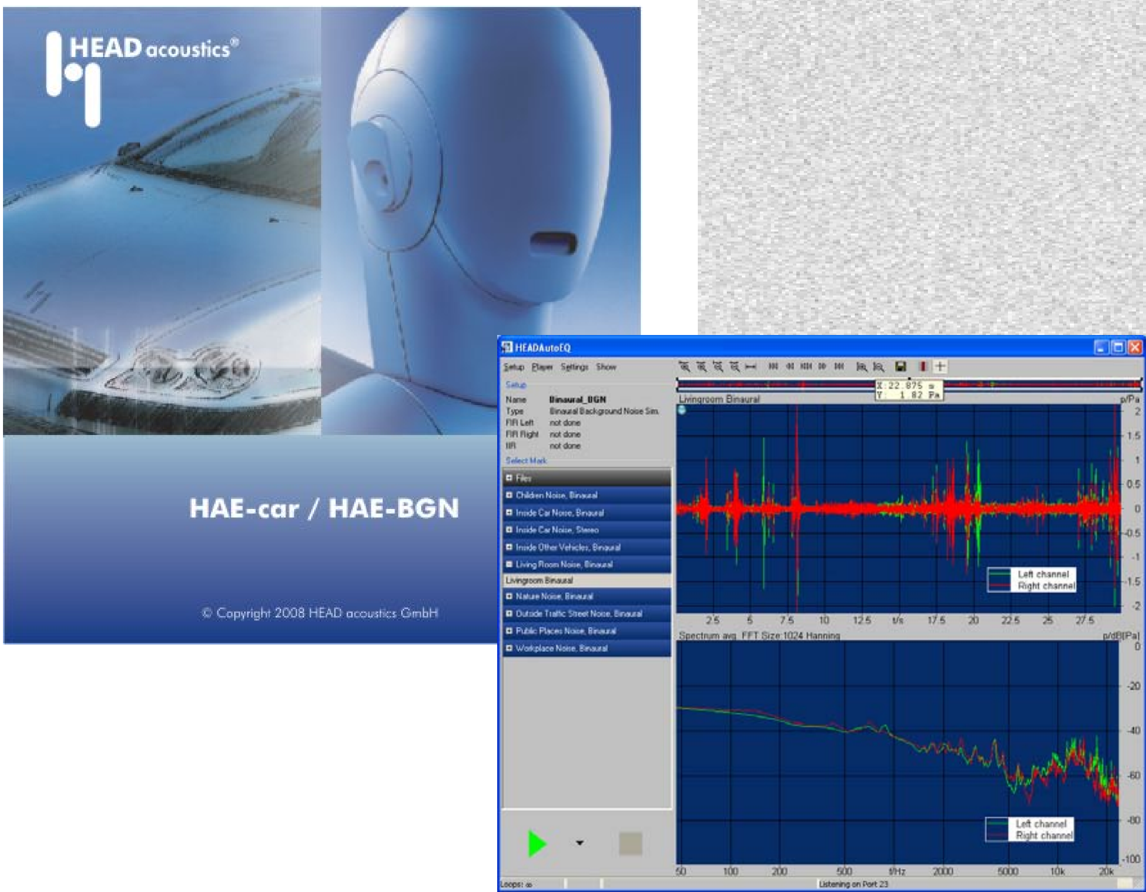
HAE-BGN: Setup and Results in Different Test Room Types



HEAD acoustics Application Note

HEAD acoustics GmbH
Ebertstraße 30a
D-52134 Herzogenrath
Tel.: +49 (0) 2407-577-0
Fax: +49 (0) 2407-577-99
E-mail: sales@head-acoustics.de
WEB: www.head.acoustics.de

HAE-BGN: Setup and Results in Different Test Room Types

Contents

1. Introduction

The ETSI standard EG 202 396-1 [1] describes a four loudspeaker plus subwoofer setup to be used in *office type* rooms as well as in *anechoic rooms* in order to realistically generate background noise in a lab-type environment. In practice test laboratories very often need to establish any kind of acoustic tests in one single room environment which is then typically an anechoic or semi-anechoic room. Due to missing reflections, such anechoic or semi-anechoic rooms may have different impact on the generated sound fields compared to an office type room, especially with regard to the sound diffusivity and the generated sound levels.

This application note describes the use of the HEAD acoustics background noise playback system HAE-BGN in different room types. The basis for the setup used in all experiments is ETSI EG 202 396-1 [1]. Experiments conducted with different mobile terminals including different noise cancellation strategies measured in different rooms are shown. Furthermore the results measured with the traditional uncorrelated pink noise field as well as the results of Frequency Response, Loudness Ratings and TOSQA mean opinion score (TMOS) [8] measurements are reported.

In detail, two test series have been executed: In a first test series, the influence of fully anechoic, semi-anechoic and office-type rooms is compared. A second series of tests has been carried out especially to determine correlations between room reverberation time and SLR, TMOS and different D-Value test results. In addition, the D-Value tests are based on different background noises.

2. Test Setups

All tests described below were made with different mobile phones. Mobile phones were used since they show a big variety of different designs and almost all of them use integrated noise cancellation techniques. Thus, both the influence of the acoustical/mechanical design as well as the influence of noise cancellation techniques could be evaluated.

2.1. Room Environments for Testing

One of the main investigations has been targeted to the question how much influence room acoustics will have on a test result in conjunction with HAE-BGN. It is e.g. a well-known fact that any test room has to be quiet enough for testing: The general telecom specification asks for a maximum ambient noise of 30 dB_{SPL}(A). However, other main parameters for describing room acoustics such as the reverberation time (RT 60) are typically only considered when anechoic or semi-anechoic rooms are required.

The first test series was conducted in the following rooms:

- Room 1: fully anechoic chamber
- Room 2: semi-anechoic room (anechoic above 300 Hz)
- Room 3: office type room

The second test series was based on a comparison of two rooms that both fulfill the recommendation of low ambient noise but are contrary regarding reverberation. The two room environments used for testing can be described as follows:

- "Test Room" is a semi-anechoic room with a constant reverberation time. The room is specifically designed for tests of telecom handsets and hands-free devices.
- "Office" is a standard office room that is equipped with furniture but furthermore empty (currently not in use). The ambient noise is only 28 dB(A), so the noise floor is comparatively low.

The following table lists the main room characteristics. The large difference of the reverberation times should be highlighted.

	Ambient Noise	Reverberation Time RT 60	Dimensions	Room Volume
Test Room	24 dB(A)	144 ms	3.3 x 2.3 m	15.8 m^3
Office	28 dB(A)	815 ms	5.2 x 3.9 m	58.8 m^3

Figure 1: Main room characteristics

As detail analysis, the picture below shows the differences of the average reverberation time vs. frequency for both rooms. Especially the frequency range between 200 Hz and 4 kHz that represents the main transmission range in telecommunication should be regarded.

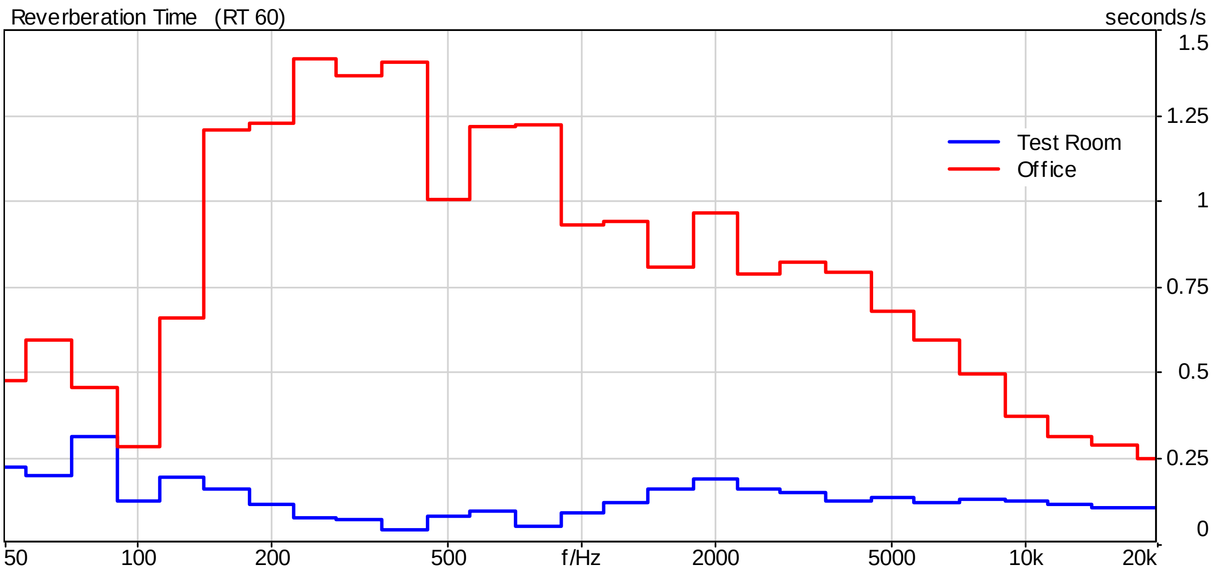


Figure 2: Reverberation times of the different rooms

2.2. Used Equipment

All tests were conducted using a HATS conforming to ITU-T Recommendation P.58 [3] equipped with an artificial ear type 3.4 (ITU-T Rec. P.57 [3]) for the first test series and ear type 3.3 for the second test series (as all tests were carried out in sending direction, the type of ear is of less relevance). The phones were positioned as described in ITU-T Recommendation P.64 [5].

The tests were conducted as described in TS 51.050 [6]. All tests were carried out in 2G (GSM 900) mode. Different types of background noises were used as described in detail.

As background noise playback system, the HEAD acoustics HAE-BGN system, mainly consisting of HAE-BGN software, programmable equalizers PEQ V, speakers and subwoofer was used. The image below shows the system setup. All tests were carried out with the HEAD acoustics Advanced Communication Quality Analysis system ACQUA.

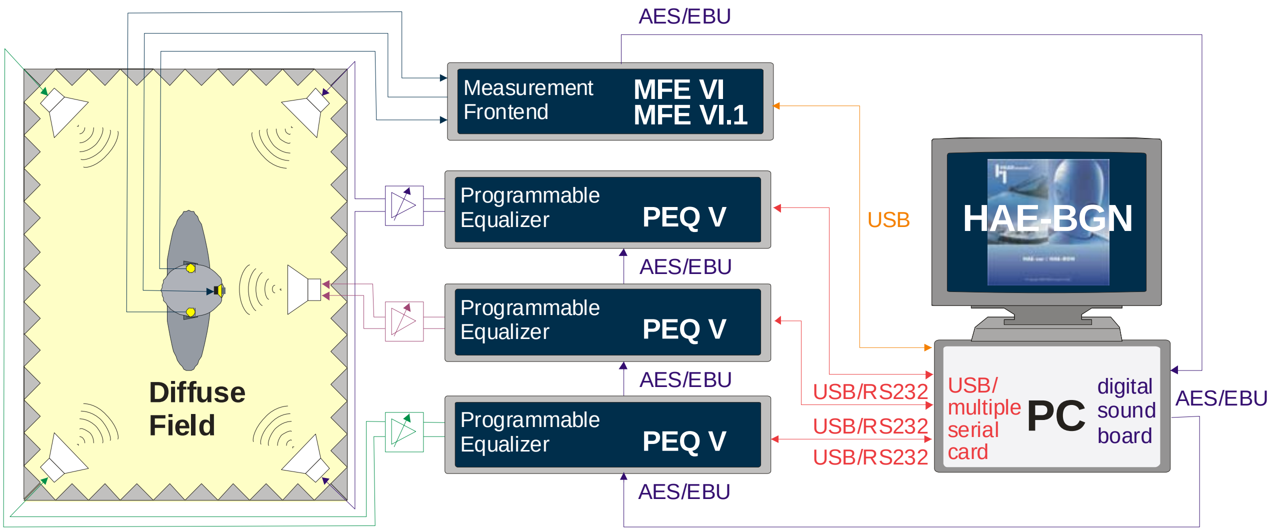


Figure 3: Equalization setup of the HAE-BGN system

The background noise simulation was equalized and calibrated as described in EG 202 396-1. Instead of time aligning the 4 loudspeakers in each path of the playback arrangement a certain delay was introduced in order to increase the diffusivity of the binaurally recorded background noise from the database in EG 202 396-1 and to avoid standing waves in the rooms. Empirical tests have shown that these delays can be used for typical anechoic rooms in telecommunication scenarios.

The delays inserted in each path are shown in the following table:

	Left	Right
Front	16 ms	51 ms
Rear	7 ms	21 ms

Figure 4: Inserted delays for equalization

After inserting the delays the equalization and calibration procedure as described in EG 202 396-1 was applied.

2.3. General Hints for Equalization

This chapter refers to general problems that may happen during the equalization process. Depending on room size and reverberation, users may face difficulties in achieving smooth frequency responses. Main causes are standing waves: First of all it may be astonishing that such a phenomenon also happens in an anechoic environment, however the background of this effect is the phase overlay between two or more single speakers.

It should be kept in mind that for binaural equalizations the source signal is a 2-channel (binaural) signal which is then feeding four speakers plus a subwoofer, so two speakers by pairs will transmit a correlated signal. Depending on speaker positioning, phasing and inserted delay (see figure 4), this correlation may result in a standing wave.

This effect is systematic. In principle, it cannot be avoided completely. Consequently, possibilities to minimize standing waves shall be taken into account:

- Change of speaker mounting: Moving speakers to varying distances will change frequencies and levels of standing waves. Depending on room infrastructure this method should be taken into account, if possible,.
- Polarity change on one single speaker: This possibility is typically easier to realize than the method described above. Changing polarity will change the phase of the resulting sound field.
- Varying delays: This is the easiest method of the described methods. Any variation in combination should be taken into account, however the maximum delay should not be chosen higher than approx. 60 ms.

In practice, it is recommended to combine different methods to achieve a maximum of efficiency. Any change needs to be verified by re-equalizing, so after any change FIR and IIR filtering needs to be re-executed. Therefore, any hardware change (speaker mounting & polarity change) should be iterated before concentrating on software changes (delay & IIR filtering).

2.4. Devices Under Test

For the two different test series, different types of phones from different manufacturers were used.

Test series 1

- Phone 1: Flip Phone with Noise Cancellation (NC)
- Phone 2: Short Phone with NC
- Phone 3: Short Phone with moderate NC
- Phone 4: Large Size Phone with Directional Microphone, no NC
- Phone 5: Medium Size Phone with strong NC
- Phone 6: Medium Size classical "Business Phone" with NC
- Phone 7: Short Phone with NC
- Phone 8: Flip Phone with NC

The tests were conducted as described in TS 51.050 [5]. Two types of background noises were used: In one experiment a diffuse pink noise field was generated using 4 uncorrelated noise sources presented over 4 loudspeakers equalized and calibrated to the different test rooms.

Test series 2

- "Flip Phone 1": Flip Phone with NC
- "Flip Phone 2": Flip Phone with NC
- "Short Phone": Short Phone with moderate NC, older type
- "Double Mic 1": Short Phone with NC as well as a double microphone solution
- "Double Mic 2": "Business Phone" with NC as well as a double microphone solution

Attention should be drawn to the last two phones: These types are equipped with a new-technology double microphone solution. An additional microphone mounted at the back side of the phone is especially used for noise cancellation. It can be assumed that such types of phones will react most strongly to different types of background noise scenario.

3. Results of the Tests

All test results are presented in detail in the following subchapters. For test series 1, all measured responses which are the basis for the different result overviews shown are found in the Chapter "Graphs".

3.1. SLR and TMOS SND Characteristics

Test series 1: SLR tests

In a first step the frequency response characteristics in sending were measured for all phones in the different rooms in order to find the general differences which can be expected when conducting these most simple and reproducible tests (from the setup point of view). Furthermore, the SLR's were determined. The underlying response characteristics can be found in Chapter 6 – Graphs.

Phone Nr.	1	2	3	4	5	6	7	8
Fully anechoic	12.7	10.0	11.6	13.3	8.5	5.2	10.9	13.6
Semi-anechoic	12.9	9.1	10.0	11.6	9.1	5.1	10.1	13.7
Office-type	12.1	12.4	11.4	11.8	7.0	4.9	9.6	13.1

Figure 5: SLR's measured for different phones in different rooms

Test series 1: Result summary of SLR tests

- Maximum scatter over all tests of the SLR has been approx 3.3 dB. However, average scatter has been below 1.5 dB.
- There is no noticeable tendency whether one room type delivers higher or lower scores in general. Deviations are distributed rather uniformly.

From the measured frequency responses as well as from the SLR results it can be seen that, although positioning and calibration was carried out very carefully, smaller differences can be expected. This is due to limited positioning accuracy, but mainly driven by the fact that most of the phones use non-linear and time-variant signal processing. This signal processing may react on slightly different signal levels (second order effect of slightly different processing). Furthermore, memory effects may be present which lead to different results when measuring the phone at different times during a connection.

Test series 2: SLR tests

For this test series, again the Sending Loudness Rating (SLR) characteristics were measured for all phones in the two different rooms. Furthermore, for this test series the TOSQA Mean Opinion Scores (TMOS) in the sending direction of all devices were determined.

Of course these tests have no relation to the performance of the HAE-BGN system as they need to be executed *in silence* (no background noise was applied). However, test results will indicate a general degree of test reproducibility and quality.

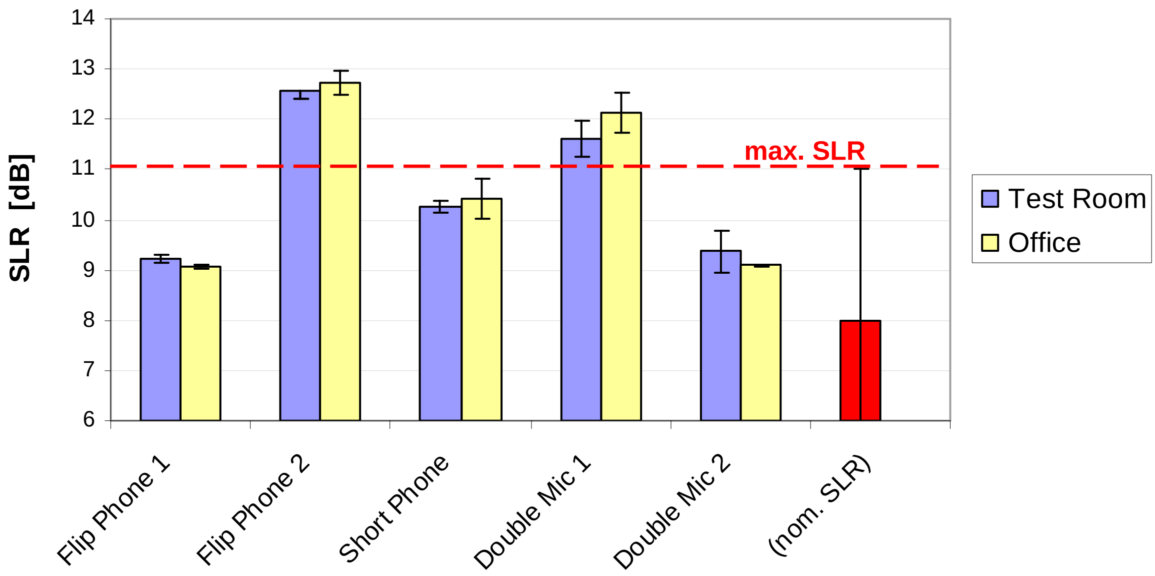


Figure 6: SLR measured for the different phones in the different rooms

The figure above shows a comparison between both rooms for SLR results of all phones. In addition, nominal as well as maximum SLR (nom. SLR = 8 dB ±3 dB) according to ETSI TS 51.010 [3] is listed. It should be kept in mind that *maximum* SLR is representative for *minimum* volume of the phone, thus the phone should have a *lower* SLR than maximum – the corresponding bar plot should be *lower* than the red dashed line of figure 6.

Test series 2: Result summary of SLR tests

- All five phones show a higher SLR than the nominal 8 dB. Two of the five devices even fail the SLR test due to being not loud enough. SLR scores are very obviously mainly depending on phone design, not on phone type, length etc.
- The SLR results measured at the two "double mic" phones seem to vary more which is indicated by slightly higher measurement deviations (shown as "whisker" lines in figure 6) than the other types.

- Maximum scatter over all tests of the SLR has been only 1.3 dB. Deviations between the two rooms are comparatively small and are not significantly different from the scatter of single tests within one room.
- There is no noticeable tendency whether one room type delivers higher or lower scores in general. Scores are distributed rather uniformly.

Test series 2: TMOS SND tests

The figure below shows the TMOS SND comparison for both rooms. The red dashed line shows the minimum TMOS SND score of MOS 3.2, this limit is taken from typical prospects of network operators. A mobile should reach this score *at least*, so the corresponding bar plot should be *higher* than the red dashed line of figure 7.

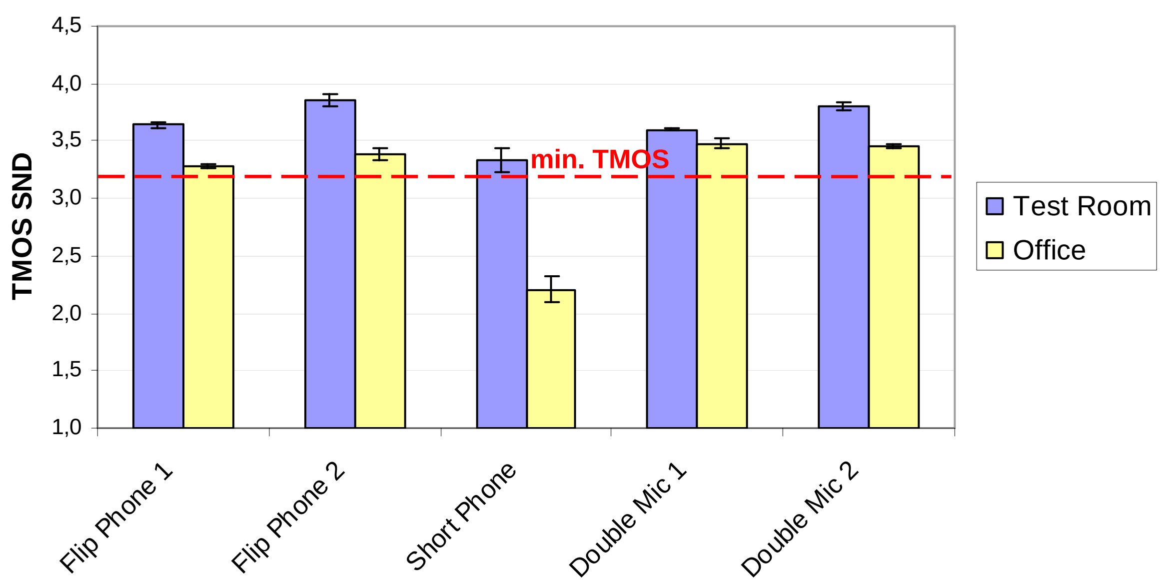


Figure 7: TMOS SND measured for the different phones in the different rooms

Test series 2: Result summary of TMOS SND tests

- Maximum scatter for one device within one room environment has been ΔTMOS 0.2, so the scatter within one test environment is low.
- Average TMOS deviation between both rooms however is large: Maximum average deviation has been ΔTMOS 1.1, maximum overall deviation (including all test repetitions) has been ΔTMOS 1.3.
- It is remarkable that the shortest phone delivers the highest TMOS deviations: A subjective check of the test recorded in office environment confirmed a more reverberant sound than in the test room. This additional reverberance causes the degradation of speech quality, both subjectively and objectively, when determined with TOSQA2001.

- Furthermore, the room comparison shows the clear trend that the low-reverberant test room always delivers significantly higher TMOS scores than the office room. The average offset between both rooms is ΔTMOS 0.5, so the test room delivers much more optimistic results.

General summary / SLR and TMOS tests

From the measured SLR results as well as from the TMOS SND results it can be seen that, although positioning and calibration was carried out very carefully, smaller differences can be expected. This is due to limited positioning accuracy, but also driven by the fact that most of the phones use non-linear and time-variant signal processing. This signal processing may react to slightly different signal levels (second order effect of slightly different processing). Furthermore, memory effects may be present which lead to different results when measuring the phone at different times during a connection.

In general, the SLR tests can be seen as proof of the general stability and reproducibility of the test procedure. The TMOS tests however indicate that – besides the well-known fact that a test room needs to be *quiet* enough – there are further room-related effects such as the reverberation time that have a significant impact on reproducibility and quality of the test result.

3.2. D-Value Tests / Test series 1

D-Values with Pink Noise

In this experiment, a Pink Noise simulation setup consisting of 4 loudspeakers and a subwoofer was used in order to determine the D-value of the phones. The underlying response characteristics can be found in Chapter 6 – Graphs. The results are shown in figure 8.

Phone Nr.	1	2	3	4	5	6	7	8
Fully anechoic	13.7	5.9	3.3	-0.4	-3.0	0.4	0.5	10.7
Semi anechoic	14.1	4.6	0.6	-1.4	-5.6	-2.9	-1.6	9.3
Office-type	13.2	5.5	3.3	-0.6	-12.9	1.5	-0.1	8.4

Figure 8: D-Values measured with Pink Noise for different phones in different rooms

As seen already for the SLR tests, differences for the D-value can also be expected. The differences observed are in the range of up to 4 dB except mobile phone no. 5 which deserves some more detailed discussion. Mobile phone no. 5 shows a behavior which often can be found in modern designs: Depending on type, level and duration of a background noise signal the phone drastically changes its behavior in sending direction. Certainly this is mostly due to the simple background noise signal which can be identified easily as background noise by a noise cancellation algorithm and typically leads to a stronger background noise cancellation than realistic background noises. As a consequence the results measured may differ considerably depending on the test condition. The behavior of this phone shows that the test conditions including the preconditioning for the tests need to be defined more thoroughly. A test lab conducting such tests always should use a preconditioning procedure. When focusing on the steady state behavior of a phone this may be e.g. the application of the background noise for some minutes before starting the measurement. If the time-variant behavior of the phone with background noise is the focus of the tests, other strategies may be used - e.g. measuring for a short period of time directly after starting the background noise and then using different time segments. Clearly, different D-values may occur in real life depending on the condition of use.

D-Values with Cafeteria Noise

Here, the simulation of a cafeteria noise taken from the ETSI background noise database was conducted. The setup used in the office type room, the semi-anechoic room and in the anechoic room was according to EG 202 396-1. Again, the measured response characteristics which are the basis for the D-value calculation are found in the chapter 6 – Graphs .

Phone Nr.	1	2	3	4	5	6	7	8
Fully anechoic	-1.8	-10.4	-9.6	-3.4	-10.3	-9.3	-9.2	2.7
Semi anechoic	-3.0	-12.2	-9.9	-6.4	-14.7	-11.7	-10.5	-0.1
Office-type	-1.8	-10.4	-9.7	-3.9	-12.9	-10.1	-9.5	0.0

Figure 9: D-Values measured with Pink Noise for different phones in different rooms

The differences in the results are in a similar range as already observed before. However, the big differences observed for mobile phone no. 5 were not observed with cafeteria noise. The results document that the ETSI EG 202 396-1 setup when used in anechoic or semi-anechoic rooms leads to similar results as found when using the setup in office type rooms. The differences observed are in the same range which can be expected when measuring the same phones at different times. The measured diffuse field sensitivity with cafeteria noise is typically even closer between the different rooms than the one measured with pink noise. In some cases the different D-value is mainly caused by a different direct sound sensitivity.

3.3. D-Value Tests / Test series 2

In a second experiment series, the tests of D-Values according to ITU-T G.111 have been conducted with further different background noises. Therefore, besides tests in the presence of Pink Noise, the following six different binaural background noises of the ETSI background noise database [1] have been in use:

- "Pink Noise": Classic pink noise sound field of -24 dBPa(A), equivalent to 70 dB_{SPL}(A). As per HAE-BGN, the noise has been equalized with a single microphone in the absence of a head and torso simulator.
- "Fullsizecar100": ETSI "Fullsize_Car1_100Km/h_binaural" signal, recorded at driver's position, average level approx. 64 dB(A). Very constant level signal, no voice content.
- "Insidebus": ETSI "Inside_Bus_Noise_binaural" recording in passenger cabin, average level approx. 77 dB(A). This signal is the loudest one of the selection, it has a lower voice content.
- "Insidetrain2": ETSI "Inside_Train_Noise2_binaural" signal, average level approx. 63 dB(A). Low voice content, varying signal level vs. time.
- "Pubnoise": ETSI "Pub_Noise_binaural_V2", recording in a pub, average level approx. 74 dB(A). The signal is rather loud and with high voice content.
- "Cafeterianoise": ETSI "Cafeteria_Noise_binaural", recording at the sales counter of a cafeteria. Average level approx. 68 dB(A), ambient voice content mixed with ambient noises.
- "Kindergarten1": ETSI "Kindergarten_Noise1_binaural", recorded in a children's playroom of a kindergarten. Average level approx. 73 dB(A), varying signal level vs. time. Almost pure ambient voice content, very little other ambient noises.

All tests have been executed with *synchronized* playback: Signal analysis has always been 2 s after the first repetition of the background noise file. This procedure is seen as essential to create sufficient reproducibility when testing with such non-linear noise signals. In practice, triggering via a Pulse Splitter Box has been established. Analysis length has always been 10 s.

In a first step, again a comparison between both rooms is made. The figure below shows the determined average (all phones) and maximum scatters of the D-Value tests for all different noises:

	Pink Noise	Fullsize-car100	Insidebus	Inside-train2	Pubnoise	Cafeteri-anoise	Kindergar-ten1
Avg. Scatter	0.56 dB	0.81 dB	1.35 dB	1.49 dB	1.82 dB	1.21 dB	1.61 dB
Max. Scatter	1.06 dB	1.20 dB	1.78 dB	3.11 dB	2.69 dB	2.20 dB	3.34 dB

Figure 10: Average (all phones) and maximum scatter of different room noises

To analyze effects of the rooms in detail, a result comparison is shown in figure 11 for Cafeteria Noise (average scatter scores, see figure 10) and in figure 12 for Kindergarten Noise (high scatter scores).

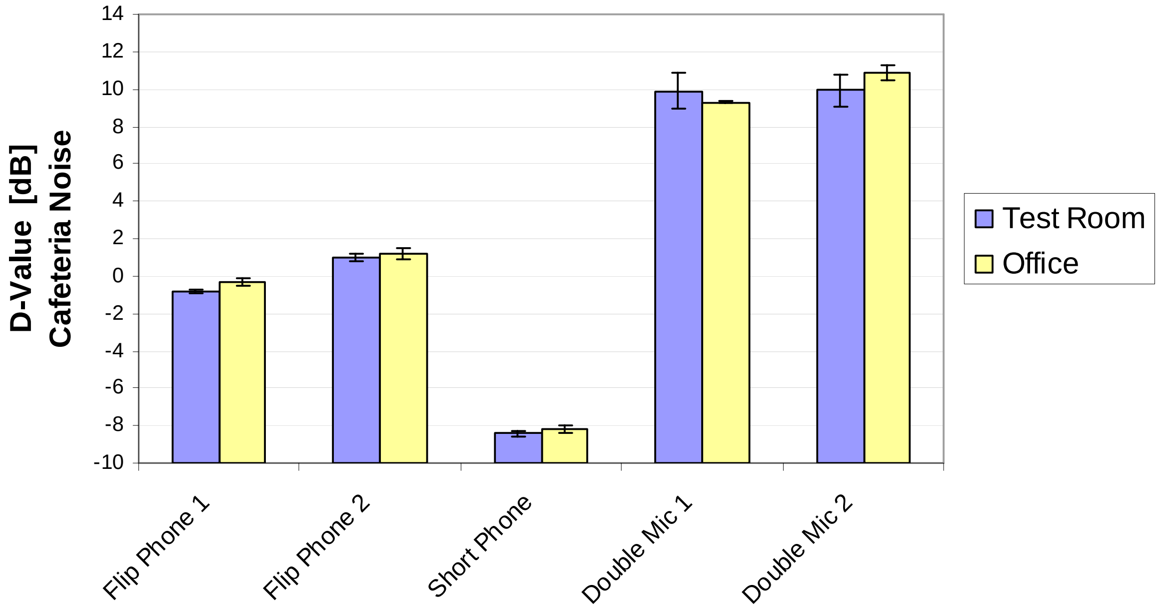


Figure 11: D-Value with Cafeteria Noise measured for the different phones in the different rooms

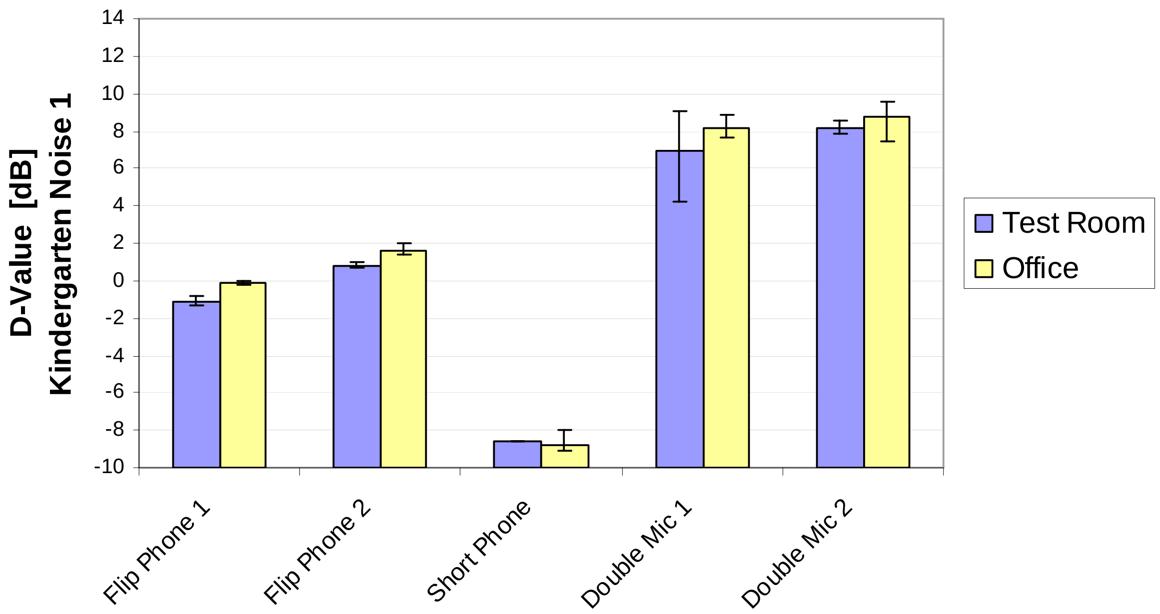


Figure 12: D-Value with Kindergarten Noise measured for the different phones in the different rooms

Result summary of D-Value tests / room comparison

- Due to their technology, both "Double Mic" phones deliver the highest D-Value scores for almost all test cases. The achieved results are a magnitude better than for all other phone types.
- On the other hand, both "Double Mic" phones show comparatively high deviations between single tests in one room environment (indicated by "whisker" lines).
- The "Short Phone" delivers the lowest D-Value scores for all background noises used. It is inferior due to its size as well as due to its internal old technology.
- The average as well as the maximum scatter of the determined D-Values varies depending on the background noise used. It can be assumed that the scatter variation is caused by the "criticalness" of the background noise: A correlation is supposed to be depending on overall level, level vs. time and especially degree of background voice content that is difficult to interpret for any noise canceller. This can be seen as the reason why Cafeteria Noise results in lower scatter scores than Kindergarten Noise, see figures 11 & 12.
- Pink Noise results in lowest average (0.56 dB) as well as lowest maximum (1.06 dB) scatter of all D-Values for all phones. The scatter scores are lower than for all used realistic noises.
- Due to its high degree of ambient voice content, Kindergarten noise seems to be the most critical noise for a D-Value determination with respect to test result reproducibility.
- Maximum achieved variation (scatter) over all tests and results has been 3.34 dB. As a consequence, result accuracy for D-Values independent from the background noise source used can be assumed to be lower than ± 2 dB.
- Deviations between the two rooms are not significantly different from the scatter of single tests within one room. There is no trend that one type of room delivers significantly higher or lower result scores for all cases. Consequently, the room type used cannot be seen as factor for D-Value tests.

Regarding the amount of different result interpretations, an additional comparison of all average D-Values for all five phones under all seven background noises was made. The comparison is shown in figure 13

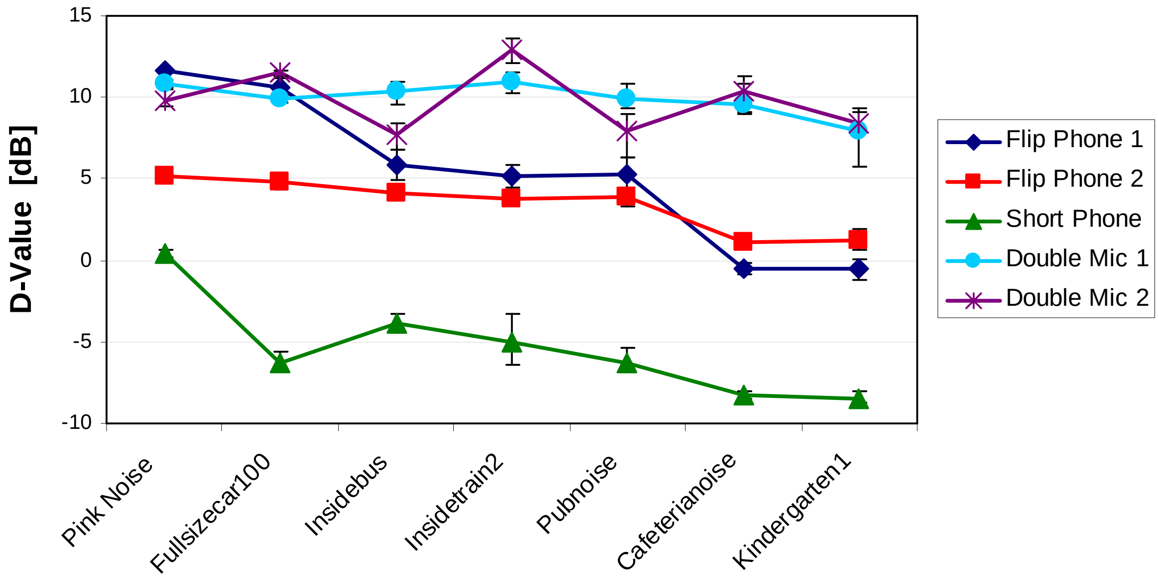


Figure 13: Comparison of D-Values for the different phones with different noises

Result summary of D-Value tests / background noise comparison

- The average curve progression for the curves show a rough tendency downward from left to right listed noise. Pink Noise delivers highest D-Value scores for almost each single phone whereas Kindergarten Noise delivers low D-Value scores for almost each phone. Cafeteria Noise is at the low end side of the measured D-Values.
- However, the "Double Mic 2" phone does not exactly follow the above stated trend. Furthermore, the phone reached the highest average scatters over all noises.
- As indicated, both "Double Mic" phones achieve highest D-Value scores whereas the "Short Phone" delivers lowest D-Values for almost all noises. Deviations are higher for more "critical" noises such as Cafeteria Noise and Kindergarten Noise. For these noises, the results can be grouped into three quality areas: "Double Mic" phones, "Flip Phones" and "Short Phone".
- Scatters of the "Short Phone" are always comparatively low, except for "Insidetrain2" noise. It was not possible to determine a specific reason for this phenomenon.

General summary / D-Value tests

To abstract the above stated results it is shown that the D-value results of Cafeteria and Kindergarten Noise are within one range whereas the corresponding scatters are different. Different rooms do not deliver different results whereas different noises have a high influence on the result for a single phone.

4. Summary

The experiments conducted lead to the following conclusions:

- The repeatability of mobile phone tests in sending direction depends on the individual phone type. Frequency response characteristics as well as SLR may differ up to 3 dB.
- The main reasons for the differences observed are the highly non-linear and time-variant signal processing techniques used in modern phones. Slight positioning inaccuracies may also contribute to differences (sometimes this is just a second order effect due to a slightly different signal level of the test signal at the mobile phone's microphone).
- TMOS SND tests showed a possible correlation on the room reverberation time, depending on the phone type. All different phone types provided significantly poorer TMOS SND results when tested in a reverberant room environment. This effect is especially of relevance for shorter types of phones.
- The D-Value differences measured are in a similar range as found for the SLR's.
- The slightly different background noise setups for different types of rooms as described in EG 202 396-1 lead to very comparable results when applied to different rooms. This means that D-Values results measured with the EG 202 396-1 background noise setup in different rooms are comparable between office rooms and semi-anechoic or fully anechoic test rooms.

5. References

[1] ETSI EG 202 396-1, Speech Processing, Transmission and Quality Aspects (STQ); Speech quality performance in the presence of background noise; Part 1: Background noise simulation technique and background noise database

[2] ETSI EG 202 396-3, Speech Processing, Transmission and Quality Aspects (STQ); Speech quality performance in the presence of background noise Part 3: Background noise transmission - Objective test methods

[3] ETSI TS 51.010, GSM/EDGE Radio Access Network: Digital cellular telecommunications system (Phase 2+); Mobile Station (MS) conformance specification; Part 1: Conformance specification

[4] ITU-T Recommendation P.57, Artificial ears

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

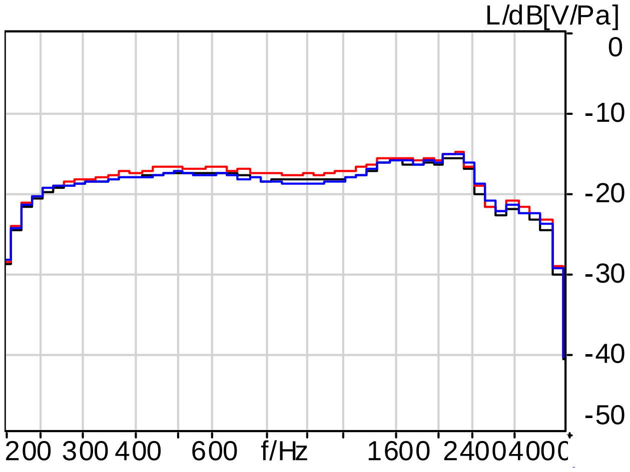
[6] ITU-T Recommendation P.64, Telephone Transmission Quality Objective Measuring Apparatus, Determination of Sensitivity/Frequency Characteristics of Local Telephone Systems

[7] ITU-T Recommendation G.111, Transmission Systems and Media, General Recommendations on the Transmission Quality for an Entire International Telephone Connection, Loudness Ratings in an International Connection

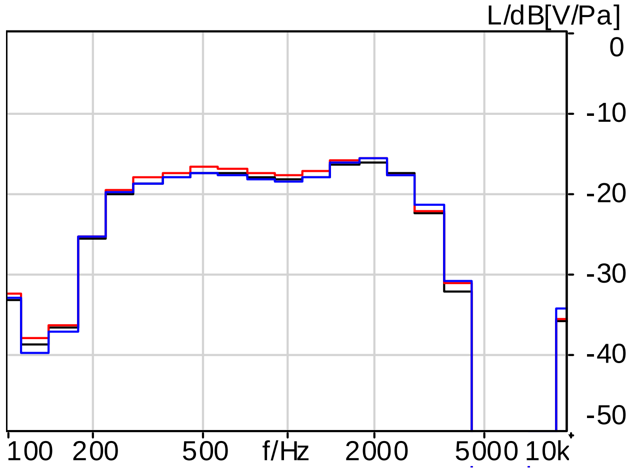
[8] HEAD acoustics Application Note, Telecommunications Objective Speech Quality Assessment

6. Graphs

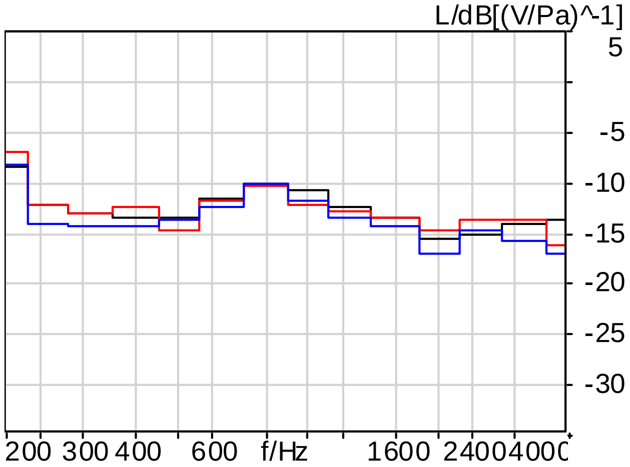
Sending Frequency Response



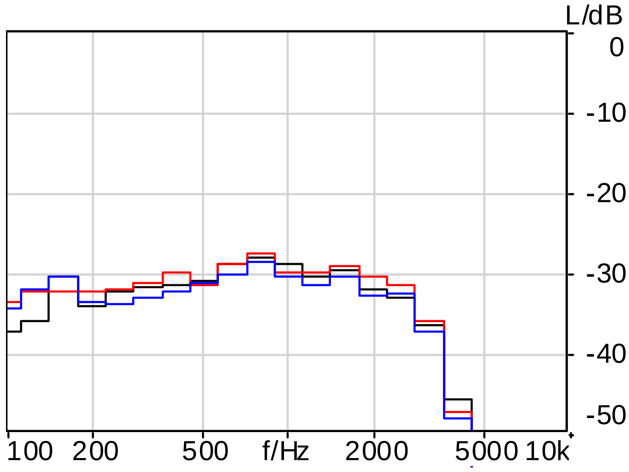
Direct Sound Sensitivity



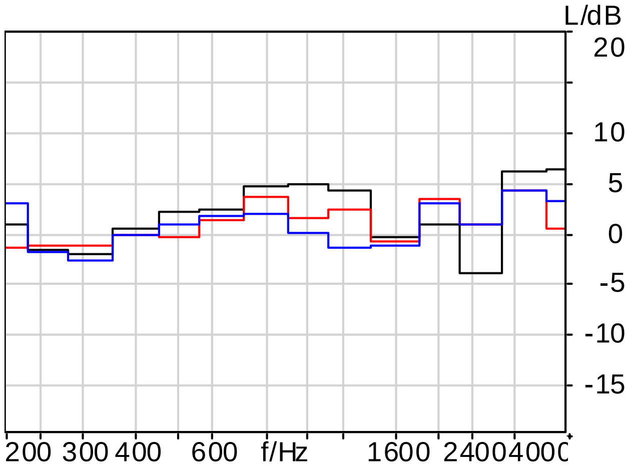
D-Value, Pink Noise



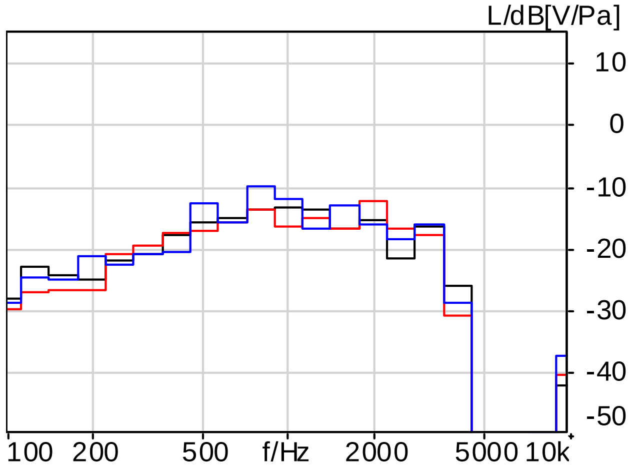
Diffuse Sound Sensitivity, Pink Noise



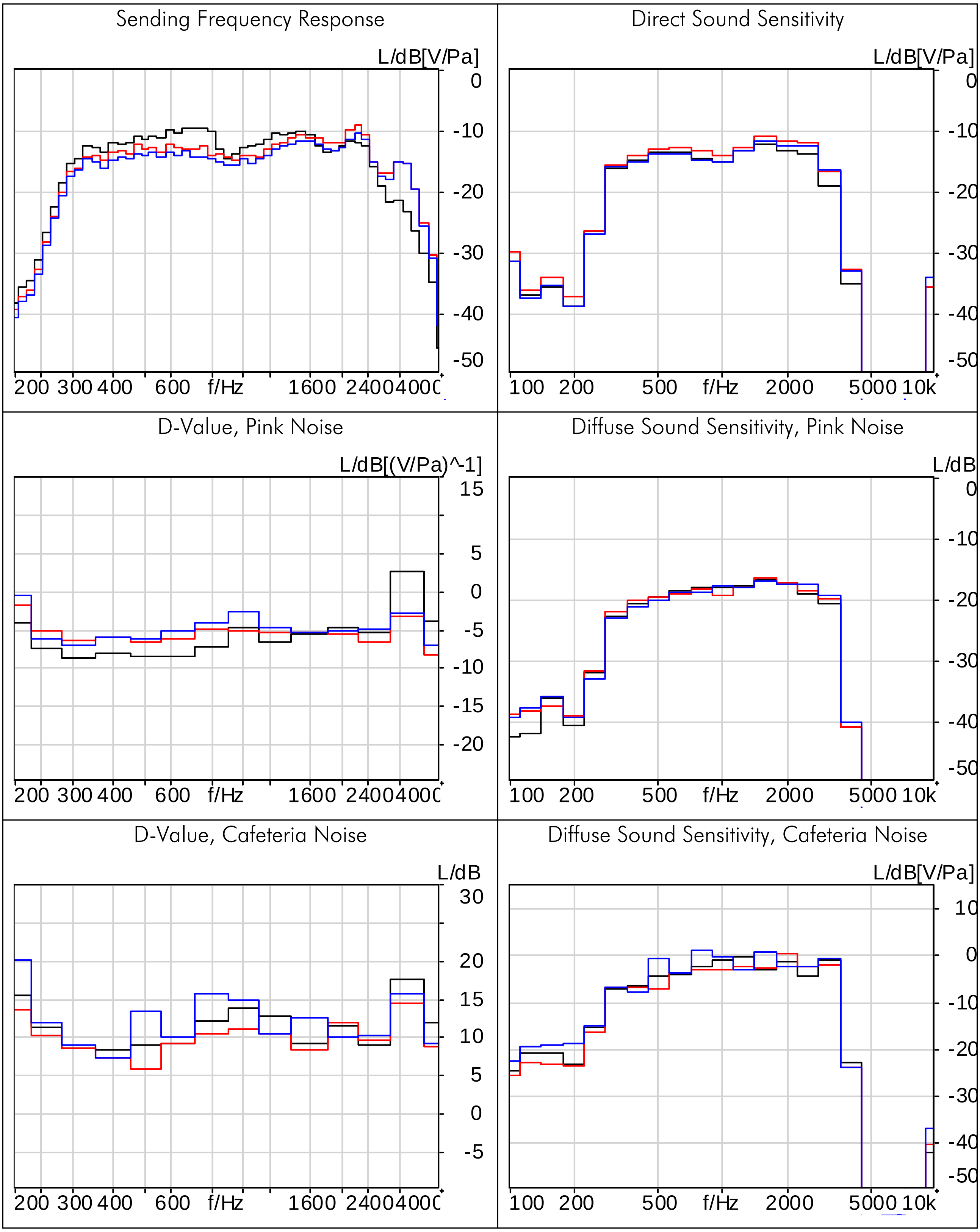
D-Value, Cafeteria Noise



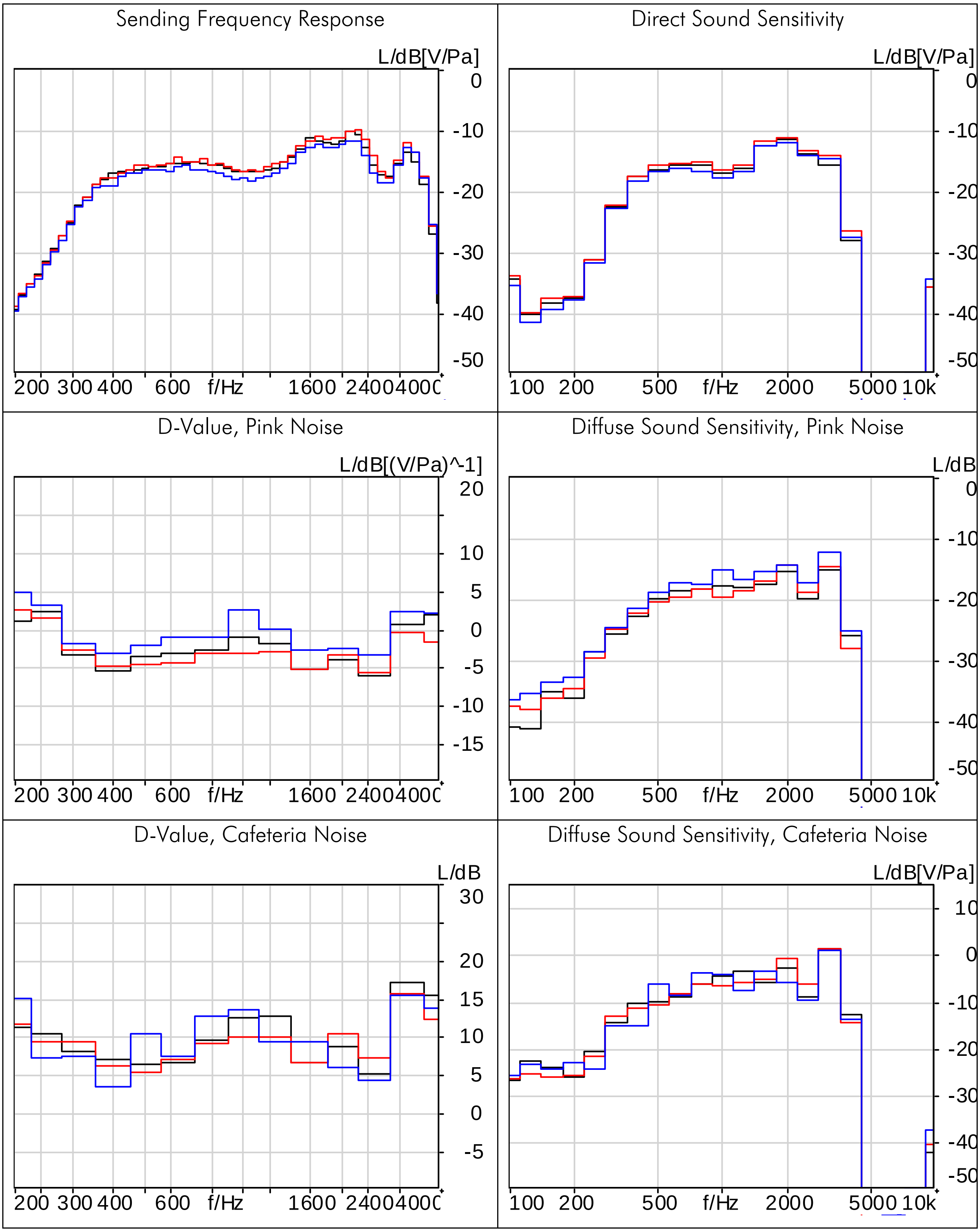
Diffuse Sound Sensitivity, Cafeteria Noise



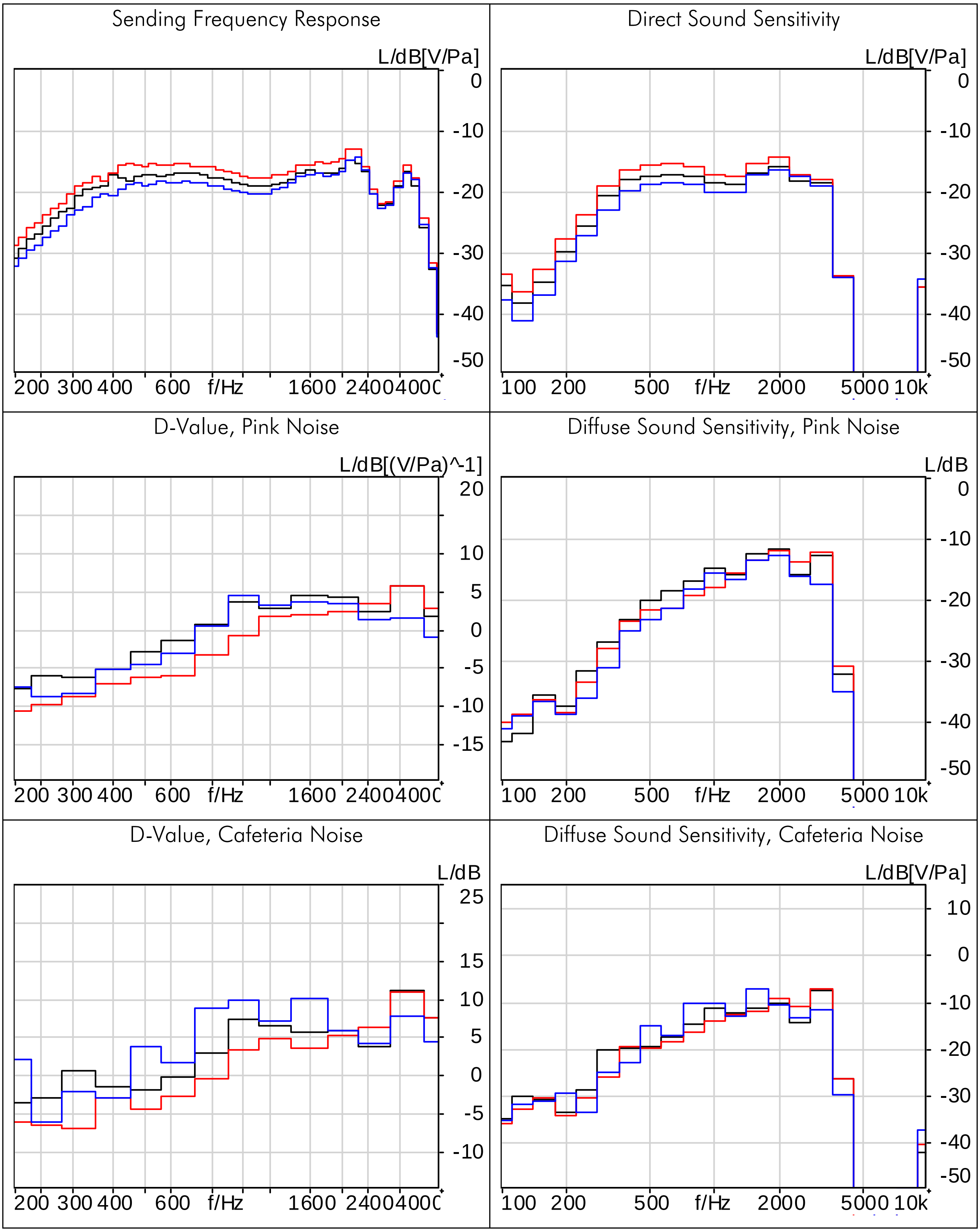
Measurements of phone 1: black – fully anechoic; red – office type room; blue – semi anechoic



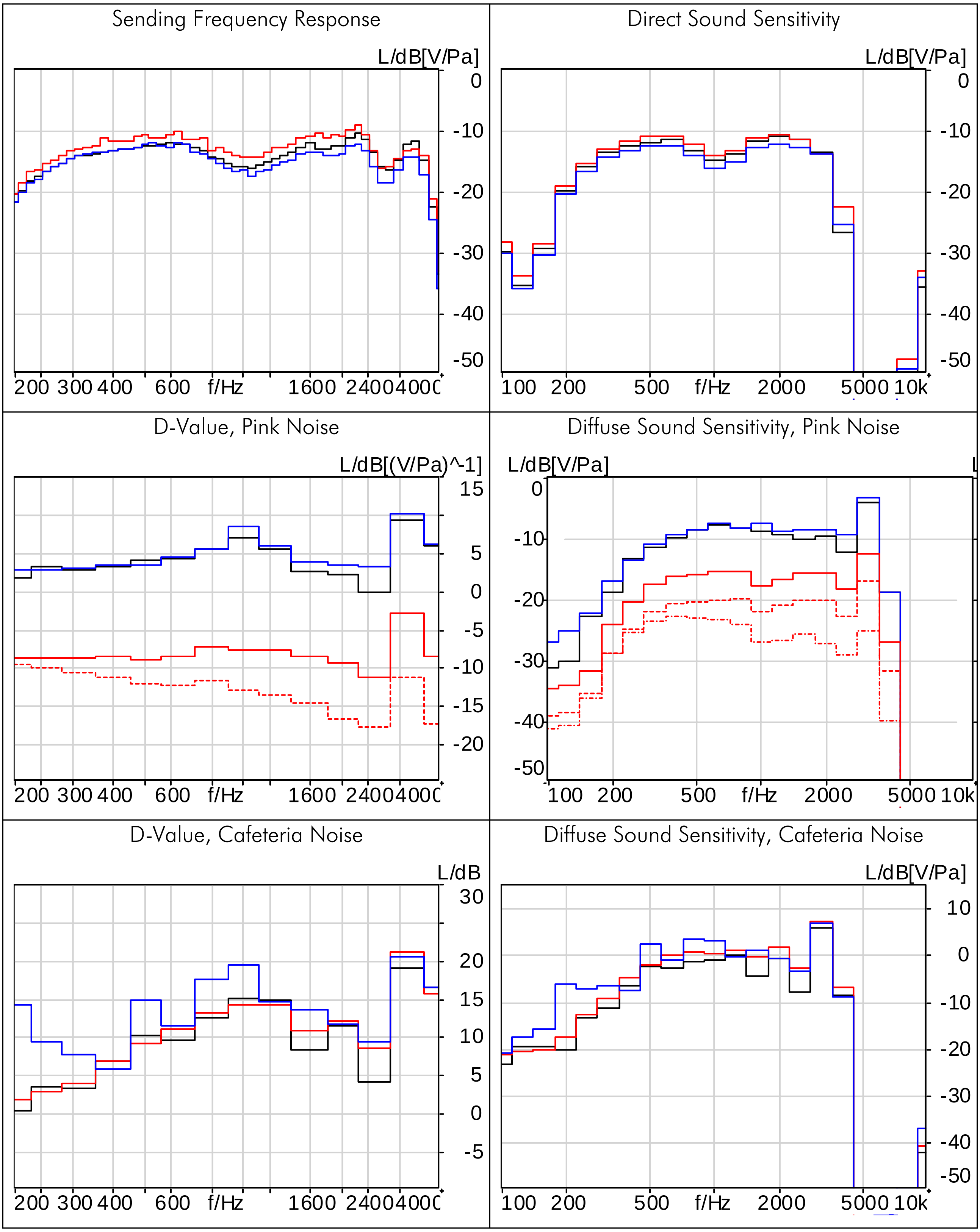
Measurements of phone 2: black – fully anechoic; red – office type room; blue – semi anechoic



Measurements of phone 3: black – fully anechoic; red – office type room; blue – semi anechoic

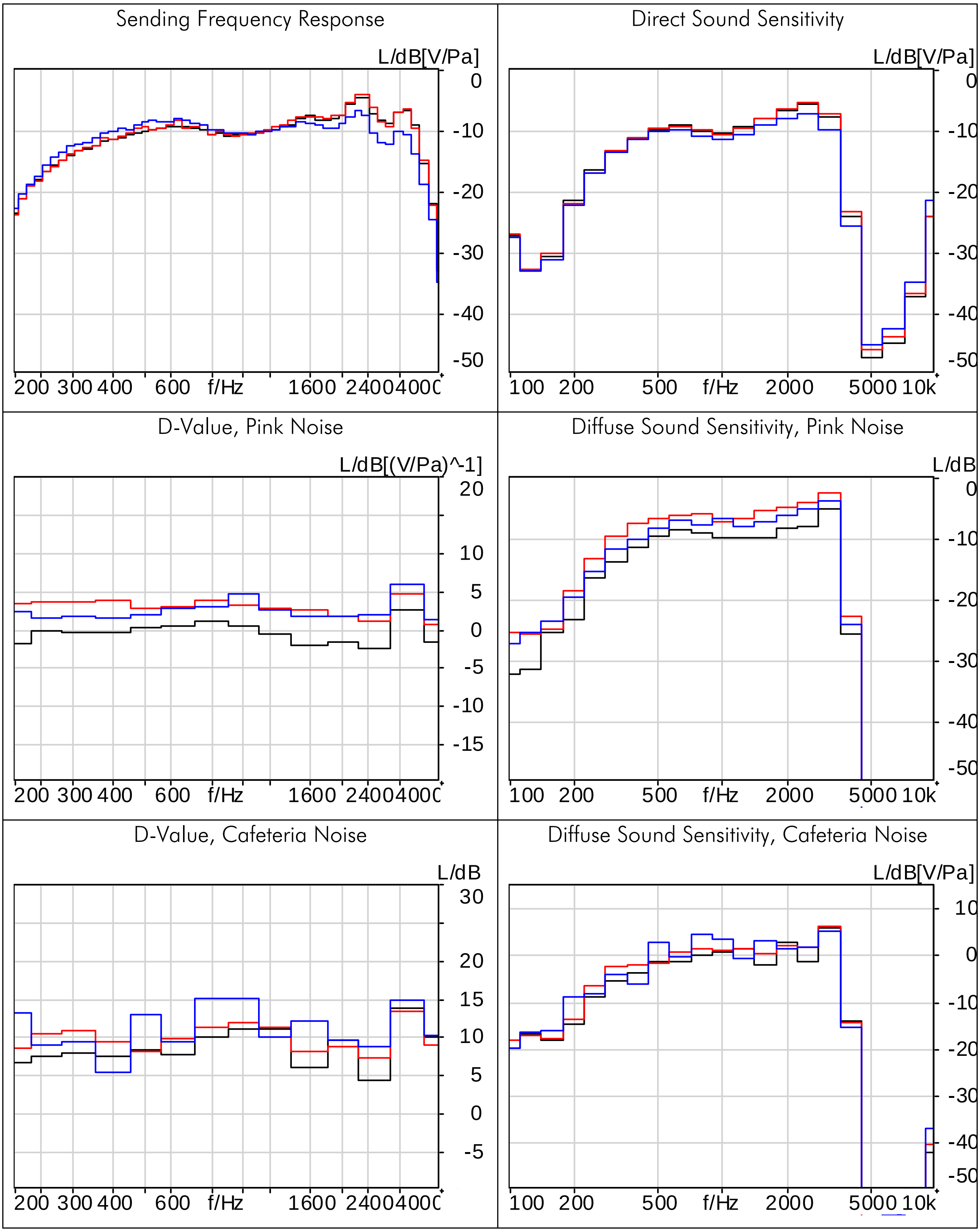


Measurements of phone 4: black – fully anechoic; red – office type room; blue – semi anechoic

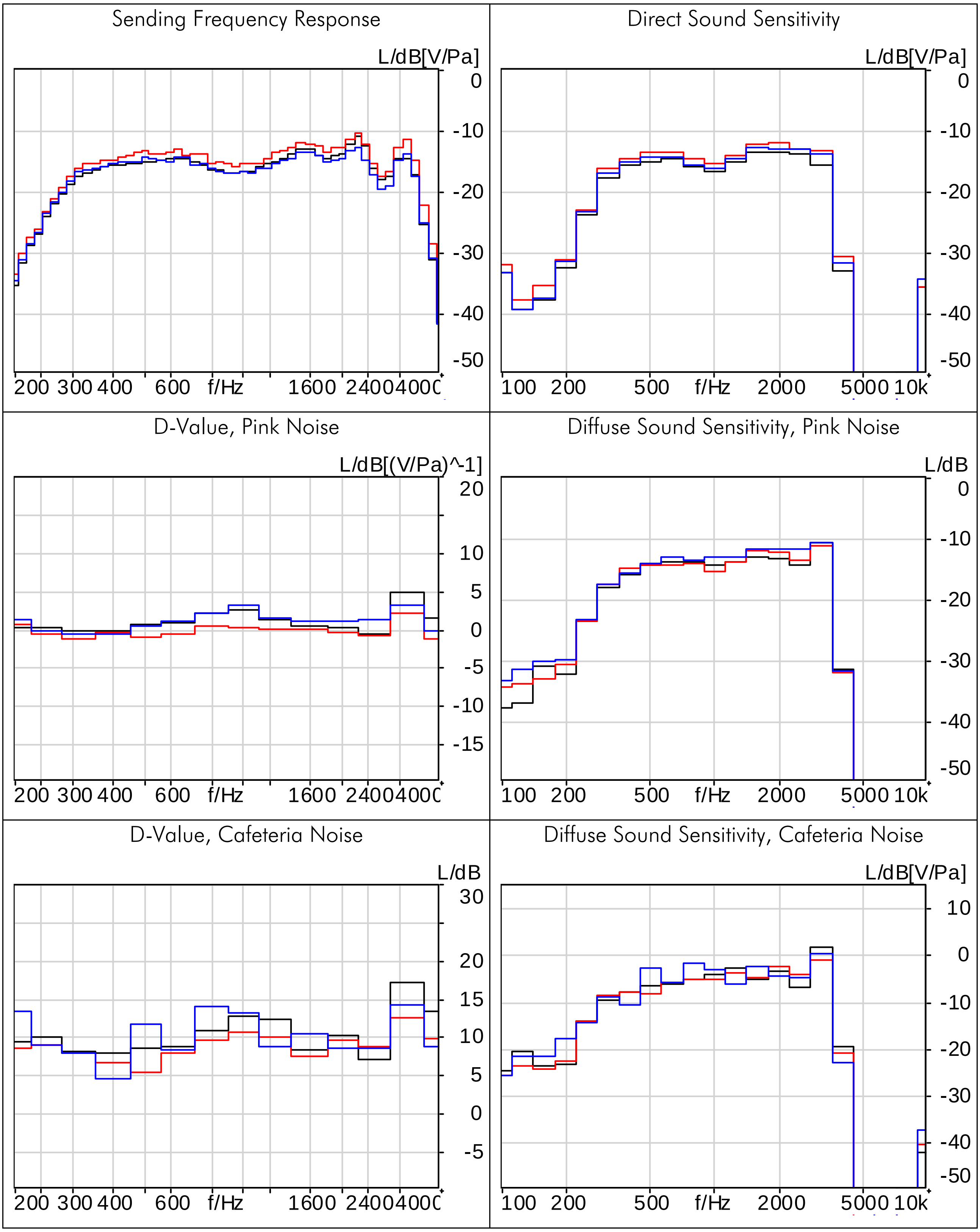


Measurements of phone 5: black – fully anechoic; red – office type room; blue – semi anechoic

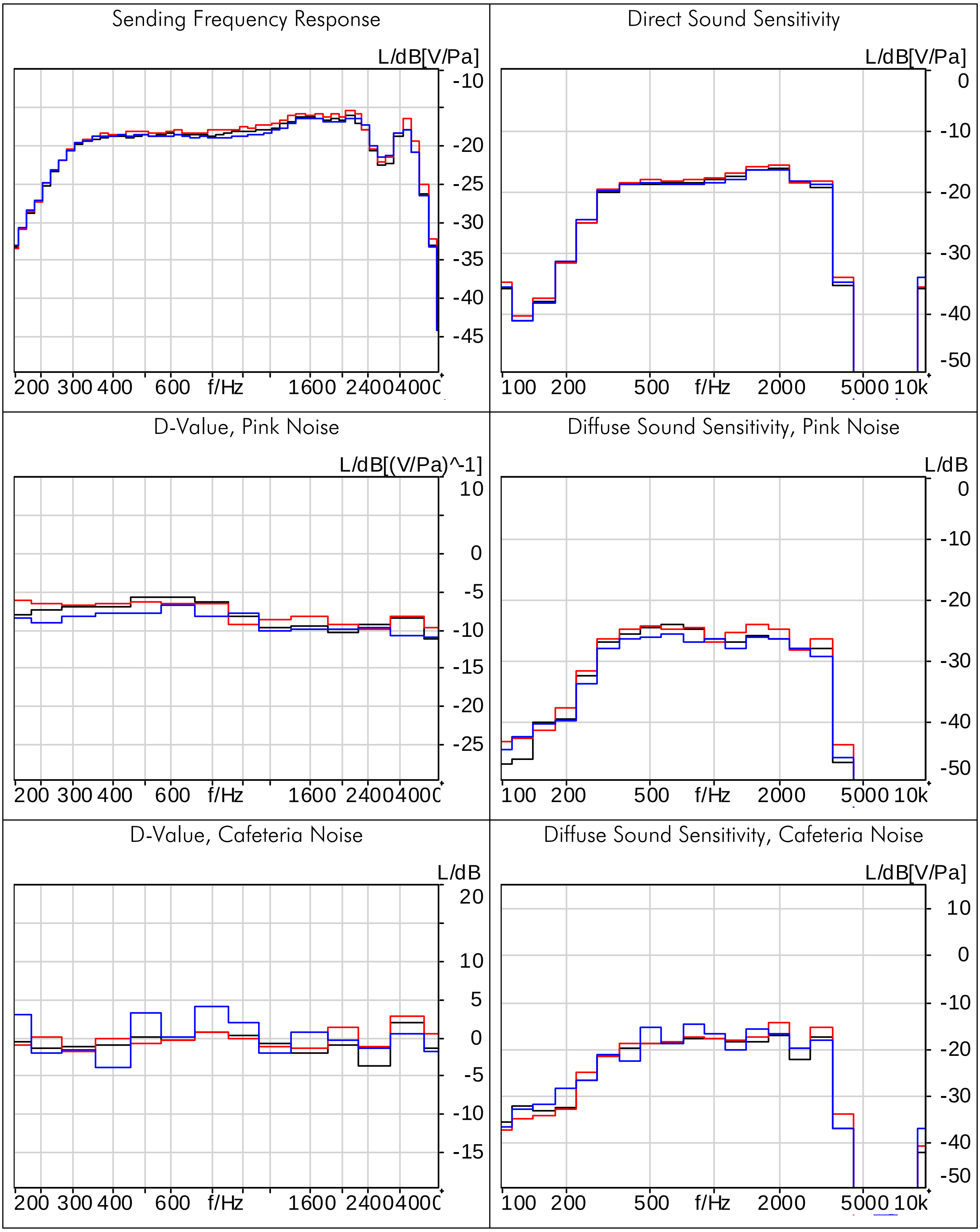
different line types = same test setup but test conducted different times with pink noise field



Measurements of phone 6: black – fully anechoic; red – office type room; blue – semi anechoic



Measurements of phone 7: black – fully anechoic; red – office type room; blue – semi anechoic



Measurements of phone 8: black – fully anechoic; red – office type room; blue – semi anechoic