs and expectations evolve with time.

To capture this often-missed area of product development, a new 'Ideas Hub' has been set up to gather direct feedback from our valued customers. When a new idea, improvement or mad professor moment happens upon a customer, they can now directly interact with the VTS Product Development team by submitting their idea and relating it to a product or service. This new initiative helps guide the VTS product range, delivering the solutions customers really need and want. Try it for yourself at https://bk-vtsuser.ideas.aha.io

EDAG: A CONTINUING SUCCESS...

EDAG Engineering GmbH, one of the automotive industry's largest independent engineering service providers with 50 years of experience and several facilities worldwide, has once again chosen Brüel & Kjær as a partner for its testing facility in Petersberg, Germany.

A new V8900-HBT750 system, including a hot and cold unit, was succesfully installed earlier this year, offering best-in-class vibration testing with balanced performance. According to EDAG, the system was chosen due to its outstanding shock performance, strong armature hydrostatic guidance and a unique power-saving profile available on the XPA-K range of amplifiers. In addition, a maintenance contract ensures high-level and continued support from Brüel & Kjær's global service team, who will keep the shaker system in peak condition to meet the testing capacity requirements set out by EDAG. EDAG is now working with us to create a reference site for potential customers.

FIVE QUESTIONS FOR SIDNEI

37-year-old Brüel & Kjær Account Manager Sidnei Luis do Prado from São Paulo is a busy salesman, but when he does have time off, he spends it enjoying family life, reading, practicing photography and playing goalkeeper for a football team. His favourite culinary delights include wine, strong coffee, Brazilian barbecue and Italian cuisine.

MOTTO: "THINK BIG AND FIGHT FOR YOUR DREAMS"

What are the challenges ahead?

The world is constantly changing and the challenge for companies is to anticipate the future needs and demands of people and the market. It is important to stay ahead of the game and be prepared to deliver new technological solutions that will add value to customers in the future. For tech companies, people are the key to success.

What drives you in your work?

I love working in sales, so, this alone motivates me. I am also driven by the opportunity to see efforts, plans and strategies convert into real results.

What is the best advice you've been given?

Be honest, transparent, patient and persistent in life. These values will make all the difference.

If you could invite three famous people to dinner, who would they be?

Warren Buffet, Bill Gates and Elon Musk.

Who do you admire most and why?

My parents. They did the best they could with the limited resources available at that time, but they always encouraged me to follow my dreams and make a better life for myself.

BW-0951-11