

VP 1	1	2	3	4	5	6	7	8	9	10
VP 1	1 X									
	1 Y									

 **VIBES**.technology

# DIRAC

high-quality FRFs from tests,  
compatible with simulations





# DEAR READER,

**The vision of VIBES is to bring promising, innovative methods for sound & vibration testing and simulation to the industry. Our ultimate goal is to significantly decrease the engineering time and effort required in sound & vibration design of vehicles – thus reducing overall development costs and time-to-market.**

In the automotive industry, full vehicle sound & vibration testing is performed only in the latest stage of product development. Results are then compared with target levels and computer simulations done at the start of the product development. This leads to iterative design cycles involving many physical prototypes, a costly and time consuming process. Combine this with industry requirements to reduce engineering cycle times while expanding the amount of vehicle models and it becomes clear that product managers and engineers need a new game plan. That's why VIBES developed DIRAC: a breakthrough application for test-based modeling. In this magazine we proudly showcase our unique software and its ability to make innovation become reality.

Even though DIRAC is remarkable on all fronts, truly outstanding are the intuitive way of guiding engineers during the measurement and the integration of the Virtual Point methodology. With the live quality indicators available in DIRAC, measurements will be done first-time-right.

The measurement flexibility DIRAC offers has never been seen before. With DIRAC, the engineer can adjust all possible measurement settings even after testing. The Virtual Point transformation allows engineers to couple measured FRFs with simulated FRFs, making reliable full-vehicle models available earlier in the development process. Overall, DIRAC helps to avoid the final-phase troubleshooting (which can postpone vehicle production) and reduces the number of prototype variants needed, as the Virtual Points allow to couple the prototype bodywork to any number of drive-line concepts – thus saving valuable time and resources.

Our partnership with Müller-BBM, and the interface with the PAK MKII G2 hardware, ensures that all this technology is available in real-time. With DIRAC we developed a solution which empowers our goal to reduce engineering time and effort, by providing the industry with cutting-edge technology and a new game plan called DIRAC! This magazine shows you exactly why DIRAC is the solution you are looking for.

# DEAR ALL,

**Digitalization is rapidly changing business models, workspaces, and processes causing multifaceted challenges for the industry. Industrialization of development and reducing process costs while increasing process security, become even more important.**

Already today, companies can benefit from these new processes across the entire product life-cycle. Those who do not create this organizational framework now, will find it difficult to keep up in the future.

Development and production will merge as well as simulation and testing. Dynamic data will be accessible from anywhere and shared across all applications, teams and facilities. It is crucial to create R&D tools early to ensure they're process-reliable for development.

We, at Müller-BBM VibroAkustik Systeme, are proud of more than 25 years in vibroacoustic measurement technology including data acquisition hardware, data analysis and data management software. Consequently, since the beginning, we have fostered this openness through incorporating standards, e.g. ASAM ODS, CAN, and EtherCAT®, and through an open platform architecture utilizing openMDM® to drive compatibility and the use of multiple applications through our PAK family products.

Powerful ecosystems are the result of this openness and now allows us the ability to record and assess all necessary data together in one place. Not all inputs need to be from one device; we can acquire data synchronously from different sources and stream it to various applications on demand.

This gives us the freedom and ability to collaborate with technology leaders. These partners can integrate high-quality physical data from our PAK device cloud or access recorded data from our PAK cloud.



Besides this, we provide an agile process integration from the commissioning and documentation of a measurement to the management and reporting of results. Thus, even more specialized tools can be integrated into a process-secured development environment. The concept benefits both "users" and "producers" of data.

We are proud to work together with VIBES.technology – the leading provider of "Dynamic Substructuring" and "component Transfer Path Analysis" topics. VIBES.technology is an innovative company committed to improving methods and processes in automotive NVH.

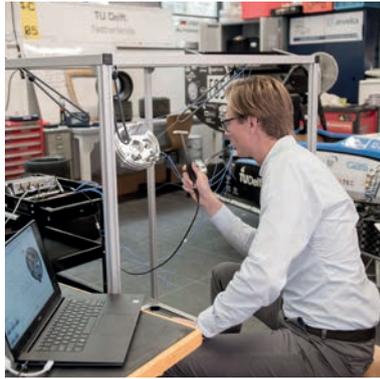
Our customers benefit greatly from the combination of process-reliable data acquisition and management with the use of highly specialized tools such as the DIRAC software from VIBES.technology.

The launch of DIRAC is a huge technological step forward for both of us, giving us yet another edge over the competition. Moreover, it is a powerful milestone in our collaboration which will only continue to expand as we collaborate – pushing the edges of innovation by solutions that inspire.

Yours sincerely,

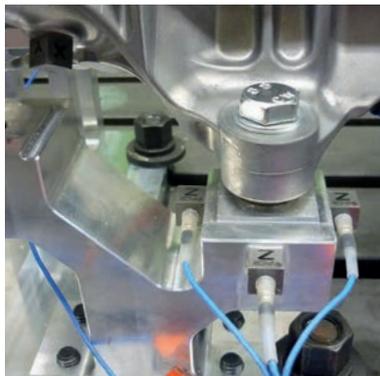
**Andreas Ansorge**  
CEO Müller-BBM VibroAkustik Systeme GmbH,  
Planegg

# INDEX



## THE PHILOSOPHY BEHIND DIRAC 08

## TRANSFER PATH ANALYSIS BEHIND THE SCENES 12



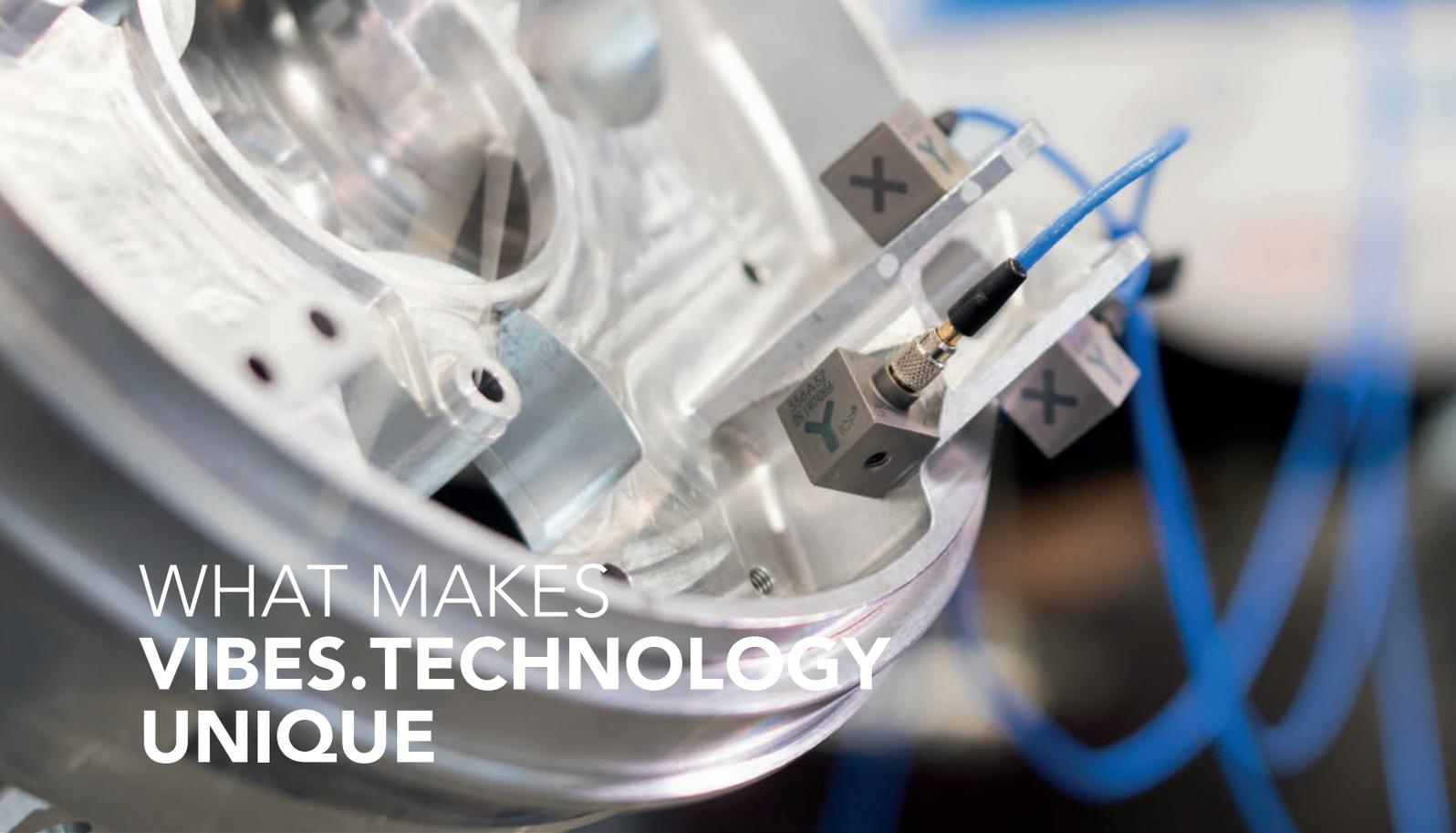
## SHOWCASES STEERING GEAR / E-COMPRESSOR 18

## A DEVELOPER'S VIEW ON DIRAC 22



WHAT MAKES **VIBES.TECHNOLOGY UNIQUE** 05 / INDUSTRY TRENDS:  
**SO WHAT?** 06 / **DIRAC CLOSE UP** 10 / **TYPICAL MEASUREMENT  
SET-UP** 17 / ADVERTORIAL **MÜLLER-BBM** 24 / THE FOUNDERS  
**OF VIBES** 26

VIBES.technology BV | info@vibestechnology.com | Molengraaffsingel 14, Delft NL | +31 85 744 09 70



# WHAT MAKES VIBES.TECHNOLOGY UNIQUE

VIBES.technology is the expert in the modular characterization of sound & vibration for automotive and high-tech industries. We are leading experts in test-based modeling (FRF, modal like, measurements on passive components), source characterization (blocked force descriptions for active components) and dynamic substructuring (combining multiple component FRF models to build up a system). The VIBES Methodology combines these technologies and with it, VIBES' engineers are improving the reliability, time-efficiency and cost-effectiveness of sound & vibration R&D.

With the unique Virtual Point Transformation, we combine test-based data with simulated data. This allows for a hybrid modeling approach where our clients can cherry-pick the best modeling approach on a case-by-case basis. We use measurements to characterize dynamic properties of components, subsystems or full vehicles. Proper dynamic characterizations are the basis of sound & vibration engineering.

#### **Our approach is unique because:**

**1. Test-based models are coupled to simulated models through virtual points, building full-vehicle models from component models before full-vehicle completed prototypes are available**

- 2. The models are a property of the test object only, independent of the testbench or environment**
- 3. The models are valid in a large frequency range, typically up to 3000Hz**
- 4. Only a single measurement is needed per component (vs. a measurement for each component-vehicle configuration)**

Engineers should be able to do these advanced analyses 'first time right' in a fast, smart and simple way. To make that happen, VIBES develops intuitive and user-friendly applications for performing high-accuracy, traceable measurements of the sound & vibration characteristics of (car) components and subsystems.

# INDUSTRY TRENDS: SO WHAT?



## ELECTRIFICATION

One of the most prominent trends in the automotive industry is electrification. Driven by increasing environmental demands, (plug-in) hybrid and full electric vehicles have found their way to the market. By phasing out the internal combustion engine, our driving experience is changing.

### So what?

*As the masking effect of the combustion engine disappears, the focus shifts to other components. As a result, the typical frequency range of interest has increased significantly (into the multi-kHz range) to cope with tonal behavior of the electrical drivetrain and other components. Also, there is an increase in vibration sources of which the battery cooler is most likely the most prominent example.*



## LIGHTWEIGHT MATERIALS

Driven by increasing environmental demands, another trend is the increased usage of light-weight materials. Copied from the high-performance vehicle segment, materials like aluminium, high-strength steel, magnesium alloys and composites using carbon-fibres are used to increase the vehicles strength-to-weight ratio, contributing to an increase in fuel efficiency.

### So what?

*Although the most significant effect of this trend is found in other fields than NVH (fuel consumption, driving dynamics, etc.), this trend does have an effect on the change in structural dynamics and choices for rubber mountings.*



## EXPLODING NUMBER OF VEHICLE MODELS

Those of us who have been browsing for a new car have undoubtedly noticed that product offering has increased drastically. Thirty years ago a product offering of four or more vehicles was considered broad. Over the past years, brands have been able to pack near 20 models in their product offering, with the goal of serving a specific product for every niche.

### So what?

*This increase in models has significantly increased the workload for the engineering staff. This does not only affect NVH departments. Engineers are pressured to do more work in less time. NVH departments specifically would benefit from an increase in measurement efficiency to cope with the additional demand of vehicles.*



## PLATFORM ENGINEERING

Fortunately, we haven't let the increasing number of vehicle models get the better of us. Platform engineering has been introduced to cope with this increase (and other things). Many vehicles share the same chassis and key-components, while the car body changes from vehicle to vehicle to enable the diversity in the product offering.

### **So what?**

*For NVH engineering in general, this means more of-the-shelf components with known vibrational behavior. More interestingly, platform components have allowed for a separation between the car body and the platform in terms of development phases in the engineering process. Platforms may be ready and available, whilst a new car body only exists as Finite Elements in computer simulations.*



**Impression**  
Volvo Car Corporation



## MODULAR MODELING

The final trend might be as old as Finite Element Modeling itself. There is an ever increasing demand in splitting up the vehicle in subsystems, components, and even sub-components so these can be designed and engineered by separate teams. As many know, mostly the challenge here does not lay in the actual splitting, but rather in the (re-)combination of the engineering efforts.

### **So what?**

*In the finite element domain this has been mastered over the past decades, but the coupling of 'real world' measured components remained challenging until recently. Smart coupling methods are required to combine the assembled behavior of multiple subsystems. Also, high-quality models in the multi-kHz range are necessary to make accurate predictions.*

# THE PHILOSOPHY BEHIND DIRAC

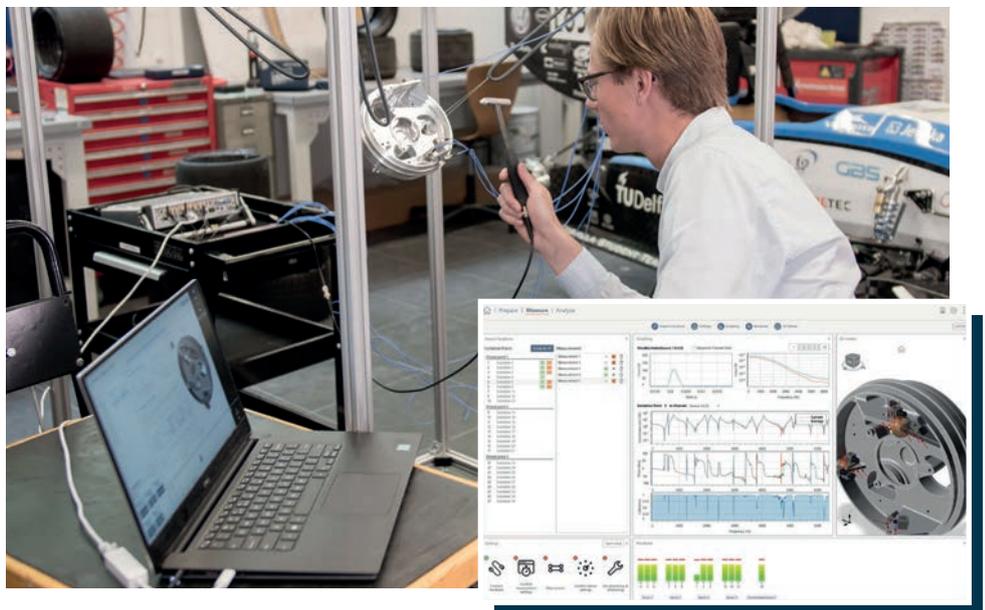
Across the automotive industry, OEMs and suppliers face the challenge to break down overall vehicle targets into component level targets while improving the accuracy of sound & vibration predictions in ever reducing time-spans. The **VIBES Methodology**, results in highly accurate models and predictions, prevents (human) error and allows for a modular way-of-working towards full vehicle predictions. The advanced checks and calculations that are the basis of our Methodology are now accessible in real-time, when the measurement is performed with DIRAC.

A truly modular engineering approach requires exact and well-defined interfaces between components. Using traditional (software) products, engineers are not able to perform measurements at the interface between two components.

## OUR UNIQUE VIRTUAL POINT TRANSFORMATION CHANGES THIS:

- Measurement data is transformed as if it were **measured at the exact interface location.**
- It allows to measure FRFs in **6 degrees of freedom (DoF)** including rotations, rather than only translations in 3-DoF.
  - At **higher frequencies**, e.g. generated by electric drivelines, rotational degrees of freedom are crucial to include because they can have a high contribution in the overall transfer and resulting sound levels.

Traditionally, FRF measurements are extremely prone to errors. A mid-sized measurement campaign easily includes 20 triaxial accelerometers being evaluated for force inputs at 50 locations. Force inputs at each location are then averaged over at least 3 hits, which



results in 9000 individual FRFs to be evaluated! To make things worse, all these sensor channels and force locations are reduced to simple lists, without checks on consistency or feasibility of the actual data and the locations. Knowing this, it is no surprise that when something unusual is spotted in the data, the quality of the measurement and the absence of human errors is always up for discussion.

DIRAC uses CAD files and an intuitive 3D environment as a basis for the measurement preparation. Sensors and force locations are all prepared in 3D, which gives **immediate visual feedback** to the user and later allows for visualization of results.

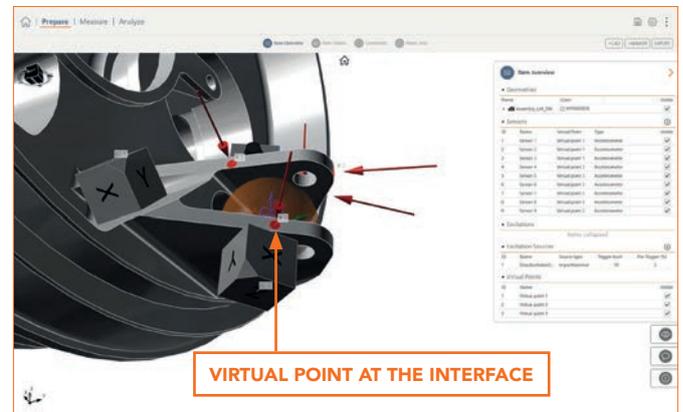
The measurement data quality is continuously controlled on multiple levels:

- **Smart data and sensor checks** ensure the measured data streams on the lowest level have no flaws, such as overloads, low signal-to-noise or double pulses.
- **Consistency calculations** ensure the measured data is in physical accordance with the known location and the orientation information as used in the Virtual Point Transformation. Wrongly mounted sensors, swapped cables and off-position impacts are detected this way.
- **Overall measurement quality** is checked against the resulting FRF model as a whole. For example, the Virtual Point Transformation allow you to check reciprocity and drive point passivity, giving valuable feedback to the engineer. This identifies whether an interface is well described or more measurements are required.

Accurate and reliable Virtual Point FRFs created with DIRAC are **key to succesful sound & vibration engineering** and are crucial to perform advanced analyses such as Dynamic Substructuring or Blocked Force source characterization.

DIRAC ensures traceability of results and indicates the quality of the measurement in a way never seen before, therefore **limiting the need to re-do measurements or to troubleshoot issues with emergency teams**. In the early stages of vehicle

R&D, full vehicle sound & vibration performance can already be estimated by combining measured and simulated FRFs. Over time these predictions can be updated to reflect changes in the design or decisions that have been made.



**VIRTUAL POINTS** A Virtual Point (VP) is at their interfaces, used to connect components, allowing the user to build up for example a full vehicle model. The point is "Virtual" because typically it cannot be measured directly. By placing sensors around the VP and by assuming the local region behaves rigidly, DIRAC transforms the measured data as if it were measured at the VP. The Virtual Point includes both translational and rotational degrees of freedom, data which traditionally is impossible to obtain. The transformation also gives valuable insights about the quality of the measured data and the resulting FRF model. Force impacts are transformed in a similar fashion.

## FREQUENCY RESPONSE FUNCTIONS

Frequency Response Functions (FRFs), and Noise Transfer Functions (NTFs), describe the transfer of vibrations through a component or a full vehicle. Designing and adjusting these FRFs is a valuable method towards obtaining comfortable sound & vibration levels in a vehicle. For example: the relationship of sound at the driver's ear, due to vibrations from an electric drive, are described by FRFs. The characteristics will vary with the frequency of the input (the vibrations) and thus FRFs are expressed in the frequency-domain. At a resonance frequency the transfer towards the driver will be high.

At an anti-resonance, the transfer will be (close to) zero. As a basis, engineers prevent to have resonances in this

FRF at the operating frequencies of the electric drive. The FRFs are obtained by applying a known force input, e.g. by using an impact hammer with built-in force sensor, to each point while measuring the resulting sound pressure using a microphone. The data is recorded over time and converted to the frequency domain. Typically, the coupling points of the electric drive to the vehicle are used as the interface for the FRF. Each coupling point (and within each coupling point, all six degrees of freedom) have their own FRF towards the sound pressure at the driver's ear. **DIRAC** ensures that all six degrees of freedom at the interface are well-described and measured with high quality – all through the usage of the Virtual Point Transformation which is continuously calculated during the measurement.

# WORKFLOW IN DIRAC FOR VIRTUAL POINT TRANSFORMED FRFs

1

## Define the interfaces

Identify the coupling points of the component to its neighboring sub-structures. At each interface a Virtual Point can be defined: a 6-DoF 'node' that allows to couple the FRF model.

2

## Prepare the measurement

Design the experiment in the CAD environment. Acceleration sensors and (force) inputs are placed close to the Virtual Points. DIRAC transforms all data as if it were measured at the Virtual Point. Sensor specifications are all specified in DIRAC to make the actual measurement plug & play.

3

## Perform the measurement

First, set up the hardware. During the measurement DIRAC shares live feedback on the data quality using the sensor specifications, the geometry of your experiment and continuous background checks. The 3D viewer guides the process.

4

## Analyze the data

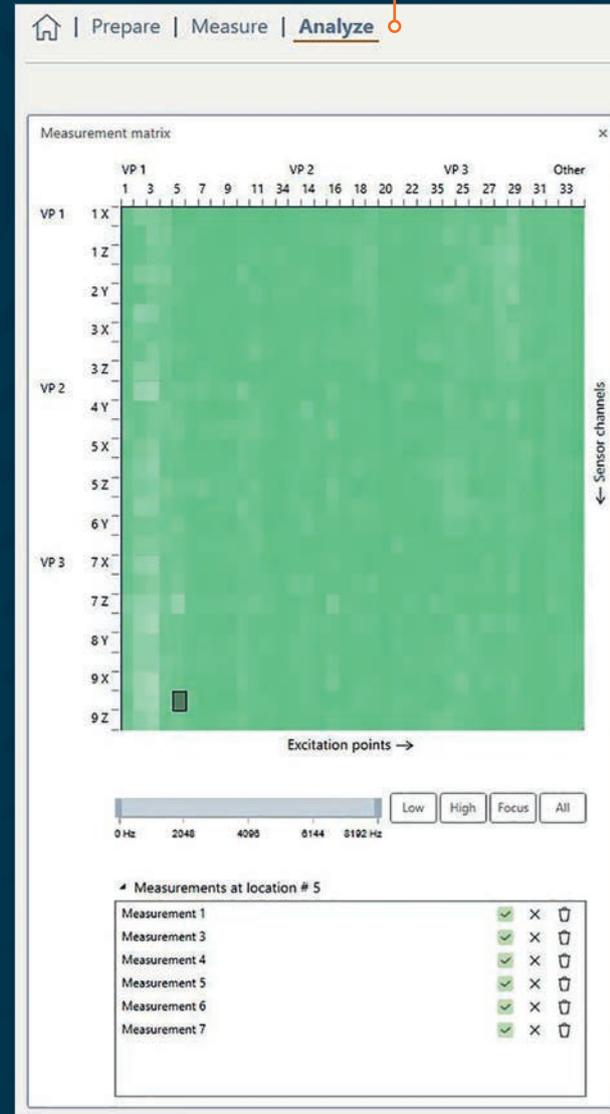
Switch to the Analyze mode to get additional insights into the model. Visualize the operational deflection shape (ODS) or use the Measurement Matrix to quickly view the measurement results as a whole or zoom in on a single FRF.

5

## Export the VP FRF model

Use the FRF model in MATLAB, in ASAM-ODS compliant software or in simulation packages like MSC Nastran for further analysis! All data formats are open to ensure DIRAC fits into existing workflows.

# DIRAC CLOSE UP



## 2D results presentation

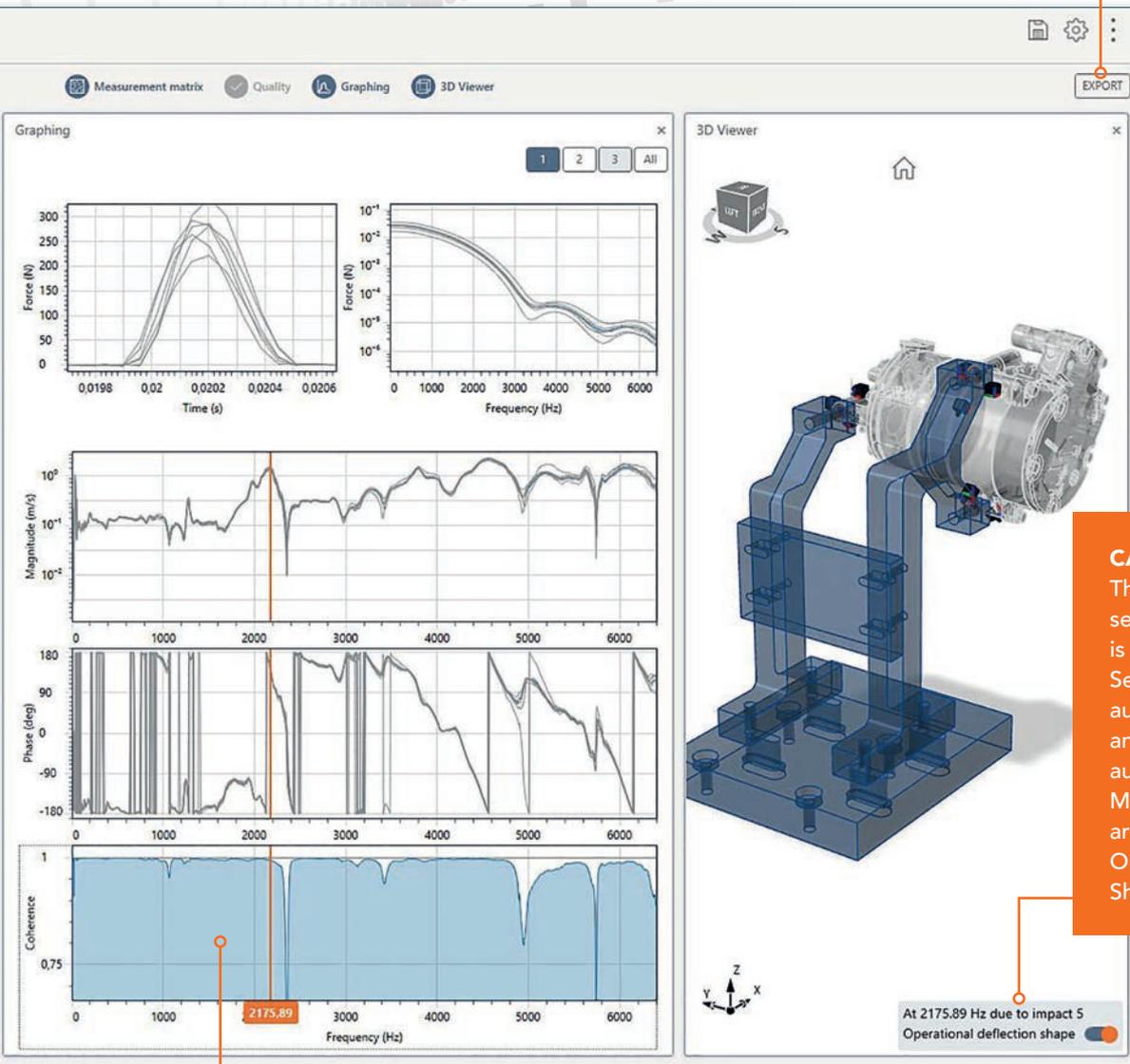
Of course, all the known graphs are there. But, we added some graphs you'll never want to work without again: evaluate your measurement as a whole in the Measurement Matrix or check impact and sensor consistencies.

## Prepare. Measure. Analyze.

Three distinct steps guide high quality measurements – with dedicated tools and layout optimized for the job.

## Open export

Open data formats are supported to ensure DIRAC fits into existing workflows. Use the FRF model in Matlab or export to ASAM-ODS or Universal File Format.



## CAD based

The positioning info on sensors and excitations is based on CAD files. Sensor orientations are automatically transformed and Virtual Points are automatically calculated. Measurement results are visualized with the Operational Deflection Shape functionality.

## Quality guaranteed

Quality checks are integrated in all steps of the measurement process, to ensure all necessary steps are taken for a high quality model.





# TRANSFER PATH ANALYSIS BEHIND THE SCENES

In order to win in today's highly innovative and competitive markets, automotive OEMs and high-tech companies are continuously improving their R&D methods. The aim is to increase product quality while reducing time and costs for both engineering and production processes. For sound & vibration engineering ('NVH' in automotive) a group of methods that has been significantly revamped over the past years is Transfer Path Analysis (TPA). With TPA, engineers evaluate the noise from various sources (e.g. road or engine noise), which propagates to the receiver (the driver or passengers) through various transfer paths.

With the variety of TPA methods growing over the past years, the need for a clear classification of methods and their pros and cons became inevitable. In 2015, VIBES' own Dr. Maarten van der Seijs and Dr. Dennis de Klerk, together with Prof. Dr. Daniel Rixen, proposed a general framework to structure the different TPA methods. For the first time, similarities between well-known classical

methods (such as mount-stiffness and matrix inversion) and the popular Operational TPA method have been made clear. More importantly, all recent approaches dealing with "Blocked Forces" were included and categorized into the component-based TPA family, in a way that helps the engineer choose the right approach, test bench design or source description for the case at hand.

# GENERAL FRAMEWORK FOR TPA

The three families of TPA as identified in the *General Framework for Transfer Path Analysis\** are listed below. The first two use some notion of force to split up in a source-transmission-receiver, while the transmissibility-based TPA is a response-only approach:

- **Classical TPA**

Classical TPA is intended to identify **transfer path contributions in existing products**. The source excitation is represented by interface forces, which are a property of the assembly they are measured in. Popular ways to obtain the interface forces are the *matrix inverse* method, the *mount stiffness* method or the *direct force* method, which uses force transducers mounted at the interfaces.

- **Component-based TPA**

Component-based TPA is powerful to simulate **component vibration levels in new products**. The source excitation is characterized by a set of equivalent forces that are an intrinsic property of the active component itself. More popularly, these forces are known as blocked forces, as they are the would-be forces (and moments!) when measured against a rigid boundary. Blocked forces are the perfect means to characterize an active source on a test bench at a supplier and allow the OEM to make NVH predictions for new assemblies by 'substructuring' the components. The blocked forces are often obtained *in-situ* using a matrix inverse procedure, where the test environment may be either a component test bench or the actual vehicle itself.

- **Transmissibility-based TPA**

Transmissibility-based TPA is **great for troubleshooting dominant sources and paths**. Classical TPA and component-based-TPA can be tedious processes, as they require FRFs to be measured on several (sub-)assemblies. If one is merely interested in the path contributions of different uncorrelated sources through their interfaces, it is faster to use a transmissibility-based approach such as *Operational TPA*. As these methods use responses only, the insights gained from it are limited to ranking of sources and their dominant paths.

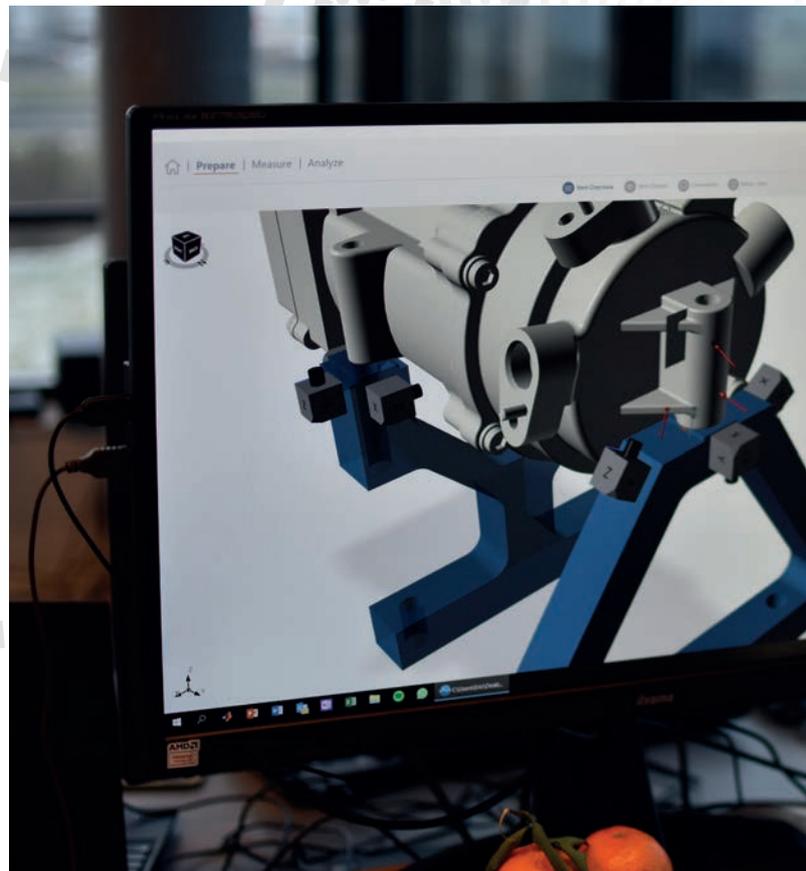
[\*] van der Seijs, de Klerk and Rixen, General framework for transfer path analysis: History, theory and classification of techniques, Mechanical Systems and Signal Processing (2016).

**Component TPA is a significant part of the VIBES Methodology.** Over the past years, VIBES further developed the component-based TPA methodologies and worked together with clients to tackle all types of sound & vibration issues based on measurements. **Vibration assessments are done faster and at an earlier stage of the design process, while being more accurate at higher frequencies.**

Our tools, both the MATLAB toolbox and DIRAC for FRF measurement, provide control and traceability while reducing both costs and risks.

We believe that a modular “component-based” way of working with open data standards (such as the ASAM-ODS ATFX-format) allows engineers to work most efficiently on challenging topics.

- Using **component-based TPA**, engineers obtain modular descriptions of individual components, with Blocked Forces being the independent quantities describing the active vibrations of the active source systems.
- Using **Frequency Based Substructuring**, component descriptions are combined to predict the behavior of a full vehicle in a modular way. To further reduce costs, engineers can even combine measured and simulated component models, enabled by the Virtual Point method.
- For active vibration sources, such as e-compressors in electric cars, the **Blocked Force approach** allows to predict sound levels in a car using a measurement of the active component at a supplier. Two ISO standards are currently proposed for this topic, of which the methods are already implemented in our software.



“



With DIRAC,  
engineers get  
real-time insight in  
the measurement  
quality

”

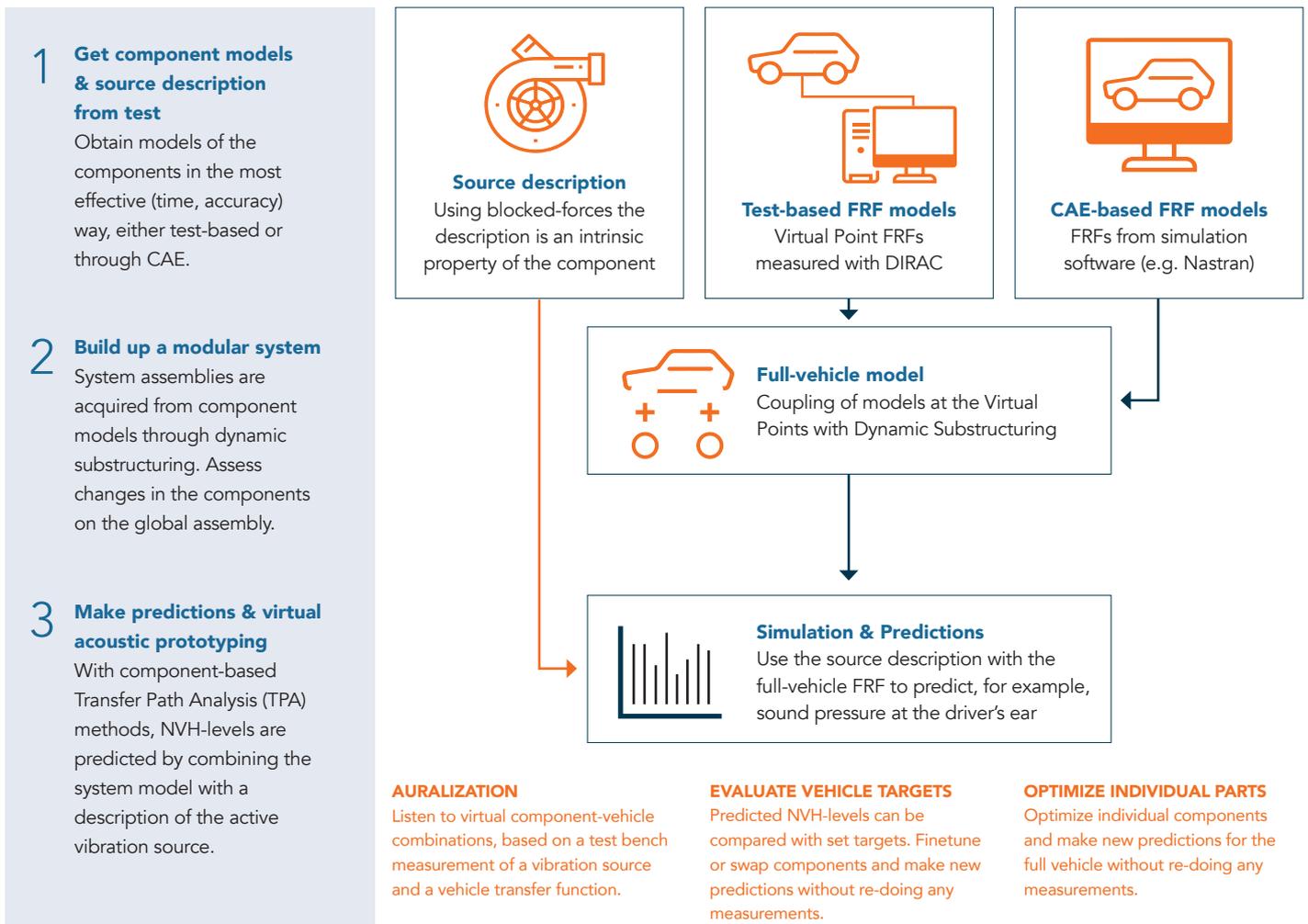


We proved the success of the VIBES Methodology with several major players in industry and are now leading experts in applying component-based TPA, Blocked Force technology and test-based modeling. With smart sensor data fusion (which is done real-time in DIRAC) typical drawbacks such as directional errors in impact hammer testing or the application of forces at connection points are efficiently dealt with – with the added benefit that the engineer gets real-time insight in the measurement quality too.

We are excited to see that our enthusiasm for the continuous development and implementation of modern TPA methods is shared and appreciated across industry. VIBES has built a professional team of dedicated experts and researchers, working together with leading partners in the industry to build the right tools and knowledge that help our clients win in competitive markets.

# THE VIBES METHODOLOGY

VIBES has a modular approach towards sound & vibration design. This allows a clear separation of responsibilities and reduces the number of measurements required.



## OUR PARTNERS

**MÜLLER-BBM**  
VibroAkustik Systeme

**MathWorks®**

**MSC Software®**

**TUM**  
Technische Universität München

**TU Delft**

**provincie ZUID HOLLAND**

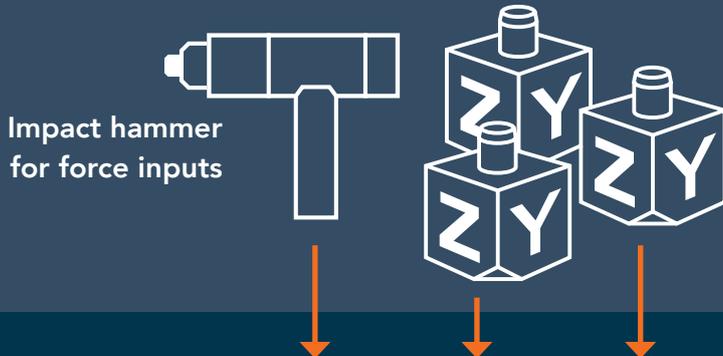
**UNIQ**  
Finance for the Future

# TYPICAL MEASUREMENT SET-UP

## OVERVIEW OF THE REQUIRED HARDWARE

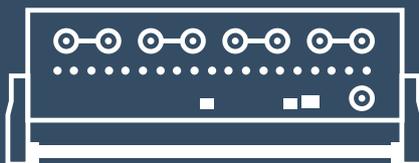
### MEASUREMENT SET-UP

Sensors: accelerometers for structural vibrations



### DATA ACQUISITION HARDWARE

PAK MKII G2  
frontend



Requires: generation 2  
device running 'live'  
firmware

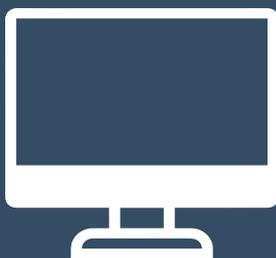
PAK  
device  
cloud



or

Direct  
(ethernet  
cable)

### COMPUTER + DIRAC SOFTWARE



Recommended specifications:

- 64-bit Windows version 7 or later
- 16GB RAM
- Dedicated GPU

### FURTHER ANALYSIS OF THE MEASURED VP FRF DATA – OPEN DATA FORMAT EXAMPLES

#### MATLAB

Matlab (.mat)-file for analysis  
in Matlab

#### UNIVERSAL FILE FORMAT

Universal File Format (.uff-file) for  
analysis in simulation packages, e.g.  
Nastran

#### ASAM-ODS

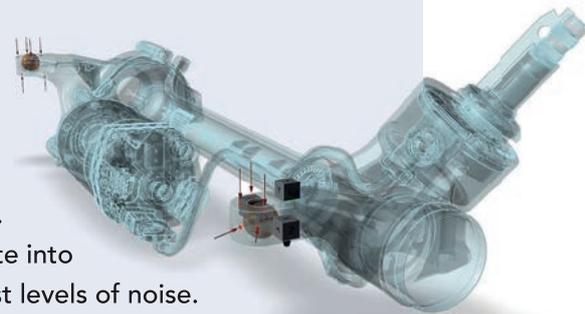
ASAM-ODS (.atfx) for analysis  
in measurement software such  
as PAK

# SHOWCASE STEERING GEAR

Using DIRAC's Virtual Point Transformation, OEMs can now predict in-vehicle Electric Power Steering sound & vibration performance based on supplier data and vehicle noise transfer functions.

## The project

For a German automotive OEM, VIBES engaged in a project analyzing the Electric Power Steering (EPS) system as a noise source. The motor and transmission parts generate vibrations, that propagate into the vehicle's interior through several structural paths, causing modest levels of noise.



The growing electrification of vehicles – and therefore the absence of the internal combustion engine (ICE) – makes the **EPS becomes more apparent as a noise source in the interior of the vehicle**. With the product fleet expanding rapidly, the number of 'EPS-vehicle'-combinations increases too, such that it becomes impossible to test all combinations on the road.

Rather than testing each combination in the vehicle, VIBES introduced **Substructuring Technology**, enabling to test each EPS system separately on a test bench and simulate the in-vehicle NVH performance using accurate

noise transfer functions (NTFs) of different vehicle models. This separation is enabled by the **Virtual Point Transformation**. The Virtual Point provides the common interface between the test bench and the vehicle chassis connection points.

### The goals

- Characterize the active vibrations of EPS systems using blocked forces and moments in the (virtual) coupling points, measured on (but independent from) the test bench.
- Simulate the in-vehicle noise at the driver's ear by combining these blocked forces and moments with vehicle NTFs, obtained once for each vehicle platform.

To put the above in a quantitative context, it amounts to measuring N EPS systems on a test bench plus obtaining M different vehicle NTFs, instead of needing to test the entire matrix of N x M combinations. For 6 EPS systems and 3 vehicle models, this already reduces the measurement effort by 50%!

**A source characterization workflow is typically subdivided in the following steps:**

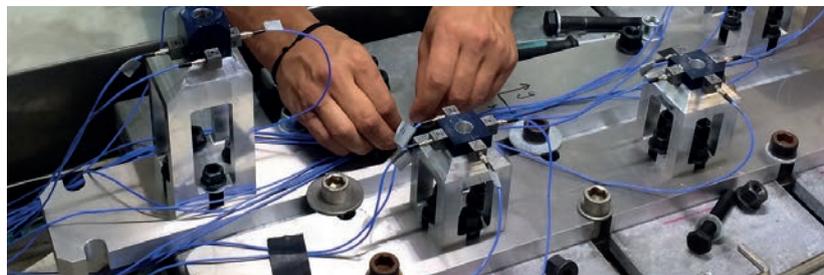
- 1. Design of Experiment** Definition of the sub-system's interfaces, as well as the positions of the accelerometers and excitation points, all performed in DIRAC.
- 2. Operational Measurement** The active component is mounted on a test bench and put in operation, typically for a variety of operational conditions, such as various load cases or speeds.
- 3. FRF Measurement** DIRAC is used to measure FRFs on the assembly of the active component on the test bench.
- 4. Virtual Point Transformation** DIRAC automatically transforms the measured FRFs into virtual point FRFs, which means that they now correspond to forces and moments in the virtual coupling points.
- 5. Blocked Force Determination** Blocked forces and moments are calculated by means of a matrix inverse procedure of the operational measurements with the virtual point FRFs.
- 6. Data Quality Assessment** Several checks are performed, such as an on-board validation and a transferability check, ensuring that the obtained blocked forces are ready-to-use for vehicle NVH simulations.
- 7. Vehicle NVH Simulation** Combining the blocked forces with vehicle NTFs, in-vehicle NVH performance of the component is simulated at positions such as the driver's ears, or even processed into audible audio streams.

**The approach**

This project was executed following the steps 1-6, as mentioned above. An important and key aspect of the measurements is the design of the supporting structure of the EPS in the testing environment. The test-rig supports had to be

carefully engineered to ensure it was strong enough to bear the load (axial) of the actuators when exerting a realistic tie-rod force on the EPS. Secondly, the dynamic behavior of the EPS on the bench had to show a good signal-to-noise ratio. Therefore, the supports were modeled in a Finite Element package to check whether the design filled the requirements.

**DIRAC was used to prepare, measure and analyze the FRF measurements.** While performing the actual measurement, every single measurement point was evaluated on the fly using virtual point technology and quality indicators. This ensured that the resulting FRF-matrix was suitable for the characterisation of the EPS with blocked forces. The vehicle's noise transfer functions – from the EPS coupling points to the microphones at driver's ears position – were measured with DIRAC too. Using the virtual point transformation, the transferability of the blocked forces was ensured, as the EPS points collocate.



**The results**

The key results in the project:

- Overall resources are reduced (the measurement effort is reduced by >50%) and the NVH evaluations of all EPS-vehicle combinations are performed efficiently without actually mounting each EPS in the vehicles.
- Improved quality of the NVH prediction in a large frequency range (multiple kHz), as the EPS is tested in a controlled environment, thereby avoiding external (noise) disturbances.
- New EPS variants can be quickly evaluated in all vehicle models using already existing vehicle NTFs, greatly benefiting early-phase development.

# SHOWCASE E-COMPRESSOR

A close-up photograph of an e-compressor assembly. The main component is a cylindrical metal housing. Attached to it are various sensors and wiring. A prominent feature is a blue cable connected to a sensor on the side. Another blue cable is connected to a sensor on the top. A yellow cable is also visible. The assembly is mounted on a metal surface, and there are other components visible in the background, including a large orange plastic component.

Using the blocked force approach an overseas OEM was able to predict the NVH performance by combining test data and FE models and reduce interior noise by ~15 dB.

## The project

For an electric vehicle OEM, VIBES analyzed the NVH performance of an e-compressor. A prototype e-compressor was available, a physical prototype of the full vehicle was not. To still obtain results, the structural contribution of an e-compressor to the interior noise was simulated using blocked forces.

The OEM had to decide on the packaging of an electric compressor. Traditionally, compressors are mounted to the internal combustion engine which helps to minimize the transmission of structural vibrations. With electric vehicles such mounting is not feasible and new isolation stages must be designed to meet the desired NVH performance in the vehicle.

### The goals

- Obtain an accurate source description with blocked forces on a test-rig, in the frequency range of 0 – 3 kHz.
- Obtain the blocked forces at a set of key operating points, such as various pressures and speeds.
- Obtain resulting force spectra compatible with Finite Element Models for further analysis and decision making – the virtual point transformation enables this compatibility naturally.

### The approach

The execution of the project follows steps 1 to 5 of the Blocked Force Workflow as the in-vehicle noise predictions themselves were performed by the customer. The compressor testing environment was provided by our partner IPETRONIK. The design of the supporting structure for the compressor was performed and analyzed in-house, to ensure a correct dynamic performance of the test bench for the characterisation.

We used DIRAC to prepare, measure and analyze the FRF measurements. While performing the actual measurement, every single measurement point was evaluated on the spot, using virtual point technology and quality indicators. This ensured that the resulting blocked forces of the compressor were independent from the testing environment.



### The results

The key results in the project:

- Using the measured blocked forces, the OEM was able to predict the NVH performance of the compressor in the vehicle – through a hybrid simulation combining test data and FE models.
- Based on the simulations, the customer decided to add an additional isolation stage at the mounts, saving ~15 dB on interior noise.
- The project demonstrated the power of a fully modular NVH approach, with a supplier in Europe and the predictions performed overseas at the OEM engineering department.

# A DEVELOPER'S VIEW ON DIRAC



The first real steps of creating DIRAC happened in the spring of 2017. At this point, it was just a one-man development team working on a proof of concept. With DIRAC, any engineer should be able to create high-accuracy models in the minimum amount of time. With this in mind, the first lines of code were put into Visual Studio and the process of creating DIRAC had begun.

**MATHIEU  
WERNSEN**



Over time the team expanded and the development speed increased rapidly. The number of features in the backlog increased from zero, at the beginning of 2017, to over a 1000 in January of 2019. As features were added, the screens started to fill up gradually. Where DIRAC was just a bare 3D viewer at the end of 2017, now in 2019, DIRAC contains the three steps one needs to perform a high-accuracy impact test (prepare-measure-analyze), it connects to external hardware components and features many export functionalities.

One of the more challenging aspects in developing DIRAC was to make it interface with a great many external hardware and software vendors. This means that importing and exporting capabilities are continuously being developed, as are hardware connectivity with external parties. The idea is to make the software as “open” as possible and to not limit users to a dedicated binary file no one can work with. As a result, many weeks were spend on implementing the ASAM-ODS format, the UFF file format, the MATLAB file format and of course the PAK device cloud.

In order to get a perfect integration, we’ve worked together with many different parties. First of all, we teamed-up with the Müller-BBM engineers to integrate DIRAC with their hardware, but we also worked with engineers from the bigger FEM companies to understand the requirements of exporting FRFs into the Universal File Format.

Being an engineer myself, and having extensive experience in impact testing, developing software to serve this purpose fits me well. Knowing first-hand the hassles of impact testing, it was obvious to me which features had to be implemented to ensure an impact test is done first-time-right. As an engineer my most enjoyable times were moments where I could come up with smart ways to guide a user through the entire process, and additionally give them appropriate visual feedback. As a developer, on the other hand, I mostly enjoyed implementing high-performance state machines that take care of all measurements and the calculations in the backend. Fortunately, DIRAC allowed me to combine both these fields.



# MÜLLER-BBM

## VibroAkustik Systeme



### EXCELLENCE IN VALIDATION PROCESSES

**Müller-BBM VibroAkustik Systeme is one of the world's leading suppliers of vibro-acoustic measurement technology, focusing on the acquisition, analysis, evaluation and management of physical data.**

We are part of the Müller-BBM Group, an international company providing consulting services, technical products, systems and software at the

highest level for over 50 years. Müller-BBM Group currently employs more than 1,000 people worldwide. Being part of the MÜLLER-BBM Group, we

NOISE AND VIBRATION	ACOUSTICS	ROTATIONAL ANALYSIS	STRUCTURAL ANALYSIS	NOISE AND VIBRATION
<ul style="list-style-type: none"> <li>• Multi-channel Data Acquisition &amp; Analysis</li> <li>• Digital Data Recording</li> <li>• High Speed Shock Capture</li> <li>• Random, Sine and Shock Data Reduction</li> <li>• Acoustic Control</li> <li>• Monitoring / Limiting</li> </ul>	<ul style="list-style-type: none"> <li>• Reverberation Measurement</li> <li>• Sound Intensity</li> <li>• Sound Power</li> <li>• Octave Analysis</li> <li>• Sound Localization</li> <li>• Exterior Noise</li> </ul>	<ul style="list-style-type: none"> <li>• Order Analysis</li> <li>• Online Monitoring</li> <li>• Kalman Filtering</li> <li>• Torsional Vibration</li> <li>• Angle-based Analysis</li> <li>• Combustion Analysis and Indices</li> </ul>	<ul style="list-style-type: none"> <li>• Impact Measurement</li> <li>• Shaker Measurement</li> <li>• MIMO, SIMO</li> <li>• Operational Deflection Shape Analysis</li> <li>• OTPA, TPS, CTC, PCA, PCCA</li> <li>• Matrix Inversion</li> <li>• Modal Analysis</li> </ul>	<ul style="list-style-type: none"> <li>• Sound Design</li> <li>• Online Filtering</li> <li>• Hearing Comparison</li> <li>• Jury Validation</li> <li>• Engine Roughness</li> <li>• Loudness</li> <li>• Modulation Analysis</li> </ul>

have benefited from the group's strong consulting reputation in vibration and acoustics. We pride ourselves on offering first-class measurement and analyzing tools in the fields of acoustics, vibration, and strength.

Our software PAK is widely used throughout the industry, especially in the automotive, aviation and machinery industry. Examples of our capabilities are:

DATA ACQUISITION	DATA ANALYSIS	DATA MANAGEMENT
<ul style="list-style-type: none"> <li>• Scalable, modular frontends for nearly all measurement quantities</li> <li>• Digital / Bus data: CAN, CAN FD, EtherCAT®, FlexRay™</li> <li>• Standalone operation</li> <li>• Continuous data streaming with PAK live technology</li> </ul>	<ul style="list-style-type: none"> <li>• Troubleshooting, quality assurance, standardized tasks, mobile measurements, test bench operation</li> <li>• Evaluations of physical data, e.g. NVH, E-Mobility-NVH, comfort etc.</li> <li>• Direct online visualization of measured quantities and spectral analyses</li> </ul>	<ul style="list-style-type: none"> <li>• Open data format: ASAM ODS ATF/X</li> <li>• Order management</li> <li>• Cloud services for data management</li> <li>• Interfaces to test bench systems</li> <li>• Interfaces to openMDM®</li> </ul>

Being one of the founding members of the ASAM organization, we are continuously involved in the definition of standards, e.g. for digital bus data, NVH data and geometry. The resulting ASAM ODS ATF/X file format enables easy sharing of measurement data between different software platforms. Our measurement data is stored in this format, already during the measurement, therefore providing a fully open data format to our customers. As such, our software solution fits to simulation software as well as any third-party data analysis software.

Since 2014, we've been active as one of the "Driver Members" in the openMDM® Eclipse working group. As such, we are committed to standardize resources and IT infrastructures for an enhanced workflow of measurement data within our customer organizations.

Our tight partnership with industry and recognized expertise in acoustics and vibration has been fundamental for our technical innovations.

It establishes us as a strong partner for future-oriented testing solutions and their turnkey integration in customers' workflows. We believe in an open software architecture and focus on embedding intelligent cloud technologies and applications within our platform. These applications might be ours, or from certified partners.

A certified partner to our open architecture is VIBES.technology. Their innovative application, DIRAC, facilitates users Test Based Modelling, Source Characterization and Blocked Force TPA on our ecosystems, the PAK device cloud and PAK cloud.

With this platform, the highest degree of automation is fostered and efficiency through digitalization is real. Let us work together with you to help shape the digital transformation in your testing processes. **THE WORLD RESONATES WITH US.** Will you join us?



### Dr. Dennis de Klerk

Dennis has profound expertise in Experimental Substructuring and he introduced Component Transfer Path Analysis to industry. He holds a PhD degree from the TU Delft on the topics mentioned above. He has been working at Müller-BBM VAS for over a decade and currently runs the business in the BeNeLux, UK and parts of Spain. Within Müller-BBM VAS, Dennis is responsible for the partnership with VIBES.

# THE FOUNDERS OF VIBES

VIBES.technology was founded by engineers at heart. A shared passion for structural engineering brought them together at Delft University of Technology. In 2016 VIBES emerged from their mission to enable experimental dynamic substructuring and modern TPA techniques for the engineering community. Nowadays, VIBES is a key player in today's innovative market, led by four technical experts.



## Eric Pasma

*Business Development*

Eric runs all commercial activities of VIBES. He holds a mechanical engineering MSc degree from the TU Delft and co-authored several papers in the domain of experimental modeling. Together with the customer, he looks how substructuring technology can be implemented in the engineering process. With a wide range of clients, each implementation demands customization. Eric translates the needs of the clients into solvable cases and matches these with the products and services VIBES offers.

✉ [epasma@vibestechnology.com](mailto:epasma@vibestechnology.com)

## Maarten van der Kooij

*Product Development*

Maarten is responsible for (new) product development and the product roadmap. He is driven to create next generation software that improves the reliability and cost-effectiveness of sound & vibration R&D. This way, VIBES helps its clients to offer the best possible perception of product quality to their customers. Maarten holds a mechanical engineering MSc degree from the TU Delft and applies his knowledge to optimize the technical aspects of VIBES' products.

✉ [mvanderkooij@vibestechnology.com](mailto:mvanderkooij@vibestechnology.com)





### **Daniël van der Bosch**

*Finance & Engineering Expert*

Daniël applies his technical expertise to several engineering projects within VIBES. He holds a mechanical engineering MSc degree from the TU Delft and is driven to finding the smartest and most innovative customized solution for every modular modeling challenge. As a consulting expert, he manages complex, end-to-end, engineering processes for clients. Furthermore, Daniël is in charge of all financial and general corporate activities; he is responsible for keeping VIBES.technology stable and sound.

### **Maarten van der Seijs**

*Technology*

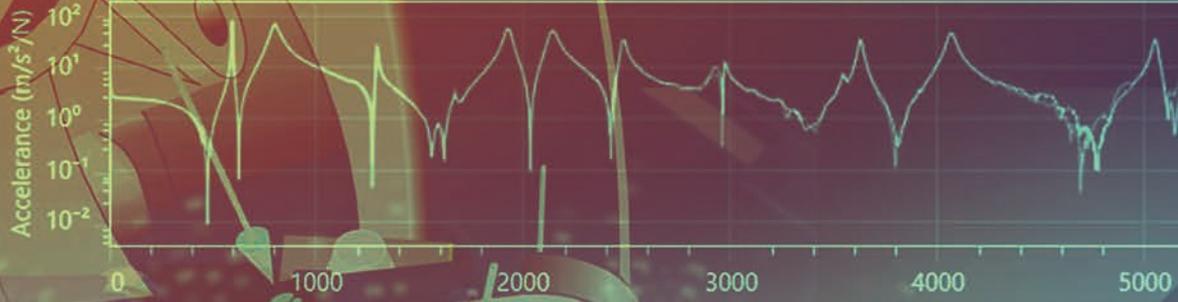
Maarten has profound expertise in substructuring, experimental modeling and Transfer Path Analysis. He holds a PhD degree from the TU Delft on dynamic substructuring. As the Head of Technology he is responsible for the technology within VIBES. He provides a technological answer to any question a client has and develops and improves technologies to that end. Maarten ensures that VIBES offers the best solutions to its clients.



Do you want to know more about how  
our DIRAC application can help you?

**Please contact us**

📞 +31 85 744 09 70 • ✉ [info@vibestechology.com](mailto:info@vibestechology.com)



x Measurement

VP 1

1 2 3 4 5 6 7 8 9 10 11 12 13

VP 1

1X

1Y

**DID DIRAC MAKE AN IMPACT?**  
 SIGN UP FOR OUR QUARTERLY NEWSLETTER  
 @ [VIBESTECHNOLOGY.COM](http://VIBESTECHNOLOGY.COM)  
 AND STAY UP TO DATE!

Other

4X

4Y

3Z

3Y

3X

2Z

2Y

2X