Acoustics Engineering

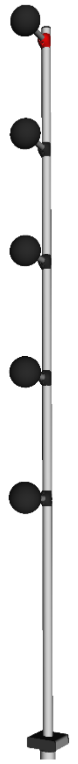
Measuring DI

TN019 - Rev. 2.0 – April 2025

Technical Note

EN 1793-4 and EN 16272-4 Measurement Procedure

Using the Zircon system



Standards: EN 1793-3 [1], EN 1793-4 [2]
EN 16272-2-3 [3], EN 16272-4 [4]

Hardware: Loudspeaker source: Zircon **LS24**
Microphone array: Zircon **MA25**
Control interface: Zircon **CI24**

Software: CI24 driver: X18 Windows Driver 5.72.0 2025-02-19
Zircon measurement: **DIRAC 7.3+** or **ZIRCON 1.0+**

Version 2.0 – April 2025

Contents

1 Introduction

This document presents a procedure to measure the in-situ sound diffraction of road traffic noise reducing devices in compliance with EN 1793-4, or of railway noise barriers in compliance with EN 16272-4, and is based on the following standards, equipment and software:

1. EN 1793-3, normalized traffic noise spectrum [1].
2. EN 1793-4, in-situ sound diffraction of road traffic noise reducing devices [2].
3. EN 16272-3-2, normalized railway noise spectrum and single number ratings [3].
4. EN 16272-4, in-situ sound diffraction of railway noise barriers [4].
5. Zircon hardware (by Acoustics Engineering), consisting of the **LS24** (or **LS14**) loudspeaker source, the **MA25** microphone array with 5 microphones and the **CI24** control interface between a computer running Zircon software, and mentioned devices.
6. Zircon software (by Acoustics Engineering), being **DIRAC 7.3+** or **ZIRCON 1.0+**, acoustics measurement software that produces a stimulus to the source, captures response signals from the measurement grid, processes these to verify the validity of the measurements, and calculates the results to be reported according to the standards.

In this procedure, familiarity with EN 1793-4 or EN 16272-4 and Zircon software is assumed. The explanations and screenshots are based on **DIRAC**, but largely similar with **ZIRCON**.

In this document, a *road traffic noise reducing device* or *railway noise barrier* is denoted by **NRD** (Noise Reducing Device).

This procedure presumes that, as prescribed by the standards, objects other than the NRD under test, potentially causing substantial parasitic reflections that might affect the measurement results, are kept at least 3 m from the microphones.

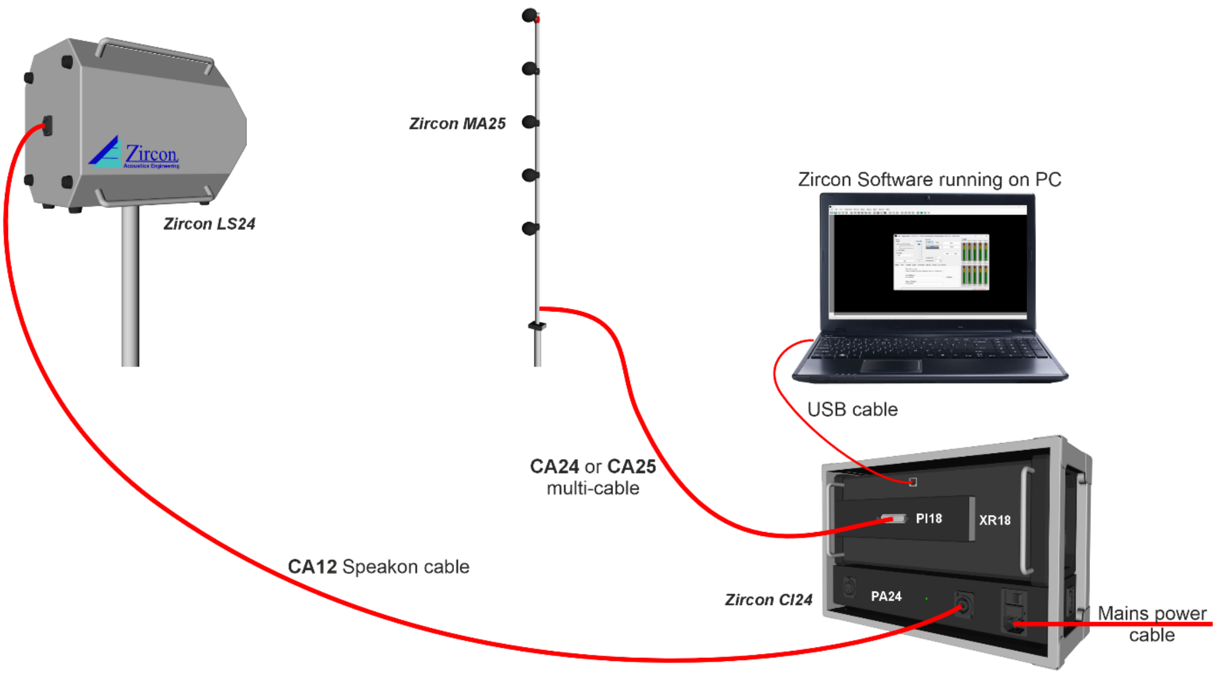
Where the loudspeaker unit is denoted as **LS24**, it may be substituted by its predecessor **LS14**, the electric and acoustic characteristics of which are substantially the same. Nevertheless, for the safest operation at these typical NRD heights, the lower weight **LS24** is recommended.

2 Measuring Equipment

2.1 Components

The measuring equipment consists of the following components:

1. Loudspeaker source: Zircon **LS24**, placed on its tripod using an **ET24** extender tube and a **TH24** tilt head.
2. Microphone array: Zircon **MA25** with 5 IEPE microphones, placed on its tripod using an **ET24** extender tube.
3. Control interface: Zircon **CI24**, comprising a multi-channel USB/Audio interface device with IEPE microphone inputs, and a power amplifier for the **LS24**.
4. Speakon cable: 2 x **CA12** (10 m) with coupler or **CA12-20m** (20 m)
5. Multi-cable: **CA24** (for 9-mics) or **CA25** (thinner, for 5 mics)
6. Windows PC running Zircon software.



2.2 Cables

The long distances require long cables to the LS24, the MA25 or both. Note that a long speaker cable is preferable to a long microphone cable. Assuming that the speaker cable is put over the NRD, a length of 20 m should do the job (**CA12-20m**). If such length is not needed in most other (non-diffraction) measurement situations, coupling two 10 m cables (**CA12**) may be preferable.

The **CA24** multi-cable (for 9 microphones) can be used with the **MA25**, but the **CA25** cable (for 5 microphones) is thinner, and therefore somewhat easier to handle.

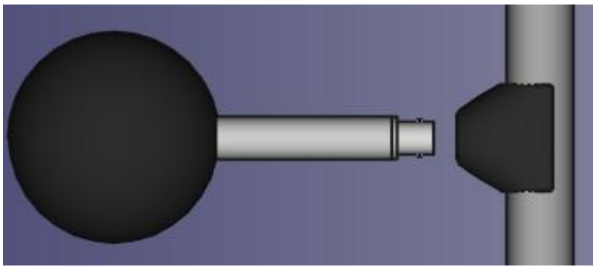
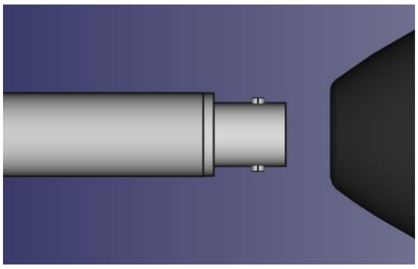
3 In-Office Installation and Preparation Procedure

3.1 Introduction

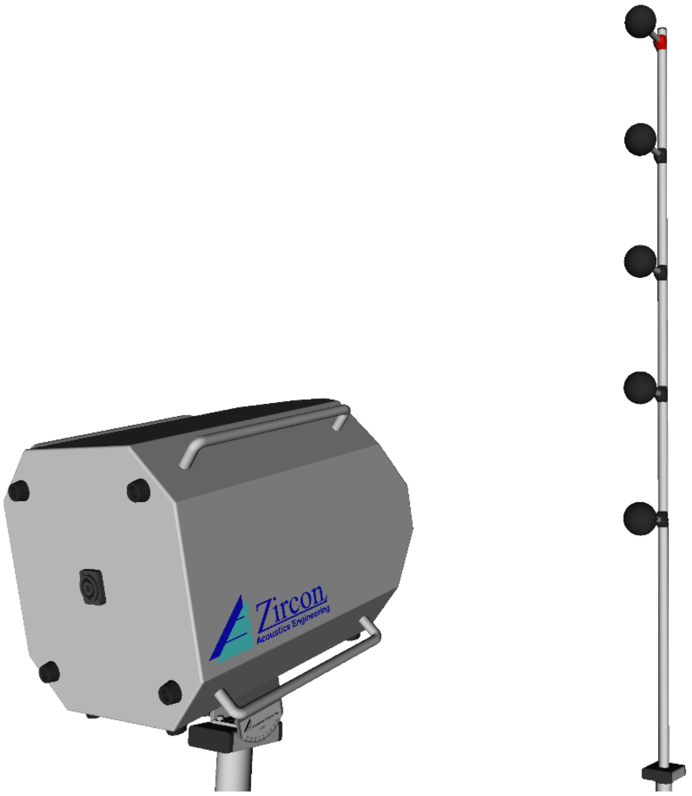
Hereafter, a kind of checklist is given for the in-office preparation of field measurements. Not all the instructions apply each time preparing a field measurement session, such as the CI24 driver installation.

1. Set up the MA25 tripod and take off the tripod head (with UNC 5/8" screw).

2. Screw the tripod head tightly enough in the MA25 bottom plate to avoid any play. The **ET24** extender tube is not convenient indoors, hence omitted here.
3. Place the **MA25** on its tripod and secure the tripod head with its screw.
4. Insert 5 microphones (bayonet movement).

5. Set up the LS24 tripod and take off the tripod head (with UNC 5/8" screw).
6. Screw the tripod head tightly enough in the LS24 bottom plate to avoid any play. The **ET24** extender tube is not convenient indoors, hence omitted here.
7. Place the **LS24** on its tripod and secure the tripod head with its screw.
8. At the right side of the **CI24**, insert the short mains power interconnection cable and set the **XR18** power switch to the On state.
9. Connect the **CI24** to the mains power through the included mains power cable.

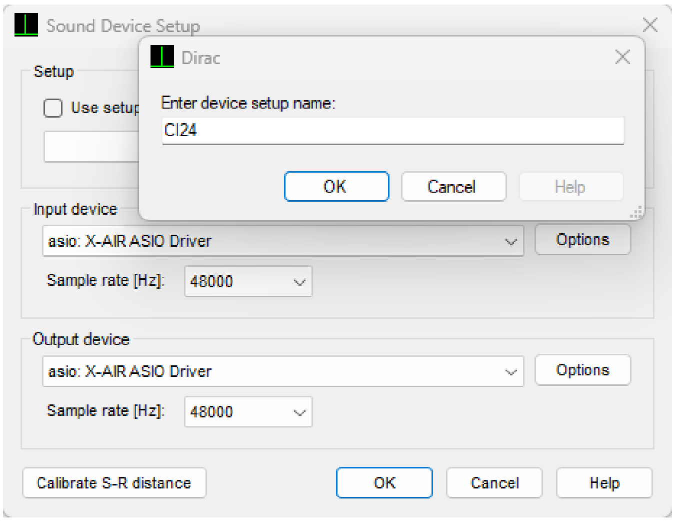



CI24 mains power interconnection cable

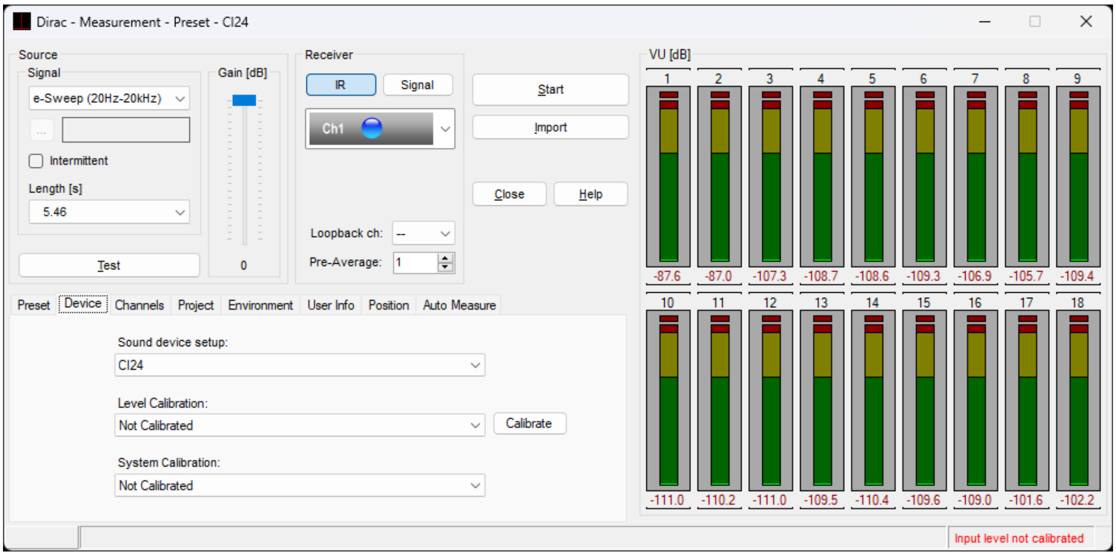
10. Connect the **CI24** to the PC through the included USB cable.
11. Attach the multi-cable to the **MA25** and the **CI24**.
12. Attach the Speakon cable to the **LS24** and the **CI24**.
13. Turn on the **CI24** by the switch above the mains power inlet. If the green LED on the power amplifier does not light, check the power. If the orange LED on the **XR18** unit does not light, turn on the **XR18** using the switch at the right side or check the interconnection cable there.
14. Install **X18 USB Audio Driver** on the PC (version 5.72.0, 2025-02-19). This driver can be found on the Behringer website by entering "XR18 driver" in the search field of the Download Center:

[Behringer | Downloads]

15. On the PC, start the Zircon software, and then from the **Setup** menu choose **Sound Device**.
16. From the **Sound Device Setup** window, select the line **asio: X-AIR ASIO Driver** for both input and output. Click 'OK' to save this setup under the name *CI24*.



17. The **Measurement** window now displays the VU meters for all **XR18** input channels:



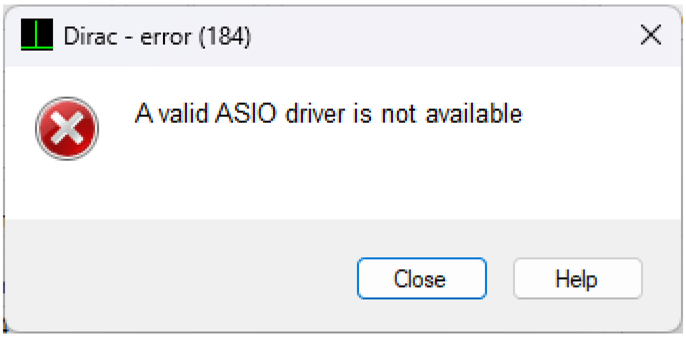
3.2 Startup sequence

After setting up the **XR18** in the Zircon software, the following startup sequence will normally be successful:

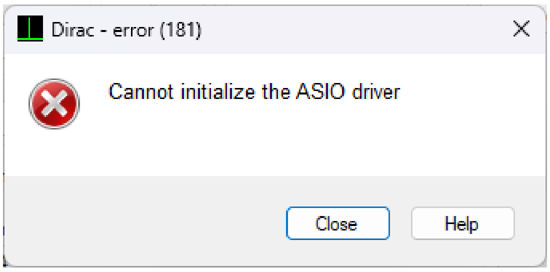
1. Connect the USB cable and turn on the CI24
2. Wait at least 11 seconds
3. Start the Zircon software and open the Measurement window

Note however, that connection and startup order matters. After turning on the CI24, it takes 11 seconds to complete starting up and, if the USB cable is connected, register with the Windows Device Manager, which then gets the ASIO driver up and running. When the Zircon software is started, it will check the availability of a valid ASIO driver only once and, upon opening the Measurement window, initialize it. Therefore:

- If the Zircon Software is started while the ASIO driver is not (yet) running, opening the Measurement window will display the following error message, and require a restart of the Zircon Software, but now with the ASIO driver running:



- If the Zircon Software is started while the ASIO driver is running, after which the CI24 has been turned off or the USB cable disconnected, opening the Measurement window will display the following error message, and require a reopening of the Measurement window after restoring the connection:

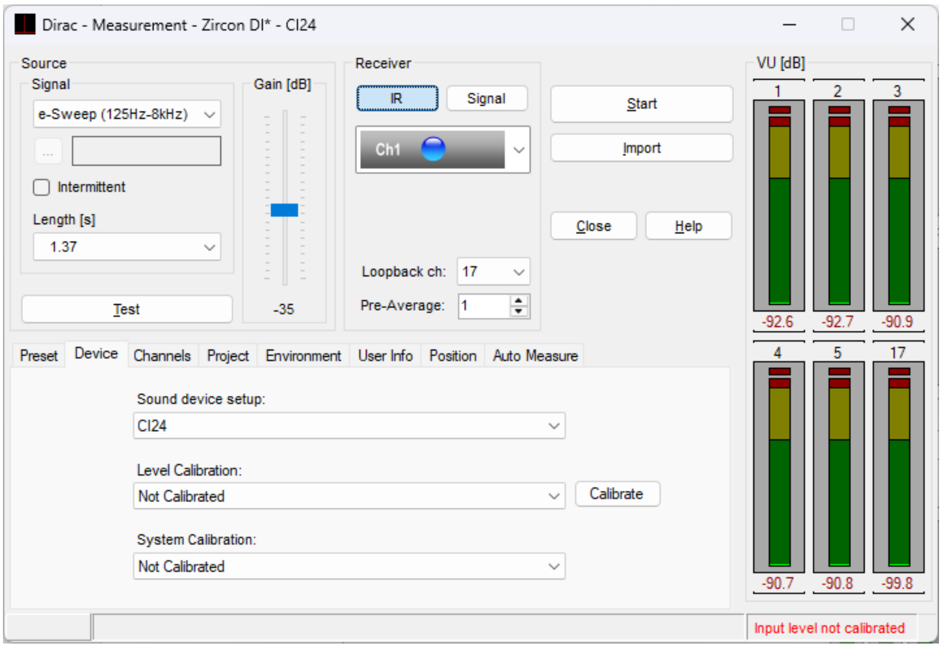


3.3 Dry run test

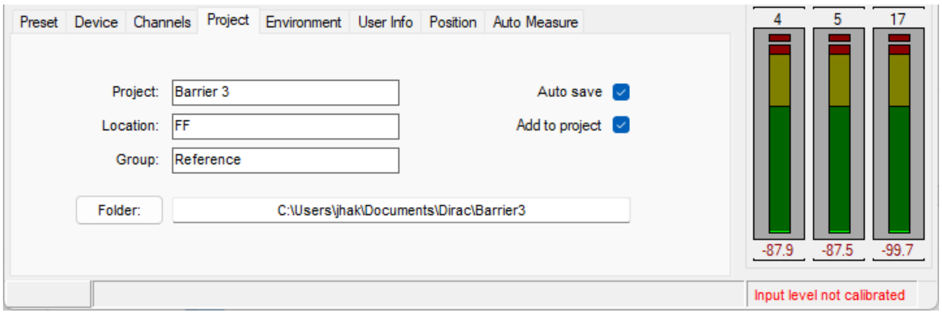
The dry run test simulates part of a field measurement in order to recall procedure steps and prepare the session along a road or railway.

3.3.1 Measurement (dry run)

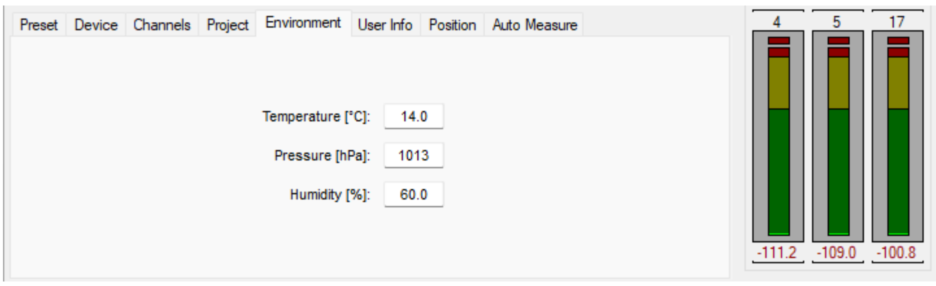
1. If applicable, on the **Preset** tab, load the **Zircon DI** setup. The preset name and associated sound device are displayed in the title bar. On the **Device** tab, sound device *CI24* is selected.
2. VU meters 1 through 5 should react to sound at microphones 1 through 5 respectively, and after clicking the Test button (mind the Gain!), a sweep should be heard from the **LS24**. Click the same button to stop the sweep. Note that for accurate source-receiver distance measurements, the **loopback channel** is used and set to 17.



3. Fill out the **Project** tab. Measured files will be saved in the designated folder. The file names will optionally include the Project and Location designations (menu **Setup** > **Options** > **Autoname**). In this example, Autoname is set to include the Project name (*Barrier3*), the Location name (*FF*), and the Source and Receiver numbers (*SmRn*, see step 6 below: **Position** tab) in the file names.

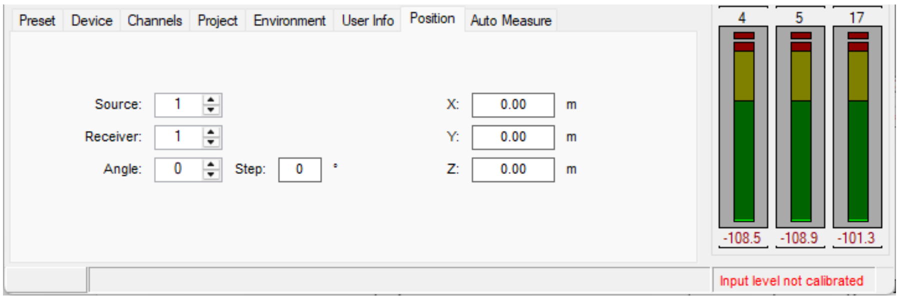


4. On the **Environment** tab, you can enter the expected environmental conditions in the field.

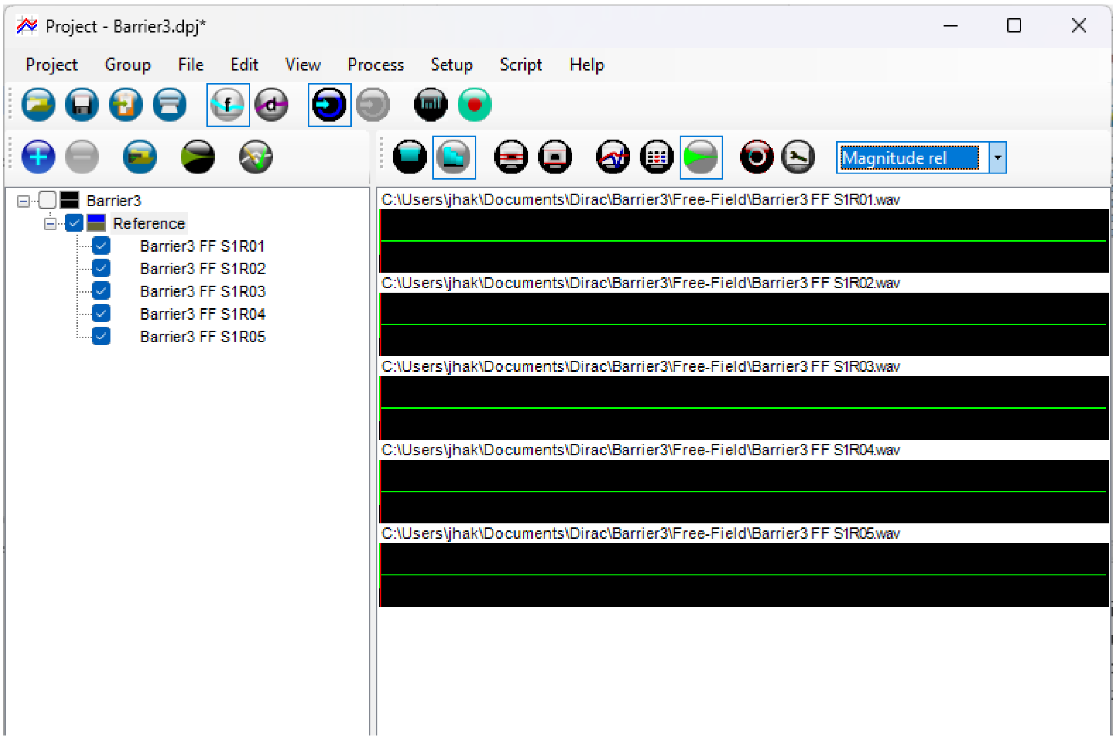


5. On the **User Info** tab, enter all remaining relevant measurement info.

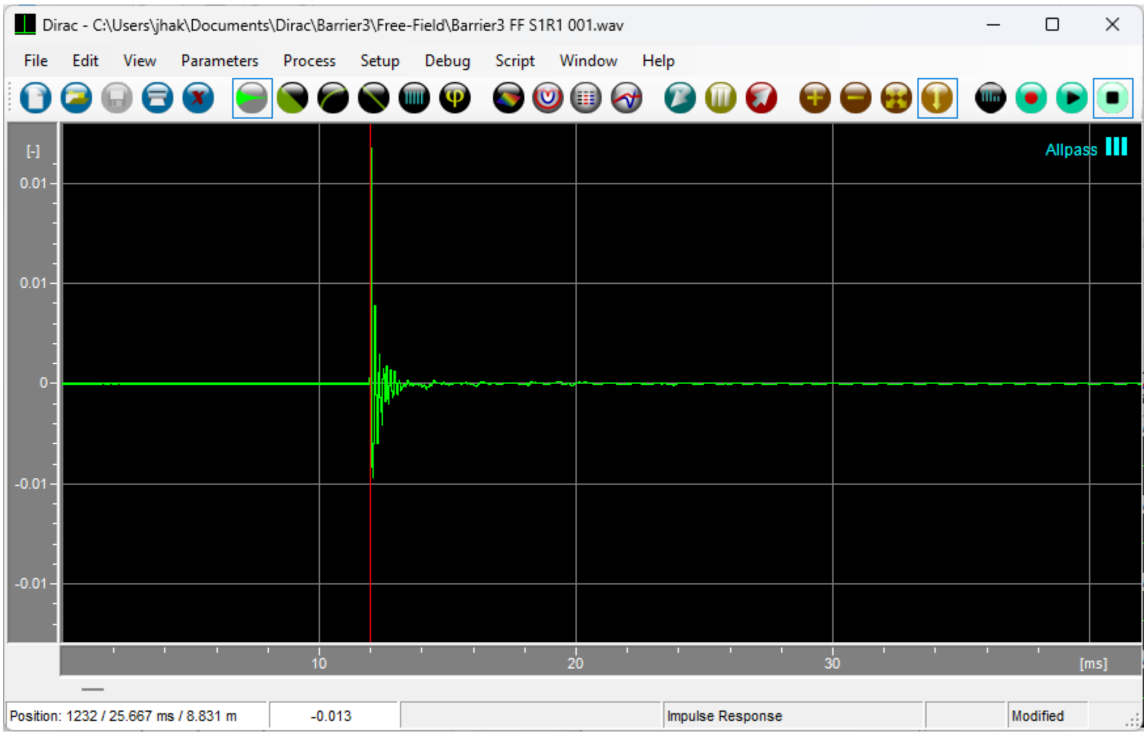
6. On the **Position** tab, enter *Source:* 1 and *Receiver:* 1.



7. Click the Test button, set the Gain slider to a reasonable sound level with respect to the background noise, and then click the Start button to perform the test measurement.
8. The **Project** window opens and finally shows 5 impulse responses, representing the free-field results for source position S1.



9. By double-clicking an impulse response, DIRAC will display it in Impulse Response view, and you can zoom in to see more details (note that below image of a synthetic impulse response is for illustration purposes only). The window can be closed again by clicking the top right corner.



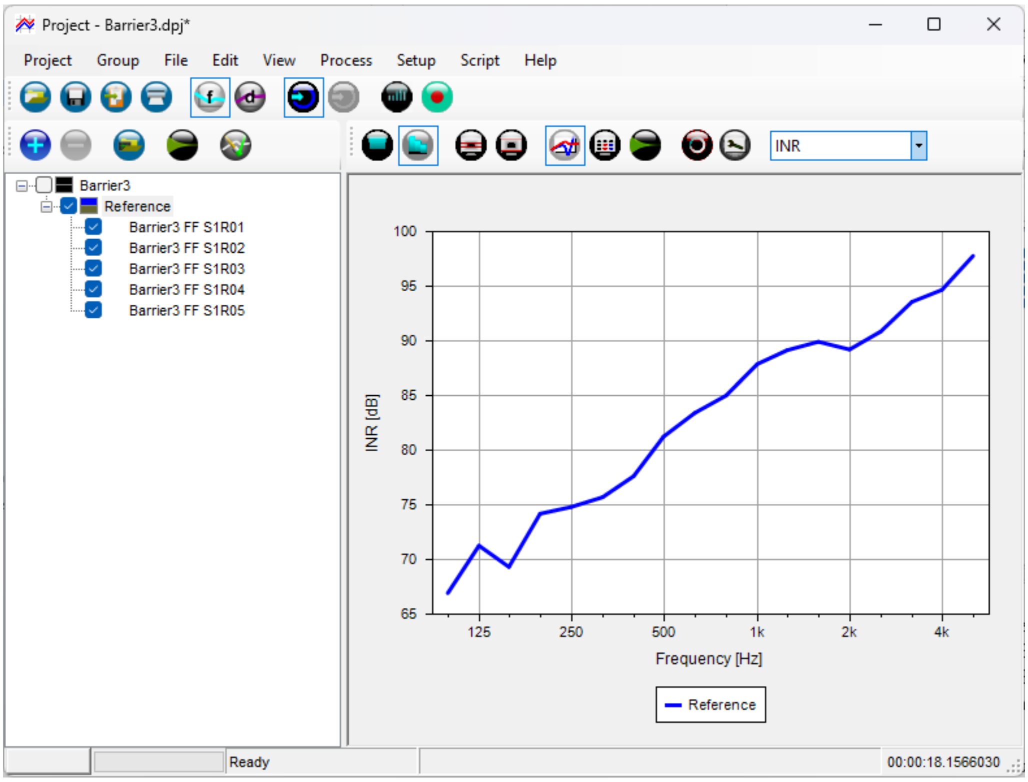
10. Select the Graph view (menu **View** > **Graph** or  ***Graph*** button).

11. Open the **Properties** dialog (**Setup** menu or  ***Properties*** button).

12. From the **Parameter** list on the left, select Levels > **INR** (Impulse response to Noise Ratio), and wait for the INR curves to appear. Below image of 5 synthetic impulse responses with identical and very high INR curves is for illustration purposes only, and not very realistic.

13. The INR reflects the quality of an impulse response measurement and should preferably exceed 25 dB for each microphone and at all third octave frequencies from 100 Hz through 5 kHz. If this is not the case, then this might be due to background noise, environmental fluctuations or an incorrect setup.

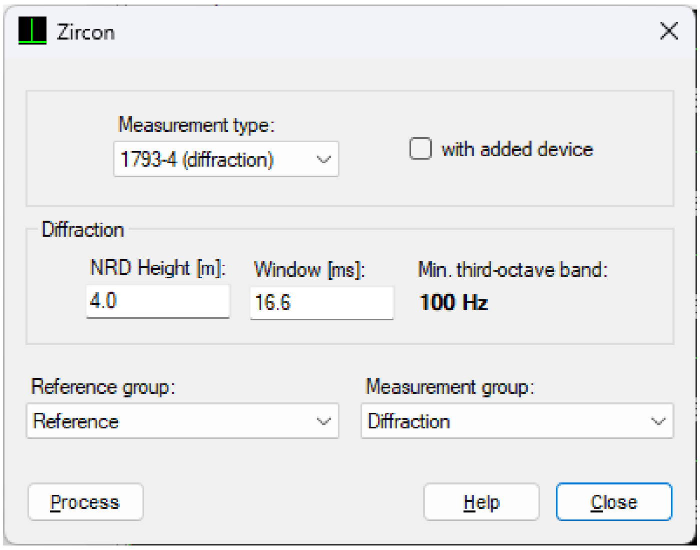
    So, if necessary, repeat the measurement with a corrected setup and/or under improved conditions, such as an adjusted source signal level or a higher Receiver Pre-Average value in the **Measurement** window, until the INR values are good or at least optimal.



14. If the measurements were repeated under different conditions to optimize the INR, delete all intermediate trial impulse response files in the folder, and then restart the measurement under the current optimal condition.

3.3.2 Processing (dry run)

1. In the Project window, from the **Process** menu, select **Zircon**.
2. Fill out the **Zircon** dialog box, entering the proper *NRD Height* and Adrienne temporal *Window* length, and selecting the *Reference* and *Measurement* groups.



3. It is not necessary now to click *Process* and carry out the calculations, yet it is recommended to prepare this dialog box before the field measurement session.
4. Close the **Zircon** dialog box and in the **Measurement** window, set the *Receiver Pre-Average* value to 16: the minimum required according to the standards.
5. Quit the Zircon software and turn off the **CI24** unit.
6. The dry-run folder can now be deleted.

3.4 LS24 and MA25 positioning

Table 1 shows the nominal angles and tripod center positions for each of the four setups with Source positions S1 through S4. The x and y coordinates are relative to the NRD Measurement Position as defined in Figure 1. The z coordinates are relative to the NRD height. Details on the calculations of the angles and positions can be found in Chapter 6 (Appendix).

Table 1. Angles and tripod positions versus Source position Sm.

Component	Parameter	S1	S2	S3	S4
LS24, MA25	Azimuth	0	0	45	45
LS24	Elevation	14	9	10	7
	X	-2.12	-2.14	-2.09	-2.10
	Y	0	0	-2.09	-2.10
	Z	-2.24	-1.88	-2.18	-1.82
MA25	X	2.11	2.11	2.08	2.08
	Y	0	0	2.08	2.08
	Z	-2.49	-2.49	-2.49	-2.49

The x coordinates are relative to the Reference Plane. To convert them to a more practical distance between tripod center and NRD, subtract part of the NRD thickness. For instance, with a constant NRD thickness of 0.50 m over the entire height, for S1 the LS24 tripod center must be placed at 2.12 – 0.25 = 1.87 m from the NRD.

The z coordinates refer to the tripod head tops, and depend on the NRD height H. For instance, with H = 4.00 m (including added device, if present), for S1 the LS24 tripod head top height must be adjusted to 4.00 – 2.24 = 1.76 m.

3.4.1 Survey measurements

For survey measurements, changing the LS24 elevation between different setups may be omitted by using a fixed value of 10° for all Source positions S_m. This hardly affects the results thanks to the favorable directional characteristic of the LS24: at the resulting maximum angle error of 4°, the LS24 level deviates less than -0.2 dB at 5 kHz, and less than -0.1 dB at 4 kHz.

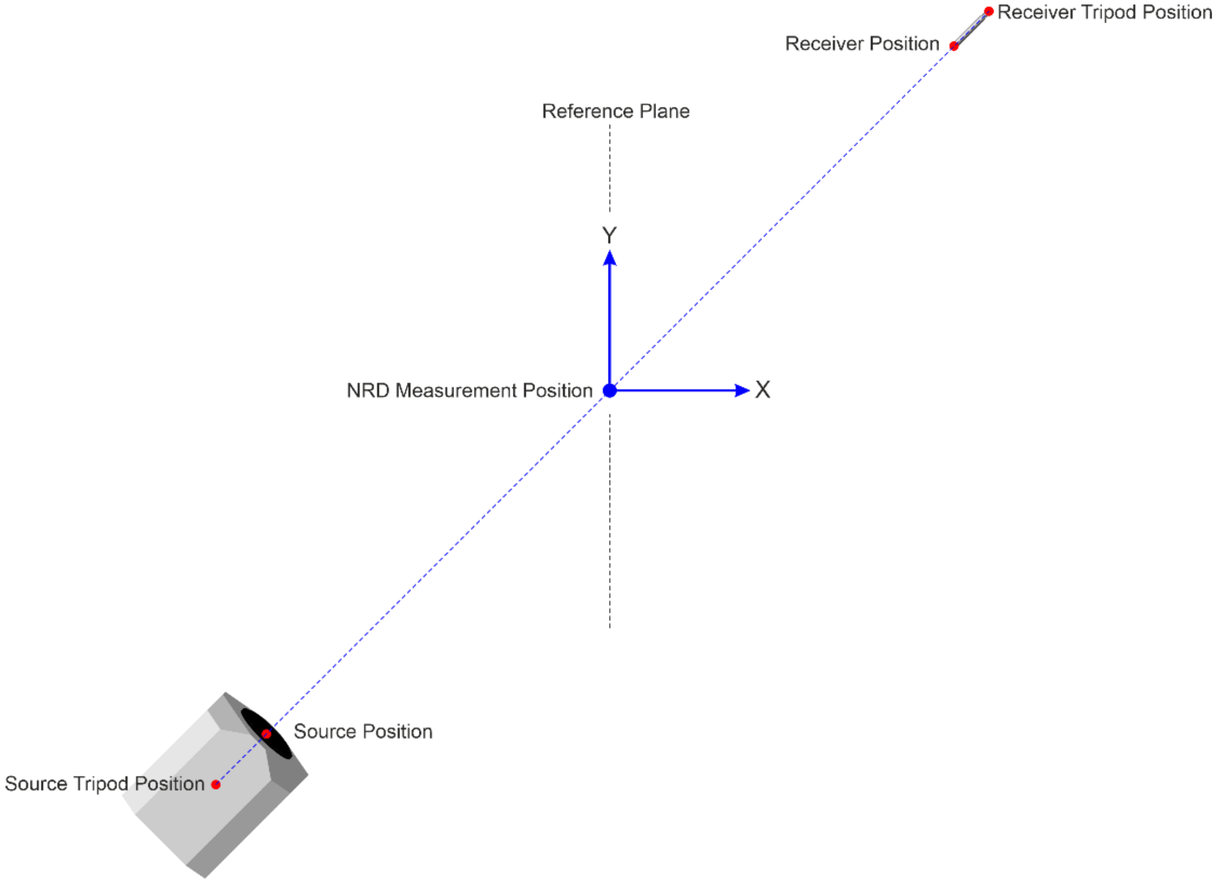


Figure 1. Definition of tripod positions relative to the NRD Measurement Position.

3.4.2 Practical tables

Table 1 can be used to build work tables for use in the field, by converting the coordinates to tripod-tripod distances, tripod-NRD distances and tripod heights. It is recommended to prepare these work tables in the office, in order to avoid calculation work in the field. Table 2 shows a template, where:

- The bracketed values refer to a fixed 10° elevation, should that option be chosen.
- DFF = Horizontal distance between tripod centers in free-field measurement
- XLNRD = distance between LS24 tripod center and NRD
- S = partial NRD thickness, measured from the Reference Plane in the LS24 direction, and at XLNRD measurement height
- YL = LS24 tripod y-coordinate relative to the NRD Measurement Position as defined in Figure 1
- ZLGND = LS24 tripod head top height relative to the ground
- H = NRD height, with or without added device, whichever applies

- XMNRD = distance between MA25 tripod center and NRD
- R = partial NRD thickness, measured from the Reference Plane in the MA25 direction, and at XMNRD measurement height
- YM = MA25 tripod y-coordinate relative to the NRD Measurement Position as defined in Figure 1
- ZMGND = MA25 tripod head top height relative to the ground

Table 2. Angles and tripod positions versus Source position Sm.

Parameter	S1	S2	S3	S4
Pos tab	S1R1	S2R1	S3R6	S4R6
Azimuth [°]	0	0	45	45
Elevation [°]	14 (10)	9 (10)	10 (10)	7 (10)
DFF [m]	4.23 (4.24)	4.25 (4.24)	5.90 (5.90)	5.91 (5.90)
XLNRD [m]	2.12 (2.13) - S	2.14 (2.13) - S	2.09 (2.09) - S	2.10 (2.09) - S
YL [m]	0	0	-2.09	-2.10
ZLGND [m]	H – 2.24 (2.24)	H – 1.88 (1.89)	H – 2.18 (2.18)	H – 1.82 (1.83)
XMNRD [m]	2.11 - R	2.11 - R	2.08 - R	2.08 - R
YM [m]	0	0	2.08	2.08
ZMGND [m]	H – 2.49	H – 2.49	H – 2.49	H – 2.49

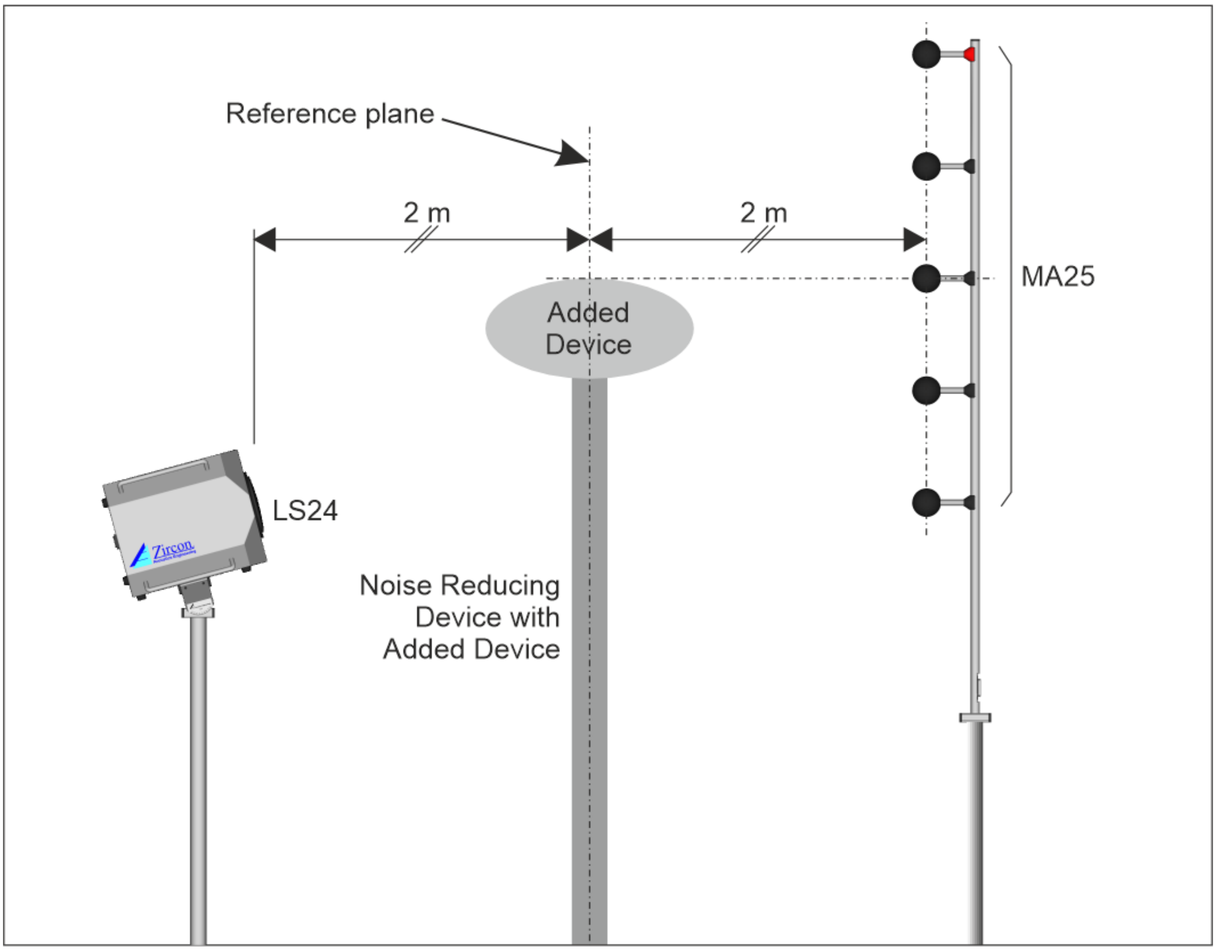
Note that H depends on the situation (with or without added device), hence so do ZLGND and ZMGND. For the free-field measurements, H must be at least the height of the NRD without added device.

3.5 Some tips

1. Make sure that the tripods are high enough for the NRD, with the legs fully spread.
2. The cable roll ties can also be used to tie the cables to the tripods.
3. The great height of the source and receivers makes it difficult to move them, so this is better done with two persons.
4. Placing 6 markers beforehand reduces the chance of mistakes and the amount of work when repeatedly using the same positions.
5. It may be convenient to have both a tape measure and a laser measure.
6. Bring rubber bands to secure typically loose parts of the source tripod, such as the crank, that otherwise might rattle during loud sine sweeps, which may be annoying.
7. Avoid any contact of connectors with the ground. After releasing a connector, do not drop it on the ground, put it in a clean place.

The preparations for the field measurements are now complete.

4 Field Measurement Procedure



Notes

1. Hereafter, text printed in italics refers to the terminology as used in the standards.
2. The screenshots shown hereafter are for illustration purposes only.
3. This procedure starts with the reference measurements, but it is also possible to start with the NRD measurements.

4.1 *Free-field* (Reference) Measurements

4.1.1 Introduction

Reference measurements must be repeated for each measurement session, each 2 hours, and when measurement conditions such as temperature or relative humidity have changed significantly since the previous *free-field* measurements.

To the extent applicable, follow the instructions hereafter (in subsections 4.1.2 through 4.1.4) for source positions S1 through S4 respectively.

In the end, the project will contain 20 free-field impulse responses.

4.1.2 Setup (free-field)

Table 3 is a template for free-field measurements, representing a filled out copy of Table 2. When using a fixed 10° elevation, apply the bracketed values.

Table 3. Free-field measurement angles and positions versus Source position Sm.

Parameter	S1	S2	S3	S4
Pos tab	S1R1	S2R1	S3R6	S4R6
Azimuth [°]	0	0	45	45
Elevation [°]	14 (10)	9 (10)	10 (10)	7 (10)
DFF [m]	4.23 (4.24)	4.25 (4.24)	5.90 (5.90)	5.91 (5.90)
XLNRD [m]	2.12 (2.13) - S	2.14 (2.13) - S	2.09 (2.09) - S	2.10 (2.09) - S
YL [m]	0	0	-2.09	-2.10
ZLGND [m]	H – 2.24 (2.24)	H – 1.88 (1.89)	H – 2.18 (2.18)	H – 1.82 (1.83)
XMNRD [m]	2.11 - R	2.11 - R	2.08 - R	2.08 - R
YM [m]	0	0	2.08	2.08
ZMGND [m]	H – 2.49	H – 2.49	H – 2.49	H – 2.49

Tripods

1. Place the LS24 and MA25 tripods at the proper distance **DFF** (Table 3), at least 3 m away from obstacles. If appropriate, first set out markings on the ground, and then place the tripods directly above them.
2. Align the tripods vertically upwards, using the integrated bubble levels or separate spirit level, and/or by visual alignment with some vertical elements in the neighborhood.

LS24

1. Place the **LS24** on a soft surface, e.g. its carry bag.
2. Attach the speakon cable and the **TH24** tilt head to the **LS24,** with the axis of rotation perpendicular to the speaker axis.
3. Adjust the **TH24** to the proper **elevation** (Table 3, **LS24** 'looking up').
4. Attach an **ET24** extender tube to the **TH24** swivel, and then the LS24 tripod head to the extender tube.
5. Tie the cable to the tube using a tie-wrap.
6. Place the **head-ET24-TH24-LS24** assembly on top of the LS24 tripod, point the LS24 to the receiver tripod and tighten the head screw.
7. Lift the tripod head top to the proper height **ZLGND** (Table 3) through the telescope tube system and the crank, and lock it by firmly tightening the locking screws.
8. Drape the cable down the tripod and tie it to the base. This will reduce the chance that the tripod is pulled over by tripping over the cable.

9. If necessary, adjust the LS24 **azimuth** (Table 3) only by applying the following sequence of actions to the tripod head: **unlock – rotate - relock**. Do not rotate the tube on top of the tripod head, to avoid accidently unscrewing it.

MA25

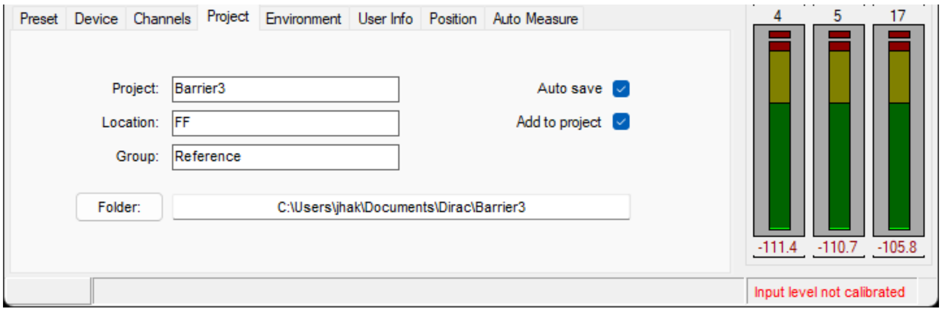
1. With the **MA25** in its protective case, insert 5 microphones with windscreens.
2. Attach a multi-cable and an **ET24** extender tube to the **MA25** microphone array, and then the MA25 tripod head to the extender tube.
3. Tie the cable to the tube using a tie-wrap.
4. Place the **head-ET24-MA25** assembly on top of the MA25 tripod, point the microphones to the LS24 tripod and tighten the head screw.
5. Lift the tripod head top to the proper height **ZMGND** (Table 3), using the tripod crank, and lock it by firmly tightening the locking screw. Do not release the crank without having locked the height.
6. Drape the cable down the tripod and tie it to the base.
7. If necessary, adjust the MA25 **azimuth** (Table 3) only by applying the following sequence of actions to the tripod head: **unlock – rotate - relock**. Do not rotate the tube on top of the tripod head, to avoid accidently unscrewing it.

CI24 and Zircon software

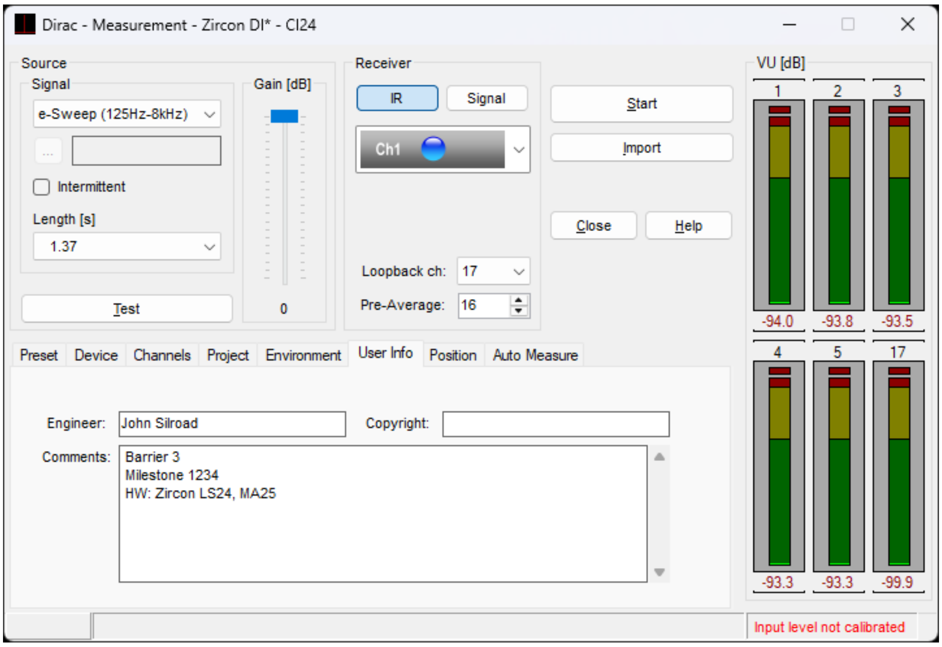
1. Place the **CI24** and laptop in a suitable location relative to the **LS24** and **MA25**.
2. Connect the cables from the **LS24** and the **MA25** to the **CI24**.
3. Connect the **CI24** and the laptop to mains power.
4. Connect the **CI24** to the laptop and turn it on.
5. Wait at least 11 s (see Section 3.2) and then start the **Zircon software**.
6. Open the **Measurement** window and, if applicable, on the **Preset** tab load the proper setup.

4.1.3 Measurement (free-field)

1. Fill out the **Project** tab: the folder name for measurement files, the Project name, and the Location name (*FF* denotes free-field measurements).



2. On the **Environment** tab, enter the environmental conditions in the field.
3. On the **User Info** tab, enter all remaining relevant measurement info.

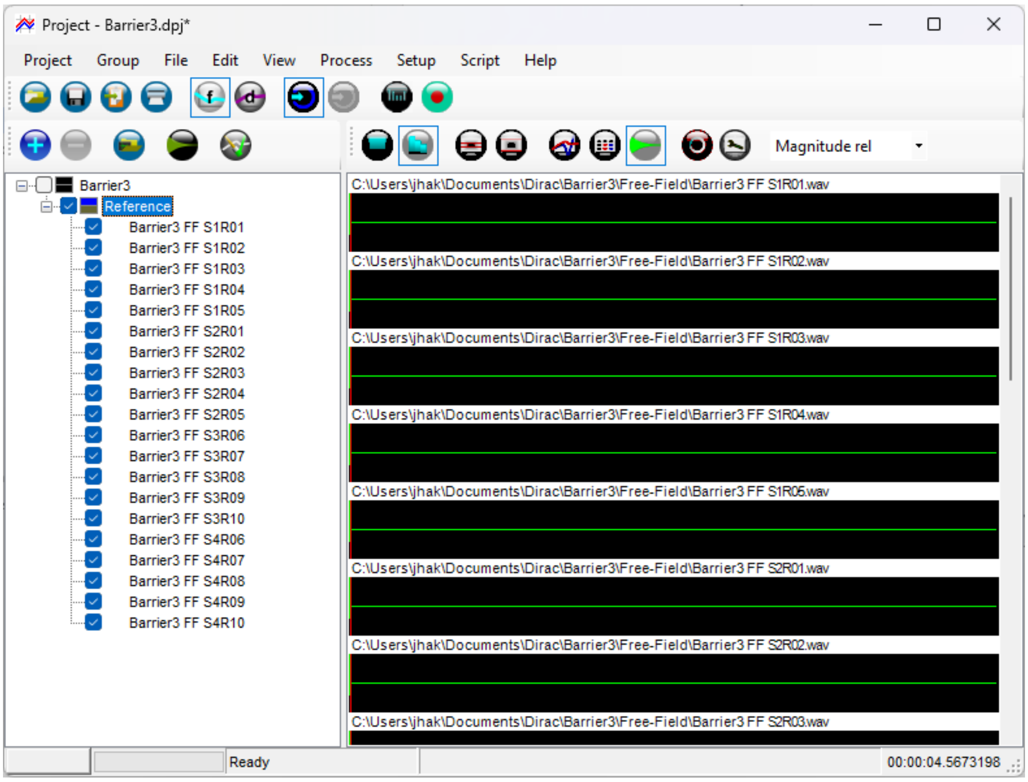


4. On the **Position** tab, enter the proper *Source* number m and *Receiver* number n (Table 3, **Pos tab**).
5. If this is not the first source position (m > 1), open the Project window and the current project, so the Zircon software can add subsequent free-field measurements to the reference Group.
6. Click the Test button to check the signal, and then click the Start button to perform the measurement.
7. After processing the measurements, the Zircon software adds 5 new free-field impulse responses to the current project. In case of no open project, the Zircon software will open the project window and create a new project.
8. Save the project.

4.1.4 Validation (free-field)

1. Select the Graph view (menu **View** > **Graph** or Graph button).
2. Select parameter **INR** and wait for the INR curves to appear.
3. If necessary, repeat the measurement with a corrected setup and/or under improved conditions, such as an increased Source Signal Gain or Receiver Pre-Average value, set in the **Measurement** window, until the INR values are good or optimal.

As mentioned in Section 4.1.1, the project finally contains 20 free-field impulse responses.



4.2 NRD Measurements

4.2.1 Introduction

This part of the procedure must be executed for each measurement position at the NRD and each added device condition (*with*/*without* added device).

To the extent applicable, follow the instructions in subsections 4.2.2 and 4.2.3 for Source positions S1 through S4 respectively, and repeat this for each NRD measurement position and applicable added device condition.

4.2.2 Setup (NRD)

Table 4 is a template for NRD measurements, representing a filled-out copy of Table 2. When using a fixed 10° elevation, apply the bracketed values.

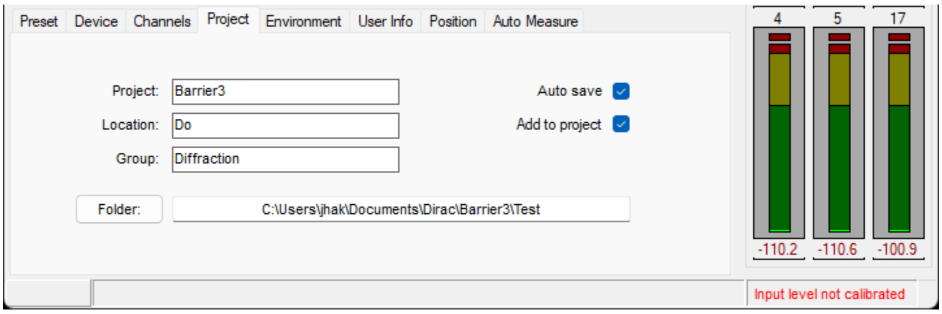
1. Place the LS24 and MA25 tripods at the proper distances **XLNRD** and **XMNRD** (Table 4) to the NRD. If appropriate, first set out markings on the ground, and then place the tripods directly above them.
2. Align the tripods vertically upwards.
3. Adjust the LS24 tripod head top to the proper height **ZLGND** (Table 4).
4. Adjust the MA25 tripod head top to the proper height **ZMGND** (Table 4).
5. Place the CI24 and laptop in a suitable location relative to the LS24 and MA25.

Table 4. NRD measurement angles and positions versus Source position Sm.

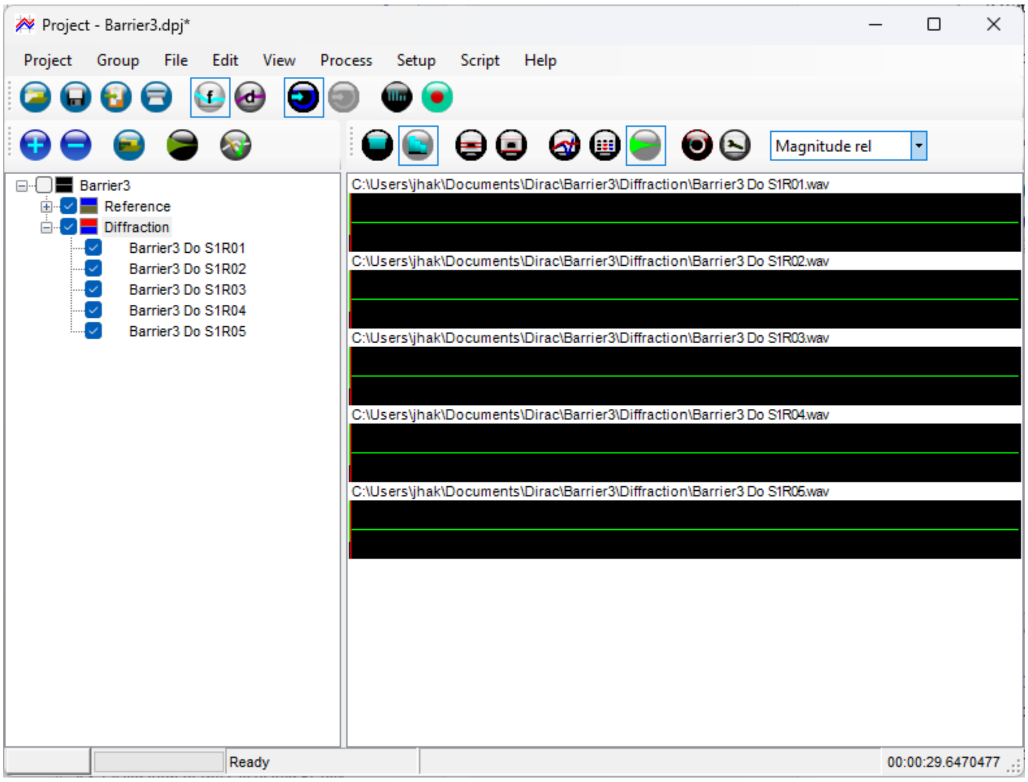
Parameter	S1	S2	S3	S4
Pos tab	S1R1	S2R1	S3R6	S4R6
Azimuth [°]	0	0	45	45
Elevation [°]	14 (10)	9 (10)	10 (10)	7 (10)
DFF [m]	4.23 (4.24)	4.25 (4.24)	5.90 (5.90)	5.91 (5.90)
XLNRD [m]	2.12 (2.13) - S	2.14 (2.13) - S	2.09 (2.09) - S	2.10 (2.09) - S
YL [m]	0	0	-2.09	-2.10
ZLGND [m]	H – 2.24 (2.24)	H – 1.88 (1.89)	H – 2.18 (2.18)	H – 1.82 (1.83)
XMNRD [m]	2.11 - R	2.11 - R	2.08 - R	2.08 - R
YM [m]	0	0	2.08	2.08
ZMGND [m]	H – 2.49	H – 2.49	H – 2.49	H – 2.49

4.2.3 Measurement (NRD)

1. Fill out the **Project** tab. In this case, Location *Do* denotes diffraction measurements on the NRD without added device).



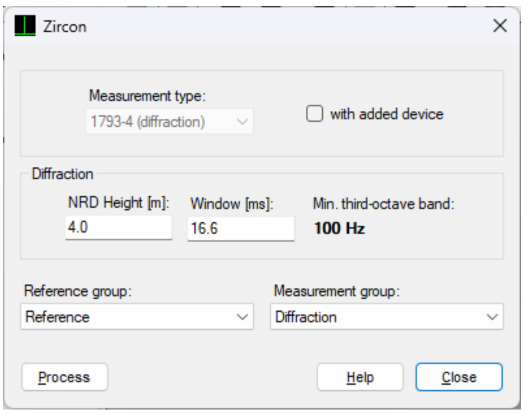
2. On the **Position** tab, enter the proper *Source* number m and *Receiver* number n (Table 4, **Pos tab**).
3. Open the Project window and the current project, so the Zircon software can add subsequent diffraction measurements to the current Group.
4. Set the Gain slider at the same value as with the reference measurement.
5. Click the Start button to perform the measurement.
6. After processing the measurements, DIRAC adds 5 new diffraction impulse responses to the current project.
7. Check the **INR** curves.
8. If necessary, repeat the measurement with a corrected setup and/or under improved conditions, until the INR values are good or optimal.
9. Save the project.

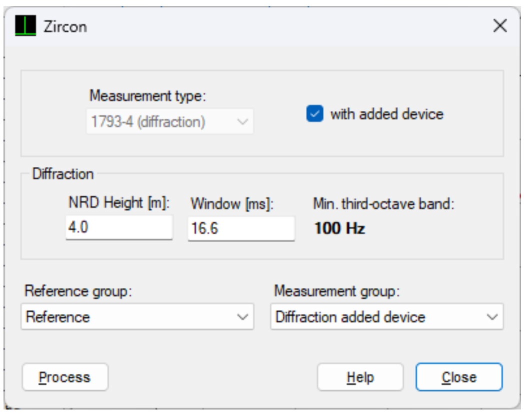


The project finally contains 20 free-field impulse responses and 20 diffraction impulse responses per position and condition.

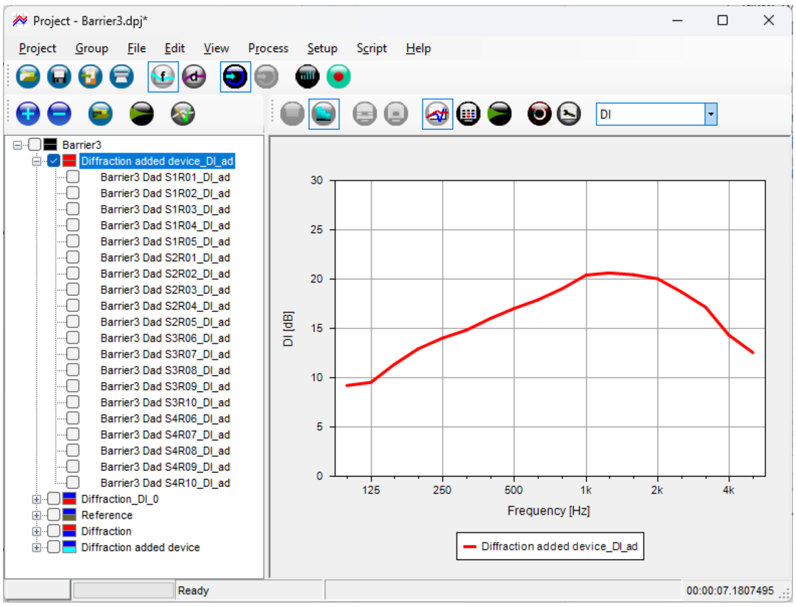
4.3 Processing

1. In the Project window, from the **Process** menu, select **Zircon**.
2. Fill out the **Zircon** dialog box, entering the NRD height and, if different from default, the Adrienne Window, as well as the name of the reference group and barrier measurement group without added device.

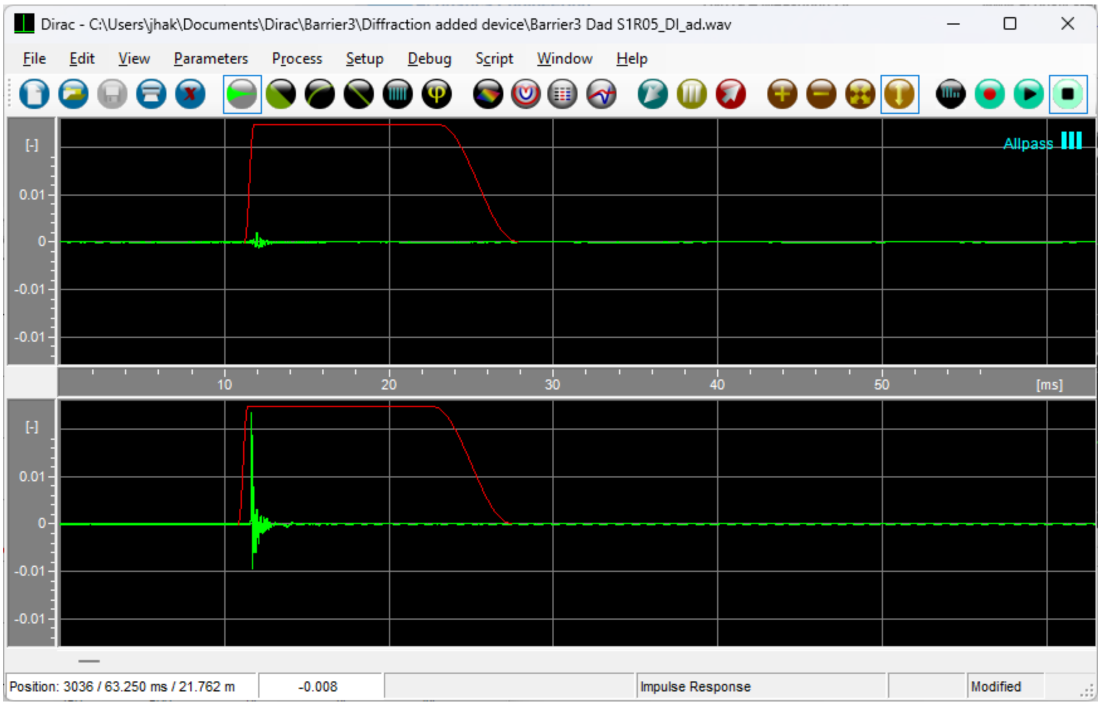




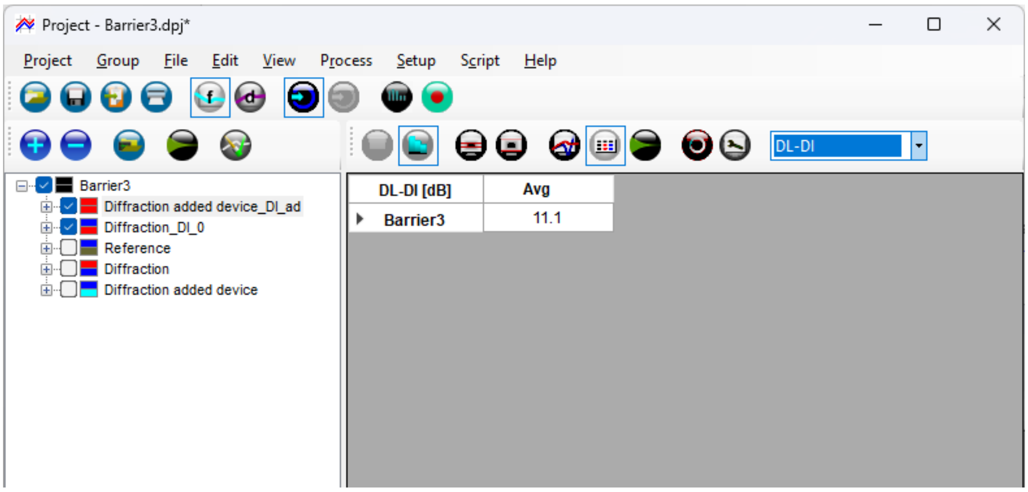
3. Click **Process**, and wait until DIRAC has created a group with the name of the processed measurement group, with extension “DI_0” (DI without added device), and containing 20 new 2-channel files with the name of the processed files, also with extension “DI_0”.
4. Repeat 2 and 3 for the measurement group with added device at the same measurement position, resulting in a group with name extension “DI_ad” (DI with added device) and containing 20 new 2-channel files with the name of the processed files, also with extension “DI_ad”.
5. Check a DI Group level checkbox and select parameter DI to view the average DI of the 20 files.



6. The DI files contain the diffraction impulse response in channel 1 and the free-field impulse response in channel 2. Click a DI file and then the *View the selected file* button to view its impulse responses, including the Adrienne windows in red.



7. Check the Project level checkbox, and two Group level checkboxes, one without added device and one with added device, to view the single number rating of sound diffraction ($DL_{\Delta DI}$). The example below is unusually high.



5 Measurement Uncertainties

Currently, an estimate of the measurement uncertainty of *DI(j)* at each third octave frequency band j and $DL_{\Delta DI}$ [dB], would best be based on the standard deviation of reproducibility. This requires multi-lab results and combines standard uncertainties of DI determinations to arrive at a Gaussian distribution. It is then common to apply a coverage factor of 1.96 to obtain a 95 % confidence level. For additional information, see the standards.

6 Appendix - LS24 and MA25 position and angle calculations

6.1 Introduction

In this section it is explained how to calculate the LS24 and MA25 angles and positions in diffraction measurements. Because the source and microphone M1 must be oriented towards each other, their angles, hence tripod heights and positions depend on the source position (S1 through S4).

6.2 Definitions

Figure 2 schematically depicts an example of the top view of a diffraction measurement setup, with a coordinate system projected onto it. In this example, the source is located at position S3. Defining the NRD Measurement Position as the origin with coordinates (x, y, z) = (0, 0, 0), the source front reference center has position (-2, -2, -0.5) [m] and the receiver has position (2, 2, 0.5) [m]. The tripod horizontal centers are located a bit further away from the origin.

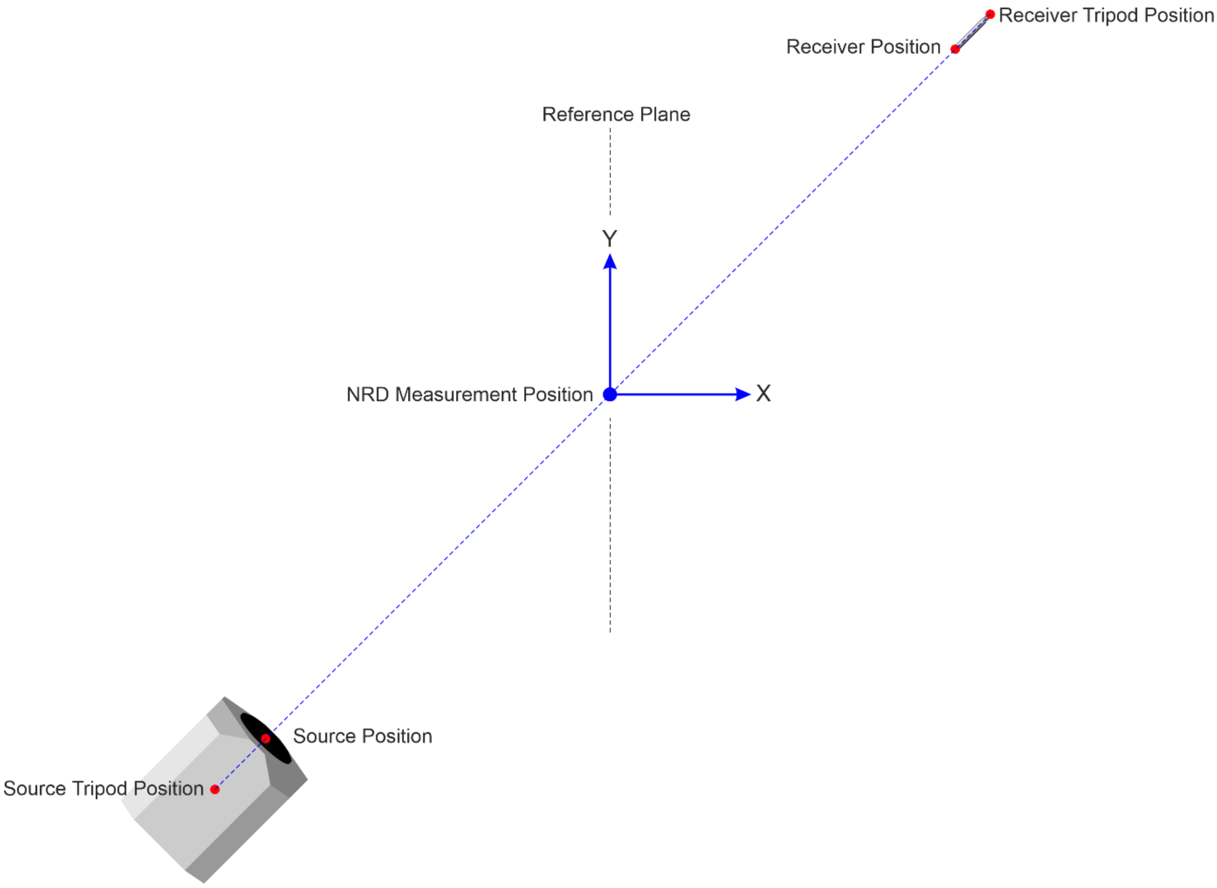


Figure 2. Definition of tripod positions relative to the NRD Measurement Position.

Hereafter, the tripod positions and heights, as well as the source angles using setups with the **LS24** and **MA25** will be calculated for source positions S1 through S4.

6.3 Calculations

Figure 3 depicts a situation with the vertical Source-Microphone plane perpendicular to the NRD, crossing its measurement position, and applicable to source positions S1 and S2.

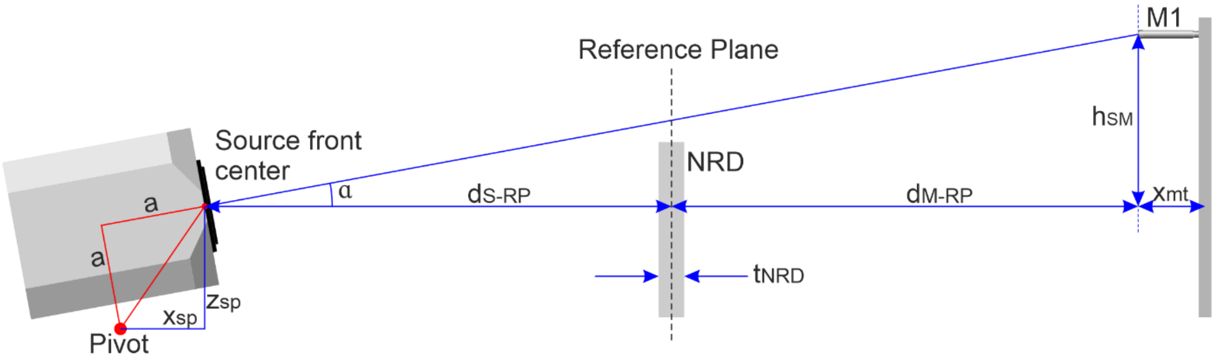


Figure 3. Schematic side view of setup with Source positions S1 and S2.

From this figure and Section 6.2, the following can be noted:

1. The source front center has distance $d_{S\text{-}RP}$ to the reference plane (RP). Its tripod/pivot center has distance $d_{S\text{-}RP} + x_{sp}$ from the RP, while the pivot center is z_{sp} lower than the source front center. It can be derived that $x_{sp} = a(\cos\alpha - \sin\alpha)$ and $z_{sp} = a(\cos\alpha + \sin\alpha)$, where a = 165 mm, and with $d_{S\text{-}RP} = d_{M\text{-}RP} = 2$ m, $\alpha = \arctan(h_{SM}/(d_{S\text{-}RP}+d_{M\text{-}RP})) = \arctan(h_{SM}/4\text{m})$. $h_{SM} = 1$ m for source position S1, and 0.65 m for source position S2.
2. The microphones have distance $d_{M\text{-}RP}$ to the RP, while their tripod center has distance $d_{M\text{-}RP} + x_{mt}$ from the RP, where $x_{mt} = 110$ mm.

Figure 4 depicts a situation with the vertical Source-Microphone plane at an angle of 45° with the NRD, crossing its measurement position, and applicable to source positions S3 and S4. Compared to the previous situation, the following can be noted:

1. The source front center has shifted -2 m from the test location, in the y-direction.
2. The horizontal distance between source and microphones is a factor √2 greater, so $\alpha = \arctan(h_{SM}/4\sqrt{2}\text{m})$. $h_{SM} = 1$ m for source position S3, and 0.65 m for source position S4.
3. The LS24 pivot center is located $(\Delta x, \Delta y, \Delta z) = -a/\sqrt{2}\cdot(\cos\alpha-\sin\alpha, \cos\alpha-\sin\alpha, \cos\alpha+\sin\alpha)$ with respect to the source location.
4. The MA25 tripod horizontal center is located $(\Delta x, \Delta y) = 110/\sqrt{2}\cdot(1, 1)$ m with respect to the receiver position.

Table 5 shows the resulting angles and coordinates for each Source position S1 through S4.

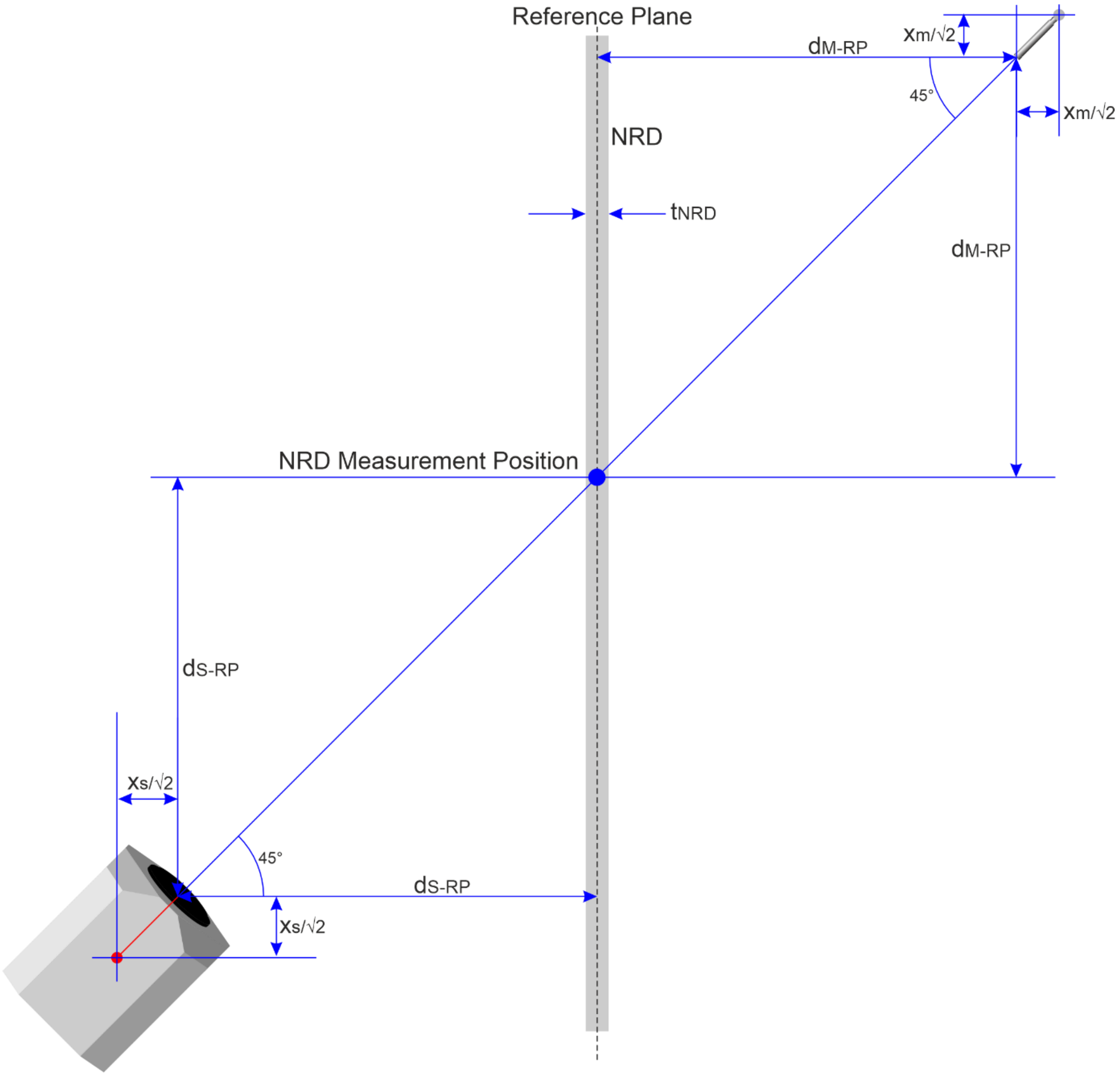


Figure 4. Schematic top view of setup with Source positions S3 and S4.

Table 5. Angles and tripod coordinates versus Sm.

Component	Parameter	S1	S2	S3	S4
LS24, MA25	**Azimuth**	0	0	45	45
LS24	**Elevation**	14	9	10	7
	X	-2.12	-2.14	-2.09	-2.10
	Y	0	0	-2.09	-2.10
	Z	-2.24	-1.88	-2.18	-1.82
MA25	**X**	2.11	2.11	2.08	2.08
	Y	0	0	2.08	2.08
	Z	-2.49	-2.49	-2.49	-2.49

7 References

Standards

[1] EN 1793-3:1997: Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 3: Normalized traffic noise spectrum

[2] EN 1793-4:2015: Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 4: Intrinsic characteristics - In situ values of sound diffraction

[3] EN 16272-3-2:2023: Railway applications - Infrastructure - Noise barriers and related devices acting on airborne sound propagation - Test method for determining the acoustic performance - Part 3-2: Normalized railway noise spectrum and single number ratings for direct sound field applications

[4] EN 16272-4:2016: Railway applications - Track - Noise barriers and related devices acting on airborne sound propagation - Test method for determining the acoustic performance - Part 4: Intrinsic characteristics - In situ values of sound diffraction under direct sound field conditions

Papers

[5] M. Garai, P. Guidorzi, "Sound reflection measurements on noise barriers in critical conditions", accepted for the publication on Building and Environment, (2015). DOI: http://dx.doi.org/10.1016/j.buildenv.2015.06.023

[6] M. Garai, E. Schoen, G. Behler, B. Bragado, M. Chudalla, M. Conter, J. Defrance, P. Demizieux, C. Glorieux, P. Guidorzi, "Repeatability and reproducibility of in situ measurements of sound reflection and airborne sound insulation index of noise barriers", Acta Acustica united with Acustica, 100, 1186-1201, (2014). DOI: http://dx.doi.org/10.3813/AAA.918797

[7] P. Guidorzi, M. Garai, "Advancements in sound reflection and airborne sound insulation measurement on noise barriers", Open Journal of Acoustics, 3(2A), 25-38, (2013). DOI: http://dx.doi.org/10.4236/oja.2013.32A004

[8] QUIESST. (2012). Inter-laboratory test to assess the uncertainty of the new measurement methods for determining the in situ values of sound reflection and airborne sound insulation of noise reducing devices under direct sound field conditions, Università di Bologna, https://www.unibo.it/en/research/projects-and-initiatives/Unibo-Projects-under-7th-Framework-Programme/cooperation-1/transport/quiesst

Technical Notes

[9] TN013 - Zircon V2 - Usage

[10] TN020 - Zircon - EN1793-5 - EN16272-5 Measurement Procedure - V2.0

[11] TN021 - Zircon - EN1793-6 - EN16272-6 Measurement Procedure - V2.0

Product Datasheets

[12] DIRAC 7 - HBK Type 7841 - bp1974

For technical notes, spreadsheets and product datasheets, visit Acoustics Engineering:

https://acoustics-engineering.com/index.html

For the DIRAC product datasheet, visit Hottinger Brüel & Kjær:

https://www.bksv.com/-/media/literature/Product-Data/bp1974.ashx

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