Intelligibility of Hands-free Phone Calls Outside the Vehicle

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Motivation

The intelligibility of telephone conversations outside the vehicle is a very important aspect but users are not always aware of this situation. The reason for this undesired effect is elementary: the downlink signal of a telephone conversation, typically being played back via the built-in loudspeakers in the front door, exciting the door structure. The whole surface emits the audible sound outside on the vehicle.

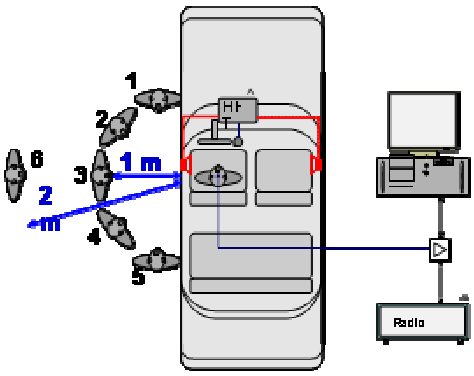

Fig. 1: Test setup to assess quality and intelligibility parameters inside and outside the vehicle

This implies, besides the privacy aspect also a political aspect: a huge effort is taken by legislation in order to lower the external vehicle sound produced e.g. by motors, exhaust systems and tires [1]. The aspect of sound played back via the internal audio systems has – so far – not been addressed.

The acoustical and/or structure-born coupling between the loudspeakers and the chassis needs to be evaluated in detail in order to identify the transmission paths and individual contributions in an individual car. Combined measures like level and spectral analyses, intelligibility and perceptual measures as well as vibration analyses are necessary in order to document it and evaluate the effect of modifications – reason enough to address this prob-lem and setup appropriate test methods to solve it.

Assessment Methods

A test setup to measure the acoustically relevant parameters is shown in **figure 1**. An artificial head measurement system (Head and Torso Simulator, HATS [2]) is positioned on the drivers' seat to measure relevant parameters inside the vehicle. Another HATS is positioned outside the car cabin in a distance of e.g. 1 and 2 m from the B-pillar. The HFT playback setting is adjusted in order to use only the front speaker in the drivers' door. Tests were carried out exemplarily in one vehicle.

The intelligibility outside the vehicle is a problem that addresses different fields of engineering - telecommunication, audio, construction and development. Combined measures are therefore necessary to provide the different information. A set of descriptive tests is necessary to document the current status and to provide a baseline to verify the efficiency of modifications.

The speech intelligibility index SII [5], can -in principle- be used. But the intelligibility of speech highly depends on the test corpus. The SII calculation is based on a weighted spectral distance between average speech and noise spectra and the results are mapped to represent the intelligibility of logatoms. The sentence intelligibility is higher due this context information [6]. For the measured car the SII was exemplarily calculated as 35 % for a Street Noise at a level of 60 dB_{SPL}.

Tab. 1: Results at different listeners positions

Position	RLR	TMOS
Inside	-16 dB	2.7
1	8.3 dB	1.9
2	10.0 dB	2.5
3	7.3 dB	1.7
4	6.8 dB	1.9
5	5.7 dB	2.0
6	12.1 dB	2.2

For the recordings a 18 dB higher playback level - compared to nominal- is chosen in order to verify the SII results at very high playback levels that might be used in driving situations. The outside recordings were made under free-field anechoic test conditions.

The loudness analyses based on the receiving loudness rating RLR [4] show difference of approximately 23 dB between both ear signals for the inside and outside recordings for this car (see **table 1, Pos. 3**). Besides the absolute level, the spectral characteristics of the transmitted speech highly contribute to intelligibility. **Figure 2** shows the spectral attenuation between the inside and outside HATS in a distance of 1 m (**figure 1, Pos. 3**).

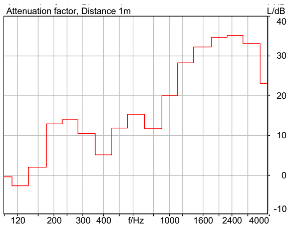

Fig. 2: Attenuation factor "Inside to outside" in a distance of 1m

The curve in **figure 2** indicates a strong low pass coupling between the loudspeaker and the chassis.

Tests focusing on speech quality instead of speech intelligibility further extend the range of analyses. Appropriate methods like the TOSQA2001 algorithm provide one-dimensional listening speech quality scores (TMOS, see e.g. [3]). These tests lead to TMOS between 1.7 and 2.5 in a 1 m distance outside the testing car (see **table 1**). These scores need to be rated in relation to a TMOS score of 2.7 - measured inside the car at the drivers' position.

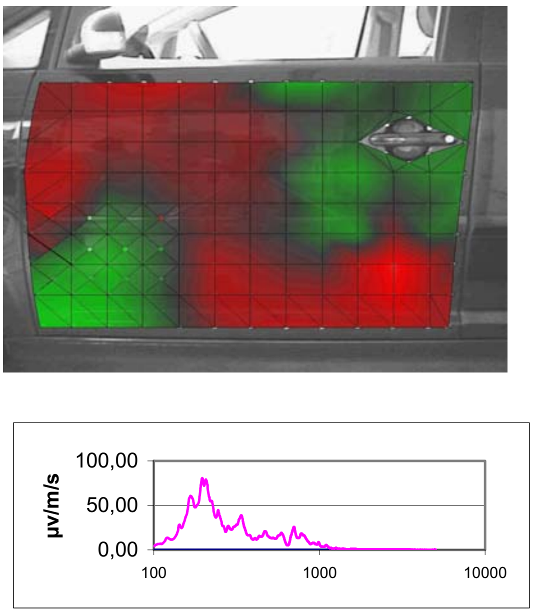

Fig. 3: Laser scan at 336 Hz, Velocity

Besides the speech-based analyses a laser scan of the drivers' door links the intelligibility to the technical source of the emitted signal - a vibration analysis. An example for a resonance at 336 Hz is shown in **figure 3**. The complete door is excited by the acoustic signal. Further tests with different loudspeaker modifications showed that the main factor for this behavior is an acoustic coupling between loudspeaker and door.

Summary and Outlook

The focus of the used analyses is to verify the suitability of test methods and also to evaluate potential reasons and the effectiveness of modifications. A set of tests suitable to cover not only the speech intelligibility parameters itself but also additional vibration analyses is currently established. The tests cover

- speech intelligibility measures including realistic background noise scenarios
- level and spectral analysis inside and outside the vehicle to derive attenuation factors
- "speech quality" parameters inside and outside the vehicle
- vibration analyses on vehicle structures (e.g. drivers' door)

The intention is

- to provide objective measures necessary to document the current status and verify the effectiveness of modifications,
- to derive hints and ideas on how to solve or at least limit the intelligibility outside the car
- to use these objective data as a basis for a cost estimate to decide about modifications.

A suggestion for reasonable limits for these analyses can be derived from a simple practical approach - the intelligibility of the driver's voice outside the vehicle or the playback via an external loudspeaker.

References

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[2] ITU-T Recommendation P.58, Head and Torso Simulators for Telephonometry

[3] Berger, J., Results of objective speech quality assessment including receiving terminals using the advanced TOSQA2001, ITU-T Contribution, Dec. 2000, COM 12-20-E

[4] ITU-T Recommendation P.79, Calculation of Loudness Rating for Telephone Sets

[5] ANSI S3.5-1997 - Methods for Calculation of the Speech Intelligibility Index

[6] Methoden zur Messung der Sprachgüte I: Verfahren zur Bestimmung der Satz- und Wortverständlichkeit, J.Sotschek, Der Fernmeldeingenieur, 1976