# Estimating Implementation Effort from Acoustic "Quick Check" Tests in Vehicles

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## Introduction

Hands-free implementations are used for regular communication from driving vehicles, but also for eCall applications or breakdown calls ("bCall"). Implementing hands-free solutions in vehicles is challenging due to the strong coupling between loudspeaker and microphone and the adverse noise environment. This applies in particular for eCall implementations, which often use some kind of backup loudspeaker and microphone solution, which additionally need to be mounted in a crash-protected area in the vehicle. The microphone and loudspeaker setup in the vehicle is therefore not always optimized under acoustical aspects.

There are test specifications like ITU-T P.1100 [1], P.1110 [2] or P.1120 [3] for narrowband, wideband and super-wideband transmission, describing tests and recommended limits for tuning and optimization. ITU-T P.1140 [5] is currently discussed for EU eCall tests, however, these tests are not mandatory for the homologation process. In contrary to performance tests according to ITU Recommendations, the Russian GOST 33468 tests are mandatory for vehicle homologation.

All kinds of hands-free implementations underlie the "hands-free problem", i.e. the acoustic coupling between loudspeaker and microphone, and suffer or benefit from the acoustic properties of a specific vehicle type. This contribution discusses an acoustic "QuickCheck" test to characterize a vehicle cabin with the given configuration of microphone, loudspeaker and driver, respectively, passenger's position. This "QuickCheck" and the implemented limits for the measured parameters are based on a high number of tested and successfully tuned hands-free implementations.

## HFT signal processing and tuning approach

Figure 1 shows a typical block diagram of hands-free signal processing including loudspeaker and microphone as acoustical components in the vehicle cabin. The positions and the orientation of these transducers are often predetermined by the car manufacturer and cannot be influenced when starting the hands-free tuning work. The first step in the signal processing tuning process is typically the frequency response and gain adjustment to ensure proper signal characteristics for the receive side in the vehicle and for the signal processing in the microphone send path.

Automatic gain control can be found in both transmission directions, mainly to properly adjust input and output signal range. The automatic volume control (AVC) in receiving direction, triggered by the noise in the microphone path, adjusts the playback volume depending on the noise conditions in the car cabin. The installation of a noise playback system in the vehicle cabin during the tuning and testing process is described in [1], [2], [3], [4], [5] and shall ensure the appropriate trigger signal for the AVS signal block.

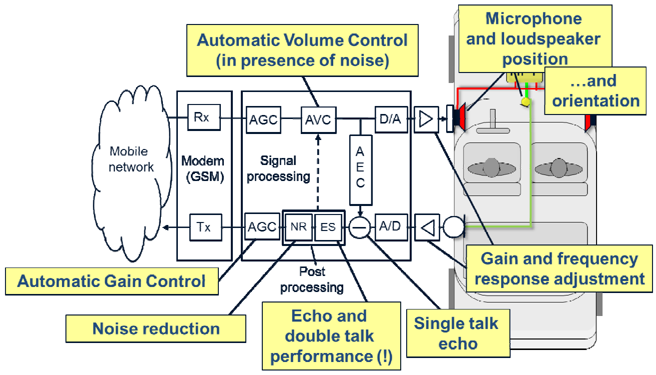


**Figure 1:** Signal processing chain of a typical hands-free implementation

Further signal processing like acoustic echo cancellation (AEC), post processing (echo suppression, ES) and noise reduction (NR) can be found in the microphone path. AEC and ES are typically tuned to avoid any echo under single talk conditions, as this is one of the most critical parameters in communications. However, the ES tuning requires well balanced settings as these directly influence double talk performance. The performance of these AEC, ES and NR signal processing blocks highly depends on the acoustic properties in the car. Parameters like the signal-to-noise ratio (SNR) at the hands-free microphone for driver's or passenger's speech as well as the speech level ratio between driver and passenger is relevant. The GOST specification for Russian eCall defines a ≥ 6 dB limit for the uplink SNR at different driving speeds in test 7.10.1 for both positions. Vice versa, ITU-T P.1140 limits the aggressiveness of NR in the "silent call" test 8.11.1 [5]. It is challenging to meet both requirements simultaneously, i.e. using the same parameter setting.

The same applies for the acoustic coupling between loudspeaker and microphone and the resulting ratio between driver's speech level and echo or passenger's speech level and echo. These ratios highly influence the double talk detection of AEC/ES and the double talk performance in general. Last but not least, the absolute noise level in a car cabin is relevant to build a well performing hands-free implementation.

All this motivates the verification of the acoustic properties in the vehicle itself, without the hands-free implementation. Such tests can be carried out using an omni-directional measurement microphone (instead of the hands-free microphone) and the target loudspeakers (as they are typically relatively easy to access). The microphone path is more critical to access; this could be realized by switching off or bypassing the hands-free signal processing, but it requires access to the implementation.

The aim of such acoustic tests, i.e. the characterization of a vehicle cabin ("acoustic fingerprint"), is the verification of the suitability of the vehicle and hands-free configuration and the estimation of the implementation effort. It can also serve to define requirements for hands-free or eCall systems, algorithms and settings.

## Car acoustic "QuickCheck" parameters

"QuickCheck" measurements and reasonable limits were derived, developed and implemented, so that they can easily be carried out in a very reasonable time. Beside the vehicle itself, access needs to be granted to the hands-free loudspeakers, a measurement microphone is installed close to the HFT or eCall microphone and an artificial head measurements system (HATS according to ITU-T Recommendation P.58 [6]) is positioned on the driver's and the passenger's position, respectively.

During drive tests, the vehicle specific driving noise signal is analyzed at the microphone position. Test signals are then applied under laboratory conditions via the artificial mouth (driver's and passenger's speech), using a -1.7 dBPa speech level adjusted according to formula [1] to cover the Lombard effect for the vehicle specific noise scenarios.

$$I(N) = \begin{cases} 0 & \text{for} \quad N < 50 \\ 0.3(N-50) & \text{for} \quad 50 \le N < 77 \\ 8.0 & \text{for} \quad N \ge 77 \end{cases}$$

where:

I = the dB increase in mouth output level due to noise level

N = the long-term A-weighted noise level measured near the driver's head position

These speech signals are also analyzed at the microphone position. The echo coupling is characterized by playing back signals via the loudspeakers and measuring the responses again at the microphone position.

The "QuickCheck" tests calculate 12 individual parameters, which can visually be represented in ITU-T P.505 [7] recommended quality pie charts as shown in figure 2. The inner red circle represents recommended limits derived from comparison measurements of different vehicle cabins with well performing hands-free implementations. The individual parameters with its specific limits are selected as follows (clockwise):

**RLR**, the receiving loudness rating at the driver's position. This parameter is adjusted via the loudspeaker playback in order to guarantee defined test conditions (range 0 ± 3 dB).

The active speech level (ASL) of driver's voice at the measurement microphone (close to the HFT microphone) in the car cabin (**Mouth2Mic DRV**). The limit of the corresponding pie slice is -30 $dB_{Pa}$ with a recommended value of -24 $dB_{Pa}$. Note, that a level of -25.7 $dB_{Pa}$ corresponds to a typical speech level in 50 cm distance from the MRP of the HATS under free-field conditions (hands-free reference point in 50 cm distance).

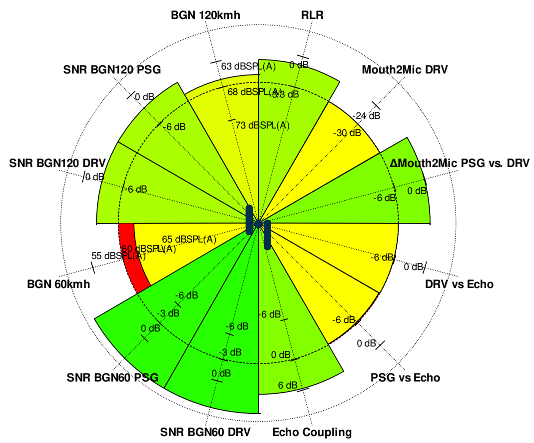


**Figure 2:** "QuickCheck" results in ITU-T P.505 Quality Pie representation

The delta speech level for passenger's and driver's voice (**ΔMouth2Mic PSG vs. DRV**) should not be higher than 6 dB (passenger's voice attenuated by 6 dB compared to driver's voice). A recommended value of 0 dB indicates a symmetric microphone position and orientation in the car cabin. In this case, the same gain settings can be used for driver's and passenger's voice; no strong amplification or compression of speech from one or both positions is necessary in order to achieve a Sending Loudness Rating range of ± 4 dB, the typical requirement in [1], [2] and [4]

The ratio of driver's speech level versus echo level (**DRV vs. Echo**) and passenger's speech level versus echo level (**PSG vs. Echo**) is calculated from the speech level for both positions and the echo coupling between loudspeaker and microphone position. Both parameters are scaled with a minimum requirement of -6 dB, with a recommended value of 0 dB. A positive speech signal to echo ratio facilitates AEC performance under double talk conditions.

The echo coupling itself is represented by the **Echo Coupling** pie slice. The limit is set to 0 dB. Note that the measurement is carried out with a playback volume adjusted to achieve a receiving loudness rating of approx. 0 dB measured at the driver's position (see RLR pie slice). The recommended echo coupling is +6 dB in this representation. A positive echo attenuation resulting already from the loudspeaker and microphone setup can typically be handled by AEC and ES implementations.

The following three Quality Pie slices represent the SNR at 60 km/h for driver's speech (**SNR BGN60 DRV**), the SNR for 60 km/h for passenger's speech (**SNR BGN60 PSG**) and the noise level itself, measured at the microphone position for the 60 km/h driving condition (**BGN 60kmh**). The SNR limits are set to -3 dB. Note that this measurement is carried out considering the Lombard effect for speech playback via the artificial mouth of the HATS positioned on the driver's, respectively passenger's seat. The limit for the 60 km/h noise level is set to 60 $dB_{SPL}$(A), recommended ≤ 55 $dB_{SPL}$(A).

The last three pie slices show the corresponding analyses for a 120 km/h driving condition, again for the SNR with speech playback from driver's side (**SNR BGN120 DRV**), from passenger's side (**SNR BGN120 PSG**) and for the driving noise level itself at 120 km/h (**BGN 120kmh**). The limits are set to -6 dB for the SNR and 68 $dB_{SPL}$(A) for the noise level, recommended ≤ 63 $dB_{SPL}$(A).

## Examples

### Typical eCall setup #1 in mid-size car

Figure 3 shows the QuickCheck quality pie chart for a mid-size car with the eCall loudspeaker positioned in the passenger's leg room (beneath the glove box) and the microphone centered in the roof console. This is a commonly used configuration for eCall modules (In-vehicle systems, IVS).

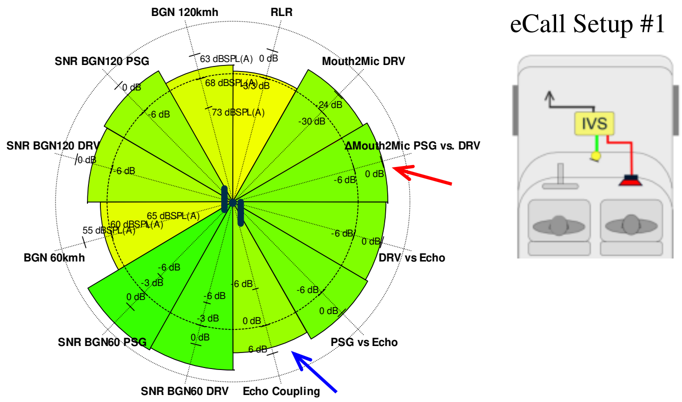


**Figure 3:** Example 1 – mid-size car 1

The symmetric microphone position is represented by the 0 dB speech level difference between passenger and driver (red arrow). The measured echo coupling is +5 dB (blue arrow). This positive value typically indicates a good working point for the echo cancellation algorithm. The noise level at 60 km/h and 120 km/h is in a reasonable range (58 $dB_{SPL}$ and 65 $dB_{SPL}$) which leads to positive signal to noise ratios for driver's and passenger's voice at 60 km/h and slightly negative signal to noise ratios for the 120 km/h driving condition. Summarizing, the acoustic properties of the vehicle are well suited for a hands-free implementation (eCall in this case).

### Typical eCall setup #2 in mid-size car

Figure 4 represents the acoustic properties of a midsize car with loudspeaker position on top of the dash board and microphone left-hand side of the roof console close to the driver's sun visor.

This asymmetric microphone position leads to 7 dB level difference between passenger and driver at the microphone position (see red arrow). As a consequence, three other parameters measured from the passenger's position violate the requirements - the speech level vs. echo ratio, the signal to noise ratio for 60 km/h and 120 km/h (blue arrows). The echo coupling of 1 dB is still positive, but significantly lower than in the example shown in figure 3.

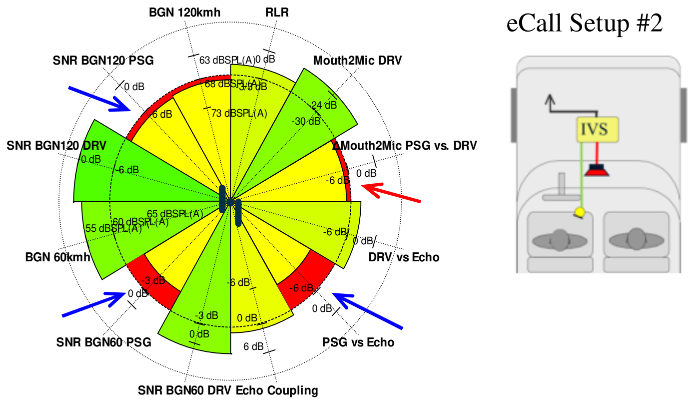


**Figure 4:** Example 2 – mid-size car 1

The low signal to echo ratio for passenger's speech may lead to problems in double talk detection, an implicit test case within the Russian GOST 33468 specification (test case 7.13, mandatory subjective evaluation based on pre-recorded conversations). Furthermore, the low SNR for passenger's speech in presence of noise requires stronger NR settings to meet the SNR ≥ 6 dB requirement in GOST 33468.

### Hands-free setup in sports car

Figure 5 represents a typical "QuickCheck" quality pie chart for a sports car. The front door speakers are used for the hands-free implementation in this case. The microphone is located in the roof console slightly orientated towards the driver.

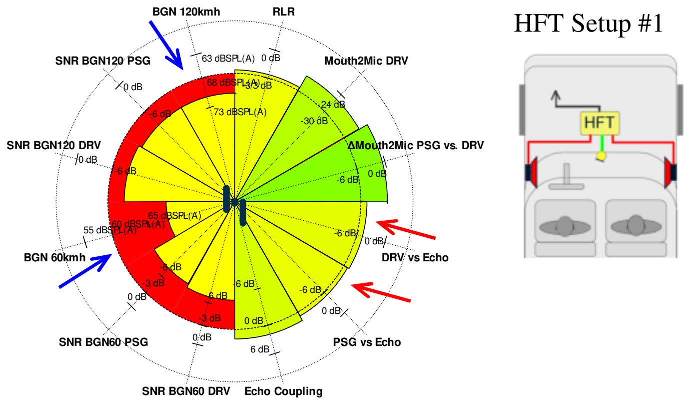


**Figure 5:** Example 3 – sports car

The sensitivities for driver's and co-driver's voice are high, almost identical and indicate a symmetrical microphone position. The ratio between driver's voice and echo and co-driver's voice and echo, respectively, is around -5 dB (see red arrows). The echo coupling itself is positive (2 dB). The green colored slices on the right-hand half of the pie chart indicate that these parameters meet the suggested requirements, which were derived from numerous successful signal processing tunings in vehicles.

However, the most challenging acoustic conditions, the high background noise at 60 km/h and 120 km/h (see blue arrow), are clearly displayed on the left-hand side of the pie chart. The very high noise level of 67 $dB_{SPL}$(A) for the 60 km/h and 70 $dB_{SPL}$(A) for the 120 km/h make it difficult to achieve high signal to noise ratios at the microphone position for both, driver's and passenger's speech. All values are negative and below the suggested limits. This puts a high demand on the implemented noise reduction algorithm in the hands-free solution.

## Summary

A set of acoustic measurements for vehicle cabins, using the inbuild hands-free or eCall loudspeakers and an omnidirectional measurement microphone and HATS were developed. These acoustic “QuickCheck” measurements characterize the acoustic properties of vehicle cabins in terms of suitability for hands-free or eCall implementations. The reasonable limits help to estimate the implementation effort for hands-free algorithms with respect to certain hands-free specifications. One important application of these tests is the estimation of implementation effort to pass eCall requirements, such as ITU-T P.1140 or the Russian GOST 33468, which is mandatory for homologation of vehicles.

Furthermore, these measurements can be used by car manufacturers to derive product requirements or optimize loudspeaker and microphone positions. In addition, hands-free suppliers can estimate the need for specific signal processing components and its settings prior to a tuning process.

These tests are independent of a particular hands-free implementation, but can also be applied using the hands-free microphone, if accessible. In this case, the microphone characteristics (directivity) are included in the chain, but the generic requirements discussed in this contribution need to be reworked.

## References

[1] ITU-T P.1100, Narrowband hands-free communication in motor vehicles, 03/2017

[2] ITU-T P.1110, Wideband hands-free communication in motor vehicles, 03/2017

[3] ITU-T P.1120, Super-wideband and fullband stereo hands-free communication in motor vehicles, 03/2017

[4] GOST 33468-2015, Test methods for verification of in-vehicle emergency call device/system conformity to requirements for loudspeaker communication in vehicle cabin, 2015

[5] ITU-T P.1140, Speech communication requirements for emergency calls originating from vehicles, 03/2017

[6] ITU-T P.58, Head and torso simulator for telephonometry, 05/2013

[7] ITU-T P.505, One-view visualization of speech quality measurement results, 11/2005