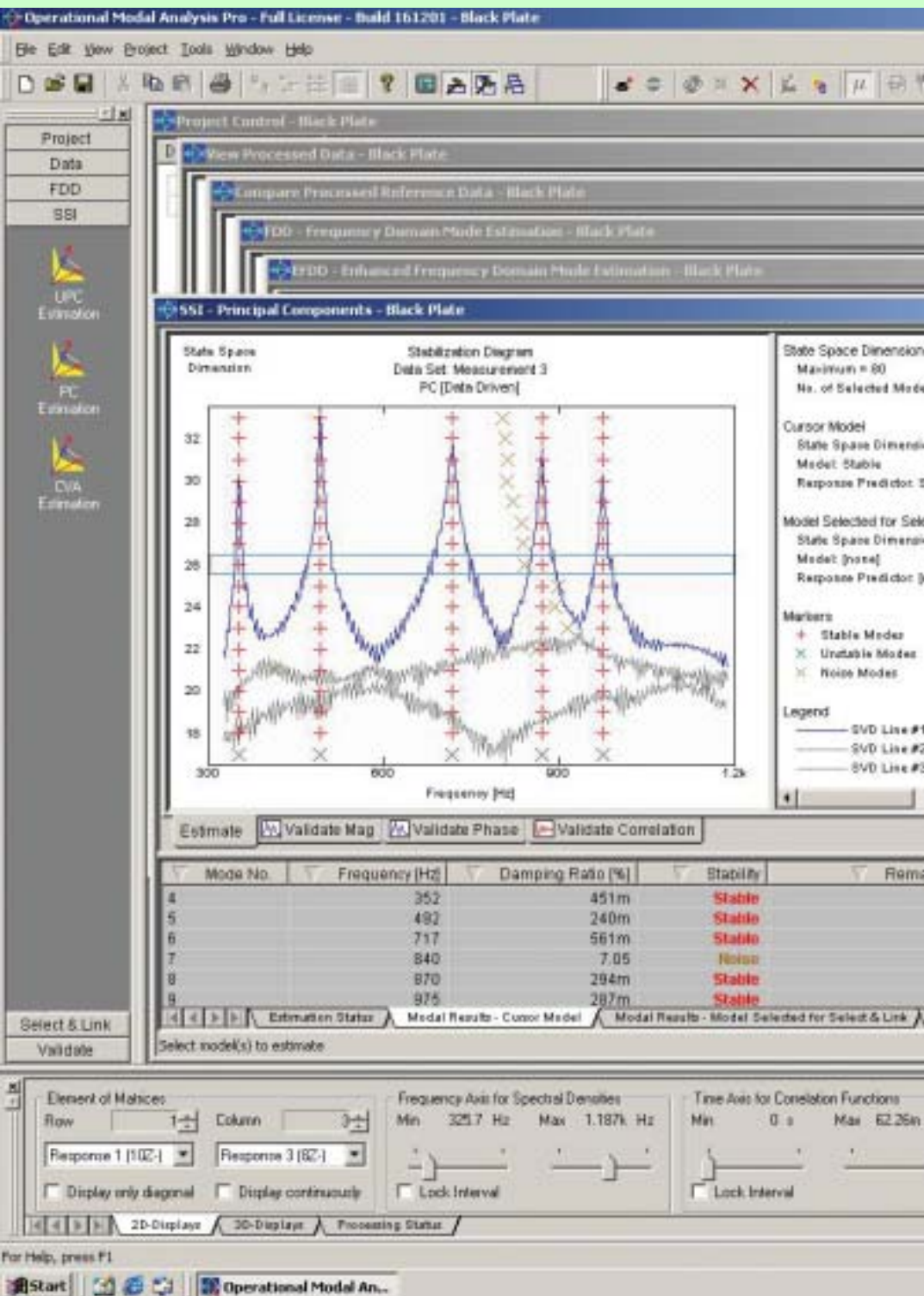# PRODUCT DATA

**Operational Modal Analysis Version 3.1 — Type 7760
for use with PULSE, the Multi-Analysis System Type 3560**

Operational Modal Analysis Type 7760 is **the** analysis tool for effective modal identification in cases where only the output is known. The software allows you to perform accurate modal identification under operational conditions and in situations where the structure is impossible or difficult to excite using externally applied forces.

PULSE™ with Modal Test Consultant™ Type 7753 is used for geometry-driven data acquisition and seamless transfer of data to Operational Modal Analysis for analysis and validation. Together, they form an integrated, easy-to-use modal test and analysis system.

Operational Modal Analysis is available in three different versions: **Pro**, **Standard** and **Light**.

7760

Brüel & Kjær

Uses and Features

USES
- ❍ Modal identification from measured responses only
- ❍ Modal identification of structures under real, operating or ambient conditions
- ❍ Modal analysis without use of shaker- or hammer-excitation
- ❍ Mode shape animation and comparison of different mode shape estimates
- ❍ Comparison of modes from Finite Element analysis with modes obtained experimentally
- ❍ Estimation of modal parameters to be used for Finite Element updating, quality control or structural health monitoring

FEATURES
- ❍ Direct geometry and data transfer from PULSE™ using ActiveX® controls
- ❍ Guided measurement procedures using Modal Test Consultant™
- ❍ User-friendly Microsoft® Windows® 2000/NT® operating systems
- ❍ Processed number of channels and amount of data only limited by PC
- ❍ Fast identification in frequency domain of mode shapes, natural frequencies and damping
- ❍ Time domain data-driven algorithms for unbiased identification of mode shapes, natural frequencies and damping
- ❍ Handles multiple data-sets and multiple reference points, including automatic mode shape merging
- ❍ Effective and easy-to-use signal-processing Wizard
- ❍ Two Frequency Domain Decomposition algorithms: Basic and Enhanced
- ❍ Three time-domain Stochastic Subspace Identification algorithms: Principal Component, Unweighted Principal Component and Canonical Variate Analysis
- ❍ Stabilisation diagrams to discriminate between physical and computational modes
- ❍ Synthesis of response spectra and correlation functions for validation
- ❍ Calculation of the Modal Assurance Criterion (MAC) matrix between mode shapes from different projects and/or identification techniques
- ❍ Transfer of all modal results in Universal File Format
- ❍ Export of all animations using AVI movie files
- ❍ ActiveX® controls support for graphics and tables
- ❍ ActiveX® support for, e.g., Microsoft® Excel and MATLAB®; also allows you to interface with the software from your own application

Basic Idea of Operational Modal Testing and Analysis

The Idea of Modal Identification

Experimental modal analysis is the process of using experimental data to determine the modal parameters of a structure for all the modes in the frequency range of interest. The modal parameters of a structure include mode shapes, natural (or resonance) frequencies and the damping properties of each mode of vibration. The mode shape is the deflection pattern that represent the relative displacement of all parts of the structure for that particular mode.

Modal parameters are important because they describe the inherent dynamic properties of a structure. The set of modal parameters constitutes a unique set of numbers that can be used for model validation, model updating, quality control and health monitoring.

In traditional modal analysis, the modal parameters are found by fitting a model to Frequency Response Functions relating excitation forces to vibration responses. In Operational Modal Analysis (OMA), the modal identification is based on the vibration responses only, and a different identification strategy is used.

The Idea of Operational Modal Testing and Analysis

Operational – or output-only – modal testing and analysis is used for civil engineering structures, large mechanical structures or structures in operation that are not easy to excite artificially by means of either hammer or shaker.

Large civil engineering structures are not easily excited and are often loaded by natural (ambient) loads that cannot easily be controlled or measured. Examples of such include wave loads on offshore structures, wind loads on buildings, and traffic loads on bridges.

Some mechanical structures are difficult to excite artificially due to their size, shape or location. Sometimes you might even need to know the modal parameters for the structure under operating conditions. This is often the case for aircraft, vehicles and operating machinery in general, as well as machine parts where the modal parameters depend on the actual operating conditions and excitation forces may be mixed up with noise.

Advantages of Using Operational Modal Testing and Analysis

Whenever the technique of output-only modal identification is used instead of traditional modal identification, the basic idea is the same. Instead of exciting the structure artificially and dealing with the force signal as an input noise source, the natural excitation is used as the input source. The main advantages of this kind of testing are:

❍ Setting up for testing is less time-consuming as equipment and elaborate fixtures for exciting the structure are not needed
❍ Testing does not interrupt or interfere with the operation of the structure
❍ The measured response is representative of the real operating conditions of the structure

Usually, operational modal analysis is used in cases where the excitation is relatively broad-banded and can be considered to be approximately Gaussian. However, it can also be used in cases involving rotating machinery if broad-band noise from bearings or other excitation forces is present. Similarly, it can be used for measurements on rotating machinery performing run-up/down tests.

Accuracy of Operational Modal Analysis

In principle, discarding the information about the input will add some uncertainty to the modal estimates. However, with the advanced algorithms included, the added uncertainty is very small. In practice, the only major difference between modal parameters estimated from traditional modal testing and those from operational modal analysis is that the operational modal analysis yields unscaled (i.e., uncalibrated) mode shapes. Scaled mode shapes are needed when simulations (such as Forced Responses and Structural Modifications) are applied to modal data.

Operational Modal Analysis has a significant advantage over traditional modal testing when only a few artificial excitation forces can be applied. In this case, higher estimation accuracy can be obtained by letting the better, spatially distributed, natural loading excite the structure. The OMA techniques are implemented as multiple-input (multiple-reference) techniques.

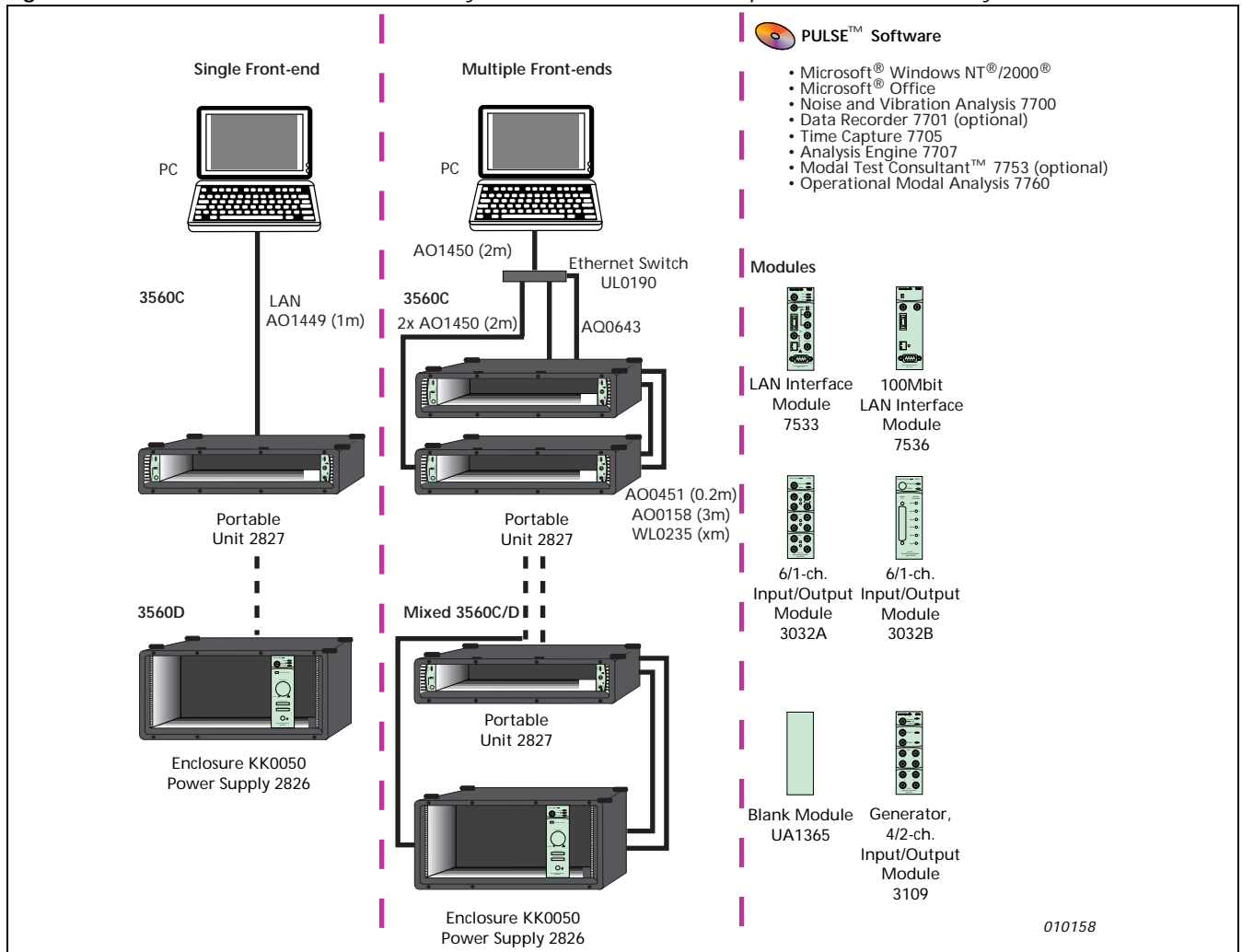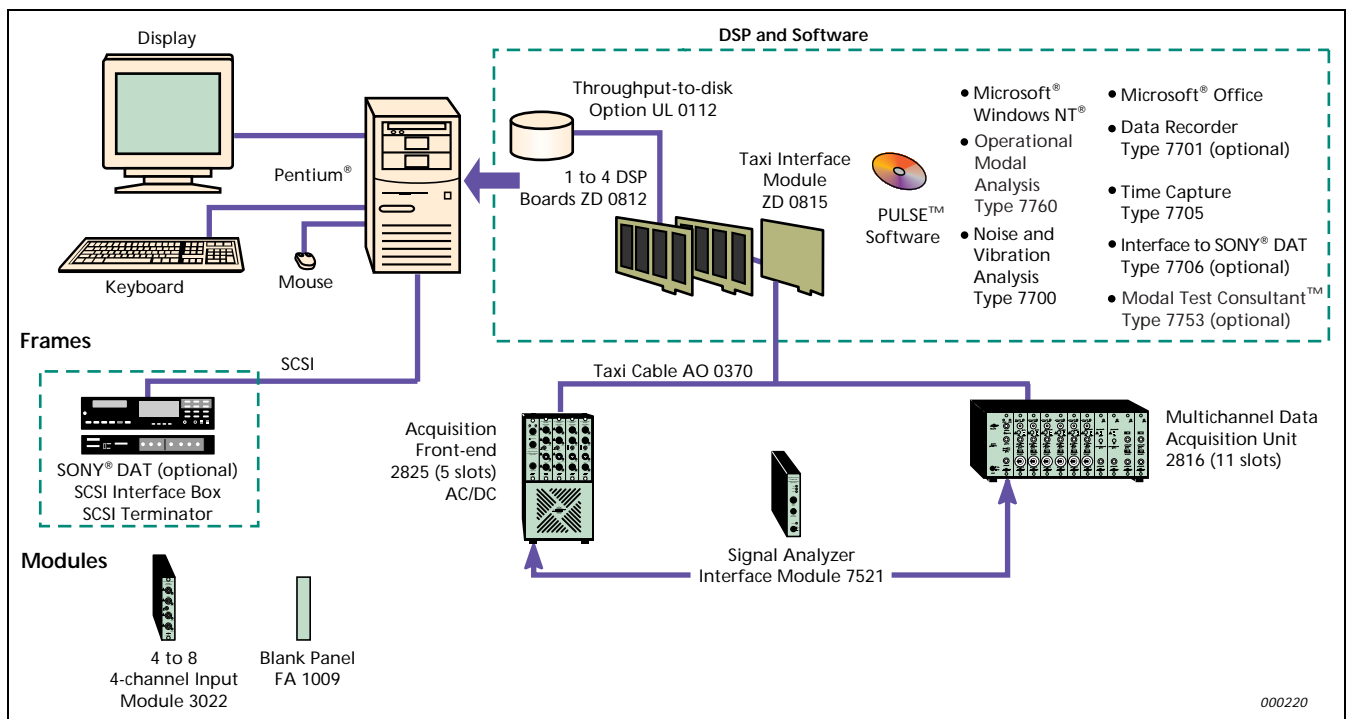**Fig. 1** *Overview of an IDA^e-based PULSE™ system suitable for use in operational modal analysis*

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Fig. 2 *Overview of a DSP-based PULSE™ system suitable for use in operational modal analysis*

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4

Easy Data Input

Import from PULSE™ with or without Modal Test Consultant™

Measured time‑domain data using Time Capture Type 7705 (or, optionally, Data Recorder Type 7701 may be included) is directly imported from the PULSE™ system via UFF-file import or, automatically, by ActiveX® controls using Modal Test Consultant™ Type 7753. Modal Test Consultant™ also provides the geometry. Thus, all geometric information can easily be generated in PULSE™, measurements can be planned and performed, and all data can be transferred directly without intermediate file storage. Using the Data Recorder, an extended frequency range can be used during recording to ensure all modes of interest are included in the data set, and that the data set is large enough. Time Capture is then used for selection, decimation and pre-investigation of data, using the Short Time Fourier Transform, before data is exported to the Operational Modal Analysis software.

Types of Data Input

For manual input of data, you need to supply information about the geometry, i.e., about measurement points, measurement directions and which lines you want to be plotted during animation of the mode shapes. You must also provide access to the measured responses and information about the sampling interval.

You also have the option of supplying information about how you want unmeasured degrees-of-freedom (DOF) to move as a linear combination of measured degrees-of-freedom.

Multiple Data Sets

Using multiple data sets allows you to obtain detailed mode shape information with a limited number of transducers. You can leave one or more transducers as references and then move the remainder around until all DOFs are measured.

ActiveX® Controls

The ActiveX® controls standard allows you to import many different data formats from other software applications under the same standard. Besides PULSE, other typical examples include Microsoft® Word and Excel, and MATLAB®. You can also write your own applications in the Visual Basic® and Visual C++® development systems and import data and geometry directly.

Import from Universal File Format

Input data can be imported using the Universal File Format (UFF), making it easy to import data from any standard measurement system.

Import from MATLAB®

Input data can be transferred directly from MATLAB® without intermediate file storage. This feature is useful for structural response simulations.

Import from ASCII Files Using the Configuration File

All geometric data can be specified in the Operational Modal Analysis configuration file, which can be generated using any ASCII file editor. In some cases, this format is more useful than the UFF format. Response data can be read from ASCII files where the data is stored in a time-series matrix organised column by column.

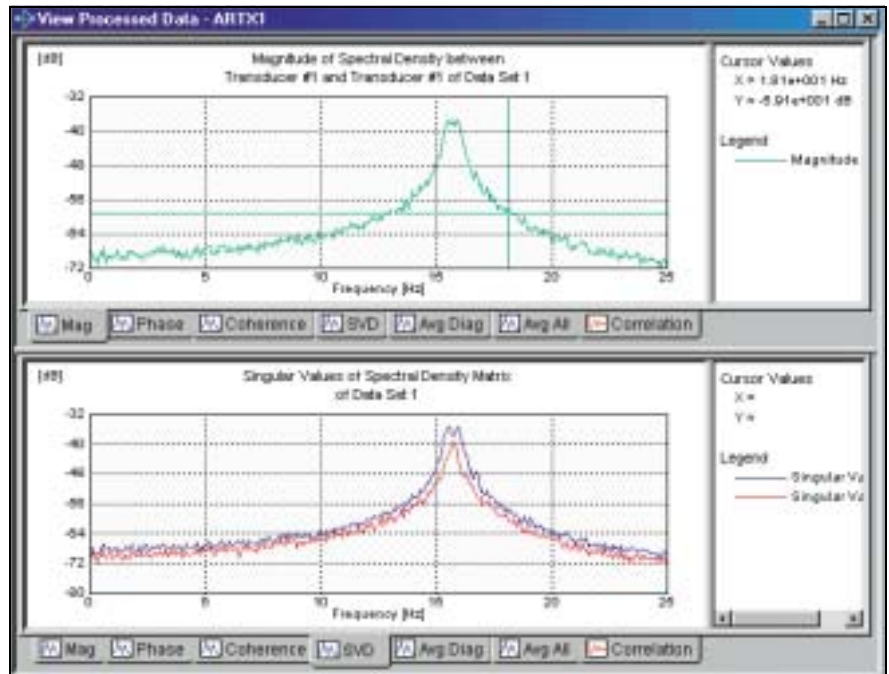# Signal-processing and Data-display Tools

Signal-processing Tools

As the first important step, different kinds of signal processing are needed on the imported time data. It is possible to reduce the sampling frequency and to apply high-pass, low-pass, band-pass and band-stop filters. Filtering can be useful to remove DC components (high-pass), to remove harmonics (band-stop), to concentrate on a small frequency range (band-pass) and to remove high frequency modes (low-pass). It is also possible to estimate and display frequency spectra and correlation functions. For sub-space identification techniques, a Hankel matrix is estimated which constitutes the basis for calculation of the stabilisation diagram.

When using multiple data sets, it is possible to test different signal-processing setups on single data sets. When the right signal-processing setup is found, the signal processing can be performed on all data sets without user interaction.

Data View

During signal processing testing and after the final signal processing, it is possible to view the data as shown in Fig. 3. All auto- and cross-spectral, coherence and correlation functions can be displayed, and condensed plots like singular value decomposition of the spectral matrix or the average of the spectral matrix or its main diagonal (trace) can be displayed.

There is also a special facility that allows users to inspect data and compare it with all other data sets to ensure that they possess the same physical information.

Frequency Domain Decomposition

Fast and Easy Identification

In the frequency domain, identification is based directly on singular value decomposition of the spectral density matrix. The singular values are interpreted as a combination of auto-power spectra for a set of single-degree-of-freedom systems (SDOFs). You identify the physics by looking at the plot, identifying the SDOF functions, and picking the peak of each function. The SDOF information is then extracted from the singular values.

Fast Peak-picking

Using the fast version of the Frequency Domain Decomposition technique, it is possible to identify the most important modal properties in a minimum of time by using the snap facility to snap on the peaks in a display. The animated mode shape can then be displayed immediately. The technique deals effectively with close modes and noise, and you can define, delete or edit modes with user-friendly, modal-editing facilities. Since information from just one single frequency line is used in this technique, the fast peak-picking method does not provide damping estimates.

Enhanced Frequency Domain Decomposition

Enhanced Technique

From a user's point of view, the enhanced FDD technique works like the fast, peak-picking technique in that you identify a mode by using the snap facility to snap on a peak. However, using the enhanced technique, the SDOFs are identified and displayed for inspection, and all SDOFs are used in the estimation procedure. The damping and an improved natural frequency are estimated from the corresponding auto-correlation function in the time domain.

Fig. 4
Modal identification by peak-picking using the Frequency Domain Decomposition technique. In this case, Enhanced FDD
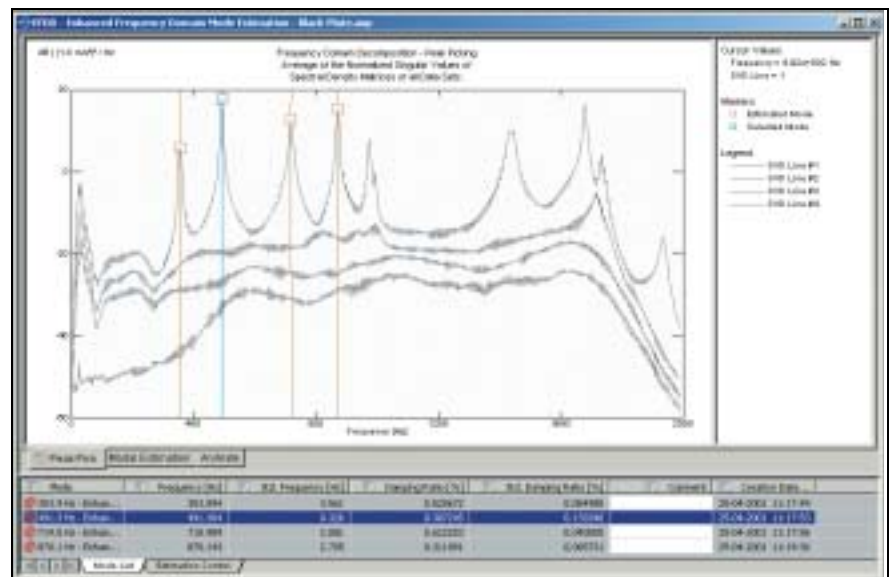
Fig. 5
Example showing an SDOF identified
using the Enhanced FDD technique
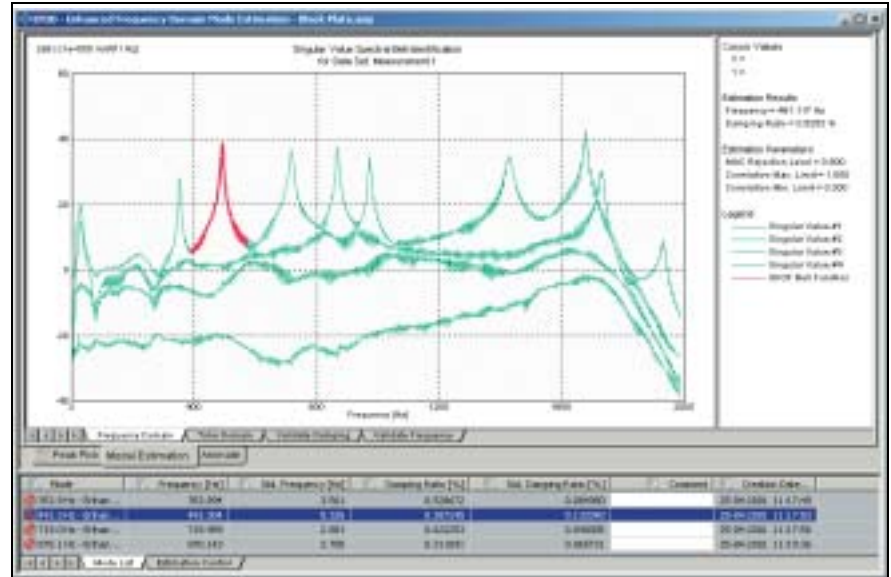
Time-domain Identification

Accurate Identification

In the time domain, you can perform modal identification using three different kinds of data-driven, stochastic, sub-space techniques. These techniques use all response data available fitting a full model in discrete time to the data in the time domain. The assumption for these advanced time-domain methods is that the input to the structure model is a stationary force signal that can be approximated by filtered, zero-mean, Gaussian white-noise. In practice, the methods work with any broad-band excitation. The use of different methods is important in order to validate extracted modal parameters by comparison.

Flexible Stabilisation Criteria

You can specify any model order from one mode to the maximum number of modes chosen in the signal-processing setup. You can also specify stabilization criteria based on knowledge of damping, maximum deviation of damping, natural frequency, mode shape Modal Assurance Criterion (MAC), and modal-amplitude MAC. The last criterion describes the quality of the statistical modelling (see Fig. 7).
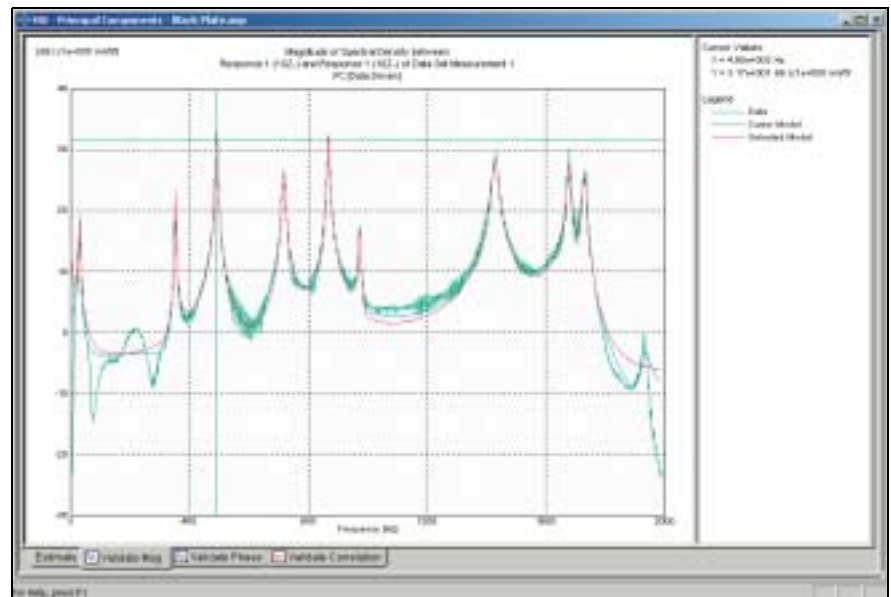
Model Validation

You can validate the quality of each model by selecting the various tabs pages in the window to inspect either the magnitude or phase of the spectral fit or the fit on the correlation function. The validation plots show the (synthesised) modal-model curves compared to the directly measured and processed curves.

Fig. 6
Stabilisation diagram showing stabilised modes in red, non-stabilised modes in green, and non-physical modes in yellow. All modes for each model can be inspected in the list below
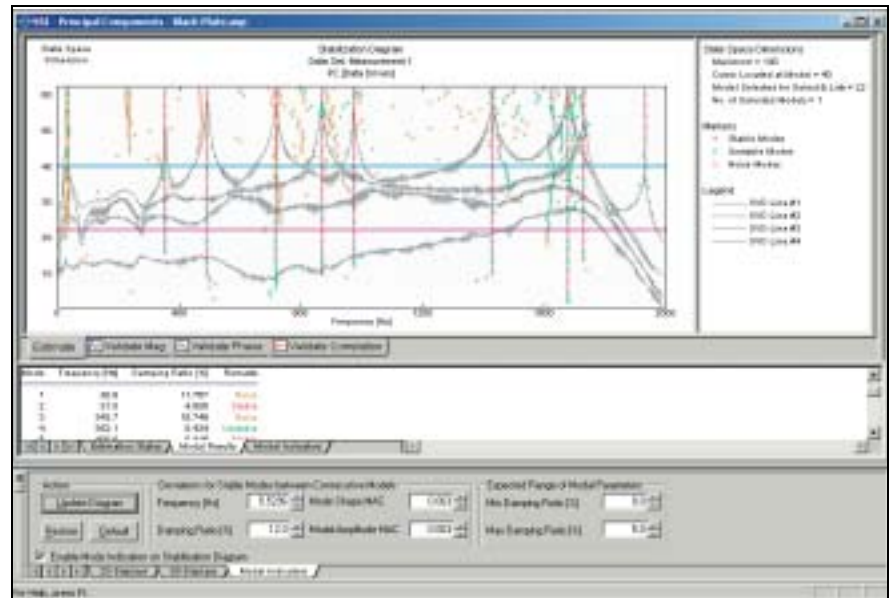
Fig. 7
The FFT-processed spectral-density function (green curve) compared to the model-density function (red curve). The model is estimated in the time domain and then transferred to the frequency domain. The extracted model shows excellent agreement with the measurement data

Validation, Reporting and Data Output

Validation of Modal Results

Among other methods, validation of the modal identification can be carried out by comparing results from different identifications. You can compare modes between different projects, i.e., earlier identifications, or compare the results of different techniques within the same project. It is also possible to import modes from other programs, such as FEM programs and traditional modal analysis programs, and to compare them with modes estimated in the Operational Modal Analysis software.

Dual-mode Animation

When validating the results of different techniques against each other, it is often very helpful to animate the mode shapes together or to animate the difference between modes (see Fig. 8 and 9).

MAC Matrix

Comparing modes from different identifications and projects, tables and plots of the Modal Assurance Criterion matrix can be obtained in order to show how well the modes compare (see Fig. 10).

Flexible Graphical Facilities

All 2-dimensional plots can be zoomed on the horizontal axis, and all 3-dimensional plots can be zoomed and rotated arbitrarily. All plots and all tables can be transferred as pictures using standard copy/paste procedures, and user comments can be transferred as strings to other applications.

Data Output

All identifications can be stored in Universal File Format to be processed by, for example, the FEMtools finite element updating software. It is also possible to export the modal results in the Operational Modal Analysis internal ASCII-file format, mode by mode. The Universal File format adapts to both UNIX and PC file formats. The user can also export estimated, parametric models from the Stochastic Subspace Identification in state-space format to an ASCII file.

AVI Movie Files

All animations can easily be exported using AVI movie files. This allows for creating live reports in, e.g., Microsoft® Word or Excel.

Fig. 8
Mode shape validation by visual inspection. Comparing the first elastic mode shape, which is a torsional mode, from frequency- and time-domain identifications in a data set where a plate is excited by a small electric motor. In this particular case, only some very small deviations are observed between the results of the two different techniques. The corresponding MAC value between the mode shapes was found to be close to one. The extracted shape is then considered to be a valid mode shape
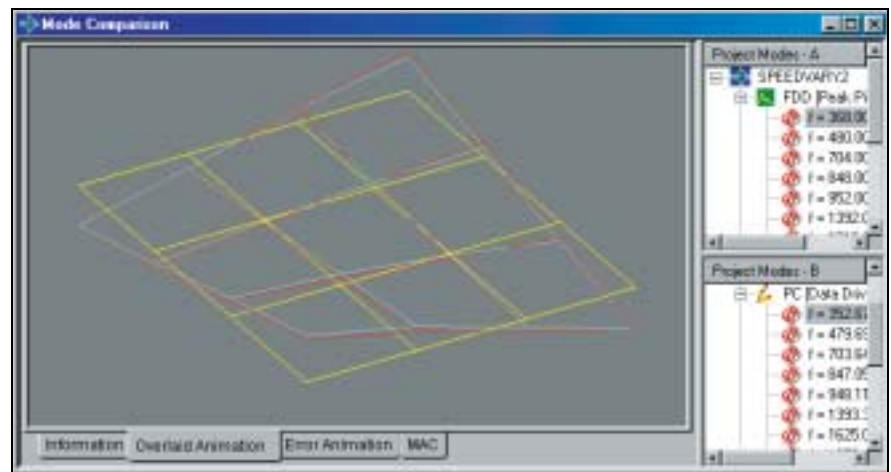
Fig. 9
Comparing the second mode shape, which is the first bending mode, from frequency and time-domain identifications on the same data set as used in Fig. 8. For this mode, no visible deviation between the two techniques is observed and the corresponding MAC value between the mode shapes is found to be one. Thus, the extracted shape is also considered to be valid
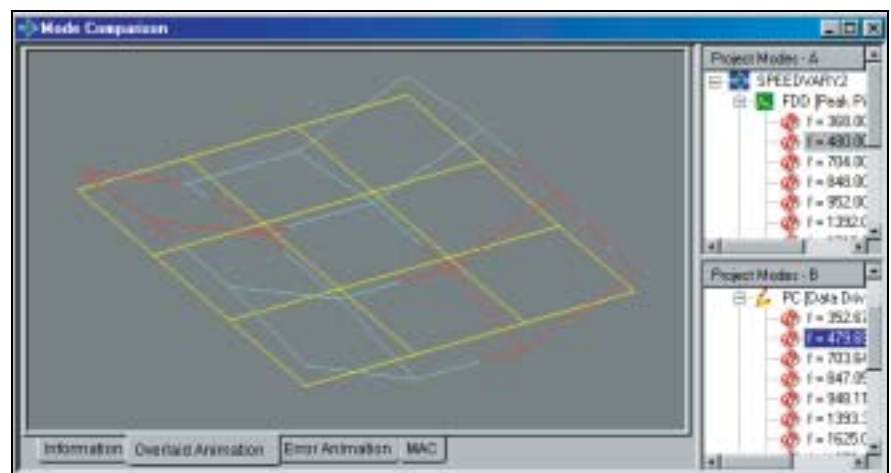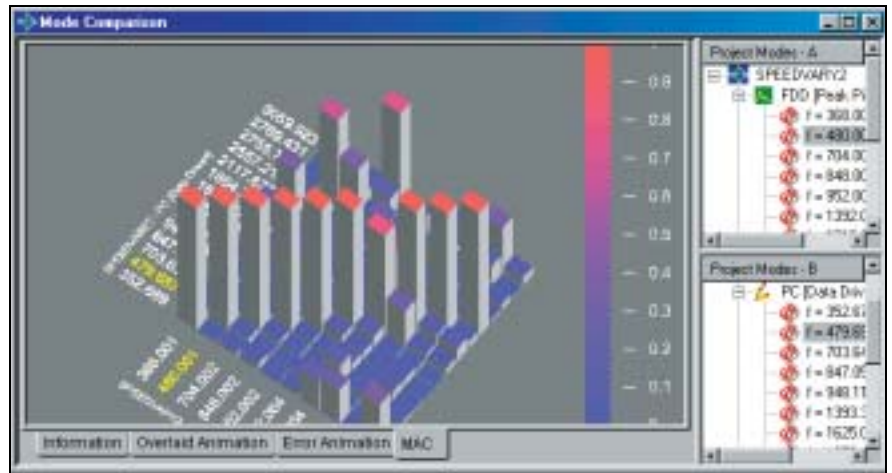
Fig. 10
Plot of the MAC matrix for the
modes estimated in the frequency
domain and the time domain

Configurations

Operational Modal Analysis Type 7760 is available in three different versions: **Pro**, **Standard** and **Light**.

The versions differ only in the number of techniques available.

Version	FDD[1]	Enhanced FDD[1]	SSI[1] Unweighted Principal Components	SSI[2] Principal Components	SSI[2] Canonical Variate Analysis
Pro	✔	✔	✔	✔	✔
Standard	✔	✔			
Light	✔				

1 Frequency Domain Decomposition
2 Stochastic Subspace Identification

Operational Modal Analysis Pro

This version is for users who want all the best techniques available, the highest accuracy, and the best validation of results. With this, the user can perform accurate identifications in time domain as well as the frequency domain using the most powerful identification tools available today.

The best validation the user can perform is to compare frequency and time-domain results with each other.

Operational Modal Analysis Standard

For users who require efficiency but can afford to compromise a little on accuracy in certain situations. This version includes efficient frequency domain identification tools for optimum user friendliness and computational efficiency.

Operational Modal Analysis Light

For users who require only a quick and easy identification of mode shapes and natural frequencies. The Frequency Domain Decomposition technique evaluates real modal properties with a few simple clicks of the mouse.

Specifications – Operational Modal Analysis Type 7760

Computer Requirements for Operational Modal Analysis Software

- One of Windows® 2000/NT® 4.0 (with Service Pack 4, or later, installed) operating systems and administrative privileges
- Microsoft® Internet Explorer® 4.0 or higher
- Pentium® III (700 MHz or higher is recommended)
- 256 MB RAM (512 MB RAM or more is recommended)
- 2 GB of free, hard-disk space (required hard-disk space is project-dependent)
- SVGA monitor, screen resolution at least 800 × 600 (1024 × 768 is recommended)

For total system, including Type 7753, refer to specifications for PULSE™

Data Input

- Time-data input from the PULSE™ System using Time Capture
- Time-data and geometry input from PULSE™ system using Modal Test Consultant
- ActiveX® controls, transfer from all other software with ActiveX® support (e.g., PULSE™, MATLAB®, MS® Excel)
- Universal File Format (ASCII) from UNIX and PC
- Operational Modal Analysis configuration file and data file (ASCII)
- Maximum number of channels: unlimited by the software
- Maximum amount of data: unlimited by the software

Data Output

- Copy/Paste and Print functions for all graphics and tables

MODAL RESULTS
- Universal File Format (ASCII) to UNIX and PC
- Operational Modal Analysis output files
- Interface to Finite Elements updating software through UFF
- Export of animations using AVI movie files

Signal Processing

- Decimation: 1 – 1000 times including digital, anti-aliasing filter, cut-off at 0.8 times Nyquist frequency
- Filtering: low-pass, high-pass, band-pass, band-stop Butterworth, filter order 1 – 50 poles, arbitrary cut-off frequencies, test for filter stability
- Spectral estimation using FFT including processing of auto- and cross-spectra. Data-segment length: radix-2 only limited by the amount of data, overlap: 66.7%, window: Hanning. Always estimates the full spectral matrix
- Correlation function estimation using the unbiased (zero-padded) FFT technique. Time length: arbitrary. Always estimates the full correlation matrix
- Data Hankel matrix estimation to be used in all subspace algorithms. Number of modes: arbitrary, but limited by the amount of data
- Possibilities for testing the signal processing, data set by data set
- Data Plotting: Magnitude and phase of auto- and cross-spectra, coherence, singular value decomposition of spectral matrix, average of spectral matrix, average of main diagonal of spectral matrix, correlation functions. Cursor read-out on all curves. Plots of raw time-data and Time-Frequency plots (STFT) are done in PULSE™, along with data annotation
- Comparison of reference-point measurements across data sets

Frequency Domain Decomposition

- Basic method: Frequency Domain Decomposition
- User choices: Frequency Domain Decomposition peak picking (FDD), FDD with enhanced modal estimation (EFDD); User choices for FDD: peak picking; User choices for EFDD: peak picking, MAC value for SDOF estimation, start-point and end-point of corresponding auto-correlation function
- Frequency resolution: defined by frequency lines in spectral-density function (FDD)
- Mode-shape estimation: Immediate animation
- Damping: EFDD provides damping estimates
- Uncertainty estimation: in case of several data sets, the standard deviation is calculated for natural frequencies and damping ratios

Time Domain Identification

- Basic method: Data-driven Stochastic Subspace Identification
- User choices: Implementation: Unweighted Principal Components, Principal Components and Canonical Variate Analysis. Model orders: from one mode to the size defined by a common input matrix
- Stabilisation criteria: natural frequency, damping, mode shape MAC, modal amplitude MAC, all limits user-defined
- Physical mode separation: Damping limits user-defined
- Select and link: Selected models from each data-set are sorted and linked in a separate window with snap functions and editing facilities
- Uncertainty estimation: In case of several data-sets, the standard deviation is calculated for natural frequencies and damping ratios
- Export of the full, estimated model (State-space System) to an ASCII file-format

Validation

- Comparison: Modal model vs. FFT-based auto- and cross-spectra
- Comparison: Modal model vs. unbiased (zero-padded FFT) auto- and cross-correlation functions
- Modal Assurance Criterion, MAC plots for comparison of mode shapes between same or different estimation techniques as well as between same or different projects
- Simultaneous animation of different mode shapes
- Animation of differences between mode shapes
- Import and comparison of modes from other systems through the Universal File Format

Graphics and Lists

- All 2-dimensional plots can be zoomed on the horizontal axis
- All 3-dimensional plots can be arbitrarily rotated and zoomed
- Cursor readings on all 2-dimensional plots
- Tables with all modal parameters
- Tables with mode shape deviation
- Tables with point coordinates
- Indication of measurement DOFs, points and directions
- Annotation feature on data display plots

On-line Help

- Tool-tips on all buttons
- Context-sensitive help on controls and plots
- Introduction to the idea of Operational Modal Analysis

- Description of all menus and control bars
- Detailed description on the whole identification process from beginning to end

Software Rights

- The Operational Modal Analysis software is developed by Structural Vibration Solutions ApS in cooperation with Brüel & Kjær
- Brüel & Kjær Sound & Vibration Measurement A/S has worldwide rights to market and sell Operational Modal Analysis Type 7760 software

Ordering Information

Type 7760 A	Operational Modal Analysis, Pro
Type 7760 B	Operational Modal Analysis, Pro (Academic Version)
Type 7760 C	Operational Modal Analysis, Standard
Type 7760 D	Operational Modal Analysis, Standard (Academic Version)
Type 7760 E	Operational Modal Analysis, Light
Type 7760 F	Operational Modal Analysis, Light (Academic Version)

With DSP-based Hardware

SOFTWARE

BZ 5217	PULSE™ LabShop CD-ROM
Type 7700 X[1]	Noise and Vibration Analysis
Type 7705	Time Capture
BZ 5197	Microsoft® Windows NT® operating system
BZ 5308 – xx[2]	Microsoft® Office XP Small Business Edition
BZ 5309 – xx[2]	Microsoft® Office XP Small Business Edition with Manuals
BZ 5321 – xx[2]	Microsoft® Office XP Professional Edition

PC
Stationary PC recommended

PC HARDWARE

ZD 0812	300 MFLOPS DSP Board (1 to 4)
ZD 0815	TAXI Interface Module
UL 0112 – 002	Throughput-to-disk Option

ACQUISITION HARDWARE

Type 2825	Acquisition Front-end
Type 2816	Multichannel Data Acquisition Unit
Type 7521	Signal Analyzer Interface Module

INPUT MODULES

Type 3022	4-channel Input Module
FA 1009	Blank Panel

With IDAe-based Hardware

SOFTWARE

BZ 5217	PULSE™ LabShop CD-ROM
Type 7700 X[1]	Noise and Vibration Analysis
Type 7705	Time Capture

1. X = A, B, C, D, E, F, H, I or J – specifies 4, 8, 16, 32, 12, 24, 48, 64 or 128-channel license (respectively)
2. xx specifies country: GB, DE, FR, ES, IT, SE

BZ 5197	Microsoft® Windows NT®
BZ 5308 – xx[2]	Microsoft® Office XP Small Business Edition
BZ 5309 – xx[2]	Microsoft® Office XP Small Business Edition with Manuals
BZ 5321 – xx[2]	Microsoft® Office XP Professional Edition

PC
Laptop PC recommended

PC HARDWARE

UL 0167	Intel® in Business 8-port 10 / 100 Switch for Ethernet
AO 1450	LAN Interface Cable with RJ 45

ACQUISITION HARDWARE

Type 2827	Portable Data Acquisition Unit
Type 7533	LAN Interface Module
Type 7536	100 Mbit LAN Interface Module
Type 2826	Power Supply
KK 0050	Enclosure

INPUT / OUTPUT MODULES

Type 3032	6 / 1-ch. Input / Output Module
Type 3109	Generator, 4 / 2-ch. Input / Output Module
UA 1365	Blank Module

Optional Accessories

Note: If using Type 7760 and Type 7700, the application is included on the PULSE™ software CD. Type 7700 must be installed as the PULSE™ protection key is used
If using Type 7760 as a stand-alone product, order Type 7450 Security Key and Type 7760 License

Type 7701	Data Recorder
DAT Recorder	See the Product Data for PULSE™ Interface to SONY® DAT Type 7706 (BP 1764)
Type 7706	PULSE™ Interface to SONY® DAT
Type 7753	Modal Test Consultant™, version 2 or higher

A wide range of Brüel & Kjær accelerometers, microphones, preamplifiers and sound intensity probes are available for use with the Type 3560 system

Services

3560 – SI1	Installation and Configuration (at Brüel & Kjær)
7700 X – MS1[1]	Software Maintenance and Upgrade Agreement
7760 Y* – MS1	Software Maintenance and Upgrade Agreement

*Y = A – F, corresponding with the different versions of Type 7760

Brüel & Kjær reserves the right to change specifications and accessories without notice.

Rosendahls Bogtrykkeri

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Brüel & Kjær