# CASE STUDY

## University of Windsor, Canada
## Modal Analysis and PULSE Reflex

Automotive Audio Systems
PULSE Software including PULSE Reflex, Transducers

*The automotive glass subwoofer technology has been in the development stage for a few years now. Read how The University of Windsor, using Brüel & Kjær hardware and PULSE software, including Reflex, has played an integral role in its development.*

*Photos courtesy of University of Windsor*

Brüel & Kjær

## The University of Windsor – Cutting Edge Research

The University of Windsor with its 16 000 full-time students is located in the Canadian province of Ontario, where the Detroit River constitutes the border between Canada and the US city of Detroit. The area is dominated by the automotive industry and includes some of the world's biggest automakers, research and development centres, OEMs and sub-suppliers. It is no wonder then that automotive research and initiatives have a high priority at the University. The involvement of partners from the automotive industry, OEMs and suppliers often results in cutting edge research and collaborative partnerships which benefit businesses and industries in Canada and beyond.

"The industries from across the border have frequently approached the University for its NVH expertise to help them develop their products and solve their NVH problems," explains Dr. Colin Novak, Assistant Professor, Department of Mechanical, Automotive and Materials Engineering at The University of Windsor. "I think that the reason for our success is partly due to the quality of the faculty and the core competencies we represent. However, the major contributor is our well-established cooperation with leading automotive companies ensuring the use of the latest research and providing our students with hands-on experience".

*Dr. Colin Novak, Assistant Professor, Department of Mechanical, Automotive and Materials Engineering at The University of Windsor*

Dr. Novak continues, "We have a full NVH program including a lot of application experience and theoretical knowledge. Companies and inventors have products they want to introduce to the market. They may have the concept but not the expertise to test product quality, nor the manpower or ability to get them launched and that's where we come in," says Dr. Novak. "And with Brüel & Kjær as our preferred supplier of sound and vibration applications we can provide our partners with accurate data and efficient service. So, for us, working with pioneers in the field of sound and vibration means that we are at the forefront of technology. In addition, Brüel & Kjær has one of the best NVH testing facilities just 45 minutes away – the unique ARC in Detroit. We enjoy using the facility together with our customers and it is also where we can learn new technologies that we can use to solve our customers' NVH problems," says Dr. Novak.

## Turning Rear Car Windows into Sound Systems

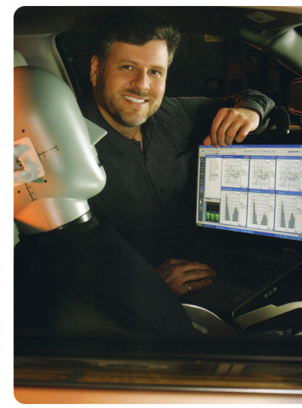
A recent project involved a large Canadian-based automotive supplier who approached The University of Windsor with an innovative Swedish audio technology it had acquired the rights to and that could potentially transform a car's rear window into a giant speaker. This would reduce the typical electrical load of an audio system by up to 75%, improve the fuel efficiency of a vehicle and provide valuable savings to vehicle manufacturers. In addition, the technology could reduce a vehicle's weight by up to nine kilograms, yet again contributing to fuel efficiency. The groundbreaking system would replace conventional subwoofers with the vehicle's rear window as the source of sound and free up space inside the vehicle.

*Installing the piezoelectric actuator*

Some in-house testing on the technology had been carried out by the automotive supplier but key areas such as psychoacoustics were missing, and this is where Dr. Novak and his team of nine graduates could help. "If we can move the glass in a particular fashion, then we can make the window act as a speaker," says Dr. Novak. His team developed a piezoelectric actuator – a bar-shaped device which receives the signal from the audio system and submits it to rigid, but highly-sensitive springs that run along the bottom of the window causing it to pulsate with the music. Dr. Novak explains, "Essentially, it's a spring system that's driven by a piezoelectric stack. We make the rear window of the car vibrate in phase with the music and that actually is the subwoofer of the car – light, simple and doesn't take up any space".


*Making measurements on the prototype installed in the Chrysler 300 test car*

The prototype was installed in a Chrysler 300, one of two test cars for the system. Dr. Novak explains, “In the vehicle at the base of the windshield, we have two of these actuators installed between the glass and the structure of the car. The glass is fixed along the top and is free to move along the two sides and the bottom, so the windshield can move. By having two of these actuators mounted to the glass, we can move the two sides of the glass independently so that the one sheet will move like two different speakers”. He continues, “Basically, the window itself will move, albeit very little – a fraction of a millimetre – because we have such a large surface area. That means the glass doesn’t have to move as much as the speaker cone would”.



*The Head and Torso Simulator at work*

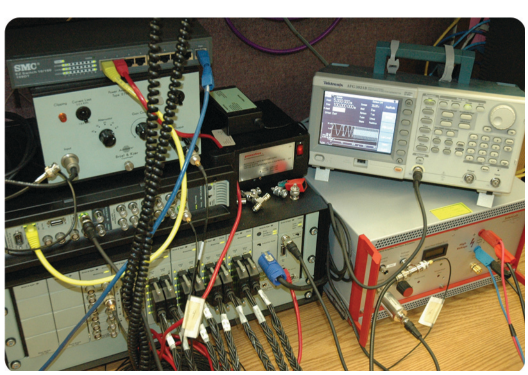
One of Dr. Novak’s main areas of expertise is psychoacoustics, so one aspect of the work of his AUTO 21 project team was to improve the quality of the sound generated by the glass speaker. To do this, a Head and Torso Simulator (HATS) and a ½-inch Prepolarized Free-field Microphone Type 4189 were used. The HATS is a mannequin with built-in mouth simulators and calibrated ear simulators that provide realistic reproduction of the acoustic properties of an average adult human head and torso.

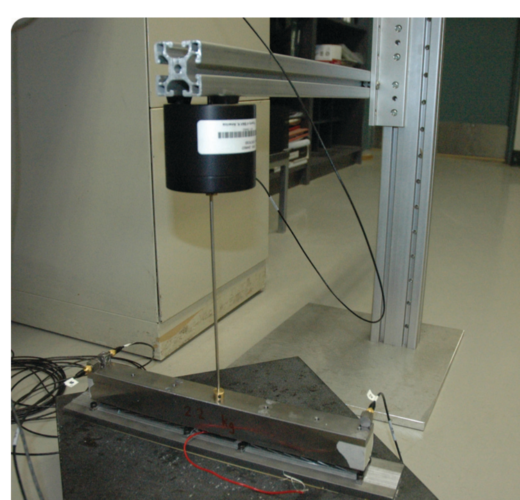
“To begin with we’ve been working on the subwoofer application on the windshield although we are looking into a more full-range speaker for the future”, says Dr. Novak. “We’re using the prototype installed in the vehicle to fine-tune the windshield’s available frequencies according to the acoustic features of the cabin, and especially the low-frequency component of the speaker system. The bigger the diameter of the speaker, the lower the frequency it’s capable of going,” he explains. “We’re aiming at between 10 and 120 Hz and hope to get it up to about 180 Hz whereas the most conventional subwoofers in your car only go up to about 90 Hz”.

One of the main challenges facing Dr. Novak’s team was the sensitivity of the actuators which function like springs and according to Dr. Novak, “have their own set of mechanical characteristics or natural frequencies”. So setting an operating range for these is a challenge as it is so far removed from the natural mode.

In order to determine the natural frequencies and acoustic properties of the actuators, modal analysis was performed on the actuators two to three times a week for about a month. The test results were sent to the manufacturer on a regular basis and who, in turn, made design adjustments and submit for re-testing.

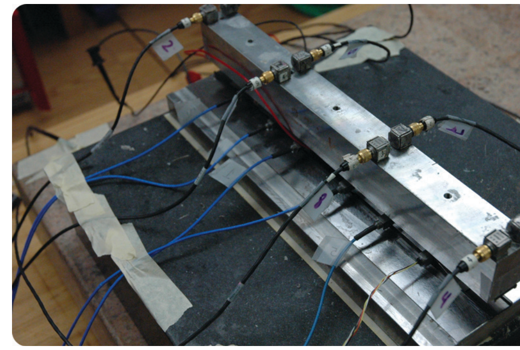
The initial testing of the actuator designs was performed on a test rig which consisted of a mass placed on top of the actuator, which had a weight equivalent to half of that of a windshield glass. Ten Miniature Triaxial DeltaTron® Accelerometers Type 4524-B were mounted at the top of the mass and also to the mechanical elements within the actuator itself. A Mini-shaker Type 4810 was used as the excitation source using both sinusoidal and random input with a frequency range of 10 to 200 Hz. Other hardware included a DeltaTron® Force Transducer Type 8230-001 and a PULSE C-frame with Type 7540 and Type 3040 Dyn-X modules. Data acquisition was done using PULSE Modal Test Consultant Type 7753.





*Front-end setup for the modal test (left); Mini-shaker Type 4810 used to shake the actuator test rig*

*Actuator instrumented with Type 4524-B triaxial accelerometers*



From the experiments, both the natural frequencies and the resulting mode shapes of the actuator were determined. This information was important as it was critical that the actuation did not have resonant frequencies within the 10 to 120 Hz operating frequency range. Using the animation capabilities of the Modal Test Consultant software, it was possible to ensure that the movement of the actuator was a linear in and out motion without a "rocking horse" effect.

Once a linearly operating prototype actuator was produced, it was installed in the Chrysler 300 test vehicle. The modal analysis activities were extended to study the characteristics of the entire system including the actuator/glass interactions.

In addition to audio applications, another innovative application for the window subwoofer device is to use the technology as the dynamic driver for an active noise control system to control automotive buffeting noise. Buffeting is a high-amplitude, low-frequency modulating noise which can occur inside the automotive cabin when a sunroof or rear window in the car is opened at moderate to high speeds. The shearing action of the outside moving air striking the static air inside the vehicle can result in the unwanted shock wave oscillations. Anyone who has experienced buffeting will appreciate how harsh this can sound. According to Professor Novak, "Given the very high amplitude and low frequency associated with buffeting noise, a very large subwoofer makes for a very good low-frequency noise source to control the onset of buffeting".

*Type 4810 Mini-shaker used to excite the rear deck of the car to determine the stiffness of the structure*

In order to implement the subwoofer in the rear glass of a vehicle, a very stiff structure to support the actuators is required. To implement this technology in a next generation vehicle design, PULSE Modal Test Consultant was again used to better understand the structural characteristics of the vehicle's rear support deck. Type 4810 Mini-shaker was roved across the instrumented rear deck in order to determine the mode shapes and deflection shapes. From this, the University of Windsor was able to help determine what structural stiffening was necessary to adapt the rear window subwoofer application to the future production car.

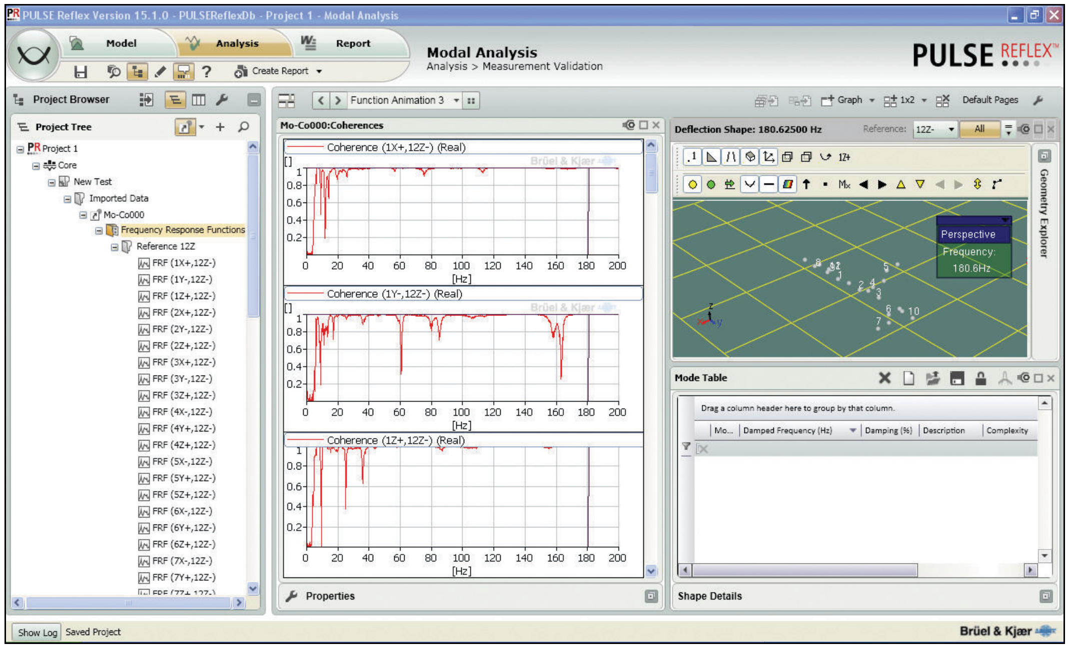
*A force transducer and Type 4524-B accelerometers and a were mounted onto the car rear deck to measure the Frequency Response Functions (FRFs)*

To better understand the buffeting phenomenon and its interaction with the vehicle, PULSE Reflex Core was used to post-process the buffeting noise measurement data and PULSE Reflex Modal Analysis for the structural measurements. Novak says, "While PULSE Modal Test Consultant has proven to be an excellent data acquisition and analysis application, PULSE Reflex has closed the loop necessary to perform curve fitting exercises to facilitate a determination of the structure's damping characteristics". Having the ability in-house will save us both time and money by not having to go to external suppliers. As one of the earlier users of PULSE Reflex, Novak says that he really likes the way that Reflex Modal Analysis can also import UFF files from previously taken data for further post-processing and analysis.

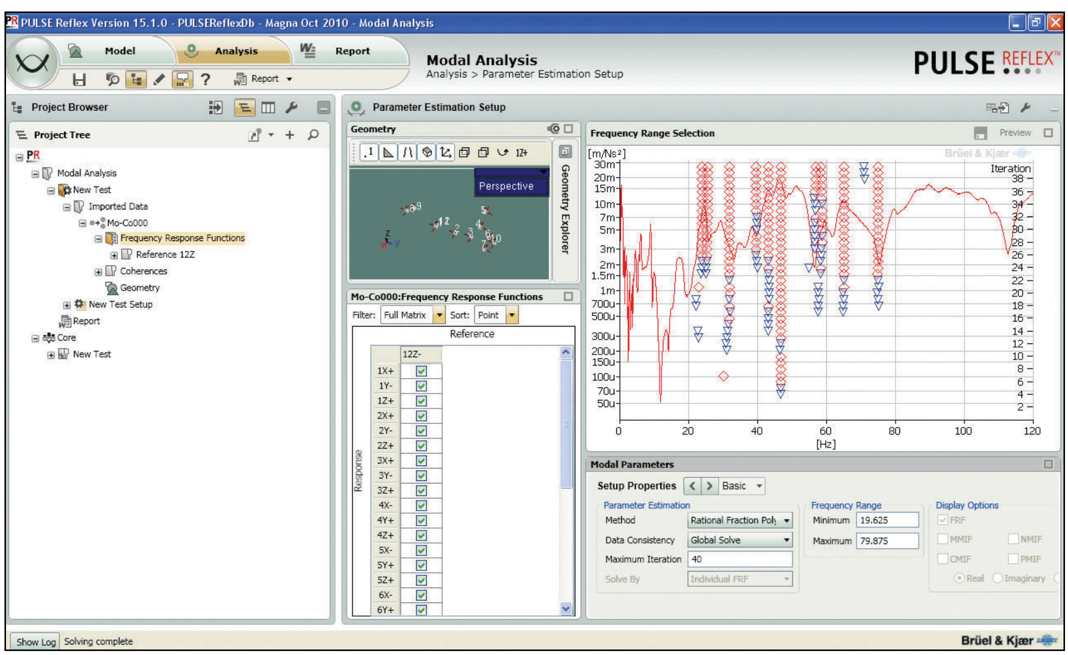
The NVH research group at Windsor is not only a research facility but is also a leader in the education of acoustics to undergraduate and graduate level engineering students. Novak says, "Reflex lends itself well to the classroom and research laboratory given how very intuitive it is to use with simple features that allow students to perform meaningful analysis of their data without a high learning curve. And once the students have completed their analysis and validation through the supplied tools, it is very easy for the students to create professional looking reports by using the reporting tools within Reflex".

The automotive glass subwoofer technology has been in the development stage for a few years now and Brüel & Kjær hardware and PULSE software, including Reflex, have played an integral role in this development. Looking ahead, Dr. Novak says, "One of our targets is the electric and hybrid electric vehicle of the future where consumption of the electrical components is a critical concern because that's what's really driving the vehicle. These vehicles aren't cheap – you might be spending $50,000 on an electric vehicle and you still want a nice sound system. Well, here we can do it, without sacrificing the whole idea of an electrical vehicle".

## Using Reflex Modal Analysis

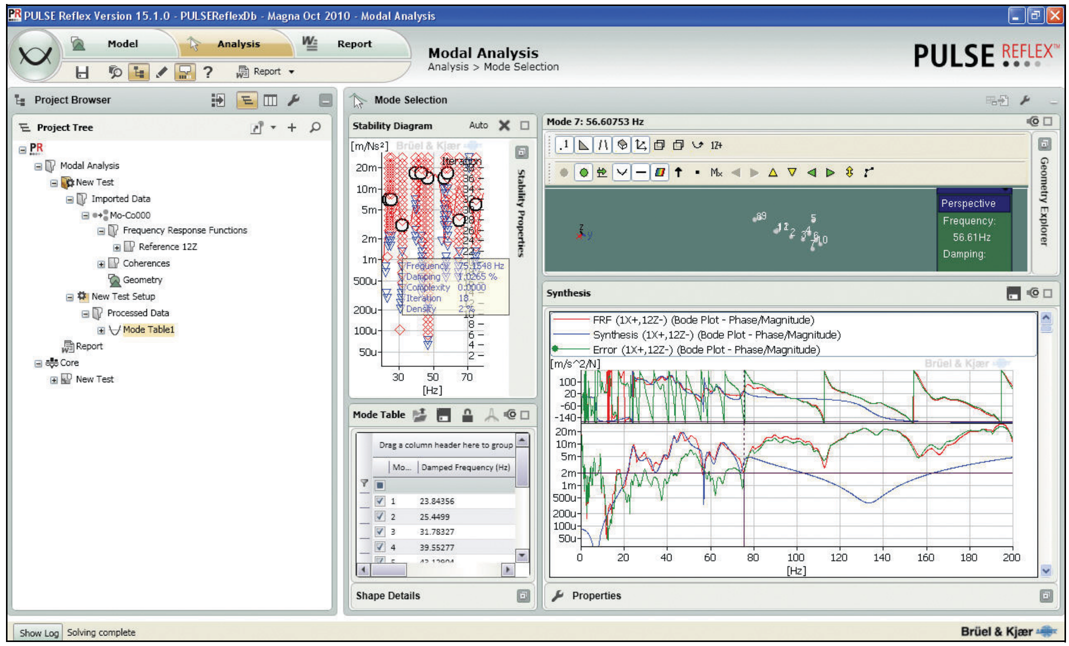


*Reflex Modal Analysis used to examine coherence functions for quality check of the measurements*

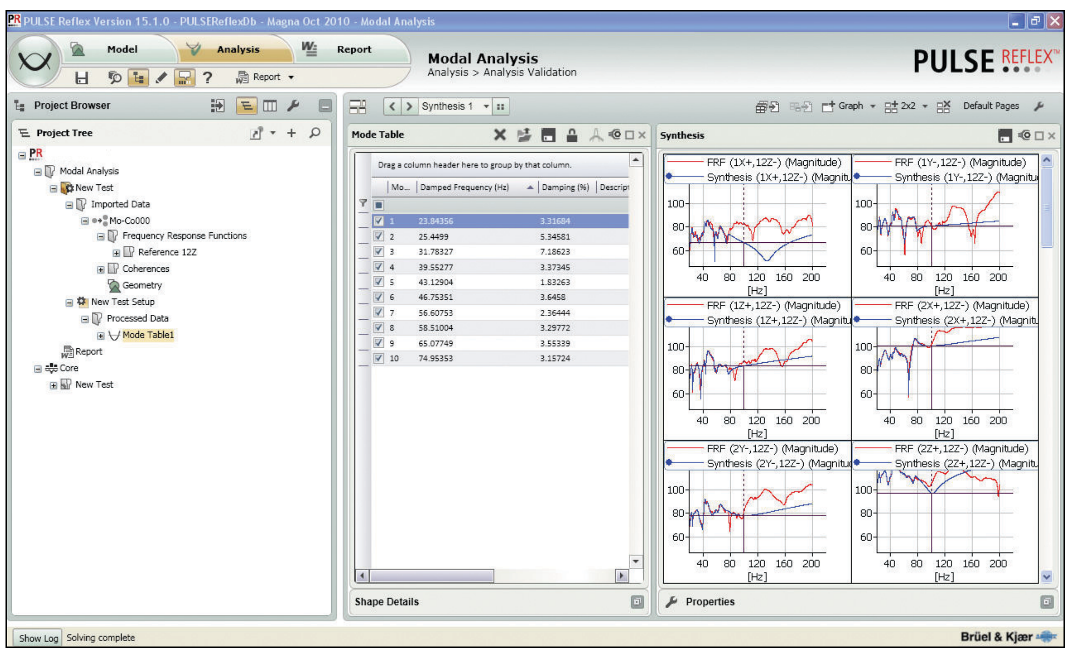


*Setting up the parameters in Reflex Modal Analysis for determination of mode strength*

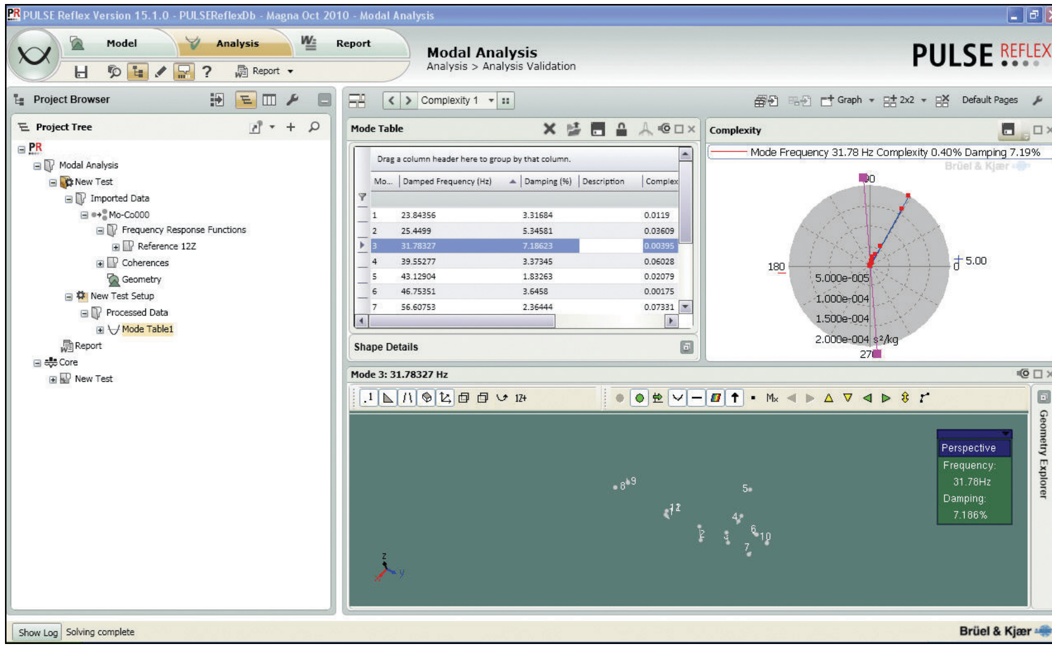
*Reflex Modal Analysis used to examine the mode strength and the Frequency Response Functions (FRFs)*



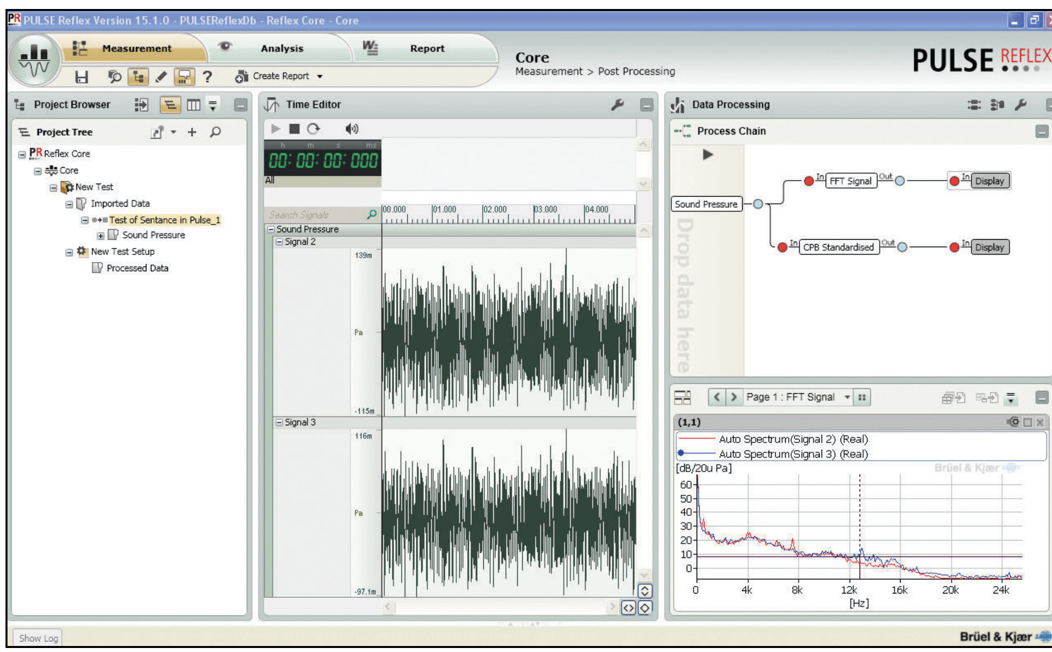

*Comparing measured to synthesised Frequency Response Functions (FRFs) using Reflex Modal Analysis*



*Validation of the mode shape complexity using Reflex Modal Analysis*




*Analysis of sound pressure recordings using Reflex Core*

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