ATPA

Advanced Transfer Path Analysis Method

Technical Information

ICR

Ingeniería para el Control del Ruido

Advanced Transfer Path Analysis (ATPA) is an advanced tool for the vibro-acoustic diagnostics of trains. ATPA provides information on the vibro-acoustic paths and the contributions of each element of the train to the overall noise. This is the informations needed for identifying the changes that should be done in order to achieve the desired noise reduction.

Vibro-acoustic diagnosis is necessary when a train manufacturer wants to reduce the interior noise level of a coach in order to meet noise comfort requirements. The challenge is to correctly quantify the noise paths and the contributions of each element of the train (bogie, engine, mechanical joints, etc.) to the total interior noise.

The ATPA method provides noise path and noise contribution information, giving numerical answers to the question of what are the changes to be made in the train in order to reduce the total noise level. Knowing the noise emitted by each part of the train allows assessing the effect of any change to the total interior noise.

ATPA by ICR is the only product in the market which gives information on the paths and the contributions regarding coherent and noncoherent addition. Thus, the analysis can be applied from very low frequencies up to very high frequencies.

Nowadays, ATPA is the reference product of the main European rolling stock manufacturers where it is being used as a privileged tool for the acoustic diagnosis of their products. Furthermore, its use also extends to any industrial sector requiring vibro-acoustics improvement in their designs.

The origin of the ATPA lies in the need to solve two different problems:

- The first problem (A) consists in quanntifying the contribution of each part of the vibrating system to the total noise measured at a given location. (see fig. 1 problem A).
- The second problem (B) consists in quantifying the noise produced by each one of the forces acting on a mechanical system. (see fig. 1 problem B).

In the 60's, the method used to solve the problem A was the Strip Tease method. In order to obtain the contributions of each vibrating element of any structure by the Strip Tease method, the vibrating surfaces of the noisy object were totally covered with insulating blankets in order to suppress the noise. Then the surfaces were uncovered one by one and the contributions of each surface were deduced from the successive measurements.

Since then, the Strip Tease method has been applied to motors, whole cars or even to whole train coaches and it is still being applied today.

A usual case of problem B consisted in estimating the contributions to the interior noise of each one of the engine supports on a car. In order to solve this problem, the practical method was to unlink the engine from the car and then to attach the supports one by one.

However, these two pure experimental methods have several disadvantages:

- The required setup of experiments takes a long time.
- The real modifications applied in order to block or disconnect some noise sources can affect the behavior of the active noise sources, providing inaccurate results.

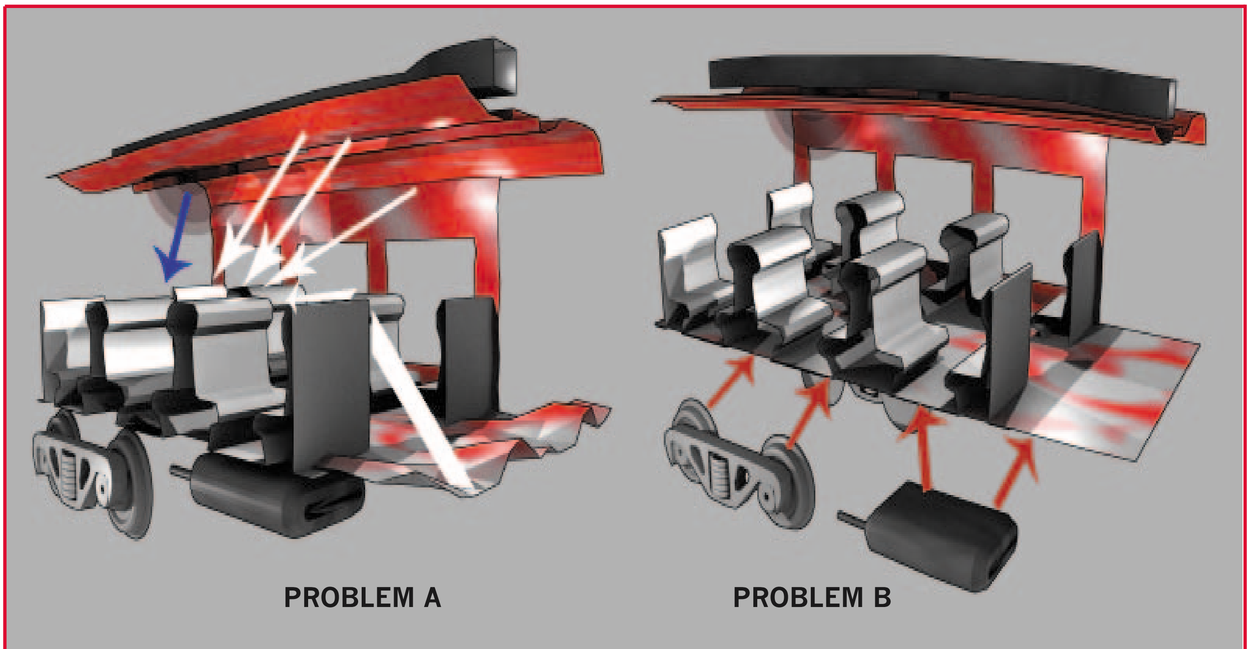


Fig. 1. The origin of the ATPA.

Solutions TPA & ATPA

The solution to problems A and B is based on the fact that they are searching to obtain a description of the noise in terms of the superposition principle, i.e. as the sum of the contributions of each noise source in terms of accelerations (problem A) or forces (problem B).

In the figure 2, the equation in the left (problem A) describes the signal (noise, acceleration or equivalent) as the superposition of the effects from the other signals plus a residual part coming from the signal itself. The equation in the right (problem B) describes the same signal as the superposition of the effects from the forces applied on each one of the faces of

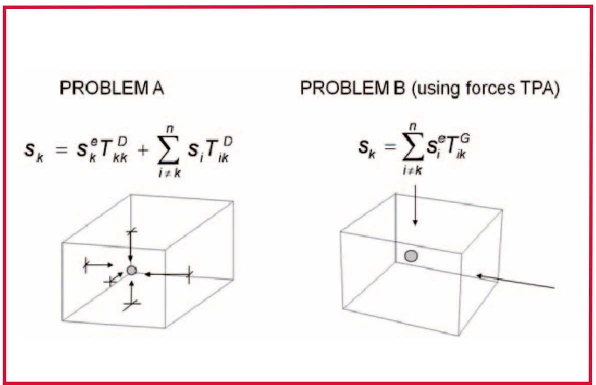
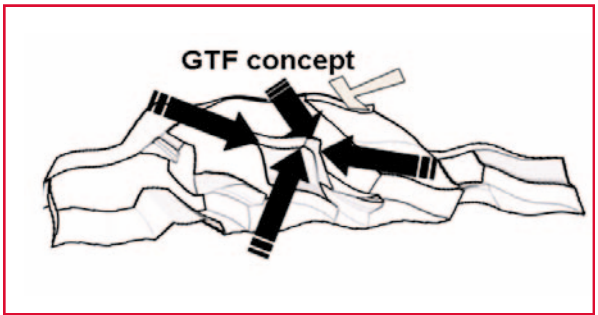


Fig.2. Problem A and problem B equations.

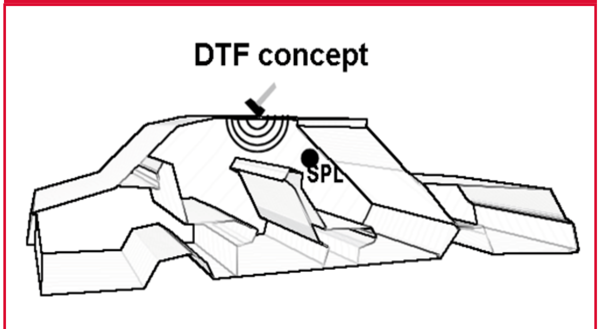
The equations describing the signal by other signals are the basis of the ATPA (problem A) and, on the other hand, those doing so by the forces are the basis of the TPA (problem B).

A direct consequence is that ATPA does not measures forces. ATPA only measures noise and acceleration. This feature is advantageous as it reduce the required time and resources for performing the test, because ATPA tests do not need to dismount the noise source (for example the engine) whereas force TPA methods do. For example, a 48 channel (48 subsystems) measurement for ATPA requires one day and half, which is far less time than what is required by classic TPA methods. In addition, not measuring forces avoid all the measurements problems and inaccuracies related to force measurement.

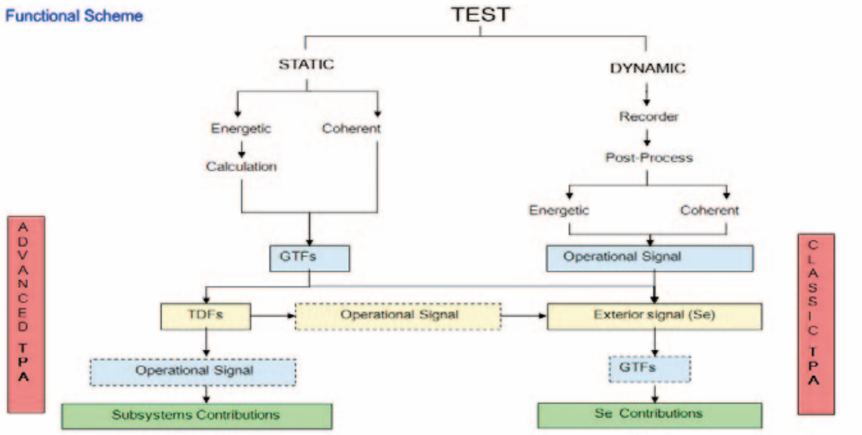
Both methods, TPA and ATPA, first appeared in the publication F.X. Magrans, Method of measuring transmission paths, Journal of Sound and Vibration 74 (3), pp. 321-330 (1981) which gives the equations relating to the transfer function that is measurable to the one that is required in ATPA under the name of Direct Transfer Function (TD factors in equations) as well as those relating the signal and the external signal to those transfer functions.



Measurable Global Transfer Functions transmition noise from all structure. Superposition principle is not applicable.



Direct Transfer Functions TD can overlap because of it only transmit noise from the excited point.



ATPA test consists of two main parts. The static test, which describes the structure and the dynamic test, which mesures the result of the real excitations of any structure. This methodology of analysis allows to approach the problematic structure (machine, room, train, etc.) into subsystems, which shall be the parts reporting about the contributions to the overall noise.

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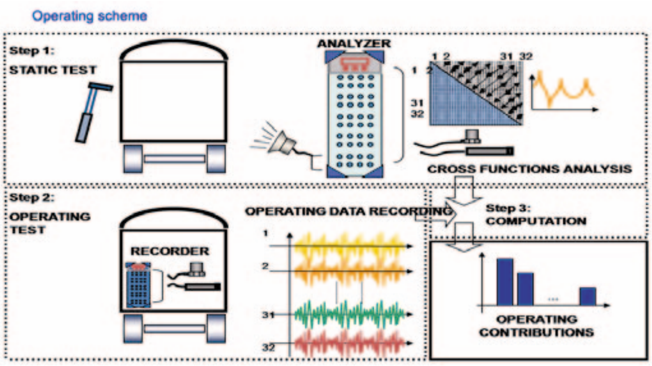
Finally, it is possible to have the external signals output equivalent to the system response to external forces exerted on it as well as the contributions. The testing requires the simultaneous measurement of a great number of cross spectra by means of a multi-channel system. The dynamic test consists in measuring simultaneously the accelerations in all the subsystems, thus making it indispensable to use a multi-channel system unless there is a sufficiently stable excitation.



Why choose ATPA? ATPA & other methods

Forces TPA & ATPA

Forces TPA	ATPA (Advanced Transfer Path Analysis)
• Forces TPA only provides information about coherent contributions (low frequency).	• ATPA is the only product capable of providing information on the contributions of all frequency ranges, working in coherent and energetic identification.
• Forces TPA implies time dismantling part of the force generator system and can produce fundamental changes to the structure.	• ATPA is an easy and fast method. Allows to make measurements without dismantling anything.
• TPA works with the Model Inversion, so that, can't identify the noise and vibration path analysis.	• ATPA has a dynamic margin at least of 40 dB which allows to quantify the transmission path of noise and vibration and give fisical information of them.

Reciprocity method & ATPA

Reciprocity method (Panel contributions)	ATPA (Advanced Transfer Path Analysis)
• LMS and Brüel & Kjaer methods results only represents reality when panels are unlinked, if not the results obtained can't be superimposed. • Microflown method is teorically perfect but shows that the result obteined is not which it is wanted. $p_k = \sum_i \lambda_i p_i + \beta_i a_i$ p_i is the pressure before subsystem i a_i is the acceleration in the subsystem i In this case $\beta_{i'}$ is the noise that will produce in microphone k an acceleration unit of the subsystem i when the acceleration of all the rest subsystems is zero and the pressure of all others, including himself, are zero.	• ATPA really identifies the elements which contributes to overall noise as the "Strip Tease" does, which applies the superposition principle. This can be expressed with this formula: $p_k = \sum_i \alpha_i a_i$ a_i is the acceleration of the subsystem i α_i direct transfer from the α_i is the noise produced in the microphone k by an acceleration with an unit value (α_i =1) when the acceleration on the other points is zero. $\alpha_i a$ is the noise produced in the microphone k by the vibration of the subsystem i in real operation. α_i are the values which ATPA can analyse.

- You will know and reduce each one of noise sourcesthe contribution to the total noise in a train.
- You will obtain a good characterization of noise and vibrations in a train allowing insulating and modifying the required elements of the structure train efficiently.
- Differentiate between interior air-borne noise and structure-borne noise contributions from each noise source.
- During the design stage of the new train, the results obtained by ATPA tests of an existing model of similar characteristics, will be advantageous for carrying out an accurate noise and vibration prediction of the new train.
- With ATPA method you will know, for example,when it comes to the total noise radiated by a window, how much noise is originated from the structure and how much comes from the exterior of the train.

Real cases

Solving a vibration problem do not have to be a difficult task if the assessed contributions of each part of the problematic structure are identified.
This can be explained through the following real cases:

- A global leader train manufacturer has required ICR ATPA knowledge in order to reduce the interior noise level of its train, as he previously changed the window without efficient results. The train manufacturer did not succeed in reducing the total interior noise as, despite the new window was able to insulate 6db more than the previous model, the door gaps were the main source of the total interior noise in that train (500 to 800Hz) within the frequency range. Being unaware that the window was not the main source of noise, the train manufacturer could have avoided these unnecessary expenses. The ATPA would have provided information on the paths of noise and vibration contribution to the total interior noise.

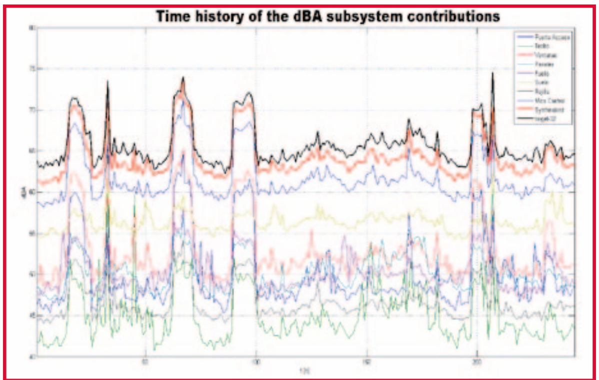
- The usual operation of an industry caused real annoyance in the acoustic comfort of its surroundings. In order to implement an efficient solution, most problematic external noise sources were insulated: compressors, fans and diesel motors, in particular, their exhaust pipes. In this case, were used acoustic booths tested for the insulation of 30dBA in white noise and reactive exhaust dampers assessed to reduce 20dBA in motors real spectra measured at 3m from exhaust. As a result, after wasting a lot of money in acoustic solutions, the manufacturer was only able to reduce 4dBA of the total noise emitted by the industry. This situation took place because the main source of noise were not been insulated: the plate walls of the industry. The plate walls of the plant emitted a noise of 4 dBA, which is equivalent to the noise reduced. The best solution would have been not to invest so much money to soundproof external noise sources through high-cost solutions. By ATPA test it would have been possible to obtain information on the contributions of each noise sources in the plant before doing any change. Once again, the problem was about being unaware of the contributions of each part to the problem.

Railways

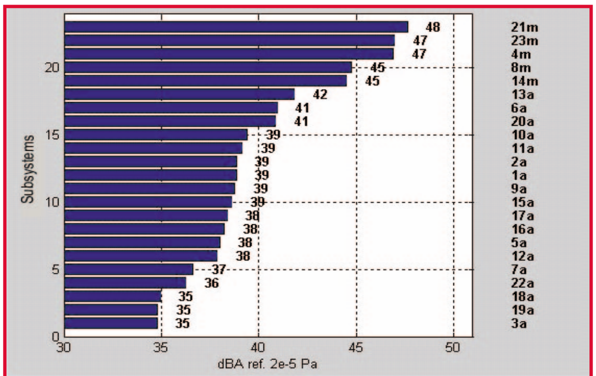
ATPA study

In trains, ATPA provides information on panels contributions, on the noise originating from any coupling point between the bogie and the bodywork and the method also identifies which part of the noise transmitted by each coupling point expands throughout every panel.

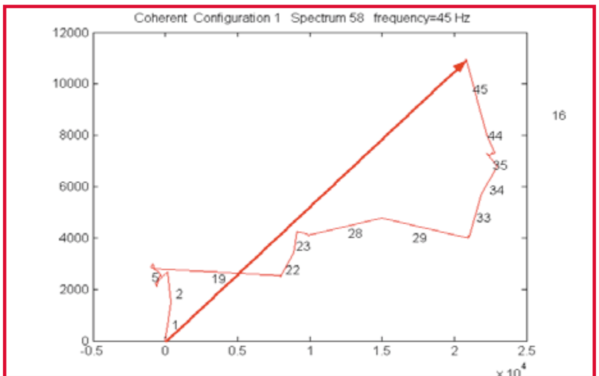
In addition, it is possible to distinguish between the structure contribution and the airborne contribution considering, for example, that part of the noise in a window is either caused by vibration transmissions from other carriage parts (structure contribution) or by the exterior emissions of the carriage.



Structural panels



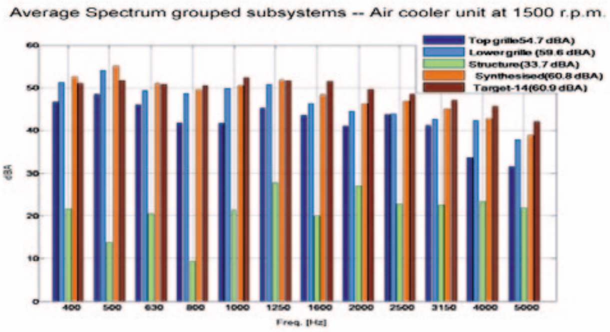
Noncoherent dBA contributions of each subsystem.

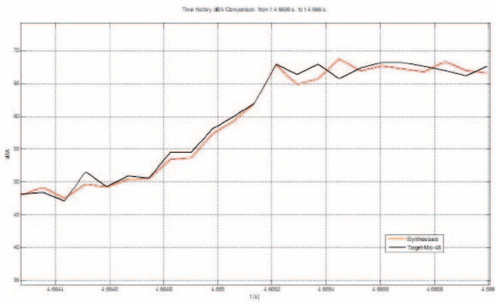


Coherent contributions to 45 Hz from 45 subsystems

Wind Power

Light blue and dark blue represent the contributions of the ventilation pipes; green line shows the contribution of the nacelle panels; light brown the aggregate of the contributions and the dark brown the measured spectrum.

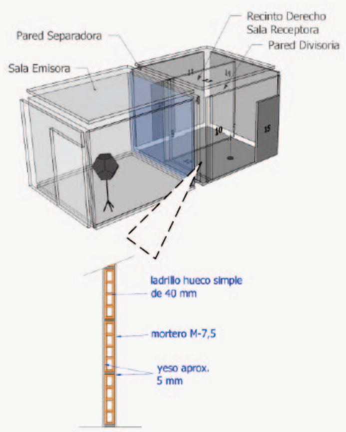




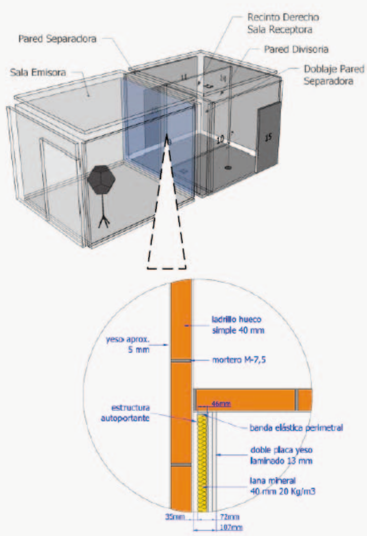
Contribution of two ventilation pipes and structure on the noise emitted by a wind turbine.

Building

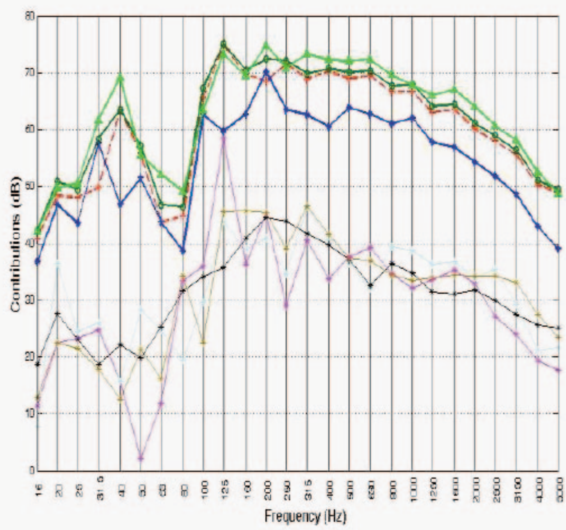
Research project Vitraso: prediction of noise and vibration transmission path in buildings. The goal is to solve problems existing in determining contributions of direct and indirect sources according to UNE EN ISO 12354 standard. A project headed up by FCC (Fomento de Construcciones y Contratas)in collaboration with ICR, Applus, IMAT and La Salle Bonanova (universitat Ramon Llull).



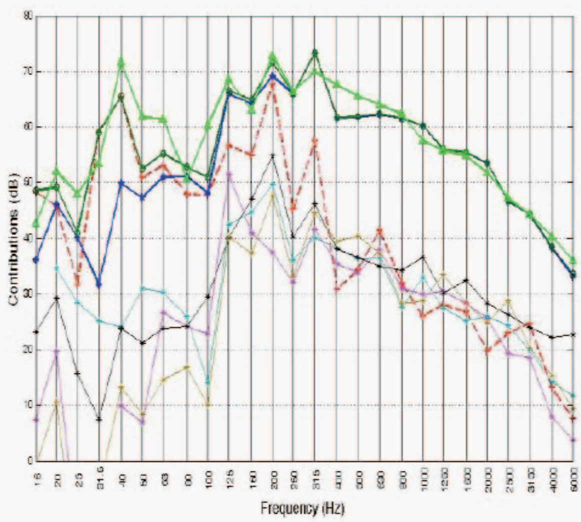
Configuration 1



Configuration 2

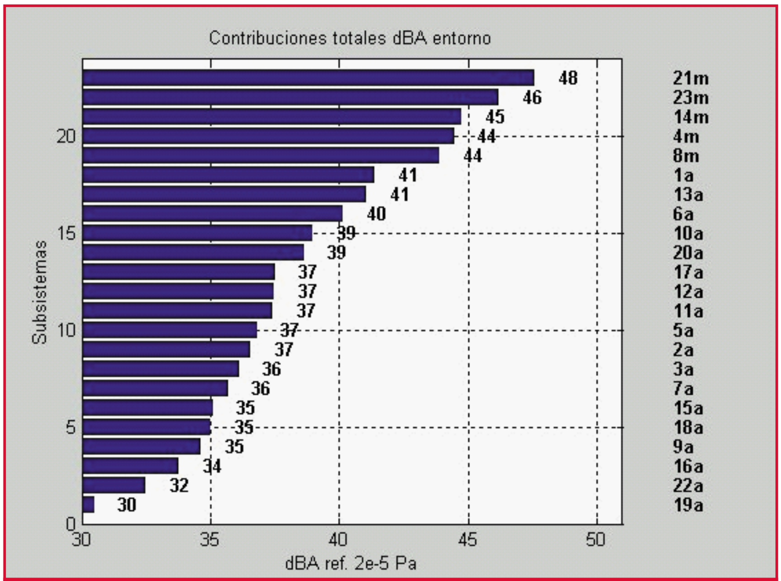


Reconstruction for configuration 1

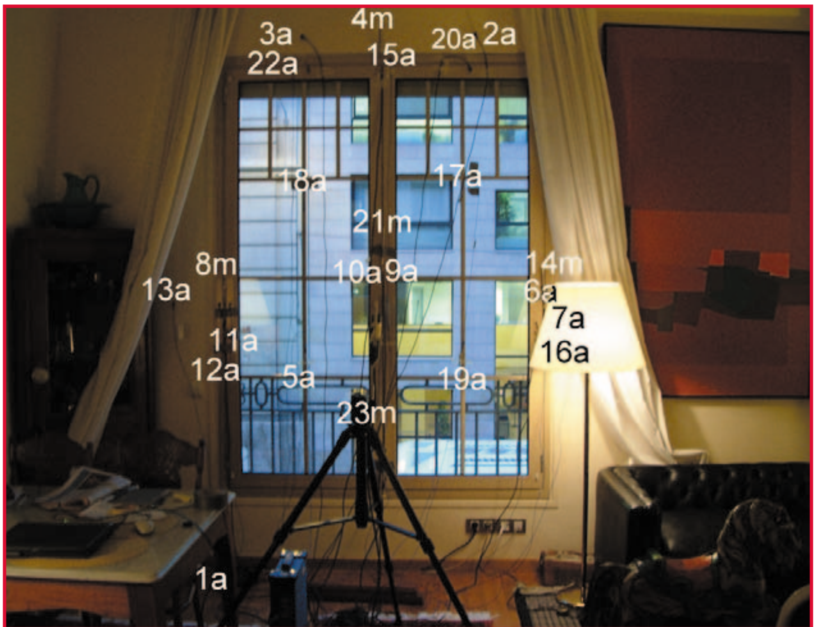


Reconstruction for configuration 2

Study of noise transmission paths in windows through frames, the joints between window and frames, the joints between glass and frames, glass, handle, etc.



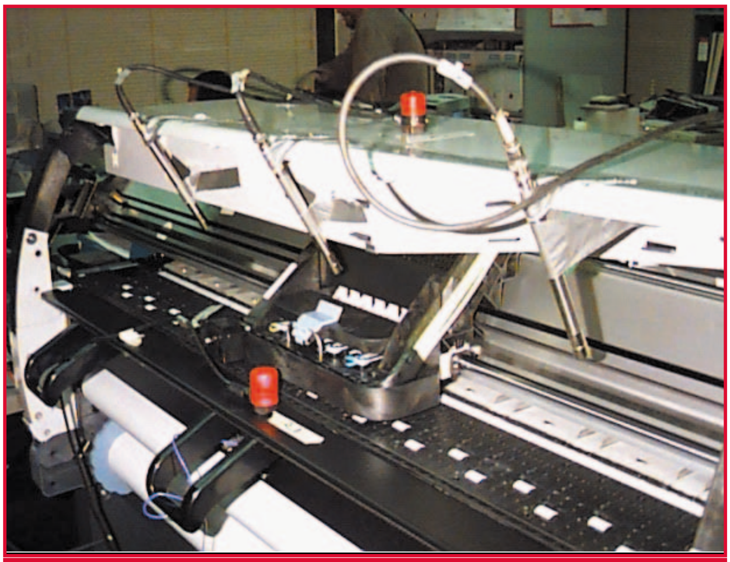
Representation of noise contributions.



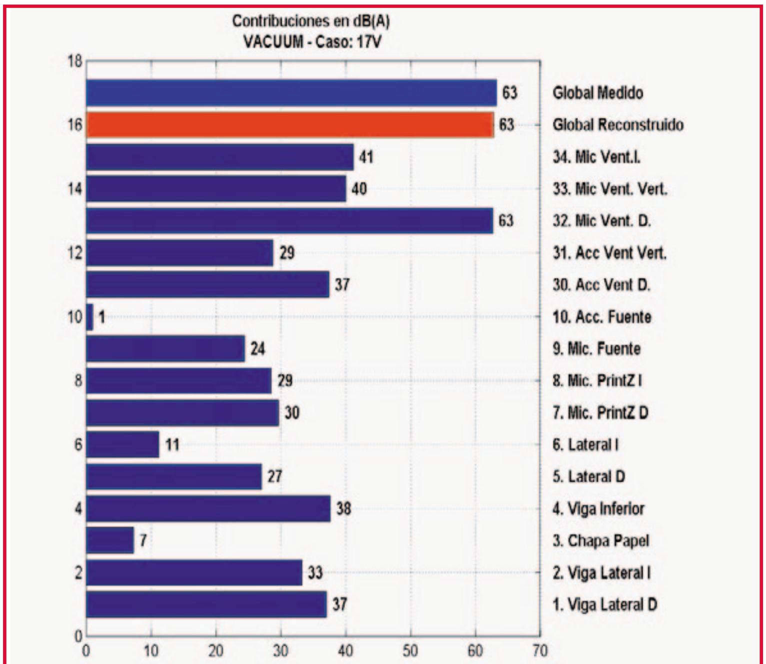
Noise measurement subsystems.

Plotter

Transmission Path Analysis and acoustic photography in a large format plotter. Taj Mahal Project for Helwet Packard. The objective was to reduce the plotter's radiated noise.

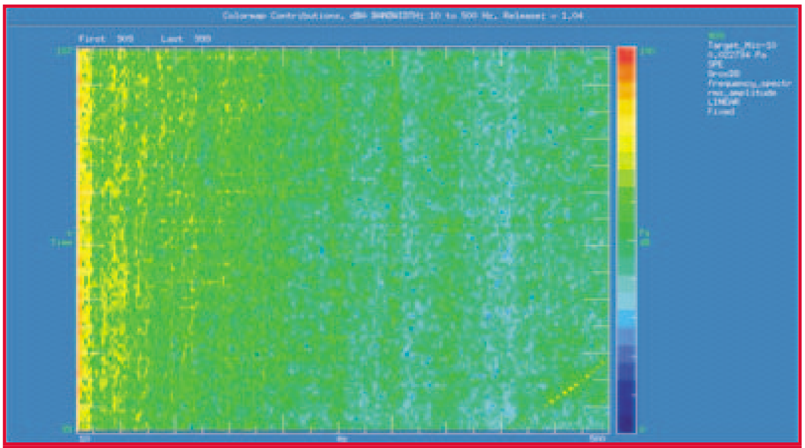


Narrow Band Results

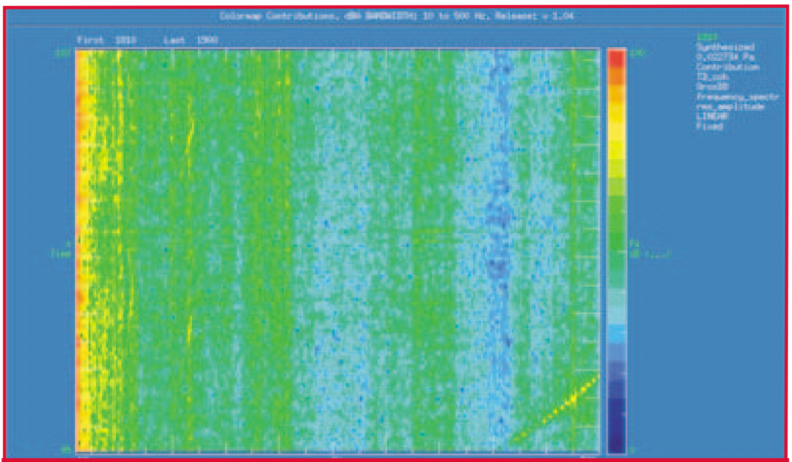


dBA results

Other examples



Spectrogram of the real noise measured in a train running at 120 Km/h.



Spectrogram of the reconstructed noise.

Within a spectrogram each line is the noise spectrum at a given instant showing the noise levels in colours. The vertical axis is time.

ATPA identifies the contribution of each subsystem, then rendering the aggregate of all contributions which must certainly be the total real noise of the device under study. This should actually happen at every instant and in any frequency. Hence, the spectrograms should be the same.

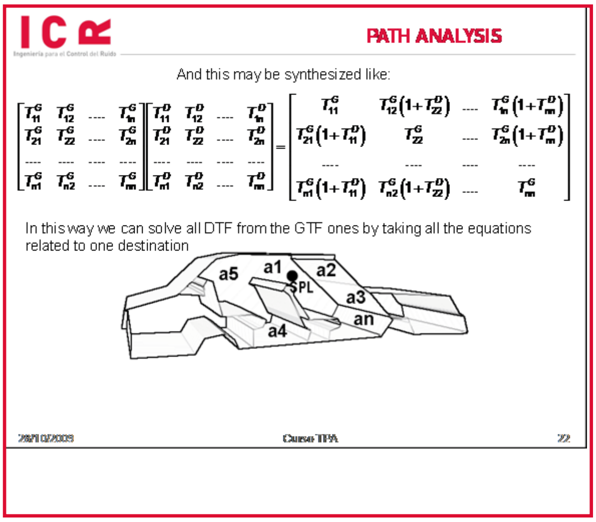
Training

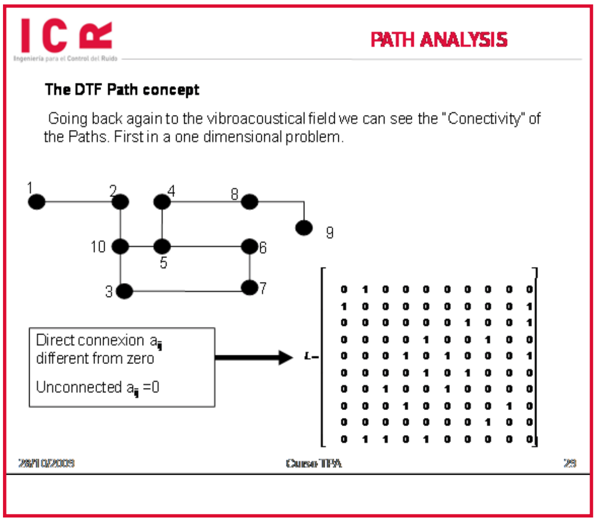
The first part of the product consists of a 50-hour course whereby the transmission paths are established and assessed through Direct Transfer. Besides, the equations relating them to the Global Transfer are assessed and described. The concept of "transmission path" is defined and the functions being used are proven to be consistent with the definition.

Furthermore, the "subsystem" concept, which is essential in the ATPA application, is defined as well as its development from its theoretical comprehension to provide self-determination up to the very final version of the subsystem.

method within the range of medium and high frequencies by using the energy variable.

Also, the differences in the measurement process between the coherent and noncoherent parts are described; the concepts about the calculation method in vibro-acoustic systems are also brought to discussion. Moreover, the signal processing concepts related to the measurement process are also defined.





Know-How

The know-how transfer is the second part of the product. ICR usually works for 30 working days in conjunction with the client´s staff to perform a series of tests that may show how the method works. During this session, ICR provides the client with the physical principles of the method in order the client to be able to decide by himself with well-grounded criteria.

Subsequently, the post-process is performed for 60 days at ICR headquarters giving the lcient the possibility to be present or to stay in contact through video-conference.

The know-how transfer also enables the client to adapt their equipment to this measurement system. The first measurements are often performed with ICR equipment while in the subsequent tests ICR make us of the client's equipment

As a final step of the ATPA know-how process, the staff in charge of this task should be finally able to apply this method to their product accordingly.

At the end of this stage, a measurement protocol is provided containing nstructions to apply this method to their product.

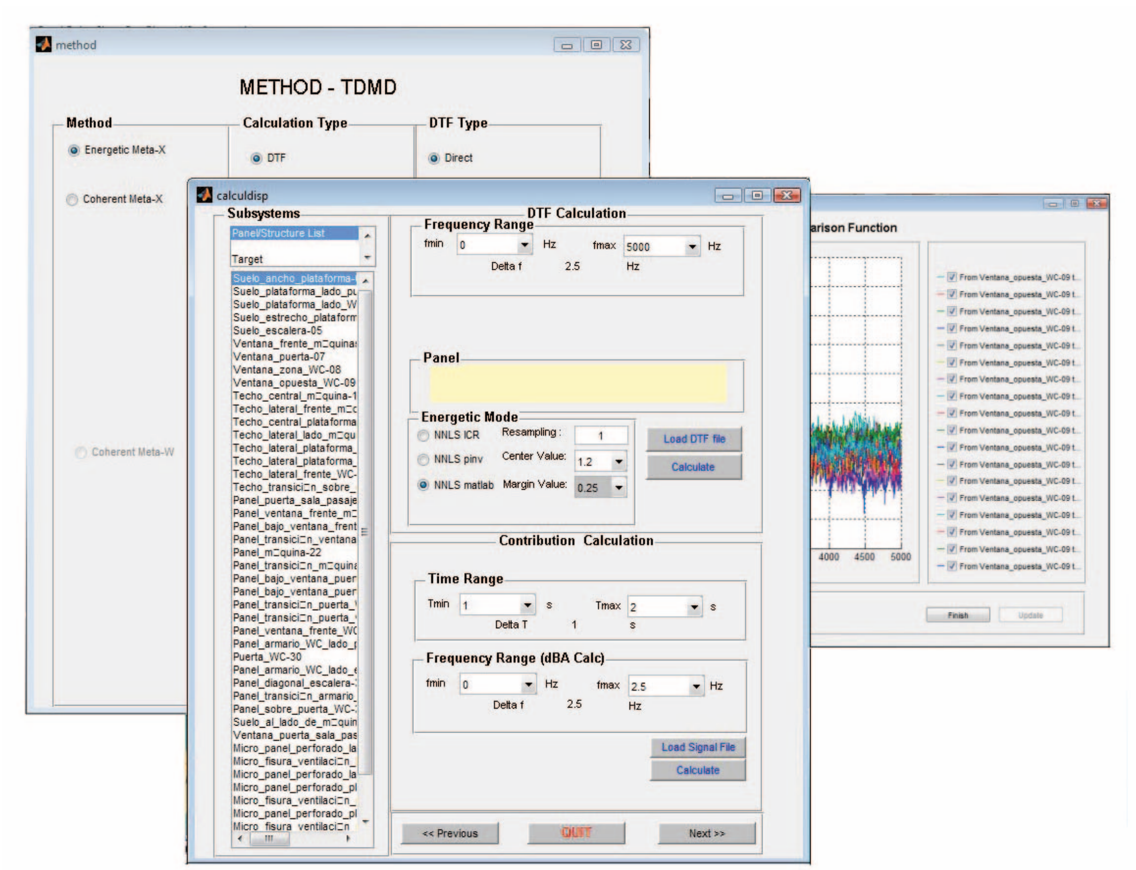
A Measurement Protocol is the final document of the Know-How transfer

Software

ICR develops an unique piece of software to apply the ATPA according to client's needs and requirements. The final software is custom designed for each client so that its application match their needs.

ICR has worked in several computer languages but usually provides its software in compiled Matlab and also programs the input processing for specific files of the equipment used by the client in Matlab workbench.

The output amount provided by the method is so large that each application uses the piece of information of more interest to the client in accordance with their product and practical implications.



ATPA projects

- Advanced Transfer Path Analysis (ATPA) of noise and vibration of the differents panels from a coach of the new OARIS AVE prototype. CAF, Construcciones y Auxiliar de Ferrocarriles.

- Vitraso research project: Diagnosis and estimate of noise transmission path in buildings. The goal of this project is to detect the paths taken by the most detrimental noise and vibration in a constructed building, as well as the subsequent design and implementation of means to eliminate these paths. FCC, Fomento de Construcción y Contratas.

- ATPA Technology Transfer Project for CAF, Construcciones y Auxiliar de Ferrocarriles. The following tasks were carried out for this project:

    1. Development of the testing procedures to obtain the vibro-acoustics specifications of the different subsystems of any train (for internal noise contributions).
    2. Evaluation of the interior noise contributions of all train different subsystems under normal operating conditions.
    3. Training: ICR trained CAF employees in the application of the ATPA procedures.

    During this project, the following trains were tested:

    - ATPA project focused on panels contributions of Metro Ligero of Sevilla.
    - ATPA project focused on panels contributions of TRDMD (Middle Distance
    - Regional Train Diesel) in Alcázar de San Juan.
    - ATPA project focused on structural contributions (diesel engine and bogie) of Sevilla.
    - ATPA project focused on bogie structure contribution of the prototype of CAF TGV.

- Transmission Path Analysis of noise and vibrations in a prototype high speed train (AGV). Alstom Transport.

- “META W: Advanced vibroacoustic analysis in railways. New technologies and computing methods.” Alstom Transport.

- Transmission Path Analysis in one unit of the suburban train CIVIA model. CAF, Construcciones y Auxiliar de Ferrocarriles.

- Advanced Tranfer Path Analysis (ATPA) of the noise and vibrations in 250-028-8 locomotive driver's cabin including test measurements according to client’s requirements. Atenasa.

- Transmission Path Analysis in the cabin of two diesel units model 333 and 334 of Vossloh. Solution consultancy. Atenasa

- Advanced Transmission Path Analysis of the engine noise and vibrations in the Ireland Railways diesel trains. CAF, Construcciones y Auxiliar de Ferrocarriles.

- META X: Advanced vibroacoustic analysis in railways. The ATPA method" for Alstom Transport. The following tasks were carried out for this project:

  1. Development of the testing procedures to obtain the vibro-acoustics specifications of the different subsystems of any train (for both internal noise contributions and external ones with the train stationary).
  2. Evaluation of the interior noise contributions of all the different subsystems of the train under normal operating conditions.
  3. Evaluation of the external noise contributions of all the different subsystems of the train for stationary operating conditions.
  4. Training: ICR trained Alstom employees in the application of the ATPA procedures.

  During this project, the following trains were tested:

  - ATPA of the West Coast Main Line train in Asfordby, UK.
  - ATPA of the Vectus train in Salzgitter Depot, Germany.
  - ATPA of the Coradia train in Salzgitter Depot, Germany.

- Advanced Transfer Path Analysis (ATPA) of noise and vibrations in Chamartin railway station. Proposal of vibro-acoustic solutions. Project 051180. Ineco Tifsa.

- Complete acoustic study in the Xin Min Line train in China including ATPA (Advanced Transfer Path Analysis) of the Varsaw subway. Alstom Transport.

- Complete acoustic study of the Nothern Spirit including an Advanced Transmission paths Analysis of the Heathrow Express. In United Kingdom. CAF, Construcciones y Auxiliar de Ferrocarriles.

- Transmission Path Analysis of noise through the windows from outside of building. Hotels Rosincs.

- ATPA (Advanced Transmission Path Analysis) of noise and vibration in a wind turbine ECO100 prototype in order to evaluate the contribution of the ventilation system to the total noise. Alstom Ecotecnia.

- Acoustic measurements and study following the TPA method on an automatic door of elevator. Selcom Aragón.

- Transmission Path Analysis and acoustic photography in a large format plotter. Helwet Packard.

- Advanced Transmission Path analysis; contribution of the vibro-acoustic sources the structure and air to the noise level perceived in the driver's cab and at an external control point. Ausa, Automóviles Utilitarios, S.A.

ATPA PAPERS

ICR ATPA papers:

• F.X. Magrans, Method of measuring transmission paths, Journal of Sound and Vibration 74 (3), pp. 321-330 (1981).

ABSTRACT

A theoretical explanation and experimental proof are presented of a method for localizing and evaluating the transmission paths of any signal in a "black box" among a set of points previously defined in it. The signal should behave linearly and the system should be able to receive external excitations separately each of this points. Such excitations need not be signal under study but they should be linearly related to it. Also presented are the equations that, once the transmission paths have been determined, allow the evaluation of the excitations which act on the system.

• O. Guasch, F.X. Magrans, P.V. Rodriguez & G. Manacorda, An innovative approach for the noise reconstruction and analysis at the medium-high frequencies. Proceedings of Euro-Noise, Munich, Germany, October, Vol I, pp.503-509 (1998).

ABSTRACT

In the last 30 years the Inverse Problem Theory has been mainly developed by geophysicians trying to model the Earth's interior from data collected at the Earth´s surface. As the Earth's interior is unaccessible, methods for extracting as much information as possible from data had been carried out. These methods turned out to be really efficient and have been applied to many other fields of applied physics and mathematics, engineering and economy. A quite complete mathematic theory has been built for them.
In our study we used some of these methods to reconstruct the medium-high frequencies noise field in the cabin of the new Ferrari 456. Our purpose was to know in what ways each of the panels in the total interior surface contribute to the measured noise at different points in the cabin. The results we obtained are very hopeful and we think that will improve in the future as we will have more information and a priori data to manage.

• O. Guasch & F.X. Magrans, The Global Transfer Direct Transfer method applied to a finite simply supported elastic beam, Journal of Sound and Vibration 276 (1-2), pp. 335-359 (2004).

ABSTRACT

The Global Transfer Direct Transfer (GTDT) method is a two-step transmission path analysis method. It is used to analyse the signal transmission among subsystems from a general N-dimensional linear network, representing a physical model under study. In the first step, the Global Transfer Functions (GTFs) are measured and the Direct Transfer Functions (DTFs) are calculated from them. In the second step, the signal vector is measured for the network running under the desired operational conditions. It is then possible to reconstruct the signal at any subsystem from the contributions of all other subsystems plus its own external excitation. This is done by means of the previously calculated DTFs.
This paper is intended to clarify how the GTDT method works. This is done by means of an analytic study of the bending wave transmission between three points in a simply supported finite elastic beam. This problem constitutes a particular 4-dimensional example of the general N-dimensional network. Concerning the first step of the method, special emphasis is given to the relationship among the DTFs and the GTFs, as well as to elucidate the role of the DTF matrix as a connectivity matrix. As for the second step of the method, the particular case of a correlated force vector acting on the beam is addressed. It is shown how the signal at any subsystem can be reconstructed from the signals at all the other subsystems. In practical implementations this allows to identify

problematic subsystems in order to perform appropriate design modifications and avoids the necessity of having to measure operational forces.

- F.X. Magrans & O. Guasch, The role of the direct transfer function matrix as a connectivity matrix and application to the Helmholtz equation in 2D: relation to numerical methods and free field radiation example. Journal of Computational Acoustics 13(2), pp.341-363 (2005).

ABSTRACT

The Direct Transfer Function (DTF) matrix was developed in the framework of the Global Transfer Direct Transfer (GTDT) method of transmission path analysis. This method aims at solving the problem of transmission paths among subsystems from a general N-dimensional linear network, representing a vibro-acoustical model under study. The DTF matrix can be calculated from the Global Transfer Functions (GTFs), which are measurable quantities, and it is built from all the Direct Transfer Functions (DTFs) between subsystem pairs. The DTFs allows define transmission paths by relating the signals between two network subsystems when the remaining ones become somehow blocked.
In this paper, the role of the DTF matrix as a connectivity matrix is first shown by solving the Helmholtz equation in a two-dimensional grid. The results are compared with those arising from the analysis of the stencils of various numerical methods. Some finite difference and finite element methods have been considered. The connectivity role of the DTF matrix is also elucidated by means of a free field radiation example.

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ABSTRACT

Advanced Transfer Path Analysis (ATPA) is a test-based numerical technique allowing the diagnosis necessary to solve vibro-acoustics problems. For vehicle applications, the main purpose consists in ranking the contributions of potential sources or potential transmitting points, distributed around a cabin, and creating noise at a receiving passenger location. The classic Transfer Path Analysis (TPA), as commonly known, has one objective: giving the contributions of the sources at the receiver points, independently of their transmission path. Using the ATPA technique, the transmission paths are quantified and ranked. This technique complements the possibilities of the classical TPA method by allowing the determination of the relative contributions of the selected structure and airborne transmission paths. Using the information extracted from the application of this theory, the mechanical component to be modified can be identified. From that point, the decision can be taken to act directly on the source or on the structural elements. This paper starts by giving a short theoretical description of the method. Then, the steps of the experimental procedure applied, the tools used, and the exploitation of the data are described based on an experimental case realized in controlled conditions. Finally, the range of application of the method and of the tools used is described based on a real case.

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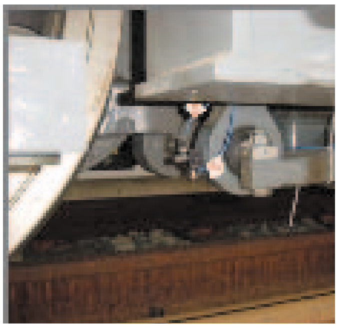


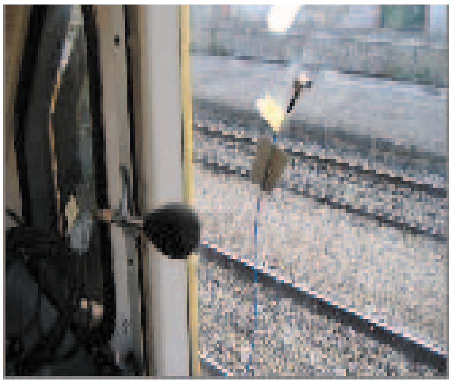

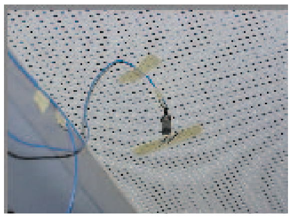

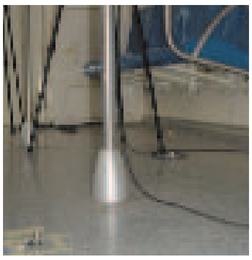


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