27th International Congress on Sound and Vibration
The annual congress of the International Institute of Acoustics and Vibration (IIAV)
11-16 July, 2021
ICSV27
Annual Congress of the International Institute of Acoustics and Vibration (IIAV)

MEASURING REVERBERATION TIME ON PROFESSIONAL INSTRUMENTS VS. ANDROID SMARTPHONES: SINE SWEEP, IMPULSE AND REPRODUCIBILITY UNCERTAINTIES

Rizzi Lorenzo, Ghelfi Gabriele and Davide Portolani
Suonoevita Ingegneria Acustica, via Cavour 18, Lecco, Italy
email: rizzi@suonoevita.it

Scotti Giulio
Independent software engineer, Lecco, Italy

The analysis of reverberation time measurements, performed with a mobile smartphone application (Acoustic Parameter Measurement Tool for Android) developed by authors, is discussed. Recently the app has been upgraded implementing also the sine sweep technique (APM Sweep app).

In-depth analysis of reverberation time measures has been carried out in a small and a large room. The scope was to define the repeatability uncertainty for both measurement system used: two professional measurement systems were compared to our APM Sweep app on different smartphones.

Both the impulse and the sine sweep reverberation time results were compared with the professional equipment and the application's algorithm. The study has been carried out first on two professional systems, then on several devices, showing how different smartphone brands, with different internal microphones (MEMS) and audio software, answer to the application. The measurements repeatability, taken with the reference system and APM Sweep, has been furthermore investigated. One Bluetooth small sound sources weas tested and they were compared to a dodecahedron loudspeaker yield.

Using the theory of uncertainty and the rules of ISO 3382-2 (precision quality), the results show a good RT accuracy and repeatability, in particular in the frequencies range 200 – 1250 Hz.

1. Introduction

An accurate measurement of reverberation time of any ordinary room, must follow the standards of ISO 3382-2[1], which means using technologies that are often bulky to transport. In the professional life, it can be convenient to have an easy tool to perform a first analysis quickly, comfortably, even with a lower precision grade.

That's why the APM Tool app was first developed in 2014, starting with the project described in [2], designed for both the IOS and Android system, tested in the field of work, by SuonoeVita in 2015 [3], which uses the direct impulse method to estimate the main acoustic parameters of any room. In 2017 the project was extended into the APM Sweep app: the indirect method of the logarithmic sine sweep [4] to evaluate the room's acoustic response has been implemented. This article looks at our application APM Sweep for Android (version 1.1.5), especially the reverberation time (T20) quality and its measurement repeatability on devices with different versions of the Android operative system in two sample rooms. It is all compared to the professional instrumentation yield.

2. Android hardware and software limitations

Measurement performances of “APM Sweep” have been analysed because of software differences and hardware characteristics of MEMS microphones that are integrated on smart devices.

The above-mentioned microphones offer a frequency response that is not linear at the frequency range ends and this is due to their structural and geometric characteristics.

MEMS microphones transform an acoustic signal in an electrical signal; this acoustic signal is fed to a fixed and mobile membrane that create a condenser with a editable capacity, these changes are transform in an electrical signal with an integrated electronics. They are thought to have omnidirectional characteristics but experiments [5] prove that: at the high frequency, there is a preferred direction and it is when the angle of incidence of signal is between 0°and 45°. This happens because of their position next to the other electronic components inside the smartphone packaging actually modifies the MEMS polar diagram making it not omni-directional.

The electrical noise is quite high [9]. Another limit is the actual dynamic range that is roughly between LAeq = 35 - 85 dBA – this requires a strict software control on clipping and the electrical gain is managed by each producer with their own AGC algorithm [2].

These limits give a measurement error of acoustic parameters compared to professional devices. In this study it was verified how critical it can be in practice for the reverberation parameter measurement. Another problem not to be underestimated is that the MEMS are more inclined to wear out as they are continuously used in everyday life. The tested phones had at least one year of use.

3. Obtaining a Room Impulse Response: direct method vs sine-sweep method

Suonoevita decided to apply two common methods to obtain the R.I.R.: the traditional direct method and the more advanced sine-sweep method, APM Sweep app now can use both methods in alternative.

3.1 Direct method

The simplest method to obtain the R.I.R. is to generate a sonic impulse and record it. This technique is still spread in the professional world, using blank-gun shots, large balloon pops or wooden clappers. These types of sources have often a good dynamic but less repeatability than indirect methods do, they suffer if the background noise is high.

In a previous article [3] Suonoevita investigated different kind of commonly used impulses:

- simple handclaps don’t generate high pressure levels and have sufficient energy above 500 Hz;
- balloon pops generate an N wave in the time domain that is detrimental to parameters such as clarity;
- wooden clapper obtains a good SNR starting from 100 Hz but has its own decay of about 0.2 sec on a 20 dB drop (due to the chambers covered by rubber, created to boost the low-end response) and it is a directive source at high frequencies [11].

This method gives practical limitations if applied on smartphones, because of their limited dynamic range compared to real-world background noise levels and real-impulse energy: sometimes it is difficult to obtain a thorough 30 dB or even 20 dB drop if background noise is high; often the impulse energy compared to the feasible distance yields too much energy on the microphone and this makes the measurement process slow.

3.2 Exponential sine-sweep method

Logarithmic sine sweep is a sinusoidal signal with exponentially increasing frequency [6]. As resumed in a previous article [4] by deconvolving the recorded sine-sweep y(t) and the calculated inverse filter it is possible to obtain a clean room’s impulse response h(t).

This method is more precise, it works well even on very low SNR, it doesn't need high an energy signal and it allows to avoid the typical AGC problems the direct method creates on smartphones, where dynamic range is limited.

4. Reverberation Time limits – the Schroeder frequency

A well-known acoustic behaviour inside closed spaces is related to the presence of resonance modes in the low frequencies. The resonance modes, or standing waves, are a function of room dimensions. The modal density increases with frequency. Above a specific frequency, called Schroeder cut-off frequency, the sum over modes indices can be approximated by an integral and normal modes can be regarded as a continuum distribution. Above this frequency they are treated from a statistical point of view and the impact of individual modes can be neglected.
Below this frequency limit Sabine's assumption of a diffuse field do not apply and the concept of reverberation time fragments into discrete decays: each room mode depicts its own and characteristic decay time that depends to the room's overall impedance [8] [10].
The formula to compute Schroeder cut-off frequency is the following:

$$f \approx 2000\sqrt{RT/_{V}} \quad (1)$$

where V is the room volume and RT is the measured reverberation time of the room.
This phenomenon limits any RT measurement quality in small rooms at low frequencies.

5. Reverberation Time – measurement uncertainty

As ISO 3382-2 [1] requires, at least 12 measurements must be made to declare a precision-level accuracy (6 to declare an engineering-level). This is because every acoustical, but in general physical, phenomenon cannot be analyzed with a low number of samples; indeed, the accuracy is directly proportional to the number of measurements. To verify the reliability of APM Sweep, the weighted average of two averages was calculated for all devices, these averages are computed in this way:

- For the direct method, 12 telephone/sound level meter positions and 3 clapper impulse positions have been used for 36 combinations of source and receiver
- For the indirect method, 12 loudspeaker positions and 3 microphone positions have been used for 36 combinations of source and receiver

To use the weighted average, you have to check the compatibility between the two averages and in fact it's necessary that the distance between the two averages must be less than the combination of the uncertainty associated with them, unless a k factor, which identifies confidence interval, in our case 95.5 % corresponding to k = 2, considering the term of covariance equal to 0 because the averages are statistically independent [7]. The uncertainty is standard deviation of the average.

The weighted averages on our data were calculated according to the formula:

$$X_w = \frac{\sum_{i=0}^{n} \frac{x_i}{\delta_i^2}}{\sum_{i=0}^{n} \frac{1}{\delta_i^2}} \quad (2)$$

The uncertainty (δ) of the averages (x) is calculated as a standard deviation on 12 samples, because APM Sweep and Noise&Work software return the averages for each telephone/sound level meter position, so it's not possible calculate the standard deviation on all 36 measurements. The uncertainty of the weighted average is calculated according to the formula:

$$\delta_{X_w} = \frac{1}{\sqrt{\sum_{i=0}^{n} \frac{1}{\delta_i^2}}} \tag{3}$$

Then the uncertainty is calculated as a relative uncertainty δ (%) on the weighted average and it is normalized on reference's uncertainty.

The uncertainty calculated in this way allows us to translate it into a **repeatability** error [7] because it follows all the conditions: the same measurement method must be maintained; must be carried out by the same operator; must be carried out with the same measuring tool; it must be done in the same place; must be carried out with the same conditions of use of the instrument and measuring; must be carried out in a short period.

6. Field test – comparing 2 methods on 2 professional instrumentations

Field-tests have been performed in order to verify the quality of the two different methods. As an example, the case study of a 42 m^3 volume (f_c = 315 Hz) ordinary small room is proposed here. Two different setups have been compared in third octave bands:

Table 1: Professional Setups

Setup	**Method**	**Source**	**Receiver**	**Software**
Professional	Indirect	Dodecahedron Loudspeaker+sub	Measurement mic (Earthworks M30)	"Aurora" for Audacity [6]
Professional	Direct	Wooden clapper	Sound Level Meter LD831	Noise & Vibration Works

To calculate T20, the weighted average of two averages was used for a total of 72 measurements. For each average 12 loudspeaker positions and 3 microphone positions were used, for a combination of 36 different source-receiver positions, similar set up for the clapper measurements, positions were always at d > 1 m from the source and randomized (the sub on the floor limited this on the indirect method test). The uncertainty was calculated as described in chapter 5: uncertainty grows below the Schroeder cut-off frequency as expected, this is evident in the Aurora set-up where the subwoofer was always on the floor: it is always well below 14%.
The SPL meter with the direct method result uncertainty is better (below 7%) than Aurora's with the indirect method: this is explained by the better randomness of the clapper positioning in the room and the directivity issues of the dodecahedron loudspeaker when measuring under a 3 m distance and with the sub always on the floor (this excites unevenly the room modes).

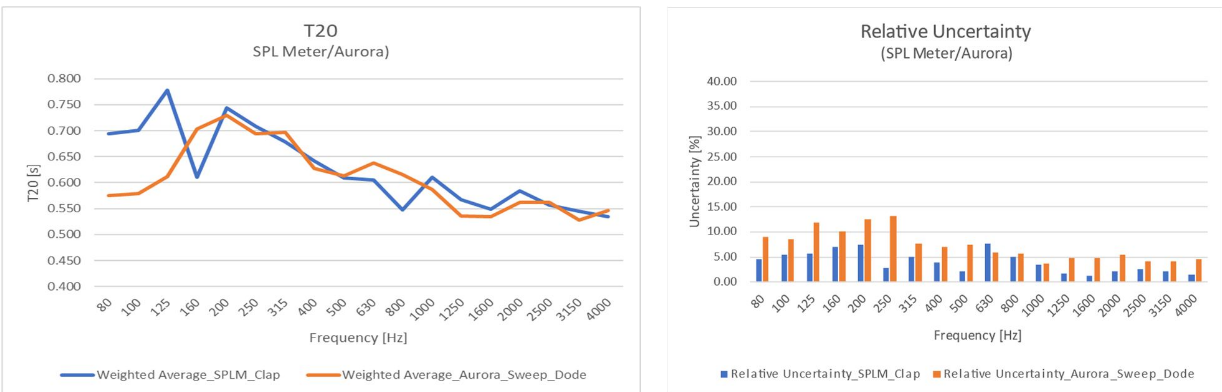

Figure 1: SPL meter and Aurora compare on T20 and uncertainty.

7. Field tests – comparing Android performance on the direct method

Field-tests were performed to verify the result quality with the direct method compared to the professional measurement setup with LD831 when using the impulse generation with a wooden clapper. The same 42 m^3 small room was used as above. Four different setups have been compared:

Table 2: Setups to direct method

Setup	Method	Source	Receiver	Software
Professional	Indirect	Dodecahedron Loud-speaker+sub	Measurement mic (Earthworks M30)	"Aurora" for Audacity [6]
Professional	Direct	Wooden clapper	Sound Level Meter LD831	Noise & Vibration Works
APM Sweep [Samsung]	Indirect	Wooden clapper	Samsung Galaxy s8	Android 8 – APM Sweep
APM Sweep [Xiaomi]	Indirect	Wooden clapper	Xiaomi M1 A2 Lite	Android 8 – APM Sweep

To calculate T20, the weighted average of 2 averages was used for a total of 72 measurements. For each average 12 loudspeaker positions and 3 microphone positions have been used, for a combination of 36 different source-receiver positions, similar set up for the clapper measurements, positions were always randomized. The uncertainty was calculated as described in chapter 5.
For Xiaomi M1 A2 Lite, T20 was calculated with only one average, for an overall 36 different source/receiver positions and so was not possible calculated the uncertainty like others device.

While the uncertainty result is very similar (always below 12%), it is clear the application RT result has a shift in all frequencies: a 20% error on Xiaomi and a 30% error on Samsung.
This can be related to the AGC effect on the clapper impulses that were quite too powerful and too close to the smartphone in such a small room, better results were observed with different phones and more control on the impulse energy in a previous study [3] (i.e. using balloon pops in larger rooms or less powerful impulses, iOS phones excel in this method [3]).

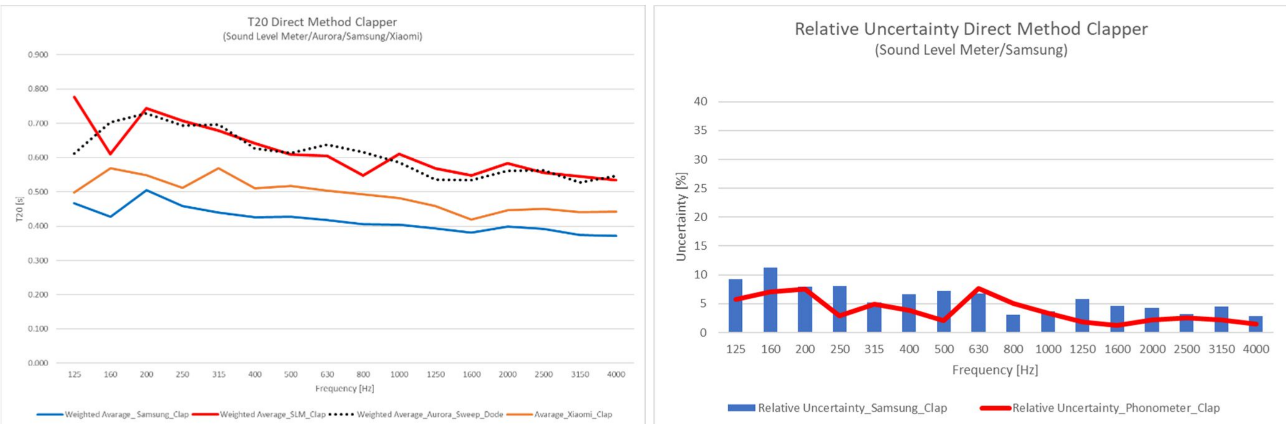

Figure 2: Xiaomi, Samsung, SPL meter, Aurora compared on T20 - Samsung, SPL meter compared on uncertainty – all with clapper/direct method.

8. Field tests – comparing Android performance on the sine-sweep method

Field-tests have been performed to verify the results' quality given by the app with the indirect method compared to a professional measurement setup with Aurora.
As an example, the case study of the same 42 m^3 volume ordinary room is proposed here. Four different setups have been compared in third octave bands:

Table 3: Setups to indirect method

Setup	Method	Source	Receiver	Software
Professional	Indirect	Dodecahedron Loud-speaker+sub	Measurement mic (Earthworks M30)	"Aurora" for Audacity [6]
APM Sweep [Xiaomi]	Indirect	Bluetooth JBL Charge 3	Xiaomi M1 A2 Lite	Android 9 – APM Sweep
APM Sweep [Samsung]	Indirect	Dodec+ sub AND Blue-tooth JBL Charge 3	Samsung Galaxy s8	Android 8 – APM Sweep
APM Sweep [Brondi]	Indirect	Bluetooth JBL Charge 3	Brondi 730-4G-HD	Android 7 – APM Sweep

For each setup 24 loudspeaker positions and 3 microphone positions were used, for an overall combination of 72 different source-receiver positions. The uncertainty was calculated as described in chapter 5.
The RT and uncertainty results using the Bluetooth source (figure 3) are good form 200 Hz up to 1250 Hz there is still a differentiation depending on the smartphone. It is clear some phones do not receive well below 200 Hz. The relative error to the reference system in % is plotted with the bars and remains below 15% on all tested smartphones from 200 to 1250 Hz, in these bands they are comparable.

Then "APM Sweep" on Samsung Galaxy S8 has been compared (figure 4) also using both a single commercial Bluetooth loudspeaker (JBL Charge 3) and dodecahedron loudspeaker.
As seen with a smaller BT source in [4] in such a small room a single sound source gives a better overall omnidirectionality than a loudspeaker (the error is below 10% from 160 Hz up to 1 KHz): the directive MEMS microphone suffers when using the dodecahedron at a close range.

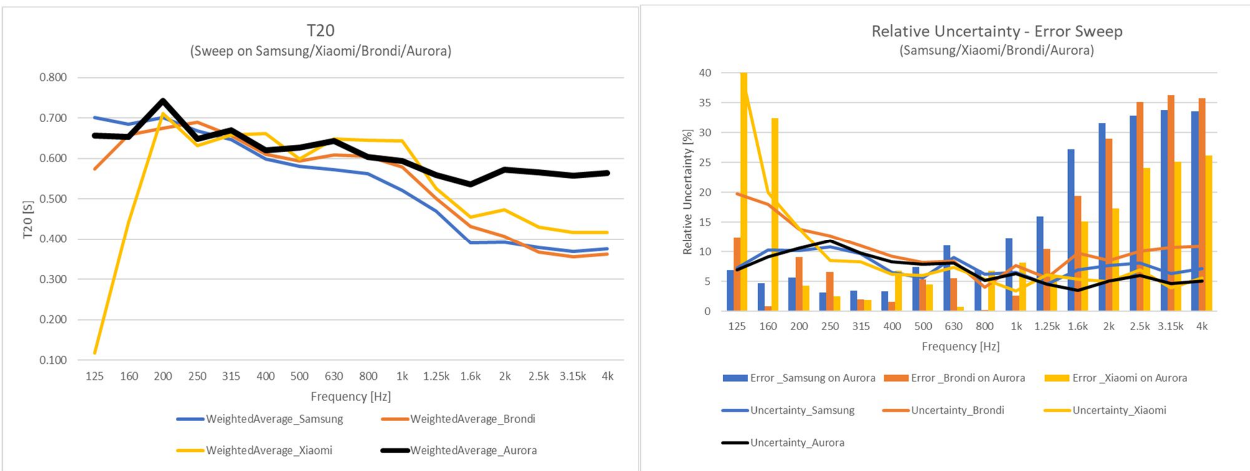

Figure 3: Xiaomi, Brondi, Samsung, Aurora with Bluetooth compared on T20 and uncertainty an error – all with ESS method

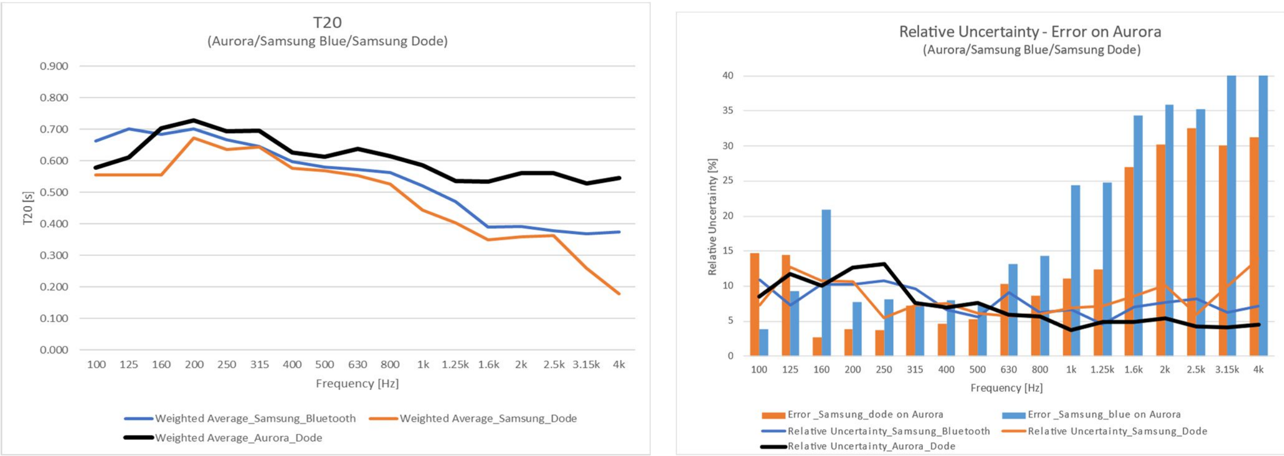

Figure 4: Aurora, Samsung compared on T20 and uncertainty with Bluetooth vs dodecahedron+sub - ESS

9. Field tests – comparing Android performance on the sine-sweep method in a Large room

As an example, the case study of a 3470 m^3 volume large room (496 m^2 floor surface) is proposed here. Two different measurement setups have been compared in octave bands:

Table 4: Setups to large room

Setup	Method	Source	Receiver	Software
Professional	Indirect	Dodecahedron Loud-speaker+sub	Measurement mic (Earthworks M30)	"Aurora" for Audacity [6]
APM tool [Brondi]	Indirect	Dodecahedron Loud-speaker+sub	Bronti 730-4G-HD	Android 7 – APM Sweep

For APM Sweep setup 12 loudspeaker positions and 3 microphone position have been used, for an overall combination of 36 different source-receiver positions.
The uncertainty was calculated as Relative Standard Deviation on 20 samples for Aurora, on 12 samples for APM Sweep. This because APM return average for each position. The results are that uncertainty is low and comparable, the smartphone's measurement error is still below 15% between 125Hz and 1KHz.

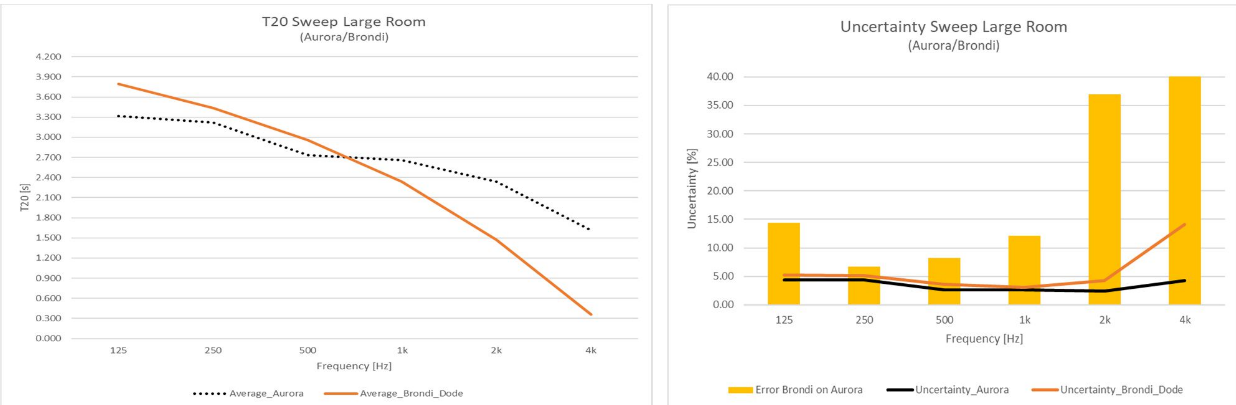

Figure 5: Brondi and Aurora compared on T20 and uncertainty in a large room – ESS method

10. Conclusions

The APM Sweep Android app RT measurement quality and uncertainty was tested in two rooms.

Measurement uncertainty were always comparable in the small room, in the large room only the higher frequencies suffered the devices directivity.

It is clear the direct method data quality on Android smartphones suffers from high level impulses, previous research demonstrated an improvement when the impulse energy is kept under control relative to distance.

The indirect method with the sine-sweep (ESS) gives better results because it works on small SNR.

Smartphone models differ in their response below 200 Hz and above 1 KHz, this is due to the audio software that differs and to the device age.

In most cases the Android system's relative error to the professional system is limited to below 15% between 200 Hz and 1250 Hz, in this region the relative error compared to the professional system measure is comparable to the measurement uncertainty.

APM Sweep with the ESS method can be used by professionals as a valuable on-field instrument in the 250 Hz, 500 Hz and 1 KHz octave bands.

REFERENCES

1 ISO 3382-2, *Acoustics – Measurement of room acoustics parameters – Part 2: Reverberation time in ordinary rooms,* 1 edition (2008)

2 Redaelli S., *Acoustical parameter measurement tool for Android: development implementation and on-field validation*. Master Thesis, Politecnico di Milano, (2013)

3 Rizzi, L., Ghelfi G., Campanini, S, Rosati A., Rapid room acoustics parameters measurements with smartphones, *Proceedings of the 22nd International Congress on Sound and Vibration*, Florence, Italy, 12–16 July, (2015).

4 Rizzi, L., Scotti, G., and Ghelfi, G., Room Acoustic measurements with logarithmic sine sweeps on Android phones, *Presented at the 144th Convention of Audio Engineering Society,* Milan, Italy, 23–26 May, (2018)

5 Djurek, I., Grubeša, T., Orlić, N., *Measurements of analog MEMS microphones*, University of Zagreb, Faculty of EE and Computing, Unska 3 , Zagreb, Croatia (2019)

6 Farina A., Simultaneous measurement of impulse response and distortion with a swept-sine technique. *Presented at the 108th Convention of Audio Engineering Society*, Paris, France 18-22 February (2000). [Online.] available : http://www.angelofarina.it/Public/Aurora-for-Audacity/

7 Svelto C., *Incertezza di misura*. [Online] available : http://home.deib.polimi.it/svelto/didattica/materiale_didattico.html

8 Rizzi L., D'Orazio D., De Cesaris S., Ascari F., Ghelfi G., Psychoacoustic perception of transient effects of resonance modes at low frequencies in a listening environment*, Presented at 45th International Congress and Exposition on Noise Control Engineering*, Hamburg, Germany, August 21-24, (2016)

9 Rizzi L., Bertolasi N., Ghelfi G., Analisi del rumore ambientale e gestione del mascheramento su strumenti iOS, *Presented at the 44th convention of Italian Association of Acoustic*, Pavia, Italy 7-9 June (2017)

10 Rizzi L., Ghelfi G., Measurement of reverberation times against modal decay times in an empty bedroom, *presented at 8th International Symposium on Temporal Design,* Bologna, Italy, 14-15 September (2017)

11 Dragana Sumarac-Pavlovic, Miomir Mijic, Husnija Kurtovic A simple impulse sound source for measurements in room acoustics, *Applied Acoustic 69 (2008), 378-383*