BIPM Capacity Building & Knowledge Transfer Programme

2025 BIPM - TÜBİTAK UME Project Placement

REPORT

Project Name	Metrological advancements in low-frequency calibration of sound level meters: Establishing traceability and accuracy standards.
Description	For accurate acoustic readings, sound level meters (SLMs) must be calibrated at low frequencies. However, several issues, including traceability gaps and variations at low frequencies, pose difficulties for current calibration techniques. These restrictions affect both measurement uniformity amongst laboratories and regulatory compliance. To ensure measurement accuracy and traceability, the proposed project addresses the urgent need for improved low-frequency calibration of sound level meters (SLMs). In this experiment, high-stability measurements using an active coupler were employed to calibrate the SLM at low frequencies, extending down to 4 Hz. Z-weighting is the most suitable approach for these considerations. The obtained results showed differences between the reference microphone and Z-weighting of SLM in order of magnitude of 2 to 5 dB, with high stability of measurements and low standard deviation. Because a framework for calibrating SLMs at low frequencies was created, the work's goal was thus accomplished. Determining the limitations for the acceptability of low and infrasound, which were not specified in the IEC, and uncertainty calculations are two examples of practical work and computations that are still being investigated.
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Date	Sept. 1st to Sept. 27th 2025

Motivation & Introduction

Noise is characterized as an undesirable sound that is perceived as unpleasant, loud, and potentially harmful to the human ear. According to physics theories, sound and noise arise from vibrations of a medium, which are perceived by the ear and transformed into electrical signals by the brain through the mechanical motion of internal structures. It is important to note that prolonged exposure to noise can result in irreparable hearing impairment, which may originate from several sources, including environmental or occupational settings. Exposure of workers to excessive noise over the permissible threshold can result in hearing impairment or deafness, therefore diminishing human performance and productivity.

Results of acoustical measurements, when sound pressure is concerned, are generally expressed in decibels (dB), a logarithmic ratio defined as:

$$dB = 20\log(\frac{P}{P_{ref.}}) \qquad (1)$$

where P represents the instantaneous sound pressure level and P_{ref} denotes the reference sound pressure level (20 µPa).

The International System of Units (SI) designates the pascal (Pa) as the derived unit of measurement for acoustical metrology.

The sound level meter (SLM) is regarded as the most extensively employed device for measuring noise. The demand for SLM calibration has increased in the current period. It has become automated methods to minimize time. The performance verification of SLM was established in accordance with the IEC 61672 series of international standards [1].

It encompasses a complete characterization of the devices, classes, and test techniques tailored to their intended function. The calibration range of this instrument is confined to the audible spectrum, and the limited experiments indicate a need for calibration in the low and infrasound ranges.

Currently, there is an urgent need for the global and European economies to transition to carbon-neutral energy production, a solution consistently highlighted across all media platforms. The primary necessity is to mitigate the effects of climate change; nevertheless, the methods to achieve this result often involve increased utilization of renewable energy sources. The drawback of utilizing these clean and sustainable energy sources is their emission of low-frequency and infrasound noise, ranging below 200 Hz and down to millihertz. This may lead to an increase in complaints from residents adjacent to renewable energy sites, such as wind turbines.

Infrasound sources globally arise from monitoring prohibited nuclear weapon tests, geophysical studies such as volcanology, early earthquake detection, tsunami research, climate investigations, upper atmospheric studies, and extreme weather forecasting related to hurricanes and storms, as well as glacier collapse analysis. The infrastructure for calibration using infrasound frequencies is now under development, involving the creation of novel main calibration methodologies and standardization initiatives. Key comparison CCAUV.A-K6 was conducted (2019-2020) and piloted by LNE (France) within this range to establish traceability, many NMIs participated and the report published in Metrologia [2]. Where two LS2P microphones were used and extension for very low frequencies performed by some NMIs. The issue lies in the development of performance measurement instruments for noise [3] , which is still in its nascent stages. In our situation, there has been minimal discourse around performance, specifications, and testing requirements for low and infrasound. We presented this point to examine the SLM calibration at in low frequencies, as it is of significant relevance and challenge in the world.

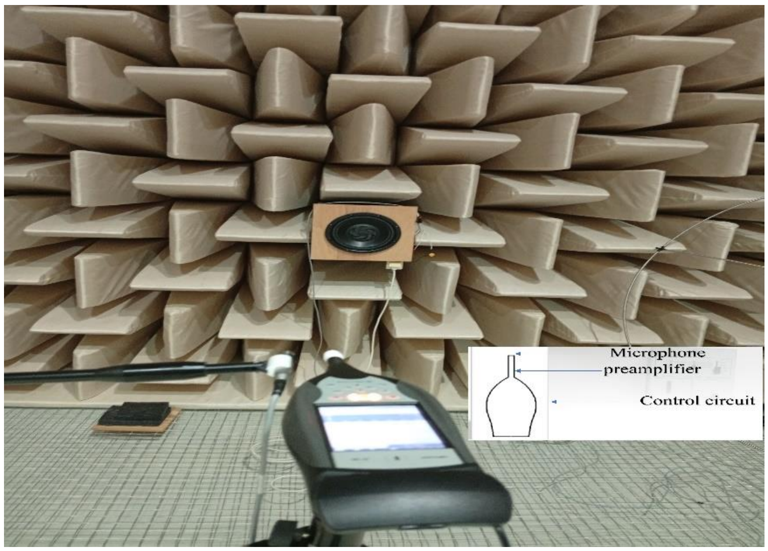


Figure 1. Representing SLM with its components (TÜBITAK UME – Anechoic room).

Table 1. List of IEC tests for SLM.

Type of SLM test(acoustical& electrical)	Description	IEC 61672 part & frequency range
Frequency weighting and band filtering	Frequency weightings allow signal filtering A-weighting C-weighting Z-weighting	defined in IEC 61672-1 only useful in the audible frequency range
Level linearity	The measured signal level to be a linear function of the sound pressure level at	IEC 61672-1

	the microphone for the entire extent of the total range of a device	It is recommended to perform the level linearity tests acoustically down to the 1 Hz third-octave band
Self-generated noise	Self-generated noise has to be declared in infrasound frequency range. It strongly depends on the effective bandwidth of the detection frequency range.	IEC 61672-1 if several frequency ranges are selectable, such as a standard frequency range and an extended low-frequency range, the requirement applies to each setting.
Time weightings, time averaging and peak levels	The standard Fast or Slow time weightings are often used in the audio frequency range, but their respective time constants of 0.125 s and 1 .	IEC 61672-1 It comparable to a low frequency acoustic period and are therefore not appropriate for infrasound applications.
Toneburst response	IEC defines a number of requirements for instrument response to single and repeated tonebursts at 4 kHz.	IEC 61672-1&2 4kHz
Environmental requirements	The requirements on stability against environmental conditions (air temperature, static pressure, humidity), electrostatic discharge, EMC and mechanical vibrations.	IEC 61672-1 It have also to be considered at infrasound frequencies.
Detection of microphone membrane defects	A potential problem in low-frequency measurements are perforations in the microphone diaphragm. These may happen due to dirt, corrosion, aggressive or hot measurement environments, or mistreatment of the microphone.	Technical issue
Electrical test	Extend electrical testing of frequency weightings A,C, Z and (C-A).	IEC 61672-1,2,3 down to the lower limit of the 1 Hz third-octave band.

The objectives can be summarized in the following points:

- Developing advanced low frequency calibration methodology by integrating stability for SLMs (i.e. this objective already achieved through the placement program at TÜBİTAK UME).
- Optimizes the calibration techniques used in TÜBİTAK UME and NIS (i.e. performed at TÜBİTAK UME and now in practical part at NIS till completing).
- Extending the frequency range of SLMs calibration (i.e this objective achieved at TÜBİTAK UME and will be achieved soon at NIS).

Research

The calibration strategy for sound level meter was planned to be performed in pressure field and free field conditions, and some other part will be performed at NIS in pressure field (under establishment). During the stay at TÜBİTAK UME, a concentration on the pressure field method for longer time, it already achieved with good stability and results. The experiments with free field method begin, but due to limited time not completed. The other method at NIS still under establishment, because we are in the stage of purchasing the required materials and parts for development constructing of a tube for low frequency calibration of SLMs with a suitable budget.

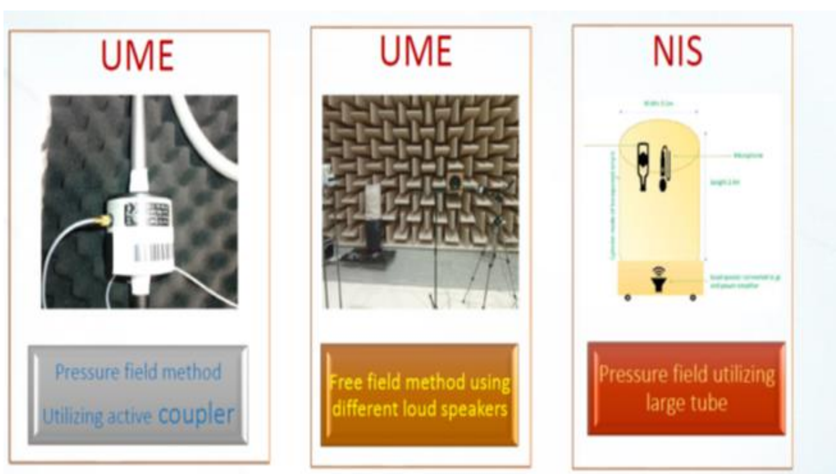


Figure 2. Calibration method strategies for SLMs in free and pressure field conditions at TÜBİTAK UME and the planned method drawing for NIS.

Table 2. List of equipment's utilized active coupler method at TÜBİTAK UME Acoustics Laboratory.

SYSTEM COMPONENT	MANUFACTURE & MODEL
Reference standard microphone ½"	B&K 4180

Preamplifier	B&K 2669
Active coupler	B&K WA-0817
Conditioning amplifier NEXUS	B&K 2690
8 ½ digital multimeter	KEYSIGHT 3458A
Function generator	STANFORD DS360
Wave generator	AGILENT 33220A
Sound level meter	B&K 2250
INTERFACE &LABVIEW PROGRAM	

The setup of the SLM calibration system is illustrated in Fig. 3. The system consists of a reference microphones (B&K4180), an active coupler (WA 0817), UUT (SLM B&K2250) in the other side., So the reference and UUT are in face to face configuration.

Reference Microphone

UUT (SLM)

Face-Face (Ref.-UUT)

Active coupler

Figure 3. The complete calibration system setup used for verifying the performance of the SLM.

A-weighting, C-weighting, Z-weighting (time weighting fast & slow), and L_{Aeq} with reference microphone are the three third octave presentations for the SLM that comprise the data acquired from the measurements in the audible range of frequencies (20 Hz to 20 kHz) in figure 4 below. Figure 5 below shows the results for the same kind of frequency weighting and time weightings for low and infrasound frequencies (16 Hz down to 4 Hz).

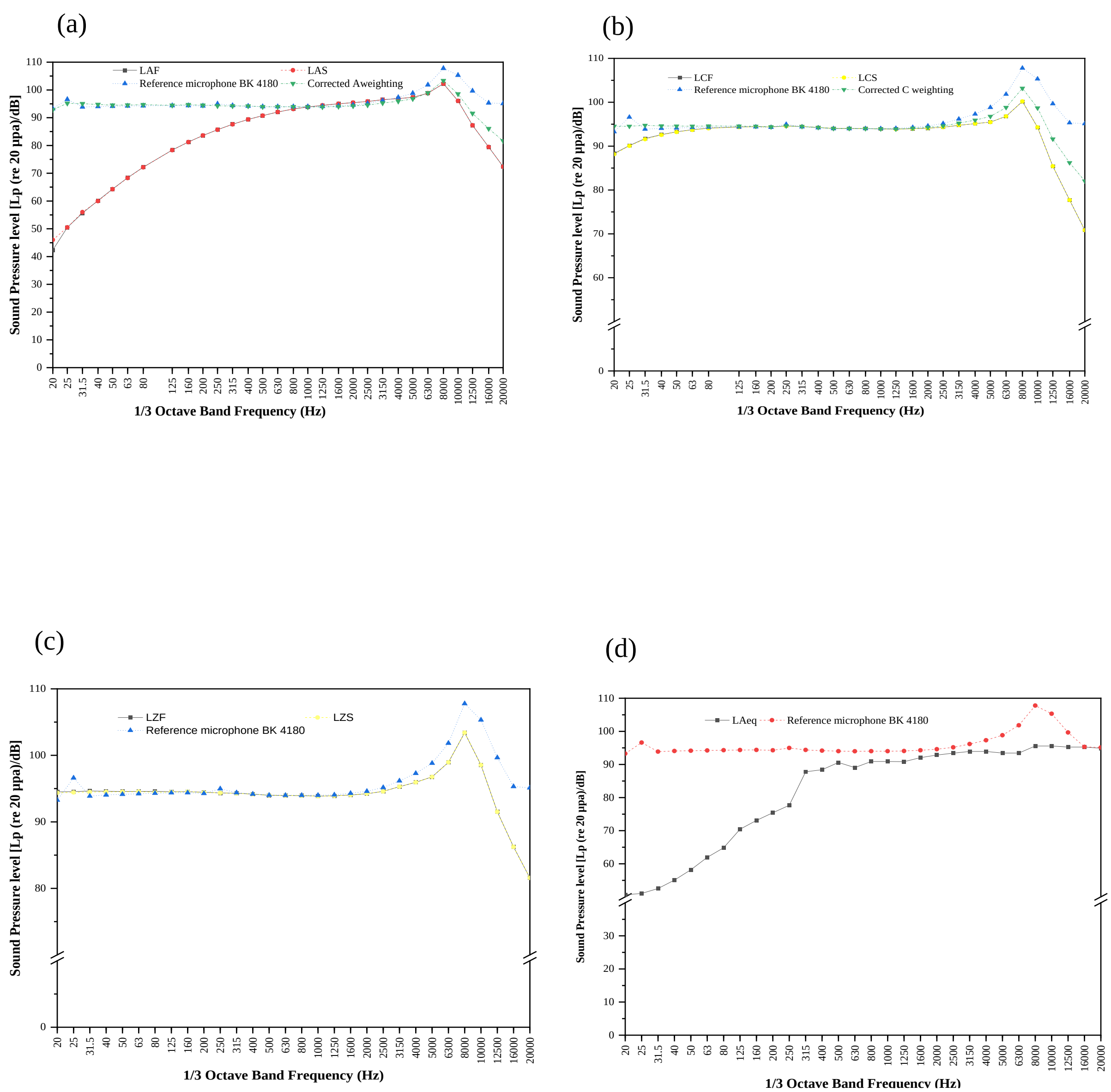
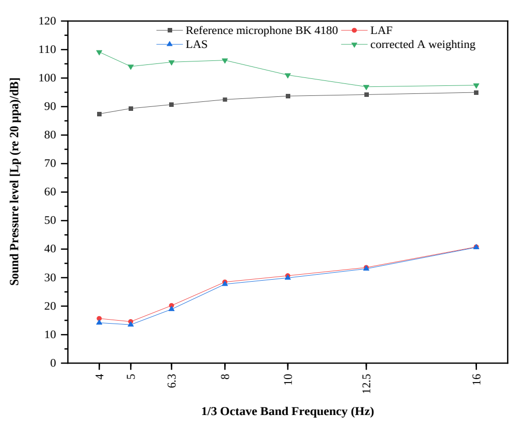


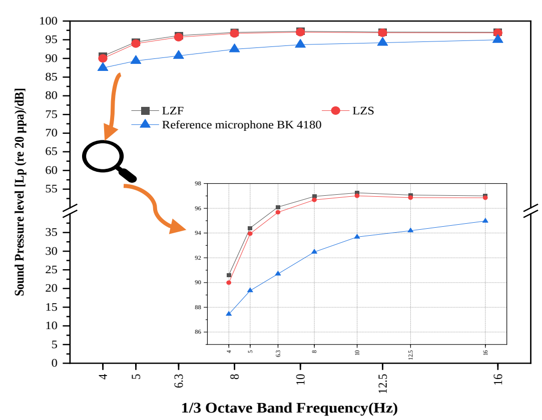
Figure 4. The results of reference microphone with (a) A-weighting and &corrected A-weighting SPL (time weighting: fast & slow); (b) C-weighting and corrected C-weighting SPL (fast & slow); (c) Z-weighing (fast & slow) ; (d) L_{Aeq} over 30 s through 20 Hz to 20 kHz.

Figure 4 (a) demonstrates that the measured sound pressure levels (SPL) utilizing SLM 2250 (L_{AF} & L_{AS}) within the frequency range are nearly identical, indicating that the alteration in time weighting has a minimal impact. However, when comparing their results to those measured with the reference microphone B&K Type 4180, significant deviations and amplitude discrepancies below 500 Hz are evident, attributable to the attenuation effects of the A-weighting mode in sound level meters. Calculations were conducted utilizing the tables within the IEC 61672 standards to aggregate the attenuation values of the measured data for comparison with the reference microphone (ref. mic). The two lines for the adjusted A-weighting SPL and reference microphone are closely aligned, with only minor deviations observable. The deviance escalated with rising frequencies, particularly over 6300 Hz. Figure 4 (b) illustrates an additional scenario, demonstrating that the discrepancy between the C-weighting SPL measurement and the reference microphone occurs across a broad spectrum of frequencies, excluding the tail areas at both high and low ends. These locations are below 200 Hz and above 6300 Hz. The values for L_{CF} and L_{CS} are essentially similar, with attenuation under C-weighting being less than that under A-weighting. Additionally, corrections can be derived from tables within IEC 61672, where the lines for reference microphone and corrected C-weighting diminish significantly at low frequencies, down to 20 Hz, while at higher frequencies, exceeding 6300 Hz, the differences are more pronounced. This phenomenon is attributable to various factors affecting both A and C-weightings, including air attenuation, which is more pronounced at elevated frequencies. Figure 4 (c) illustrates that all the lines are well aligned, with deviations only increasing at high frequencies exceeding 6300 Hz. However, the benefit here is that no correction for Z-weighting is required, and all values are close to the reference microphone values. Furthermore, the curves for L_{ZF} and L_{ZS} are approximately adjacent to one another.

(a)



(b)



(c)

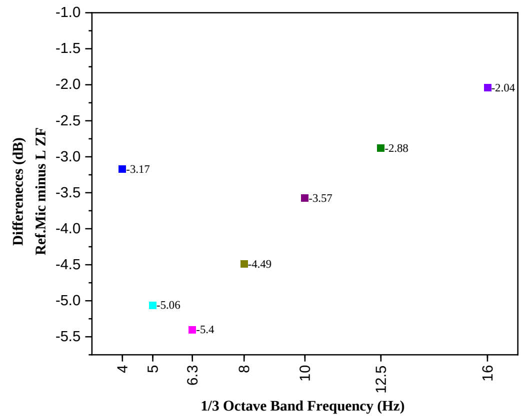


Figure 5. The results of reference microphone with (a) A-weighting and corrected A-weighting SPL (fast and slow); (b) Z-weighing (fast and slow); (c) Differences between reference microphone and Z-weighting (fast) within the frequencies from 16 Hz down to 4 Hz.

Figure 5 (a) illustrates significant discrepancies in the measured values for SLM using the A-weighting method, namely at extremely low and infra frequencies, across both time weighting scenarios (F, S). However, upon calculating the adjustment for A-weighting, the revised line for the corrected A-weighted sound pressure level exhibits a diminished discrepancy with reference microphone values. Although this difference is minor at 16 Hz, corresponding to around 3 dB, the disparities increase as the frequencies decrease. In this instance, A-weighted measurements are not advisable below 10 Hz due to non-linear behavior and attenuation. Figure 5 (b) demonstrates that the lines for L_{ZF} and L_{ZS} are nearly indistinguishable, exhibiting only minor differences. Upon comparison with the reference microphone, it is evident that the discrepancies range from -2 dB to -5.4 dB (reference microphone minus SLM reading), a finding that is both intriguing and fosters optimism regarding these variations. Figure 5 (c) shows the calculated differences between the ref.mic and measured L_Z at each frequency from 16 Hz down to 4 Hz. It is noteworthy that numerous technical procedures and directives were implemented throughout the measurements, as obtaining precise data without experience is challenging.

It is noteworthy that IEC 61672 standard does not specify acceptability limits for low frequencies below 10 Hz for both classes (1 and 2) of SLMs, and calculations in this project will be conducted using the equations provided in the appendices below. Currently, it is undergoing preparation and study; this work will proceed to conduct all necessary calibration tests for SLMs in accordance with IEC 61672, with a particular focus on certain critical acoustical tests in the future after the program.

Capacity building skills

The BIPM-UME placement provided an opportunity for me to conduct specialized measurements that require certain competences. This difficulty of calibrating SLMs within low and infrasound frequency ranges could not be accomplished without the requisite capabilities. The work atmosphere at TÜBITAK UME was exceptional for development and knowledge transfer through collaboration with eminent academics and specialists. Continuous assistance enhanced my confidence, skills, and technical awareness, enabling me to execute this type of calibration within my institute utilizing novel methods. This engagement paved the way for prospective chances for further cooperation and collaborative endeavors.

Expected Outcomes for TÜBİTAK UME and NIS

- TÜBİTAK UME:
  - Establishment of a robust low-frequency calibration methodology for SLMs.
  - Extending the range for calibration of SLMs
- NIS:
  - Strengthened collaborations with international NMIs.
  - Establishment of new system for calibrating SLMs at low frequencies standing on the previous experience in dealing with low frequencies.

Conclusions and Future Work

The results gained from this project showed the technical challenge and metrological constrains that may be arises in calibration of SLMs at low frequencies. The deviations obtained between the measured SLM's values and reference microphone utilizing A and C-weightings confirm the non-linearity and reduced sensitivity in this range. Strong attenuation observed for both weightings (A and C) which may put limitation in usage for low frequencies. Although Z-weighting gave good values and the stability was excellent and the standard deviation observed was in the order of magnitude of 0.01 for the amplitude till frequency 4 Hz. The differences between the reference microphone values and measured values using Z-weighting were in order of magnitude of 2 to 5 dB and this is not high difference for this range. Thus, the pressure field method implemented utilizing active coupler at TÜBITAK UME proved to be stable and effective, producing reliable data. The free field was executed, but the data is not presented here due to time constraints for completion. The project successfully enhanced the abilities necessary for conducting low and infrasound calibrations of SLM, and the information acquired throughout the placement is currently being utilized to develop a system anticipated to be operational by 2026 at NIS.

Acknowledgements

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 8th cycle of BIPM - TÜBİTAK UME Project Placements.

I would also like to extend my sincere appreciation to Assoc. Prof. Dr. Mustafa Çetintaş, Director of TÜBİTAK UME, for his outstanding leadership and continuous support to the BIPM–UME program. His openness, accessibility, and genuine interest in facilitating the success of all participants created an exceptionally welcoming environment throughout my stay. I am truly grateful for the way he simplified administrative procedures, ensured that every need was addressed promptly, and maintained an open-door policy that encouraged communication and collaboration. His dedication to strengthening international cooperation and supporting the development of young researchers made a significant and positive impact on my experience at UME.

My deepest appreciation goes to Dr. Enver Sadikoğlu for his continuous supervision and insightful discussions. I also extend my heartfelt thanks to Dr. Cafer Kırbaş for his dedicated mentorship, technical advices, help in all the practical work and encouragement, which contributed significantly to the success of this project. Dr. Cafer Kırbaş , guided me during all the placement in technical issues and help me a lot through the whole program. I would like to express my appreciation to Dr. Esra Okumuş for her assistance. I also thank Mr. Younus Baysal, 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 Unit of TÜBİTAK -UME, especially Ms. Müge ATAM and all the staff. I express my sincere thanks to 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 wonderful colleagues coming from different NMIs through this capacity building, they make everything amazing by friendship. 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.

References

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2- Rodrigues, D., Olsen, E. S., Llamas, O., Dobrowolska, D., Soares, Z. M. D., Cho, W. H., ... & Golovin, D. (2023). Final report on the key comparison CCAUV. A-K6. Metrologia, 60(1A), 09001.
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