Prospects of Improving Vehicle Sound Quality by Means of ANC

Görgün A. Necati, Ford-Werke AG, Cologne Germany

Introduction

Beyond the global target of reducing the sound pressure level in a vehicle interior, it may be desirable to affect the interior *sound quality* and to grant the vehicle a strived interior *sound character*, i.e. "pleasant", "sporty", "powerful", etc. In most cases, achievement of such targets by means of usual hardware modifications is difficult, time consuming, costly, often not feasible and, least of all, sometimes not possible. Conversely, application of the active noise control (ANC) techniques has the potential to skip these disadvantages and may help to achieve the anticipated sound quality.

ANC Experience in the Past

To improve the sound quality in a motor vehicle, first the annoying high sound pressure levels (SPL) have to be cancelled. These are either high SPLs of engine harmonics, very often the 2nd engine order of 4-cylinder engines, or random type road or wind noise.

In the past, several experimental passenger cars have been prepared to prove out the performance of ANC systems, mainly tackling with the engine harmonics. However, the two main obstacles that have been the major handicaps for a final introduction of ANC in the passenger cars were:

(i) The space needed to package the actuators,
(ii) The high cost level of the systems.

The higher the frequencies of an ANC application are, the higher will be the number of needed sensors and the actuators. If loudspeakers as typically used actuators are to be implemented, the former constraint will very quickly be exceeded.

Electro-Mechanical Film

Using flat actuators capable to be integrated in the headliner, trim or headrests, may solve this conflict. The newly developed thin, biaxially oriented, flexible electret film, called Electro-Mechanical Film (EMFi) [1], may be used to construct such flat loudspeakers. In addition to the low cost level of this new material, the drastically falling price of powerful electronic hardware for ANC controllers will improve the prospects to introduce the ANC technology into the passenger cars of future. The EMFi is made of polypropylene and it is only 35 µm thick. The biaxial orientation produces flat voids in the material, giving the film good charge stability characteristics. When exposed to pressure, causing a change in thickness, EMFi generates a voltage, working as a sensor. Vice versa, EMFi converts the

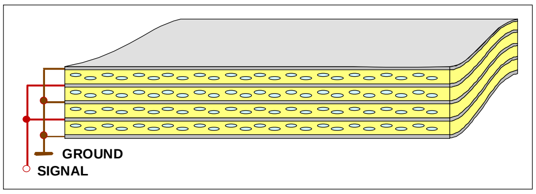


Fig. 1: Thickness mode actuator

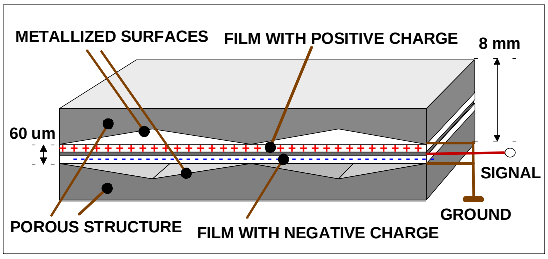


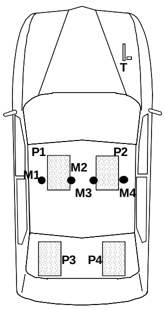
Fig. 2: Membrane mode actuator

electrical energy to vibration and sound, operating as an actuator. However, if used as an actuator the thickness variation of EMFi produces modest sound pressure levels. Two actuator constructions are possible to improve this situation: To achieve higher sound levels *(i)* either a stack of EMFi layers operating in *thickness mode*, Fig.1 or *(ii)* the s.c. *membrane mode* actuators can be used. In case of *membrane mode* the EMFi vibrates in the cavities of two porous stator panels, Fig. 2.

EMFi as Actuator

Within the framework of the EU supported Brite/Euram project FACTS ('**F**ilm **A**ctuators and **A**ctive Noise **C**ontrol for Comfort in **T**ransportation **S**ystems') the above-mentioned EMFi based flat loudspeaker designs have been appraised for their utility for an ANC system in a car. Two exercises were performed [2]:

1. <u>*Treatment of Engine Harmonics*</u>: A mid-size vehicle with a



P1…P4:
EMFi panels

M1…M4:
Microphones

T:
RPM meter

Fig. 3: EMFi panels in vehicle

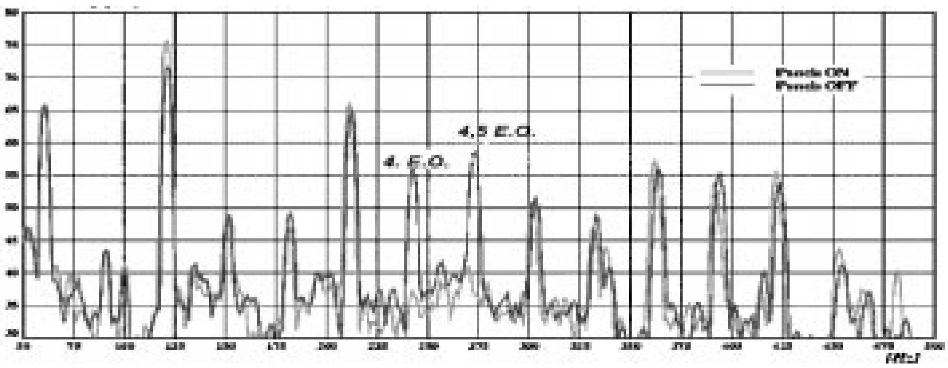


Fig. 4: 4th and 4,5th engine orders being tackled by ANC system (courtesy CRF)

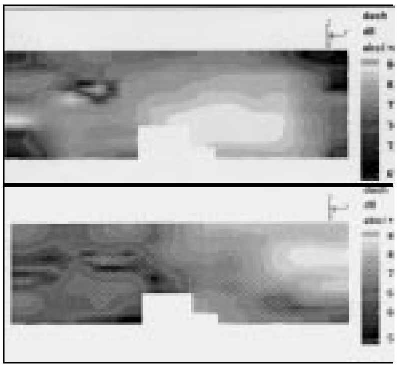


Fig. 5: Sound intensity mapping at 200 and 500 Hz

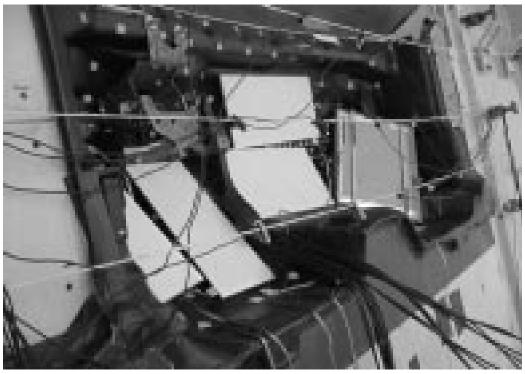


Fig. 6: EMFi actuators and error microphones on the dash panel assy (FORD)

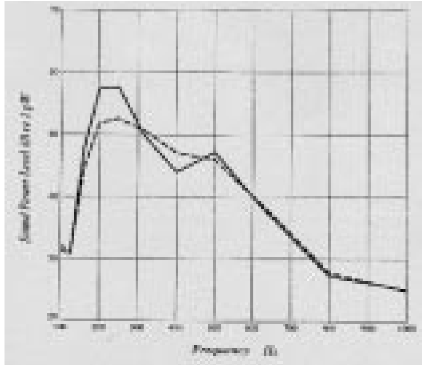


Fig. 7: ANC performance (sound power) upon random excitation

4-cylinder engine was equipped with a feed-forward ANC system, containing four EMFi panels of *membrane* type; two of them being integrated in the headliner and two on the package tray (supplier: *VTT*, Finland), Fig. 3. The half engine orders (E.O.) usually have a negative impact on the sound quality, therefore the 4,5th E.O was - in addition to the 4th engine order - also treated by the ANC system. This task was performed by the *FACTS*-partner *CRF* (Italy) and the results are given in Fig. 4, indicating the subject system as capable to reduce the mentioned engine orders.

2. *Treatment of Random Noise:* The front end of a mid-size vehicle containing the production level dash insulator and accessories was set up in the Transmission Loss Lab of FORD (Germany) to investigate the ANC performance upon random airborne type excitation (white noise, 200…600 Hz) [3]. As preliminary tests *(i)* the sound power level in the receiver room (excitation: white noise 200...600 Hz) and *(ii)* the sound intensity mapping of the sound radiation into the receiver room were recorded. The sound power results indicate a primary peak at 200...250 Hz range and a further peak at 500 Hz, see Fig. 7, solid line. The sound intensity recordings at 200 and 500 Hz exhibit the primarily active ranges of the vehicle front end at subject frequencies, Fig. 5. These results have finally been used for proper positioning of the 5 EMFi actuators (*membrane* and *thickness mode* type) and 15 error microphones, see Fig. 6. An adaptive MIMO ANC algorithm, developed by FACTS partner *TNO* (Holland), has been applied. The results are shown in Fig. 6, dotted line, showing that a sound power reduction of 6 dB is achievable with this approach.

Sound Quality Improvement Prospects

The application of flat loudspeakers as actuators in ANC systems to tackle annoying sound of periodic or random type is principally possible. The frequency range 200…600 Hz (or higher) seems to be realistic if EMFi based elements are fitted in vehicle. For lower frequencies than 200 Hz classical loudspeakers (preferably those of the vehicle-own audio system) may be incorporated.

The sound quality improvement strategy for a passenger car applying ANC may be set up in three steps:

- Reduction of annoying high SPL engine orders (i.e. 2nd E.O. of 4-cylinder, 4-stroke engines),
- Reduction of annoying random type noise (i.e. road noise),
- Reduction and/or balancing of even, odd and half E.O.

In the past, various car manufacturers have already experimented and proven out the technology of reducing the high-SLP engine orders (i.e. *booms*) with using an ANC system. The experience shows that these boom frequencies are very often coinciding with the vehicle interior cavity modes, therefore the mode shapes of the interior cavity are to be taken into consideration in positioning the actuators, error microphones, etc. In many cases the loudspeakers of the vehicle audio system may be used as ANC actuators.

If the road noise issue is at very low frequencies and mainly addressing the first interior cavity mode, an 'analogue' modal approach as above may be striven. However, in case of higher frequencies 200...600 or 800 Hz, the mainly radiating body areas should first be identified and then treated by using flat ANC actuators diminishing the strength of the respective dominant local source. One (or more) EMFi actuator(s), preferably incorporated with a near field PU pick up as error sensor (i.e. *JMC* element) [2] may be applied.

Appropriate '*composition*' strategies for the even, odd and half engine orders will enable a desired *sound quality* being granted to a vehicle. If a '*smooth* and *pleasant'* sound is required, the even engine orders should stand in proper ratios to each other and the levels of odd and half orders should be reduced. On the contrary, if a '*sporty'* sound is required, some odd E.O. may be raised during accelerating the car. Thus, in course of 'tuning' the desired sound quality, the SPL of some orders may be reduced and some of them even be raised. On principle this kind of tuning can be deployed by means of ANC techniques. As the higher engine orders mean higher frequencies, a modal approach as mentioned above will not be functional, as the modal density of the interior cavity increases exponentially with increasing frequency. In this case, the space in the proximity of each passenger's head may acoustically be treated. That can be reached e.g. if EMFi and error microphones are positioned in the headliner of the vehicle or a loudspeaker and a microphone is integrated into the headrest [4].

References:

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[2] *FACTS – Final Technical Report*, Tampere, 2000
[3] Necati, G. A., et al. *Noise radiation reduction of a car dash panel*, ISMA 25, Leuven, 2000
[4] Carme, et al. *The ANCAS seat: Extensions and industrial applications*, ACTIVE 97, Budapest, 1997