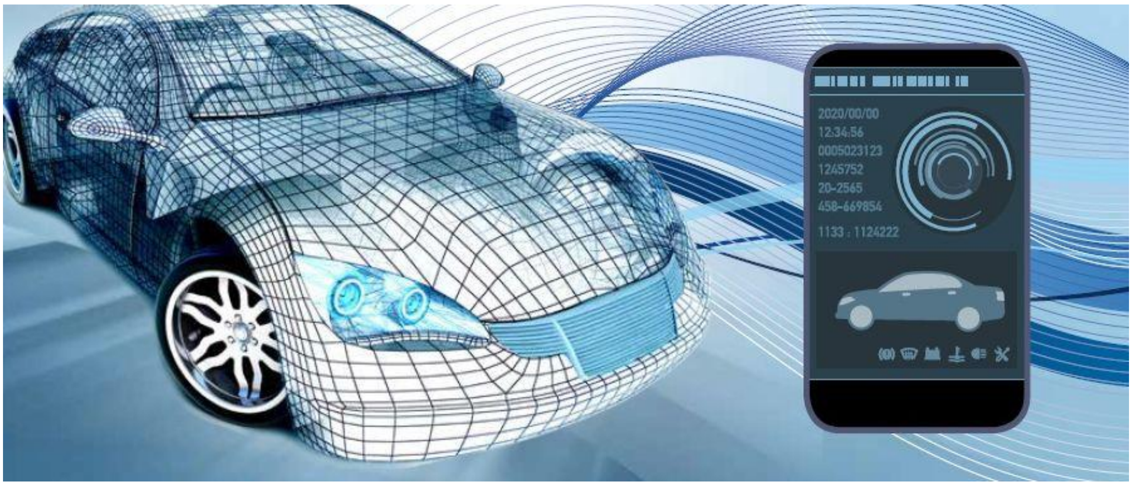
Test Report

3rd ITU Test Event: Performance Assessment of Mobile Phones as Gateways to Car Hands-free Systems

15-16 November 2016



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Background

In continuation of the 1st and 2nd Test Event in May 2014 and May 2016, respectively, ITU has organized a 3rd Test Event “Performance assessment of mobile phones as gateways to car hands-free systems”. The test event was held during the ITU Telecom World 2016 in Bangkok, Thailand on November 15 and 16, 2016.

This event as well as the previous events is organized according to the request received from automotive industry to test mobile phones against ITU-T Recommendations which specify the transmission performance requirements for mobile phones connected with Hands-free Telephone system (HFT) using Short-Range Wireless (SRW) interface.

The key goal of such event is to draw attention of mobile phone vendors to some issues, which relate to the phone configuration in wireless connection and quality of voice communication in and from a car, and to request them to make relevant updates in their mobile phones, if necessary. ITU updates the “List of mobile phones” compliant with chapter 12 of ITU-T P.1100 and ITU-T P.1110.

The events further provide the possibility to compare the performance of the sample of mobile phones to those measured during the 1st and 2nd Test Events.

The tests were performed by HEAD acoustics GmbH, based on the ‘Chapter 12 tests’ of Recommendations ITU-T P.1100 and ITU-T P.1110, standards for narrow-band and wideband communications involving motor vehicles. The test requirements, the methodology and results are fed back into an ongoing process to refine the standards.

This report was written by HEAD acoustics which is responsible for the test conduction and the analysis of the test results. Test results have been anonymized in this report.

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1. Motivation

Car manufacturers spend high effort to tune HFT systems in their vehicles to provide high quality communication in vehicles and need to consider the individual influence of mobile phones, as their performance is still far from being uniform. In the typical use case, the driver uses his mobile phone and links it via wireless communication to the vehicle's hands-free system. Thus, the mobile phone provides the mobile network access. It acts as an "audio gateway" between the vehicle hands-free system and the mobile network and should provide fully transparent voice transmission in uplink and downlink. The relevant signal processing is performed solely by the vehicle's hands-free system; mandating that the signal-processing functionality of a mobile phone be disabled while the phone is mounted on a hands-free system.

The wireless connection, typically realized via Bluetooth® today, can be controlled via appropriate AT commands [7]. However, even if the AT command exchange between hands-free system and mobile phone works properly and the mobile phone replies with "ok", it is not always guaranteed that the mobile phone behaves transparently and only provides gateway functionality. If speech processing algorithms (such as echo cancellation or noise reduction), signal amplification or attenuation or equalizers are not disabled in the mobile phone, the phone may significantly degrade the quality of the whole system.

Recommendations ITU-T P.1100 [1] and ITU-T P.1110 [2] describe corresponding speech quality tests for verification of transparency in Chapter 12 ("Verification of the transmission performance of short-range wireless (SRW) transmission enabled phones"). These tests have been used during the previous and the current test event.

Mobile phones which successfully pass the tests are listed by ITU in the "List of mobile phones" [8]. The list is generated and updated based on results of the ITU Test Events.

ITU provided the opportunity to test mobile phones during the 3rd Test Event during the ITU Telecom World 2016 in Bangkok, Thailand. Following the discussion of these results between vendors, car manufactures, test house and ITU, the current Recommendations ITU-T P.1100/P.1110 were updated by more clearly describing mandatory and optional parameters, the relevant criteria of the Chapter 12 of these Recommendations have been revised accordingly [3], [4]. Tests were repeated with updated software versions on the phones.

The most important conclusions are drawn in Chapter 2 of this report. Chapter 3 gives brief background information about the influence of cascaded algorithms. The setup together with a short introduction of the tests itself and the result representation is given in Chapter 4. Chapter 5 analyses the results. References can be found in Chapter 6.

2. Summary

The most important findings can be summarized as follows:

- 6 mobile phones were tested, one device in narrowband mode only (wideband not enabled), one device in wideband mode only ("on-the-go" tests). Thus, a total number of 10 tests was conducted, 5 in narrowband and 5 in wideband mode.
- None of the tested mobile phones at the 3rd test event met the requirements of the ITU-T P.1100 [1] / P.1110 [2] (2015). However, some phones were very close to the requirements and passed most of the tests.
- Vendors reacted to these outcomes for these mobile phones with updated Software and retests were scheduled.
- In parallel, the results were fed back into the standardization process requesting an improvement of the current Recommendations ITU-T P.1100/P.1110 by more clearly describing mandatory and optional parameters. Mandatory requirements in general identify pass/fail criteria for such kind of testing.
- The relevant criteria of the Chapter 12 of these Recommendations have been revised accordingly. As of now, new versions of the ITU-T P.1100 [3] and ITU-T P.1110 [4] are available on the ITU web page.
- After the scheduled retests, these mobile phones completely met the requirements of the ITU-T P.1100 and ITU-T P.1110 (2017) respectively.
- As already seen during the 1st and 2nd test event [5], [6], all tested mobile phones in NB and WB mode respond with "ok" to the "AT+NREC=0" command, indicating that the internal signal processing (noise reduction, echo cancellation) is disabled.
- One device significantly exceeded the round-trip delay requirement in narrowband mode. The measured delay of more than 300 ms is far out of range and will likely hamper communication quality. Such outliers have been seen during the events in the past and indicate that this topic is not always in focus during development.
- All tested devices disable noise reduction and echo cancellation.
- All devices show almost level transparent transmission in narrowband and wideband mode in both transmission directions. Listening speech quality degradations were measured for one device in narrowband mode.
- Informative cross connection tests in WB Bluetooth® connection in combination with WB and NB network access indicate the expected inband level transparency for all WB capable devices. The limited number of tested devices is not exhaustive, but the same could already be observed during the 2nd event, whereas the results from the 1st test event still indicated at least some devices with strong inband level mismatch.
- An additional informative aspect covers the fact that Bluetooth® headsets communicating with mobile phones also via the hands-free profile [7], often rely on the phone's signal processing. The phone should therefore keep signal processing active, when the "AT+NREC=0" command is not sent. Tests during previous events show, that many devices disable echo cancellation, although it is not (!) requested by the accessories. All phones tested now, except one, kept echo cancellation and noise reduction enabled in this test case, as recommended.

3. Cascaded Algorithms

According to the Hands-free Profile V1.7 [7], a vehicle mounted hands-free system may request the mobile phone to disable the internal signal processing, such as echo cancellation and noise reduction, in order to avoid cascaded algorithms and conversational quality impairments.

Figure 3.1 shows the different components, i.e. mobile network, the mobile phone, which acts as audio gateway between network and hands-free system (HFT), the HFT itself, the audio playback system and the HFT microphone system in the vehicle. The connection between the HFT system and mobile phone is today typically realized via Bluetooth®.

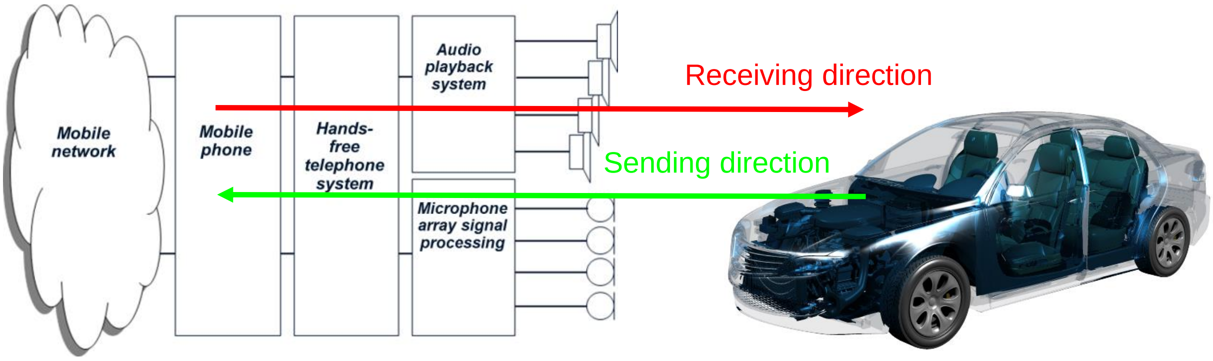


Fig. 3.1: Principle block diagram and definition of transmission directions

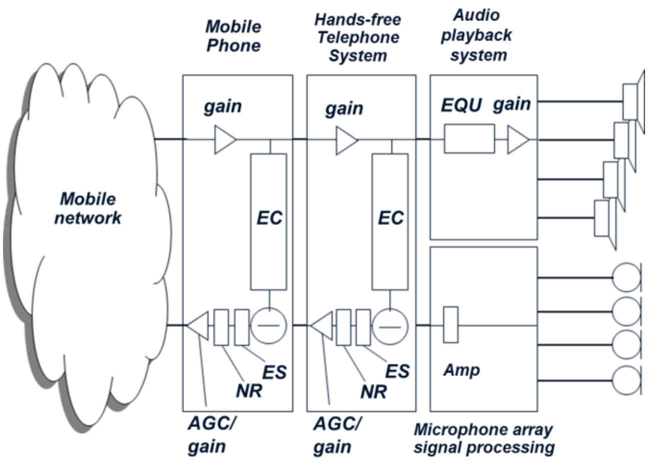


Fig. 3.2: Cascaded signal processing

Figure 3.2 shows the typical signal processing components in this set-up. In principle, both, the HFT and the mobile phone, provide the same signal processing, i.e. echo cancellation (EC), the additional processing to suppress residual echo components (echo suppression "ES"), noise reduction ("NR") and gain adjustment including possible automatic gain control ("AGC").

This may lead to cascaded signal processing, if they are not bypassed or disabled in the mobile phone.

This should, under all circumstances, be avoided as the components in the HFT system are already optimized on the acoustic environment in each vehicle. Tandem EC and ES may significantly hamper the very important double talk performance. Cascaded noise reduction algorithms (NR) degrade speech transmission quality, especially if the driver is talking from the driving car. Driver's voice sounds artificial, unnatural, "metallic" or "sharp". Additional signal gain (e.g. automatic gain control, static gain) introduced by the mobile phone may lead to signal saturation or too low voice signal in case of attenuation.

4. Test Description

The SRW connection was realized as a Bluetooth® connection, representing the most common use case connecting a mobile phone to a vehicle hands-free system today.

4.1 Test Setup

The tests on the mobile phones are carried out between two electrical interfaces as shown in **figure 4.1**. The phone is connected to a mobile network simulator on the far end side and a Bluetooth® reference interface (MFE XI, Measurement frontend provided by HEAD acoustics) on the near end side. The MFE XI communicates via the hands-free profile to the mobile phone. A narrowband and wideband Bluetooth® connection can be setup if the mobile phone supports the both options. Wideband Bluetooth® connection uses the mSBC codec, a narrowband connection the CVSD speech codec.

On the network side a network simulator (CMW500, Rohde & Schwarz) was used providing the capability of establishing a narrowband or wideband connection to the mobile phone.

In narrowband mode, the AMR codec operated at 12.2 kbit/s was used, the AMR-WB codec at 12.65 kbit/s was used in WB mode.

The Bluetooth® reference interface MFE XI is directly connected to the test system ACQUA. The network simulator is connected via unbalanced analog input and output connectors to the MFE VI.1 to the ACQUA measurement system (see test setup in **figure 4.1**). The clocks between both frontends, MFE XI and MFE VI.1 are synchronized via a digital AES/EBU connection.

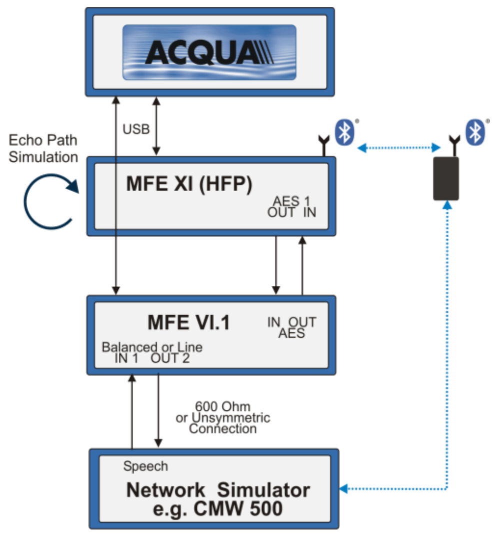


Fig. 4.1: Test setup, mobile phone connected to Bluetooth® reference frontend MFE XI and network simulator

Definition of transmission directions:

- Sending direction (see also **fig. 3.1**): The sending direction (uplink) represents the transmission from the Bluetooth® interface (representing the car hands-free unit) via the mobile phone to the network simulator.
- Receiving direction (see also **fig. 3.1**): The receiving direction (downlink) is defined as the transmission from the network simulator through the mobile phone to the Bluetooth® interface representing the hands-free unit in a vehicle.

In order to verify the echo performance of the mobile phones in such a simulated Bluetooth® connection, an echo path can be simulated in the MFE XI. This is indicated in **figure 4.1**. In this case, the downlink signal received via Bluetooth® at the MFE XI is coupled back in sending direction of the Bluetooth® connection with defined echo attenuation. The test setup guarantees an automatic test run for all devices under all test conditions.

4.2 Requirements of Revised Test Criteria for the Test Event

After the results of the test event were fed back into the standardization process requesting an improvement of the current Recommendations ITU-T P.1100/P.1110 by more clearly describing mandatory and optional parameters, the relevant criteria of the Chapter 12 of these Recommendations have been revised accordingly.

Recommendations ITU-T P.1100 (03/2017) and P.1110 (03/2017) established the following limits for the test parameters:

Parameters	**Limit in accordance with Rec. ITU-T P.1100**	**Limit in accordance with Rec. ITU-T P.1110**
Delay	190 ms[1)]	190 ms[1)]
JLR SND	0 ± 2 dB	0 ± 2 dB
JLR RCV	0 ± 2 dB[2)]	0 ± 2 dB[2)]
Linearity SND	JLR SND ± 2 dB	JLR SND ± 2 dB
Linearity RCV	JLR RCV ± 2 dB	JLR RCV ± 2 dB
SFR	Tolerance scheme	Tolerance scheme
RFR	Tolerance scheme	Tolerance scheme
Noise Reduction	disabled (± 4 dB)	disabled (± 4 dB)
MOS-LQOn,w SND	4.0 MOS-LQOn	3.8 MOS-LQOw
MOS-LQOn,w RCV	4.0 MOS-LQOn	3.8 MOS-LQOw
Echo Canceller	disabled (TCLw 20 ± 2 dB)	disabled (TCL 20 ± 2 dB)

1) Performance objective: < 150 ms

2) No additional volume control shall be active

Additional tests were performed on an informative basis:

Double talk test in SND

In addition to the echo control test an automatic double talk type test according to ITU-T P.502 Amendment 1 Appendix 3 was informatively performed in SND in order to double check the disabled state of the echo control signal processing.

Tests with new service level connection and without sending the “AT+NREC=0” command.

In order to verify that the deactivation of the NR and EC signal processing is really triggered by the dedicated AT command “AT+NREC=0” (and not by other indicators, e.g. the detection of a Bluetooth connection), a subset of tests is repeated after setting up a new service level connection and WITHOUT sending the “AT+NREC=0” command:

- Delay SND/RCV
- JLR SND/RCV
- Sensitivity frequency response SND/RCV
- Noise reduction test in SND
- Verification of disabled echo control
- Automatic double talk test in SND

These tests are of special importance for accessories like headsets using the hands-free profile to connect to mobile phones but relying on the phones' signal processing.

Cross connection tests (Recommendation ITU-T P.1110 only)

Codec negotiation mechanisms between the SRW (Bluetooth®) side and the mobile network side of mobile phones are not clearly defined. Considering the assumption, that in most cases today the head units in vehicles are wideband capable on the Bluetooth® link, interconnection tests are limited to wideband connection on the Bluetooth® side (ITU-T P.1110 test case). The additional test is performed as follows:

- SRW connection in wideband mode and mobile network connection in wideband mode, JLR (JLR_{SRWsnd} and JLR_{SRWrcv}) and frequency response measurements in both directions (test cases 12.2 and 12.3.)

- Test repetition in SRW wideband connection and mobile network connection in narrowband mode. Comparison of measured JLR and frequency responses to test 12.2 and 12.3 results.

4.4 Result Representation

A two-page test report was generated for each mobile phone and test run including a "Quality Pie" chart summary according to Recommendation ITU-T P.505 [11] of the most important results. A summary of the most important findings is given together with graphs for the sending and receiving frequency responses, the noise reduction performance and the spectral echo attenuation tested with a 20 dB simulated echo path and frequency response curves without sending the "AT+NREC=0" command. In case of wideband, the reports are further extended by the results and curves from the informative cross connection tests.

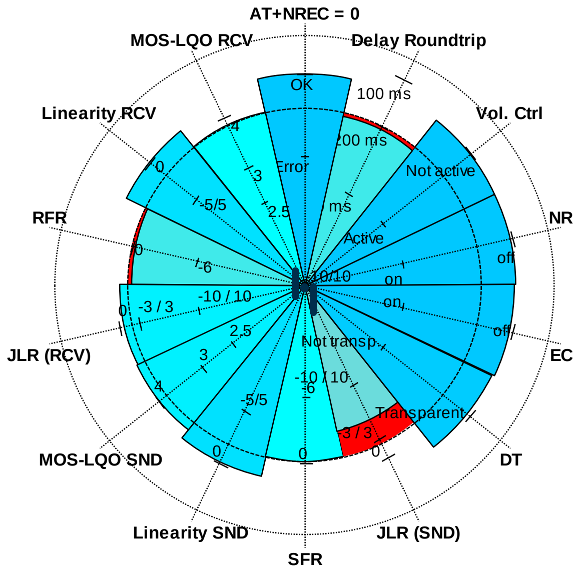


Fig. 4.2: Quality Pie Chart according to Recommendation ITU-T P.505

One example for the "Quality Pie" chart according to Recommendation ITU-T P.505 from the test event together with a short description of the selected parameters and requirements is shown in **figure 4.2**. The "Quality Pie" slices represent the following parameters and requirements (clockwise):

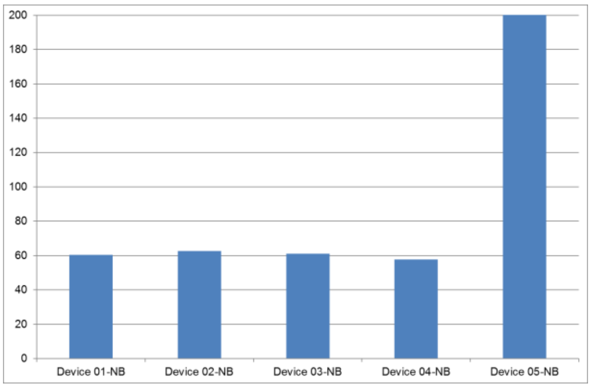
- The "AT+NREC=0" pie slice indicates the reply of the mobile phone on this command from the reference Bluetooth® interface. The pie slice is scaled between "OK" and "Error".
- The round-trip delay slice is scaled in ms (with the 190 ms wideband limit).
- The pie slice "Vol. Ctrl." is also digitally scaled between "Not active" and "Active". The volume control on the mobile phone should not influence the sensitivity of the Bluetooth® connection, independent if the remote volume control feature is supported by the hands-free unit or not. In case the hands-free unit supports this feature, it is expected, that the volume control adjustment on the mobile phone may control the hands-free unit playback volume. However, the mobile phones' volume control should not influence the sensitivity of the Bluetooth® link itself.
- The very important verification, if the implemented noise reduction in the mobile phone is still active in the Bluetooth® connection after sending the "AT+NREC=0" command, is indicated by the "NR" pie slice. The slice represents two possible states, disabled as expected ("off" in the Quality Pie) or enabled ("on").
- The verification of the active echo cancellation algorithm in the mobile phone after receiving the "AT+NREC=0" command from the Bluetooth® reference interface is scaled in a similar way. Again, two different stages, "off" (as required) or "on" are represented in the corresponding pie slice ("EC").
- Informatively the influence of implemented signal processing on double talk performance is represented by the "DT" pie slice. Two different stages are possible, the pie slice is scaled between "transparent" (as recommended) or "not transp.".

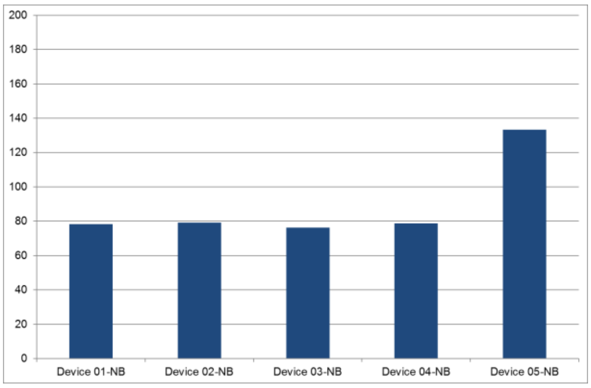
- The sending sensitivity expressed by the measured Junction Loudness Rating ("JLR (SND)") is scaled in dB. The limit, given by the inner red circle, represents an attenuation or amplification of 2 dB (JLR range 0 ± 2 dB).
- The Quality Pie slice "SFR" is also scaled in dB. It represents the violation of the suggested tolerance by the measured sending frequency response (SFR) in dB.
- The "Linearity SND" pie slice indicates the gain adjustment (amplification or attenuation) introduced in sending direction by the mobile phone, when applying different test signal levels. This pie slice is scaled in dB, the inner red circle represents the minimum requirement of ± 2 dB.
- Listening speech quality measured in sending direction using the Recommendation ITU-T P.863 POLQA method is used for scaling of the "MOS-LQO SND" pie slice. The scale directly represents the measured $MOS\text{-}LQO_n$ or $MOS\text{-}LQO_w$ scores. The limit represented by the inner red circle is given by the numerical value 3.8 (4.0 in the narrowband case).
- The receiving sensitivity (Junction Loudness Rating ("JLR (RCV)") is scaled in dB. The inner red circle represents attenuation or amplification of 2 dB (JLR 0 ± 2 dB).
- The Quality Pie slice "RFR" (receiving frequency response) is scaled in dB and indicates the violation of the suggested tolerance by the measured curve.
- The "Linearity RCV" pie slice indicates the gain adjustment (amplification or attenuation) introduced in receiving direction by the mobile phone, when applying different test signal levels. This pie slice is scaled in dB, the inner red circle represents the minimum requirement of ± 2 dB.
- Listening speech quality in receiving direction is given by the "MOS-LQO RCV" pie slice. The limit represented by the inner red circle is given by the numerical value 3.8 (wideband), and 4.0 respectively (narrowband) as described above (see Chapter 4.2).

5. Analyses Results

5.1 Overview - Narrowband

The measured delay values in sending direction (uplink, UL), receiving direction (downlink, DL) and the round-trip delay (RT) are analyzed in **figure 5.1a** to **5.1c**. The delay introduced by the test setup (frontend delay, network simulator) is considered and subtracted. Both one-way delays are informative in **figure 5.1a** and **5.1b**. The limit of 190 ms is verified in **figure 5.1c** for the round-trip delay as indicated in **chapter 4.2**.





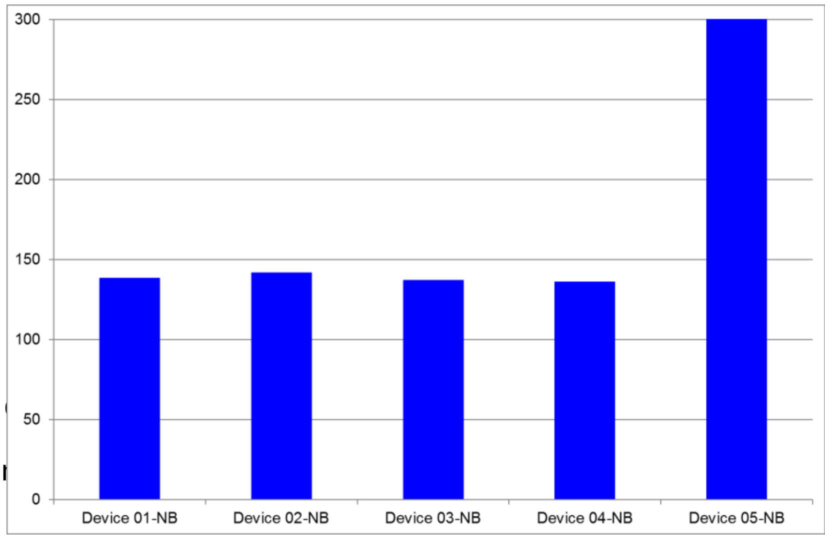


Fig. 5.1c: Round trip

4 devices meet the rou ereas one device significantly cantly too high. Such outliers have been seen during previous events in the past and indicate that this topic is not always in focus during development.

Figure 5.2 analyzes 14 individual parameters in order to provide an overview about the 5 mobile phones tested in narrowband mode. The green segments of each bar represent the number of mobile phones meeting the limits for each specific parameter. Vice versa the red segments indicate the number of limit violations.

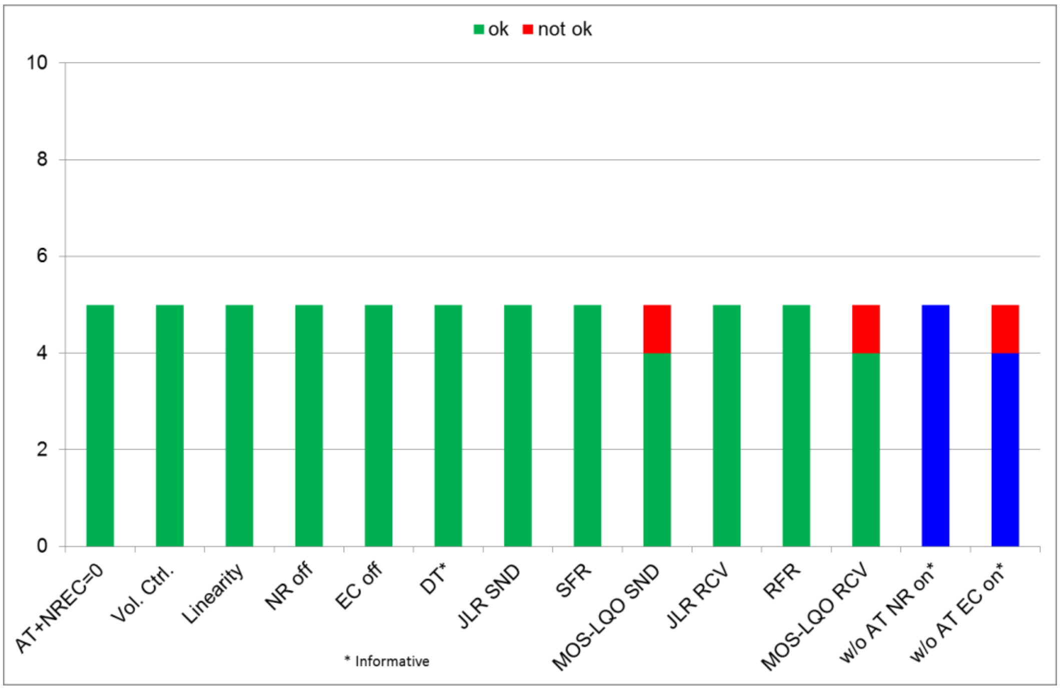


Fig. 5.2: Narrowband test result overview, 5 tested mobile phones

The two blue bars on the right-hand side represent the additional informative tests carried out without sending the AT+NREC=0 command. They represent the verification of enabled noise reduction or echo cancellation ("NR on", "EC on"). Without sending the AT+NREC=0 command, both algorithms are supposed to be enabled.

The following conclusions can be drawn:

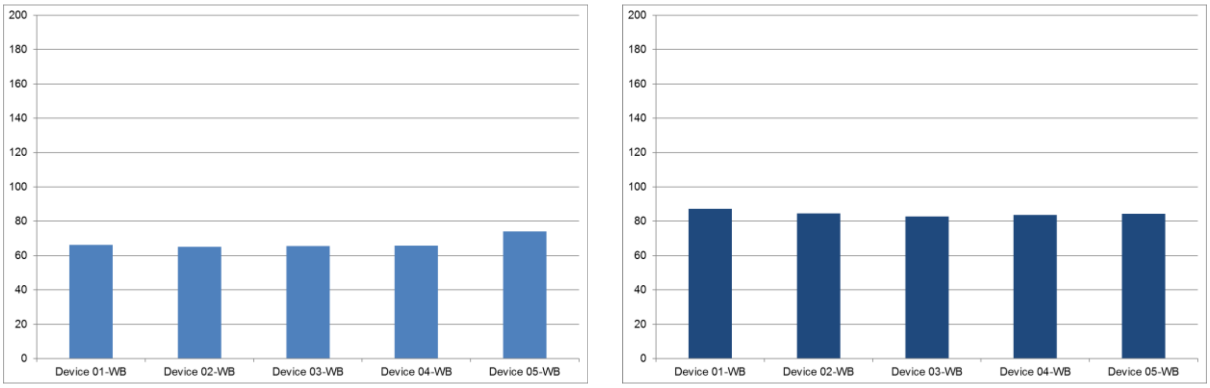
- The 5 phones all respond with "Ok" to the AT+NREC=0 command.
- All parameters are within the recommended limits except the MOS-LQO scores of one device in sending and receiving direction ("MOS-LQO SND" and ("MOS-LQO RCV")).

The two additional test results in **figure 5.2** measured without sending the AT command show,

- that one device disables echo cancellation, although the AT command is not sent. This device obviously disables this signal processing block triggered by the detection of a Bluetooth® link independent if the AT command is received or not. This has already been seen for a number of devices in previous events. Bluetooth® headsets without own implemented signal processing may rely on the algorithms in the paired mobile phone. Consequently, echo disturbances and a low communication quality in noisy environment may occur.

5.2 Overview - Wideband

The measured delay values in wideband mode are analyzed in **figure 5.3a** to **5.3c**. Both one-way delays are informative only and the suggested limit of 200 ms is only applicable for the round-trip delay in **figure 5.3c**. Again, the delay introduced by the test setup is considered in these analyses.



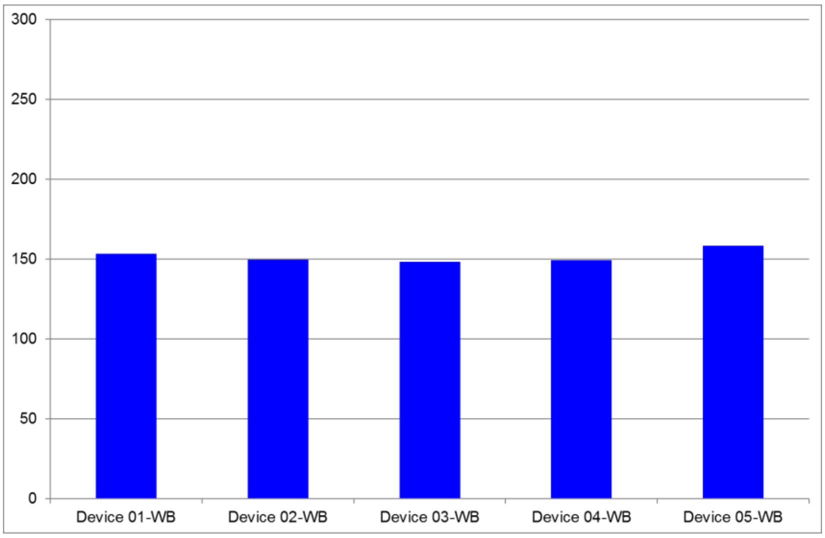


Fig. 5.3c: Round trip delay $T_{AG,RT}$, wideband, 5 tested mobile phones

All 5 tested phones show a delay around 150 ms in wideband connection. The round-trip delay limit of 200 ms is met.

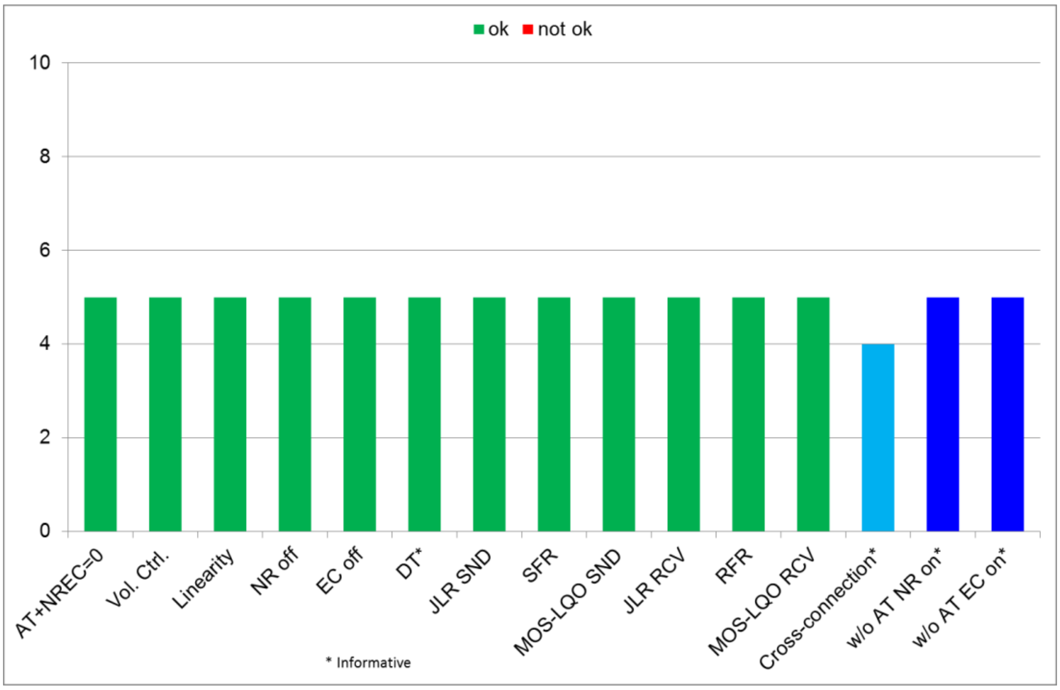


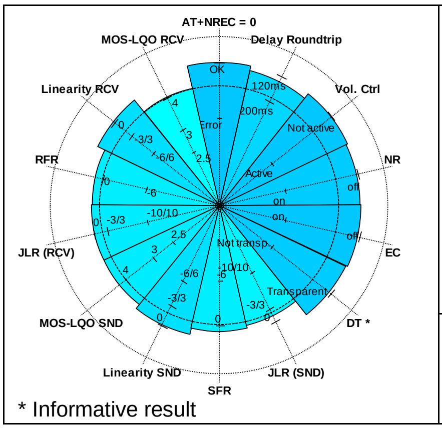
Fig. 5.4: Wideband test result overview, 5 tested mobile phones

The wideband results in **figure 5.4** show, that all devices respond with "Ok" to the AT+NREC=0 command, disable the relevant signal processing and can be regarded as transparent.

The cross-connection tests were carried out for 4 of 5 devices, as one was only tested in wideband mode. All tests showed the expected level transparency in the cross-connection tests. The frequency responses mainly differ in the band limitations. Audible level contrasts are not expected e.g. if the mobile network codec dynamically switches from wideband to narrowband mode during an ongoing audio connection.

The test results <u>without sending the AT command</u> (blue bars) also show that the tested mobile phones keep noise reduction and echo cancellation active, as expected. Again, this is important in conjunction with Bluetooth® enabled headsets without own implemented signal processing. Disabled algorithms in this setup may lead to echo disturbances and a low communication quality, e.g. if the headset is used in noisy environment.

5.3 Individual Summary – Narrowband



* Informative result

Device: 1-NB

Volume control disabled

NR and EC disabled, transparent double talk performance

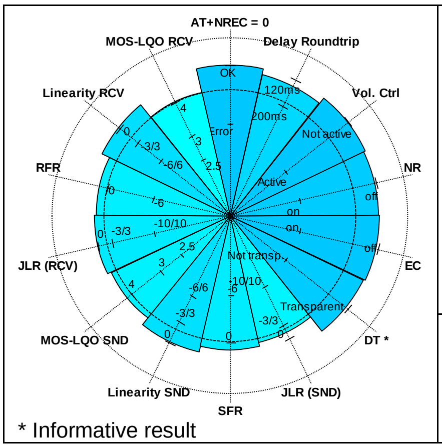
Uplink and downlink sensitivities in recommended range

MOS-LQO values sufficiently high

➢ transparent device, high speech quality

<u>**w/o sending "AT+NREC=0"**</u>

Noise reduction: enabled
Echo canceller: enabled



* Informative result

Device: 2-NB

Volume control disabled

NR and EC disabled, transparent double talk performance

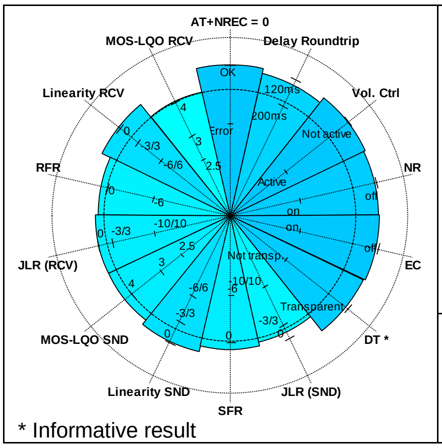
Uplink and downlink sensitivities in recommended range

MOS-LQO values sufficiently high

➢ transparent device, high speech quality

<u>**w/o sending "AT+NREC=0"**</u>

Noise reduction: enabled
Echo canceller: enabled



* Informative result

Device: 3-NB

Volume control disabled

NR and EC disabled, transparent double talk performance

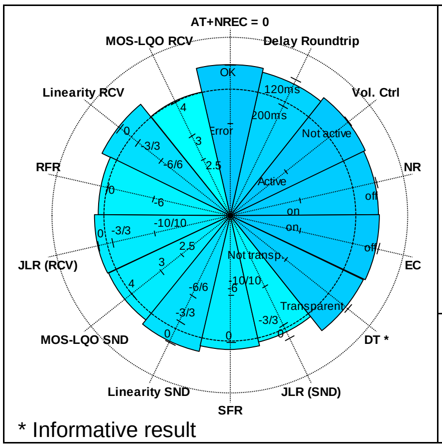
Uplink and downlink sensitivities in recommended range

MOS-LQO values sufficiently high

➢ transparent device, high speech quality

<u>**w/o sending "AT+NREC=0"**</u>

Noise reduction: enabled
Echo canceller: enabled



* Informative result

Device: 4-NB

Volume control disabled

NR and EC disabled, transparent double talk performance

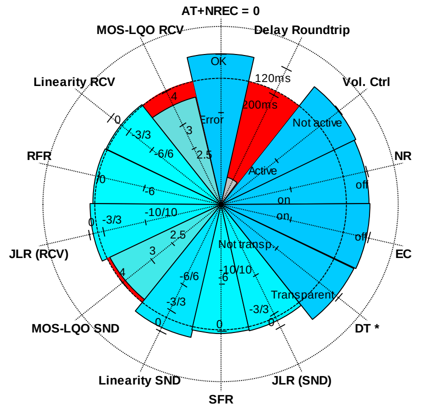
Uplink and downlink sensitivities in recommended range

MOS-LQO values sufficiently high

➢ transparent device, high speech quality

<u>**w/o sending "AT+NREC=0"**</u>

Noise reduction: enabled
Echo canceller: enabled



* Informative result

Device: 5-NB

Volume control disabled, very high round trip delay

NR and EC disabled, transparent double talk performance

Uplink and downlink sensitivities in recommended range

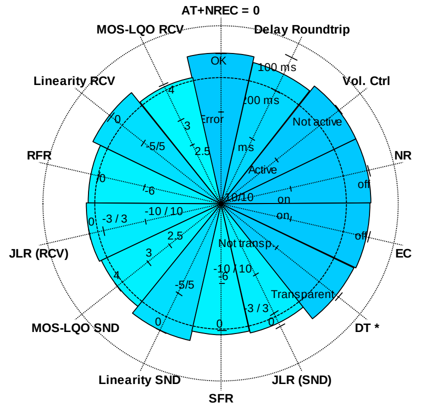
MOS-LQO values slightly low

- ➢ not transparent, high delay hampers communication quality

w/o sending "AT+NREC=0"

Noise reduction: enabled
Echo canceller: **disabled**

5.4 Individual Summary – Wideband



* Informative result

Device: 1-WB

Volume control disabled

NR and EC disabled, transparent double talk performance

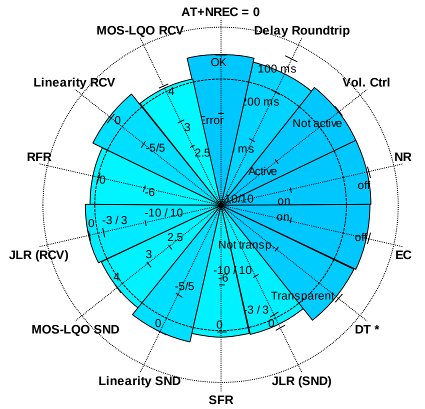
Uplink and downlink sensitivities in recommended range

MOS-LQO values sufficiently high

- ➢ transparent device, high speech quality

w/o sending "AT+NREC=0"

Noise reduction: enabled
Echo canceller: enabled



* Informative result

Device: 2-WB

Volume control disabled

NR and EC disabled, transparent double talk performance

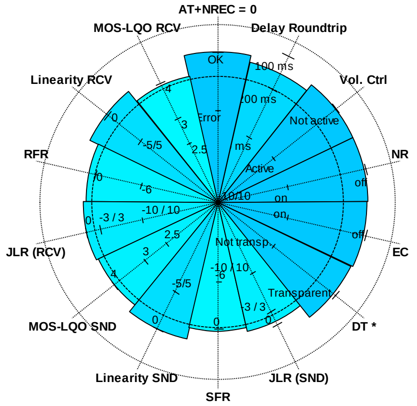
Uplink and downlink sensitivities in recommended range

MOS-LQO values sufficiently high

- ➢ transparent device, high speech quality

w/o sending "AT+NREC=0"

Noise reduction: enabled
Echo canceller: enabled



* Informative result

Device: 3-WB

Volume control disabled

NR and EC disabled, transparent double talk performance

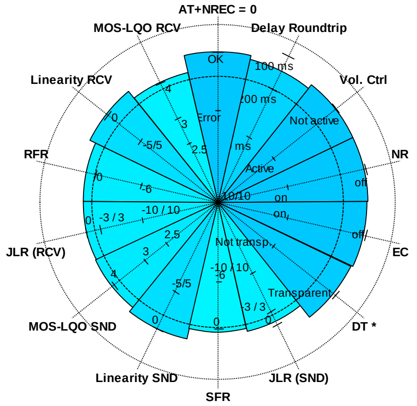
Uplink and downlink sensitivities in recommended range

MOS-LQO values sufficiently high

- ➢ transparent device, high speech quality

<u>**w/o sending "AT+NREC=0"**</u>

Noise reduction: enabled
Echo canceller: enabled



* Informative result

Device: 4-WB

Volume control disabled

NR and EC disabled, transparent double talk performance

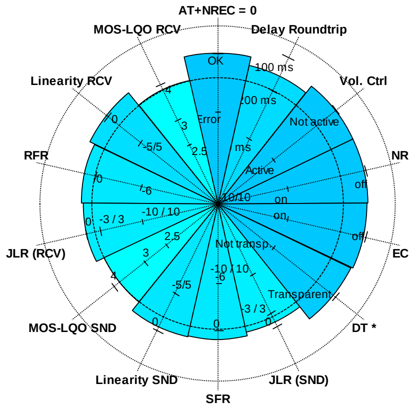
Uplink and downlink sensitivities in recommended range

MOS-LQO values sufficiently high

- ➢ transparent device, high speech quality

<u>**w/o sending "AT+NREC=0"**</u>

Noise reduction: enabled
Echo canceller: enabled



* Informative result

Device: 5-WB

Volume control disabled

NR and EC disabled, transparent double talk performance

Uplink and downlink sensitivities in recommended range

MOS-LQO values sufficiently high

- ➢ transparent device, high speech quality

<u>**w/o sending "AT+NREC=0"**</u>

Noise reduction: enabled
Echo canceller: enabled

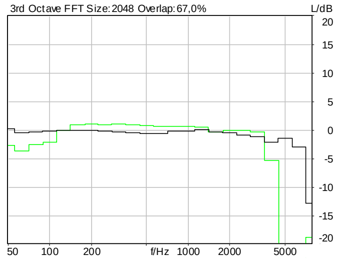
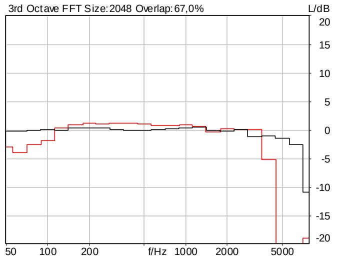
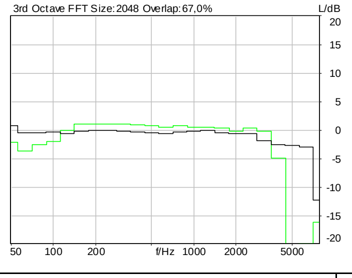
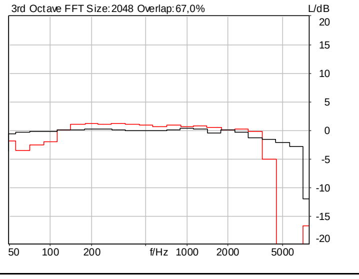
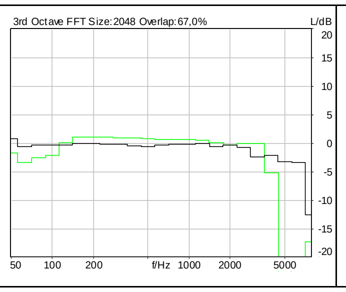
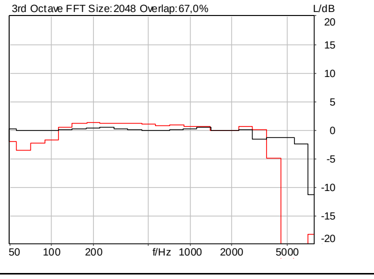
5.5 Cross-Connection Tests (Informative results)

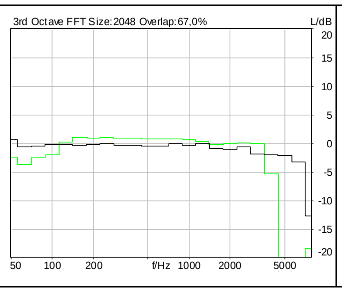
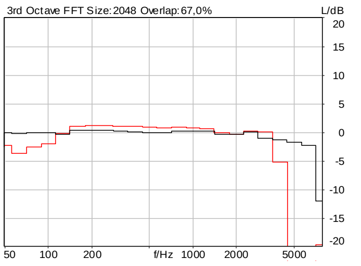
The sending and receiving sensitivities and possible level contrasts are analyzed in cross-connection scenarios, cascading a Bluetooth® connection in wideband mode (BT WB) with wideband and narrowband network connections. These tests can only be carried out for wideband Bluetooth® capable phones. It can be assumed that head units in vehicles today are wideband Bluetooth® capable and connect in wideband mode to the mobile phone.

The following figures compare the wideband sensitivities in sending (SFR) and receiving direction (RFR) to the narrowband network connection and the measured JLR values:

- the SFR curves are measured and compared for the wideband connection (wideband Bluetooth® and wideband network, **black curve**) and the cross connection (wideband Bluetooth® and narrowband network, **green curve**) in the left hand figures.
- Correspondingly the RFR curves are compared in the right hand figures (wideband Bluetooth® and wideband network, **black curve**; wideband Bluetooth® and narrow-band network, **red curve**).

All devices show a more or less constant sensitivity in the narrowband transmission range. The sensitivity differences are all below 1 dB, no noticeable level offset between the narrowband network connection and the wideband network connection can be observed. Neither the driver (receiving direction) nor the far end subscriber (sending direction) will notice any level contrast, if the network connection switches from wideband to narrowband.

<table>
<tr><td rowspan="4">1-WB</td><td rowspan="4">
</td><td rowspan="4">
</td><td>JLR (SND)</td><td>0.3 dB</td></tr>
<tr><td>JLRcross (SND):</td><td>-0.6 dB</td></tr>
<tr><td>JLR (RCV):</td><td>-0.1 dB</td></tr>
<tr><td>JLRcross (RCV):</td><td>-0.8 dB</td></tr>
<tr><td rowspan="4">2-WB</td><td rowspan="4">
</td><td rowspan="4">
</td><td>JLR (SND)</td><td>0.4 dB</td></tr>
<tr><td>JLRcross (SND):</td><td>-0.6 dB</td></tr>
<tr><td>JLR (RCV):</td><td>0.0 dB</td></tr>
<tr><td>JLRcross (RCV):</td><td>-0.8 dB</td></tr>
<tr><td rowspan="4">3-WB</td><td rowspan="4">
</td><td rowspan="4">
</td><td>JLR (SND)</td><td>0.4 dB</td></tr>
<tr><td>JLRcross (SND):</td><td>-0.6 dB</td></tr>
<tr><td>JLR (RCV):</td><td>-0.1 dB</td></tr>
<tr><td>JLRcross (RCV):</td><td>-0.8 dB</td></tr>
</table>

4-WB			JLR (SND)	0.4 dB
			JLR_{cross} (SND):	-0.6 dB
			JLR (RCV):	-0.1 dB
			JLR_{cross} (RCV):	-0.7 dB

6. References

[1] Recommendation ITU-T P.1100; Narrowband hands-free communication in motor vehicles, 01-2015

[2] Recommendation ITU-T P.1110; Wideband hands-free communication in motor vehicles, 01-2015

[3] Recommendation ITU-T P.1100; Narrowband hands-free communication in motor vehicles, 03-2017

[4] Recommendation ITU-T P.1110; Wideband hands-free communication in motor vehicles, 03-2017

[5] Performance assessment of vehicle-mounted mobile phones in conjunction with Hands-free Terminals according to Recommendations ITU-T P.1100 and ITU-T P.1110 - Final Version; http://www.itu.int/en/ITU-T/C-I/Pages/test_event_Feb14.aspx

[6] 2nd ITU Test Event: Performance of Mobile Phones as Gateways to Car Hands-free Systems, Geneva 23-25 May 2016**;** https://www.itu.int/en/ITU-T/C-I/Pages/HFT-mobile-tests/test_event_2.aspx

[7] Bluetooth® Telephony Working Group: Hands-free Profile 1.7, Bluetooth Profile Specification, Revision V1.7.0, September 18, 2014

[8] Compatibility of mobile phones and vehicle hands-free terminals, https://www.itu.int/en/ITU-T/C-I/Pages/HFT-mobile-tests/HFT_testing.aspx

[9] Recommendation ITU-T P.501; Test signals for use in telephonometry, 03-2017

[10] Recommendation ITU-T P.863; Perceptual objective listening quality assessment, 09-2014

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