
# RAPID ROOM ACOUSTICS PARAMETERS MEASUREMENTS WITH SMARTPHONES

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An application for rapid, direct estimation of acoustical parameters was developed for Android and iOs smartphones and it was tested on the field with iphone devices in two mid-large rooms. The paper compares clarity and reverberation time measurements to professional instrumentation results complying with ISO 3382 requirements. The paper highlights the utility and limitations of this rapid tool looking into the nature of simply generated impulses and the changes due to the use of external microphones.

## 1. Introduction

The APM Tool application for rapid estimation of acoustical parameters ($T_{20}$, $T_{30}$, *EDT*, $C_{50}$, $D_{50}$) was developed for Android and iOs smartphones, it uses simple impulsive sources like balloon burst, hand claps or wooden claps. Its primary objective is to provide the user with a fast, simple and intuitive tool allowing a first survey of any room's acoustic properties. The app does not aim to replace professional measurement instruments, but it will help spreading an acoustic conscience in the architecture and building business.

Despite the explicit intent to maintain the data acquisition process as simple as possible, the formal correctness of the data elaboration was maintained: acoustic parameters evaluation follows the indications of ISO 3382 "Measurement of the acoustic parameters of the environment" [1] parts 1 and 2.

On field tests were performed during all the stages of application lifecycle. A set of tests in mid-small rooms is described in [2] showing good results for reverberation time above 250 Hz compared to professional measurement instruments. In 2015 the app was tested with i-phone devices in two mid-large rooms: the "Casa della Musica" auditorium and the San Giovanni Evangelista church, both in Parma (Italy).

## 2. Audio Hardware on mobile devices

Nowadays the most popular operating system on mobile devices are Android by Google Inc. and iOS by Apple.  Android is (partially) open and it can be modified by hardware producers: it is installed on thousands of different devices in every price range. On the other hand, iOS is installed on a very limited number of models, completely controlled by Apple itself.

It is not realistic to develop an audio-optimized Android application, because it will be installed on devices with huge differences in the audio segment, whose hardware features are jealously preserved by manufacturers. Apple instead provides a limited set of devices with audio features addressed to high-end audio even if it should be stressed that no smartphone can be compared to a professional Class-A measurement system (starting from a not omni-directional measurement microphone).

Describing the main characteristics and limitations of a mobile device it is useful to analyze the block diagram of the typical audio acquisition chain  ("Fig. 1").

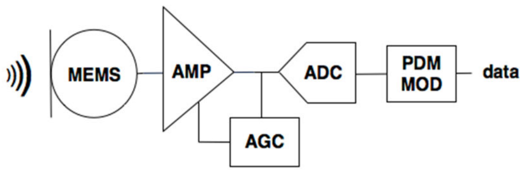



**Figure 1 –** Mobile devices audio acquisition chain

The MEMS (Micro Electro-Mechanical Systems) microphones integrate in the same chip, transducer sensor and its dedicated electronics, reducing size and power consumption. These microphones cannot provide the same performance in terms of extension of the frequency response, linearity and directionality usually guaranteed by professional mics used in the acoustic field.

The signal received by the MEMS is sent to the amplifier section. The amplifier lowers the output impedance in order to provide usable signals to the remaining audio chain. The behaviour of the section is controlled by the Automatic Gain Control (AGC) whose function is to define the right amplifier gain to avoid clipping and unwanted signal distortion.

AGC management has been a crucial part of the application development. An initial transient pulse with high sound pressure level (i.e. the impulse generated by a bursting balloon) can lead to AGC activation, radically changing the waveform profile of the recorded impulse. Figure 2 shows an impulse response in which the intervention of the AGC is particularly evident.

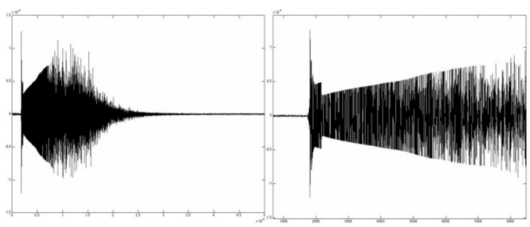


**Figure 2 –** Automatic Gain Control modification on room impulse response profile

The remaining part of the hardware audio chain is represented by an analog to digital converter (ADC) stage followed by a PDM (Pulse Density Modulation) that allows avoiding electromagnetic fields interferences. The signal recorded by the device has a good audio quality: mono, 44100 Hz sampling frequency and 16 bit quantization.

### 2.1 Android

In Android operated devices, the AGC behaviour changes significantly depending on the manufacturer, hence a simple recognition system of AGC intervention was developed. If the app detects a recorded waveform different from expected, it discards the measure, asking the user to rerun the impulse. Under certain conditions, it is likely that the AGC control forces the user to repeat numerous attempts in order to record a compliant impulse: an option flag has been added to activate or not the AGC control system but a dedicated alert warns the user about possible risks.

If the AGC control is disabled, the app accepts any measurement, but the starting point of the decay curve is moved to the instant when the AGC stops its influence on room impulse response profile. On-field tests showed how the delay of decay curve creation does not influence reverberation time measurement (compared with one obtained by professional measurement systems), when the SNR in the room is good. The APM Tool app is able to handle high pressure levels, as the ones generated by bursting balloons or wooden clappers.

### 2.2 iOS

Thanks to the manufacturer's control on the hardware part, the app development for iOS devices allows the adoption of more sophisticated algorithms. Unlike Android, AGC is a property of just a few sessions of CoreAudio framework. For example, in "Measurement" session, AGC is disabled while in "Voice Chat" session it is activated: the first one has been chosen and the AGC problem has been completely solved.

The Apple Software Development Kit (SDK) provides a library of functions – called vDSP – addressed to digital signal processing, through which it is possible to make the calculation process strictly standard-compliant, without heavy loading to the processor.

The main limitations are related to microphone part, which was certainly not designed for performing acoustic measurements. The tested microphones are characterized by reduced sensitivity with the purpose of rejecting background noise during conversations: during measurement phase, this fact leads easily to clipping.

## 3. Measurement methodology

Before starting the new set of on-field test sessions, the most common impulsive sources were investigated. Four different impulsive sources were studied: hand claps, wooden clapper, bursting balloons with 20 cm diameter, bursting balloons with 40 cm diameter.

An experimental measurement session in an open-air free field approximation was carried out. Impulsive sources and receiver (LD 831 sound level meter measurement microphone) was placed 6 m apart on a mountain meadow near Lecco (Italy) with few reflectors (120 ms of anechoic window) and low background noise ($L_{Aeq}$ = 30 dBA). There were two operators: one near the microphone and one near the sources (in order to generate them) as occurs during typical use.

It must be stressed that the APM Tool app has the objective to be an instrument for survey analysis of acoustical parameters: the app does not aim to replace professional measurement systems.

### 3.1 Recorded impulses waveform analysis

Observing the waveforms of recorded impulses it can be noticed that the N-Wave type pressure waveform [3] is generated, as known [4], by the bursting balloons but also by the wooden clapper. The N-Wave is less evident for 40 cm diameter balloon pop.

It is known that the N-Wave waveform [5] creates problems in the estimation of acoustical parameters which need precision in the first milliseconds (as in the case of $C_{50}$). There are no problems instead in the estimation of reverberation time thanks to the implemented Schroeder backward integration method.

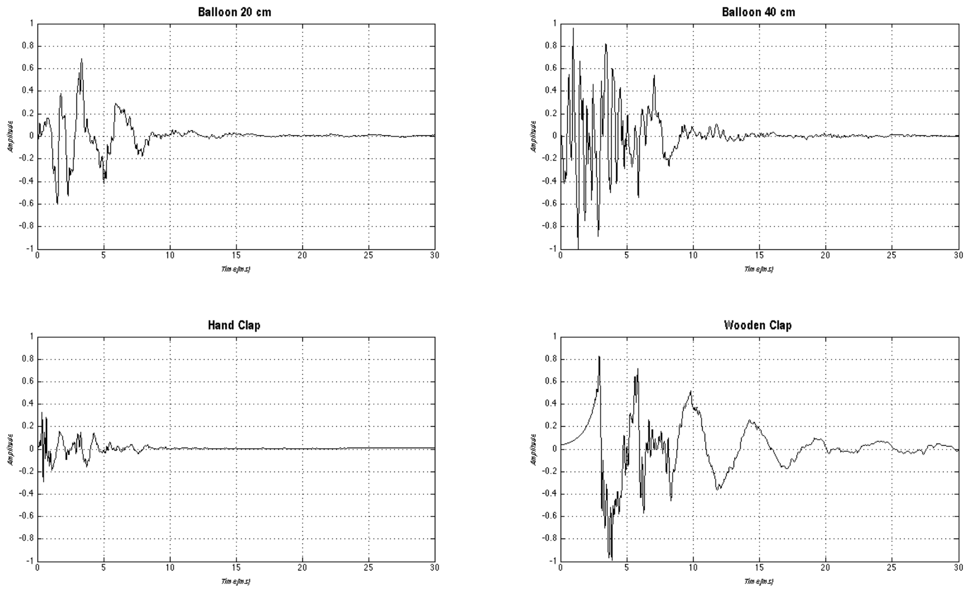



**Figure 3 –** Recorded impulses waveforms

A study of the energy time-decay of the 4 impulses has been carried out, enlightening the following aspects:

- Balloon pops (both 40 cm and 20 cm) concentrate their energy in the first 10 ms. After this interval the energy produced by the impulse is -20 dB respect to direct sound.
- Wooden clap maintains their energy for a longer time interval: the -20 dB decay arrives after 20 ms.

## 3.2 Recorded impulses spectra analysis

Figure 4 shows the average spectra on 3 recorded impulses generated by each source: hand claps, bursting balloons (20 cm and 40 cm diameter) and wooden clapper (recorded both in front of the operator that above is head).

The following aspects are noteworthy:

- Hand claps have the least amount of energy among the considered sources and have no energy at all in the low frequencies section. If they are used with the app, the obtained results can be considered reliable only above 500 Hz and in small, quiet rooms.
- Balloon pops with 40 cm diameter present well-energized spectra from 250 Hz. Their performances are higher in level than the 20 cm balloon pops’ but below 250 Hz they both are not totally reliable.
- Wooden clap presents significant energy also in the low end. It has to be noticed that the wooden clap used in this experimental session has resonance chambers created in order to improve low frequencies response.

Table 1 reports the average of sound pressure level peaks related to the considered sources. It is interesting that the 40 cm diameter balloon presents the highest sound pressure level peak while the hand clap, as expected, has the lowest.

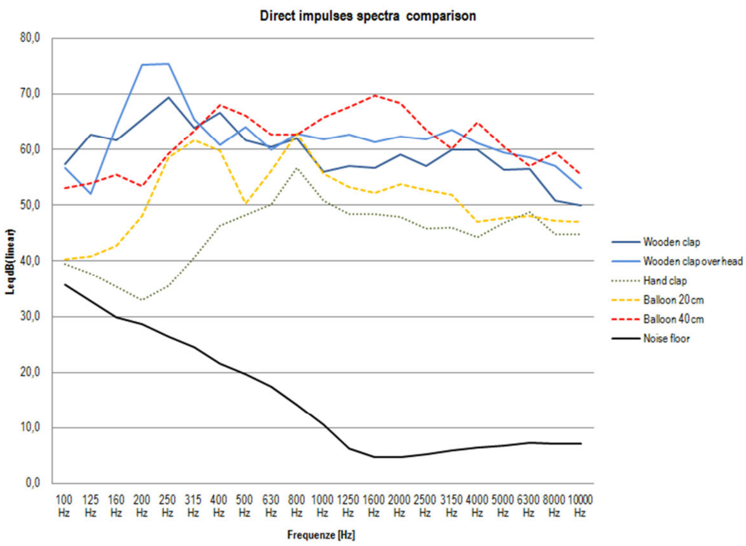



**Figure 4 –** Recorded impulses spectra

**Table 1.** Sound pressure level peaks.

| Source | Peak dB(A) - average |
|---|---|
| Wooden Clap | 87.3 |
| Hand Clap | 75.8 |
| Balloon 20 cm | 79.8 |
| Balloon 40 cm | 92.3 |

### 3.3 Measurement process

ISO 3382 specifies that, in order to obtain a reliable measurement of acoustical parameters, it is necessary to average the results obtained on different measuring points. The APM Tool app integrates this principle, prompting the user to make different measures in different positions within the room.

Once an appropriate number of impulses have been recorded, it is possible to display the results (available in one third-octave band in "APM Tool full" and in octave band in "APM Tool lite") as shown in "Fig. 5".

## 4. Room acoustic correction wizard

The full version of the application (APM Tool Full) provides the user with an automated wizard to estimate a room acoustic correction according to the room's intended use. This is useful for quick decisions in environments where cost saving is primary compared to the quality ensured by a real acoustic project.

The first request of the wizard is to set the intended use of the room among a list of available options (recording studio, broadcast studio, classroom, conference room, small auditorium...). Reverberation time target are taken from norms (UNI 11367, UNI 11532) and from scientific bibliography.

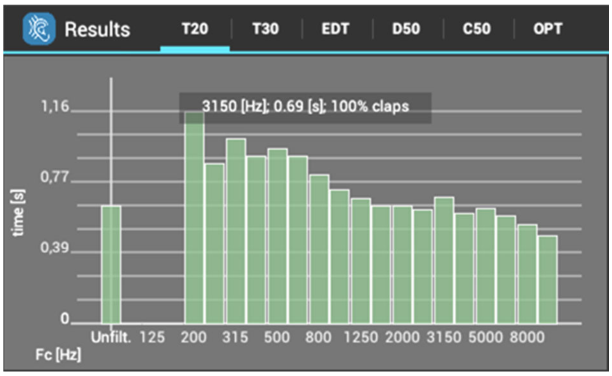



**Figure 5 –** APM Tool Full results display

The user is prompted to enter the room's basic geometric information. If the room volume is less than 300 $m^3$, an alert informs that the environment is non Sabinian at lf. The user enters the existent ceiling and floor material. The last step is the choice of material to be used on the ceiling. This can be chosen within a list of materials: at this stage, the new reverberation time is calculated between 250 and 4000 Hz after the laying of the new ceiling comparing it to the measured values.

The reverberation time variation is performed calculating the change of the average absorption coefficient, using two well-known formulas for predicting $T_{60}$ in environments with not uniform acoustic treatment: Norris-Eyring formula and the one of Arau [6]. Results are reported at 500 Hz.

## 5. Case studies: i-phone use in mid-sized and large rooms

Two mid-large environments were selected: an auditorium and a church. As impulsive source 30 cm diameter balloon pops were preferred because they are more practical for larger rooms and slightly noisy environments. Specific experimental measurement sessions (paragraph 3) shew how the balloon pops have the shortest decay and that reliable results can be expected above 250 Hz.

In this test session two Apple iPhone (model 4s and 5s) were used: in a previous set of tests iPhone shew better behavior for what concern AGC aspects. The two iPhone have been tested using both internal microphone and a commercial external microphone.

As reference measurement system a Larson Davis 2541 measurement microphone connected to a Larson Davis 824 Sound Level Meter with Aurora elaboration was used.

### 5.1 Auditorium "Casa della musica"

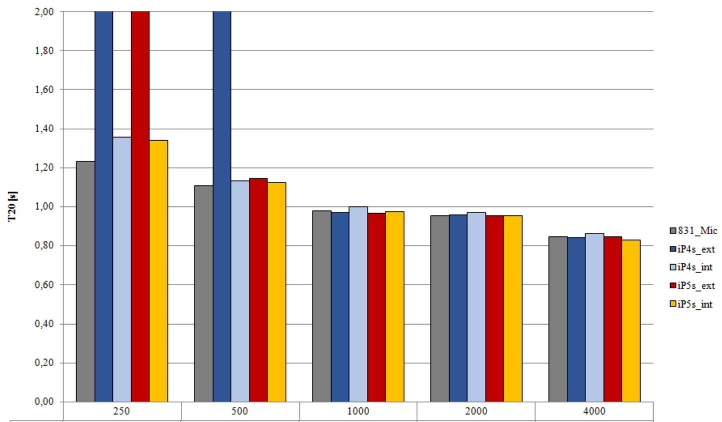
The auditorium "Casa della musica" is located inside Palazzo Cusani in Parma. Palazzo Cusani is an historical palace built in 1400. The auditorium has 177 seats, a floor surface of 200 $m^2$ and an overall volume of 2000 $m^3$.

Using the commercial external microphone 5 different measurement points were investigated; using the internal microphone, three different measurement points.

#### *5.1.1 Reverberation time $T_{20}$*

Figure 6 reports the reverberation time results for the Auditorium "Casa della Musica": reference microphone reports a $T_{20}$ = 1.11 s at 500 Hz.

The internal microphone for both iPhone models (4s and 5s) gives similar results to the reference system for all the considered octave bands. The measurement uncertainty, calculated according Annex A of ISO 3382, shown by the internal microphone is comparable to the reference microphone's and it is aligned to the desired survey quality. The commercial external microphone attached to the two iPhone models has good results from 500 Hz in the case of iPhone 5s and from 1000 Hz in the case of iPhone 4s.




| | 250 | 500 | 1000 | 2000 | 4000 |
|---|---|---|---|---|---|
| 831_Mic | 1,23 | 1,11 | 0,98 | 0,95 | 0,84 |
| iP4s_ext | 7,40 | 3,89 | 0,97 | 0,96 | 0,84 |
| iP4s_int | 1,35 | 1,13 | 1,00 | 0,97 | 0,86 |
| iP5s_ext | 6,20 | 1,14 | 0,96 | 0,95 | 0,85 |
| iP5s_int | 1,34 | 1,12 | 0,97 | 0,95 | 0,83 |

Frequencies [Hz]

**Figure 6 –** Auditorium "Casa della Musica" T20

### 5.1.2 Clarity index $C_{50}$

Due to N-wave problems related to the impulsive source itself, the reliability of the clarity index $C_{50}$ measurement is poor even for the reference microphone system. This kind of measurement should be performed using indirect methods for impulse responses such as exponential sine sweep.

Since the purpose of the APM Tool application is to provide a first, rapid survey of acoustical characteristic of a room, it is interesting to note the $C_{50}$ sign: the simple fact of knowing if the parameter is positive of negative, gives a very useful information to the user. For rooms dedicated to speech, the UNI 11367 norm [7] recommends $C_{50} \geq 0$ as a reference of quality.

Observing the sign trend of results given by the application in all the considered setups in each position (iPhone 4s and 5s with and without external microphone) we calculated that the sign given by the app is the same of the one given by the reference system in 88% of cases.

## 5.2 St. John the Evangelist Church

The church of St. John the Evangelist in Parma was built between 1490 and 1519. The church has an overall length of 67 m and a width of 20 m. The height of the nave is 19 m and the aisles are 10 m height, for an estimate volume of 19.000 m$^3$.

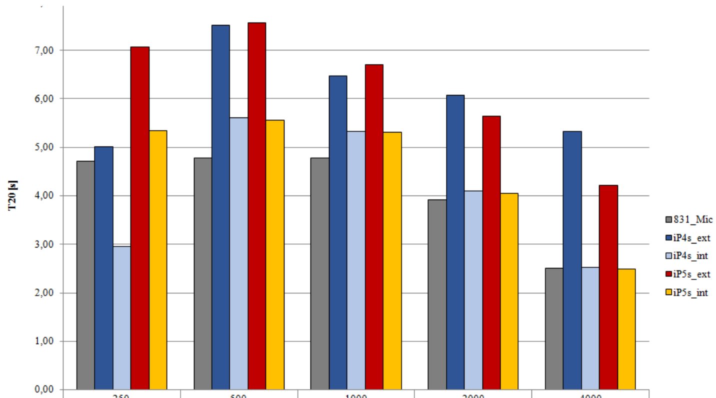
The commercial external microphone was used in 5 different measurement points; the internal microphone in three different measurement points.

### 5.2.1 Reverberation time $T_{20}$

Figure 7 reports the reverberation time results for St. John the Evangelist Church: reference microphone reports a $T_{20}$ = 4.79 s at 500 Hz. Also in this case the iPhone 4s and iPhone 5s internal microphone shows closer results to those of reference microphone, while external microphone results are longer in all the considered octave bands.

### 5.2.2 Clarity index $C_{50}$

For the clarity index, considerations similar to those of the previous case can be made. For the intended survey purpose of the application it is useful to analyze the sign trend of clarity index rather than the single numerical values. For St. John the Evangelist church case, the sign given by the app is the same of the one given by the reference system in 80% of cases.




| | 250 | 500 | 1000 | 2000 | 4000 |
|---|---|---|---|---|---|
| 831_Mic | 4,71 | 4,79 | 4,78 | 3,92 | 2,50 |
| iP4s_ext | 5,02 | 7,52 | 6,47 | 6,07 | 5,32 |
| iP4s_int | 2,96 | 5,61 | 5,33 | 4,10 | 2,52 |
| iP5s_ext | 7,07 | 7,57 | 6,71 | 5,64 | 4,22 |
| iP5s_int | 5,34 | 5,55 | 5,32 | 4,05 | 2,50 |

Frequencies [Hz]

**Figure 7 –** St. John the Evangelist Church T20

## 6. Conclusions and future works

After an experimental analysis of different common impulsive source, the performances of the APM Tool application for rapid acoustical parameters estimation was tested in mid-sized and large environments on i-phones. Using 30 cm balloon pops good survey quality results were obtained above 250 Hz for reverberation time measurements compared to reference system. Clarity index estimation suffers from problems that are intrinsic into the selected impulsive sources: useful information can be extracted observing the parameter sign trend which was found to be reliable. Future work will integrate indirect methods, obtaining better impulses and more precision.

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