MÜLLER-BBM
VibroAkustik Systeme

transfer path analysis.

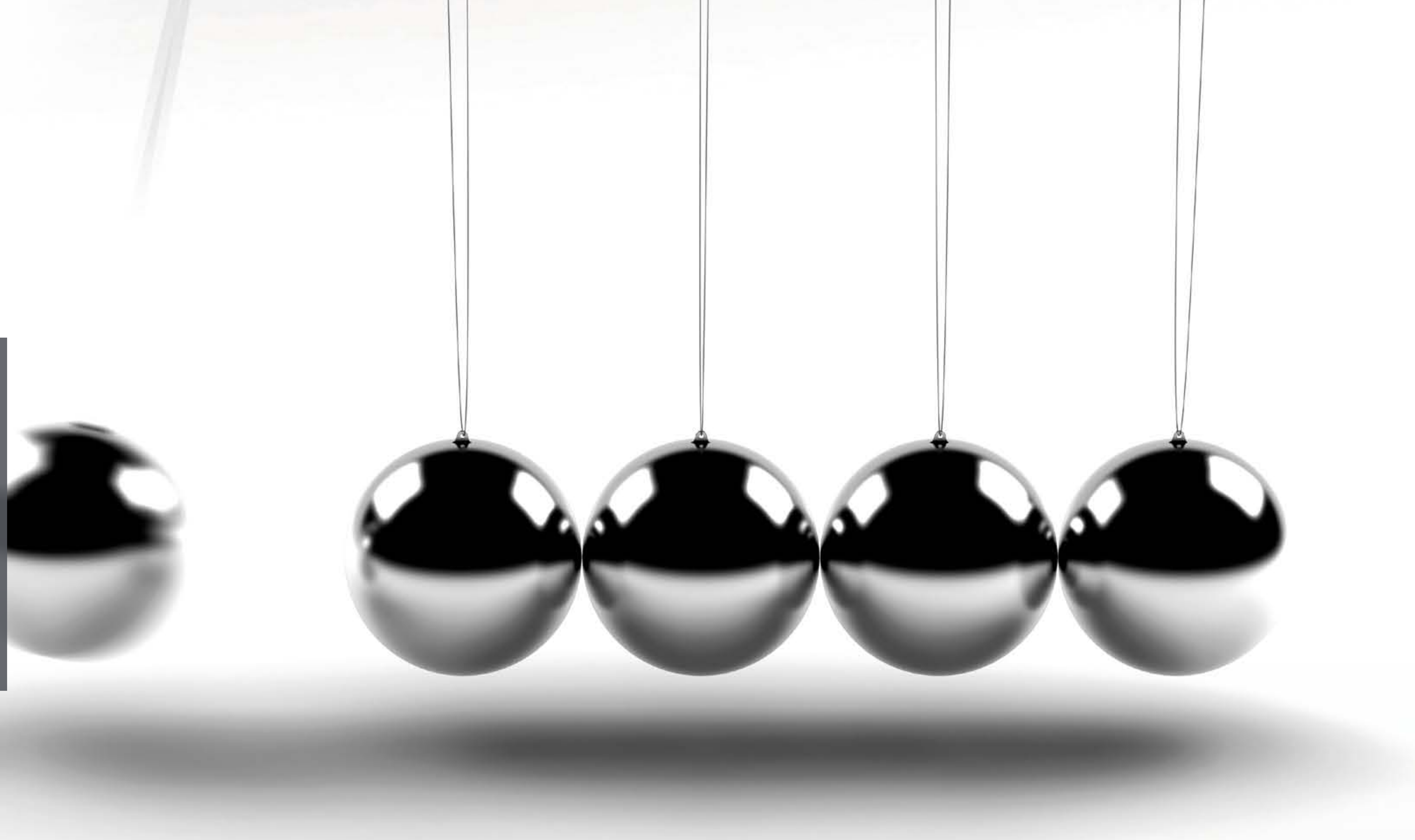
Fast. Accurate. Attainable.

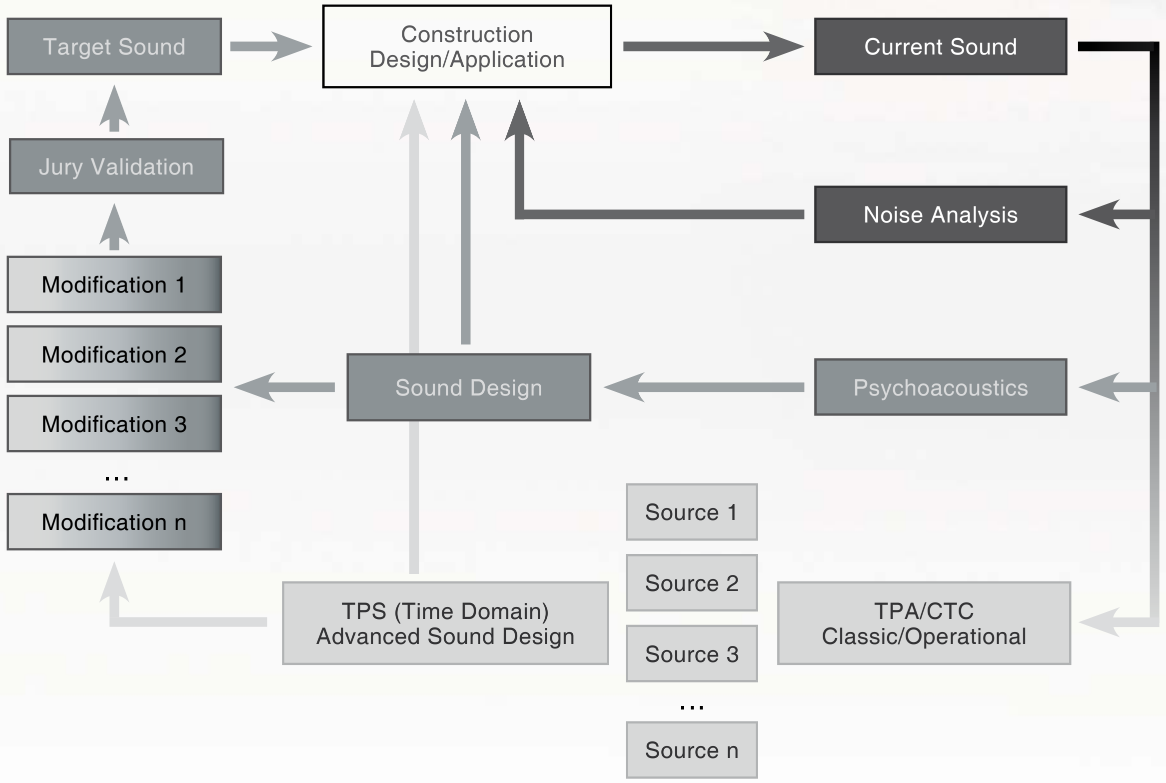
Ensuring reliable product development while maximizing cost efficiency is a major engineering challenge today. Innovative technologies facilitate these demanding development processes. By successfully evaluating transfer characteristics, PAK Transfer Path Analysis generates a contributing advantage as a faster and more sustainable solution for vibroacoustic enhancements.

PAK MKII
PAK
edp

Tune the engineering process

Today's product development process involves detailed testing accompanied by high demands for cost and resource efficiency. Tight development times and shorter product life-cycles raise development complexity. Ever increasing requirements for comfort, safety, emissions and environmental standards force engineers to reconsider their design, analysis and development procedures. The need for a product which reflects typical brand attributes like sound or design elements creates additional pressure.





NVH characteristics can be purposefully tailored by identifying components which generate specific sounds. When defining a target sound, it has become common practice to compare the measured sound of the current product status to an electronically modified sound in a sound studio. Development engineers thereafter empirically deduce to what extent individual sources need to be modified in order to achieve the specific sound target.

When determining the defined target sound, current sounds are iteratively modified through different development loops such as noise analysis, psychoacoustic analysis, sound design and jury testing. An efficient alternative for the entire step-by-step process lies in combining structural analysis and psychoacoustics. Strong dependencies between component characteristics and systematic modifications are crucial for a detailed survey of transfer functions or paths. Thus the need for Transfer Path Analysis is confirmed.

Transfer Path Analysis

The development process must overcome many obstacles. Due to the multiple interactions between many components within a system, developers face a large workload when evaluating all the different component's transfer behaviors in the system. Furhermore a necessity exists to identify the component excitations and its transmissions in the system. Simply put, Transfer Path Analysis describes how sound and vibration propagate through complex structures and breaks down the relationship between the performance in a source excitation, transfer paths and responses.

As Transfer Path Analysis (TPA) aims to separate the total noise at the receiver into different sound source excitations and vibration paths, Users can determine which sources and paths are important or dominant, which ones contribute and which ones cancel each other out. To accommodate the given challenges, traditional force-based models are used to describe the sources and identify their transfers and responses. Testing with mounted force sensors assures the possibility of depicting the forces directly. In most cases this testing is very intricate, requires a large amount of effort and modifies the system. As such, forces are quite often indirectly calculated by means of Matrix Inversion or Mount Stiffness. The deterministic approach is however still valid for linear, time-invariant systems and useful for simulation calculations.

Excitation	Measurable source sided response		Transfer		Receiver sided response
Combustion Wind Wheel/Road Rotating parts Hydro pulsation etc.	Acceleration Strain Force Sound Pressure Hydro Pressure etc.	X	Structure - Structure Acoustic - Structure Structure - Acoustic Acoustic - Acoustic	=	Vibration $R = \sum H_i L_i$ Noise

A less time consuming approach is Operational TPA. Here transfer coefficients between sources and receivers are determined under actual load conditions while taking other influences like temperature and excitation amplitude into consideration. The Users' gain is twofold: firstly Operational TPA indicates causes of phenomena and secondly Operational TPA provides troubleshooting assistance. The simultaneous, phase-correct acquisition and detection of operational acceleration, sound pressure, velocity etc., perfectly reproduces the operating status of the system (test candidate) – separated into its different components. This assures a contribution analysis and enables Users to specifically adapt the system according to the known sources and transfer paths.

As part of TPA, Transfer Path Synthesis (TPS) allows the synthesis of the total noise and/or sub-system noise contributions. A TPS network is graphically displayed as a series of excitation sources connected to transfer paths. Users are empowered to resolve the cause since the network not only describes from where what noise or contribution is coming from but can also simulate modifications.

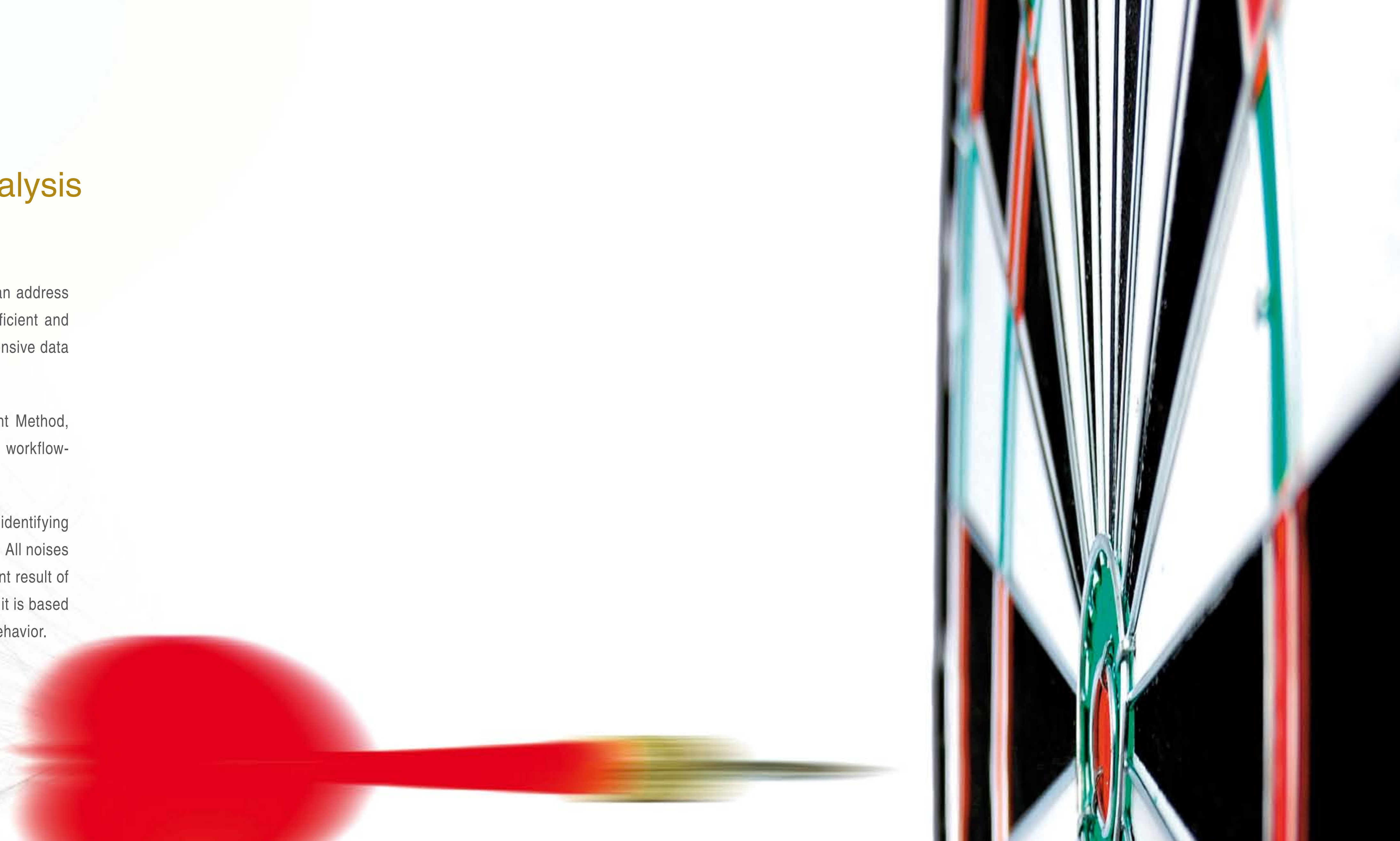
PAK Operational Transfer Path Analysis

Detailed insight from one Measurement

Strengthened by a limitless channel count, PAK is a versatile partner which can address any measurement task for both mobile and laboratory use. PAK combines efficient and precise data acquisition with highly accurate evaluation supported by comprehensive data management.

PAK Operational Transfer Path Analysis with its tools Advanced Measurement Method, Crosstalk Cancelation and Transfer Path Synthesis in the Time Domain, is a workflow-oriented solution embedded in the PAK system.

With one operational measurement, PAK Users pioneer an efficient way of identifying critical vibration paths and source contributions within the test candidate design. All noises and vibrations under the specific load conditions are acquired. The measurement result of the complete test candidate provides direction for further development steps as it is based on the actual characteristics of the test candidate and displays its operational behavior.

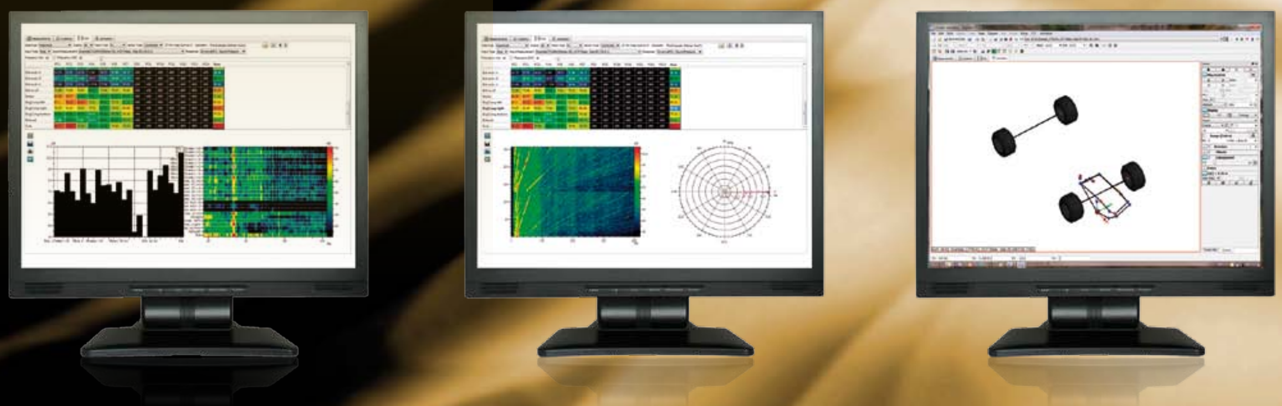


PAK Software and the PAK MKII frontend form a formidable measurement alliance for the achievement of your targets

PAK's Operational TPA is distinguished by the highest accuracy and quality in combination with a vastly reduced measurement time. This is assured as the linearized transfer functions are determined between a set of chosen input and output channels from the operational measurement. The crosstalk is automatically included as only the reactions to all excitations are measured (source side and receiver side). The correct separation of airborne and structure-borne noises is achieved as the airborne and structure-borne contributions can be processed simultaneously. Furthermore, typical problems with impact testing (e.g. limited space, angle) do not occur as no artificial excitation is needed. With this method the operating state is described rather than the idle structure - in other words the result is not distorted by incorrect temperatures for example.

PAK Operational TPA demonstrates its specific strength when several causes contribute to a single conspicuous disturbance and their contributions to the total energy must be determined. Designed to detect the most dominant contribution, Operational TPA can quickly and reliably identify conspicuous phenomena.

Combine PAK's
steps of efficiency
for an integrated
solution



Crosstalk Cancelation

Calculating transfer characteristics

With the Crosstalk Cancelation (CTC) module Users compute transfer characteristics between chosen input (reference) and output (response) channels in which cross coupling effects are accounted for. To calculate these transfer characteristics, the structure can be conventionally excited by hammer, shaker or loudspeaker. The CTC module is based on Principle Component Analysis (PCA) and statistically analyses simultaneously captured response and reference signals. An algorithm separates the response signal(s) into contributions of single reference signals.

The use of Crosstalk Cancelation facilitates the correlation of NVH phenomena to the vibration behavior of specific sub-assemblies. Determining phase relationships between transfer paths in particular provides an analytical foundation for the assessment of superimposed vibrations. PAK's CTC draws an excitation sensitivity diagram as it detects transfer paths which react extremely sensitively upon excitation.

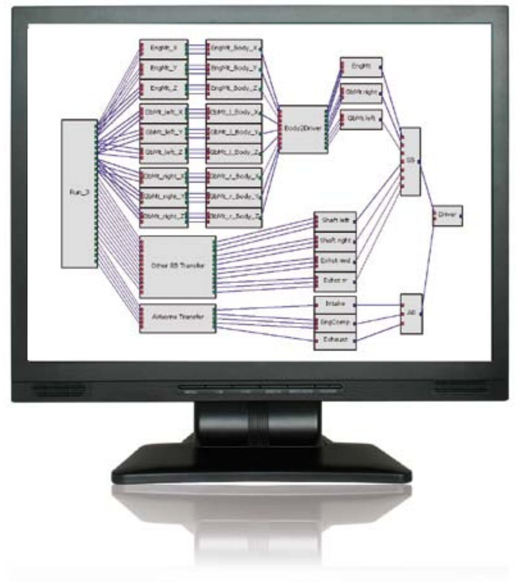
Reconciling Operational TPA results with an Operational Deflection Shape (ODS) analysis allows Users to perform further detailed analyses of rotational and translational vibrations in order to holistically assess the relevant components. PAK's CTC module deploys an illustration of such movement patterns through the integrated ODS functionality. Single principle components resulting from the decomposition of input data (e.g. acceleration) can therefore be animated - separately or in combination. This comprehensive approach assists engineers in developing component variations that merit testing.

Advanced Measurement Method

Processing operational measurement data

To correlate the noise and vibration with specific causes and events, throughput data and operational conditions are required. The Advanced Measurement Method (AMM) is an add-on of the CTC module which displays the induced airborne and structure-borne noise simultaneously from mixed excitation quantities like sound pressure, sound particle velocity, acceleration or any other data. AMM additionally provides the necessary weighting of these different physical units. This enhancement serves as a structural analysis of a receiver deduced from a single operational measurement which in turn determines the transfer behavior of a system under authentic operating conditions. Each source can be assigned to its exact structure-borne and airborne related contributions thereafter. Eventual phase cancelations between paths are accounted for. By facilitating a fast identification of dominant parts, AMM is indeed a strong tool for the enhancement of effectiveness as intricate and time consuming impact measurements are no longer essential.

The need for TPA in the time domain has grown over time



Transfer Path Synthesis in the time domain

Giving excitations a face

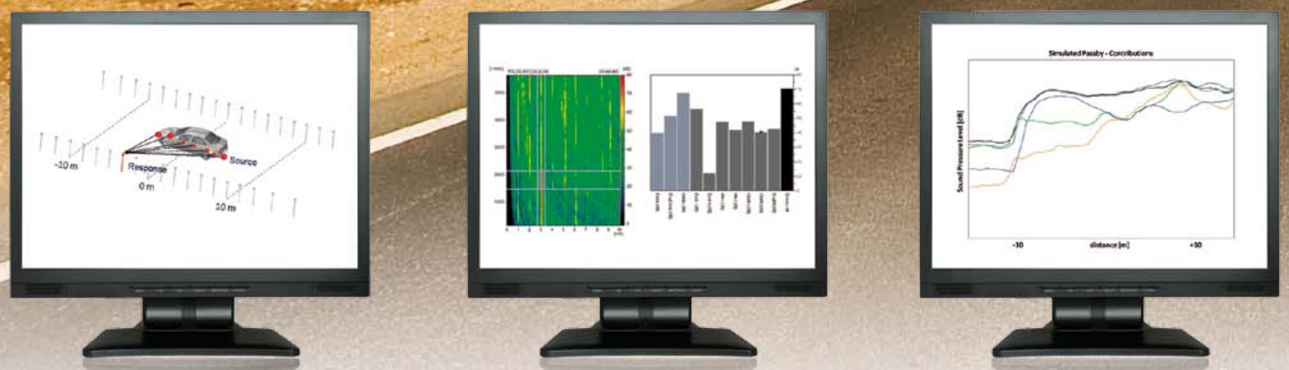
The interaction of both the AMM and CTC modules detects transfer functions suitable for a Transfer Path Synthesis (TPS). Applying transmissibilities, from CTC or AMM for example, to actual operational (throughput) data results in operational contributions. As the method is based on throughput data, all post-processing analyses in the time domain are available e.g. Detector, Signature, Order Tracking etc. Additionally direct playback of single and overall contributions is possible.

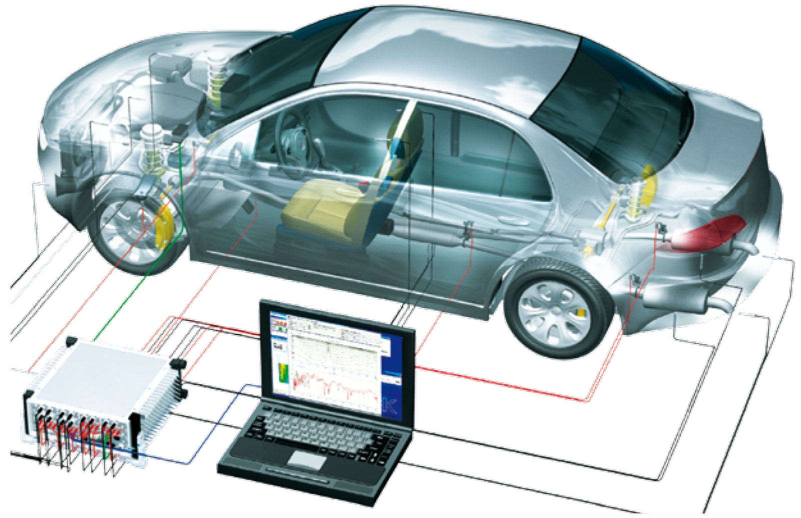
The TPS module calculates the contributions and synthesizes the overall signals. The contribution on the receiver position is then calculated from the input throughput data and the transfer function. Different contributions of single sources or paths (time signals) may be added to sub-system contributions or to a total synthesized signal at the receiver position as well as added for a sub-system analysis. For simulation testing, contributions are weighted differently during addition if desired.

Throughout it's flexibility of data usage (operational, simulated and measured data) and support of other methods, PAK's TPS is extremely useful in creating a graphical network of filters from excitation to end point/receiver. From this Users achieve an authentic model of the acoustic properties of a prototype and the optimization thereof. The simulation of constructional modifications supports engineers in evaluating design improvements and solving specific construction problems – amongst others, examples include changing of source data to simulate changed (amended) excitations; changing of transfers to test reinforcements; changing of single contributions/damping and inserting calculation results to forecast modification effects.

Looking beyond the obvious

NVH characteristics are purposefully tailored by identifying the properties of those components and applications which generate specific sound components. By combining TPA with further analyses, Users benefit from highly accurate load identification in the context of a wide range of NVH post-processing.





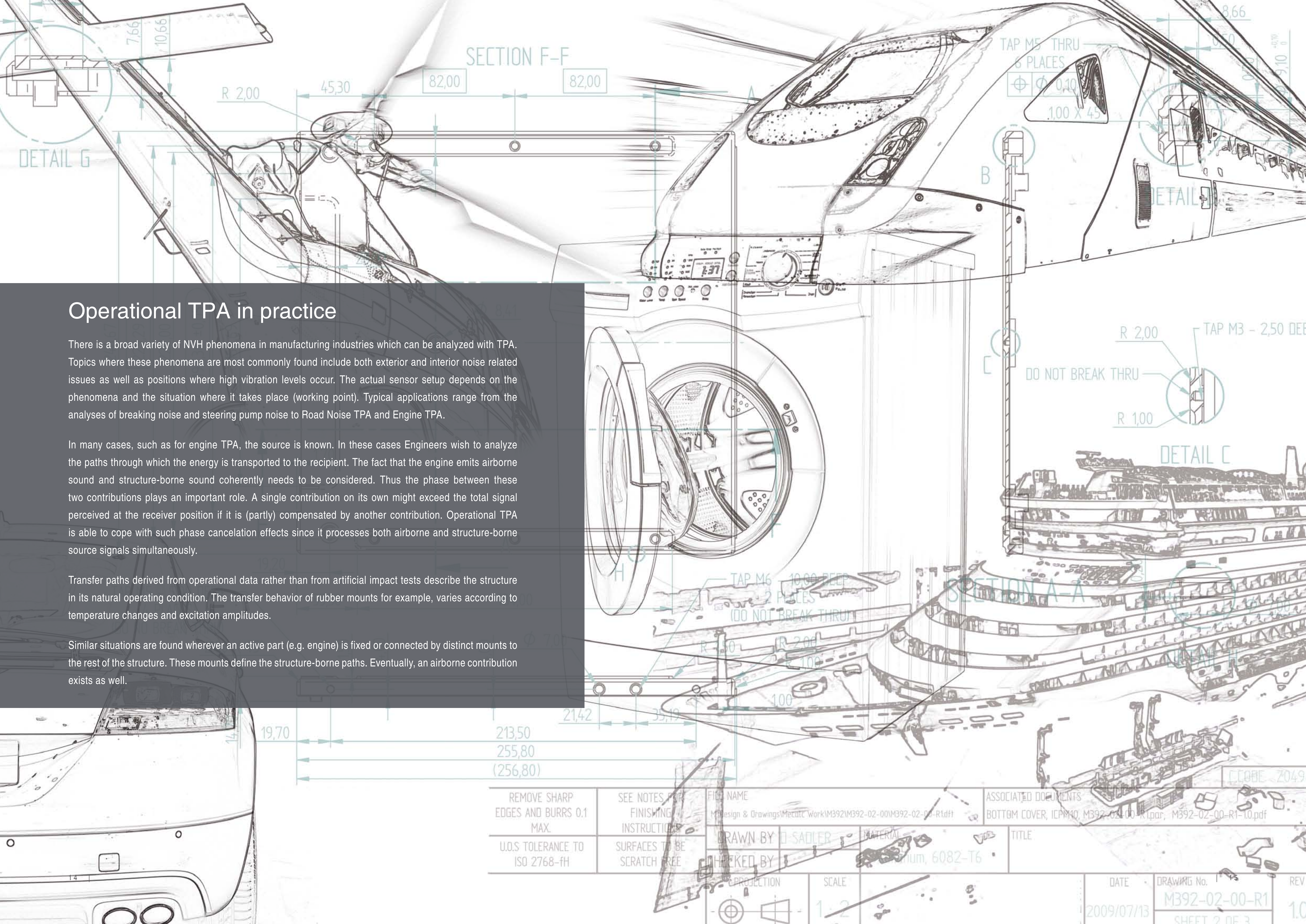
Simulated Pass By Measurement

Simulated Pass By is an effective tool for the design of exterior noise during the automotive development process for example. This tool proves its considerable potential when combined with Operational TPA as together they formulate the evaluation of the exterior noise contributions in Pass By situations. Thus, it is obvious that to acquire direct access to single sources (masking of sources) requires intense focus and effort. As Operational TPA offers a complete solution for direct analysis of source contributions, not only the total Pass By noise but also individual components like the engine, gearbox etc. can be examined.

For a manufacturer, it is not only interesting to know about the total noise but also to know what contributions this total noise comprises of. To ascertain this information with the least additional effort, is to measure the sources. Now Operational TPA can be used to perform a TPA analysis for each of the Pass By microphones. The result of such an analysis is a separation of the total simulated Pass By measurement into equivalent measurements containing only the single contributions.

Contribution analysis

The Operational TPA of a Simulated Pass By configuration is just one example of TPA with multiple inputs/references and multiple outputs/responses. For such configurations the amount of produced analysis data can quickly become enormous. In order to better address and structure such tasks, PAK Contribution Analysis is a competent handling tool for the easy management of Operational TPA in one analysis window.



Operational TPA in practice

There is a broad variety of NVH phenomena in manufacturing industries which can be analyzed with TPA. Topics where these phenomena are most commonly found include both exterior and interior noise related issues as well as positions where high vibration levels occur. The actual sensor setup depends on the phenomena and the situation where it takes place (working point). Typical applications range from the analyses of breaking noise and steering pump noise to Road Noise TPA and Engine TPA.

In many cases, such as for engine TPA, the source is known. In these cases Engineers wish to analyze the paths through which the energy is transported to the recipient. The fact that the engine emits airborne sound and structure-borne sound coherently needs to be considered. Thus the phase between these two contributions plays an important role. A single contribution on its own might exceed the total signal perceived at the receiver position if it is (partly) compensated by another contribution. Operational TPA is able to cope with such phase cancelation effects since it processes both airborne and structure-borne source signals simultaneously.

Transfer paths derived from operational data rather than from artificial impact tests describe the structure in its natural operating condition. The transfer behavior of rubber mounts for example, varies according to temperature changes and excitation amplitudes.

Similar situations are found wherever an active part (e.g. engine) is fixed or connected by distinct mounts to the rest of the structure. These mounts define the structure-borne paths. Eventually, an airborne contribution exists as well.

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