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SOPRANOISE

D4.1 Report on the development of the new quick methods in laboratory

June 30, 2021

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Task	T4.2 – Development of the new quick methods in laboratory
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1. Introduction

The Work Package 4 “Quick & safe methods alongside roads” includes the following tasks:

- **Task 4.1** has the goal of reviewing existing measurement methods that could be good candidates for being quickly applied in situ. This task is completed and reported in the (non-public) report ending the *Milestone M4.1*.

- **Task 4.2** has the goal of doing the development and testing (in the laboratory) of reliable quick methods for in-situ characterization sound absorption and airborne sound insulation of noise barriers. In this task, relying on the outcomes of Task 4.1 and the consortium expertise in developing the EN full methods, new quick methods have to be designed and tested on laboratory samples. Both the procedure and the equipment have to be simpler and faster than for full tests, allowing the use by normal operators after a short training. The quick methods have to give fair and quantitative conclusions on the NB performances. The same samples have to be tested also with the full EN methods, in order to assess the degree of correlation of the quick methods with the acknowledged qualification standards. At the end of this task, a new quick method will be ready for validation in real on-site conditions.

  The present report constitutes the final *Deliverable D4.1* including the outcomes of Task 4.2. This report includes the detailed comparison of the laboratory tests on real-size samples of noise barriers applying both the new quick methods for sound absorption and sound insulation developed in T4.2 and applying the full EN methods (EN 1793-5 and EN 1793-6).

- **Task 4.3** has the goal of doing the in situ validation of quick method developed in Task 4.2 by comparison with full EN methods. This task will be done applying both the new quick methods and the full EN methods on noise barriers installed along the A22 motorway connecting Northern-Italy to Austria. the completion Task 4.3 is due by November 30th, 2021.

- **Task 4.4** has the goal of writing a final, comprehensive report on the new quick methods developed in the frame of the present research project (*Deliverable D4.2*). It will include design, laboratory testing, validation along a real motorway and comparison with full EN methods. It will include the data measured in Task T4.3. It will also include recommendations for proper use of the quick methods.

The present D4.1 report is organized as follows: Section 2 outlines the scope of the quick methods; Section 3 recalls the general requirements for quick methods for determining the intrinsic acoustic characteristics of noise barriers (sound absorption and airborne sound insulation); Section 4 details the main choices done in designing the new measuring equipment, specifically conceived for the quick methods; Section 5 reports the preliminary laboratory tests done with the new measuring equipment at UNIBO; and finally, Section 6 presents the main conclusions and an outlook of the future activities.

2. Scope of the quick method

The SOPRANOISE project outlines a 3-steps approach to characterize the intrinsic acoustic characteristics of installed noise barriers (see Figure 1).

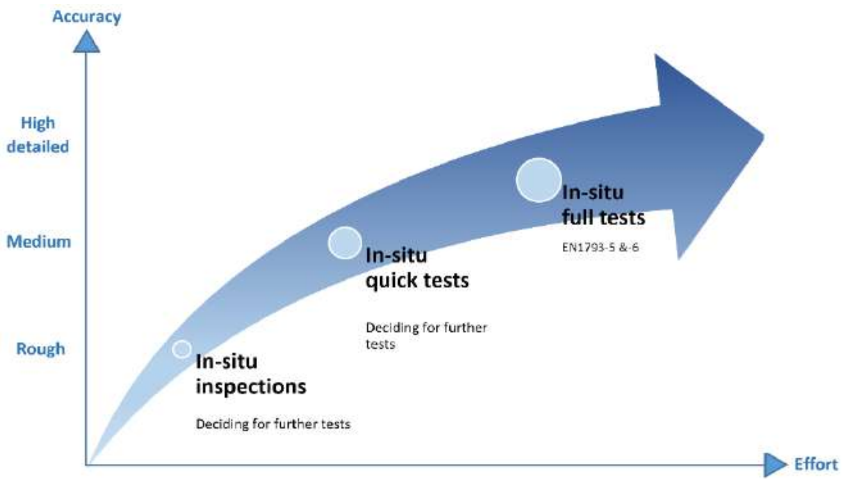


Figure 1. SOPRANOISE progressive 3-steps approach to characterize the intrinsic acoustic characteristics of installed noise barriers.

The quick methods under development in WP4 correspond to the second step of this 3-steps approach. As the equipment and the measuring technique is similar for both sound reflection and for airborne sound insulation, from now on, these quick methods will be called "quick method" using the singular. This quick method is intended to reduce the amount of EN 1793 measurements required to qualify the noise barrier under test. To this aim, the quick method is repeatedly applied in several locations along the noise barrier under test, giving a reasonable estimate of the noise barrier performance, and of the related range of variability, even if with an uncertainty could be greater than that one of the full EN standards. Relying on the results of this systematic scan of the noise barrier, two or three sites where to apply the full EN standards could be then selected.

The quick method differs from the visual/aural inspection method used in step 1, because the quick method gives *quantitative* indications, based on *measured* values of the acoustic performance of the noise barrier. Using these values, it will then be possible to select the best sites for definitive assessment of the noise barrier under full test according to EN 1793-5 and EN 1793-6.

The quick method differs from the full EN standards EN 1793-5 and EN 1793-6 used in step 3 because it is designed for quick and easy application, at the price of a possible reduced accuracy compared to that one of the full EN standards.

It must be remarked that, in all situations where legally binding values of the intrinsic characteristics of a noise barrier in a direct sound field - typically expressed as DL_{RI} and DL_{SI} - are required, e.g. to check the compliance of a new noise barrier with the specifications book, the only way to assess them is to use the full EN standards EN 1793-5 and EN 1793-6, while steps 1 (in-situ inspections) and 2 (quick method) are very useful tools to prepare the selection of the elements / posts to be tested in full.

Figure 2 shows a flow chart visualising the scope of the SOPRANOISE 3-step approach and the role of the quick method in it: a detailed description of the flow chart is included in Deliverable D3.1.

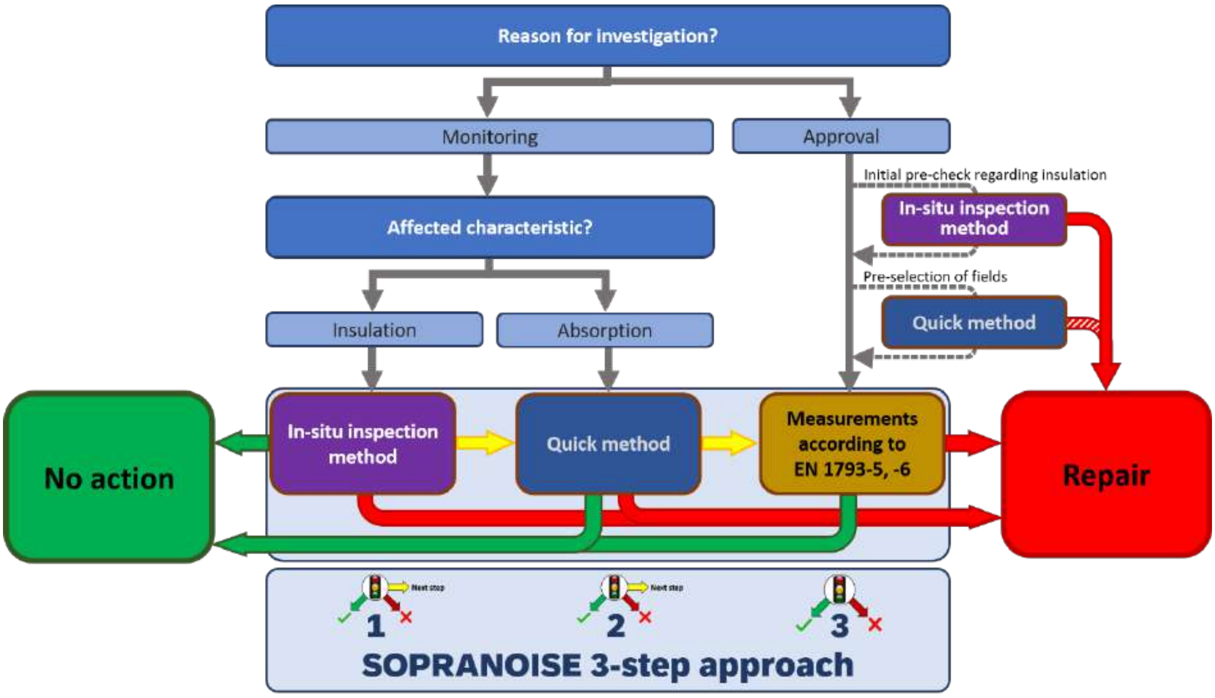


Figure 2. Flow chart visualising the scope of the SOPRANOISE 3-step approach.

3. General requirements for a quick method for determining the intrinsic acoustic characteristics of noise barriers

In the Task 4.1, a comparative analysis of existing or potential quick methods has been done: this qualitative assessment of the main characteristics of such methods from the point of view of practical *in-situ* application to noise barriers, included the following characteristics:

- Working frequency range (in one-third octave bands)
- Immunity to background noise (essential for in-situ measurements)
- Degree of expertise required to operators
- Lightness of the equipment
- Easiness of in-situ operation
- Demonstrated correlation with full EN 1793-5 or EN 1793-6 results
- Demonstrated reproducibility of the results

The evaluation of the easiness of in-situ operation regards only the handling of the equipment and does not take int account the safety measures, such as closing to traffic the lane adjacent to the barrier during the measurements, which depend on country and managing authority specific regulations.

The result of this comparative analysis was that a simplified version of the methods standardized in EN 1793-5 and EN 1793-6 would be the quickest way to achieve the intended goal while maintaining a good correlation of the measured values with those resulting from the application of full EN 1793-5 or EN 1793-6 procedures.

However, this implies a considerable effort in making the hardware lighter and easily portable and in adapting the software to this new hardware. This is the task pursued by UNIBO researchers during Task T4.2.

Table 1 reports the main improvements vs. EN 1793-5 and EN 1793-6 to be reached during Task T4.2.

Table 1: Main improvements vs. EN 1793-5 and EN 1793-6 to be reached in Task T4.2.

Factors considered	SOPRANOISE Step 2	EN 1793-5 and EN 1793-6
Safety:		
- distance to the device under test	≤ 1-1,5 m (equipment included)	≥ 2-2,5 m (equipment included) problems with guard-rails (?)
- equipment weight	5 kg portable by 1 operator	~ 25 kg, some equip. on table 2 operators needed
Time:		
- easiness of installation	5 min (place and go) easy placement of the array / much less bulky tripods, equipment	45 min (for mounting) strongly depends on place and cannot be guaranteed for all situations
- easiness of measurements	3 min	5 min
- easiness of moving from one site to another	0 min: moves with operator	45 min for dismounting / mounting
Overall time for one measurement	8 min	≥ 95 min
Cost:		
- equipment (including software)	~ 8 k€	~ 40 k€
- operators (on-site part)	~ 8-16 man-minutes / measurement	~ 4 man-hours / measurement
Representativity:		
- full operating procedure developed	Yes, after T4.3	Yes (reference)
- closeness to EN standards	~ 60-80% ? (to be assessed in T4.3)	100%

4. Design of a new measuring equipment

First of all, it was necessary to design a completely new equipment corresponding to the strict requirements in Table 1. The general layout of the equipment design conceived at UNIBO is shown in Figure 3.

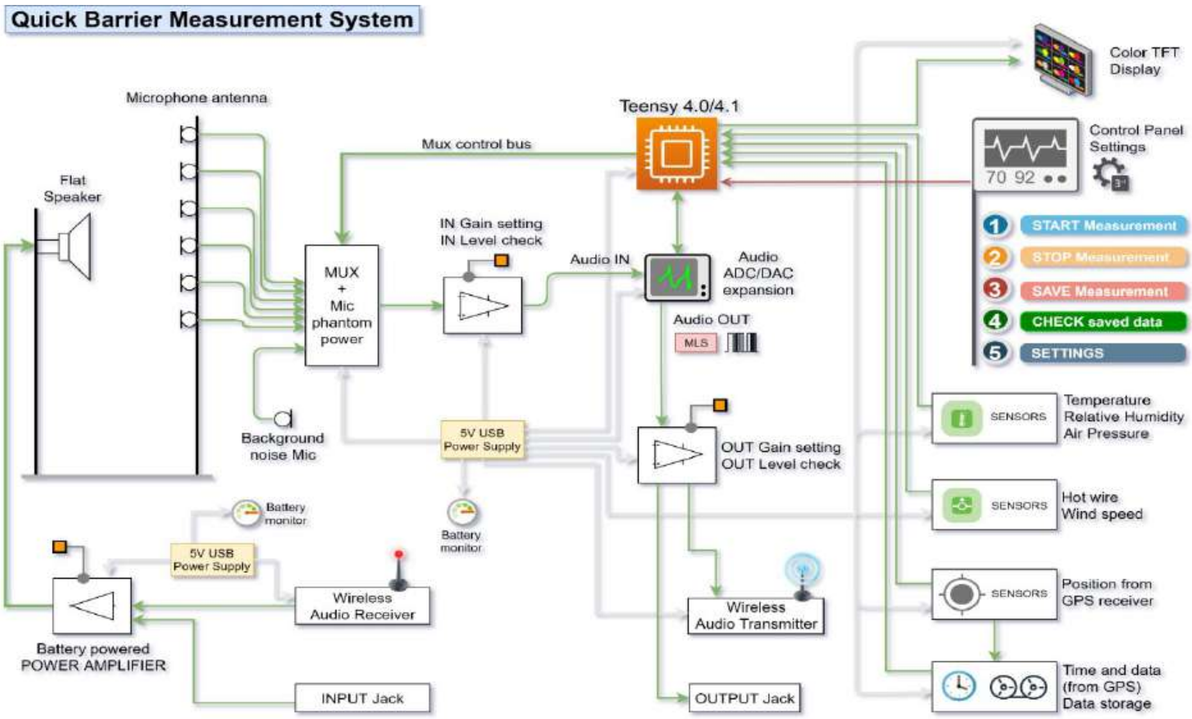


Figure 3. General layout of the equipment design conceived at UNIBO.

4.1. Control and processing unit

The control and processing system is based on a Teensy 4.0 system, including an Arm Cortex-M7 processor, the highest performance member of the energy-efficient Cortex-M processor family. The Cortex-M7 has been designed to deliver a very high level of performance, while maintaining the excellent responsiveness and ease-of-use of the Armv7-M architecture. Its industry leading high-performance and flexible system interfaces are ideal for a wide variety of application areas including automotive, industrial automation, medical devices, high-end audio, image and voice processing, sensor fusion and motor control.

Table 2 reports the main technical specifications of Teensy 4.0. More information can be found on the Teensy website: https://www.pjrc.com/store/teensy41.html

Figure 4 shows the on-board system Teensy 4.0.

Figure 5 shows its audio adaptor board.

Figure 6 shows the on-board system Teensy 4.0 and its audio adaptor board during the assembling step.

Table 2: Main technical specifications of the Teensy 4.0 system.

Processor	ARM Cortex-M7 at 600 MHz
RAM	1024K RAM (512K is tightly coupled)
Flash memory	2048K Flash (64K reserved for recovery & EEPROM emulation)
USB ports	2 USB ports, both 480 MBit/sec
CAN Bus	3 CAN Bus (1 with CAN FD)
I2S ports	2 I2S Digital Audio
S/PDIF ports	1 S/PDIF Digital Audio
SD	1 SDIO (4 bit) native SD
SPI	3 SPI, all with 16 word FIFO
I2C	3 I2C, all with 4 byte FIFO
Serial I/O	7 Serial, all with 4 byte FIFO
DMA channels	32 general purpose DMA channels
PWM pins	31 PWM pins
Digital pins	40 digital pins, all interrupt capable
Cryptographic Acceleration	yes
Random Number Generator	yes
RTC for date/time	yes
Programmable FlexIO	yes
Pixel Processing Pipeline	yes
Peripheral cross triggering	yes
Power On/Off management	yes

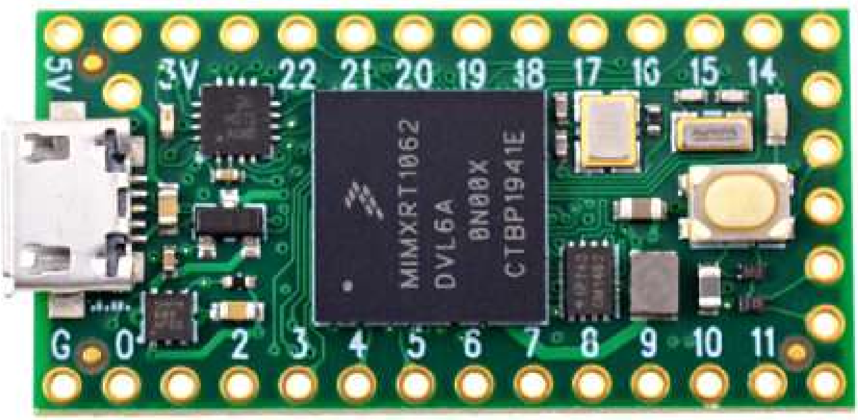


Figure 4. The on-board system Teensy 4.0.

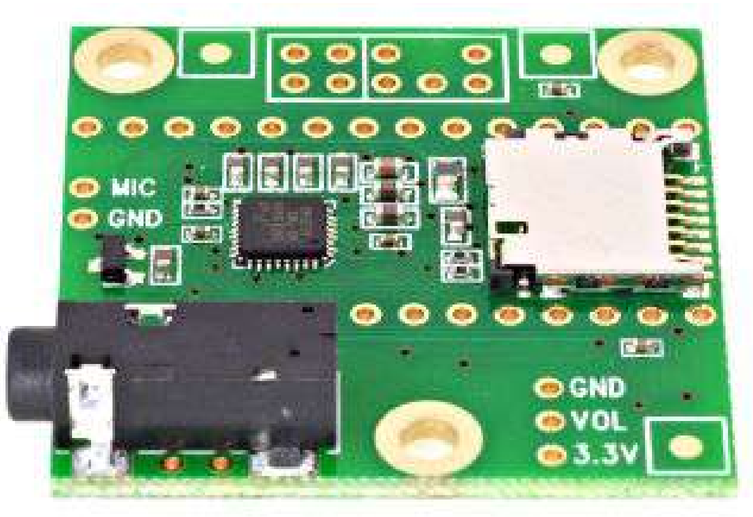


Figure 5. The audio adaptor board for Teensy 4.0.

Figure 6. Assembling the on-board system Teensy 4.0 and its audio adaptor.

It was necessary to increase the input dynamics and signal-to-noise ratio through the use of a custom designed external analogue preamplifier with digitally programmable gain (1X, 2X, 4X, 8X, 16X, 32X, 64X, 128X, 256X). A LED is used to check the presence of the input signal.

Figure 7 shows the design of the input section.

Figure 8 shows the assembled control and processing hardware.
Of course, other systems than Teensy could be used as well. This first prototype is just a proof that the control and processing device can be made lightweight.

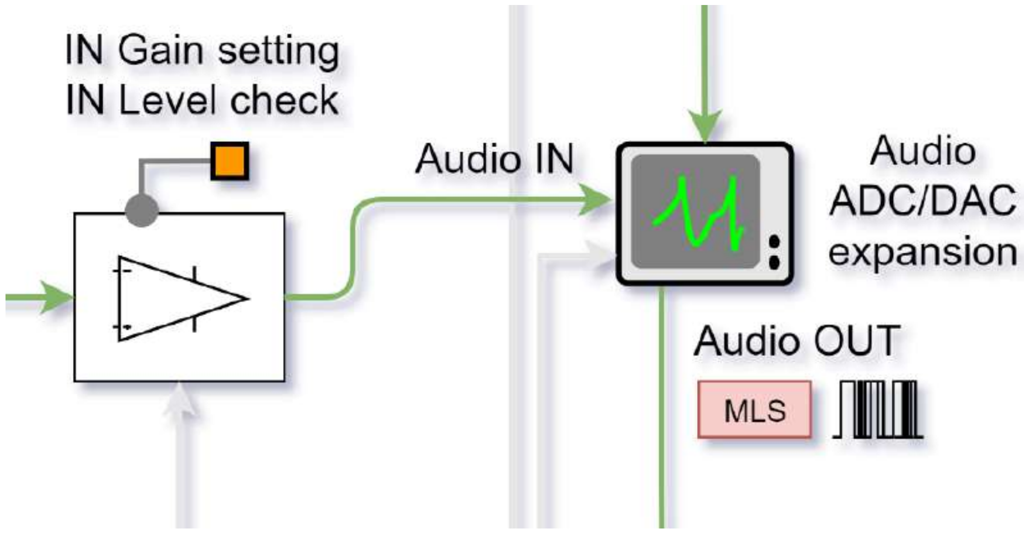


Figure 7. Design of the input section.

Figure 8. The assembled control and processing hardware.

4.2. Microphones

As input sensors, robust and inexpensive electret microphones CMA-4544PF-W have been selected (see Figure 9). They are delivered worldwide by AZ Delivery with the code *5 x GY-MAX4466 Electret Microphone with amplifier* (open circuit sensitivity -44 ±2 dB frequency response 20-20000 Hz, typical S/N 60 dB(A)).

The electret microphone is connected to the LINE IN (not MIC IN) input of the Teensy external soundcard chip SGTL5000 without any other circuit o pre-amplifier, except the multiplexer, that act simply as an ON/OFF switch, to select one of the 6 microphones. The ADC has 85 dB S/N, -73 dB THD+N. The internal digital preamp inside SGTL5000 is kept at unity gain. The phantom power supply (3.3V) is given to the electret capsule by means of a 2.2 kOhm resistor, switchable ON or OFF in case other kind of microphones are used. A decoupling capacitor is inserted to eliminate DC voltage.

The input and output analog gain are fixed (no different settings allowed), in order to avoid measurement errors due to gain changes during the measurement session.

Figure 10 shows the magnitude of the frequency response of an electret microphone compared with that of a PCB microphone adopted for the EN 1793 square array (The curve of the electret microphone has been shifted upward by 11 dB for a better readability). As can be seen, they are nearly identical in the relevant frequency range (100-5000 Hz in one-third octave bands).

Figure 9. One out of six electret microphone mounted on a vertical aluminium stick.

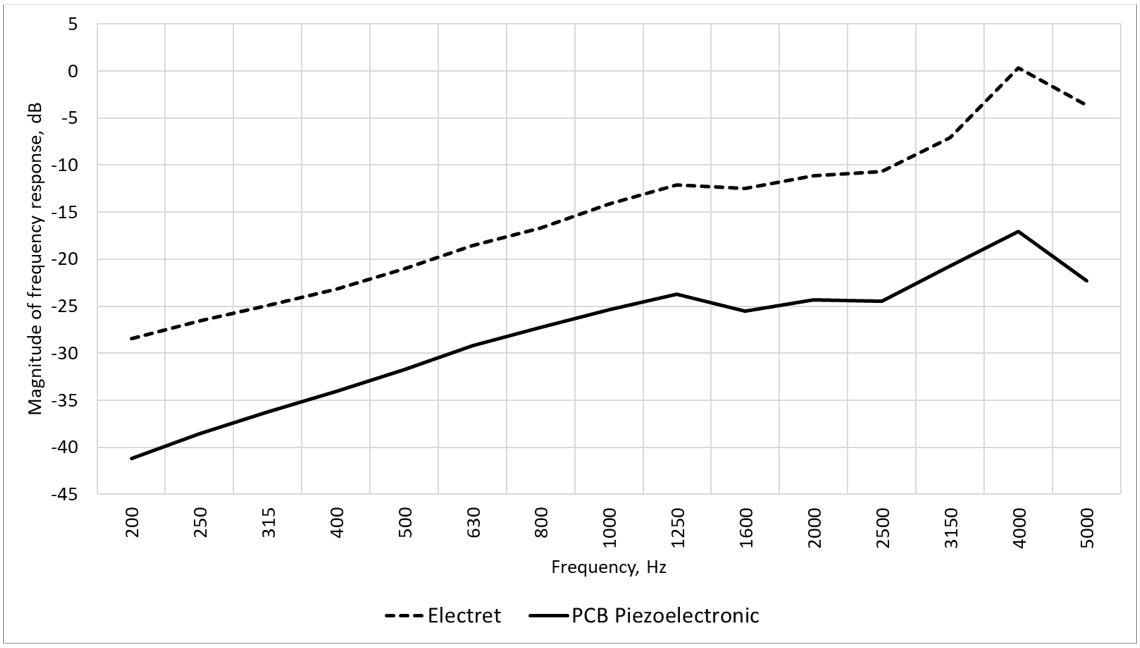


Figure 10. The magnitude of the frequency response of an electret microphone compared with that of a PCB microphone adopted for the EN 1793 square array in the interesting frequency range for this kind of measurements. The Y-axis is in dB with an arbitrary reference. The curve of the electret microphone has been shifted upward by 11 dB for a better readability.

As there is no analog pre-amplifier, it is not possible to have a figure for the conventional dynamic range of microphone + pre-amplifier alone. The S/N of the microphone and the connected measurement chain should be considered instead.

The SGL5000 chip ADCs and DACs work internally at 24 bit, while audio data in current Teensy version are exchanged with 16 bit resolution. This allows approximately a nominal S/N equal to 96 dB on signal input and output.

Loopback measurements on the quick system (signal output connected directly to signal input with a cable), have been done in order to measure the performance of the quick system audio chain without microphone and loudspeaker (DAC → output → input → ADC). A long MLS signal have been used to get the impulse response (see Figure 11). The results are:

- RMS power of time data measured far away from the peak of the impulse response ("internal noise"): -5,57 dB;
- RMS power of time data measured around the loopback impulse response ("signal"): 76,79 dB.

Then an effective dynamic range of 82,4 dB can be estimated: 76,8 – (-5,6) = 82,4 dB.

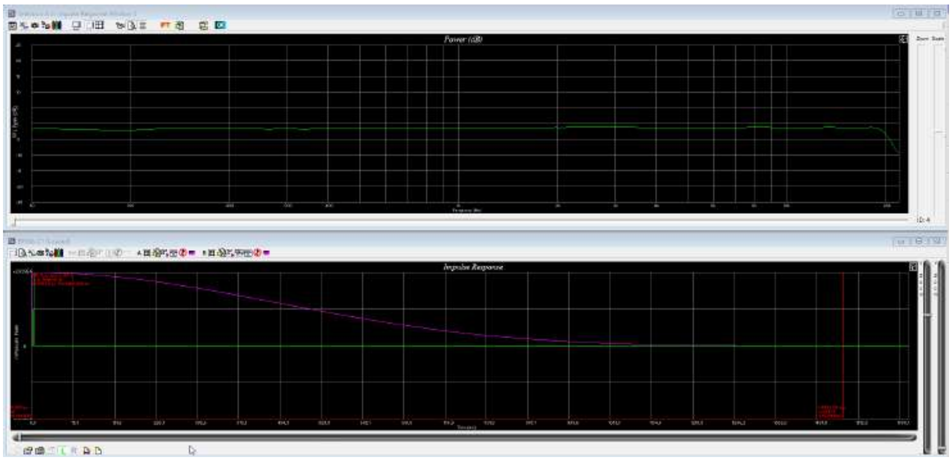


Figure 11. Narrow band frequency response of the loopback impulse response of the newly developed quick system .

Apart these considerations, the goal here is to get results with the newly developed quick system close to those from the standard equipment complying to EN 1793-5 and EN 1793-6. The measurements shown in Chapter 5 proof that this is the case.

The electret microphones are mounted on a lightweight aluminium stick, made from two pieces that can be easily assembled and disassembled and transported in a car. When mounted, it supports six microphones on a vertical line, covering the whole height of a noise barrier 4 m high (Figure 12). It is important to point out from now on that *not all of the 6* microphones are essential for the quick method: the 3 central microphones probably will suffice, but the other 3 (one below and two above the 3 central ones) allow quick tests of the full capabilities of the method in unusual spots on the noise barrier without the need to move or adapt the linear antenna. These possibilities will be tested in T4.3.

Figure 12. The linear microphone antenna. In background, a directive loudspeaker.

4.3. Loudspeaker

For the acoustic signal output, a loudspeaker has to be selected and compared with the standard Zircon loudspeaker already in use in several European laboratories for EN 1793-5 and EN 1793-6 measurements, including UNIBO.

At first, UNIBO decided to try a lightweight and ultra-directional loudspeaker, in order to focus the sound power on each microphone of the linear microphone antenna. The selected loudspeaker is an Audio Spotlight AS-16i by Holosonics (2 kg including the integrated amplifier). The technical specifications of this loudspeaker are reported in Table 3 (see also Figure 13 and Figure 14).

Table 3: Main technical specifications of the Audio Spotlight AS-16i loudspeaker, as declared by the manufacturer.

Manufacturer	Holosonics Research Labs, Inc. (USA)
Length x Width	16”x16“ (40x40 cm)
Thickness	1”3/8 (3,5 cm)
Weight	4,5 lbs (2,0 kg)
Amplifier	Built-in ultra-efficient
Stereo line-level input	1/8” (3.5 mm)
Balanced audio/power input	Phoenix connector
Audio output	Sub/Thru
MicroSD flash player	yes
IR remote control	yes
Worldwide power input	100-240V, 50/60Hz
Mounting inserts	VESA 100 and M6
Programmable FlexIO	yes
Pixel Processing Pipeline	yes
Peripheral cross triggering	yes
Power On/Off management	yes

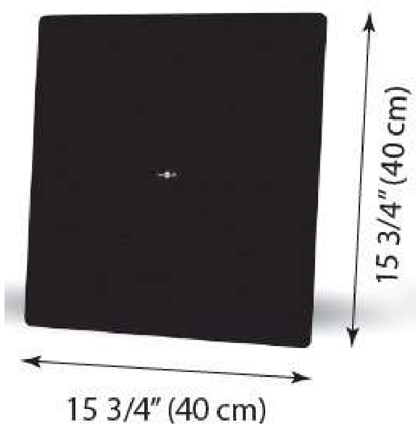


Figure 13. The Audio Spotlight AS-16i loudspeaker (front view).

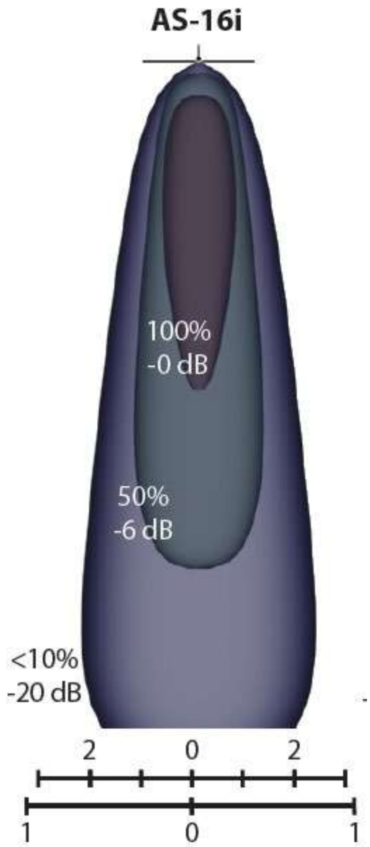


Figure 14. The directivity of the Audio Spotlight AS-16i loudspeaker on a 4 m distance.

Moreover, UNIBO built a lightweight loudspeaker with a broadband driver available at the UNIBO Acoustics Laboratory. It is a 6NDL38 LF Driver by B&C Speakers. Table 4 and Figure 15 show the main data on this loudspeaker. Annex A provides the full data sheet.

Table 4: Main technical specifications of the 6NDL38 LF Driver by B&C Speakers, as declared by the manufacturer.

Manufacturer	B&C Speakers (Italy)
Nominal Diameter	170 mm (6,5 in)
Nominal Impedance	8 Ω
Minimum Impedance	6,0 Ω
Nominal Power Handling	150 W
Continuous Power Handling	300 W
Sensitivity	92,0 dB
Frequency Range	70 - 6000 Hz
Voice Coil Diameter	38 mm (1,5 in)
Winding Material	Copper
Former Material	Kapton
Winding Depth	12,0 mm (0,5 in)
Magnetic Gap Depth	6,0 mm (0,25 in)
Flux Density	1,15 T

Figure 15. The three loudspeakers tested. From left to right: Zircon loudspeaker, Audio Spotlight AS-16i loudspeaker and lab-made loudspeaker.

All three loudspeakers were tested to get their frequency response (at microphone 5, centre grid): see Figure 16. As a further improvement, a wireless transmitter/receiver system by dB Technologies, available at the UNIBO Acoustics Laboratory, was tested for wireless transmission of the input signal to the loudspeaker.

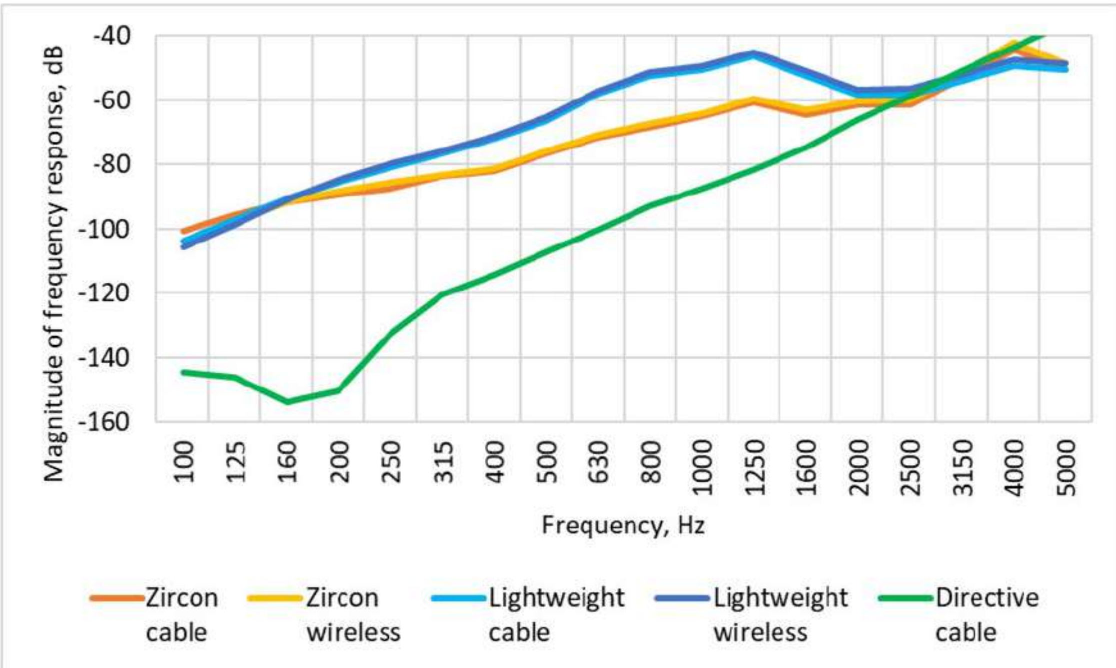


Figure 16. Magnitude of the frequency response of the three different loudspeakers.

Figure 17. Wireless transmitter/receiver system connected to the control and processing system (left) and to the UNIBO lab-made lightweight loudspeaker (right).

Figure 16 shows that the magnitude of the frequency response of the lightweight loudspeaker is greater or equal to that of the Zircon loudspeaker from the 160 Hz to the 2500 Hz one-third octave bands and thus the heavier Zircon loudspeaker can be replaced by the lighter one, portable by one operator, without affecting the results. On the other hand, the directive loudspeaker has a poor response at low frequencies and thus it was discarded to go on quickly with the project. Maybe it will be reconsidered later on for localized spot tests on specific parts of the noise barrier under test.

Figure 18 shows the impulse response of the lightweight loudspeaker overlapped by a 3 ms window; Figure 19 shows the impulse response of the Zircon loudspeaker overlapped by a 3 ms window. It can be seen that they have more or less the same length, even if the Zircon impulse response is more ringing.

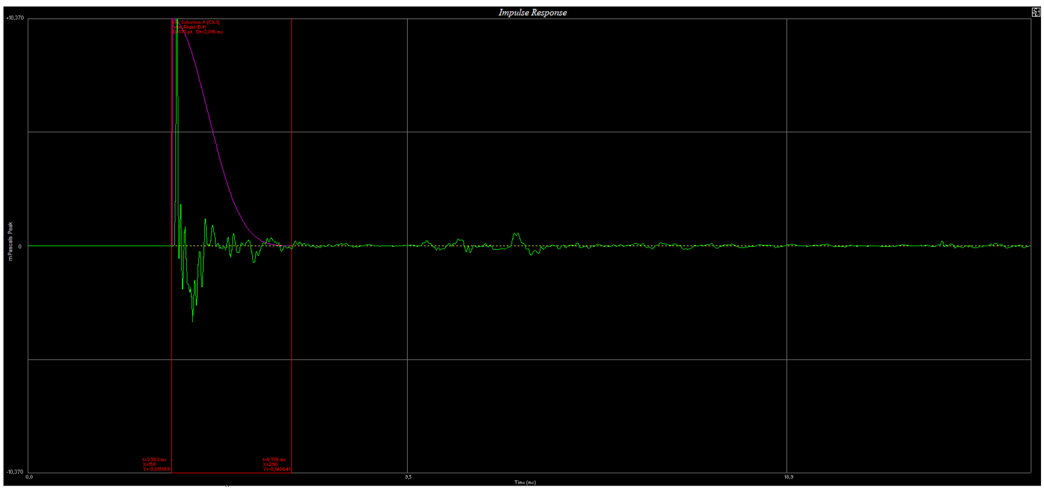


Figure 18. Impulse response of the lightweight loudspeaker overlapped by a 3 ms window.

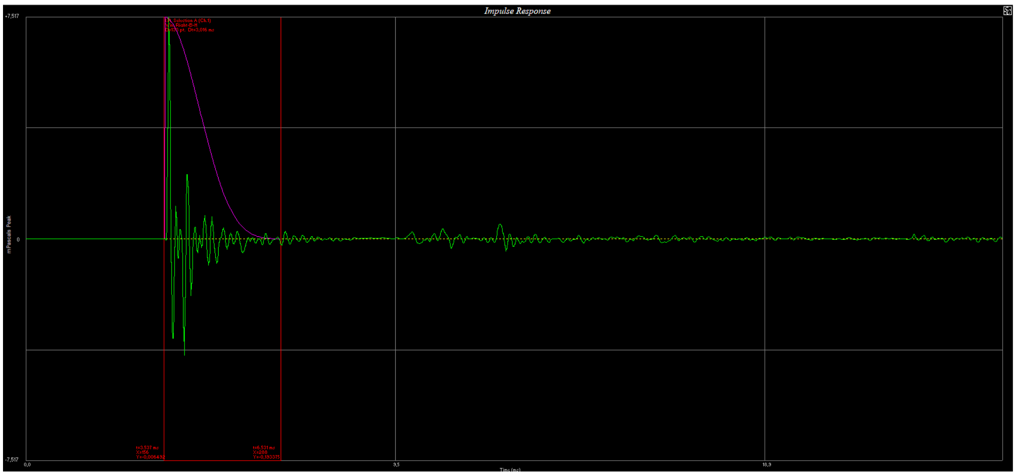


Figure 19. Impulse response of the Zircon loudspeaker overlapped by a 3 ms window.

Figure 16 also shows that the wireless system does not alter the magnitude of the frequency response of the loudspeaker and thus can be used. Of course, in-situ tests have to be done on this wireless system or an equivalent one, in order to see how robust it is against vibrations, high/low temperatures, rough handling, etc. as can happen when operating along a motorway.

4.4. State of the prototype equipment and future implementations

The box with the prototype control and processing system is battery operated and can be easily transported by the operator with a shoulder strap (see Figure 20).

Figure 20. Operating the control and processing system.

The loudspeaker needs only a lightweight battery, which can be carried together with the loudspeaker and its tripod, being the total weight about 3 kg.

The microphone antenna weights about 2 kg.

Thus, the total weight can be easily handled by one operator.

Of course, the final weight of the complete system might vary in the future after the feedback from the in-situ tests programmed in Task T4.3.

The Teensy 4.0 system has the capability to integrate future additional sensors for measuring the wind speed, the position from a GPS receiver, etc.

As of June 30th, 2021, the on-board software includes the complete modules for generating MLS signals, sending them to the loudspeaker, acquiring the signal from the microphones, computing and saving the impulse responses. A quality control check of measured signals has been added (see Figure 21).

Currently UNIBO is transferring its proprietary software for doing the complete processing according to EN 1793-5 and EN 1793-6 to the new on-board computer.

Finally, it is remarked that all the preceding design details are public and the selected components are easily found on the market (see websites in References); so, the equipment for the quick method can be easily replicated by anyone interested in making a similar measuring system.

Figure 21. The control and processing unit confirming that the quality control of a measured impulse response has been passed.

5. Preliminary laboratory tests

5.1. Measuring procedure

The measuring procedure is borrowed with less changes as possible from EN 1793-5 and EN 1793-6 and is supposed to be known to the reader. Therefore, it will not be repeated here; only the changes from the standard procedure will be highlighted.

The initially proposed procedure is as follows:

1. The microphone array, which in the EN standards is a 0,80 x 0,80 m square grid of 9 microphones is replaced with a linear array of 3 microphones (+ 3 additional ones), regularly spaced by 0,40 m from the height of 1,60 m above ground to 2,40 m. The additional microphones are at the height of 1,20 m, 2,80 m and 3,20 m (see Figure 12).
2. Loudspeaker and microphone are placed at the same distance to the noise barrier under test as in EN 1793-5 and EN 1793-6 (see Figure 22 and Figure 23).
3. The test signal is generated and 3 (6) impulse responses are acquired.
4. For each microphone position in front of the device under test, a free-field impulse response with the measurement set-up oriented toward the free space is acquired.
5. Each set of impulse responses – in front of the device under test and in the free-field – are processed as in EN standards to get the final sound reflection index, *RI*, or sound insulation index, *SI*.

The laboratory tests have also the goal of verifying:

- if the procedure is applicable keeping the distances of the loudspeaker and microphones to the noise barrier specified in EN standards;
- if the values of the sound reflection index and sound insulation index values obtained with the 3 central microphones of linear antenna are close to those obtained with the standard square 9-mic. antenna;
- if the values of the sound reflection index and sound insulation index values obtained with the 3 central microphones of linear antenna, repeating the measurements 3 times with a horizontal shift of 0,40 m each time ("virtual grid" mode) can reconstruct those obtained with the standard square 9-mic. antenna (see Figure 24).

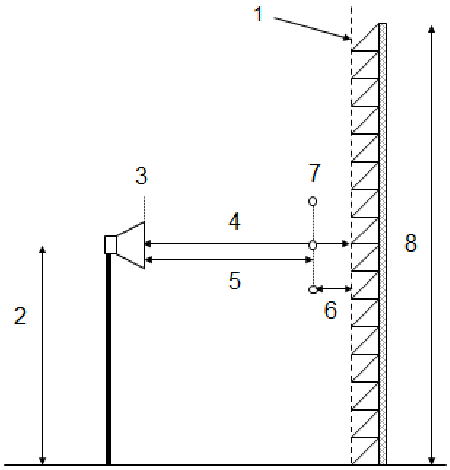


Figure 22. (not to scale) Sketch of the sound source and the measurement grid in front of the noise barrier under test for sound reflection index measurements. 1: source and microphone reference surface; 2: reference height h_S [m]; 3: loudspeaker front panel; 4: distance between the loudspeaker front panel and the reference surface, d_S = 1,50 m; 5: distance between the loudspeaker front panel and the measurement grid, d_{SM} = 1,25 m; 6: distance between the measurement grid and the reference surface, d_M = 0,25 m; 7: measurement grid; 8: noise reducing device height, h_B [m] (from prEN 1793-5:2021).

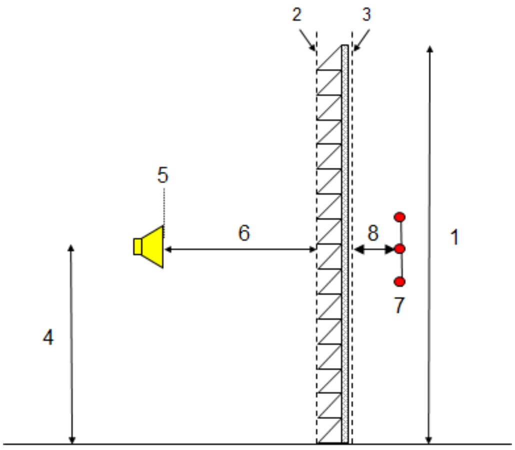


Figure 23. (not to scale) Sketch of the sound source and the measurement grid near the noise barrier under test for sound insulation index measurements. 1: road traffic noise reducing device height, h_B [m]; 2: source reference surface; 3: microphone reference surface; 4 reference height, h_s = $h_B/2$ [m]; 5: loudspeaker front panel; 6: distance between the loudspeaker front panel and source reference surface, d_S = 1,00 m; 7: microphone grid; 8: distance between the microphone grid and the microphone reference surface, d_M = 0,25 m (from prEN 1793-6:2021).

The first laboratory check will be measuring with the new portable equipment three vertical lines of 3 microphones, spaced 0,40 m apart (lines 1, 2 and 3) and reconstructing from them a “virtual grid”, which is the combinations of all the 9 preceding microphone positions. This should permit a direct comparison with the standard 9-mic. grid used in EN 1793-5 and -6.

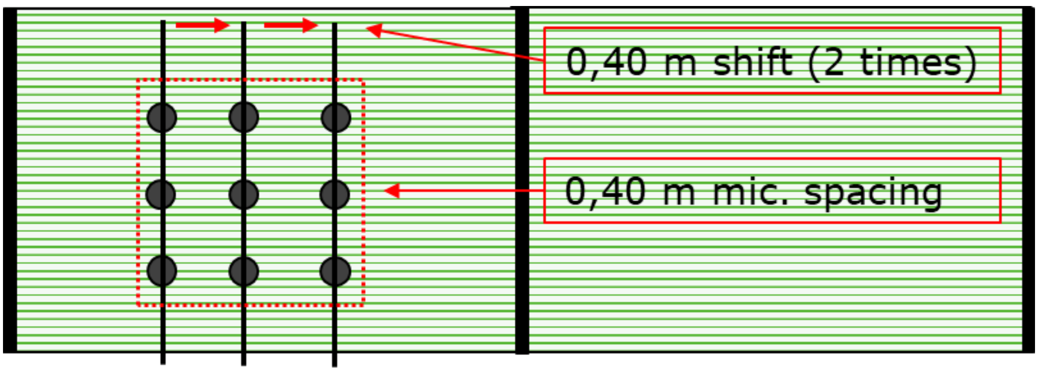


Figure 24. (not to scale) Sketch of the “virtual grid” mode using the linear antenna: the linear mic. array, kept vertical, is horizontally shifted in three different positions at a distance of 0,40 m, keeping the same distance from the noise barrier; then the signals from the 3 central microphones (3 x 3 = 9 signals) are processed as with the standard square 9-mic. antenna.

Moreover, single-line measurements using a linear antenna allow a quick, even if less accurate, scan of a noise barrier in its full extension detecting all possible defects. The linear antenna should be kept vertical and manually displaced in short steps, e.g. 1 m wide, to scan the full extension of the noise barrier. Strong differences between one single measurement and the average of all measurements should point to a local defect. Using the standard square 9-microphones array this would require many careful adjustments of the array, i.e. a very long measurement time (see Figure 25).

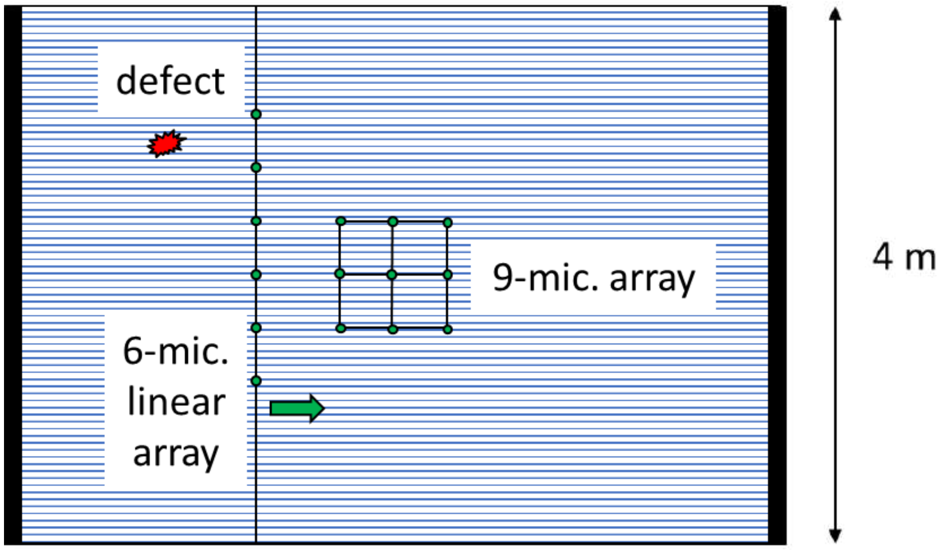


Figure 25. (not to scale) A span of a 4 m high noise barrier between two posts. A defect is indicated by the red spot. The microphones are indicated by green circles.

Finally, it should be pointed out that the linear array includes only 6 microphones because placing additional microphones would mean to place them closer to the ground or the top edge of the noise barrier, which are sources of unwanted reflections (ground) or diffractions (top edge). Especially ground reflections are of concern (see Figure 26).

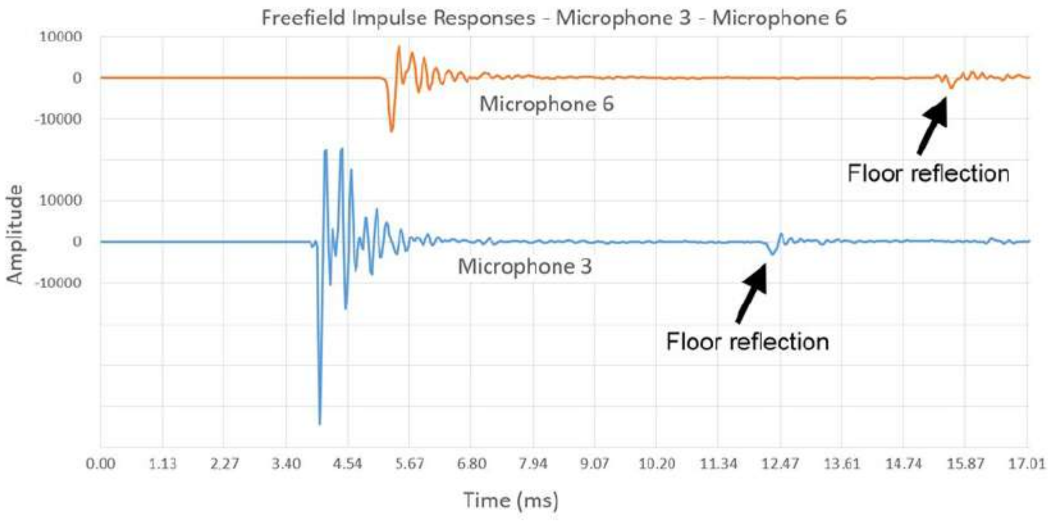


Figure 26. Examples of impulse responses in the free-field, keeping a source to linear array horizontal distance equal to 1,34 m and a source height of 2 m. Height at mic. 3 = 2 m, height at mic. 6 = 3,20 m. Barrier height = 4 m.

5.2. Laboratory measurements

5.2.1 The noise barrier under test

A timber noise barrier sample, available at UNIBO Acoustics Laboratory, has been tested. The noise barrier is made up of wooden panels with a sound-absorbing face (street side) and a face in wooden matchboard (external side). The barrier is built by overlapping two wooden panels of the same length, 3,00 m, and the same height, 2,00 m. The panels are inserted into HeA 160 posts spaced 3,00 m apart. The overall height of the barrier is 4,00 m. Each wooden panel is composed of a pine wood frame with beams and uprights at a distance of 0,605 m, to which a wooden panelling is fixed on the external side with self-tapping screws. In between there is a OSB-type plank in wood chips impregnated with phenolic resins and fixed with self-tapping screws. On the street side there are diagonal beams in pine wood 50x25 mm, bevelled on two sides and fixed with self-tapping screws. The battens hold a black HDPE sheet against the frame. A sound-absorbing layer, 120 mm thick, made of thermoregulated synthetic fibres of recycled polyester with a density ≥ 30 kg / m^3 is placed in the interspace between the rear matchboard and the HDPE sheet. The joints are sealed with an EPDM gasket (see Figure 27).

5.2.2 Evaluation criterion for single-number ratings

As most tenders specify the noise barrier intrinsic performances in terms of the single-number ratings, a comparison of the values of DL_{RI} and DL_{SI} obtained using the full EN method (reference) and the quick method has been done in all cases. These values should be compared keeping in mind the measurement uncertainty values specified in EN 1793-5 and EN 1793-6:

- From EN 1793-5: expanded uncertainty on DL_{RI}: U_{95} = ±1,4 dB (95% confidence)
- From EN 1793-6: expanded uncertainty on $DL_{SI,E}$: U_{95} = ±2,1 dB (95% confidence)
- From EN 1793-6: expanded uncertainty on $DL_{SI,P}$: U_{95} = ±1,4 dB (95% confidence)

The simplest way to do this is comparing the difference between the single-number rating obtained with the quick method and the single-number rating obtained with the full EN method in the same conditions:

$$\Delta_{RI} = DL_{RI}(quick\ method) - DL_{RI}(EN\ 1793-5)\ \ dB \quad (1)$$

$$\Delta_{SI} = DL_{SI}(quick\ method) - DL_{SI}(EN\ 1793-6)\ \ dB \quad (2)$$

These simple indices will be used in the following.

5.2.3 Round 1 - Sound reflection index measurements

Laboratory reflection index tests have been done placing the linear antenna in three positions displaced horizontally 0,40 m apart and three sound reflection index measurements have been taken and processed, considering only the three central microphones: n. 2, 3 and 4 (height above ground 1,60 m, 2,00 m and 2,40 m). The loudspeaker was at an height of 2,00 m above ground. The lab-made lightweight loudspeaker was used. The noise barrier has been also measured applying the full EN 1793-5 procedure with the standard equipment (see Figure 27).

Figure 27. Laboratory reflection index measurement test on a timber noise barrier with the standard equipment for EN 1793-5. Sound source height: 2,00 m above ground.

Figure 28 reports the comparison of the sound reflection indices obtained with the quick method using the lightweight loudspeaker and the EN 1793-5 using the standard equipment. The overall trend is similar, apart in the 5 kHz one-third octave band.

The two single-number ratings are quite similar (see Table 5). In the present case, Δ_{RI} = 0,8 dB, which is well below the expanded uncertainty value at 95% confidence level according to EN 1793-5.

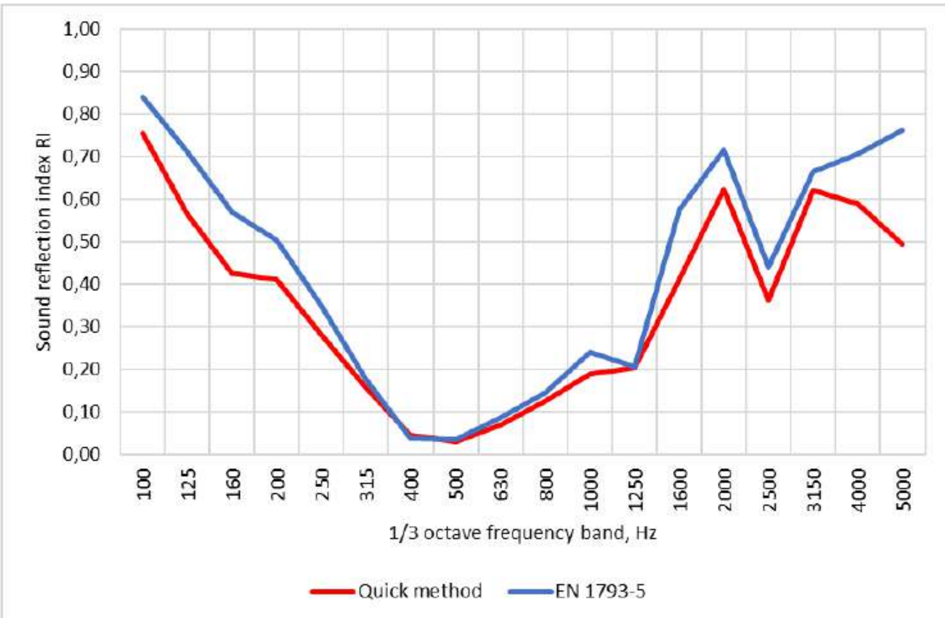


Figure 28. Comparison of laboratory measurements RI on a timber noise barrier with the new equipment for the quick method and the EN 1793-5 equipment.

Table 5: Single-number ratings of sound reflection index DL_{RI} in round 1 (see Figure 28 and Figure 29).

Measurement Method	DL_{RI}, dB	Δ_{RI}, dB	U_{95}, in dB, from EN 1793-5
Full EN method,	5,1	reference	±1,4
Quick method	5,9	0,8	±1,4

5.2.4 Round 1 - Sound insulation index measurements

Laboratory sound insulation index tests have been done on the same timber barrier used for the sound reflection index tests. The linear antenna has been subsequently placed close to the acoustic elements and close to a post. Sound insulation index measurements have been taken and processed, considering only the three central microphones: n. 2, 3 and 4 (height above ground 1,60 m, 2,00 m and 2,40 m). The lightweight loudspeaker was at an height of 2,00 m above ground (see Figure 29).

The noise barrier has been also measured applying the full EN 1793-6 procedure.

Figure 30 reports the comparison of the sound insulation indices obtained measuring across the acoustic elements. Figure 31 reports the comparison of the sound insulation indices obtained measuring across a post. The overall trend is very similar in both cases. In the post measurements a little difference is observed in the low frequency range.

Table 6 reports the single-number ratings.

The Δ_{SI} value is well below the expanded uncertainty value at 95% confidence level according to EN 1793-6 for the acoustic elements, while it is slightly over for the post.

Figure 29. Laboratory sound insulation index measurement test on a timber noise barrier with the new equipment. Left: across the acoustic elements. Right: across a post. Sound source height: 2,00 m above ground.

Table 6: Single-number ratings of airborne sound insulation index DL_{SI} in round 1.

Measurement Method	DL_{SI}, dB	Δ_{SI}, dB	U_{95}, in dB, from EN 1793-6
Full EN method, elements	28,5	reference	±2,1
Full EN method, post	28,7	reference	±1,4
Quick method, elements	29,3	0,8	±2,1
Quick method, post	30,4	1,7	±1,4

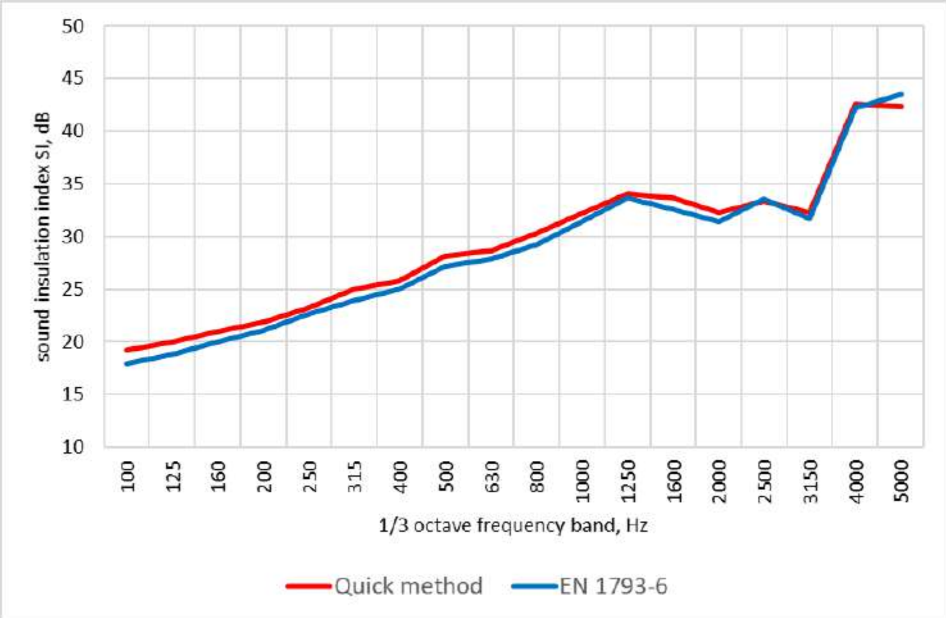


Figure 30. Comparison of laboratory measurements of SI across the acoustic elements of a timber noise barrier with the new equipment for the quick method and the EN 1793-6 equipment.

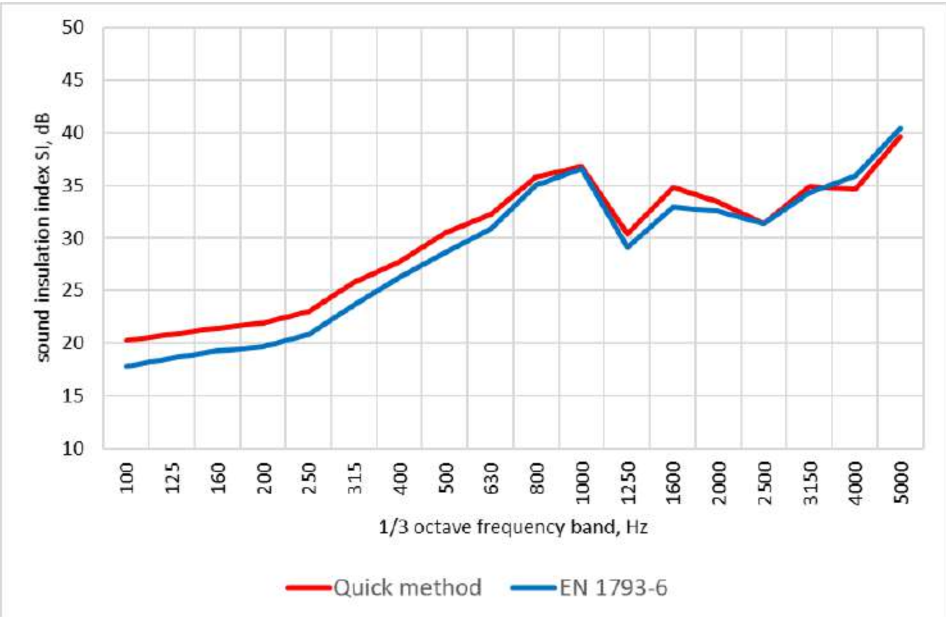


Figure 31. Comparison of laboratory measurements of SI across the post of a timber noise barrier with the new equipment for the quick method and the standard EN 1793-6 equipment.

5.2.5 Round 2 - Sound reflection index measurements

In a second round of tests on the same noise barrier, laboratory reflection index measurements have been done placing the linear antenna in three positions displaced horizontally 0,40 m apart and three sound reflection index measurements have been taken and processed, considering only the three central microphones: n. 2, 3 and 4 (height above ground 1,60 m, 2,00 m and 2,40 m). The loudspeaker was at an height of 2,00 m above ground.

In a first trial, the Zircon loudspeaker was used together with the new control/processing device.

Figure 32 reports the comparison of the sound reflection indices obtained with the quick method in each position separately (line 1, line 2 and line 3) and combining the three measurement positions (vertical microphone lines) in a single virtual grid. The results for single lines differ starting from the 2000 Hz one-third octave band, probably due to the local surface irregularities created by the diagonal timber beams.

Table 7 reports the single-number ratings. The Δ_{RI} values are well below the expanded uncertainty value at 95% confidence level according to EN 1793-5.

The same experiment was repeated with the Zircon loudspeaker connected through the wireless system. Figure 33 reports the comparison of the sound reflection indices obtained with the quick method in each position separately (line 1, line 2 and line 3) and combining the three measurement positions (vertical microphone lines) in a single virtual grid. Table 8 reports the single-number ratings.

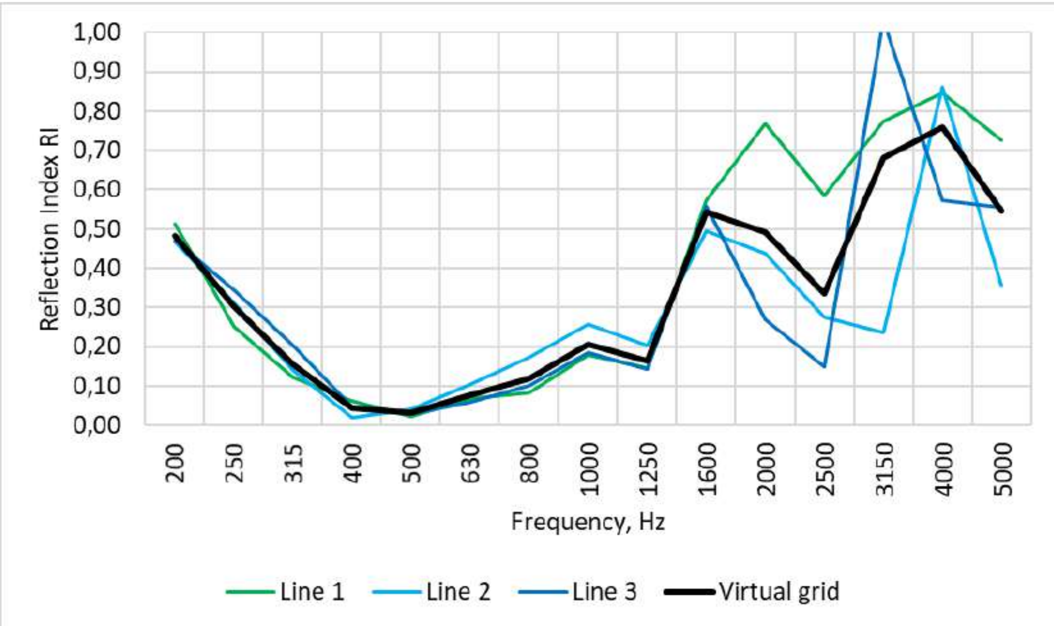


Figure 32. Comparison of laboratory measurements of sound reflection index on a timber noise barrier with the new equipment for the quick method (Zircon loudspeaker, cabled). Lines 1, 2 and 3 refer to three vertical lines of 3 microphones, spaced 0,40 m apart. Virtual grid means the combinations of all the 9 preceding microphone positions.

Table 7: Single-number ratings of sound reflection index DL_{RI} in round 2. New device and Zircon loudspeaker, cabled (see Figure 29).

Microphone disposition	DL_{RI}, dB	Δ_{RI}, dB	U_{95}, in dB, from EN 1793-5
Line 1	5,3	0,2	±1,4
Line 2	5,9	0,7	±1,4
Line 3	6,2	1,1	±1,4
Virtual grid	5,8	0,7	±1,4

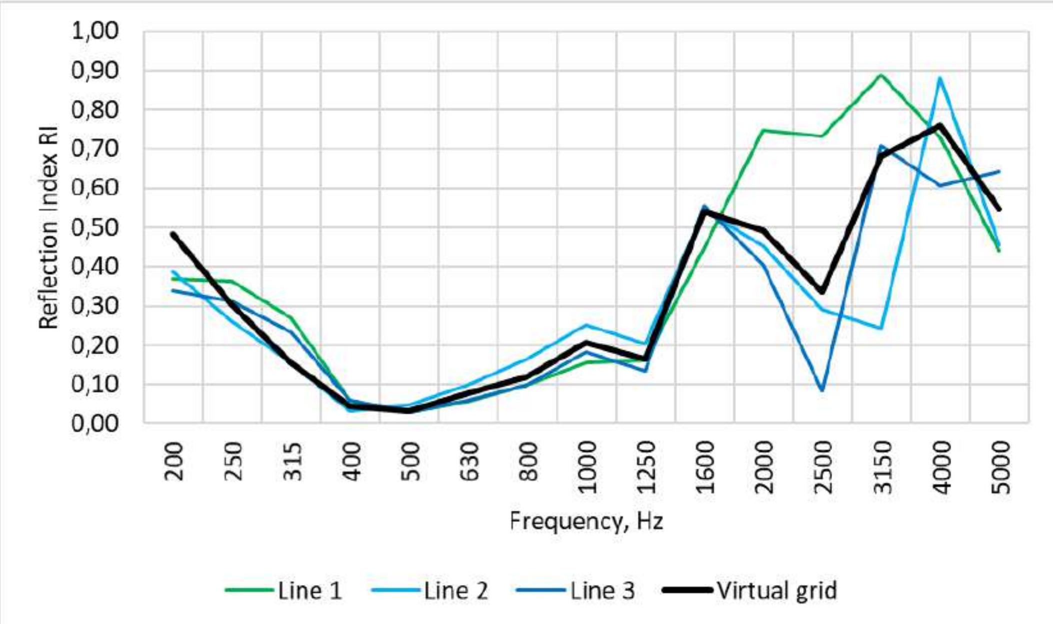


Figure 33. Comparison of laboratory measurements of sound reflection index on a timber noise barrier with the new equipment for the quick method (Zircon loudspeaker, wireless connected). Lines 1, 2 and 3 refer to three vertical lines of 3 microphones, spaced 0,40 m apart. Virtual grid means the combinations of all the 9 preceding microphone positions.

Table 8: Single-number ratings of sound reflection index DL_{RI} in round 2. New device and Zircon loudspeaker, wireless (see Figure 33).

Microphone disposition	DL_{RI}, dB	Δ_{RI}, dB	U_{95}, in dB, from EN 1793-5
Line 1	5,3	0,2	±1,4
Line 2	5,8	0,6	±1,4
Line 3	6,3	1,2	±1,4
Virtual grid	5,8	0,7	±1,4

Again the results for single lines differ from the 2000 Hz one-third octave band, probably due to the local surface irregularities created by the diagonal timber beams. However, the Δ_{RI} values are all below the expanded uncertainty value at 95% confidence level according to EN 1793-5.

The single-number ratings obtained reconstructing the virtual grid are the same for the cabled and wireless loudspeaker. This proves that the wireless transmission is effective for RI measurements, at least in laboratory.

In a second trial, the lab-made lightweight loudspeaker was used.

Figure 34 reports the comparison of the sound reflection indices obtained with the quick method in each position separately (line 1, line 2 and line 3) and combining the three measurement positions (vertical microphone lines) in a single virtual grid. Table 9 reports the single-number ratings.

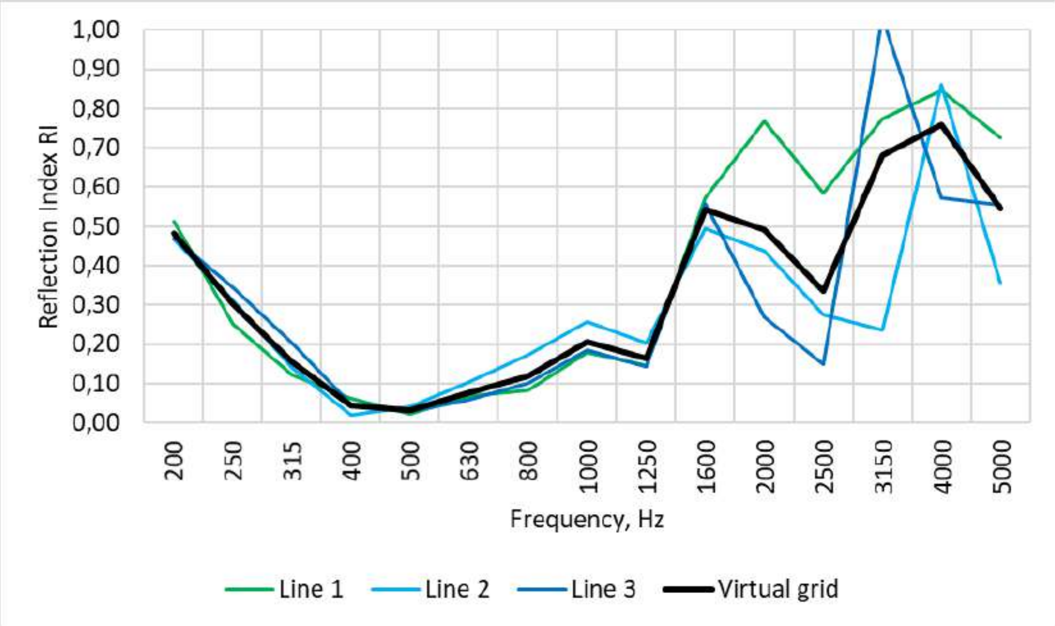


Figure 34. Comparison of laboratory measurements of sound reflection index on a timber noise barrier with the new equipment for the quick method (lightweight loudspeaker, cabled). Lines 1, 2 and 3 refer to three vertical lines of 3 microphones, spaced 0,40 m apart. Virtual grid means the combinations of all the 9 preceding microphone positions.

Table 9: Single-number ratings of sound reflection index DL_{RI} in round 2. New device and lightweight loudspeaker, cabled (see Figure 34).

Microphone disposition	**DL_{RI}, dB**	**Δ_{RI}, dB**	**U_{95}, in dB, from EN 1793-5**
Line 1	4,8	0,3	±1,4
Line 2	5,8	0,7	±1,4
Line 3	6,5	1,4	±1,4
Virtual grid	5,7	0,6	±1,4

The results for single lines differ from the 2000 Hz one-third octave band, probably due to the local surface irregularities created by the diagonal timber beams. However, the Δ_{RI} values are well below the expanded uncertainty value at 95% confidence level according to EN 1793-5, apart for line 3, which gives a value nearly equal to the expanded uncertainty.

The same experiment was repeated with the Zircon loudspeaker connected through the wireless system. Figure 35 reports the comparison of the sound reflection indices obtained with the quick method in each position separately (line 1, line 2 and line 3) and combining the three measurement positions (vertical microphone lines) in a single virtual grid. Table 10 reports the single-number ratings.

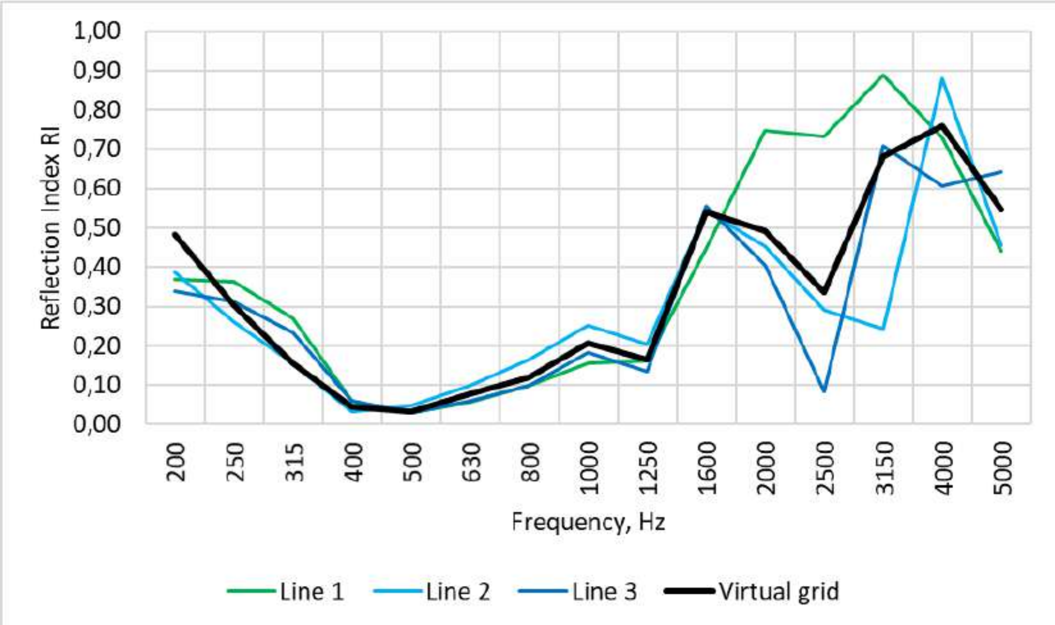


Figure 35. Comparison of laboratory measurements of sound reflection index on a timber noise barrier with the new equipment for the quick method (lightweight loudspeaker, wireless connected). Lines 1, 2 and 3 refer to three vertical lines of 3 microphones, spaced 0,40 m apart. Virtual grid means the combinations of all the 9 preceding microphone positions.

Table 10: Single-number ratings of sound reflection index DL_{RI} in round 2. New device and lightweight loudspeaker, wireless (see Figure 35).

Microphone disposition	DL_{RI}, dB	Δ_{RI}, dB	U_{95}, in dB, from EN 1793-5
Line 1	4,8	0,3	±1,4
Line 2	5,7	0,6	±1,4
Line 3	6,6	1,5	±1,4
Virtual grid	5,7	0,6	±1,4

Again, the results for single lines differ from the 2000 Hz one-third octave band, probably due to the local surface irregularities created by the diagonal timber beams. However, the Δ_{RI} value is well below the expanded uncertainty value at 95% confidence level according to EN 1793-5, apart for line 3, which gives a value 0,1 dB over the expanded uncertainty. The single-number ratings obtained reconstructing the virtual grid are the same for the cabled and wireless loudspeaker. This proves that the wireless transmission is effective for RI measurements, at least in laboratory.

5.2.6 Round 2 - Sound insulation index measurements

In a second round of tests on the same noise barrier, laboratory sound insulation index measurements have been done on the same timber barrier used for round 1. The linear antenna has been subsequently placed in three different positions close to the acoustic elements. Sound insulation index measurements have been taken and processed, considering only the three central microphones: n. 2, 3 and 4 (height above ground 1,60 m, 2,00 m and 2,40 m). The loudspeaker was at an height of 2,00 m above ground (see Figure 29).

In a first trial, the Zircon loudspeaker was used.

Figure 36 reports the comparison of the sound insulation indices obtained with the quick method in each position separately (line 1, line 2 and line 3) and combining the three measurement positions (vertical microphone lines) in a single virtual grid. The overall trend is similar in all cases. A little variation is observed in the 1000-1600 Hz one-third octave bands.

The single-number ratings are reported in Table 11. The Δ_{SI} values are well below the expanded uncertainty value at 95% confidence level according to EN 1793-6.

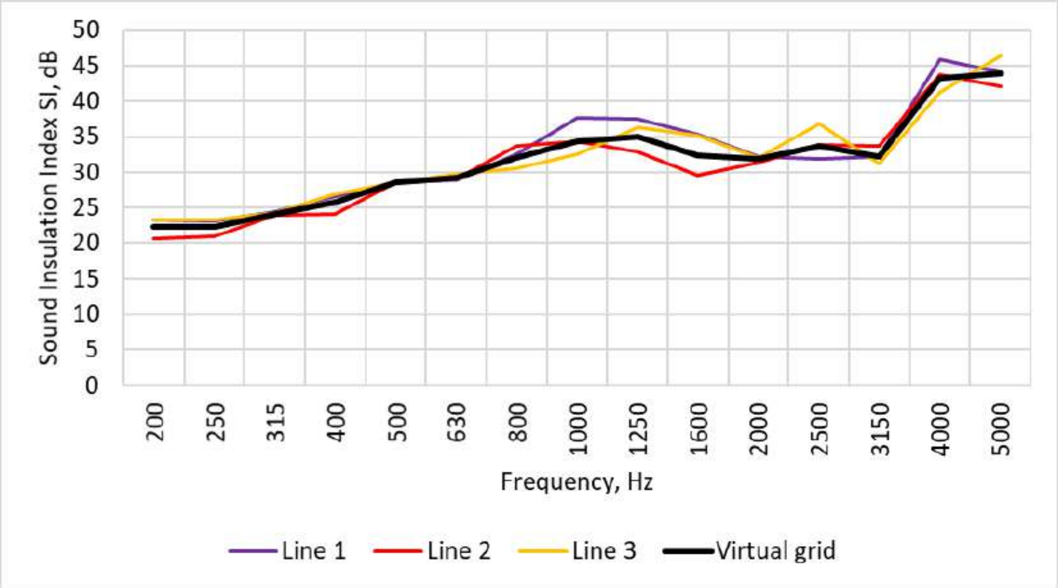


Figure 36. Comparison of laboratory measurements of sound insulation index across the elements a timber noise barrier with the new equipment for the quick method (Zircon loudspeaker, cabled). Lines 1, 2 and 3 refer to three vertical lines of 3 microphones, spaced 0,40 m apart. Virtual grid means the combinations of all the 9 preceding microphone positions.

Table 11: Single-number ratings of airborne sound insulation index DL_{SI} using the quick method with the Zircon loudspeaker, cabled (see Figure 36).

Microphone disposition	DL_{SI}, dB	Δ_{SI}, dB	U_{95}, in dB, from EN 1793-6
Line 1	30,2	1,7	±2,1
Line 2	28,6	0,1	±2,1
Line 3	29,9	1,4	±2,1
Virtual grid	29,5	1,0	±2,1

The same experiment was repeated with the Zircon loudspeaker connected through the wireless system. Figure 37 reports the comparison of the sound insulation indices obtained with the quick method in each position separately (line 1, line 2 and line 3) and combining the three measurement positions (vertical microphone lines) in a single virtual grid. The overall trend is similar in all cases. A little variation is observed in the 1000-1600 Hz one-third octave bands.

The single-number ratings are reported in Table 12. The Δ_{SI} values are well below the expanded uncertainty value at 95% confidence level according to EN 1793-6.

The single-number ratings obtained reconstructing the virtual grid differ only by 0,2 dB for the cabled and wireless loudspeaker. This proves that the wireless transmission is effective for SI measurements, at least in laboratory.

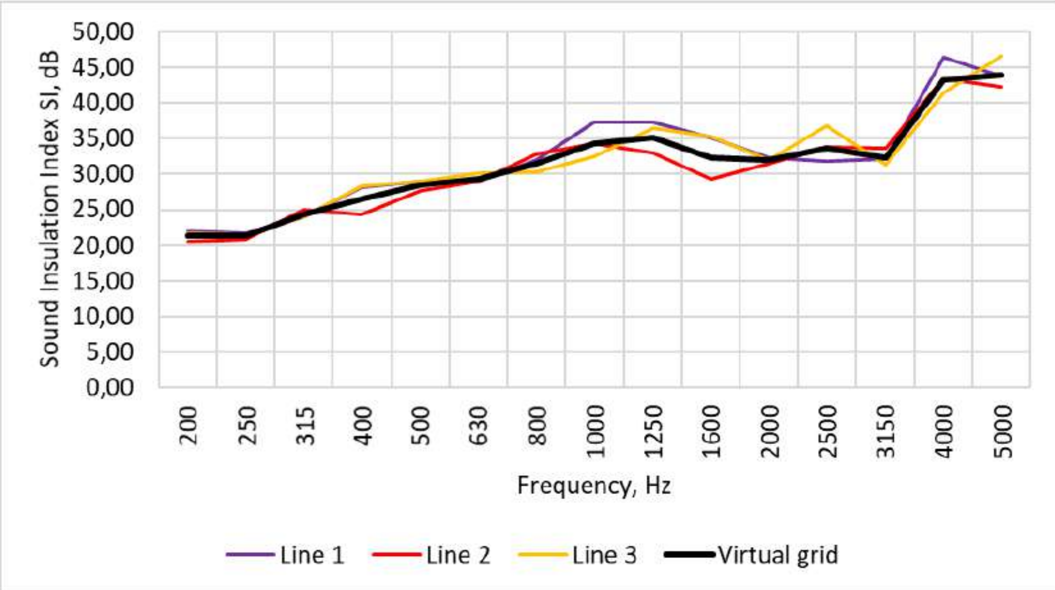


Figure 37. Comparison of laboratory measurements of sound insulation index across the elements a timber noise barrier with the new equipment for the quick method (Zircon loudspeaker, wireless connected). Lines 1, 2 and 3 refer to three vertical lines of 3 microphones, spaced 0,40 m apart. Virtual grid means the combinations of all the 9 preceding microphone positions.

Table 12: Single-number ratings of airborne sound insulation index DL_{SI} using the quick method with the Zircon loudspeaker, wireless (see Figure 37).

Microphone disposition	DL_{SI}, dB	Δ_{SI}, dB	U_{95}, in dB, from EN 1793-6
Line 1	29,8	1,3	±2,1
Line 2	28,5	0	±2,1
Line 3	29,5	1,0	±2,1
Virtual grid	29,3	0,8	±2,1

In a second trial, the lab-made lightweight loudspeaker was used.

Figure 38 reports the comparison of the sound insulation indices obtained with the quick method in each position separately (line 1, line 2 and line 3) and combining the three measurement positions (vertical microphone lines) in a single virtual grid. The overall trend is similar in all cases. A little variation is observed in the 1000-1600 Hz one-third octave bands.

The single-number ratings are reported in Table 13. The Δ_{SI} values are well below the expanded uncertainty value at 95% confidence level according to EN 1793-6.

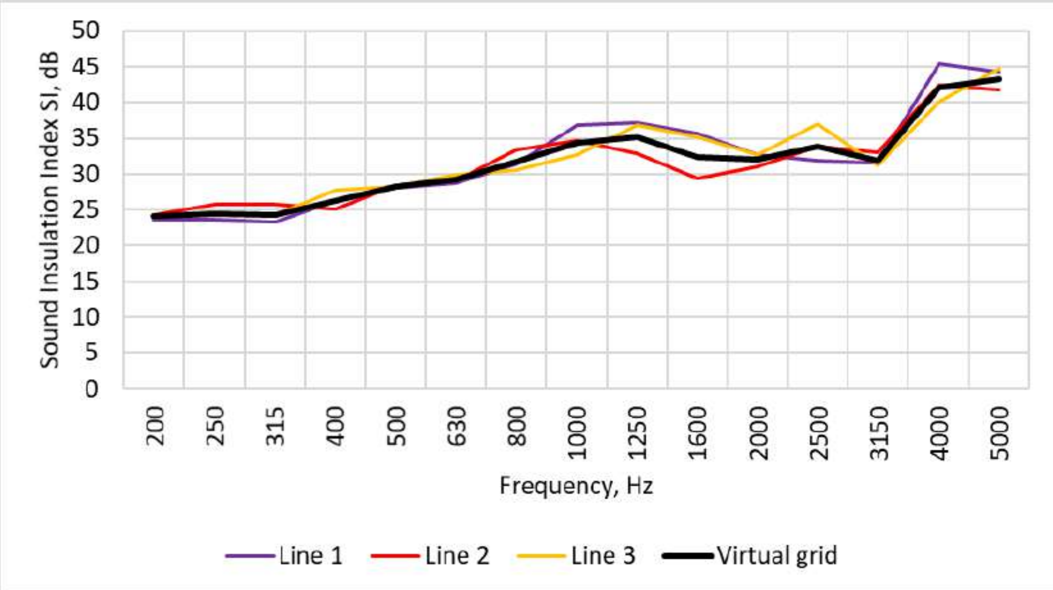


Figure 38. Comparison of laboratory measurements of sound insulation index across the elements a timber noise barrier with the new equipment for the quick method (lightweight loudspeaker, cabled). Lines 1, 2 and 3 refer to three vertical lines of 3 microphones, spaced 0,40 m apart. Virtual grid means the combinations of all the 9 preceding microphone positions.

Table 13: Single-number ratings of airborne sound insulation index DL_{SI} using the quick method with the lightweight loudspeaker, cabled (see Figure 38).

Microphone disposition	**DL_{SI}, dB**	**Δ_{SI}, dB**	**U_{95}, in dB, from EN 1793-6**
Line 1	29,9	1,4	±2,1
Line 2	29,9	1,4	±2,1
Line 3	30,2	1,7	±2,1
Virtual grid	30,0	1,5	±2,1

The same experiment was repeated with the lightweight loudspeaker connected through the wireless system. Figure 39 reports the comparison of the sound insulation indices obtained with the quick method in each position separately (line 1, line 2 and line 3) and combining the three measurement positions (vertical microphone lines) in a single virtual grid.

The single-number ratings are reported in Table 14. The Δ_{SI} values are well below the expanded uncertainty value at 95% confidence level according to EN 1793-6.

The single-number ratings obtained reconstructing the virtual grid differ only by 0,1 dB for the cabled and wireless loudspeaker. This proves that the wireless transmission is effective for SI measurements, at least in laboratory.

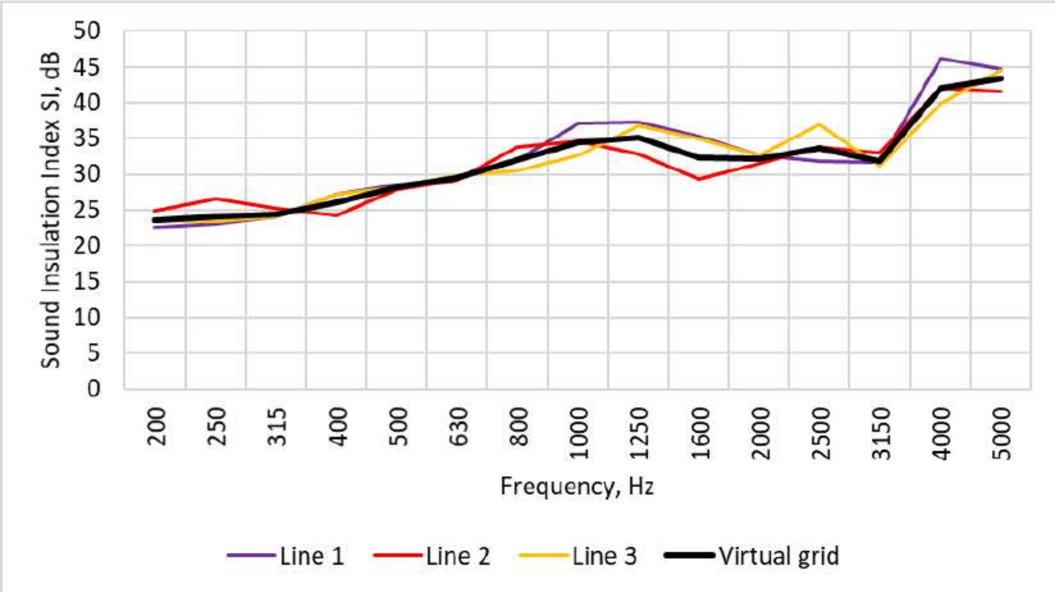


Figure 39. Comparison of laboratory measurements of sound insulation index across the elements a timber noise barrier with the new equipment for the quick method (lightweight loudspeaker, wireless connected). Lines 1, 2 and 3 refer to three vertical lines of 3 microphones, spaced 0,40 m apart. Virtual grid means the combinations of all the 9 preceding microphone positions.

Table 14: Single-number ratings of airborne sound insulation index DL_{SI} using the quick method with the lightweight loudspeaker, wireless (see Figure 39).

Microphone disposition	**DL_{SI}, dB**	**Δ_{SI}, dB**	**U_{95}, in dB, from EN 1793-6**
Line 1	30,1	1,6	±2,1
Line 2	29,8	1,3	±2,1
Line 3	29,9	1,4	±2,1
Virtual grid	29,9	1,4	±2,1

5.2.7 Round 3 - The noise barrier under test

In order to test a different kind of noise barrier, a metal noise barrier sample, available at UNIBO laboratory, has been tested for sound reflection and airborne sound insulation.

Figure 40. Laboratory reflection index measurement test on a metal noise barrier with the equipment for the new quick method. Sound source height: 2,00 m above ground.

The noise barrier under test is made up of modular metal soundproofing and sound-absorbing panels made with full half-shell and perforated half-shell, 34% drilling, obtained by cold profiling of aluminium sheets, in Al-Mg-Mn 3105 series 1,2 mm thick, painted with polyester powder cycle polymerized in the oven, assembled with double bituminous sound-absorbing sheath, one with a weight of 3 kg / m^2 and one with a weight of 5 kg / m^2 and polyester fibre mat 70 mm thick, density 40 kg / m^3. Inside the panels are inserted C-shaped reinforcement profiles in galvanized steel sheet, thickness 1,5 mm, which hold together the half-shells fixed with rivets. The ends of the panels are closed with end caps in moulded polypropylene. The panels are inserted into HeA 160 posts spaced 3,00 m apart. The joints are sealed with an EPDM gasket (see Figure 40).

5.2.8 Round 3 - Sound reflection index measurements

Laboratory reflection index tests have been done both following the full EN 1793-5 procedure and the new quick method. The latter was applied placing the linear antenna in three positions displaced horizontally 0,40 m apart and three sound reflection index measurements have been taken and processed, considering only the three central microphones: n. 2, 3 and 4 (height above ground 1,60 m, 2,00 m and 2,40 m). The loudspeaker was at an height of 2,00 m above ground.

The lightweight loudspeaker was used in both cases, so the differences between measurements are due only to the input sensors (3 x 3 microphone grid or linear antenna with cheap microphones) and the processing device (portable computer or new control device).

Figure 41 reports the comparison of the sound reflection indices obtained with the EN 1793-5 procedure and the quick method in each position separately (line 1, line 2 and line 3) and combining the three measurement positions (vertical microphone lines) in a single virtual grid. The results for single lines differ under the 630 Hz one-third octave band, but the average is really close to the EN 1793-5 curve. Actually, an irregular trend, like the one for line 3 from the 200 Hz to the 630 Hz one-third octave band, is common also for the standard 9-microphones grid when considering the responses from just 3, 2 or even 1 microphone. This is due to very local irregularities of the sample under test, e.g. causing a node or a spike of the sound pressure exactly where a microphone is placed. This is the reason why according to EN 1793-5, the final result is the average over the 9 microphones of the grid. On the other hand, for a quick method, a fast and easy applicability is preferred at the expense of some approximation. It is worth noting that the single-number rating, which is the quantity most used in tenders, is much more stable.

Table 15 reports the single-number ratings. The Δ_{RI} values are well below the expanded uncertainty value at 95% confidence level according to EN 1793-5.

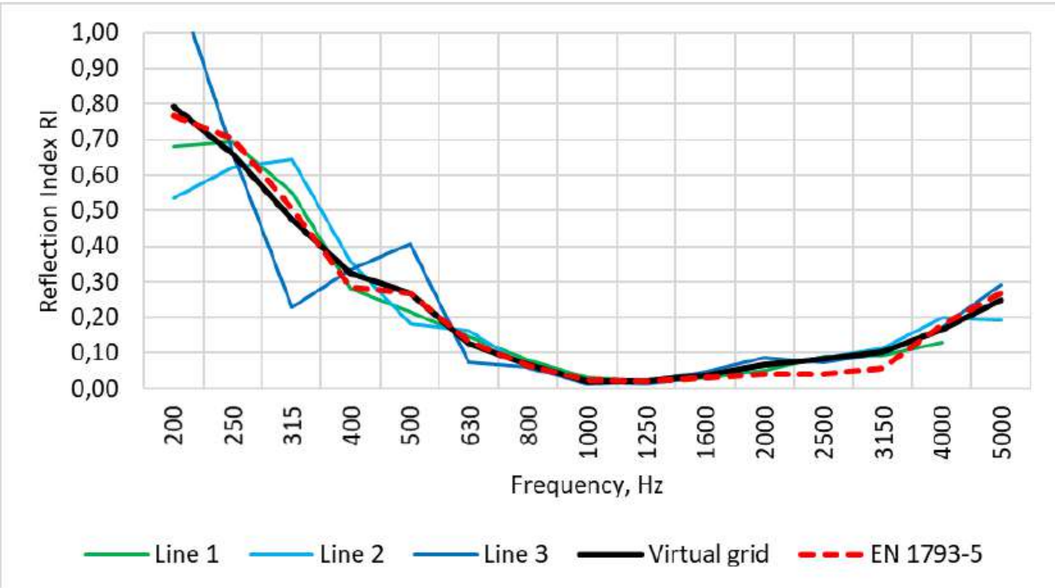


Figure 41. Comparison of laboratory measurements of sound reflection index on a metal noise barrier with the EN 1793-5 procedure and the new quick method (lightweight loudspeaker, cabled). Lines 1, 2 and 3 refer to three vertical lines of 3 microphones, spaced 0,40 m apart. Virtual grid means the combinations of all the 9 preceding microphone positions.

Table 15: Single-number ratings of sound reflection index DL_{RI} in round 3. New device and lightweight loudspeaker, cabled (see Figure 41).

Microphone disposition	DL_{RI}, dB	Δ_{RI}, dB	U_{95}, in dB, from EN 1793-5
EN 1793-5	8,6	reference	±1,4
Line 1	8,5	-0,1	±1,4
Line 2	8,6	0	±1,4
Line 3	8,3	-0,3	±1,4
Virtual grid	8,5	-0,1	±1,4

5.2.9 Round 3 - Sound insulation index measurements

Laboratory sound insulation index tests have been done on the same metal noise barrier both following the full EN 1793-6 procedure and the new quick method. The latter was applied placing the linear antenna in three positions close to the acoustic elements. Sound insulation index measurements have been taken and processed, considering only the three central microphones: n. 2, 3 and 4 (height above ground 1,60 m, 2,00 m and 2,40 m). The loudspeaker was at an height of 2,00 m above ground (see Figure 39).

Figure 42 reports the comparison of the sound insulation indices obtained with the EN 1793-6 procedure and the quick method in each position separately (line 1, line 2 and line 3) and combining the three measurement positions (vertical microphone lines) in a single virtual grid. The overall trend is similar in all cases. A variation is observed in the 800-1600 Hz one-third octave bands for line 2.

The single-number ratings are reported in Table 16. The Δ_{SI} value is well below the expanded uncertainty value at 95% confidence level according to EN 1793-6.

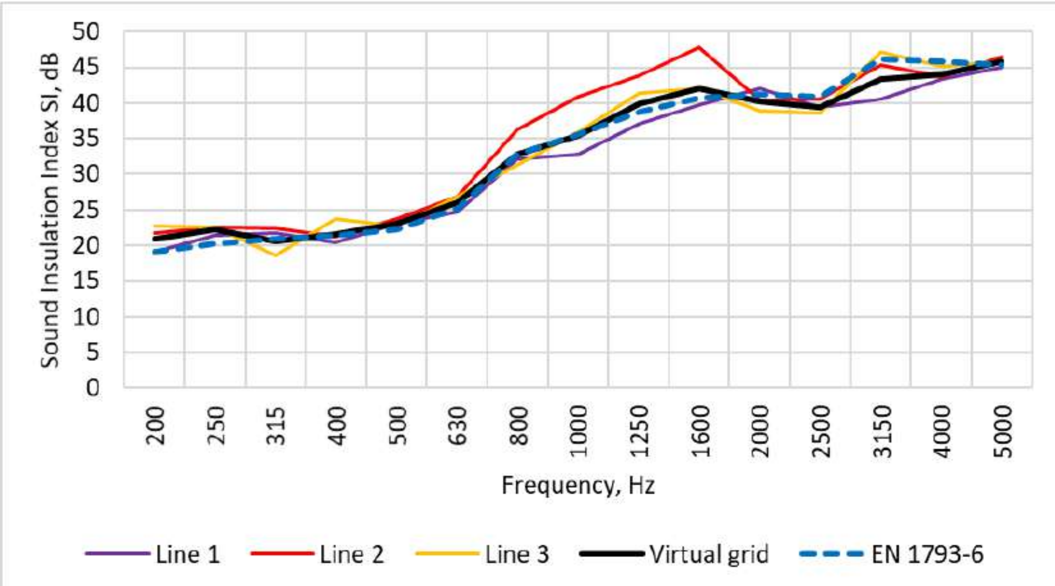


Figure 42. Comparison of laboratory measurements of sound insulation index across the elements of a metal noise barrier with the EN 1793-6 procedure and the new quick method (lightweight loudspeaker, cabled). Lines 1, 2 and 3 refer to three vertical lines of 3 microphones, spaced 0,40 m apart. Virtual grid means the combinations of all the 9 preceding microphone positions.

Table 16: Single-number ratings of airborne sound insulation index DL_{SI} in round 3. New device and lightweight loudspeaker, cabled (see Figure 36).

Microphone disposition	DL_{SI}, dB	Δ_{SI}, dB	U_{95}, in dB, from EN 1793-6
EN 1793-6	26,9	reference	±2,1
Line 1	26,9	0	±2,1
Line 2	28,4	1,5	±2,1
Line 3	27,6	0,7	±2,1
Virtual grid	27,6	0,7	±2,1

6. Conclusion and outlook

At the present stage of the research (end of T4.2) it can be said that all the objectives specified in Section 3 (General requirements for a quick method) have been reached:

- A new quick method has been designed and implemented, building a new portable prototype equipment.
- The new portable prototype equipment is based on a portable control/processing unit, built with hardware components available on the market with an overall cost of less than 4000 € and a weight smaller than 0,5 kg (see Figure 8).
- The new portable prototype equipment includes a lightweight linear antenna with robust and inexpensive electret microphones; it weighs less than 2 kg (see Figure 10).
- The new portable prototype equipment includes a lightweight loudspeaker, it weights less than 3 kg, including a lightweight battery and a tripod. Any other lightweight loudspeaker can be used, provided it has a regular frequency response (see Figure 16).
- The measurement and post-processing software already developed at UNIBO for the full EN method has been simplified and transferred to the new portable equipment.
- The new portable prototype equipment has proved to work effectively on real-size test samples available at UNIBO Acoustics Laboratory. Moreover, a wireless system has been successfully used in the laboratory to send the input signal to the loudspeaker.
- The working frequency range of the quick method is 200 – 5k Hz in one-third octave bands, the same as EN 1793-5 and EN 1793-6.
- The quick method uses an MLS signal, which has the best immunity to background noise, essential for in-situ measurements.
- The quick method is fully automated: the operators have to place the loudspeaker and the microphones at prescribed distances from the noise barrier and push few buttons. Thus, the degree of expertise required to operators is not so strict as for applying the full EN 1793-5 and EN 1793-6 method.
- The easiness of in-situ operation will be checked in real conditions on the A22 motorway in Task 4.3; however, the results already obtained are very encouraging.
- In the laboratory tests, the new quick method demonstrated a very high correlation with full EN 1793-5 or EN 1793-6 results. In the light of this, during Task 4.3 a procedure will be outlined to do quick scans along the entire extension of the noise barrier under test to improve the speed of execution, even at the price of controlled reduction of the correlation with full EN standards.

- In the laboratory tests, the new quick method demonstrated a very high reproducibility of the results when used to reconstruct the results of the full measurement with the 9-mic. grid prescribed in EN 1793-5 and EN 1793-6 standards (virtual grid mode). When the quick method is used on a single vertical line, the results are more sensitive to local characteristics of the noise barrier under test: this is the property of the method that will be exploited to perform a quick scan in search of local defects.

In order to better appreciate the last two points, Tables 17 and 18 summarize the comparison of all values of DL_{RI} and DL_{SI} obtained in the laboratory tests. This is particularly important because most tenders specify the noise barrier intrinsic performances in terms of the single-number ratings. The difference between the value of the single-number rating of the sound reflection index obtained measuring with the linear antenna and the value obtained measuring with the full EN 1793-5 equipment, Δ_{RI} in dB, is always not greater than the expanded uncertainty range of the full EN 1793-5 method. This has to be considered a very good results, even beyond the expectations.

The difference between the value of the single-number rating of the sound insulation index obtained measuring with the linear antenna and the value obtained measuring with the full EN 1793-6 equipment across the acoustic elements, Δ_{SI} in dB, is always not greater than the expanded uncertainty range of the full EN 1793-6 method, with just one exception. This has to be considered a very good results, even beyond the expectations.

Table 17: Comparison of single-number ratings of sound absorption DL_{RI} under a direct sound field from laboratory tests.

Test	Test method	DL_{RI}, dB	Δ_{RI}, dB
Round 1 - timber barrier lightweight loudspeaker, cabled	EN 1793-5	5,1	-
Round 1 - timber barrier lightweight loudspeaker, cabled	Quick method	5,9 virtual grid	0,8
Round 2 - timber barrier lightweight loudspeaker, cabled	Quick method	4,8 line 1 5,8 line 2 6,5 line 3 5,7 virtual grid	-0,3 0,7 1,4 0,6
Round 2 - timber barrier lightweight loudspeaker, wireless	Quick method	4,8 line 1 5,7 line 2 6,6 line 3 5,7 virtual grid	-0,3 0,6 1,5 0,6
Round 3 – metal barrier lightweight loudspeaker, cabled	EN 1793-5	8,6	-
Round 3 – metal barrier lightweight loudspeaker, cabled	Quick method	8,5 line 1 8,6 line 2 8,3 line 3 8,5 virtual grid	-0,1 0 -0,3 -0,1

Table 18: Comparison of single-number ratings of airborne sound insulation DL_{SI} under a direct sound field from laboratory tests.

Test	Test method	DL_{SI}, dB	Δ_{SI}, dB
Round 1 - timber barrier lightweight loudspeaker, cabled	EN 1793-6	28,5 elements 28,7 post	- -
Round 1 - timber barrier lightweight loudspeaker, cabled	Quick method	29,3 elements 30,4 post	0,8 1,7
Round 2 - timber barrier Zircon loudspeaker, cabled	Quick method elements	30,2 line 1 28,6 line 2 29,9 line 3 29,5 virtual grid	1,7 0,6 1,7 1,0
Round 2 - timber barrier Zircon loudspeaker, wireless	Quick method elements	29,8 line 1 28,5 line 2 29,5 line 3 29,3 virtual grid	1,3 0 1,0 1,8
Round 2 - timber barrier lightweight loudspeaker, cabled	Quick method elements	29,9 line 1 29,9 line 2 30,2 line 3 30,0 virtual grid	1,4 1,4 1,7 1,5
Round 2 - timber barrier lightweight loudspeaker, wireless	Quick method elements	30,1 line 1 29,8 line 2 29,9 line 3 29,9 virtual grid	1,6 1,3 1,4 1,4
Round 3 – metal barrier lightweight loudspeaker, cabled	EN 1793-6	26,9	-
Round 3 – metal barrier lightweight loudspeaker, cabled	Quick method	26,9 line 1 28,4 line 2 27,6 line 3 27,6 virtual grid	0 1,5 0,7 0,7

Regarding the future activities in Task 4.3, a preliminary selection of sites for in-situ tests on noise barriers installed along the A22 motorway "Autostrada del Brennero" (Italy-Austria) has been done. The final selection and the days for testing have to be confirmed by the competent road authority after having considered the traffic flow expected in the summer months (July-September) on the A22 motorway and possible criticalities due to urgent road repair works, accidents, etc.

As already said, during Task 4.3, when testing on the A22 motorway, a procedure will be outlined to do quick scans along the entire extension of the noise barrier under test to improve the speed of execution, even at the price of a controlled reduction of the correlation with full EN standards.

Due to the fact that the availability of test sites and the freedom of movement to/from them depend on the permission by road authorities, which may change unexpectedly, and that some restrictions for border crossing due to the pandemic may also change unexpectedly, UNIBO will organize the tests for the quick method (step 2 of the 3-step approach) and the associated visual inspections (step 1 of the 3-step approach) independently from the other partners. This will assure the quickest reactivity to exploit all opportunities. Of course, all other partners will be kept informed so that they can reach the test sites on the allowed days, if possible.

Table 19 summarizes the activities already done at UNIBO or to be done in the near future in the frame of Tasks T4.1, T4.2, T4.3, T4.4.

Table 19: Summary of sub-tasks already done or to be done in Tasks T4.1, T4.2, T4.3, T4.4.

Task	Activity	Timing
T4.1	Review of the state of the art of existing in-situ measurement methods of sound absorption and sound insulation of noise barriers	Done June-August 2020
T4.2	Concept of a quick measurement method	Done April-September 2020
T4.2	On-board computer selection and purchase	Done Sept.-October 2020
T4.2	Assembling new on-board computer	Done October-December 2020
T4.2	Laboratory tests of signal input/output	Done November-December 2020
T4.2	Selection and purchase of an ultra-directive loudspeaker	Done November 2020 to March 2021 (some difficulties due to shipment from USA to Italy)
T4.2	Construction of a portable lightweight loudspeaker	Done May 2021
T4.2	Laboratory tests at UNIBO	Done February-June 2021
T4.3	Selection of sites for in situ tests on A22 “Autostrada del Brennero” (Italy-Austria)	Preliminary selection done January-May 2021 Final selection to be confirmed by road authority after having considered the traffic flow expected in the next months and other possible criticalities
T4.3	In-situ tests UNIBO	July – November 2021, depending on the permission by road authorities
T4.3	In-situ tests UNIBO + other partners	July – November 2021, depending on the permission by road authorities and on the restrictions for border crossing due to the pandemic
T4.4	Writing final WP4 report (D4.2 for M4.4)	From August 2021 depending on availability of data from T4.3

7. References

[1] M. Garai, P. Guidorzi. Report SOPRANOISE - WP4 – Task 4.1 – M4.1 State of the art review of existing methods for measuring in-situ the intrinsic acoustic characteristics of noise barriers, vr. 2.0 August 31st, 2020 (confidential).

[2] 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).

[3] EN 1793-5:2016/AC:2018. Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 5: Intrinsic characteristics - In situ values of sound reflection under direct sound field conditions.

[4] EN 1793-6:2018+A1:2021. Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 6: Intrinsic characteristics - In situ values of airborne sound insulation under direct sound field conditions.

[5] Teensy website (accessed June 15th, 2021): https://www.pjrc.com/store/teensy41.html

[6] Amazon web page of the electret microphones (accessed June 15th, 2021): https://www.amazon.it/AZDelivery-GY-MAX4466-Microfono-Amplificatore-compatibile/dp/B08T1Y58HR/

[7] B&C driver website (accessed June 15th, 2021): https://bcspeakers.com/en/products/lf-driver/6-5/8/6ndl38-8

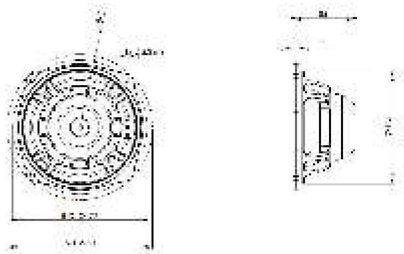
Annex A – B&C Loudspeaker data sheet

B&C SPEAKERS

6NDL38

8Ω

LF Drivers - 6.5 Inches

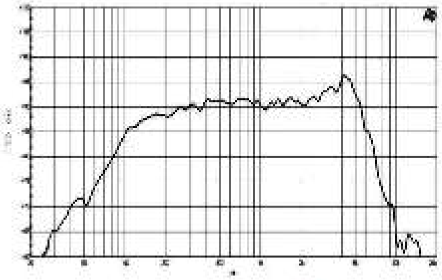


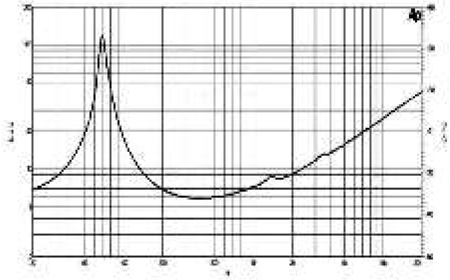
- 38 mm (1.5 in) copper voice coil
- 70 - 6000 Hz response
- 92 dB sensitivity
- Neodymium magnet allows a very light yet powerful motor assembly
- Aluminium demodulating ring allows a very low distortion figure
- 300 W continuous program power capacity

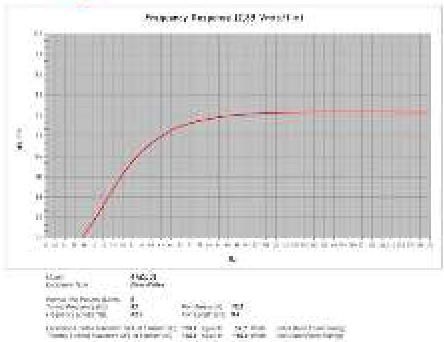
B&C Speakers s.p.a.
Via Poggiomoro, 1 - Loc. Vallina, 50012 Bagno a Ripoli (FI) - ITALY - Tel. +39 055 65721 - Fax +39 055 6572312 - mail@bcspeakers.com

6NDL38

LF Drivers- 6.5 Inches







SPECIFICATIONS

Nominal Diameter	170 mm (6.5 in)
Nominal Impedance	8 Ω
Minimum Impedance	6.0 Ω
Nominal Power Handling[1]	150 W
Continuous Power Handling[2]	300 W
Sensitivity[3]	92.0 dB
Frequency Range	70 - 6000 Hz
Voice Coil Diameter	38 mm (1.5 in)
Winding Material	Copper
Former Material	Kapton
Winding Depth	12.0 mm (0.5 in)
Magnetic Gap Depth	6.0 mm (0.25 in)
Flux Density	1.15 T

DESIGN

Surround Shape	Roll
Cone Shape	Exponential
Magnet Material	Neodymium Ring
Spider	Single
Pole Design	T-Pole
Woofer Cone Treatment	WP Waterproof Front Side
Recommended Enclosure	9.0 dm³ (0.32 ft³)
Recommended Tuning	62 Hz

PARAMETERS[4]

Resonance Frequency	72 Hz
Re	5.2 Ω
Qes	0.44
Qms	11.5
Qts	0.42
Vas	7.0 dm³ (0.25 ft³)
Sd	132.0 cm² (20.5 in²)
η₀	0.6 %
Xmax	± 6.0 mm
Xvar	± 5.5 mm
Mms	17.0 g
Bl	9.5 Txm
Le	0.6 mH
EBP	163 Hz

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MOUNTING AND SHIPPING INFO	
Overall Diameter	187 mm (7.4 in)
Bolt Circle Diameter	172 mm (6.7 in)
Baffle Cutout Diameter	145.0 mm (5.7 in)
Depth	85 mm (3.3 in)
Flange and Gasket Thickness	11 mm (0.4 in)
Air Volume Occupied by Horn	0.63 dm^3 (0.02 ft^3)
Net Weight	1.2 kg (2.6 lb)
Shipping Units	1
Shipping Weight	1.4 kg (3.09 lb)
Shipping Box	210x210x125 mm (8.27x8.27x4.92 in)

SERVICE KIT	
Recone kit	RCK06NDL38B

1. 2 hours test made with continuous pink noise signal within the range Fs-10Fs. Power calculated on rated minumum impedance. Loudspeaker in free air.
2. Power on Continuous Program is defined as 3 dB greater than the Nominal rating.
3. Applied RMS Voltage is set to 2.83 V for 8 ohms Nominal impedance.
4. Thiele-Small parameters are measured after a high level 20 Hz sine wave preconditioning test.

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