In-Car Communication – Performance Parameters and Testing Procedures from the Users Point of View

H. W. Gierlich

HEAD acoustics GmbH, E-Mail: H.W.Gierlich@head-acoustics.de

1 Introduction

Modern cars are usually equipped with a variety of loudspeakers, microphones and a sufficient amount of signal processing which can be used for various purposes. Until today, the most required functionality was car hands-free and even more important emergency call systems. However, since all the electro-acoustic components are available in a car, in-car communication systems (ICC) can be realized today with a minimum of additional components. In general signal processing power available in the head unit of modern cars allows the integration of ICC systems in addition to the co-existing systems such as car radio, car hands-free and others.

The idea of in-car communication systems in general is simple. ICC systems should provide the same communicational quality as people would have if they would communicate e.g. face to face under different driving conditions. The main purpose of ICC systems especially in cars where the talker and listener are far away (cars with three rows of seats, big, spacious cars, cars with high interior acoustical attenuation between front seats and backseats) is to increase speech intelligibility, to lower the listening effort as well as to lower the talking effort. This should be provided in an almost seamless manner. This means ideally ICC systems are not noticeable by the users. Such ICC systems should preserve the naturalness of speech and should ensure high speech quality especially in the presence of background noise. It is very important that under no conditions there should be any artifact audible to the people in the car. Finally the localization of the different talkers in the car should be perceived, e.g. the speech of the driver should always be perceived from the front left position (in case of left wheel steered cars) regardless of the background noise in the car and regardless of the state of amplification in the ICC system.

2 Elements of ICC systems

In order to provide the desired functionality ICC systems must contain at least the components as depicted in **figure 1**.

In general, noise cancellation (NC) must be provided for all types of ICC systems. Noise cancellation is unavoidable in order to reduce the background noise produced by the car and to mainly pick up the speech signal produced by the near end talker. Equalization (EQ) is needed in order to adapt the frequency response of the microphone depending on car type, driving conditions, background noise conditions. Typically equalization is dynamic and depends highly on the background noise under the different driving conditions. Automatic gain control (AGC) is unavoidable. The AGC control is a function of the background noise level as well. The higher the background noise in the car the more gain has to be introduced by the ICC system in order to provide a sufficient speech level at the listener's side. Echo cancellation (EC) or feedback cancellation is required to prevent instabilities resulting from the loudspeaker signal being picked up by the ICC microphone.

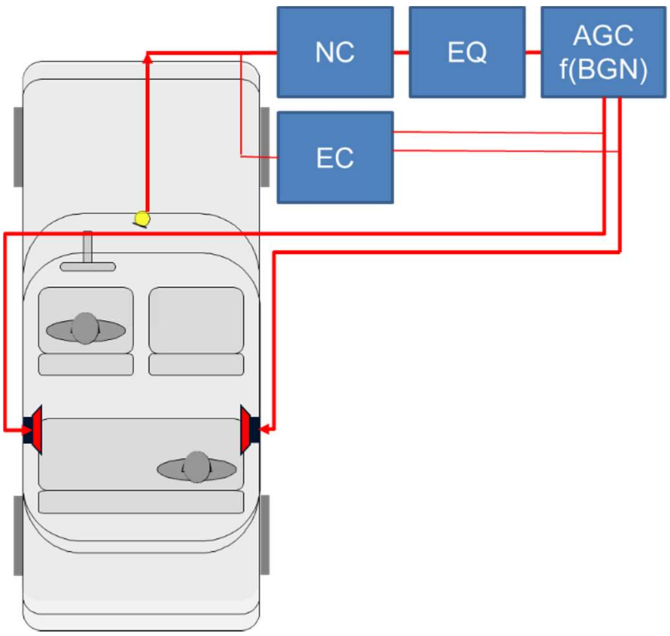

Figure 1: Components of ICC Systems

The speech level and the improvement of the signal to noise ratio by the ICC system mainly influence speech intelligibility and listening effort. The speech quality as perceived by the listener is mainly influenced by the gain factor which again is a function of signal and noise, the frequency response, any artifact introduced by the ICC system and of course the delay introduced by the ICC system. From the user's point of view all those parameters have to be optimized in such a way that ICC increases speech intelligibility, decreases listening effort and provides high speech quality under the various driving conditions.

3 Test setup

The test setup for ICC systems in general is similar to car hands-free systems [1]. However a variety of differences need to be noted. **Figure 2** shows the general setup of a two-channel ICC system. Like for car hands-free testing [1] it is intended to simulate the driving conditions most accurate in a lab-type environment.

According to the current draft of P.ICC [2] the various seats in a car are defined as zones. The zones always start with the driver's seat which is zone one, the co-driver's seat is zone two and the other seats are numbered accordingly. In the example of **figure 2** a system is shown which provides ICC from zone one to zone five and from zone five to zone one. In contrast to car hands-free systems ICC systems are measured using two artificial heads. One artificial head as seen in **figure 2** is producing the speech signals while the second artificial head is used for recording the speech sequences. For simulating double talk both artificial heads can be used to generate and record speech samples simultaneously. The setup shown in **figure 2** in general can be used for all zones in a car where ICC is intended to work separately for.

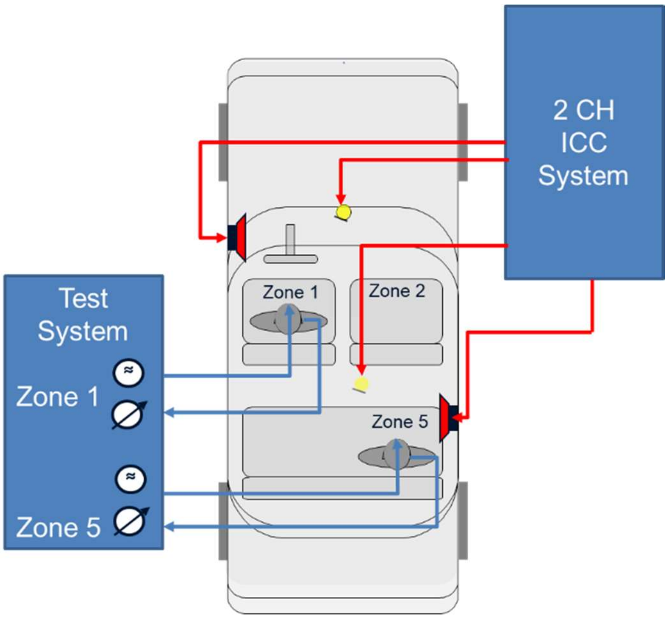

Figure 2: Test arrangement for ICC systems

Special consideration has to be given to the recording and reproduction of the background noise. While in car hands-free systems it is sufficient to record the background noise just at the hands-free microphone (S) in ICC systems the background noise pick up is required at various positions in the car. In order to properly activate ICC systems the background noise produced by the car under the various driving conditions has to be produced correctly at all microphone positions simultaneously. In order to measure other parameters such as signal to noise ratio, signal to noise ratio improvement, speech quality, listening effort etc. the background noise has to be reproduced at the artificial ears of the artificial head simultaneously in a correct manner. **Figure 3** shows the background noise recording and reproduction system which is using a multichannel sound field recording and reproduction technology as described in [3]. As in car hands-free systems the background noise is recorded individually in the target car under different driving positions. However the recording now is made using a simultaneous recording of the microphone signals as well as of the ear signals of the artificial head. The reproduction of these recordings is performed by using a multi loudspeaker system which has to be installed in the car according to [3]. In general the equalization is performed automatically based on the minimization of the reproduction error at each microphone position. Further details can be found in [3].

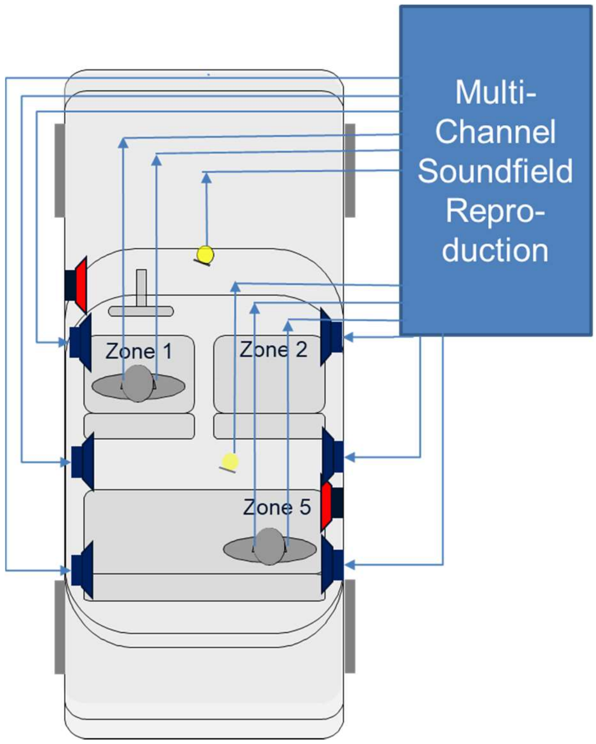

Figure 3: Background noise simulation setup for ICC systems

4 Parameters to be tested

Currently, there is a lot of discussion about parameters to be tested in order to provide good speech quality for ICC systems from the user's point of view. The main work currently is conducted in ITU-T, study group 12, question 4 where a new standard for the qualification of ICC systems is developed. The main parameters currently under discussion are as follows:

Stability

Delay

Speech intelligibility

Speech intelligibility during short term variability

Adaptive reinforcement

Speech level

Noise transmission characteristics

Signal to noise ratio

Speech quality

Double talk attenuation

Media interaction

Many of the parameters listed above are not yet completely defined nor is a measurement method available yet. A test of stability certainly is targeted to the system stability under various driving conditions including changes in the car cabin such as people moving which may impact the echo path and as such the echo/feedback canceller. The delay introduced by ICC systems again is an important parameter. The shorter the delay the higher signal processing requirements are. It is obvious that the delay introduced by the ICC systems is mainly observed in cases where the direct sound is present simultaneously with the reinforced sound. The main objective is to have the delay in such a range that neither additional reverberation nor any echo effect can be observed by the listener in the car. The currently discussed numbers range from 10 to 20 ms. However, auditory tests providing limits are still missing. Speech intelligibility is discussed. However it is likely that this parameter might be replaced by listening effort. The measurement of speech intelligibility based on an instrumental procedure is strongly language dependent and will most likely not be possible with a reasonable amount of effort to be invested in such a method. The listening effort to some extend may serve as a good indicator for speech intelligibility as already shown in [4]. Currently a variety of subjective tests are conducted, first results are shown in 4.3. Speech level, noise transmission characteristics and consequently signal to noise ratio are very basic parameters which characterize ICC systems and where limits are to be found in a similar manner. Speech quality is perceptional different than listening effort and should serve as a further indicator for the quality of ICC systems. Again, no validated instrumental test procedure is available yet and consequently auditory testing is unavoidable to derive an instrumental test method as well as limits for ICC systems. The double talk interaction characterizes the ability of the system to seamlessly work even if multi talkers are present simultaneously. In the section media interaction it will be defined in which way ICC systems are intended to work in case e.g. music is played in the car using the car audio system.

Currently neither talker effort nor positional correctness are discussed as parameters in P.ICC. Some studies [5, 6] show that talking effort may be reduced by ICC systems and such speech level may be lowered in case the ICC systems are active. This might have some impact on testing and might also serve as a quality criteria for the performance of an ICC system. In a similar way the positional correctness is a parameter which should determine the quality of an ICC system. Again, auditory tests leading to performance parameters and limits are missing.

For some parameters more detailed information is available already. These are introduced briefly in the following.

4.1 Preferred SNR

Auditory investigations on the preferred signal to noise ratio in ICC systems were already introduced in [7]. These investigations clearly show that the desired speech level is depending on the noise level in the car. For low noise levels the preferred signal to noise ratio is significantly higher than for high noise levels. The reason for this effect is mainly the preference of listening speech level of users. In high noise levels the speech level would get too high and such would get annoying if the same signal to noise ratio would be realized as for low noise conditions. In consequence the speech level enhancement provided by ICC is limited - more by psycho-physical effects than by technical limitations in the ICC system. Based on these investigations the current P.ICC in ITU-T [2] proposes a corridor of preferred signal to noise ratios depending on background noise level in the car. This diagram is shown in **figure 4**.

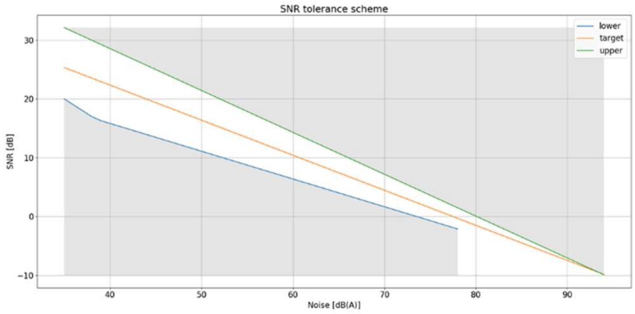

Figure 4: Upper and lower SNR level as a function of noise level in the car

In the figure it can be seen that the corridor which represents the limit of ± 0.5 MOS deviation from the optimal signal to noise ratio is getting more narrow for higher background noises. For background noises above about 78 dB(A) the SNR gets negative and above about 90 dB(A) noise level in the car it can be expected that ICC systems would not contribute to an increased intelligibility and/or speech quality any more.

4.2 Listening effort & speech quality

The development and validation of a method for the measurement of speech intelligibility is most likely impossible within the period where a recommendation in ITU-T has to be finalized. Therefore, the measurement of listening effort might be considered as an alternative. Basic investigations in [4] show that there is quite a strong relationship between listening effort and speech intelligibility in ICC systems. During the ITU-T Q4 rapporteur meeting in January 2018 a study was introduced which was targeted to the auditory investigation of listening effort and speech quality in ICC systems. This study was conducted based on different settings of one ICC system under the following conditions:

- Driving condition: 110 km/h
- Speech level including Lombard effect
- Normal, soft (-3 dB) and loud (+3 dB) talker
- sixteen sentences German speech material, eight talkers male and female
- Three different settings of an ICC system (-3, 0, 3 dB amplification)
- 24 test subjects (German)
- Twelve votes per sample, 96 votes per condition

In the experiment the ITU-T listening effort scale [8] and the speech quality scale [8] were used. Based on this auditory investigation the following findings were derived.

In silence both listening effort and speech quality are rated high, the listening effort MOS is higher than speech quality MOS. However the listening effort is also highly dependent on the speech level produced by the talker. For a loud talker the listening effort is lowest, for a low level talker the listening level is lower in all cases. An ICC system – independent of the ICC setting – may slightly decrease the listening effort.

Speech quality again is talker level dependent, however less talker level dependent than listening effort. Speech quality is almost not enhanced by the ICC system for nominal and high level talkers independent of the ICC setting. For low level talkers the speech quality is slightly increased by the ICC system used in this test.

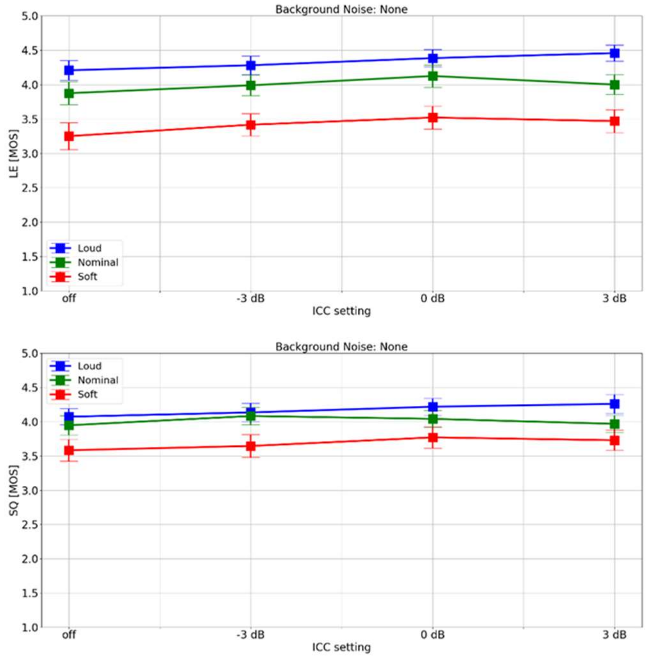

Figure 5: Listening effort (upper) and speech quality (lower) in silence

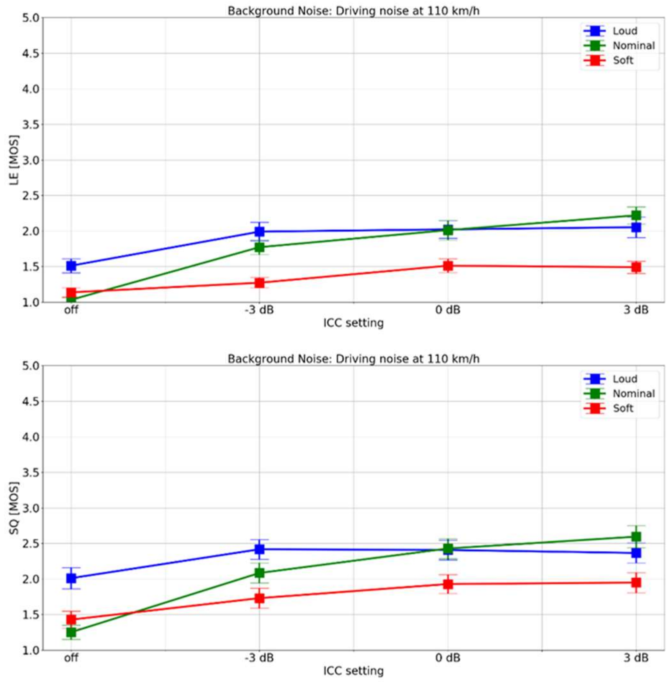

Figure 6: Listening effort (upper) and speech quality (lower) in noise

In background noise (110 km/h) the situation changes significantly. Listening effort drops dramatically. It can be seen that depending on the talker level ICC may well contribute to enhancement of the listening level and as such to reduce listening effort. The highest effect is observed for low level and average level talkers. For high level talkers the effect of ICC is moderate. The speech quality does not drop as strong as listening effort. Again, for low level talkers and for normal level talkers the effect of ICC is most obvious. For high level talkers the effect of the ICC system can be observed at -3 dB setting of the ICC system. Additional amplification does not lead to higher performance.

It must be noted that these results are purely based on one ICC system at two different driving conditions. Further experiments including different ICC systems and driving conditions are needed to get an overview about the performance of ICC systems in a wider range. Such investigations then can be used to develop new or validate existing models for the instrumental prediction of listening effort and speech quality.

5 Summary

The characterization and testing of ICC systems is a challenging topic. Although for a variety of parameters are known testing methods and limits representing the quality as perceived by the user are not available yet. Basic investigations and auditory testing are briefly introduced. It is expected that a lot of additional effort in auditory testing is required to derive adequate limits for the different parameters currently under discussion.

In addition to parameters characterizing perceptual degradations of ICC systems parameters for optimizing specific technical parameters are required. These are specifically needed for tuning and optimization of ICC systems.

6 References

[1] Recommendation ITU-T P.1100: Narrowband hands-free communication in motor vehicles.

[2] Draft Recommendation ITU-T P.ICC: In-Car Communication audio specification.

[3] ETSI TS 103 224: Speech and multimedia Transmission Quality (STQ); A sound field reproduction method for terminal testing including a background noise database.

[4] Reimes: Listening effort vs. speech intelligibility in car environments. In Fortschritte der Akustik - DAGA 2015. DEGA e.V., Berlin, 2015.

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[6] R. Landgraf, G. Schmidt, M. Grimm, O. Niebuhr, and T. John: Man höre und staune - Perzeptive Evidenz für die Funktionalität eines ICC-Systems anhand von Dialogdaten aus einer multimodalen Fahrsimulation, In Fortschritte der Akustik - DAGA, München, 2018.

[7] U. Müsch, F. Kettler: Instrumental Testing of In-Car Communication Systems, In Fortschritte der Akustik - DAGA, Nürnberg, 2015.

[8] Recommendation ITU-T P.800: Methods for subjective determination of transmission quality.