

## **„Intelligent Materials for Active Noise Reduction“—Overview & Results**

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### **Abstract**

Noise is a serious form of environmental pollution believed to affect the lives of some 100 million European citizens. The cost of the associated damage is estimated at more than ten billion euro per year. Within this context, the under NMP funded IP 'Intelligent materials for active noise reduction' (InMAR) aims to reduce noise levels associated with road and rail transport, both interior and exterior, as well as associated infrastructure such as bridges. InMAR will bring together top research institutes and universities, OEMs from the automotive and railway sectors, components producers, and eight SMEs that specialise in smart structures and materials. An overview of the project's objectives and structure and first results will be given in the presentation.

## 1.0 Introduction

During the last decade fundamental research on smart structures using intelligent materials has raised industrial interest in applying these results to many problems found in commercial and civil life. The main objective of smart structure technology is noise and vibration reduction in civil engineering, machine tools, automobiles, trains, and aerospace engineering. Both strongly coupled phenomena limit the design of highly advanced and efficient lightweight structures, whereby nowadays noise is considered one of the worst forms of environmental pollution worldwide. In addition to simply being annoying, day-to-day noise exposure may cause serious health problems such as sleep disturbance, stress, disturbance of mental activities, hardness of hearing, and even deafness as well as an increased risk of heart attacks. Taking into consideration only road and rail traffic, 32% of the population is seriously disturbed by an outdoor noise level of  $L_{eq} > 55$  dB (A) and 13% of the population has serious health problems as the result of outdoor noise levels above 65 dB (A). But, due to increasing traffic, noise exposure in Europe by road and rail has already reached its highest levels. The EU is defining new standards for the year 2010 to compensate for these noise emissions, targeting a reduction of 19 dB(A) for road traffic and an even higher required reduction of 21 – 26 dB(A) for freight rail traffic. It is obvious that these goals cannot be achieved with advanced traffic management or political methods (e.g. traffic restriction) alone. An approach based on lightweight design and smart structure technology combined with traffic management concepts has to be pursued.

There are a number of different approaches that can be taken, of which one is the use of intelligent materials that create opposing vibrations to counter or cancel those created by the noise source. Presently, many intelligent materials systems such as fiber composites with embedded piezo-ceramics or shape memory alloys are derived, characterized, and applied in smart structures on a laboratory scale without having an impact yet on the design rules for engineered structures or without their application in mass products. Although their potential could be demonstrated and realized to a certain extent in prototype structures, the performance of intelligent material systems is still insufficient. They require an unacceptable electronic periphery, data on their durability and reliability is lacking and, most importantly, they are not yet included in standard design and manufacturing processes. These deficits should be overcome by the IP InMAR. The overall objective of InMAR is the research and realization of intelligent, high-performance, adaptive material systems with integrated electronics for different individual applications. Aside from the development of the materials or material systems themselves, this research also includes their characterization, simulation tools for the design process, handling and manufacturing techniques as well as the reliability of these material systems.

## 2.0 Scientific and Technological Objectives

In order to bring advances in intelligent materials to the level of industrial use in integrated applications, the material design process has to become part of the complete product creation process. This demands that the product's functional performance and respective simulation models, which are the cornerstone of today's design process, be capable of supporting the specific aspects related to advanced materials, active systems, actuators, sensors, and control, and that these be integrated into system-level and virtual prototype models. An essential requirement for this is the coupling of various physical disciplines such as structural mechanics, acoustics, electro-magnetism, or durability with control algorithms within one simulation. Moreover, effects on a very different scale need to be interconnected, ranging from the micro-structure of the active materials to the acoustic far-field enclosing the structure under consid-

eration, which, in turn, will be the controlling variable for the intelligent material. This level of bi-directional integration is not known in other engineering disciplines and requires a new class of models and tools. Finally, proper parameterization, a reduction of the applicable models, and the fast recalculation of various design alternatives will be key elements in deriving an optimal system and material design. Such a modeling approach will be established in the *InMAR* project. Based on this approach, the simulation of full-system behavior can be performed, taking into account the characteristics of the innovative material as well as multi-attribute performance goals. This then allows for the proper target setting on the level of the materials and material systems (essential for “materials by design”) as well as for the development of optimization procedures for the material parameters and material system configuration.

The biggest achievements in weight reduction, size reduction and probably cost reduction are obtained when all functional components are fully integrated. Even stronger, it is unlikely that such systems will be introduced if they are not fully integrated. In order to realize these objectives, some of the components could be given multiple functions, such as thin active layers which are used for mounting the electronic components, for the interconnections, and for example the face layers in sandwich constructions. The design of such systems should be done in an interdisciplinary manner and with constraints given by the industrial partners. The design of the system is complicated by the fact that the control of multi-channel systems for broadband noise reductions is computationally rather demanding, and usually requires heavy signal processing hardware because fully programmable systems such as a Personal Computer or Digital Signal Processor are used. So reduction of computational complexity and hardware implementation of certain parts of the algorithm have a direct influence on the possibility to achieve the desired goals and should be taken into account in the overall design process. Additionally, at relatively high sound pressure levels and vibration levels, also the weight and size of the power amplifiers should be reduced. The combination of detailed simulation models is needed to optimize overall system performance. However, from a practical point of view, the availability of simpler design rules is important. These simple design rules can be on the component level but also at a subsystem level or even system level.

The main objectives of the technology areas are to understand, to design and to develop:

- new complex multifunctional passive, semi-active and active materials and material structures,
- actuator and sensor systems based on the developed materials, fully operational under harsh environment, high and broad-band load and under large deformation
- their manufacturing technologies,

and

- novel, miniaturized control and electronic systems for multifunctional materials, and for actuator and sensor systems
- simulation and optimization tools for the design of intelligent systems
- technologies to integrate intelligent material systems in structural components and
- methods and procedures to assess their reliability, environmental impact and life-cycle including condition monitoring

to be used in the macro-scale application of active noise reduction. The expected innovations on intelligent material systems in total will increase the acceptance of smart structure technology and the industrial applications in order to replace classical, ineffective methods of noise and vibration suppression.

Beside the fact that the automotive industry is a driving factor in the economy, automobiles are to be considered as one of the major contributors to noise emission. Beyond the aspect of exterior noise, major effort is undertaken to improve or design the interior noise of automobiles. Most concepts are based on absorption and state a contradiction to light weight design. Therefore, automobiles are an ideal application for active noise reduction concepts. The train industry is facing similar problems where the major noise sources are the rolling noise and the power train. Research performed on infrastructure such as buildings or bridges has to be seen in context with an overall reduction of noise affection for the population. Although within this Integrated Project concepts are being considered to reduce the noise at the source, a significant noise level will remain to affect people. Particularly for buildings at inner urban roads or close to rails or airports the remaining noise level will still exceed the tolerable limits for people. Therefore, as an accompanying measure the transmitted noise through windows and facades should actively be controlled. Furthermore, bridges and tunnels are important noise and vibration sources generated mainly by railway and highway traffic. Noise reduction in all above fields can find great benefits from new intelligent material systems, new components and devices and new noise control systems as derived in the technology areas. Of course, the cost aspects are quite relevant when the balance benefit/cost is taken into account to decide whether a technical solution is ready for production. Besides, also innovative simulation tools can help to better understand phenomena and problems, so that new applications of existing technologies or technologies derived are envisaged. The main objectives of the application scenarios are to design and develop advanced active noise reduction concepts for

- exterior noise of automotive and trains,
- interior noise in automotive, trains and buildings
- and sound quality design of interiors

as cost-effective solutions for a broad-band noise reduction up to 10 db (A) or higher for exterior and interior noise.

### **3.0 Project Structure**

In order to gap the bridge between fundamental research and applied technology the consortium of the IP *InMAR* consists of all leading research institutions in Europe (8 research organizations, 11 universities) in the field of smart structures and intelligent material systems as well as most of the major industries of the intended applications (23 companies), 8 of which are considered SMEs. The consortium combines researchers from various, complementary specialties and enables the cross-frontier cooperation of partners beyond their traditional target markets by providing S&T excellence and by ensuring the quality of the consortium.

Industry		SME's		RTD		University	
Volkswagen	GER	ERAS	GER	FhG	GER	HSU-HH	GER
Ford	GER	IGAM	GER	DLR	GER	TU DA	GER
EADS	GER	Smart Mat.	GER	TNO	NL	ULB	B
Siemens	GER	Panphonics	FIN	VTT	FIN	KUL	B
FEV	GER	Micromega	B	CIRA	I	KTH	S
LMS Int.	B	D2S Int.	B	C.R.F.	I	ISVR	UK
AVL	A	Techno First	F	INASMET	E	UTW	NL
Rieter	CH	IMMG	GR	EMPA	CH	TU Delft	NL
Schindler	CH					CNAM	F
Saint-Gobain	F					PoliMi	I
Renault	F					BUTE	H
Volvo	S						
Bombardier	S						
Lucchini	I						

Table 1 InMAR Consortium

The scientific and technological objectives are reflected in the structure of the IP as shown in Figure 1 below. According to these objectives, the IP *InMAR* is structured in three complementary technology areas (sub-projects) dealing with intelligent material systems and their integration, simulation, and life-cycle aspects. These technology areas strictly concentrate on providing the enabling technology required for the application scenarios but at the same time strongly rely on the system definitions and requirements provided by them. The application scenarios again are divided into three sub-projects for application, integration, and verification in automotives, trains, and infrastructure.

Cluster 1: Technology Area		Enabling Technology ⇒ ⇐ System Requirements		Cluster 2: Application Scenarios	
Sub-Project	Work Areas	Sub-Project	Work Areas	Sub-Project	Work Areas
TA 1 Intelligent Material Systems	Material Systems	AS 1 Noise Reduction by Automotives	Tire & Breaks	AS 2 Noise Reduction by Trains	Power Train
	Actuator & Sensor Systems		Sheet Metal Parts		
	Manufacturing		Car & Truck Bodies		
	Control		Sound Quality of Interior Noise		
	Electronics		Noise Transmission of Windows		
TA 2 System Integration	Simulation & Optimization	AS 3 Noise Reduction by Infrastructure	Wheels & Breaks	AS 3 Noise Reduction by Infrastructure	Windows & Facades
	Electronic & Control Systems		Power Train & Bogie		
	System integration		Ventilation		
	Characterization & Validation				
TA 3 Life-Cycle	Reliability		Windows & Facades		Bridges & Tunnels
	Condition Monitoring		Elevators		

Fig. 1 Project Structure

## 4.0 First selected results

### 4.1 Power Trains and Bogies

The work area “Power Train and Bogies” considers the propulsion system, i.e. powertrain (diesel engine and gearbox) and the bogie as the main issue, especially in the case of diesel propelled vehicles. Background is a Diesel Multiple Unit vehicle by Bombardier, developed

to the state of the art with passive Noise Vibration and Harshness (NVH) technologies. Three major operating areas were pre-selected so far, decoupling, shell noise and encapsulation. Whereas in total four ANR applications are actually under investigation:

- Diesel engine encapsulation by active shielding
- Active in-duct valve system in exhaust system
- Active vertical damper in secondary bogie suspension
- Active vibration control in second suspension stage of Diesel engine

Two major noise and vibration test campaigns were carried out to provide baseline data for the AGC train. In parallel, a vibro-acoustic model of the train engine in view of active control design was established including an experimental study of the noise components and building an experimental and a numerical boundary element model to derive surface-level source descriptions. Based on these models, a coupled vibro-acoustic model of an encapsulated engine was derived and validated with experimental data. This model was then used as the basis for building models including active noise control which can be used in optimization algorithms for position and strength of active monopole sources. With respect to structure-borne noise and vibration from diesel engines, an FEM model of the DMU (Diesel Multiple Unit: engine and generator) was set-up and first simulations with regard to power train vibration excitation and the related power train vibration natural vibration modes were performed (Fig 2). The environment for a smart interface to reduce the power train vibration transmission via the sub frame mountings into the train chassis (car body) and the active device mechanical characteristics required were assessed based upon experimental data. A piezoceramic-technology based interface seems to represent the technical solution able to cover the desired frequency range and to provide the necessary displacement / force profile.

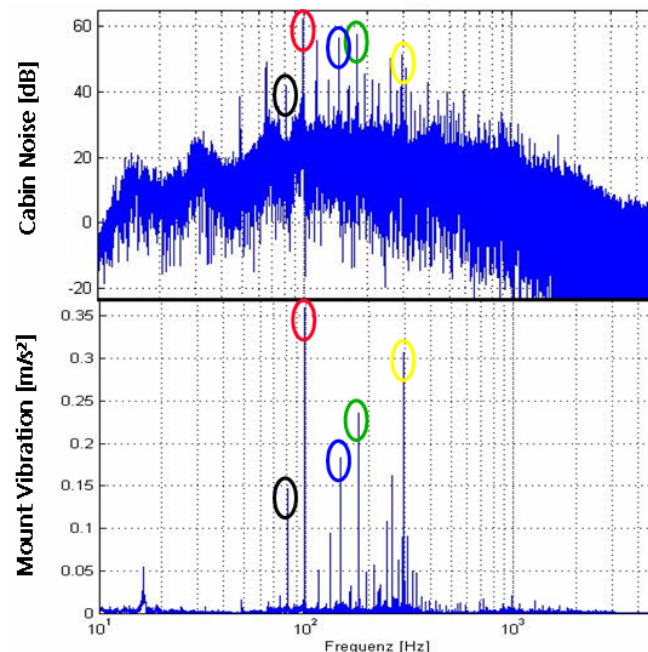


Fig. 2 Correlation Mount Vibration / Cabin Noise (Source FEV)

## 4.2 Bridges and Tunnels

The work area aims at developing active solutions for noise reduction of steel bridges and reduction of squeal noise in tunnels. The effort spent so far has been focused on different activities such as investigation on bridge noise and squeal noise, conceptual design of noise reduction solutions, selection of actuator concepts and extensive numerical and experimental study. Based on these outcomes and requirements, the design of the active systems will be reviewed and optimized with special attention to noise reduction performance, actuator design and integration, control strategy, and feasibility considerations.

Regarding bridges it was shown that the bottom plates of the railway bridge, due to their large radiating areas, are the main contributors to the far field pass-by noise levels. It was further concluded that using Active Damping Devices (ADD) to reduce structural resonances of the lateral steel plates of the bridge would not be effective in reducing the far field noise. According to these results, it has been necessary to envisage the wide-band control of the bottom plates of the steel bridges. This can be done with the ADD providing that actuator is stiffened to allow for vertical operation and that the analog control board is replaced by a digital one. The latter would allow implementing either (i) wide-band feedback controllers, (ii) noise-cancellation feed forward controllers or (iii) local active damping controllers, as the analog version, but with a higher degree of flexibility.

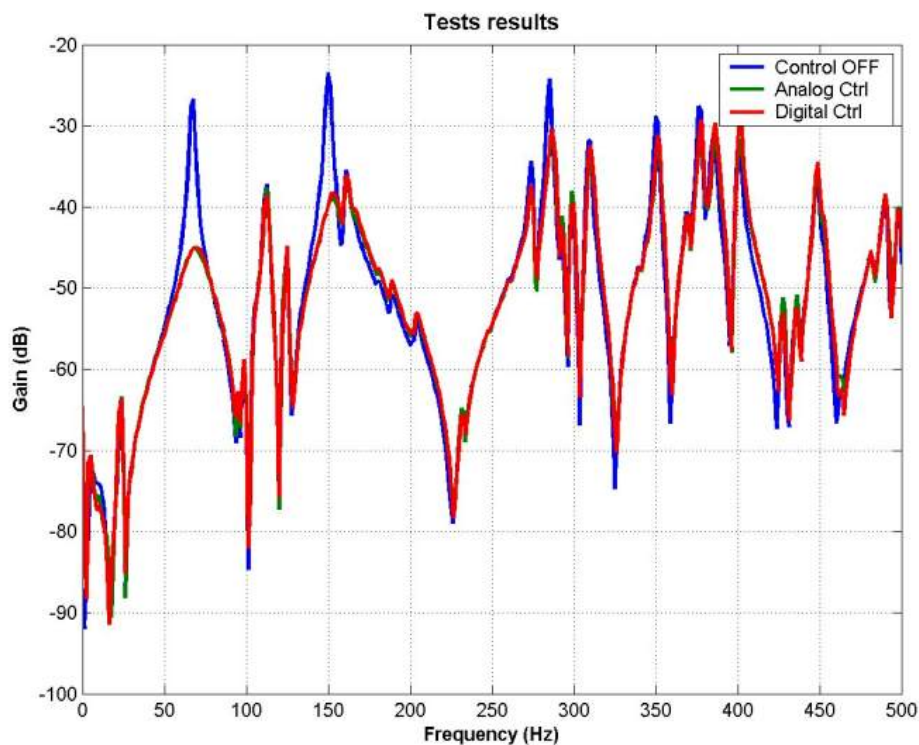


Fig. 3 Performance of the active damping device (Source D2S)

## 5.0 Acknowledgement

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