BIPM Capacity Building & Knowledge Transfer Programme

2023 BIPM - TÜBİTAK UME Project Placement

REPORT

Project Name	Sound Scattering Coefficient Measurement in Reverberation Room
Description	The aim of this project is to establish a measurement system for measuring the random incidence sound scattering coefficients of surfaces in reverberation room according to ISO 17497-1:2004
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1. Motivation & Introduction

Sound scattering coefficient measurement plays a crucial role in determination of the acoustical quality of different acoustic environments such as (Conference rooms, Concert halls, Theatre rooms, Airport and etc.). It provides valuable insights into how sound waves interact with objects and surfaces in the environment, contributing to our understanding of sound propagation and the quality of acoustic spaces. The measurement of sound scattering coefficients provides quantitative information about the scattering properties of materials, surfaces, and objects. By accurately characterizing the scattering behavior, we can predict and control the acoustic performance of spaces and optimize designs for specific applications. For example, in architectural acoustics, understanding the scattering properties of room surfaces helps architects and engineers design concert halls, auditoriums, or recording studios with optimal sound diffusion and reverberation characteristics. By strategically placing scattering elements or designing diffusing surfaces, one can enhance sound quality, minimize echoes, and create an immersive auditory experience for listeners. Using surfaces of high or low sound scattering coefficients are depending on the purpose behind the construction of the room. For example, high sound scattering surfaces are beneficial in large concert halls, theaters or auditoriums because they help in redirect the sound in multiple directions and this can enhance the sound quality for audience. While, surfaces with low scattering coefficients are preferred in situations where the sound absorption or noise control is desired such as recording studios or offices, the low sound scattering surfaces combined with sound absorbing materials can reduce the sound reflections and control the reverberations. The aim of this project was to establish a measurement system for measuring the sound scattering coefficient in reverberation room according to ISO 17497-1. This will allow TÜBİTAK-UME Acoustic Laboratory to extend its measurement capabilities and provide me with a lot of experience to transfer the gained knowledge to establish such service in my laboratory in Egypt.

2. Research

2.1 Theoretical Aspects

This part of ISO 17497 specifies a method of measuring the random-incidence scattering coefficient of surfaces as caused by surface roughness. The measurements are made in a full-scale reverberation room. The measurement results can be used to describe how much the sound reflection from a surface deviates from a specular reflection Figure (1). The principle of the measurement method is to extract the specular energy from the reflected pulses. This is done by synchronized (phase-locked) averaging of the impulse responses obtained for different sample orientations Figures (2 & 3). It is shown from Figure 2 that the initial part of the reflections is highly correlated which represents the specular reflections. While the late part which represents the scattered sound is not in phase and this makes the scattered sound energy interfere destructively after the averaging, consequently it cancels each other.

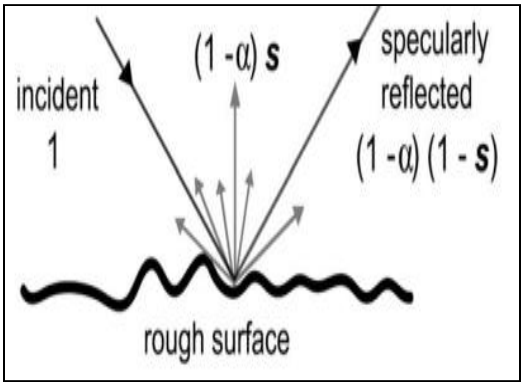

Fig.1 Scattering from rough surface

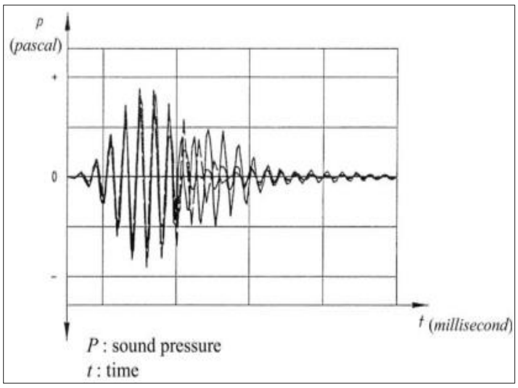

Fig.2 Reflected pulses obtained for three different sample orientations

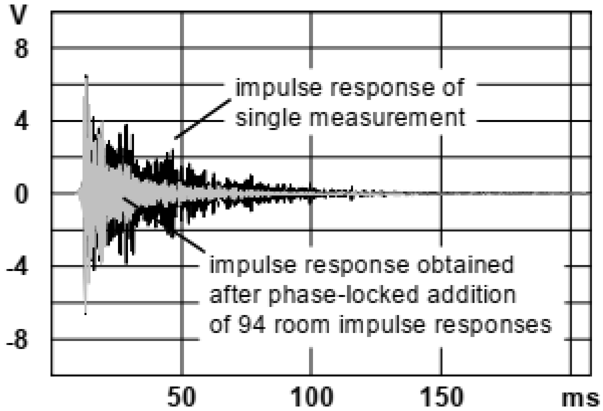

Fig.3 Impulse responses measured in a reverberation room

The random-incident scattering coefficient is defined as the ratio of non - specular reflected sound energy to the total sound energy reflected from a surface in a diffuse sound field which is calculated using the following equations:

$$S = \frac{\alpha_{spec} - \alpha_s}{1 - \alpha_s} \tag{1}$$

$$\alpha_s = 55.3\,\frac{V}{S}\left(\frac{1}{C_2 T_2} - \frac{1}{C_1 T_1}\right) - \frac{4V}{S}\,(m_2 - m_1) \tag{2}$$

$$\alpha_{spec} = 55.3\,\frac{V}{S}\left(\frac{1}{C_4 T_4} - \frac{1}{C_3 T_3}\right) - \frac{4V}{S}\,(m_4 - m_3) \tag{3}$$

Where, α_s and α_{spec} are the absorption coefficient and the specular absorption coefficient respectively. V is the volume of the reverberation room, S is the area of the sample, T_1 to T_4 are the reverberation times as shown in table 1. C_1 to C_4 are the sound velocities in air, and m_1 to m_4 are the energy attenuation coefficients of air during the measurements of T_1 to T_4.

Table 1. Measurement conditions for the four different reverberation times.

Reverberation time	Sample	Turntable
T_1	Not present	Not rotating
T_2	Present	Not rotating
T_3	Not present	Rotating
T_4	Present	Rotating

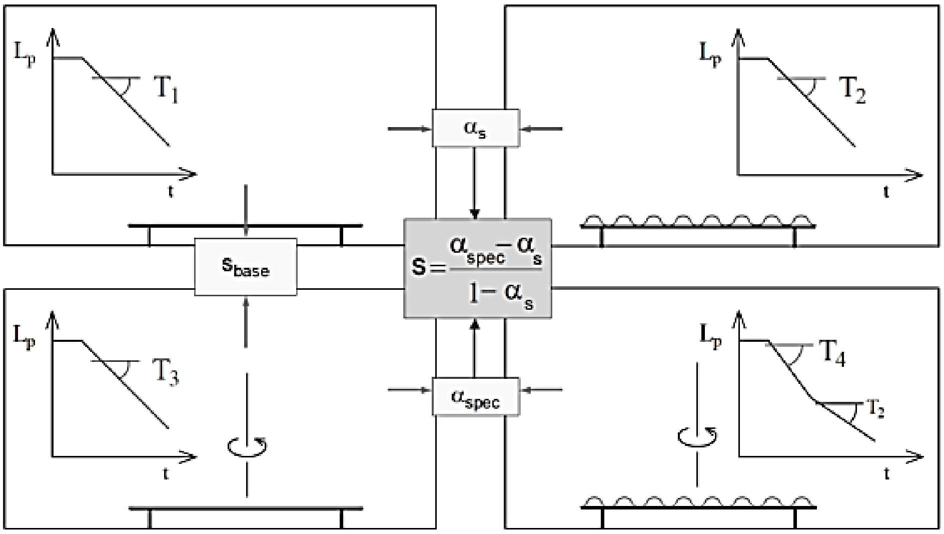

Fig.4 Reverberation time: T_1 and T_3 without sample (fixed and rotating turntable)
T_2 and T_4 with sample (fixed and rotating turntable)

the key parameter that used to calculate either the absorption coefficient or the scattering coefficient is the reverberation time. According to ISO 354 there are two techniques for measuring the reverberation time; the first is the interrupted noise or the decay curve; it is a direct recording of the sound pressure decay with time. And the second technique is the integrated impulse response that recommended by the standard is used to calculate the reverberation time from the linear fitting of the backward integration of the squared third octave filtered impulse response. The impulse response represents the output of the system when an impulse signal is applied as an input as shown in Figure (5).

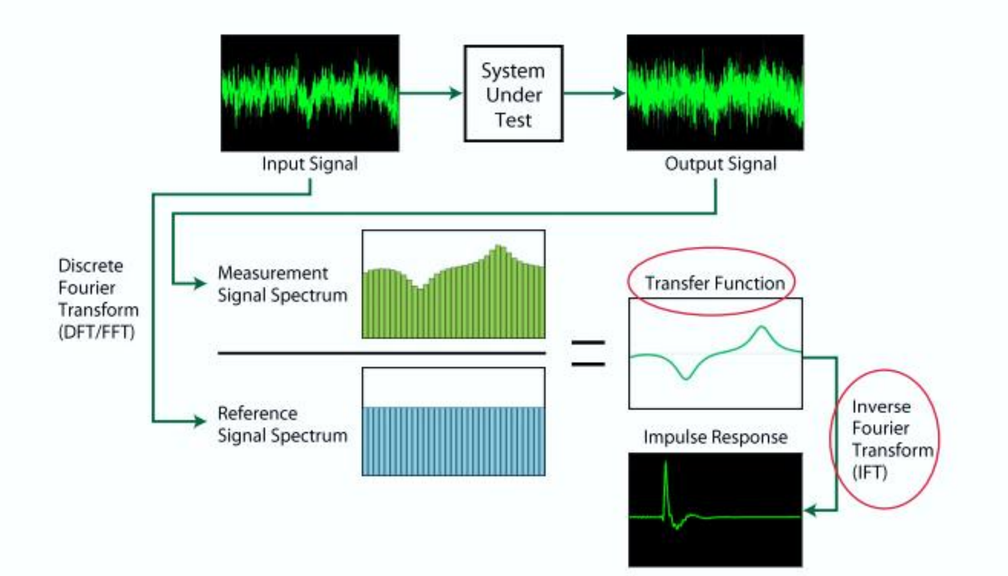

Fig.5 Block diagram of FFT transfer function IR measurement

2.2 Test Arrangement

2.2.1 Reverberation Room

The measurements were performed in TÜBİTAK-UME Acoustic Laboratory a full-scale reverberation room of volume 263 m^3 and a total surface area of 262 m^2. It is constructed as a separate box resting on springs inside the main construction. The inner surfaces of the room are concrete painted with epoxy paint. Diffusers are suspended from the ceiling to provide the diffuse field. In order to adjust the reverberation time and equivalent absorption area of the room, sound absorber panels are mounted on the side walls as seen in Figure 6.

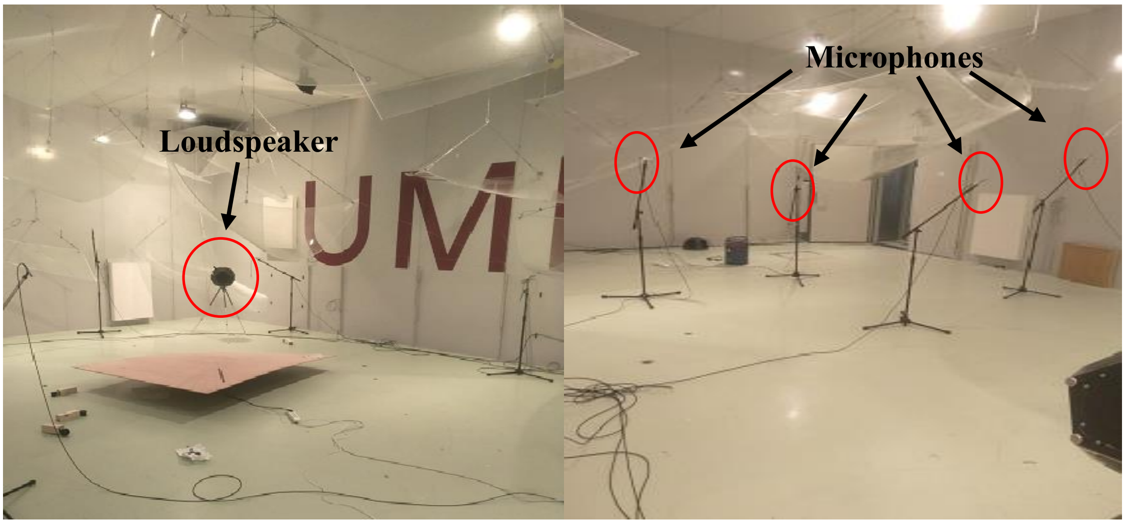

Fig.6 Reverberation Room in TÜBİTAK UME Acoustics Laboratory

2.2.2 Turntable and base plate

A turntable was required to rotate the sample in order to obtain measurements from multiple orientations for accurately assessing the scattering behavior of the samples. The turntable was provided with a rigid base plate in order to provide a stable and secure platform for mounting the samples and helps in isolating the sample from the external vibrations and provides a mechanical barrier between the sample and the turntable. Both the turntable and the base plate were prepared in UME mechanical workshop. The rotation of the turntable was controlled by a device outside the room through an electrical wire as shown in Figure 7.

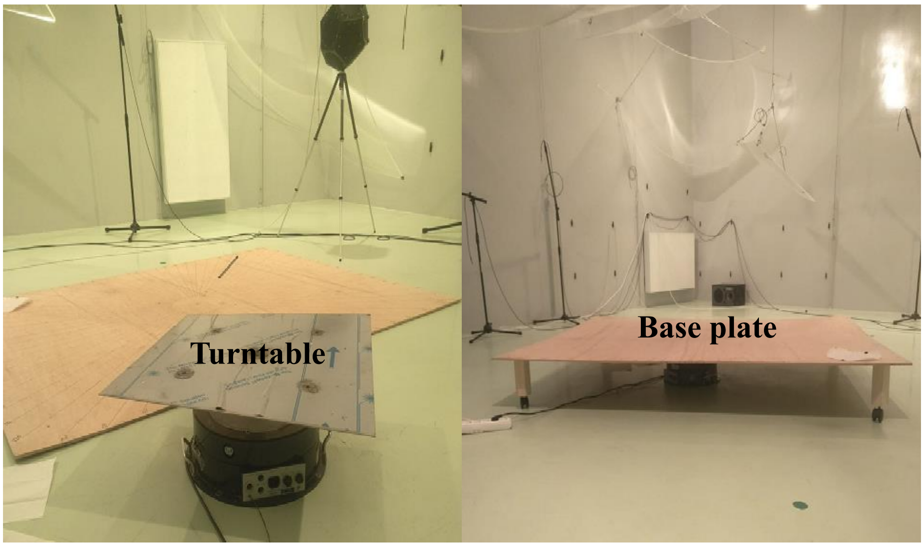

Fig.7 Turntable and baseplate

2.3 Measurement Method

During the measurements, a Pink MLS signal of total time length 43.7 seconds in the range from 100 Hz to 5000 Hz was used to measure the impulse response and the four reverberation (T_1, T_2, T_3 and T_4). This period length was choosing to be double of the reverberation time of the room in order to increase the signal to noise ration and consequently suppress the background noise. Dirac B&K 7841 software was used for generating and recording the signal. Two Omni-directional loudspeakers and one ½ inch microphones in three different positions were used. A scatter of dimensions 60 cm x 60 cm was used to measure the reverberation times T_2 and T_4. For each combination of source and microphone position, three of Pink MLS signals were radiated and averaged while the turntable was fixed and rotated. The temperature and relative humidity were checked throughout the entire measurement process.

Fig.8 Measurement chain: **left**: Control Room – **Middle**: Pulse analyzer & Power amplifier – **Right**: Turntable and base plate

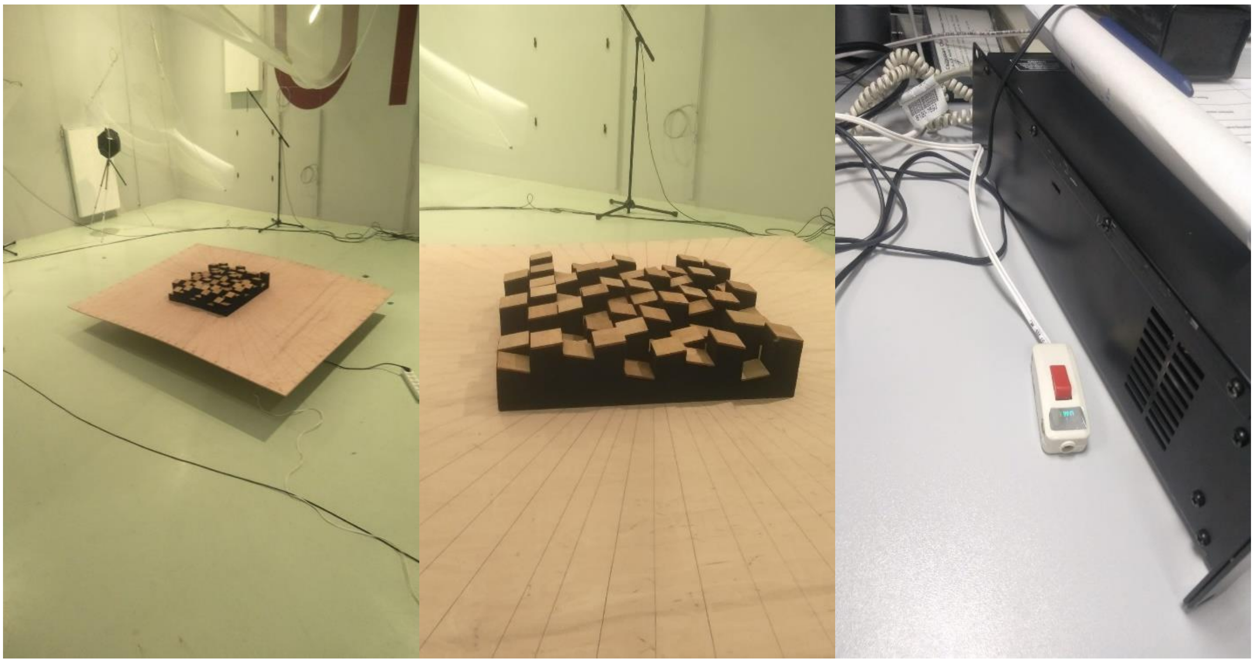

Fig.9 Scatter on the turntable and the control key for turning on & off the turntable

3. Working packages (WPs)

WP 1: When I arrived to TÜBİTAK-UME, I began with studying the standard and literatures used in these measurements. I assembled the measurement setup for scattering coefficient measurements in reverberation room, which involving the determination of source and microphone positions in reverberation room, preparing the turntable and the base plate in the mechanical workshop and fixing them on the floor of reverberation room, doing connections to power amplifiers and analyzer and creating the measurement project in the Pulse labshop software.

WP 2: I had a training about the measurement equipment and the measurement method from the academic advisor. I performed some initial measurements of the setup that built in WP 1. I carried out some time domain and frequency domain measurements to obtain the impulse response of the room in order to calculate the reverberation times. Because the Pulse labshop software did not measure directly either the reverberation time or the impulse response, Python and MATLAB programing codes were written in order to calculate the reverberation time from the impulse response after analyzing the time domain data taken from the measurement software.

WP 3: At the end of the three months duration, my advisor managed to get a license for Dirac B&K 7841 software that used for measuring the reverberation time and many of the room acoustic parameters and this software was used to measure the impulse response and the four reverberation times (T_1, T_2, T_3 and T_4).

4. Risk Management

4.1 Risk: Turn Table Control

- **Risk Management:**

In the measurement of scattering coefficients, the impulse responses shall be measured at different angles on the test sample, the test sample shall be turned at 5º angles. The difficulty of controlling the turntable will extend measurement time in overall. The rotation of the turntable was controlled by a device outside the room through an electric wire which was prepared in the electronic workshop. Another challenge regarding this issue is, to find a powerful motor in order to rotate the turntable with both the base plate and the samples effectively without occurring any sudden stops during measurements and also to be more silent in order not to affect the measurements accuracy of the sound scattering.

4.2 Risk: Data Analysis Using signal processing

- **Risk Management:**

Unfortunately, the measurement software did not measure the impulse response directly and a signal processing was needed to obtain the impulse response. Too much time has been spent for preparing Python and MATLAB programing codes in order to calculate the reverberation time from the impulse response after analyzing the time domain data taken from the measurement software.

4.3 Risk: the short duration time

- **Risk Management:**

Because establishing a new system for measuring the sound scattering properties requires more time, especially in national metrological institutes, because it needs more validation in order to ensure the accuracy of the measurements and to provide the service for customers in a satisfactory manner. So, I hope in the nearest future to be another chance to back again to UME in order to complete this valuable project.

5. Measurements the key parameter (Reverberation Time T_{20})

5.1 Judging the quality of the impulse response

When performing a series of measurements and to ensure about the quality of the impulse response, we looking at the tail of the signal that should be flat which means that there is no more noise in the signal as shown in Figures 10 and 11.

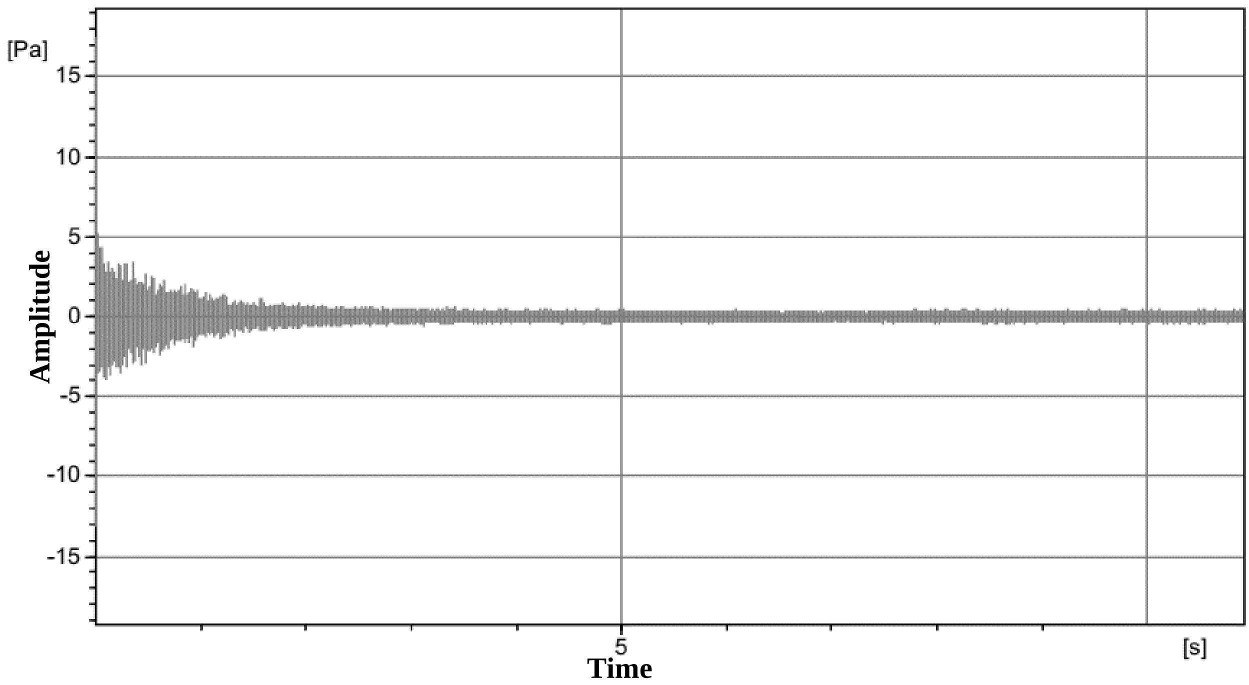

Fig.10 Impulse Response of MLS with period length 10.9 sec.

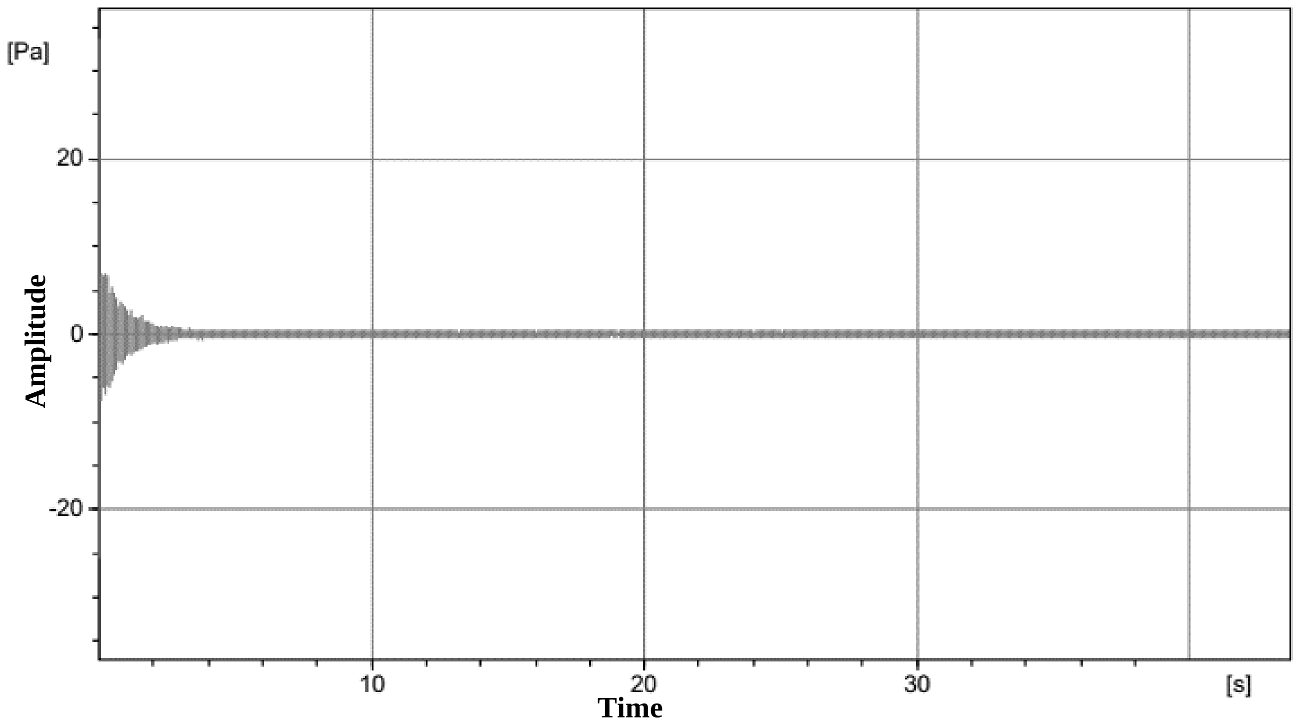

Fig.11 Impulse Response of MLS with period length 43.7 sec.

It is revealed from Figures 10 and 11 that, by increasing the excitation time of MLS from 10.9 s to 43.7 s, the impulse response signal became more flat without noise in the tail. Longer excitation times can be used to suppress the background noise where each doubling of the excitation time results in 3 dB reduction in the noise floor.

5.2 Changing the signal type

In the continuous rotation of the turntable, the standard specifies that, a multiple of a periodic pseudo random signal MLS should be used. In Figure (12), the reverberation time of three different kinds of signals (MLS, Pink MLS and exponential sweep) in empty reverberation room were compared to find the most adequate signal for these measurements.

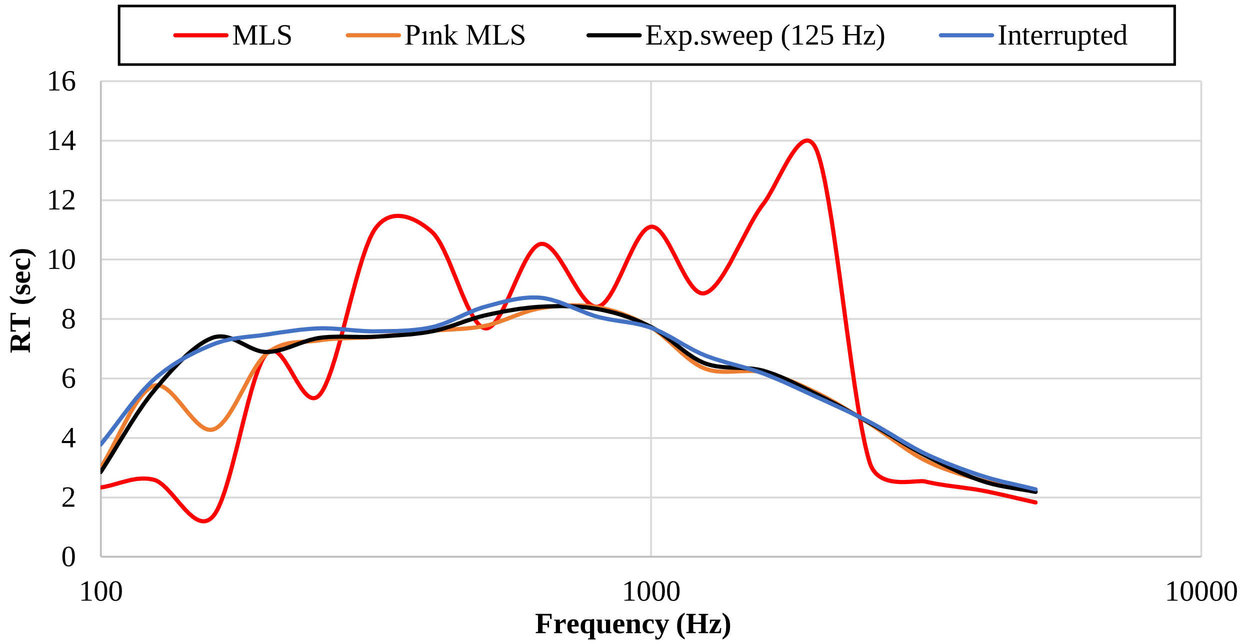

Fig.12 Comparing of RT of different signals with RT of interrupted noise in empty reverberation room

From figure 12, by comparing the reverberation time of the different signals with the reverberation time measured by the interrupted noise method, it was demonstrated that most adequate signals that coincide with the interrupted noise technique was the Pink MLS and the exponential sweep as they provided the best impulse to noise ratio compared to MLS signal.

5.3 Measuring the reverberation times (T_1, T_2, T_3 and T_4)

By using the Pink MLS signal the four reverberation times were measured, where T_1 and T_3 were without the sample in case of fixed and rotating turntable respectively and T_2 and T_4 were with the sample in case fixed and rotating turntable respectively as seen in Figure (13). The reverberation times T_{20} were measured from the linear regression within the range from -5 dB to -25 dB of the backward integration of the squared filtered impulse response. The continuous rotation approach of the turntable was used in these measurements.

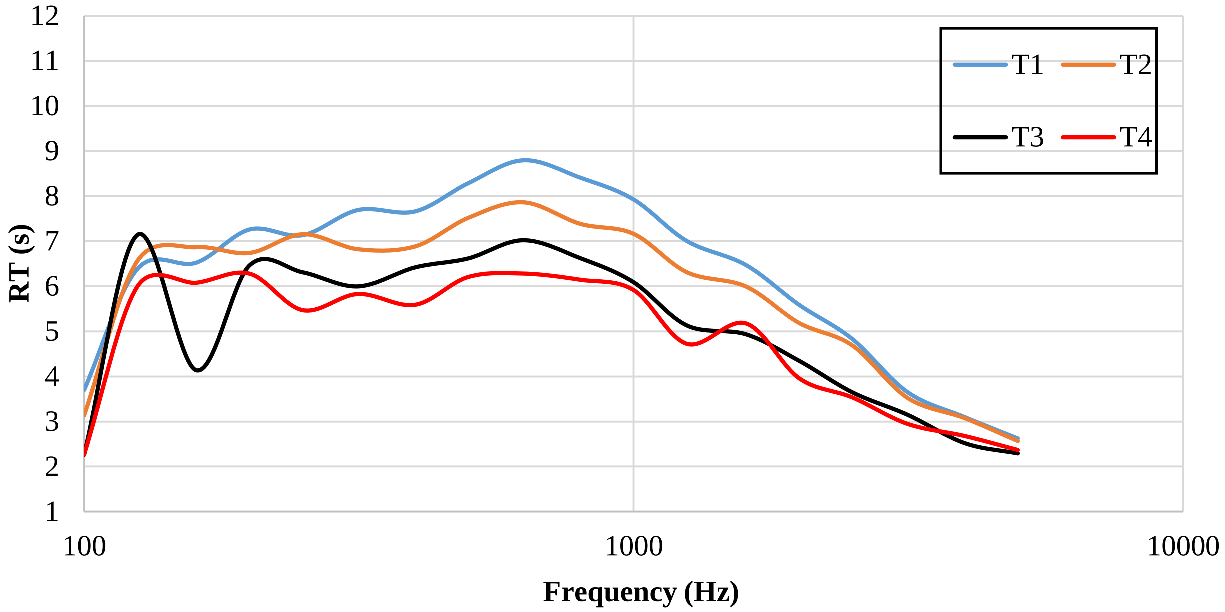

Fig.13 measured Four reverberation times (T_1, T_2, T_3 and T_4)

Despite that the dimensions of the measured scatter did not as recommended by the standard, it is shown from Figure 13 that, there was a difference in the reverberation times with and without the sample and with fixed and rotated the turntable. It was revealed that, the reverberation time T_2 decreased when the scatter was used comparing to the reverberation time T_1 without the scatter. Where, the average reverberation time T_1 in the frequency range from 100 Hz to 5000 Hz was 5.8 sec and decreased to 5.4 sec after using the scatter. Also, by comparing the reverberation time in the case of a rotating turntable versus a fixed rotating table, it is shown that the reverberation time decreased in case of rotating table compared to the fixed table. The reason behind this may be that, the rotating turntable introduces additional complexity to the sound field, as the scattering properties vary depending on the angle of rotation. This can help to disperse sound energy more efficiently, leading to a faster decay of sound levels and a lower reverberation time compared to a fixed rotating table. For example, by comparing the average reverberation times T_1 and T_3, it was shown that the values were 5.8 sec and 4.6 sec respectively.

5.4 Calculation of the scattering coefficient

After measuring T_1, T_2, T_3 and T_4, the sound scattering coefficient for the non-standard scatter was calculated using equations 1,2 and 3 as shown in Figure (14).

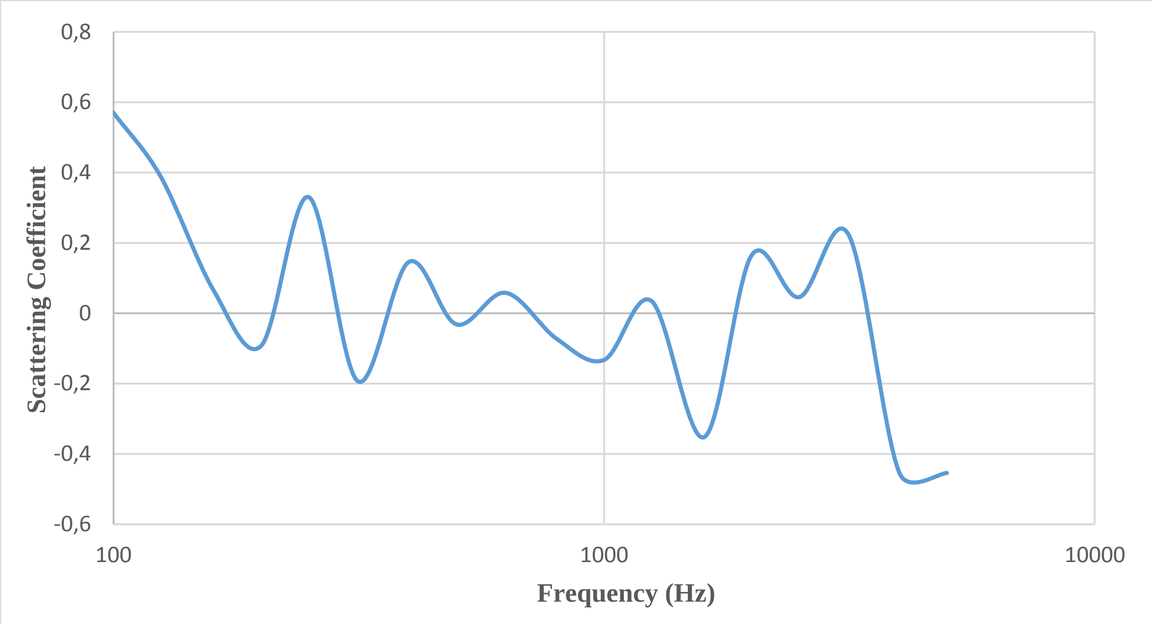

Fig.14 measured scattering coefficient for 60 cm x 60 cm scatter

6. Outcomes of the project and Future Work

From my point of view, I can summarize this duration in some strong and weak points as the following:

1. Strong Points

- Gaining all information about the theoretical basics and measurement equipment and procedures required for establishing such system in my home laboratory in the future.
- Preparing Python and MATLAB codes for the signal processing and analyzing the data for obtaining the impulse response and the reverberation time.
- Participating with the lab. Staff in calibration and measurement activities.
- Opening communication channels with members of host laboratory for future scientific cooperation.

2. Weak Points

- A ready software was not available in the host laboratory for scattering coefficient measurements.
- Mounting the circle base plate and the turntable under the reverberation room floor could not be possible during the researcher work period.
- The time period for the project was short, as the project requires a time period of no less than 6 months in order to take real measurements for the sound scattering and to study sufficiently all the parameters that may affect the sound scattering results and to ensure that the service will be provided to the customers in a satisfactory manner.

Finally, In the near future, I hope to have the opportunity to return back again to UME to complete what we started in this project by taking real measurements and study the effect of different factors which affect the sound scattering behavior.

Acknowledgments

I would like to express sincere thanks and appreciation to the people behind this joint training initiative, for allowing me to learn from experts and experience the state-of-the-art laboratories of an advanced NMI like TÜBİTAK UME through participating in this 6th cycle of BIPM- TÜBİTAK UME Project Placements.

I would like to extend my deepest thanks to my supervisor, Dr. Cafer Kirbas, who never hesitated to teach me a lot about my project in particular and about acoustics in general. He was the best help and support despite his extreme preoccupation with laboratory matters. I would also like to thank the head of the laboratory, Dr. Eyüp Bilgiç, who made me participate with him in many calibration activities in the laboratory, and I actually learned a lot from him. I also thank Mr. Ibrahim Gün, the technician in the laboratory, for helping me during the period of my project. Last but not the least, thank you to the International Relations Department of TÜBİTAK UME, Dr. Enver Sadikoġlu, Ms. Müge Atam, and the support groups from the drivers, security personnel, housekeepers, and food attendants, for taking good care of our needs and requests in making participant's training duration a memorable and comfortable one. Aside from the new experience and learnings, I would like to thank all of my colleagues coming from different NMIs through this capacity building. I am hoping for the continuation of the alike partnership and to be a gateway to more collaboration for developing a better world through the science of measurement. Hoping that this will not be our last in participating in the BIPM - TÜBİTAK UME Project Placement as we still have a lot of things to learn and implement in our NMIs.