Subject:	Investigation to clarify the specifications in accordance with Appendix G TSI PRM (Door Warning and Finding Signals)

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S Management Summary - Proposals for clarification of the PRM TSI Appendix G

In order to clarify the specifications for door finding signals in the TSI PRM Appendix G, a study was carried out on behalf of the Federal Office of Transportation of the Swiss Confederation (BAV) with the involvement of an advisory group. The advisory group consisted of the following representatives:

- Bundesamt für Verkehr der Schweizerischen Eidgenossenschaft, BAV (client)
- Schweizerische Bundesbahnen AG, SBB (Rail Production and Fleet Strategy)
- Deutsche Bahn AG, DB (Innovation, Gremienarbeit und Service Technik Schienenfz., FE.EF 33)
- Deutsche Bahn AG, DB (Kompetenzzentrum Akustik und Erschütterungen, TT.TVE 35)
- EAO AG (manufacturer of signaling devices, Switzerland)
- TSL-ESCHA GmbH (manufacturer of signaling devices, Germany)
- TAC - Technische Akustik (contractor)

The results were discussed in detail within the working group, and the below described coordinated recommendations were developed. The recommendations are also described in Section 7 and are summarised below:

S.1.1 Definitions

In accordance with Section 3.4.2, the signal definitions should first be clarified:

L_S = sound pressure level of the signalling device measured as L_{AFmax} (the maximum sound level with frequency-weighting 'A' and time-weighting during the measurement period 'Fast')

L_{Smax} = maximum signal level L_S (measured as L_{AFmax})

L_{Smin} = minimum signal level L_S (measured as L_{AFmax})

L_N = level of the background noise, measured as follows:

S.1.2 Measurement of background noise

The background noise measurement is to be carried out as an energetic sum over 3 octaves. Alternatively, it has been shown that for most platform noises, even a broadband but A-weighted sum level gives almost the same results. From a technical point of view, the octave method offers a certain advantage, because for all types of background noise (at least to a large extent) only those frequency ranges are taken into account that also contribute to masking the door signals. In both cases, the signal processing of the microphones which detect the noise situation must perform appropriate frequency filtering.

A significant improvement in terms of readability and comprehension of Appendix G is given if a distinction is made between the definition of the signal, the detection of noise during train operation, and the detection of noise during type approval.

S.1.2.1 Signal definition and measurement of background noise during train operation

Accordingly, the following clarifications can be made as an alternative:

a.) Similar to the previous definitions in TSI PRM Annex G:

L_N = Level of the background noise

L_N is to be measured as an energetic sum over 3 octaves as follows:

$$L_N = 10 \cdot \log_{10} \sum \left(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}} + 10^{\frac{L_3}{10}} \right)$$

$$L_1 = L_{oct,500Hz}$$
$$L_2 = L_{oct,1000Hz}$$
$$L_3 = L_{oct,2000Hz}$$

L_N is determined as an energy-equivalent continuous sound level over a time period T:

$$L_N = L_{eq,T}$$

The measurement of the background noise on the platform starts immediately before the emission of the door finding signal and then continuously during the respective signal pauses of the door finding signal as follows:

For the single tone signal, the individual measurements must be carried out during each signal pause over a period of at least 200 ms. The individual measurements for the dual tone signal are to be carried out within one signal period during the long signal pause over a length of at least 800 ms.

From the individual measurements, a sliding energetic average is to be formed over 5 s. For the sliding average, all consecutive individual measurements shall be averaged, with all measurements occurring more than 5 s in the past being removed from the calculation.

Note: When recording the background noise with a microphone positioned at the door, the level occurring there is 3 dB higher than at the reference point due to the reflection at the boundary surface.

S.1.2.2 Measurement of ambient noise at the vehicle

It is necessary to decide whether the TSI PRM Appendix G should also include statements on measurements at the vehicle. In any case, it is advisable to consider the following notes and suggestions.

When measuring at the vehicle, an artificial background noise must be generated. For this purpose, the use of pink noise is suitable as a substitute source. In this case, it must be ensured that the signal level is determined at the reference point, but the noise level is determined at the train door via the built-in microphone. The noise level determined at the train door must be recorded in parallel with a suitable sound level meter (comparative measurement). The background noise, which is generated by means of pink noise, is thus determined directly at the door. The location of the sound source must be chosen in such a way that the difference in level between the reference point and the measuring point on the door, taking into account the boundary surface situation, is negligible (typ. ΔL < 1dB).

Attention: When detecting background noise with a microphone at the surface of the door, the level occurring there is 3 dB higher than at the reference point due to the reflection at the boundary surface. This must be taken into account when determining a measurement method for measurements at the vehicle.

When performing measurements at the vehicle, the averaging time should be at least T = 20 s.

S.1.3 Determination of signal levels and S/N ratios

a.) The studies show that a fixed signal level for the door finding signals is **not an adequate solution** to the trade-off to be achieved between audibility and excessive sound emission.

It is therefore proposed that door finding signals should be mandated to be adaptive signals.

b.) For better audibility, the waveform should be required to be rectangular and not sinusoidal.

c.) Based on the feedback of the test subjects, the single tone signal should be emitted at the lowest possible rate of occurrence.

Therefore, the number of pulses should be reduced from 3 to 5 per second to 3 to 4 per second.

d.) As a compromise between audibility at an acceptable distance and thus the safe location of the door and the noise immission protection, an **S/N ratio of -6 dB** must be achieved for the **single tone signal**. Due to the poorer perceptibility of the **dual tone signal** compared to the single tone signal, an **S/N ratio of -3 dB** is recommended.

In addition, it is important to make sure that the signals are not audible at too far away a distance (typically > 6 m), otherwise confusion and mislocation could arise in relation to trains on the opposite platform that are also sending out door finding signals.

If adaptive signals are implemented exclusively, the requirements of immission control are also reliably fulfilled, because the door finding signal noise components emitted by the doors are safely lost in the background noise from a distance > 10 m anyway and can therefore no longer disturb the neighbourhood.

e.) As shown in Section 4 with platform noise statistics, the L_{AF10}, which is approximately 75 dB for most situations, has been chosen as the basis for safety concerns when setting levels for safety alerting via the PA system. Since door finding signals are not safety signals in the strict sense, it is recommended to attenuate the requirement and use the L_{AF20} percentile level, which is typically around 70 dB. With a sufficient S/N ratio of -3 dB or -6 dB, this would result in maximum levels of approx. L_{AFmax} = 67 dB and L_{AFmax} = 64 dB, respectively.

G. 3.1. Single tone signal

Characteristics	Tone impulse (rectangle), no fade in or fade out, impulse waveform rectangle (no sinusoidal impulse) - signal impulse duration = 5 ms ± 1ms „on“ (tone signal) - signal time pattern of 3 to 4 pulses per second
Frequency	- f_{signal} = 630 Hz ± 50 Hz
Sound pressure level adaptive (not static)	- $L_S \geq L_N$ – 6 dB - $L_{S\ min}$ = 40 dB ± 2 dB - $L_{S\ max}$ = 67 dB ± 2dB

G. 3.1. **Dual tone signal**

Characteristics	***without changes***
Frequency	- ***without changes***
Sound pressure level adaptive (not static)	- $L_S \geq L_N - 3$ dB - $L_{S\,min} =$ 45 dB ± 2 dB - $L_{S\,max} =$ 70 dB ± 2 dB

The dynamic range of 25 dB proposed here is appropriate from an acoustic point of view. However, it must be discussed with the manufacturers of the signalling devices to what extent such a dynamic range can be implemented in the electronics.

It is important to note that even with S/N ratios < 6 dB (down to about -10 dB), the door can still be found reliably in the event of changes occurring in the ambient noise. This "merely" reduces the distance to the door (approx. 3 m), from which the signal can still be heard and serve as an acoustic guide.

S.1.4 Additional clarifications

Another important question for determining the signal levels is the placement of the signal transmitter. If it is attached to the top of the door, it is much easier to install larger and more powerful sound transmitters. This should also be taken into account.

Experiments and interviews with the visually impaired have shown that a signal transmitter for door finding signals can also be installed above the door. However, the same or similar certainty for locating the door button only appears to be given if an additional tactile aid is introduced, e.g. in the form of a rubber strip or similar. Examples of this can be seen in the following illustrations.

Figure 0.1.1 a-b: View of a train door with tactile aid (blind strip)

Last but not least, the contents of Section 4.2.2.3.2 "Exterior doors" of the Commission Regulation [6] also need to be adapted as follows.

(10) The sound source for door signals shall either be placed above the door in the middle of the doorway or in the area local to the control device.

If there is no control device and the sound source cannot be placed above the door, the sound source for door signals shall be located adjacent to the doorway.

If a separate sound source is used for the door closing signal, it can be either local to the control device or adjacent to the doorway.

If an external door signal is provided, its sound source shall either be placed above the door in the middle of the doorway or in the area local to the control device. If the sound source is placed above the door, an additional tactile aid (guidance strip) must be integrated into the door to aid with locating the door button. The tactile aid must be mounted both above and below the door button with sufficient length. The contrast to the background according to EN 16584-1 must be observed.

It is also necessary to consider where the following addition is to be added to the TSI PRM.

Door finding signals shall not be emitted at the same time as door opening and closing signals.

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1 Introduction

The TSIs - Technical Specifications for Interoperability - set out technical specifications to ensure interoperability in rail transport and its structural subsystems in the European Economic Area. The TSIs are also mandatory in Switzerland. They are published in the Official Journal of the European Union.

The TSI PRM - Technical Specifications for Interoperability: Persons with Reduced Mobility [1] -, a cross-subsystem TSI – Vehicles and Infrastructure, regulates accessibility for persons with disabilities and with reduced mobility. For example, it specifies how exterior doors of rail vehicles must be equipped with regard to acoustic signalling, among other topics. In particular, there are specifications for the presence of door opening and closing signals.

In 2023, the TSI PRM (made mandatory by the Official Journal of the European Union [6]) stipulated that so-called door finding signals can also be used in the area of external doors as an option. In contrast to the door opening and closing signals, the door finding signals are not warning signals, but signals that are intended to make it easier for visually impaired people to find the door. Although there are specifications for door opening and door closing signals in EN 14752 "Railway applications – Bodyside entrance systems for rolling stock" [2] and in EN 16584-2 [4], the TSI PRM has its own specifications for door opening and door closing signals as well as for door finding signals, which have not yet been specified in any standard. For example, "Section 4.2.2.3.2 Exterior doors" specifies the arrangement and placement of the signalling devices and the manner in which the signal is to be presented. In Appendix G of the PRM TSI, the individual signals are defined in terms of their frequency, their waveform, as well as their signal level.

With regard to door-finding signals, Appendix G of the TSI PRM defines two fundamentally different signals. On the one hand there is a clocked impulse (single tone signal), as it is known from German traffic lights for example, and on the other hand a swelling two-tone signal (dual tone signal). The definition of the clocked pulse goes back to its proposal and use in Germany, the definition of the two-tone signal to its already established use in Switzerland. In addition to the actual signal definition, Appendix G also contains specifications for the sound pressure levels of the signals to be realized, also in relation to background noise.

The audibility of signals is strongly dependent on the ratio of its signal level to the background noise (ambient noise). Therefore, there are two different specifications for the signal level to be realized in Appendix G, depending on whether a measurement of the background noise is carried out and thus the signal level can be adapted to it (adaptive level), or whether a fixed signal level must be set without knowledge of the background noise.

It should already be mentioned here in the introduction that the background noise is noise on the platforms that is caused by the interaction of all sound sources in the area of influence. These are speaking persons, announcements via the public address system, and trains entering or leaving on other tracks. Rarely, if ever, is the background noise caused by the train where the door is supposed to be found. So, as a rule of thumb, the background noise has no direct correlation with the sounds of the train at which the signal is to be found. An exception to this are diesel locomotives, whose engines in close proximity to the doors contribute significantly to the background noise level.

With regard to the adaptive adjustment of the door signals explained above, one might think that there is no need for such an adjustment if only it is set "loud enough" such that the level is sufficient for all applications (i.e. for all background noise situations). While comparatively high levels can and must be used for door opening and closing signals, which function as warning signals and must therefore be perceived in any case, there is a considerable conflict of interest and thus conflict of objectives, especially when determining the levels for door finding signals.

With regard to the volume of door warning and door finding signals, the conflict of interest exists between, on the one hand, the needs of people with visual impairments in particular, who may also have a hearing impairment (need for audibility and locating of the signal) and prefer a particularly loud door-finding signal, and on the other hand, the noise protection needs of the general public or the residents in the neighbourhood of railway stations and other passengers, who in turn require a very quiet signal. In principle, this conflict of interest can be mitigated by adapting the volume of the signals to the respective ambient noise, as already explained. Although it is therefore obvious a priori that adaptive control is absolutely necessary for the reconciliation of interests, it remains unclear for the time being which signal level must be set in comparison to the background level for safe audibility.

It is also necessary to explore this conflict of interest by applying the two types of signals described in the TSI PRM, namely the single tone signal and the dual tone signal. Due to their differences, the two signal levels must be set in such a way that the above objectives are met in a similar way for both signals.

The current TSI PRM already contains definitions for the above issues, but these have given rise to criticism on some points and therefore need to be adapted and clarified. The points of criticism were in detail:

- The level set for the door detection signals is too high.
- The type of signal definition differs from that of door opening and closing signals and should be standardised.
- The measurement methodology for door opening and closing signals should be reviewed and aligned with the method of door finding signals.
- The levels for both types of door detection signals should be evaluated and adjusted.

Another point of criticism is related to the location of the door signal transmitter. According to the currently applicable specifications of the TSI PRM for door finding signals, it should be located near the door button. This takes into account the fact that the door finding signal, as it was conceived at least in Switzerland, was intended to be a door **button** finding signal in the true sense of the word, and thus the fixed positioning seems to make sense. However, the manufacturers of such signalling devices argue that it is easier and less costly to place the signal transmitter above the door. In this case, the signalling devices could perform several functions at once and could be adequately equipped in terms of level and power. The latter is difficult to implement in the door. In this respect, the question remains open as to whether the door or the door button can be found with sufficient reliability using a signal transmitter placed above the door – or, depending on the situation (e.g. other passengers waiting at the platform) even better than with a transmitter placed near the button.

In order to clarify the above question, the Federal Office of Transport (BAV) has commissioned a three-part study with the aim of reviewing, supplementing and explaining the revised specifications of Annex G of the TSI PRM [6] or, if available, the final adapted version of the TSI PRM with regard to the above conflict of objectives.

The study is divided into three parts:

Part A Theoretical considerations and calculations

On the basis of theoretical considerations, the following questions will be examined and answered in the best possible way:

- What types of noise are typically to be expected at railway stations in terms of levels and frequencies (background noise levels)?
- Which frequency range is effective as a masking range (interference efficacy range) for the application of the door finding signals?
- At what distance and direction to the open door should the door finding signal be reliably detected for people with normal hearing?
- What are the possible consequences for the hearing impaired?
- What is the minimum level that must always be reached?
- What maximum level should not be exceeded?
- Which level should be preferred for dual tone signals with non-adaptive control (static level)?
- What dynamic range (difference between the lowest and the highest level) should the door finding signal have, taking into account theoretical, but also practical aspects (dynamic range of the signal transmitters used)?
- How are the background noises to be captured for adaptive control?

- To what extent can the considerations be transferred to the clocked pulse signal (German application)?
- How can the signal types (single tone signal and dual tone signal) be aligned with regard to the conflicting goals (lowest possible levels with the best possible signal detection)?
- How should the associated signal parameters with regard to each signal be defined?

Part B Listening tests

The practical investigations are to be carried out with an appropriate number (typically up to 10 people) of representatives of persons with visual impairments as well as age-related (mild) hearing and visual impairments both in the laboratory and, whenever possible, in the field (i.e. at railway stations/stops with built-in acoustic signalling devices). The investigations should include the following points

- Verify the theoretical investigations for various noise and signal situations
- If necessary, adapt the findings found in the theoretical investigations on the basis of the practical investigations

Part C Discussion and reporting

- Summarize the investigations in a report on the results.
- Prepare a proposal for the adaptation of the TSI PRM.

For this assignment, an advisory group was formed, which accompanied the questions and the procedure of the experiment in terms of content and which finally developed the corresponding recommendations for the specification of the TSI PRM Appendix G on the basis of the results and the associated conclusions.

The entire advisory group consisted of representatives of:

- Bundesamt für Verkehr der Schweizerischen Eidgenossenschaft, BAV (client)
- Schweizerische Bundesbahnen AG, SBB (Rail Production an Fleet Strategy)
- Deutsche Bahn AG, DB (Innovation, Gremienarbeit und Service Technik Schienenfz., FE.EF 33)
- Deutsche Bahn AG, DB (Kompetenzzentrum Akustik und Erschütterungen, TT.TVE 35)
- EAO AG (manufacturer of signaling devices, Switzerland)
- TSL-ESCHA GmbH (manufacturer of signaling devices, Germany)
- TAC - Technische Akustik (contractor)

The summary of the results obtained in the study is the subject of this report.

2 Signals, levels and sound fields

The purpose of this section is to provide a brief explanation of the essential principles of acoustic signals, their detection and assessment, in order to be able to understand the signal definitions given in the standards, their contradictions as the case may be, as well as the subsequent conclusions and recommendations. If the acoustic basics are known, this section can be skipped.

2.1 Sound pressure level and time weighting

Alternating sound pressure *p*, or sound pressure for short, is the term used to describe the pressure fluctuations around the static quiescent pressure that occur due to the presence of sound waves. The corresponding time signal is marked with *p(t)*. The sound pressure in the hearing range typically covers a frequency range of 20 Hz to 20,000 Hz. The frequency range of human speech ranges from about 100 Hz for the low tones to 7000 Hz for the high parts of speech such as hissing and plosive sounds. As a rule, an energetic consideration is used to measure the sound intensity. To do this, the time function is first squared ($p(t)^2$), since the energy of the signal is proportional to the square of the sound pressure. Because of the wide dynamic range that the human ear is able to perceive, as well as because of the basic laws of loudness perception, the sound intensity is not given in the form of the time signal *p(t)* or in the form $p(t)^2$ proportional to the energy, but as the so-called sound pressure level curve $L_p(t)$, where the "*L*" stands for "*level*" and the index "*p*" for "*pressure*". The sound pressure level L_p is defined as a relative logarithmic measure according to equation 1. p_0 is the reference sound pressure that corresponds to the human hearing threshold at 1 kHz with $p_0 = 2 \cdot 10^{-5}$ N/m².

$$L_p(t) = 10\log\frac{p(t)^2}{{p_0}^2} \tag{1}$$

The pseudo-unit of sound pressure level is the decibel (dB). The index $_P$ is often omitted from the sound pressure level, especially when it is clear that a sound pressure level is meant. Therefore, for better understanding and readability in accordance with DIN EN 61672-1:2014-07 [5], the index p is not listed below, as the levels discussed here are always sound pressure levels. With the help of the sound pressure level, a quantity proportional to the energy of the sound signal can be displayed on a logarithmic scale. Historically, analogue sound level meters with a pointer display were used to determine the sound pressure level. If the sound pressure level curve of any sound signal in the hearing range is displayed with such a pointer representation, the pointer display is very fidgety and unreadable due to the strong fluctuations in the sound pressure level curve. For this reason, as well as other reasons of hearing physiology, a pointer inertia was introduced with the help of simple technology, which calmed the fidgeting of the display and thus made reading it possible. This pointer inertia was realized with the help of a simple electronic circuit, in which a so-called RC link (electr. resistor and capacitor). A characteristic feature of such circuits is that for very narrow, impulse-containing noises (technically Dirac functions), the rise and fall of energy behaves according to an exponential law (see also [5]). At the time, two time constants were defined:

a.) "F" = "fast" for low pointer inertia, time constant τ=125 ms

b.) „S“ = „slow“ for high pointer inertia, time constant τ=1 s

In practice, this means that the level curves are subjected to a short-term averaging with an exponential window. Roughly and for easy understanding, it can be said that the signals are always energetically averaged within a time window of 125 ms or 1 s, depending on the "F" or "S" setting. The representation of an $L_{pF}(t)$ or $L_F(t)$ is therefore the representation of a sound pressure level curve energetically averaged over the time constant. At the "*F*" setting, the level can drop with a maximum decay rate of 34.75 dB/s after switching off a pulse. At the "*S*" setting, the maximum decay rate is 4.35 dB/s.

In practice, the time constant "*F*" is most often used to represent sound pressure level curves, because on the one hand this time constant still allows a sufficient temporal resolution of the level curve, but on the other hand it also ensures good readability. In addition, the time constant "*F*" is roughly correlated with the time constant of human hearing.

In practice, however, time-varying sound pressure level curves are characterized either in terms of their maximum or in terms of their mean value. The use of maximum values is always useful when it comes to so-called transient signals, i.e. time-volatile signals. The corresponding characteristic value is then called the maximum sound pressure level L_{Fmax}.

Averages are usually used when the signals are largely stationary and thus fluctuate only slightly in their energy over time. The mean value is measured by the so-called energy-equivalent continuous sound level L_{eq}. Equation 2 shows the corresponding mathematical definition.

$$L_{eq} = 10\log\left(\frac{1}{T}\int_0^T \frac{p(t)^2}{p_0^2}\,dt\right) \qquad (2)$$

However, it is not uncommon for signals that are not stationary, i.e. that contain significant impulsive or transient components, to be indicated with an energy-equivalent continuous sound level L_{eq}. In such an approach, however, the averaging time must always be specified in addition, since in the case of transient signals, the average value achieved depends to a considerable extent on the averaging time. An extreme example makes this clear: If, for example, the sound pressure level of a hammer blow, which consists only of a short pulse, were to be represented as L_{eq}, it would depend on the duration of the averaging time which value comes out for the hammer blow. If the averaging time doubles, the energy of the impulse is distributed on average over twice as long a time. The characteristic sound pressure level would drop by 3 dB if the averaging time were doubled. The averaging time is indicated by an additional index (e.g. L_{eq30}), whereby it is defined beforehand whether these are seconds, minutes, hours, etc.

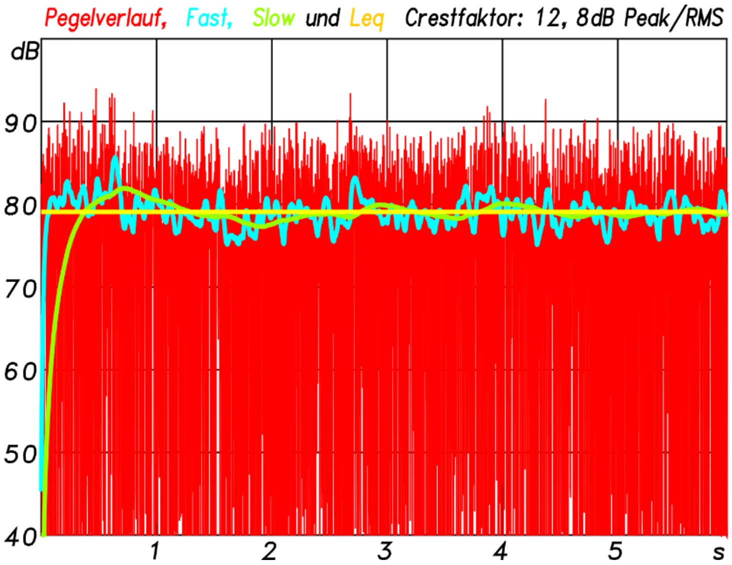


Figure 2.1: Exemplary sound pressure level curve using different time constants (red = momentary, blue = fast, green = slow , yellow = Leq)

In summary, Figure 2.1 shows an example of a sound pressure level curve using different time constants.

2.2 Sound pressure level and frequency weighting

Just as sounds can be labelled and characterized differently in terms of their temporal behavior, this can also happen in the frequency domain. An ideal sound level meter would detect and display the sound pressure of all frequencies with the same sensitivity in the specified frequency range (e.g. listening range 20 Hz to 20 kHz). In many cases, however, it is necessary to carry out a so-called frequency weighting. On the one hand, sound analysis can be carried out in individual frequency groups. Here, the frequency band is divided into individual sections, usually thirds or octaves (see

Figure 2.2). The sound analysis is then carried out separately for each frequency band. Sound analyses can also be carried out as an energetic sum over several third-octave or octave bands, as long as only this frequency range is relevant.

Norm-Frequenz f_m [Hz]	
Terz	Oktave
16	16
20	
25	
31,5	31,5
40	
50	
63	63
80	
100	
125	125
160	
200	
250	250
315	
400	
500	500
630	
800	
1000	1000
1250	
1600	
2000	2000
2500	
3150	
4000	4000
5000	
6300	
8000	8000
10000	
12500	
16000	16000
20000	

Figure 2.2: Standard third-octave and octave bands

Another form of frequency analysis is the inclusion of the properties of human hearing. Human hearing is not equally sensitive to all frequencies. Thus, it has its maximum sensitivity at medium frequencies, but the sensitivity drops sharply at low frequencies and also decreases at very high frequencies. In addition, the overall sensitivity of the human ear is also dependent on the absolute level: the higher the level, the smaller the differences in sensitivity between the mid and the low or the mid and the high frequencies.

To take this into account, every sound level meter has so-called frequency weighting functions. These functions are based on the sensitivity of the human ear for different level ranges. The level ranges were divided into different segments, from A, B, C, to D, with each of their ranges assigned its own frequency weighting function. The most commonly used rating curve is the so-called A-weighting curve, which reflects the sensitivity curve of the ear at relatively low absolute levels between 20 dB and 40 dB. It should be noted that due to new measurements of human perception (hearing threshold according to DIN ISO 226 [7]), the A-weighting today corresponds to the sensitivity of the ear between 40 dB and 60 dB.

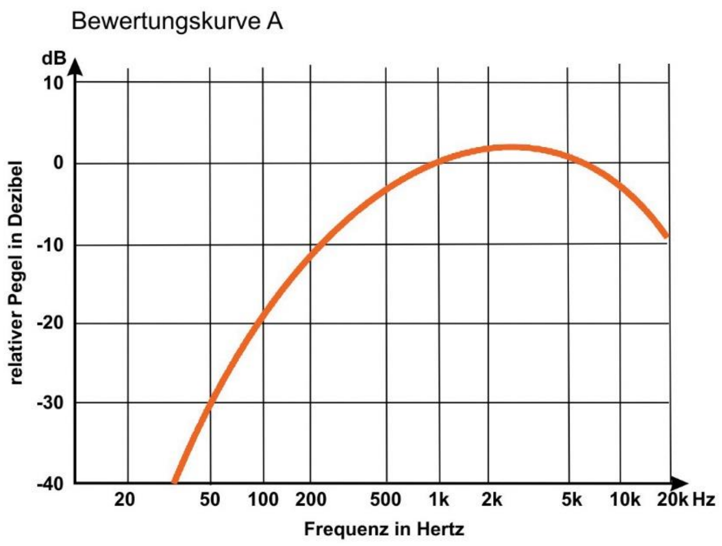


Figure 2.3: A-weighting curve

Figure 2.3 shows the frequency-dependent curve of the A-weighting curve. Sound events that receive an A-weighting via the sound level meter are therefore lowered at low frequencies analogous to the sensitivity of human hearing and reduced accordingly at very high frequencies. On the other hand, frequencies between 1 kHz and about 6 kHz are slightly boosted to take account of the higher sensitivity of the ear in this frequency range. The sound pressure level determined in this way is called the A-weighted sound pressure level L_A. Correctly, an A-weighted sound pressure level labelled L_A is also given as the unit dB. However, it is not uncommon to use the unit dB(A) to clarify that it is an A-weighted sound pressure level.

In order to clearly distinguish whether it is a frequency-weighted sound pressure level or a non-weighted level, an index z for "zero" – (L_z) is added to unweighted levels.

Basically, it follows that for broadband sounds, which do not have the most energy in the mid-frequency range, the unweighted sound pressure level L_z differs significantly from the A-weighted sound pressure level L_A. As a rule, the A-weighted sound pressure level is then lower than the unweighted sound pressure level.

2.3 Consequences for signal acquisition

As can be seen from the previous sections, for each signal definition and signal analysis, it is necessary to determine the temporal and frequency evaluation on which the data is based.

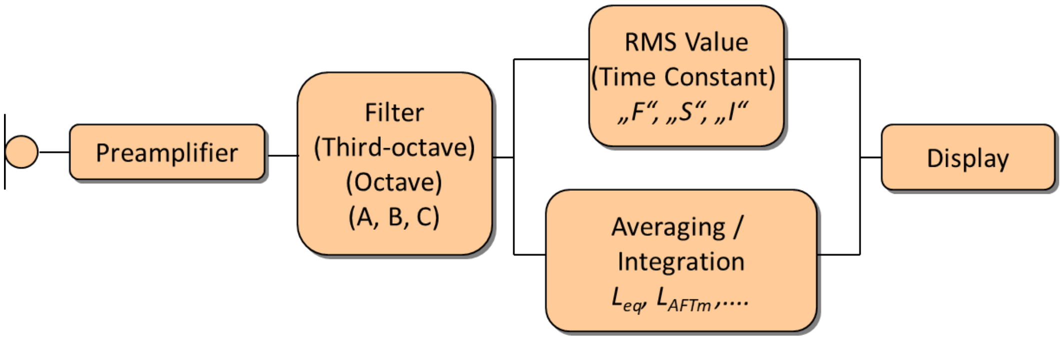


Figure 2.4: Principle diagram of a sound level meter

Figure 2.4 shows the basic structure of a sound level meter. From this it can be seen that when sound is measured, a frequency evaluation is first carried out and then a corresponding time evaluation. Without the concrete definition of these variables, the corresponding numerical values cannot be evaluated and cannot be compared.

As a consequence, this means that the aspects described here must be taken into account and appropriately applied for the door opening and closing signals as well as the door finding signals that will be dealt with later. For example, the signals are to be defined or measured as the maximum A-weighted sound pressure level L_{AFmax} measured with the time constant "*Fast*" or the A-weighted, energy-equivalent continuous sound level L_{Aeq}.

2.4 Percentile levels

In order to be able to answer the question of the occurring background or noise pressure levels for the later considerations, the term "percentile level" will be briefly explained here.

This is a statistical quantity and refers to an evaluation of a sound pressure level distribution. It represents the level that was reached or exceeded during the measurement time to *x%* of the measurement time. With the help of the percentile level, it can later be answered which levels occur frequently and which occur less frequently as background noise on the platform and thus the limits for the observations are determined.

2.5 Level addition and audibility of level differences

Calculating with levels is sometimes a bit difficult. In principle, an addition in the logarithmic range corresponds to a multiplication in the linear range. Figure 2.5 shows how the change in sound pressure level is related to the energy of the signal (or the sound power of the source). Accordingly, an increase of the sound pressure level by 3 dB corresponds to a doubling of the signal power and conversely, a decrease of the sound pressure level by 3 dB corresponds to a halving of the signal power.

However, the audibility of level differences does not follow linear laws, but logarithmic laws. To double the loudness (the loudness is a measure of the perceived(!) sound intensity), the signal energy does not have to be doubled, but increased tenfold. This means that the sound pressure level must be increased by 10 dB instead of 3 dB. Conversely, the loudness is only halved when the level is reduced by 10 dB and not when the signal energy is halved by 3 dB. This dependence applies in a good approximation to all absolute sound pressure levels above 40 dB and thus to those sound pressure level ranges as we find them on railway platforms.

Sound Pressure Level Changes	Corresponding Power Factor
+ 1 dB	1,25
+ 3 dB	2
+ 6 dB	4
+10 dB	10
+ 20 dB	100
-1 dB	0,79
- 3 dB	0,5
- 6 dB	1/4 = 0,25
- 10 dB	1/10 = 0,1
- 20 dB	1/100 = 0,01

Figure 2.5: Level change versus power change in a signal

It should also be noted that there is no long-term acoustic memory. Level differences of 3 dB can be easily perceived in the A-B comparison, i.e. the direct and immediate comparison between two situations. Level differences of 1 dB are only audible under very good boundary conditions in the A-B comparison. It follows that level definitions should be made carefully. If, for example, a 3 dB higher sound pressure level is required, this means a perceptible increase in loudness, but by no means a doubling. The power of the signal transmitter, on the other hand, must be provided at twice the height due to the doubling of the signal energy at a level increase of +3 dB. A careful consideration of the necessary sound pressure levels therefore has a direct and significant influence on the technical characteristics of the signaling device. This should also be taken into account in the following.

2.6 Audibility of signals with background noise

Basically, all sound signals are perceptible (audible) if their signal energy is above the so-called hearing threshold. The hearing threshold of humans has been studied many times and is currently laid down in DIN ISO 226 [7]. In the interplay of two signals, in which one signal is defined as a useful signal, i.e. as the signal to be heard, and the other as an interfering signal. The representation of the audibility of the useful signal with the level L_S (L_S = "level signal") is much more complicated when the interference signal is present at the same time as the level L_N (L_N = "level noise"). Essentially, the audibility of the useful signal depends on two factors:

a.) the so-called masking effect

b.) the effect of the binaural masking level difference (BMLD)

Both effects are briefly explained below and the consequences for further considerations are drawn.

2.7 Masking effect

The masking effect in hearing refers to the property of the human ear to cover up or "mask" certain sound information (in this case the useful signal) when other signals (in this case interfering noise) are present at the same time. This effect plays an important role in auditory perception and explains why certain sounds are harder to hear in noisy environments.

In the cases considered here, it is a case of so-called simultaneous masking. In the case of simultaneous masking, the useful signal and the interfering signal are present at the same time. The key to simultaneous masking is that sounds can only mask each other if they are in the same or immediately adjacent frequency ranges. More detailed studies on this can be found in Zwicker's standard work "Psychoacoustics" [8].

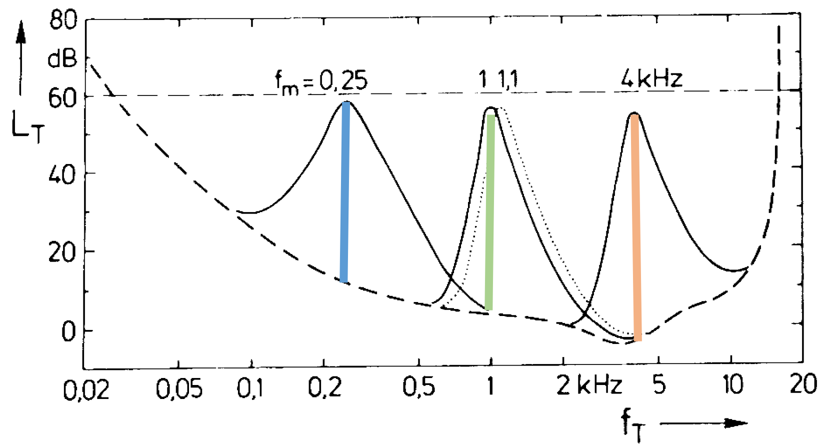


Figure 2.6: Masking effect – Listening thresholds for three masking frequencies according to Zwicker [8]

Figure 2.6 shows the principle of simultaneous masking. You can see the absolute hearing threshold as well as the frequency-dependent listening thresholds generated by a signal, here with the examples 250 Hz, 1 kHz, and 5 kHz. All sounds that are present at the same time and are below the listening threshold in terms of frequency and level are masked and are therefore not audible at the same time. In these areas, the loud signal obscures ("masks") the quiet.

The principle of masking is comparatively well studied for the diotic case (presentation of two identical signals in both ears). From this simple representation, one would conclude that signals are clearly audible in the presence of noise if the useful signal has a higher level for the worst case (the frequencies or frequency ranges of the useful and interfering signal are the same). This is referred to as the S/N (signal to noise) ratio, which should typically be 3-5 dB for safe audibility in these cases. However, this consideration is far from sufficient for the relationship considered in this study. This is explained in the following sections.

2.8 Direct sound level and diffuse sound level

The starting point to be considered in the following is that a useful signal, in this case a door finding signal, is superimposed by an interfering noise starting from a discrete point (in this case train door), which, however, does not arrive from a discrete direction, but diffusely.

From a technical point of view, the door signal transmitter corresponds to a so-called point sound source. Sound emanating from a source propagates as a spherical wave (or, in the case of door signaling devices, as a hemispherical wave) and in the course of its propagation experiences a reduction in the sound pressure level of -6 dB per doubling of distance due to the ever-increasing spherical surfaces. The sound pressure level of the door signals decreases accordingly with the distance to the door.

However, the background noise is mainly caused by people talking, announcements over the public address system and trains entering or leaving on other tracks. The sum of all these sound sources generates a diffuse sound field in a good approximation. Diffuse sound fields basically have two properties: On the one hand, the sound energy arrives uniformly from all directions at a selected point; there is no preferential direction in terms of incident energy. On the other hand, the sound pressure level in a diffuse sound field, provided that it is averaged in time and frequency within certain limits, is almost location-independent.

Background noise on the platforms can be regarded as diffuse in very good approximation.

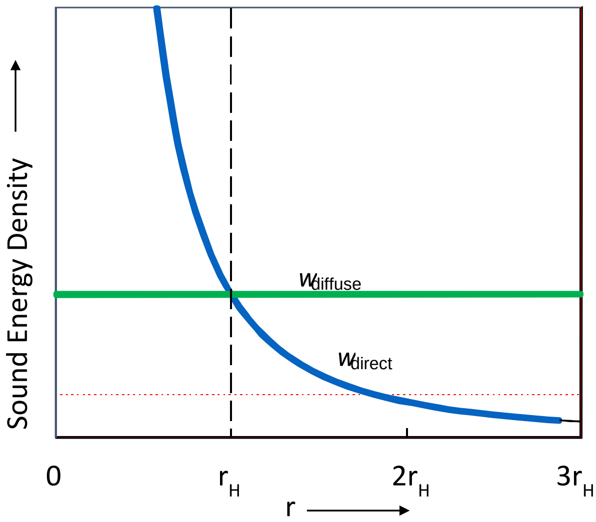


Figure 2.7: Energy density of direct sound field (spherical wave) and diffuse sound field over distance

Figure 2.7 shows the principal behavior of the energy densities generated by a direct sound field and a room diffuse sound field over the distance. The graph clearly shows that at a certain distance > r_H (so-called critical distance), the energy density of the direct sound field drops below that of the diffuse sound field.

2.9 Binaural masking and the binaural masking level difference (BMLD)

As briefly explained in the previous section, the perception of door signals on platforms is a superimposition of two sound components. The useful signal is a point source that emits sound from a discrete direction, the interfering signal forms a diffuse sound field in which the sound energy spreads more or less evenly on the platform, regardless of direction.

In this constellation of sound signals, two further effects are important with regard to the audibility of the useful signal from an interfering signal:

a.) Directivity of the ears, which leads to a reduction of the diffuse parts compared to the parts from the "front" direction.

b.) Binaural signal processing (cross-correlation between the ear signals), which causes an additional increase in S/N.

The sum of both effects is known as the "cocktail party effect". The cocktail party effect refers to the ability of the human ear to filter out relevant information from a variety of sounds, especially in a noisy environment such as a cocktail party. Even if there are many conversations and sounds going on at the same time, a person can focus their attention on a particular voice or sound. The result of the two effects a.) and b.) can be technically well labelled with the so-called binaural masking level difference (BMLD). The BMLD describes the additional gain of the S/N ratio through the perception of sounds in binaural hearing through the effects a.) and b.) compared to mono-aural hearing. The exact amount of the BMLD can vary and is dependent on various factors, including the type of sound signal, the frequency of the sound, the direction of the sound source, and individual differences in the individual's hearing. Nevertheless, it can be concluded from the studies so far that the BMLD can be several dB and up to well over 10 dB [8].

At this point, there is no need for a detailed theoretical consideration, but only the knowledge of this effect and its implications, because this is also important for the explanation of the levels to be set for door signals.

3 Door finding signals

3.1 Requirements of the visually impaired

The requirements of the visually impaired for door finding signals seems obvious at first. Visually impaired people want to move freely and without the help of another person on the platform with the help of their cane or guide dog, and accordingly find the train door and the door button for boarding and disembarking. In the course of the hearing tests planned for this study and described later, the visually impaired people who wanted to participate in the study were asked in advance about their requirements. Accordingly, it must first be stated that visually impaired persons on the platform have usually acquired a corresponding procedure pattern with regard to finding the train door. This pattern is essentially the same in Germany and Switzerland, but there are certain differences.

In Germany, accessibility is implemented, among other things, through the use of tactile guidance to the platform and tactile guide strips for the blind on the platform. The tactile guide strips for the blind are usually located at a distance of 40-50 cm from the edge of the platform. To find the door, the visually impaired person walks towards the train to the guide strip for the blind, then along the train until ideally the door finding signal is audible and helps with finding the destination and the door that is open or still closed. The door finding signal is also used to locate the door button when the door is still closed. In Germany, about 63% of platforms are currently equipped with tactile guide strips for the blind. If there is no guide strip for the blind on the platforms, the edge of the platform is felt with the cane and serves as a corresponding "replacement" orientation.

In Switzerland, the areas of the platform are divided into so-called "safe areas" and "danger zones". The safe area is an area where passengers can stay without exposing themselves to dangerous risks of interaction with the train. The danger zone identifies the area that may only be entered by all users if a train has fully stopped, and only then is it possible to interact with the train (pressing the door opening button, scanning of the outer wall by the visually impaired, getting on / off the train). The danger zone is always marked by a tactile-visual safety line (similar to the guide strip for the blind in Germany). According to a research report by the FOT [11], the minimum width is 2.20 m from the centre of the track (corresponds to 40-60 cm in front of the edge of the platform).

Basically, however, the procedure for finding the door is the same here. The visually impaired look for the tactile lines at the edge of the danger zone, walk along it until they hear the door finding signal and then let themselves be guided acoustically to the door.

The claims of the visually impaired can be summarised as follows from this process and after consultation with affected persons:

1. The door finding signal should be salient and recognisable.
2. The audibility of the signal must exist at a **sufficient distance** such that a safe guide to find the door is present.
3. When the door is closed, the door finding signal must help to find the **door button** reliably.
4. The door finding signal should be as loud as possible in order to be able to guide people with visual and hearing impairments accordingly.
5. The situation on the platform should be designed in such a way that blocking of the signal transmitter or covering by other persons is avoided as much as possible.

It is already clear here that not all criteria can be implemented without contradiction. Initially, it is preferred that the door finding signal is sent out from the button or from near the button, so that the button itself can also be reliably found by means of acoustic guidance. However, since Section 4.2.2.3.2 of the PRM TSI requires the button to be located at a height of 800 mm to 1200 mm above the platform, it is not possible to prevent the signal emitted from there from being obscured or, in the worst case, completely screened by bystanders. In this respect, the positioning of the signal transmitter is definitely an important question. For example, positioning the signal transmitter above the door could completely avoid this potential screen effect, but at the expense of possibly making it more difficult to locate the button inside or on the door. Furthermore, the requirements for the highest possible sound pressure level is, of course, at odds with the requirements of noise protection.

Furthermore, it is in no way obvious and specified at what distance from the train door the door finding signal should be heard reliably. According to information provided by the Federal Office of Transport (BAV), when door finding signals were implemented in Swiss federal law at the time, it was assumed that audibility at a distance of **about 3-6 m from the train door** was sufficient and expedient. At the time, this requirement was also discussed and agreed upon with the Swiss national representatives for the visually impaired and initially also serves as the basis for further considerations.

3.2 Requirements of the manufacturers

The current version of the TSI PRM Appendix G requires the optional installation of the signalling device for door finding signals in the immediate vicinity of the button (see also section 3.4.1). As already explained, the original intention was to use this signal to find not only the door, but also the door button directly. However, this means that in order to make the best possible use of the acoustic guidance, the best implementation is the direct installation of the signal transmitter in the door button itself. Since the implementation of signal transmitters in the door buttons is an additional technical equipment, the unit of the door button and signal transmitter should be as small and cost-effective as possible. However, the higher the sound pressure levels to be realized, the larger and more powerful the signal transmitter would have to be. In addition, there are requirements for dust and water protection, as the signalling device is completely exposed to the weather. On the other hand, the housing of the button cannot be completely sealed, as this would significantly reduce the acoustic radiation capacity of the signalling device. In addition, the implementation of the signal transmitter in the door button results in higher costs for installation, approval and maintenance. In this respect, it would also be the wish of the manufacturers for the signalling devices to radiate the door finding signals through a signalling device above the door. If necessary, it would also be possible to combine it with the signal transmitters for the door opening and closing signals. The extent to which such a positioning is possible and sensible is also discussed in the context of this study.

3.3 Further requirements

3.3.1 Noise immission control

The term noise immission control is used to describe the effect of sound on a specific place. The term noise immission control is usually understood as the protection of persons from unreasonable noise exposure who do not participate directly in the occurrence of the noise emission. In the case of noise emissions from stations and platforms, this particularly affects residents who do not participate in what is happening at the station. For example, residents are burdened by the following types of emissions due to the operation of railway stations:

1. Rail traffic of incoming and outgoing trains
2. Announcements on the platforms
3. Warning and safety signals of trains and train doors

In Germany, noise immission control is regulated in the ‘16. Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (16. BImSchV)‘, which includes the calculation methods for rating levels from rail vehicles (Schall 03) [12]. More detailed information can be found in the explanatory notes to Schall 03 [13]. It says (translated from German):

relating to 2. Definitions, Regulations

relating to 2.1.7 Railway

The definition of the railway track as a track system with a substructure and superstructure, including an overhead line, on which noise emissions are caused by driving processes, restricts the scope of application of Schall 03 compared to Schall 03 [1990] and Akustik 04. This means that noises that are not emitted by driving processes on railways, e.g. truck journeys in container facilities, container cranes and loudspeaker announcements, must be calculated and assessed according to TA Lärm [11]. This also applies to aggregate and drive noises from vehicles parked in train parking facilities/train formation facilities or at final stops. In accordance with the TA Lärm, driving processes on railways that are not used to handle traffic, such as railways in repair and repair shops or within commercial facilities, must continue to be calculated and assessed.

Furthermore:

relating to 4.3 Velocities

In the area of railway stations line speeds are taken into account when calculating the noise immissions, but at least at a speed of 70 km/h. The actual speed of trains in station areas is usually far below these speeds. Due to the resulting overestimation of noise immissions, the noise from the aggregate and drive noises of stationary trains, from the sounds of passengers getting on and off (speech, door slamming) and transport carts for supplying the trains are taken into account. This does not include loudspeaker announcements. These noises, as well as the aggregate and drive noises of vehicles parked in train parking facilities or at termini are to be determined and assessed in accordance with the specifications of the TA Lärm [11].

As can be seen from the two extracts, the most important noises occurring at stations are listed, but not the door signals, although these can have a considerable immission potential and a corresponding nuisance effect. This means that the emissions of door signals are not regulated in Germany, or at least a regulation cannot be derived from the current directives.

In this respect, the question of the noise emissions from door signals in Germany is at least in a grey area.

It is therefore absolutely understandable that especially in rural areas, where smaller stations with open platforms are often found, complaints from residents about door signals occur more frequently, especially at night. Most of the complaints relate to the door opening and closing signals, as these can be found almost continuously on every train.

It should already be mentioned here that in the interest of immission control or the residents, door signals should always be designed to be adaptive. Adaptive means that the sound pressure level of the signal transmitters is adjusted depending on the background noise at hand.

At night, for example, the signals could be correspondingly quieter at a rural station with low background noise, and correspondingly higher in a station hall with a high volume of people and traffic. A fixed level for door signals would not allow this variation and inevitably lead to either deficient audibility at high background noise or annoyance at low background noise.

3.3.2 Overstimulation

Signalling is based on the fact that a sensory stimulus is generated that stands out from the environment, i.e. which can be detected and to which a meaning can be assigned. This works particularly well when several senses are involved in signal perception. This means that, for example, light signals are only effective if they stand out from the standard environment. The same applies to acoustic signals, which are only meaningful if they stand out of the standard situation in an obvious way. It has also been well studied that if events are signalled too frequently and too densely, the effect of overstimulation sets in and the signalling no longer has the attention-catching characteristics it could actually have without sensory overload. In this respect, sometimes less and more targeted signalling is more effective than a universal and all-encompassing one. In the context of door finding signals, this means designing the level and perceptibility of the signals in such a way that they do their job in a limited spatial environment (3-6 m around the door) without creating too much additional stress on the station and the acoustic soundscape.

3.4 Standards and regulations

As already mentioned in the introduction, the TSI PRM, which will be revised as of 2023, defines door finding signals for the first time, the definition of which is mandatory for the use of such signals in the interoperable rail sector. When dealing with door signals in general, three standards and regulations are important here.

a.) EN 17285 Railway applications – Acoustics – Measuring of door audible warnings
b.) EN 14752 Railway applications – Bodyside entrance systems for rolling stock
c.) TSI PRM Appendix G TSI PRM 2023 Technical Specifications for Interoperability: Persons with reduced Mobility

Below are the current regulations for all door signals included in the TSI PRM 2023 (blue frame) and will be discussed further.

Section 4.2.2.3.2. Exterior doors from [6] reads as follows:

(10) The sound source for door signals shall be in the area local to the control device.

If there is no control device, the sound source for door signals shall be located adjacent to the doorway.

If a separate sound source is used for the door closing signal, it can be either local to the control device or adjacent to the doorway.

If an external door finding signal is provided, its sound source shall be located in the area local to the control device, and the sound source for the door closing signal shall be located in the area adjacent to the doorway.

(15) The centre of exterior door opening control, operable from the platform, shall be not less than 800 mm and not more than 1 200 mm measured vertically above platforms, for all platforms for which the train is designed. If the train is designed for a single platform height, the centre of exterior door opening control shall be not less than 800 mm and not more than 1 100 mm measured vertically above that platform height.

G.1. Definitions

The following terms are used in this Appendix:

f_{signal} = frequency of excitation tone

L_S = sound pressure level measured as L_{AFmax} the maximum Sound Level with 'A' Frequency weighting and Fast Time weighting during the measurement period.

L_{Smax} = *maximum* L_{AFmax}

L_{Smin} = *minimum* L_{AFmax}

L_N = surrounding noise level measured as follows:

a) frequency range energetic sum of three octave bands

$$L_N = \sum\left(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}} + 10^{\frac{L_3}{10}}\right)$$

where:

L_1 = $L_{oct.500\ Hz}$

L_2 = $L_{oct.1000\ Hz}$

L_3 = $L_{oct.2000\ Hz}$

b) Sound Pressure level measured as an energy equivalent level of 20 s (L_{Aeq20})

G.2.1 **Door opening signal**

Characteristics	A slow pulse multi tone (up to 2 pulses per second) of 2 tones emitted sequential
Frequencies	– $f_{signal1}$ = 2200 Hz +/– 100 Hz – $f_{signal2}$ =1760 Hz +/– 100 Hz
Sound pressure level	Adaptive device — $L_S \geq L_N$ + 5 dB — L_{Smax} = 70 dB (+ 6/– 0) – Non adaptive device — L_S = 70 dB (+ 6/– 0)

G.2.2 **Door closing signal**

Characteristics	– A fast pulsed tone (6-10 pulses per second)
Frequency	– f_{signal} = 1900 Hz +/– 100 Hz
Sound pressure level	Adaptive device — $L_S \geq L_N$ + 5 dB — L_{Smax} = 70 dB (+ 6/– 0) – Non adaptive device — L_S = 70 dB (+ 6/– 0)

G.3. Door finding signals

The door finding signal can be a single tone signal (in accordance with point G.3.1) or a dual tone signal (in accordance with point G.3.2). Both signal types shall be equally accepted in all Member States.

G.3.1 Single Tone Signal

Characteristics	Interval of tone (rectangle), none fade in and fade out — signal impulse duration = 5 ms ± 1 ms "on" (pure tone impulse) — signal time pattern of 3 to 5 pulses per second
Frequency	— f_{signal} = 630 Hz ± 50 Hz
Sound pressure level	Adaptive device — $L_S \geq L_N$ +5 dB — L_{Smin} = 45 dB (+/- 2) — L_{Smax} = 65 dB (+/- 2) Non adaptive device — L_S = 60 dB

G.3.2 Dual Tone Signal

Characteristics	Interval of tones (signal definition) — 100 ms sound pressure level fade in — 100 ms sound first tone 550 Hz ± 50 Hz — 100 ms sound pressure level fade out — 200 ms off — 100 ms sound pressure level fade in — 100 ms sound second tone 750 Hz ± 50 Hz — 100 ms sound pressure level fade out — 900 ms off — signal repetition time = 1 700 ms
Frequency	$f_{signal1}$ = 550 Hz ± 50 Hz $f_{signal2}$ = 750 Hz ± 50 Hz
Sound pressure level	Adaptive device — $L_S \geq L_N$ + 5 dB — L_{Smin} = 50 dB (+/- 2 dB) — L_{Smax} = 70 dB (+/- 2 dB) Non adaptive device — L_S = 70 dB

G.4. **Measuring Positions**

The microphone position for the measurements of audible door signals shall be in accordance with the specification referenced in Appendix A, Index [20]. The specification shall also be used for the microphone position of the door finding signal despite the scope of the specification excluding the door finding signal.

Measurements to demonstrate compliance shall be carried out at three door locations on a train. The door shall be fully open for the close test and fully closed for the open test.';

3.4.1 Button position according to 4.2.2.3.2 Exterior doors of TSI PRM

According to this section, the presence of a door finding signal is an option and not mandatory. However, the text in the red area requires that the signal transmitter of the door finding signal must always be in the vicinity of the button. This requirement is based on the idea that the door finding signal is in the true sense of the word a door **button** finding signal and that a reliable location only appears to be given if they are in close proximity to each other. As already mentioned, this section is also controversially discussed, as it is not clear whether this spatial proximity is really necessary, or whether a signal transmitter above the door is also sufficient to find the button.

This is a question that will be discussed at length in the further course of the study.

3.4.2 G. 1. Definitions

As a general rule, attention must be paid to the use of indices when defining and labelling sound pressure levels. Indices can be used to characterize the sound source (S = signal, N = noise) or the way of recording sound levels ("F" = "fast", "S" = "slow"). Since L_S in this section always refers to the level of the signal transmitter, i.e. the useful signal, it is already proposed here to make the following clarification in the definition of Appendix G.

L_S = Sound pressure level of the signal transmitter, measured as L_{pAFmax} (maximum "A"-weighted sound pressure level measured with the time constant "Fast")

Accordingly, the other definitions should also be clarified as follows:

L_{Smax} = maximum signal level L_{pS} (measured as L_{AFmax})

L_{Smin} = minimum signal level L_{pS} (measured as L_{AFmax})

L_N = sound pressure level of background noise, measured as follows:

Furthermore, it is determined that the background noise level is to be formed as an energetic sum of three octaves. This definition is intended to take account of the fact that the relevant door signals can essentially only be masked by corresponding interfering noises in this frequency range, i.e. can be obscured by them. This issue will be discussed in more detail in a later section. Furthermore, it is problematic that the background noise is to be measured here as an energetic average level L_{eq} over 20s. That duration is not available in practice, at least when measuring background noise during the operation of the vehicle. Here, further considerations must be made as to the way in which the background noise should be detected.

At this point, it becomes clear that another problem arises, which also requires further clarification. In the strict sense, a clear distinction must be made here between

a.) a signal definition

b.) a regulation how the background noise is recorded and processed during operation

c.) a measurement specification on how the type approval on the vehicle is to be carried out.

On the one hand, the TSI PRM Appendix G does not contain a sufficiently good distinction here, and on the other hand, there is no accompanying provision on how the doors are ultimately to be tested with regard to their suitability by means of measurements at the vehicle. **These should not be included in the TSI PRM, but in EN 17285 "Measuring of door audible warnings" [3] and in EN 16584-2 "Railway applications - Design for PRM use - General requirements - Part 2: Information".**

3.4.3 G. 2. Door opening and closing signals

The definition of door opening and closing signals essentially corresponds to the definitions of EN 14752 "Bodyside entrance systems for rolling stock" [2] and are apparently taken from there. From an acoustic point of view, it should be noted that when setting the frequency, the waveform remains undefined. Thus, it can be a sine wave signal as well as a square wave signal. While a sine wave signal has only one frequency, the square wave signal has additional odd-numbered harmonics. This has some effect on the audibility of the signal and on the associated masking effect.

A major difference between the specifications in TSI PRM Appendix G to EN 14752 lies in the detection of background noise. While in TSI PRM Appendix G the background noise is recorded in three octaves (500 Hz, 1000 Hz and 2000 Hz), which corresponds to a real frequency range of 350 Hz to 2800 Hz, EN 14752 specifies a frequency range of 500 Hz to 5000 Hz and is therefore slightly higher. Again, this difference will be discussed in later sections.

In the case of door opening and closing signals, it is important to define the necessary transmission level L_S in comparison to the noise level L_N. An S/N > +5 dB is required here. The maximum signal level L_{Smax} is set at 70 dB. As far as can be seen, the requirement S/N > +5 dB is also included in

EN 17285. In addition, EN 17285 contains a proposed assessment of tonal highlighting based on ISO 1886-2 [10] in Appendix A, with the intention of clearly favouring tonals signals over speech output.

3.4.4 G. 3. Door finding signals

The definition of two different door finding signals goes back to history. It defines the already mentioned pulse-containing "tok-tok" signal (called single tone signal in this report), which is mainly used in Germany, and the so-called Dual Tone "weep-weep" signal (in this report dual tone signal), which is used in Switzerland. Both signals are equally applicable.

Basically, the signal definitions are made in the same way as they have historically been implemented in the countries. However, with the pulse signal, there is some freedom in terms of the number of signal pulses per second, which can be varied between 3 and 5 pulses per second. The dual tone signal, on the other hand, is largely predefined in its time characteristics and offers few tolerances.

However, it is not specified whether the pulse of the single-tone must be generated using a sine wave, a square wave signal, or another waveform. Typically, because of the simpler design, it makes sense to build up the frequency with the help of a square wave signal. Figure 3.1 shows the difference between the time signals using the example of the single tone signal for generation using a square wave and a sine wave. It should be emphasized that the audibility of pulses based on square wave signals is better given than with pulses based on sine waves due to the presence of odd-numbered harmonics.

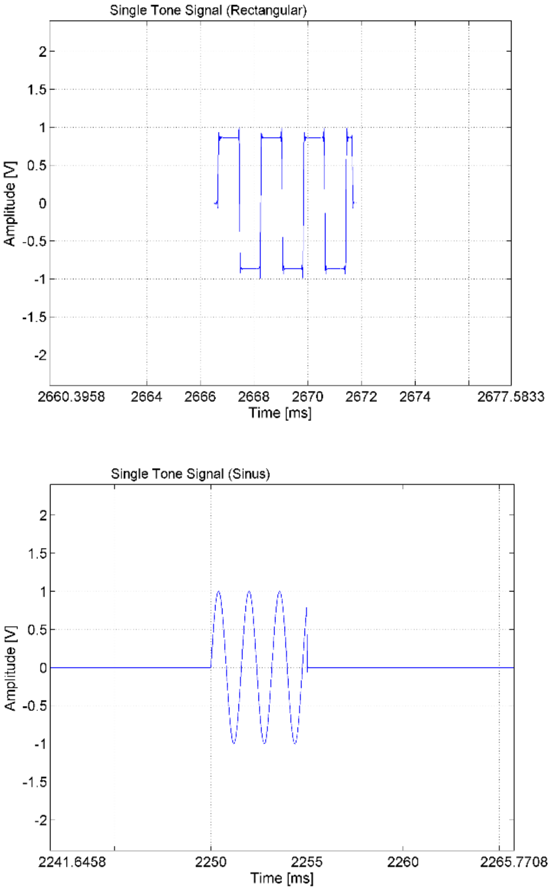


Figure 3.1 a-b: Time excerpt of a single tone signal; a–rectangle, b-sine wave

The following figures show the waveform of the door-finding signals as well as their associated spectra.

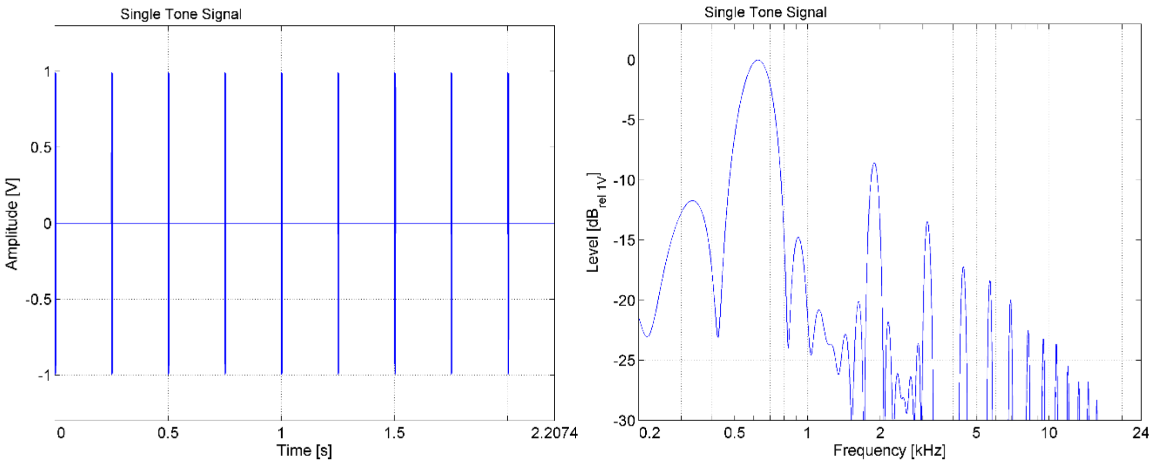


Figure 3.2 a-b: Time signal and spectrum of the 4 Hz single tone signal (based on square wave signals)

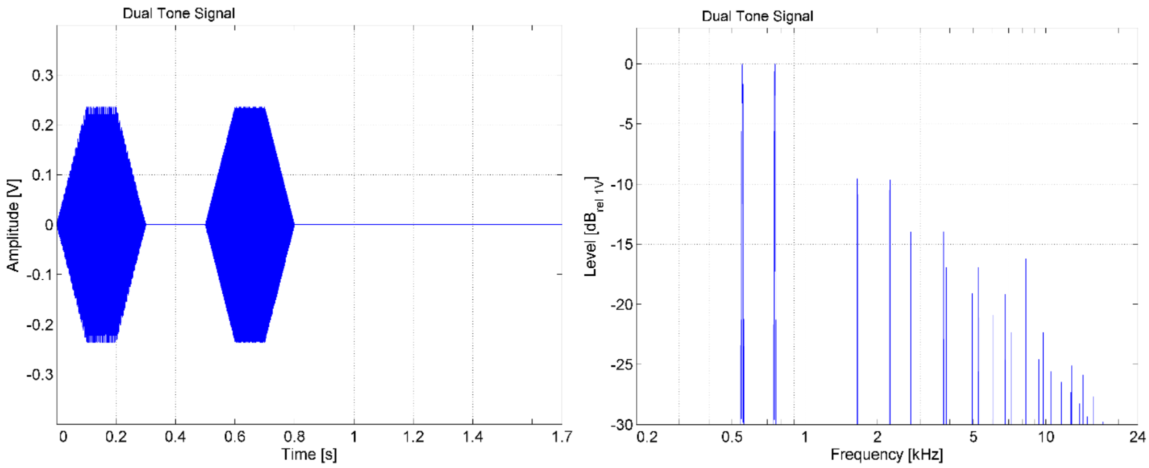


Figure 3.3 a-b: Time signal and spectrum of the dual tone signal (based on square wave signals)

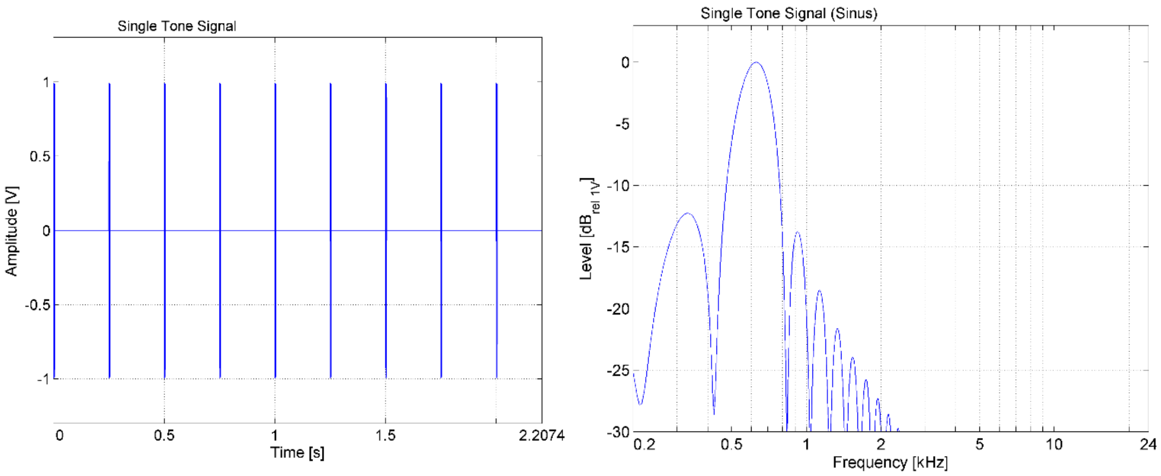


Figure 3.4 a-b: Time signal and spectrum of the 4Hz single tone signal (based on sine wave signals)

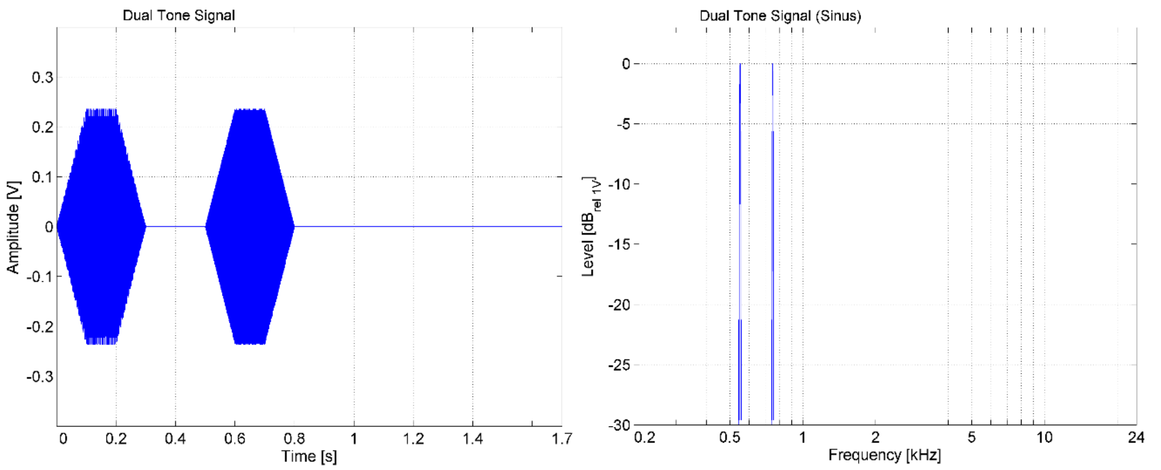


Figure 3.5 a-b: Time signal and spectrum of the dual tone signal (based on sine wave signals)

As can be seen from the figures, all signals have their relevant energy in a frequency range of 500-1000 Hz. Furthermore, it can be seen that the generation of the signals with the help of rectangles leads to corresponding energies in the harmonics, the odd multiples of the fundamental frequency. As a result, rectangular-based door-finding signals sound "sharper", while sine-based door-finding signals sound "softer" and more pleasant. This point will also be discussed later. Furthermore, it can be seen that the limitation of the detection of the noise to three octaves (absolute frequency range 350 Hz to 2800 Hz) appears at first glance to be clearly appropriate for the useful signal energies. This is all the more so because in the frequency range up to 2800 Hz, the first harmonic of the signals is also included in the potential range of noise masking. The extent to which the limitation of noise detection to three octaves is critical will also be explained in a later section.

Particular attention should be paid to the definition of the necessary S/N (ratio of the level of the signal to the level of the noise) of the door finding signals. This is set at +5 dB for all signals, analogous to the specification for door opening and closing signals, and is criticized from some sides. Furthermore, the determination of the maximum level for door finding signals, which were incomprehensibly defined differently for the two types of signal with the current state of knowledge, is viewed critically. For example, the maximum level for the single tone signal is L_{Smax} = 65 dB, for the dual tone signal L_{Smax} = 70 dB for the adaptive case. For the non-adaptively controlled door finding signals, the difference with $L_{S(Single)}$ = 60 dB and $L_{S(Dual)}$ = 70 dB is even 10 dB.

It is important to note that the levels of the useful and interfering signals must be determined at a measuring position at a distance of 1.5 m, at a vertical distance in front of the centre of the door and at a height of 1.5 m.

These guidelines do not seem to be consistent or congruent. The main task of this study is to examine and specify both the necessary signal-to-noise ratio S/N and the maximum level, as these specifications have a direct impact on the trade-off described at the beginning, which requires that the signals be kept clearly intelligible, but only radiated as loud as necessary.

In the following, therefore, taking into account all the boundary conditions described so far as well as the additional criteria mentioned in the next section, the question must be answered as to which S/N ratio is really necessary to reliably achieve the specified goals of a door finding signal and which maximum levels should be sensibly defined for the signals.

4 Station noise

First of all, the fact already described in the introduction should be reiterated here that background noise is noise on the platforms that is caused by the interaction of **all sound sources** in the area of influence. These include people speaking, announcements via the public address system and trains entering or leaving on other tracks. Rarely, if ever, is it background noise caused by the train where the door is to be found. So, as a rule, the background noise has no direct correlation with the sounds of the train on which the signal is to be found.

4.1 Level distribution

Background noise at stations, for example, fluctuates very strongly in the short term when trains arrive, but also has broader temporal fluctuations over the course of the day, which are directly related to the volume of people and traffic. There can also be significant spikes caused by special situations. For example, a group of football fans can move through the station "with drums and trumpets" and thus cause considerable level increases for a short time, which are then often in the level range of L_{AFmax} = 95 dB as background noise L_N.

At such peak levels, it becomes clear that public address systems on platforms (background of the study) as well as door signals cannot "drown out" every conceivable background noise and cannot therefore always be audible without exception. Rather, it is a matter of defining a sensible limit within the framework of a risk analysis up to which background noise level a reliable detection of the signals should still be possible.

For example, it is necessary to consider which levels typically occur on platforms and how high the corresponding frequency is.

Platform noise, its level distributions, time courses and frequency spectra have therefore been extensively investigated in the past and have been incorporated into the 2021 Deutsche Bahn Guideline on the Sound Reinforcement of Platforms [9]. The results of the study can be used directly for this study.

For the preparation of the guideline, long-term measurements (24-hour level measurements over several days) were made at stations of various categories. Deutsche Bahn distinguishes between 7 categories as follows:

Category 1: important large long-distance railway stations (e.g. Berlin Central Station)
Category 2: main stations of larger cities (e.g. Saarbrücken or Bremen main stations)
Category 3: main stations of small and medium-sized cities
(e.g. Aalen or Baden-Baden main stations)
Category 4: stations marked by regional and city traffic
(e.g. Starnberg station, Hannover Trade Fair station).

Category 5: small town stations
Category 6: stations in sparsely populated areas
Category 7: stations in rural areas with little infrastructure

Continuous measurements were carried out, documented and interpreted at 6 stations of category 2, 3, 4 and 6. The key messages are reproduced below.

On page 44 of the Platform Public Address Directive [9] (translated) it is stated:

> Numerous noise measurements on platforms have shown the following: If the noise levels that are achieved are plotted on a graph corresponding to their respective frequency, the curve runs smoothly from 100% frequency at low levels to 10% frequency at higher levels. Below the 10% level frequency, however, the associated noise levels rise sharply. This range below a 10% percentile level indicates the peaks in the level that occurred during the measurement. The noise level applicable to the platform on the basis of the measurement is determined directly by the A-weighted, 10% percentile level L_{AF10}, because
>
> – 90% of the time the noise level is the same or lower and thus the level peaks that occur only 10% of the time do not dominate the characteristic value, and
>
> – a sensible definition of interfering noise is made, which still allows for sufficiently good, but also feasible sound levels for a public address system to be planned later.

This will be illustrated using the example of the measurements at Aachen station as an excerpt from [9]. The following figures (taken from [9] and numbered) show the measurement results for two measuring points:

- Measuring point 1: Platform tracks 2-3 within the track hall
- Measuring point 2: Open platform tracks 2-3 outside the track hall

As shown in Figure 4.1 and Figure 4.3:

- Measurement results of the 24-h level curve as 5s L_{Aeq}
- Sliding 60 min averaging level $L_{Aeq\ 60'}$
- Sliding 60 min 10% percentile value $L_{AF10\ 60'}$

As shown in Figure 4.4 and Figure 4.5:

- Proportion of time in % (x-axis) within the period of time considered in which a certain level value SPL in dB(A) (y-axis) is not exceeded.

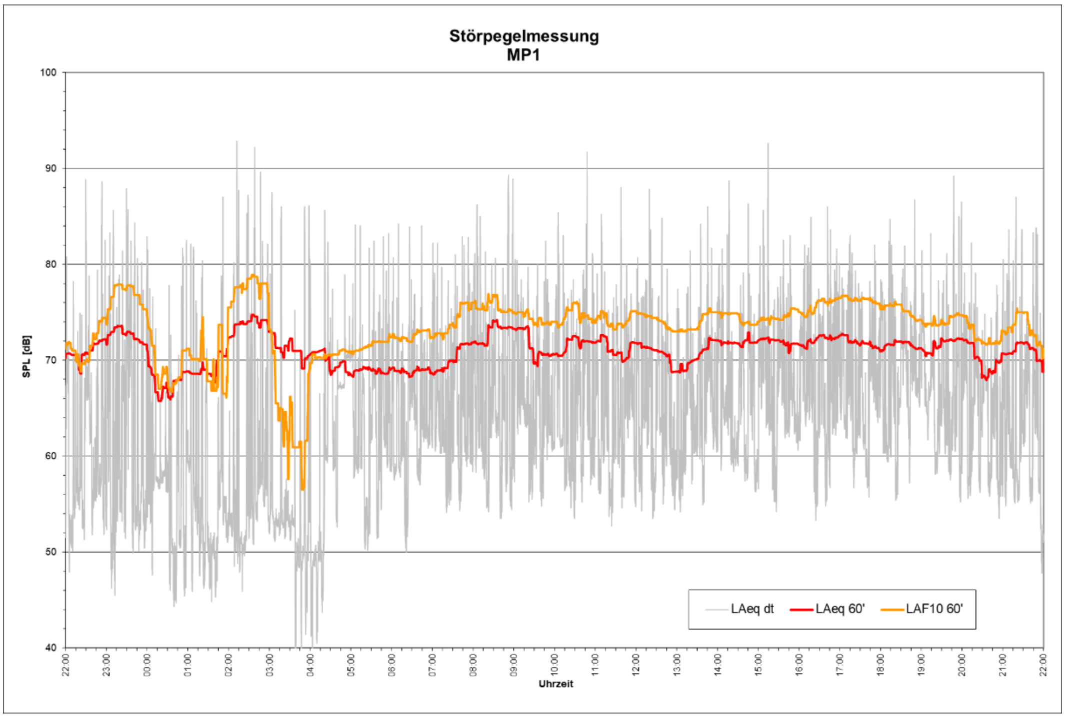


Figure 4.1: 24-hour noise level measurement:
Grey: 24-h level curve with individual values as 5s L_{Aeq}
Red: Sliding 60 min averaging level $L_{Aeq\,60'}$
Orange: Sliding 60 min 10% percentile value $L_{AF10\,60'}$

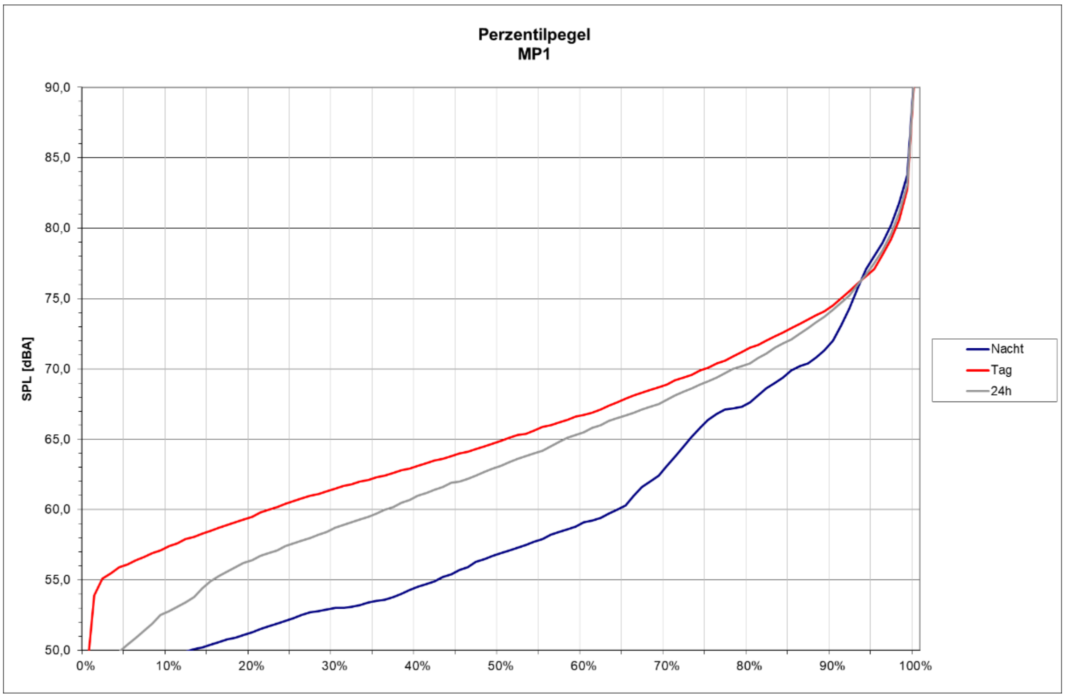


Figure 4.2: Proportion of time in % (x-axis) within the period of time considered in which a certain level value SPL in dB(A) (y-axis) is not exceeded.

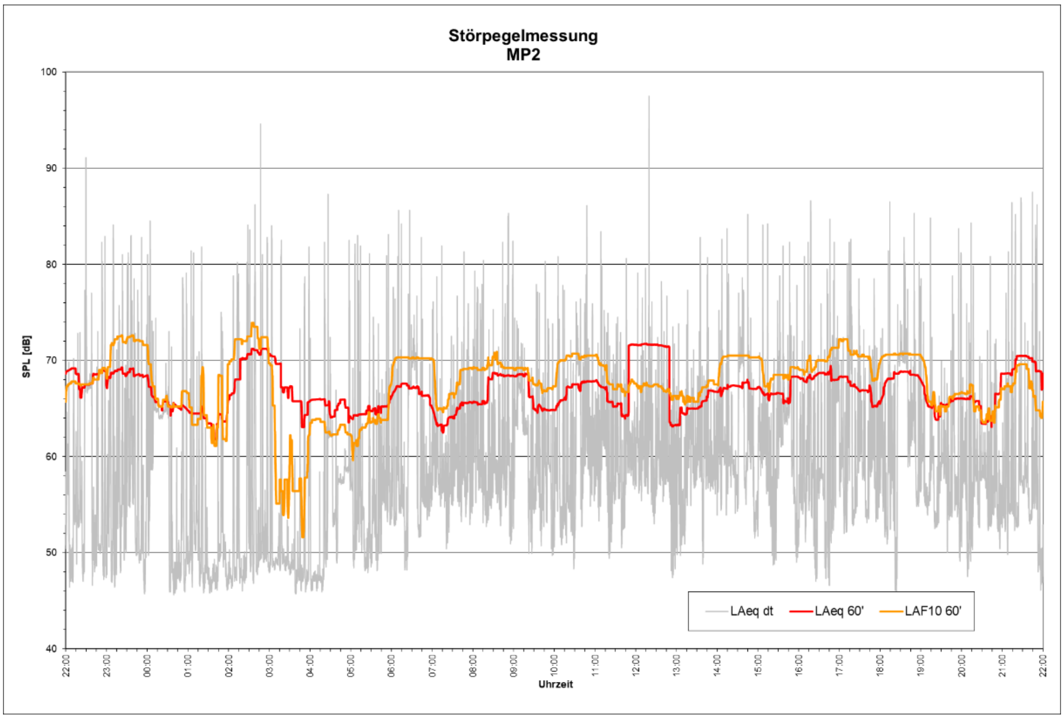


Figure 4.3: 24-hour noise level measurement:
Grey: 24-h level curve with individual values as 5s L_{Aeq}
Red: Sliding 60 min averaging level $L_{Aeq\ 60'}$
Orange: Sliding 60 min 10% percentile value $L_{AF10\ 60'}$

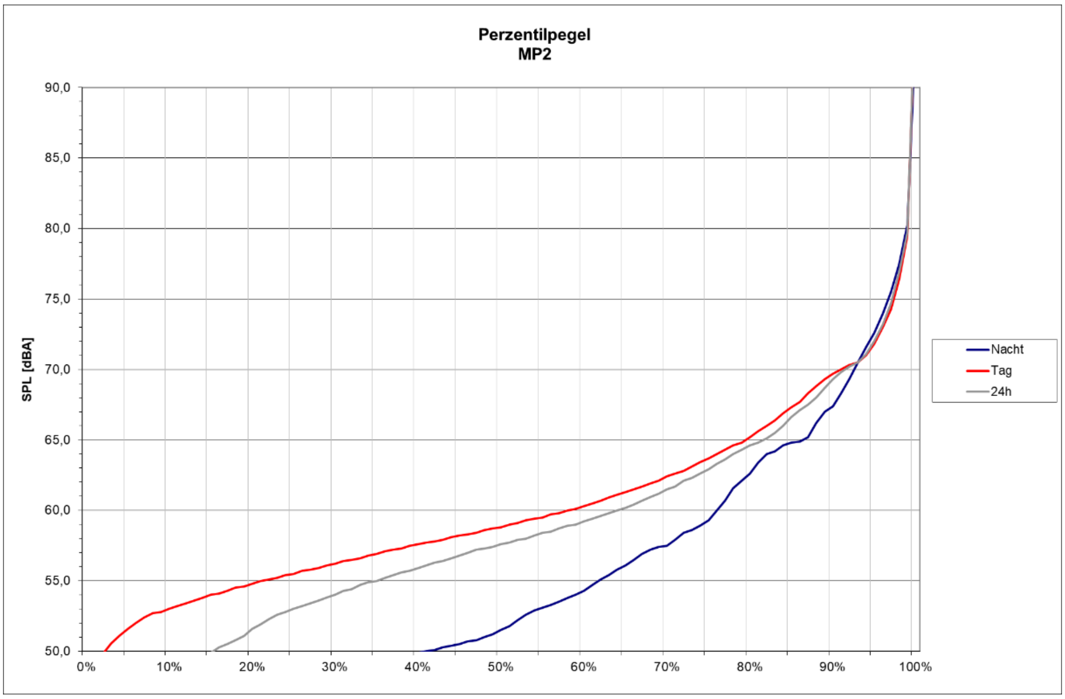


Figure 4.4: Proportion of time in % (x-axis) within the period of time considered in which a certain level value SPL in dB(A) (y-axis) is not exceeded.

Attention(!): In the illustration in Figure 4.2 and Figure 4.4, the x-value corresponds to a frequency at which the level is undercut or reached. However, the percentile level is the range that is reached or exceeded in x percent of cases. Thus, the percentile level L_{AF10} results from the figures as the 90% value of the representation in the graph.

As can be seen from this example, the levels fluctuate as described in short periods of time as well as globally over the course of the day. Level peaks of L_{AFmax} > 95 dB occur over a 24-hour course.

However, it can be clearly seen that the large level peaks occur only very rarely, i.e. to a small percentage. The corresponding distribution curves change their course in the range of 90% (up to this range 90% of all levels occur) and then rise much steeper. This behavior can be found at all stations and measuring points in pretty much the same way in the determined measurement curves.

With regard to the risk assessment in the dimensioning of public address systems, the 90% limit was therefore used as the basis for the interference level for which the system must provide sufficient speech intelligibility in the event of an alarm (emergency).

An analogous conclusion can also be drawn for door signals, although of course the risk assessment for door opening and door closing signals could be different.

Therefore, it is recommended to use the 90% value of the sum frequency (which corresponds to the percentile level L_{AF10}) as the basis for noise analysis for door signals as well.

Figure 4.5 shows the summary of the results from [9]. Although the measurement results for the L_{AF10} vary over the loudest 60 minutes, **it can be deduced with good approximation that a L_{AF10} = 75 dB is a sufficiently good basis for determining the noise level for door signals.**

Furthermore, it is recommended to again distinguish between door **warning signals** (door opening and closing signals) and **non-warning signals** (door finding signals). In the case of door finding signals, the risk of inaudibility can be set at a lower level. **Here, for example, a value for the background noise L_N of the sum frequency of 80% could be used. From the graphs, it can be deduced that the underlying percentile level L_{AF20} with L_{AF20} ≈ 70 dB is then about 5 dB lower. Such a definition of the maximum background noise level is a good and sensible compromise between the statistical occurrence of levels up to the maximum value (here 80%) compared to the existing risk.**

The significance of a possible determination of the maximum background noise level L_{Nmax} = L_{AF20} ≈ 70 dB on the necessary maximum sound pressure levels for door finding signals is discussed in connection with the subsequent hearing test results.

Type	Position		Day (6:00 – 22:00)		Night (22:00 – 6:00)	
	MP	Location	$L_{AF10,60'}$ dB(A)	$L_{AF10,all}$ dB(A)	$L_{AF10,60'}$ dB(A)	$L_{AF10,all}$ dB(A)
1) Cat II	1	Track hall	**76,9**	74,5	78,9	72,0
	2	Open	**72,2**	69,7	73,9	67,4
	3	Track hall	**79,8**	75,5	80,7	73,0
	4	Track hall	**79,9**	75,2	74,6	73,1
2) Cat V	1	Open	**72,2**	67,7	69,5	62,9
	2	Open	**72,5**	68,5	69,5	63,7
	3	Open	**72,3**	68,2	69,4	65,6
	4	Open	**72,9**	67,6	69,0	64,1
3) Cat VI	1	Ceiling	**79,4**	64,9	65,1	54,2
	2	Open	**69,4**	60,1	62,4	52,0
Values as L_{AF5}	3	Open	**73,6**	62,9	64,9	52,8
	4	Ceiling	**83,7**	66,0	61,4	53,4
4) Cat III	1	Ceiling	**71,4**	67,1	61,8	56,0
	2	Open	**71,9**	67,2	62,3	56,8
	3	Open	**68,7**	66,0	62,7	58,3
	4	Ceiling	**72,8**	68,7	67,0	57,7
5) Cat III	1	Ceiling	**73,7**	71,8	72,1	69,1
	2	Open	**70,2**	68,7	68,5	66,3
	3	Open	**68,7**	66,0	62,7	58,3
	4	Ceiling	**72,8**	68,7	67,0	57,7
6) Cat II	1	Ceiling	77,0	74,8	73,1	66,1
	2	Ceiling	77,3	74,7	72,2	57,7
	3	Open	73,7	71,5	72,2	61,9
	4	Ceiling	73,9	71,4	71,2	59,4

Table 4.1: Measured values of the 24-hour noise level measurement at various stations. The values show the 10% percentile level of the entire day or night period (all) and the loudest hour (60') of the day or night period.

1) Medium-sized station in a curve with many freight train passages (even at night).
2) Small stop with many slow train passages, freight trains at night
3) Small stop with fast passages (hence evaluation of the L_{AF5})
4) Inner-city, four tracks, lots of travelers
5) Inner-city, four tracks, many travelers even at night
6) Medium-sized station with 5 platform tracks (Attention: construction site during the day measurements!)

Figure 4.5: Excerpt from [9] as a summary of the results.

4.2 Frequency spectra of station noise

The frequency spectrum of railway noise, represented as an instantaneous value, can also fluctuate more strongly if individual events, such as a brake squeak or an announcement, dominate the background level. Basically, however, it turns out that the temporal averaging spectra are relatively constant and very similar for most station situations. Figure 4.6 shows the spectral curve of the background noise normalized to 0 dB at the maximum for 60 min averaging time and sliding thirds averaging (1/3 octave) using the example of the railway station in Basel. In addition, the spectral curve of "pink" noise is marked with dashes.

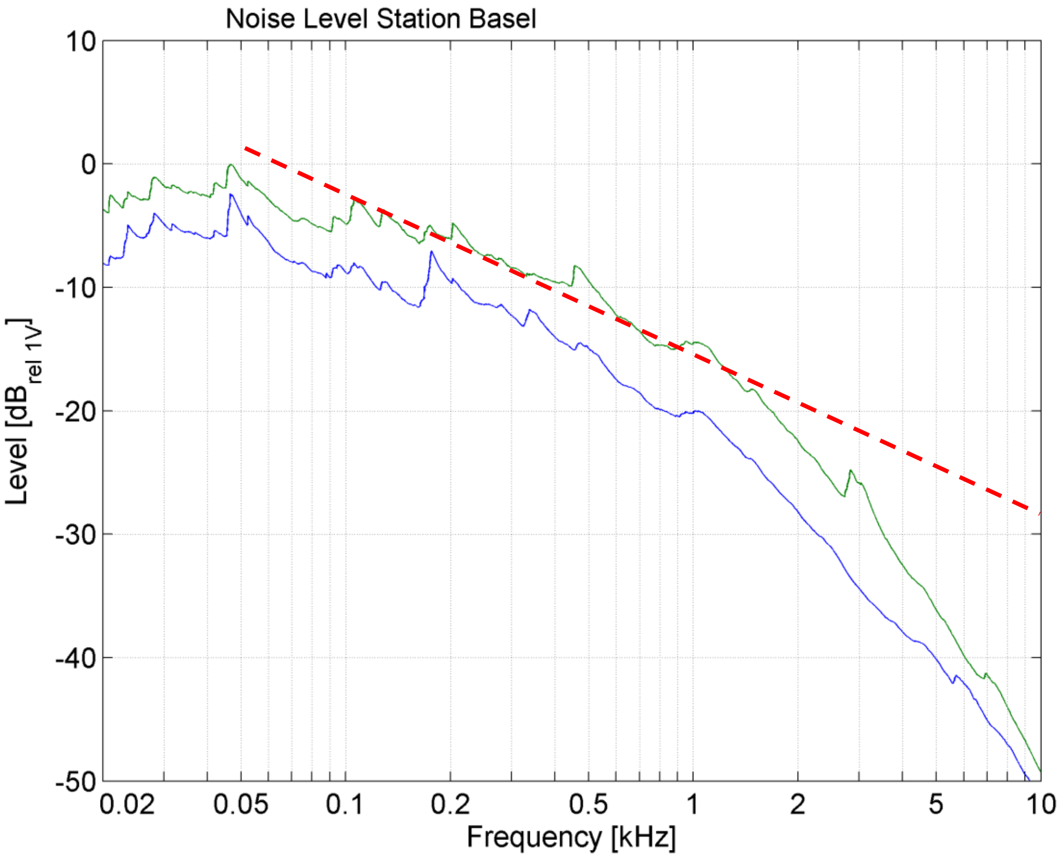


Figure 4.6: Averaged frequency spectrum 60 min Basel station, sliding average 1/3 octave (blue = quiet hour, green = rush hour, red = "pink" noise)

As can be seen in the figure, the background noise from 100 Hz to about 1.5 kHz has a spectral gradient similar to pink noise, which by definition has a spectral energy density drop of 3 dB per octave or 10 dB per decade. It can also be seen that the average spectrum does not depend on the absolute level. This basic spectral distribution is also evident for most other stations.

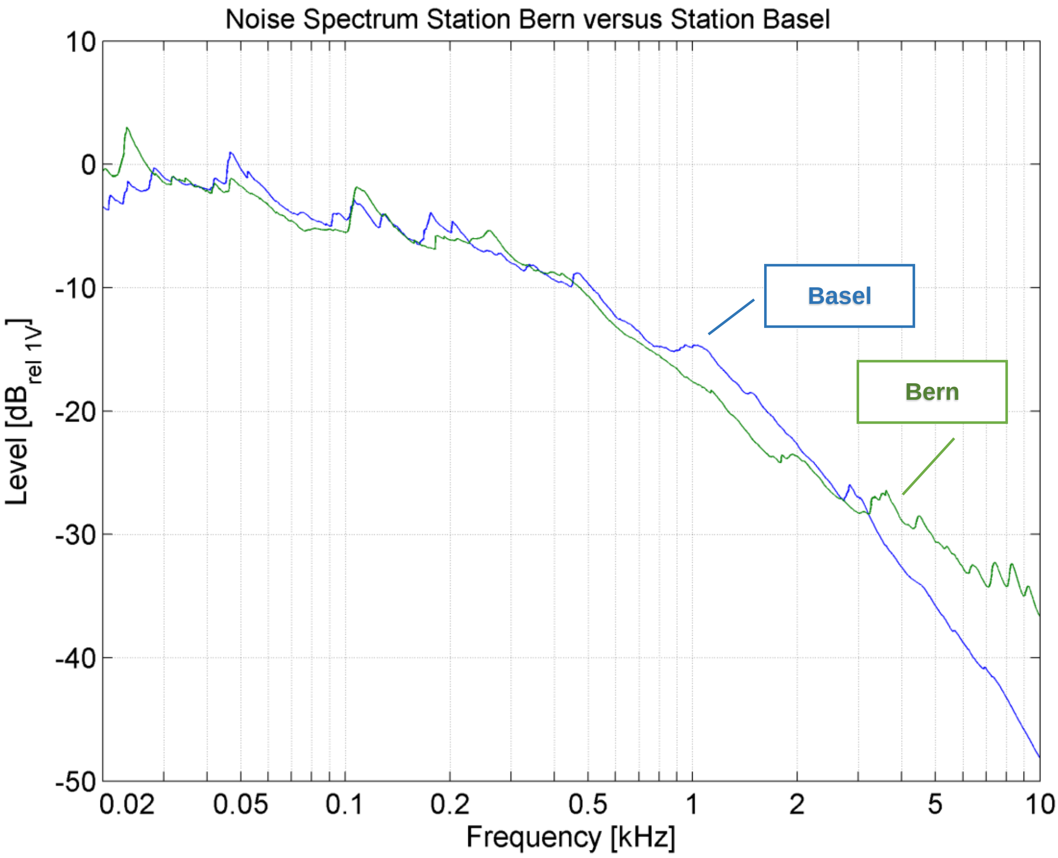


Figure 4.7: Averaged frequency spectrum 60 min Basel station versus Bern station, sliding averaged 1/3 octave (blue = Basel, green = Bern)

Deviations can be found at special stations, such as Bern station, which is known for its unique acoustic properties: The tracks at Bern station are curved, such that when trains enter and exit the station, there is a strong squeaking or screeching, and thus louder middle- and high-frequency background noises are generated than is the case in other stations.

Figure 4.7 shows the spectral distribution for Bern station, also as an energetic mean over 60 min and sliding thirds averaging (1/3 octave), Figure 4.8 shows the same comparison for the A-weighted spectra. It can be seen that the main differences in the frequency range are above 3 kHz and here are 5-10 dB. In relation to the A-weighted sound pressure level, this high-frequency increase results in differences in the overall level of just 1 dB. Since these differences are very small anyway and the frequency range is outside the masking range for the door signals, these differences are not relevant here.

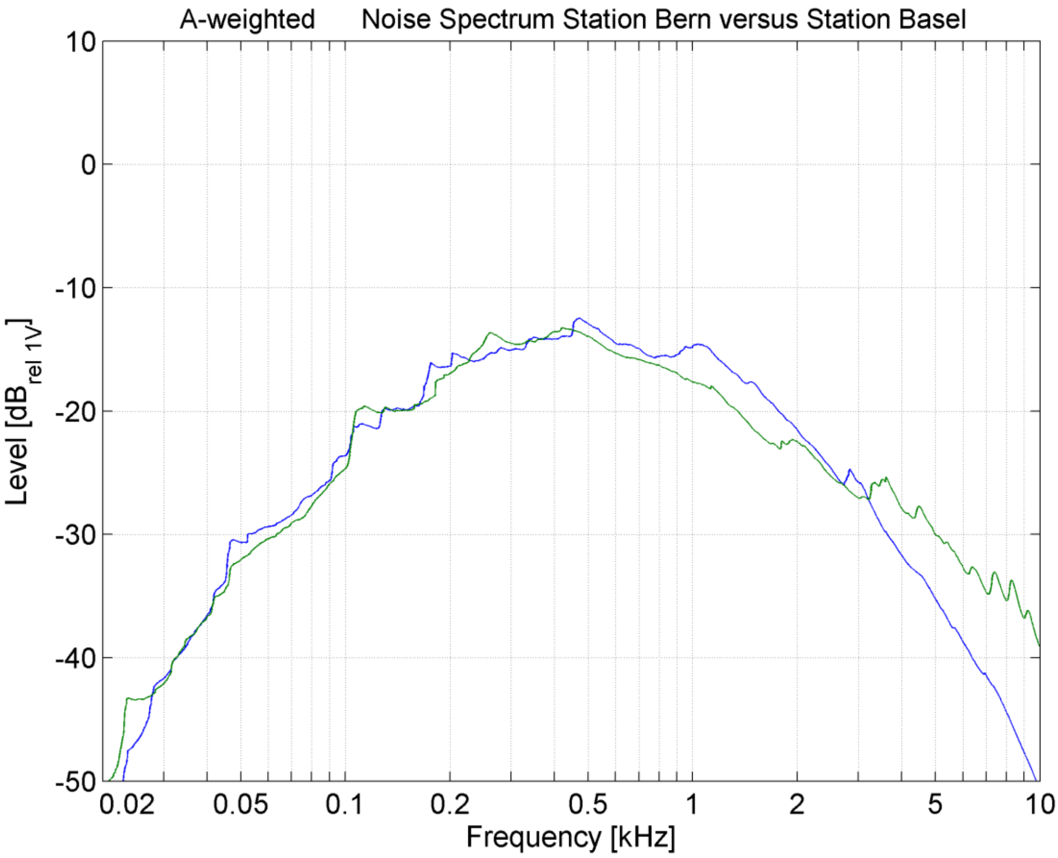


Figure 4.8: Averaged A-weighted frequency spectrum 60 min Basel station versus Bern station, sliding average 1/3 octave (blue = Basel, green = Bern)

In the following, the question of how the noise level should be measured will be examined once again. In the TSI PRM Appendix G, the noise level is to be determined as an unweighted level in the frequency range of the 3 octaves 500 Hz, 1 kHz and 2 kHz. It should be mentioned again that the frequency specifications are octave center frequencies. The effective frequency range comprised by these three octaves ranges from 353 Hz to 2.83 kHz. Figure 4.9 shows the comparison of the two spectra for Basel station, once as an A-weighted total level and the level as a sum over the three unweighted octave levels.

The difference between the A-weighted sound pressure level of the entire signal and the level obtained in octaves is merely 0.8 dB. On average, both methods can be used equally to measure the noise situation without having to adjust the values for the signal level. As an instantaneous level, however, the deviations can be higher.

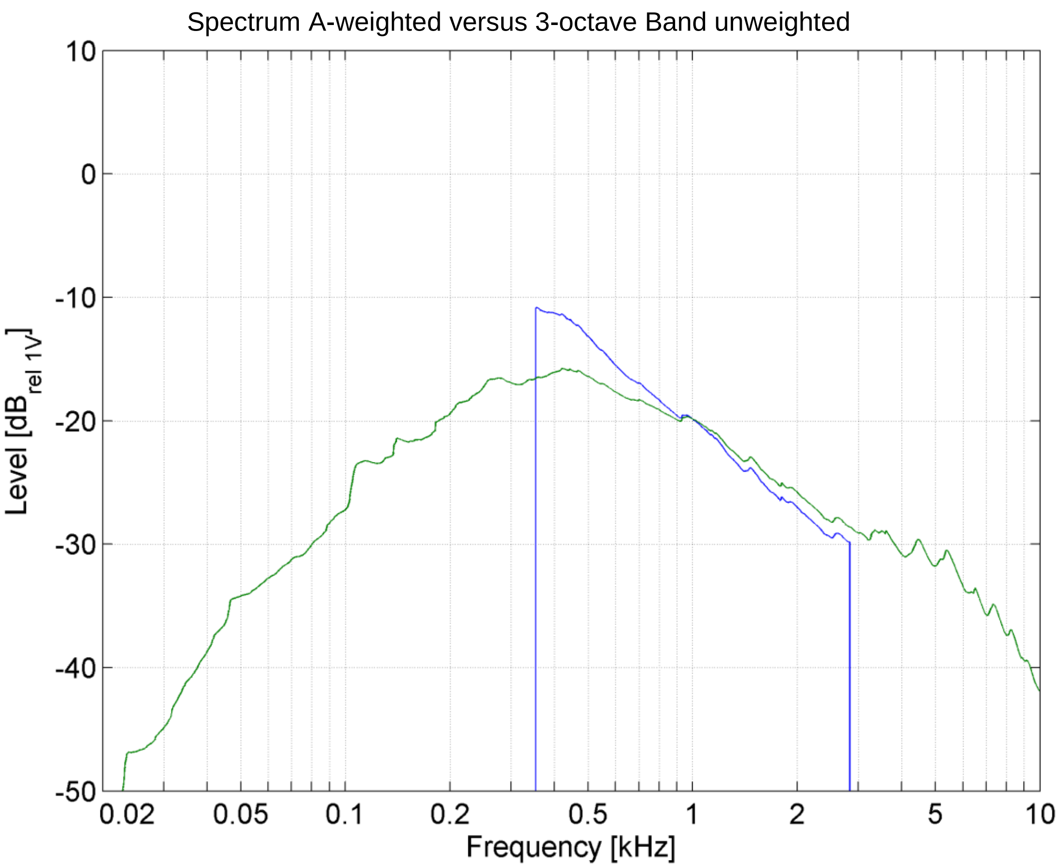


Figure 4.9: Comparison of an time-averaged background noise spectrum (60 min) at Bern station, A-weighted frequency (green) versus unweighted octave-bad spectrum of 3 octaves (blue)

5 Listening tests

In the last sections, a number of questions about door finding signals have already been discussed. However, the following important points have not yet been sufficiently clarified:

- Which signal-to-noise ratio S/N must be realized in order to ensure an "appropriate" audibility of the door finding signals?
- What are the disadvantages of positioning the signal transmitter above the door compared to positioning it near the button?
- What are the differences in terms of locatibility between the single tone signal and the dual tone signal?
- What are the maximum levels to be set for the finding signals?
- What dynamics for adaptive signals should be implemented?
- Which signal levels should be defined for the static (non-adaptive) door detection signals?

Although these questions can be roughly answered on the basis of theoretical considerations in the laboratory, they can ultimately only be answered sufficiently clearly by suitable listening experiments. For this reason, a listening test concept was developed that should be able to precisely answer these questions in a targeted manner.

In the run-up to the tests, it was extensively evaluated which criteria such a listening test must meet in order to have an appropriate informative value. This was especially true since the time and effort involved in the study had to be limited and concentrated on the essential points.

According to the mandate of the FOT, typically 10 visually impaired test subjects, ideally 5 from Germany and 5 from Switzerland, should be invited to participate in the listening tests to find doors and door buttons with the help of door finding signals.

In order to address the above questions, the following parameters had to be varied in the listening test:

– Variation of the S/N ratio to a sufficient extent
– Comparison of the two door finding signals - Single Tone and Dual Tone
– Comparison of a signal transmitter close to the button with a signal transmitter above the door

The following boundary conditions should be taken into account:

– A realistic scenario
– Evaluation of all desired parameters
– Sufficient time to carry out the experiments
– Reasonable strain and effort asked of the test persons

5.1 Testdesign

After extensive research and consideration of all possibilities, the following test design was chosen:

a.) A total of 9 visually impaired test persons were recruited for the experiment, 5 from Germany and 4 from Switzerland.

b.) The test was carried out at Leipzig station on track 17, which was completely closed for 3 days for the listening tests and was therefore available exclusively for the listening test.

c.) The test object was the advanced TrainLab (aTL) test train of Deutsche Bahn, which was specially converted by Deutsche Bahn for use as a test vehicle and is used for research purposes of all kinds.

d.) One of the train's doors served as an experimental door. A small additional casing was attached to this door, which contained a button and a loudspeaker for emitting the door finding signal.

e.) The same arrangement was also placed above the door, although the button had no relevance there.

f.) With the help of a special loudspeaker setup, an area of approx. 35 m (17.5 m on the left and 17.5 m on the right) from the door on the platform was exposed to 4 different diffuse, controlled background noises.

g.) The S/N ratio could be controlled by varying the background noise levels as well as the signal levels. 4 background levels with 4 S/N ratios each were investigated.

h.) The 16 different situations from g.) should be carried out for each of the two types of door finding signals and for the two different positions of the signal transmitters, such that a total of 64 runs should be carried out for each person. Each person was to pseudo-randomly assess 8 test blocks, each with 8 different situations.

i.) The test persons were asked to approach the train from 4 different starting points in the middle of the platform, walk along the train and find the door with the help of the door finding signal. The persons were asked to give an arm signal as soon as they were able to hear the signal, then move on, find the button and press it accordingly.

j.) All experiments were recorded from three perspectives with the help of three cameras, such that an evaluation of the arm signals and the finding situation could later be assessed.

k.) The real background noise levels were recorded during the tests with the help of a microphone on the upper edge of the door, such that the real S/N ratio prevailing during the test was always documented.

l.) The entire experiment was computer-controlled. For each detection process, all three camera positions, the interference levels, the finding time and the test parameters were recorded.

m.) After each finding process, the test persons were asked about the situation and the answers were recorded.

n.) An in-depth interview was conducted with each person about further accompanying questions.

5.2 Test persons

The 9 test persons were obtained with the help of the respective associations of the visually impaired in Switzerland and Germany. A pre-selection could not be made due to the small number of voluntary participants. Prior to the test, the test subjects provided the following information about themselves:

Table 5.1: Information provided by the test subjects about themselves

Age	Sex	Country of origin	Cause of the visual impairment	Visus (L,R)	Degree of disablement	Other disabilities	Hearing impairment	Hearing aid
52	m	DE	Genetically determined, rare RP-disease	not measureable, not measureable	100	/	/	/
51	m	CH	Retinitis pigmentosa RP	ca. 1, not measureable	not defined	/	/	/
71	m	DE	Dominantly inherited cone-rod dystrophy	2,1	100	/	Hearing impairment	Yes
65	m	DE	Nystagmus, optic nerve atrophy, corneal opacity	1,1	100	/	Deaf on the left ear	/
56	m	CH	Retinal disease (RP)	not defined	not defined	/	Hearing impairment	Yes
57	m	CH	Genetic birth defect	0,2	40	/	No; still an active piano tuner	/
25	m	CH	Cataract and glaucoma	0,0	not defined	I can walk with the orthosis, but only very slowly		/
61	f	DE	Congenital retinal scarring due to rubella infection	0, not measureable (ca. 0.03)	100	/	/	/
42	m	DE	Optic atrophy following polytrauma	<1, totally blind	100	Musculoskeletal limitations due to polytrauma	/	/

In this context, the term "visus" in the narrower sense refers to visual acuity, i.e. the ability of the retina to perceive two points as separate. A visual acuity of 100% corresponds to a value of 1.0. Visual acuity is usually age-dependent and is around 1.0 to 1.6 in a 20-year-old person. An 80-year-old person, on the other hand, only has a visual acuity of 0.6 to 1.0. The reason for this is that visus or visual acuity decreases with age.

5.3 Test setup at Leipzig Central Station

According to Wikipedia, Leipzig Central Station is described as follows (translated from German):

„Leipzig Central Station is the central passenger station in Leipzig and is one of the 15 busiest long-distance stations of the Deutsche Bahn with around 135.000 passengers and visitors every day. The railway junction and terminus station with 23 platform tracks, 22 of which are used for passenger traffic, is one of the 21 stations in the highest price range of DB Station&Service. With a covered floor area of 83.640 square metres, it is the largest terminus station in Europe. The façade of the station building facing the city centre is 298 metres wide."

The track area in the hall is approx. 215 m long. As a test platform, Deutsche Bahn provided track 17 of Leipzig station for 3 full days from 1 to 3 November. Figure 5.1 shows the layout and location of track 17 at Leipzig station.

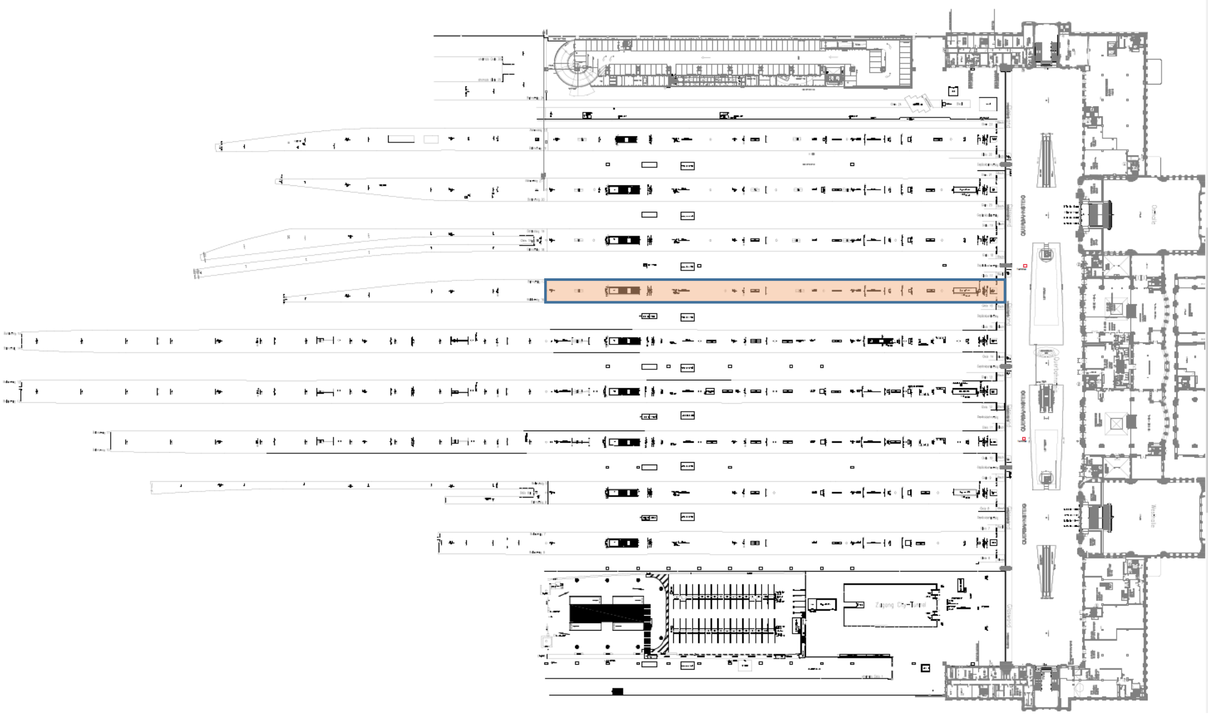


Figure 5.1: Floor plan of Leipzig station with marking of the hall area of track 17

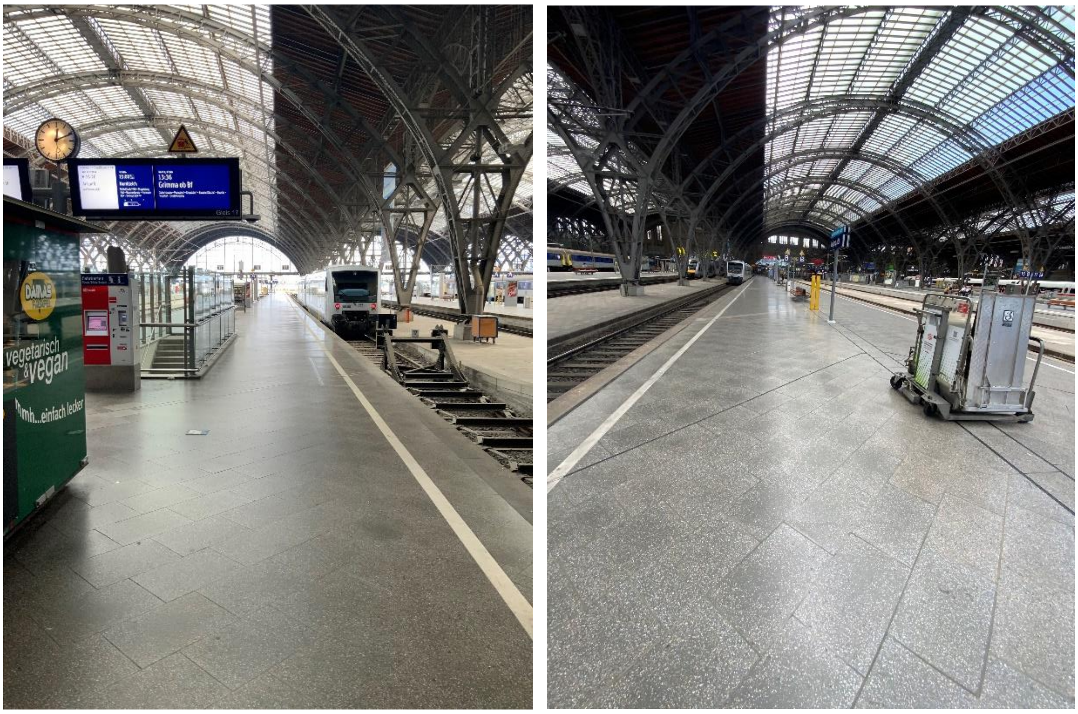


Figure 5.2 a-b: View of track 17 with view a. from the head area b. from the end of the hall

The station was chosen because, on the one hand, it has a large hall that creates a natural environment, has short distances for the visually impaired to the shops and toilets, and is close to the location of the advanced TrainLab test train in Halle.

Track 17 does not have any guide strips for the blind or other tactile platform orientations. Only a white stripe, located about 50 cm from the edge of the platform, serves for visual orientation, which could not be used by the visually impaired. For the experiments, therefore, the platform edge had to serve as orientation for the test subjects. The platform has a width of 4.5 m from the centre of the platform to the edge of the platform. This entire width could be used for the experiment.

5.4 Preparation of the test train advanced TrainLab

The test train was the aforementioned advanced TrainLab of Deutsche Bahn. Advanced TrainLab (aTL) is the name given by Deutsche Bahn to two Class 605 units that serve as test vehicles for various technologies. They are “intended to be available to the entire rail industry for experiments and to represent the spectrum of tests of innovative technologies that is not possible with DB's regular passenger or freight trains.“

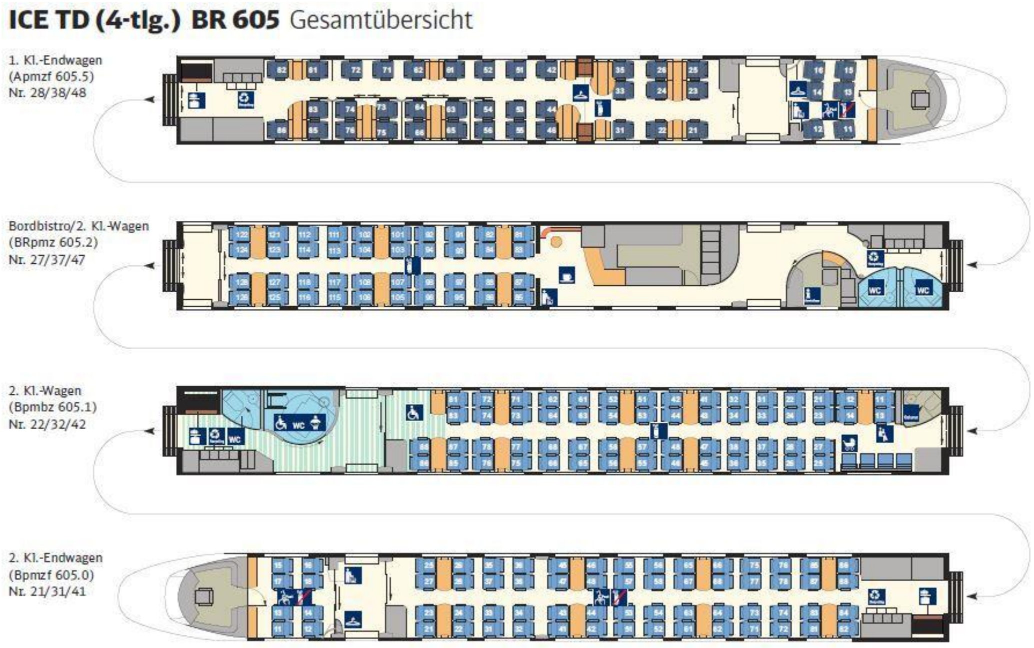


Figure 5.3: Overview of the structure of the advanced TrainLab

Figure 5.3 shows the schematic plan of the test train, Figure 5.4 shows sections of the train at Leipzig Central Station.

Figure 5.4 a-b: Views of Deutsche Bahn's advanced TrainLab at Leipzig Central Station

The train consists of four wagons, each about 25 m long and has a total length of 105 m. Figure 5.5 shows the layout of the train with the test door marked.

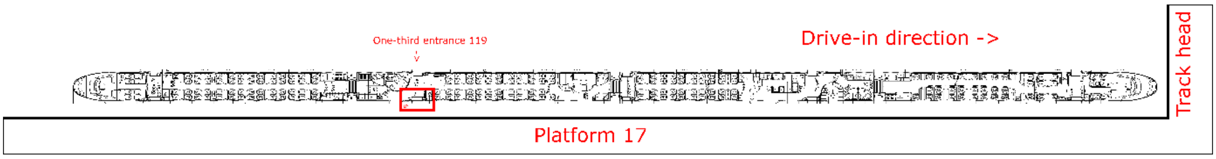


Figure 5.5: Arrangement of the test train on track 17

Accordingly, the door at the one-third entrance 119 (second-to-last car in the direction of the hall exit) was chosen as the test door, because on the one hand there was sufficient distance between the test area and the busy front area of the station, but also because there was still a sufficient length of the train available on both sides of the door.

Figure 5.6 a-b: View of the prepared test door (a. open, b. closed)

The test door was prepared as follows:

- Installation of a case with a sound transmitter and door button in the door area at a height of 1 m
- Installation of a second identical box above the door at a height of 2.2 m
- Attachment of a measurement microphone as an interboundary microphone on the door (approx. 2 m height) to record the real noise level as $L_{Aeq,5}$ (5 s average value)

Figure 5.7: Loudspeaker and door button of the prepared test door

A loudspeaker from Visaton was used as the signal transmitter.

Figure 5.8: View of the loudspeaker (Visaton PL 7 RV) used as the signal transmitter

The Visaton PL 7 RV loudspeaker was chosen as the signal transmitter because it can reliably generate the required test sound levels of up to $L_{AFmax} > 80$ dB at a distance of 1 m with a comparatively small size, but also has a very wide polar pattern. The data sheet is included in the appendix. It should be noted that it was not intended to use a real signal transmitter already in use, but one capable of reproducing all the levels to be generated for the experiment with very good quality.

Although the additional transmitter and button arrangement applied to the door did not correspond to the real case of a button recessed into the door and carriage construction and could be felt more tactilely due to the height of the case, the arrangement was sufficient to determine with certainty whether and how the area of the button could be found with the help of the door finding signal or not. The button itself was to be pressed after the button had been found and served as an acknowledgment at the end of each finding process.

With the help of this arrangement, the signal level at the reference point could be precisely adjusted and varied in a controlled manner during the experiment. Analogous to the previous door measurement standards, a measuring point of 1.5 m perpendicular to the centre of the door at a height of 1.5 m was chosen as the reference measuring point.

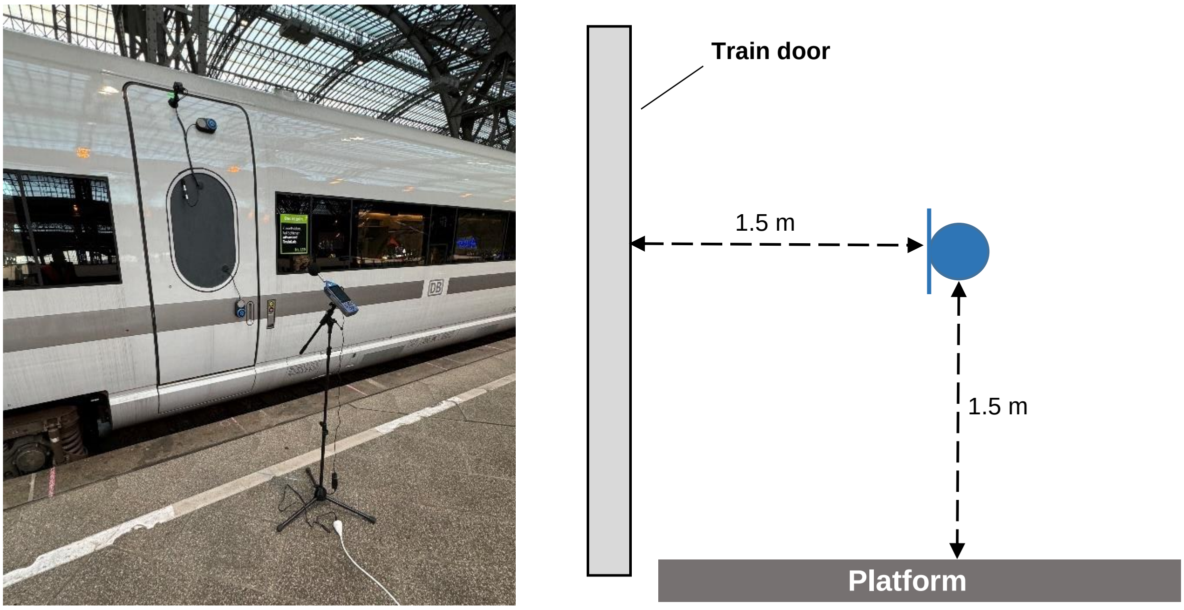


Figure 5.9 a-b: Measurement arrangement for level calibration and schematic sketch

5.5 Implementation of a controlled background noise

For the targeted variation of the background noise, an experimental setup had to be selected that was able to depict the following parameters:

- Production of a largely diffuse sound field within the test zone
- Low level variation within the test zone (< 1.5 dB as $L_{Aeq,5}$)
- Low level variation over the test time (< 1.5 dB measured as $L_{Aeq,5}$)
- Creation of a realistic station environment
- Mapping of different types of background noise with different levels

In particular, the requirement for the implementation of a realistic acoustic station environment required some special effort. With a simplified experimental setup, noise at different levels could have been played back in a simple way via appropriate loudspeakers. However, this type of experiment did not seem suitable in view of the increased sensitivity of visually impaired people to audio signals. Therefore, real-world but fully controllable scenarios were generated.

5.5.1 Recording technology and raw data

To generate the base sounds, different sounds were spatially recorded at different locations. The recording and playback of the signals was carried out with the help of the Ambisonics method. Ambisonics is a method for recording and reproducing a sound field. In contrast to channel-oriented transmission methods, there is no fixed number of loudspeakers for playback. The respective signals are calculated according to mathematical specifications from the transmitted values for sound pressure and sound velocity for each individual speaker position.

The following components were used to record the signals:

- **Zylia ZM-1 3rd Order Ambisonics Microphone Array**, 19 digital MEMS capsules on a spherical surface, 48 kHz 24 Bit audio recording
- **Zylia ZR-1 Portable Recorder** records 19-channel Multichannel-WAV files

Figure 5.10: Recording sphere Zylia ZM-1

One advantage of the method is that the elevation plane can also be decoded according to mathematical relationships for any speaker position. As a result, a three-dimensional sound field is generated with just four transmission channels. In this sound field, no spatial axis is preferred, all loudspeakers contribute their share. Conventional surround sound methods are still distinctly two-dimensional, even with six transmission channels.

As the number of decoded speaker channels increases, the sound field becomes more stable. It can then even be perceived by listeners outside the speaker arrangement. The speakers do not need to be positioned in fixed positions in a regular rectangle; this allows for better adaptation to the practical conditions of playback.

With additional transmission channels, the stability of the spatial mapping can be further increased. At the same time, the process always remains backwards compatible, i.e. the decoding of individual channels can simply be omitted.

When using several playback loudspeakers, this creates a very spatial and natural sound field.

The following raw recordings served as the basis for the final signals generated for the experiment:

- Background noise at Bern railway station
- Background noise at Basel railway station
- Background noise at Düsseldorf railway station
- Reverberation chamber recordings of speech
- Construction site noise at Bern railway station
- Construction site noise (road construction site)

5.5.2 Playback setup

To playback the background noise, a loudspeaker arrangement consisting of 8 individual loudspeakers was chosen, which was set up in a line along the middle of the platform. The loudspeakers were positioned at a distance of 5 m, alternating between a height of 2 m and a position on the floor.

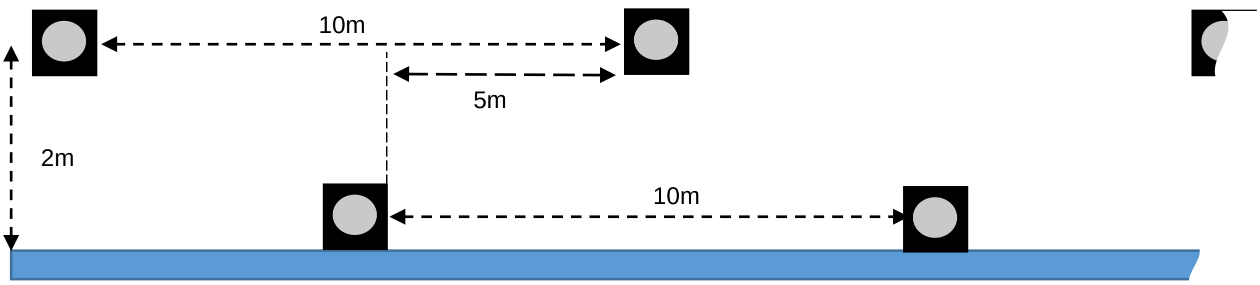


Figure 5.11: Principle sketch of the LS-structure for background sound reinforcement

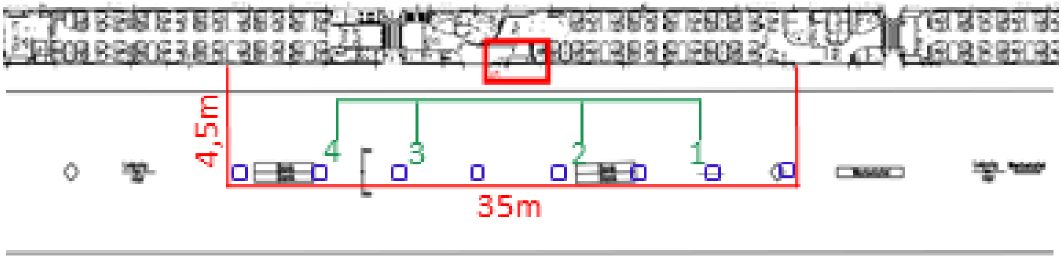


Figure 5.12: Marking of loudspeaker positions (blue), test area (red) and walking paths (green)

Figure 5.11 shows the basic arrangement, Figure 5.12 shows the 35 m wide test zone, which results from the selected loudspeaker arrangement. In addition, the starting positions to which the test subjects were led are marked.

All loudspeaker systems featured high-quality Radian 5208C drivers, which were digitally equalized with the help of a digital controller to create a linear frequency response. Playback was provided by an eight-channel Electro Voice CP S8.5 power amplifier.

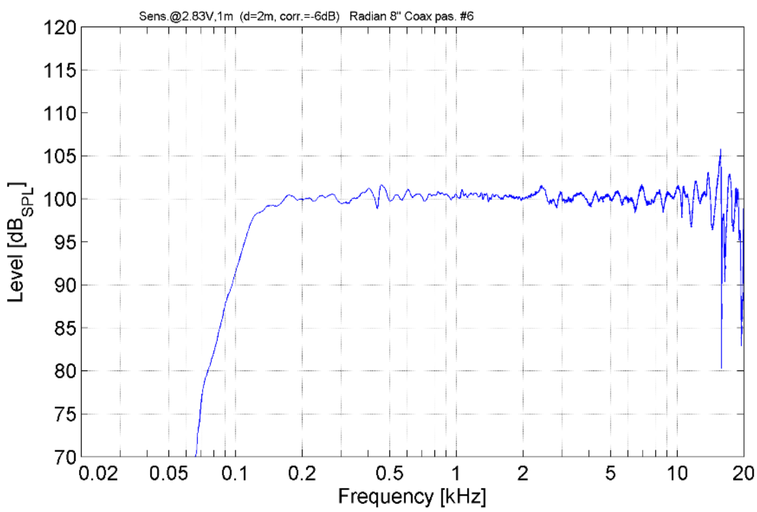


Figure 5.13: Frequency response of the digitally equalized playback speaker

5.5.3 Background noise generation

The variation of the background noise level should not only be done by raising or lowering the level, but also by changing the type of noise. Thus, realistic scenarios can also be stored for the different level variations.

For the experiments, four different realistic background noise scenarios were generated with corresponding noise levels.

Table 5.2: Background noise scenarios

Number	Scenario	Description	*Level L_{Aeq}*
1	Basic background noise	Overlay of sound recordings in Basel station without any information or speech.	**60 dB**
2	Speech quiet	Recording in the station hall of Düsseldorf main station, with little information content due to passenger traffic	**70 dB**
3	Voice announcement loud	AI-generated speech signals, recorded in the reverberation chamber as a simulation of loud informational announcements	**75 dB**
4	Construction site	Superposition of machine and work noise at construction sites. Overlay of several recordings from Bern and road construction sites	**78 dB**

Since the signals should have little variation over time, different signals of one type were mixed together in such a way that the temporal fluctuations of the 5-second mean value **$\Delta L_{Aeq,5}$ < 1.5 dB**. In the mix, however, all spatial references were retained.

For signal processing, the program Reaper with the IEM plugin suite was used. The AIIRADecoder from the suite allows the calculation of an Ambisonics decoder for an individual speaker layout in 3rd Order Ambisonics. It is assumed that the 8-channel speaker arrangement described above is located on a hemisphere with a large radius. The 8 speaker positions are entered into the plugin according to their order and positioned appropriately via azimuth/elevation. The channels of the recording are converted to the 8-channel positioning. The outputs of the plugin are then the 8-channel files used for the experiment.

Advantages of using this method are:

- No "sticking" of the signals to the loudspeaker, acoustic detachment from the LS-position
- Extremely realistic sound field generation
- Preservation of spatial resolution and directional references

Both in the development listening phase and during the test itself, the background sound field generated in this way within the test range was denoted by extremely realistic reproduction characteristics. Neither the participants nor the other people present during the experiment were able to distinguish whether the sound field was natural or generated by the loudspeaker arrangement.

The background scenarios were generated in a length of 10 minutes each and played back as a loop depending on the experiment.

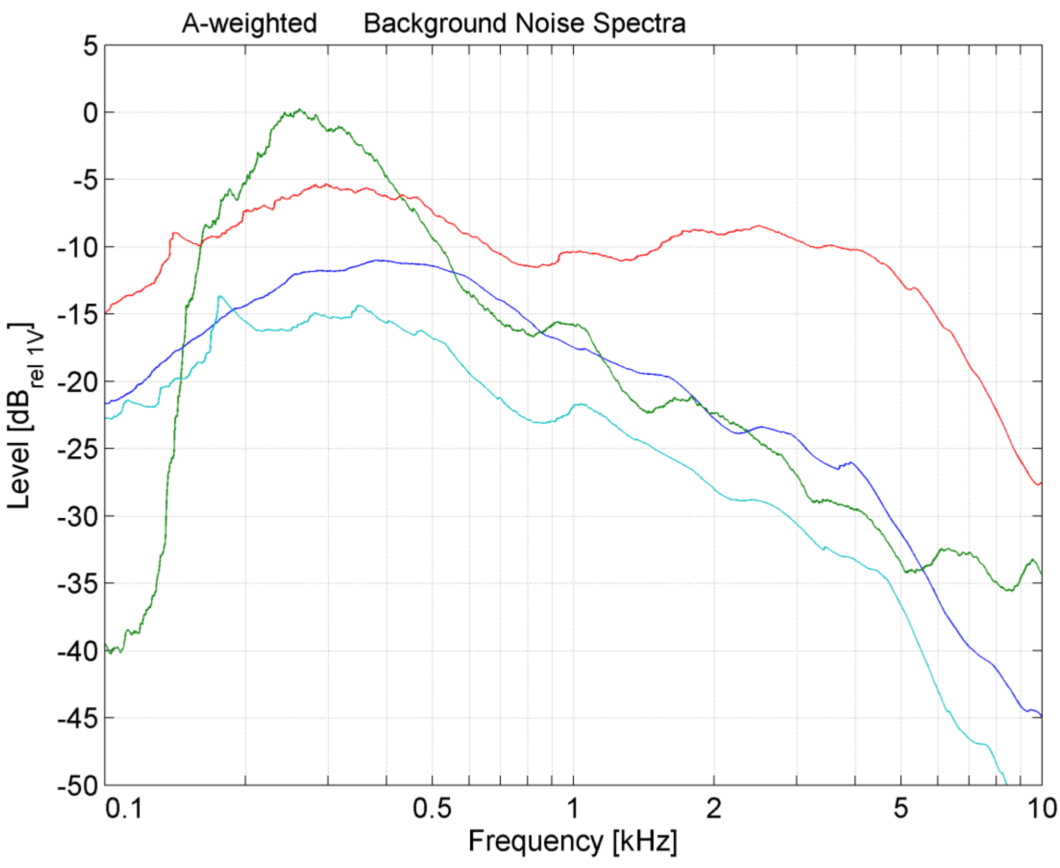


Figure 5.14: A-weighted spectra of the 4 background noise scenarios, relative representation normalized to 0 dB at maximum (turquoise = 1, blue = 2, green = 3, red = 4)

Figure 5.14 shows the spectra of the background noise scenarios, which are normalized to 0 dB at the maximum, but sorted with respect to their set A-weighted sum sound pressure level. It can be seen that the construction site noise (red) contains significantly more high-frequency components and the loud speech signals (green) have a level increase between 200 Hz and 400 Hz.

As explained in Section 2, according to the current definition in TSI PRM Appendix G, the noise should be the sum of three octaves (500 Hz, 1 kHz and 2 kHz). As further shown, the unweighted sum levels over the three octaves do not differ significantly from the A-weighted sum levels in the usual background spectra. Since the spectra generated here for scenarios 3 and 4 deviate from the usual spectrum, Table 5.3 shows the calculations of the level differences for all 4 scenarios.

Table 5.3: Level differences between A-weighted sum level and unweighted sum of three octaves for the 4 background noise scenarios

Szenario	1	2	3	4
$L_{Aeq} – L_{okt(500,1k,2k)}$	-0.3 dB	-0.6 dB	0.9 dB	2.8 dB

The table shows that the deviations for scenarios 1-3 are negligible in the context of the considerations made here. Only for the "unusual" construction site scenario, slightly larger deviations do occur.

In this respect, it should be noted once again that the background noise measurement, which is carried out over 3 octaves in the previous definition of TSI PRM Appendix G, can also be carried out in a very good approximation as an A-weighted sum sound pressure level for most platform scenarios.

A purely linear sum level should not be used to identify the background noise.

5.6 Determination of the scenarios and calibration of the arrangement

Within the framework of preliminary tests, which were carried out with the project participants as "test subjects", the entire test set-up was prepared and tested in front of a building façade (as a rough simulation of a train side). In particular, the sound quality of the background noise, the temporal and spatial uniformity of the level distribution, the functionality of the signal transmitter and other parameters were tested. In particular, it was also investigated within which level range the S/N ratio must be varied by the upper and lower level range (reliable detection or almost inaudible). This was based on the basic premise already explained, namely that door finding signals should be perceptible and locatable in a range of 3-6 m around the door.

The levels of useful signal and background noise were determined and set as follows:

1. Signal level of the door finding signal; Maximum A-weighted "Fast" sound pressure level L_{AFmax}
2. Signal level of background noise; energy-equivalent, A-weighted continuous sound level L_{Aeq}

3. The measurement position for determining signal and background levels is the reference position shown in Figure 5.9 (1.5 m door distance, 1.5 m height)

The preliminary tests revealed the following fundamental findings about the sound field:

1. The temporal uniformity of the simulated sound fields was very high. The deviations of 5-second A-weighted averaging levels were $\Delta L_{Aeq.5} \leq 1.5$ dB
2. The spatial uniformity of the simulated sound fields was also very high. The deviations from 5-second A-weighted averaging levels in the test range spanned by the loudspeakers (width x depth, 30m x 4m) were also $\Delta L_{Aeq.5} \leq 1.5$ dB

In addition, the preliminary tests yielded the following important findings on the S/N ratio:

1. **The door signals were always reliably audible and locatable in the door range of 3m - 6m with an S/N = 0 dB.**
2. **Only from an S/N < - 9 dB did the audibility become significantly poor and detection was only possible with increased effort.**

Based on the findings of the preliminary tests as well as the parameters signal type and signal transmitter height, the following matrix of the investigations to be carried out was created:

Table 5.4: Matrix of the 64 different listening test parameters

	Excitation 1m Height above Platform (Button)							
	Single Tone				Dual Tone			
S/N	1	2	3	4	1	2	3	4
0	x	x	x	x	x	x	x	x
-3	x	x	x	x	x	x	x	x
-6	x	x	x	x	x	x	x	x
-9	x	x	x	x	x	x	x	x

	Excitation 2.6m Height above Platform (above the Door)							
	Single Tone				Dual Tone			
S/N	1	2	3	4	1	2	3	4
0	x	x	x	x	x	x	x	x
-3	x	x	x	x	x	x	x	x
-6	x	x	x	x	x	x	x	x
-9	x	x	x	x	x	x	x	x

According to this, there are 64 different combinations that each of the 9 people was to go through.

This corresponds to a total of 576 test runs. A test time of approx. 70 seconds was planned for each test run, so that a net test time of 11 hours had to be achieved.

5.7 Supervision and execution of the experiments

All test scenarios were prepared in advance of the listening tests by programming control software in such a way that the experiments were automatically pseudo-randomized. The tests were divided into two blocks, block 1 with 32 scenarios contained only tests with the signal transmitter near the button, the other block corresponding to 32 scenarios with the signal transmitter above the door.

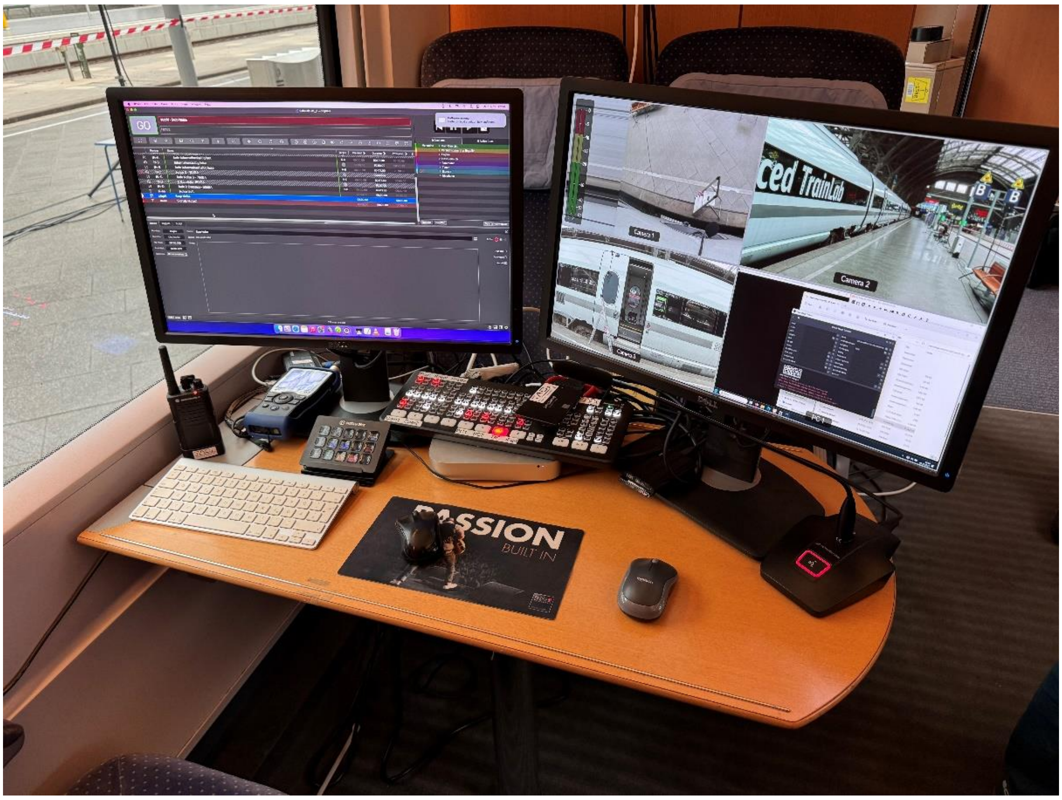


Figure 5.15: View of the test supervision and control station

Each test subject completed 8 blocks, each with 8 door-finding processes. The starting position was also pseudo-randomized.

Figure 5.15 shows the workstation of the control center. There, each scenario was automatically called up by software. All finding processes were recorded with three cameras from three perspectives. In addition, the actual background level was recorded, as the ongoing operation of the station could result in louder noise than the nominal artificial noise presented. The evaluation was carried out using the real measured S/N ratio, not the nominal S/N ratio.

The test persons were guided by a chaperon to the different starting positions with their heads facing the train. People were told in which direction to move after finding the edge of the platform. This was necessary so that the test persons did not walk out of the test zone in the wrong direction. The test persons were asked to give a hand signal as soon as they could perceive the finding signal, then move on to find and press the door button. Pressing the button stopped the experiment with a signal. The finding time was also recorded.

After each run, the subjects were asked 2 questions:

1. Was the moment (in terms of time and place) of perception of the door finding signal sufficient?
2. Did the door finding signal serve as an aid in finding the door?

The answer options could be given in 4 steps:

4 = very well
3 = well
2 = not good
1 = bad

In addition, a detailed interview was conducted with each test subject. The main results have also been summarised below.

5.8 Evaluation of the experiments

The test evaluation was essentially carried out following three steps:

a.) Evaluation of the answered questions after each finding process in 4 steps

b.) In addition to the answers to the questions asked after each finding, the video recordings were also analysed according to two criteria.

  1. How well could the door be found?
  2. How well could the door button be found?

  This evaluation was carried out in 5 steps:

  5 = Very well
  4 = well
  3 = not good
  2 = bad
  1 = not at all

Using the hand movement as well as markings applied to the ground near the door, the distance of perception could be evaluated retrospectively.

5.9 Results of the experiments

Of the nominal total of 576 runs, 560 could be carried out and evaluated. The evaluation was carried out as a point cloud diagram with calculation of a corresponding trend line as well as its uncertainty. In the following, the most important evaluation diagrams are presented and discussed.

First, the evaluations from the video recordings are displayed. It should be noted in advance that the diagrams also contain S/N ratios of up to -20 dB. This always happened when a nominally low background noise was drowned out by loud station noises. However, since the real S/N ratios were included in the analysis, this fact is essentially taken into account. Figure 5.16 shows the evaluation for locating the door, Figure 5.17 for locating the door **button**.

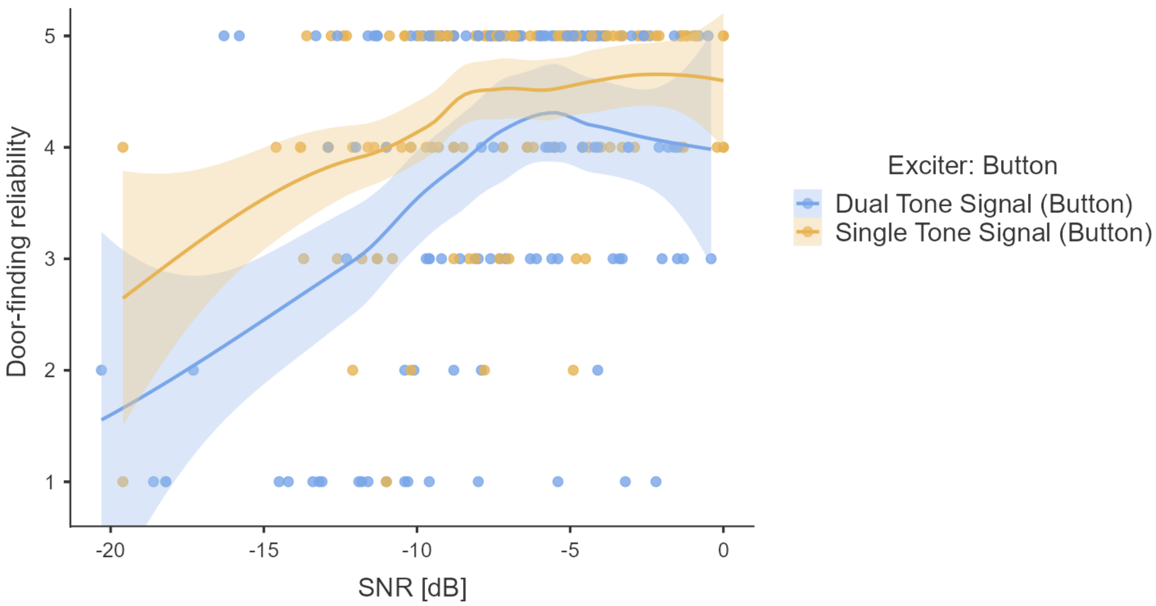


Figure 5.16: Evaluation of the "**Door**-finding reliability", Exciter: **Button**

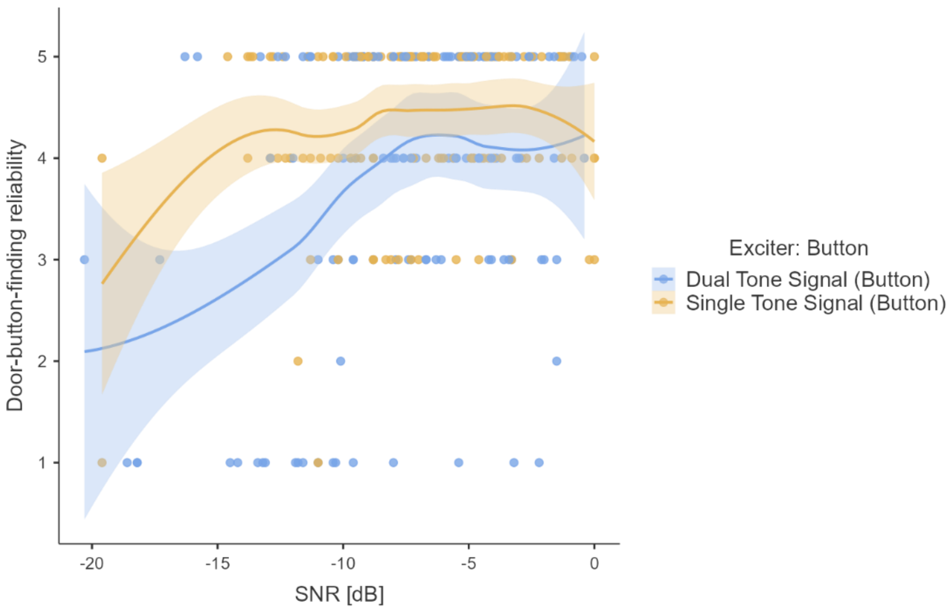


Figure 5.17: Evaluation of the "**Door-button-**finding reliability", Exciter: **Button**

The following statements are already clear from the first diagrams:

a.) With an S/N ratio of 0 dB to -7 dB, **the door** can be found reliably without significant differences.

b.) The **door button** can also be found with an S/N ratio of 0 dB to -7 dB without any significant differences.

c.) The uncertainty for the results from S/N = 0 dB to -7 dB is comparatively small, such that the results can be considered significant.

d.) On average, the dual tone signal performs slightly worse than the single tone signal.

It should be noted again that due to the effect of the binaural masking level difference (BMLD) described in Section 2, a nominally negative S/N ratio also leads to good audibility of signals in a diffuse noise environment. However, it was unclear how exactly this would affect the door finding signals.

The following evaluations show the same diagrams, but with the emission of the door finding signals from above the door.

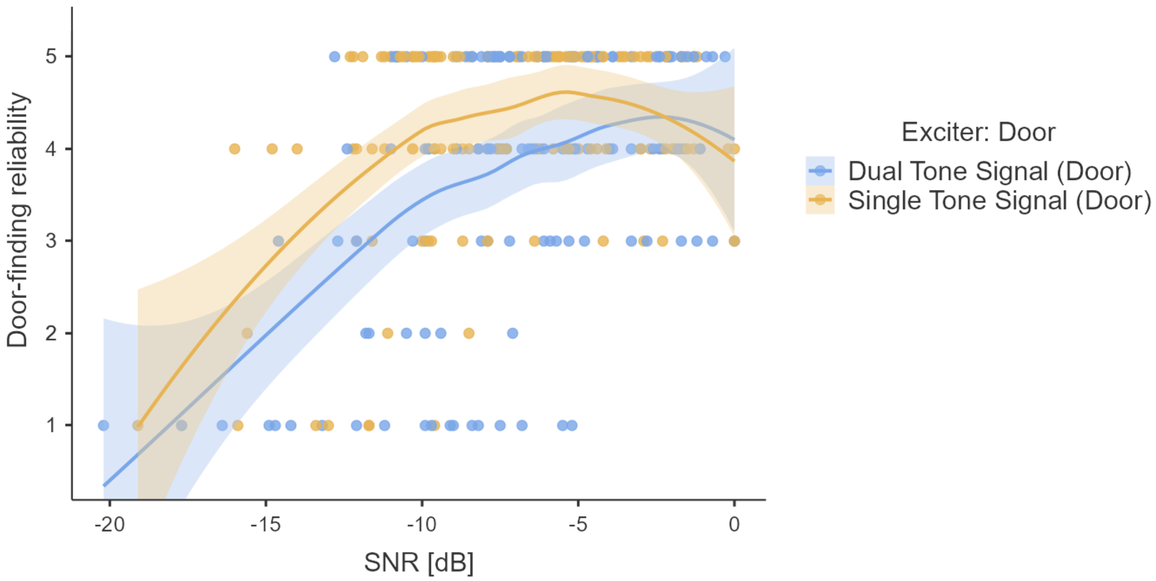


Figure 5.18: Evaluation of the "**Door**-finding reliability", Exciter: **above the Door**

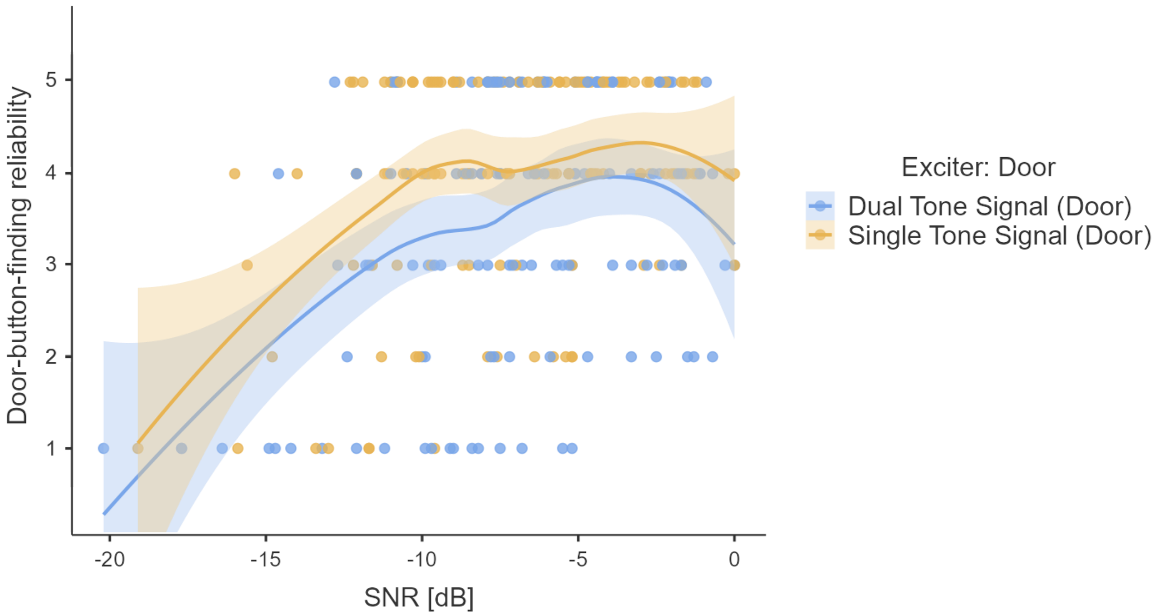


Figure 5.19: Evaluation of the "**Door-button**-finding reliability", Exciter: **above the Door**

The diagrams for the signal transmitter above the door show a very similar picture. Contrary to expectations, both the door and the door button were found in a similar way and under similar S/N conditions. The videos showed that, of course, after the first test runs, a certain strategy of the test persons set in to find the button. For example, after locating the door, the protruding button was found quickly by wiping movements. This is to be taken into account here in the interpretation.

Below, the diagrams are compiled in a different way, such that the position in the button is compared with the position above the door for the same type of signal.

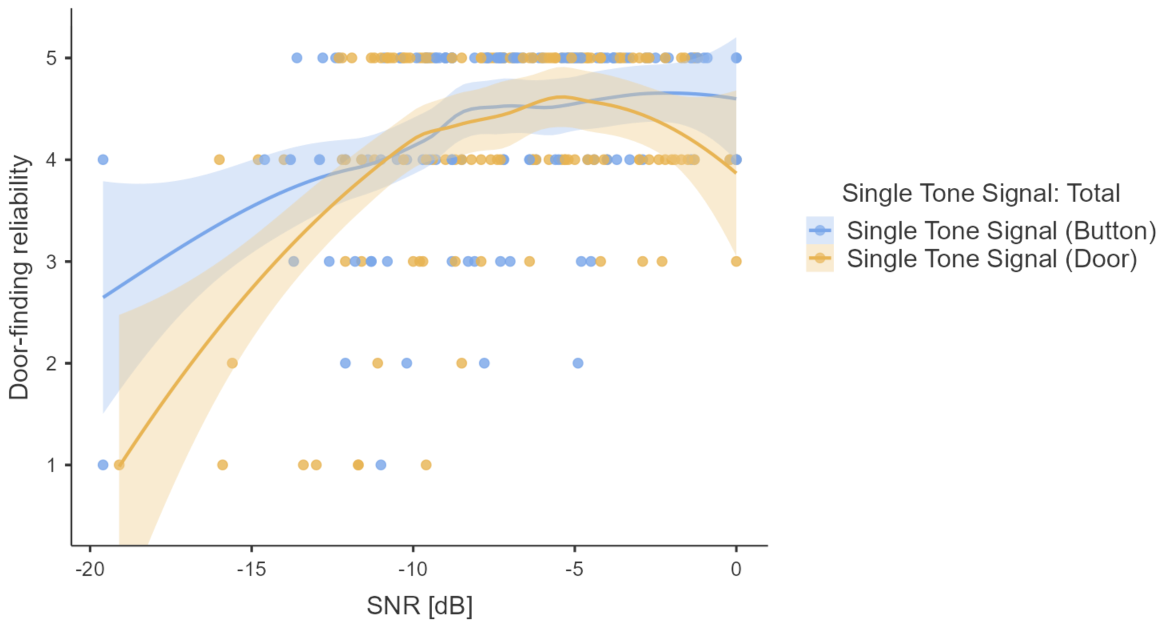


Figure 5.20: Evaluation of the "**Door**-finding reliability", **All <u>single tone</u> signals**

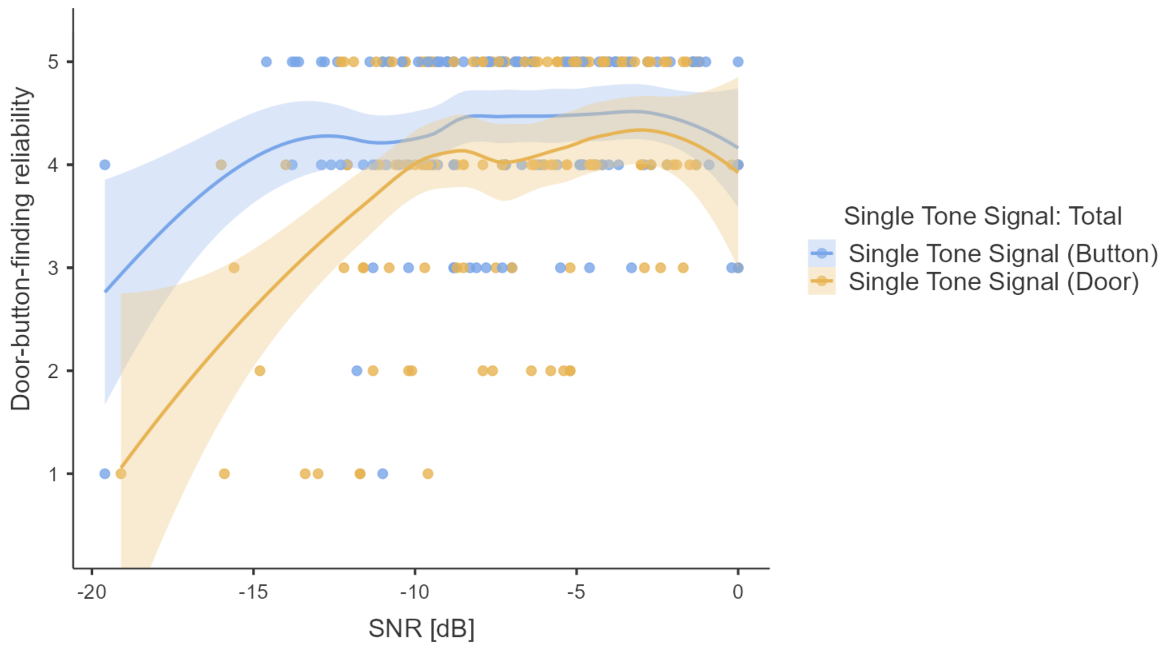


Figure 5.21: Evaluation of the "**Door-button**-finding reliability", **All single tone signals**

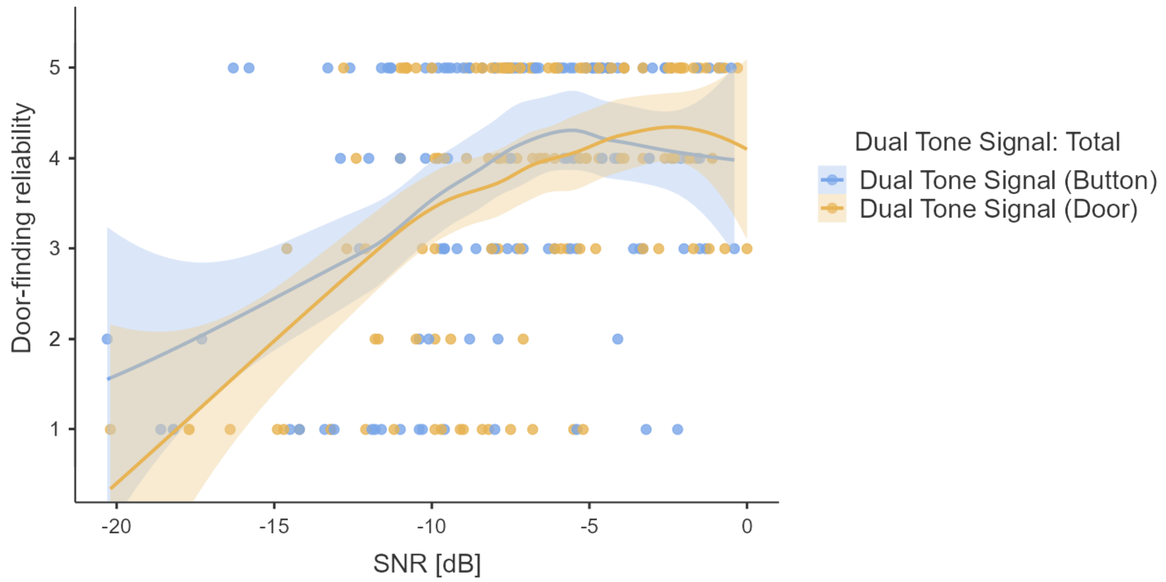


Figure 5.22: Evaluation of the "**Door**-finding reliability", **All dual tone signals**

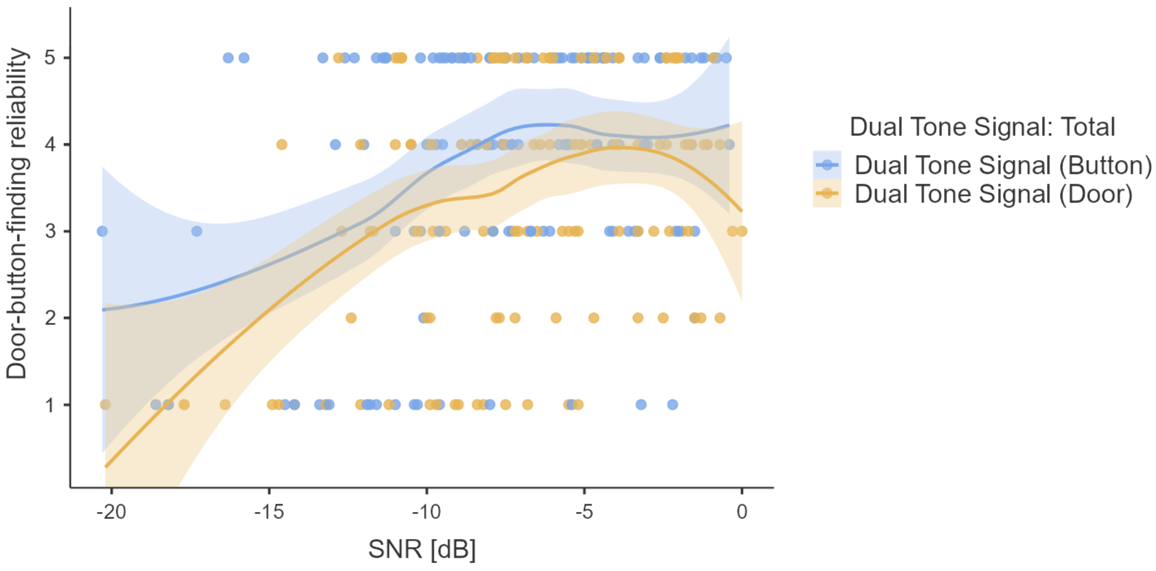


Figure 5.23: Evaluation of the "**Door-<u>button</u>**-finding reliability", **All <u>dual tone</u> signals**

All these diagrams confirm the statements made in the first interpretation.

Now the question remains at what distance the signals are perceptible depending on the S/N ratio. Orientation is provided by the 4.5 m mark, which is considered the middle in the range of 3 m to 6 m as a desirable perceptibility threshold. The evaluations are shown in the following figures.

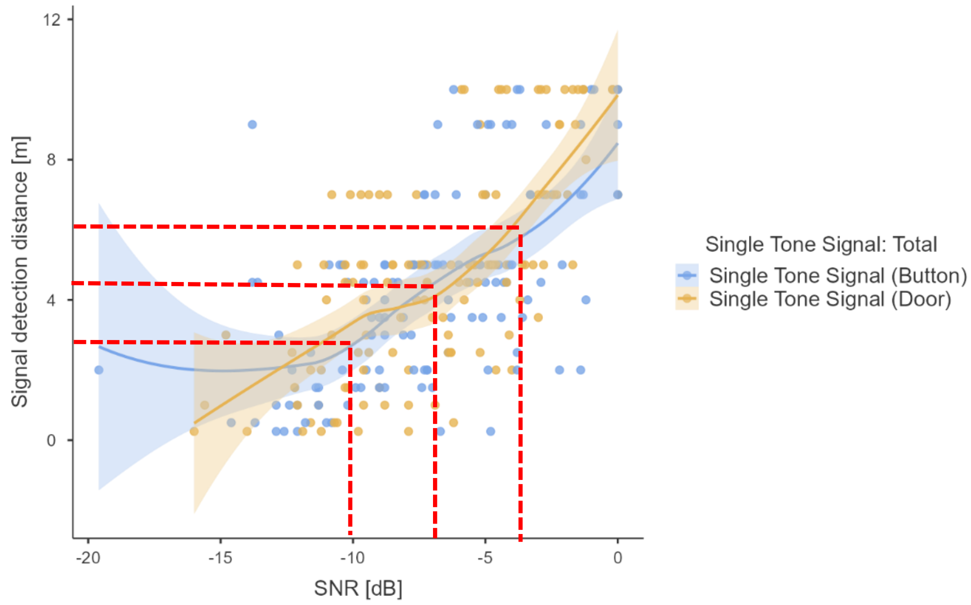


Figure 5.24: Evaluation **"Signal detection distance", single tone** with 3 m (S/N ≈ -10 dB), 4,5 m (S/N ≈ -7 dB) and 6 m-line (S/N ≈ -4 dB) (red)

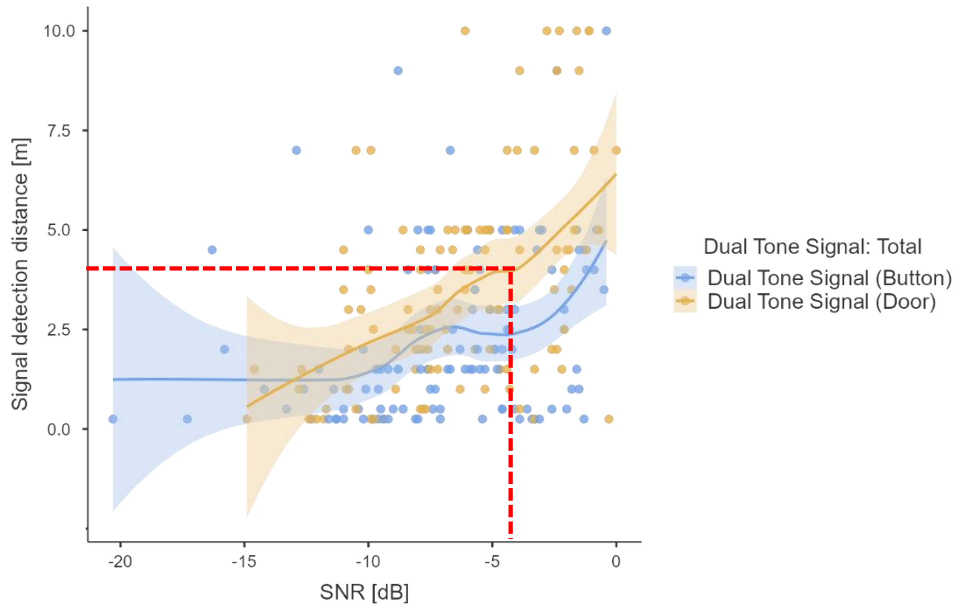


Figure 5.25: Evaluation **"Signal detection distance", dual tone** with 4,5 m line (red)

The results in the graphs can be interpreted as follows:

1. The single-tone signal is perceived in an S/N range of -4 dB to -10 dB at a corresponding distance of 6 m to 3 m. The average perceptual distance of 4.5 m is achieved with an S/N ratio of approx. -7 dB.
2. For the single tone signal, the results for excitation from the door button and above the door are almost the same.
3. The dual tone signal is consistently less perceptible than the single tone signal at the same level ratios.
4. The dual tone signal is perceptible at a greater distance when emitted above the door than when positioned at the button (at the same level in each case).

5.10 Further results of the experiments

During the breaks in the experiments, various other listening experiments were carried out with the other persons present during the experiment. The results, which were already apparent from the test subjects, could be recreated and confirmed by all participants. These evidence trials with non-disabled persons confirmed the following facts in particular:

1. The audibility determined by the test subjects as a function of the S/N ratio could be confirmed.
2. The dual tone signal is less noticeable than the single tone signal at the same level L_{AFmax}.
3. The position of the signal transmitter above the door was also judged to be well suited for locating the door. The differences to the situation with the signal transmitter from the door button were considered to be comparatively minor.
4. The audibility of the signals is between 10 m and 4 m for an S/N ratio of -3 dB to -6 dB.
5. The perceptual distance was considered good and sufficient, especially with an S/N ratio between -3 dB and -6 dB.

The interviewing of the test persons in the course of an in-depth survey revealed further important aspects:

- Door finding signals with square-shaped waveforms are better perceptible than those based on sine wave signals because of their greater "sharpness".

- The majority of visually impaired people can orient themselves based on the contrast of the train, but this is not sufficiently successful with all trains. People with more extensive blindness cannot not use this contrast either.
- Door finding signals clearly facilitate and speed up the boarding of trains due to more precise locating.
- Door finding signals cause less stress and more independence when traveling.
- Door finding signals emitted from the button prevent the entire door from having to be scanned by hand.
- Single tone signals are generally judged to be better perceptible than dual tone signals.
- However, dual tone signals are judged to be more pleasant and less stressful.
- Single tone signals with a lower frequency of occurrence are preferred over those with a higher frequency of occurrence. The lower the occurrence , the lower the stress triggered, because a higher frequency of occurrence implies: "Hurry up, the door is about to close".
- Doors should be audible at a distance of at least 2 m, preferably up to 6 m.
- Ideally, the door finding signal should reach half a distance between the doors. In this way, a signal (next door on the right or left) can always be detected.
- In principle, the emission of a door finding signal from near the button is preferred, although there is a problem of it being covered up. This problem of screening may be less if there are people in front of the door, because then the door has already been "found".
- If the door finding signal comes from above the door, an additional vertical tactile aid must be installed at the door, as the door button is not always located directly below the signal transmitter.
- It would be desirable to install signalling devices at both positions. In this case, the door button would be easier to find in the immediate vicinity, but for slightly longer distances, screening the transmitter close to the button would have no effect.
- Without door finding signals, the door can only be found by "swiping" along the car body or with the help of others. Otherwise, it is not possible to find it.
- Door finding signals not only make it easier to find the door, they also take away the worry of not finding the door (and thus missing the train) and thus significantly reduce the stress of travelling.

- The test subjects expect the study to find a good compromise between the audibility of the signals and immission control with the help of the listening tests.

6 Proposals for clarification of the PRM TSI Appendix G

In order to clarify the specifications for door finding signals in the TSI PRM Appendix G, a study was carried out on behalf of the Federal Office of Transport of the Swiss Confederation (BAV) with the involvement of an advisory group. The advisory group consisted of the following representatives:

- Bundesamt für Verkehr der Schweizerischen Eidgenossenschaft, BAV (client)
- Schweizerische Bundesbahnen AG, SBB (Rail Production an Fleet Strategy)
- Deutsche Bahn AG, DB (Innovation, Gremienarbeit und Service Technik Schienenfz., FE.EF 33)
- Deutsche Bahn AG, DB (Kompetenzzentrum Akustik und Erschütterungen, TT.TVE 35)
- EAO AG (manufacturer of signaling devices, Switzerland)
- TSL-ESCHA GmbH (manufacturer of signaling devices, Germany)
- TAC - Technische Akustik (contractor)

The results were discussed in detail in the working group and the below described coordinated recommendations were developed. The recommendations are also described in Section 7 and are summarised below:

6.1 Definitions

In accordance with Section 3.4.2, the signal definitions should first be clarified:

L_S = sound pressure level of the signalling device measured as L_{AFmax} (the maximum sound level with frequency-weighting 'A' and time-weighting during the measurement period 'Fast')

L_{Smax} = maximum signal level L_S (measured as L_{AFmax})

L_{Smin} = minimum signal level L_S (measured as L_{AFmax})

L_N = level of the background noise, measured as follows:

6.2 Measurement of background noise

The background noise measurement is to be carried out as an energetic sum over 3 octaves. Alternatively, it has been shown that for most platform noises, even a broadband but A-weighted sum level gives almost the same results. From a technical point of view, the octave method offers a certain advantage, because for all types of background noise (at least to a large extent) only those frequency ranges are taken into account that also contribute to masking the door signals. In both cases, the signal processing of the microphones which detect the noise situation must perform appropriate frequency filtering.

A significant improvement in terms of readability and comprehension of Appendix G is given if a distinction is made between the definition of the signal, the detection of noise during train operation, and the detection of noise during type approval.

6.2.1 Signal definition and measurement of background noise during train operation

Accordingly, the following clarifications can be made as an alternative:

b.) Similar to the previous definitions in TSI PRM Annex G:

L_N = Level of the background noise

L_N is to be measured as an energetic sum over 3 octaves as follows:

$$L_N = 10 \cdot \log_{10} \sum \left(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}} + 10^{\frac{L_3}{10}} \right)$$

$$L_1 = L_{oct,500Hz}$$
$$L_2 = L_{oct,1000Hz}$$
$$L_3 = L_{oct,2000Hz}$$

L_N is determined as an energy-equivalent continous sound level over a time period T:

L_N is determined as an energy-equivalent continuous sound level over a time period T:

$$L_N = L_{eq,T}$$

The measurement of the background noise on the platform starts immediately before the emission of the door finding signal and then continuously during the respective signal pauses of the door finding signal as follows:

For the single tone signal, the individual measurements must be carried out during each signal pause over a period of at least 200 ms. The individual measurements for the dual tone signal are to be carried out within one signal period during the long signal pause over a length of at least 800 ms.

From the individual measurements, a sliding energetic average is to be formed over 5 s. For the sliding average, all consecutive individual measurements shall be averaged, with all measurements occurring more than 5 s in the past being removed from the calculation.

Note: When recording the background noise with a microphone positioned at the door, the level occurring there is 3 dB higher than at the reference point due to the reflection at the boundary surface.

6.2.2 Measurement of ambient noise at the vehicle

It is necessary to decide whether the TSI PRM Appendix G should also include statements on measurements at the vehicle. In any case, it is advisable to consider the following tips and suggestions.

When measuring at the vehicle, an artificial background noise must be generated. For this purpose, the use of pink noise is suitable as a substitute source. In this case, it must be ensured that the signal level is determined at the reference point, but the noise level is determined at the train door via the built-in microphone. The noise level determined at the train door must be recorded in parallel with a suitable sound level meter (comparative measurement). The background noise, which is generated by means of pink noise, is thus determined directly at the door. The location of the sound source must be chosen in such a way that the difference in level between the reference point and the measuring point on the door, taking into account the boundary surface situation, is negligible (typ. $\Delta L < 1$dB).

Attention: When detecting background noise with a microphone at the surface of the door, the level occurring there is 3 dB higher than at the reference point due to the reflection at the boundary surface. This must be taken into account when determining a measurement method for measurements at the vehicle.

When performing measurements at the vehicle, the averaging time should be at least T = 20 s.

6.3 Determination of signal levels and S/N ratios

f.) The studies show that a fixed signal level for the door finding signals is **not an adequate solution** to the trade-off to be achieved between audibility and excessive sound emission.

It is therefore proposed that door finding signals should be mandated to be adaptive signals.

g.) For better audibility, the waveform should be required to be rectangular and not sinusoidal.

h.) Based on the feedback of the test subjects, the single tone signal should be emitted at the lowest possible rate of occurence.

Therefore, the number of pulses should be reduced from 3 to 5 per second to 3 to 4 per second.

i.) As a compromise between audibility at an acceptable distance and thus the safe location of the door and the noise immission protection, an **S/N ratio of -6 dB** must be achieved for the **single tone signal**. Due to the poorer perceptibility of the **dual tone signal** compared to the single tone signal, an **S/N ratio of -3 dB** is recommended.

In addition, it is important to make sure that the signals are not audible at too far away a distance (typically > 6 m), otherwise confusion and mislocation could arise in relation to trains on the opposite platform that are also sending out door finding signals.

If adaptive signals are implemented exclusively, the requirements of immission control are also reliably fulfilled, because the door finding signal noise components emitted by the doors are safely lost in the background noise from a distance > 10 m anyway and can therefore no longer disturb the neighbourhood.

j.) As shown in Section 4 with platform noise statistics, the L_{AF10}, which is approximately 75 dB for most situations, has been chosen as the basis for safety concerns when setting levels for safety alerting via the PA system. Since door finding signals are not safety signals in the strict sense, it is recommended to attenuate the requirement and use the L_{AF20} percentile level, which is typically around 70 dB. With a sufficient S/N ratio of -3 dB or -6 dB, this would result in maximum levels of approx. L_{AFmax} = 67 dB and L_{AFmax} = 64 dB, respectively.

G. 3.1. Single tone signal

Characteristics	Tone impulse (rectangle), no fade in or fade out, impulse waveform rectangle (no sinusoidal impulse) - signal impulse duration = 5 ms ± 1ms „on“ (tone signal) - signal time pattern of 3 to 4 pulses per second
Frequency	- f_{signal} = 630 Hz ± 50 Hz
Sound pressure level adaptive (not static)	- $L_S \geq L_N$ – 6 dB - $L_{S\ min}$ = 40 dB ± 2 dB - $L_{S\ max}$ = 67 dB ± 2dB

G. 3.1. **Dual tone signal**

Characteristics	***without changes***
Frequency	- ***without changes***
Sound pressure level adaptive (not static)	- $L_S \geq L_N - 3$ dB - $L_{S\,min} =$ 45 dB ± 2 dB - $L_{S\,max} =$ 70 dB ± 2 dB

The dynamic range of 25 dB proposed here is appropriate from an acoustic point of view. However, it must be discussed with the manufacturers of the signalling devices to what extent such a dynamic range can be implemented in the electronics.

It is important to note that even with S/N ratios < 6 dB (down to about -10 dB), the door can still be found reliably in the event of changes occurring in the ambient noise. This "merely" reduces the distance to the door (approx. 3 m), from which the signal can still be heard and serve as an acoustic guide.

6.4 Additional clarifications

Another important question for determining the signal levels is the placement of the signal transmitter. If it is attached to the top of the door, it is much easier to install larger and more powerful sound transmitters. This should also be taken into account.

Experiments and interviews with the visually impaired have shown that a signal transmitter for door finding signals can also be installed above the door. However, the same or similar certainty for locating the door button only appears to be given if an additional tactile aid is introduced, e.g. in the form of a rubber strip or similar. Examples of this can be seen in the following illustrations.

Figure 6.1.1 a-b: View of a train door with tactile aid (blind strip)

Last but not least, the contents of Section 4.2.2.3.2 "Exterior doors" of the Commission Regulation [6] also need to be adapted as follows.

(10) The sound source for door signals shall either be placed above the door in the middle of the doorway or in the area local to the control device.

If there is no control device and the sound source cannot be placed above the door, the sound source for door signals shall be located adjacent to the doorway.

If a separate sound source is used for the door closing signal, it can be either local to the control device or adjacent to the doorway.

If an external door signal is provided, its sound source shall either be placed above the door in the middle of the doorway or in the area local to the control device. If the sound source is placed above the door, an additional tactile aid (guidance strip) must be integrated into the door to aid with locating the door button. The tactile aid must be mounted both above and below the door button with sufficient length. The contrast to the background according to EN 16584-1 must be observed.

It is also necessary to consider where the following addition is to be added to the TSI PRM.

Door finding signals shall not be emitted at the same time as door opening and closing signals.

Grevenbroich, December 6th 2023

Prof. Dr.-Ing. Alfred Schmitz

Prof. Dr.-Ing. Anselm Goertz

Nicolas Sünn, B.Eng.

Daniel Labuda

Standards, Guidelines and Documents Used

[1] Appendix G TSI PRM 2023
Technical Specifications for Interoperability: Persons with reduced Mobility

[2] DIN EN 14752:2022-03
Bahnanwendungen - Seiteneinstiegssysteme für Schienenfahrzeuge; Deutsche Fassung EN 14752:2019+A1:2021

[3] DIN EN 17285:2021-12
Bahnanwendung - Akustik - Messung akustischer Türsignale; Deutsche Fassung EN 17285:2020

[4] DIN EN 16584-2:2022-06 - Entwurf
Bahnanwendungen - Gestaltung für die Nutzung durch PRM - Allgemeine Anforderungen - Teil 2: Informationen; Deutsche und Englische Fassung prEN 16584-2:2022

[5] DIN EN 61672-1:2014-07
Elektroakustik - Schallpegelmesser - Teil 1: Anforderungen (IEC 61672-1:2013); Deutsche Fassung EN 61672-1:2013

[6] Commission Implementing Regulation (EU) 2023/1694 of 10 August 2023, published in the Official Journal of the European Union on the 08.09.2023

[7] DIN ISO 226:2006-04
Akustik - Normalkurven gleicher Lautstärkepegel (ISO 226:2003)

[8] Psychoacoustics – Facts and Models, Hugo Fastl; Eberhard Zwicker
Springer Verlag, 3th Edition

[9] Beschallung auf Bahnsteigen
Leitfaden Akustik
DB-Station&Service AG, Version 1.0, 16.09.2021

[10] ISO 1996-2:2017-07
Akustik - Beschreibung, Beurteilung und Messung von Umweltlärm - Teil 2: Bestimmung des Umgebungslärmpegels

[11] Abstände auf Perrons
Gefahrenbereiche- Sicherer Bereich
Forschungsbericht 2011, BAV Schweiz

[12] Berechnung des Beurteilungspegels für Schienenfahrzeuge (Schall 03)
Deutscher Bundestag Drucksache 18/1280

[13] Erläuterungsbericht zur Anlage 2 der 16.BImSchV
Berechnung des Beurteilungspegels für Schienenfahrzeuge (Schall 03)
Teil 1: Erläuterungsbericht

[14] Laute Türsignale in Zügen verwirrende Blinde
Kassensturz Espresso, 24.04.2023

Appendix A.1 Datasheet of the Loudspeaker Visaton PL 7 RV

VISATON GERMANY

PL 7 RV

Art. No. 4477 (NCS S 3000-N) – 4 Ω
Art. No. 4474 (NCS S 3000-N) – 8 Ω

7 cm (2,5") Einbaulautsprecher mit Gewindering am Kunststoffgehäuse zur einfachen Montage in einer kreisrunden Öffnung ohne zusätzliche Schrauben. Hoher Wirkungsgrad im sprachrelevanten Frequenzbereich. Inklusive 60 cm Kabel.

Anwendungsmöglichkeiten
- Armaturenbretter, Tür- oder andere Verkleidungen in Fahrzeugen

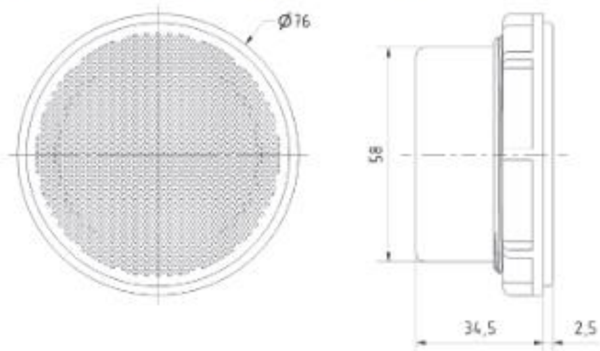
Zubehör: Distanzring DR PL 7 RV (NCS S 3000-N) (Art. No. 4489)

***7 cm (2.5") flush-mounted speaker** with a threaded mounting ring at the plastic housing for easy installation in round openings without additional screws. High efficiency at frequencies relevant for speech reproduction. Including 60 cm cable.*

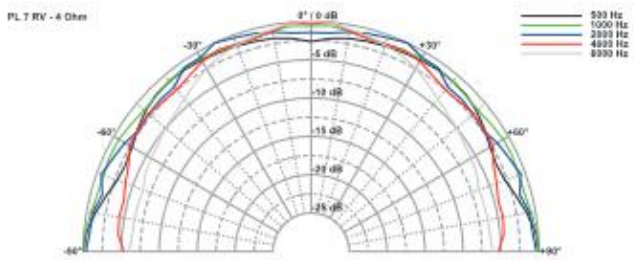
Typical applications
- *Dashboards, door panels or other panels in vehicles*

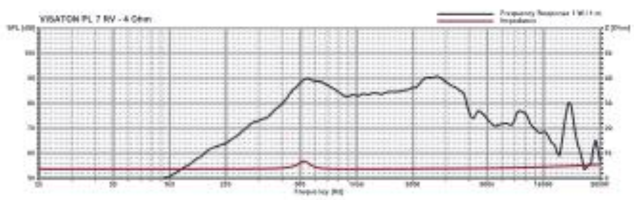
***Accessories:** Spacer ring DR PL 7 RV (NCS S 3000-N) (Art. No. 4489)*

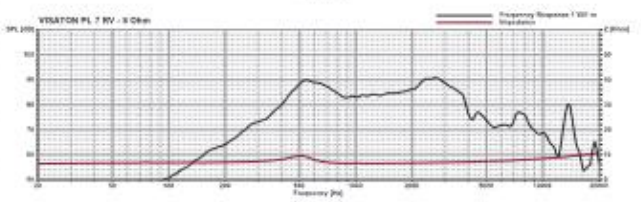
Art. No. 4489



Technische Daten / *Technical Data*	
Nennbelastbarkeit / *Rated power*	10 W
Impedanz / *Impedance*	4 Ω / 8 Ω
Übertragungsbereich (-10 dB) / *Frequency response (-10 dB)*	400–5000 Hz
Mittlerer Schalldruckpegel / *Mean sound pressure level*	88 dB (1 W/1 m)
Resonanzfrequenz / *Resonant*	550 Hz
Einbauöffnung / *Cutout diameter*	64,5 mm
max. Wandstärke / *max. thickness panel*	7,5 mm
Kabellänge / *Length of cable*	0,6 m
Gewicht netto / *Net weight*	0,160 kg
Farben / *Colours*	NCS S 3000-N (grau / grey)







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Appendix A.1 Datasheet Radian 5208C

5208C 8" Coaxial driver

- designed for high SPL applications where precise 100° conical coverage in a very compact coaxial system is required
- ideal for high performance pro sound applications and surround systems in small cinema rooms for immersive digital audio formats
- Radian proprietary Aluminum alloy diaphragm with highest tensile strength to weight ratio and fatigue resistance
- dual magnet design with independent magnetic gaps eliminates flux modulation and dramatically reduces intermodulation distortion in HF range
- 500 W continuous program power
- maximum power, edge-wound ribbon copper clad aluminum voice coil on fiberglass former
- extended to 25kHz frequency range
- high transparency and resolution
- optional premium XO
- optional matching 70V transformers

SPECIFICATIONS GENERAL/LF

Nominal diameter	8"/205mm
Rated impedance	8 Ω
Power handling [1]	250 W
Continuous program power [2]	500 W
Sensitivity[3]	95 dB
Effective frequency range[4]	60 Hz – 25 kHz
Coverage angle [5]	100° conical
Recommended max. XO frequency	2.0 kHz
Minimum impedance	7.2 Ω
Cone material	Paper/Kevlar composite
Voice coil diameter	51 mm (2")
Voice coil winding	edge wound ribbon
Voice coil wire	copper clad Aluminum
Voice coil former	Fiberglass
Displacement limit for VC	14 mm
Voice coil winding height	11mm
Magnetic gap height	8 mm
Suspension	M-roll, Poly-cotton
Magnet	Ferrite ring
Frame	Cast Aluminum

Thiele-Small parameters

Fs	90 Hz
Sd	221.0 cm2
Re	5.9 Ω
Qms	6.8
Qes	0.66
Qts	0.61
Vas	10.8 dm^3 (L)
Cms	0.155 mm/N
Mms	19.9 g
BL	10.1 N/A
Le	0.7 mH
Xmax[6]	3.5 mm

SPECIFICATIONS HF

Nominal exit diameter	1"
Rated impedance	16 Ω (8 Ω optional)
Power handling [1]	40 W
Continuous program power [2]	80 W
Sensitivity[3]	105 dB
Effective frequency range[4]	800 Hz – 25 kHz
Min. XO frequency (12 dB/oct.)	1.2kHz
Dome/surround material	Aluminum alloy/polymer
Voice coil diameter	44 mm (1.5")
Voice coil winding	edge wound ribbon
Voice coil wire	Aluminum
Magnet	Ferrite ring