Report on Activities and Measurement Capabilities in Acoustics, Ultrasound and Vibration Metrology of CMS

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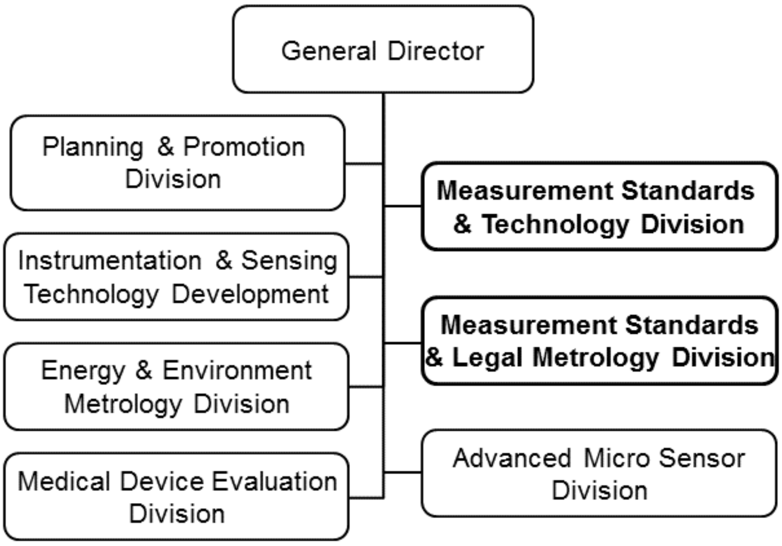
Introduction

Industrial Technology Research Institute (ITRI) is a nonprofit R&D organization engaging in applied research and technical services for innovating a better future. Founded in 1973, ITRI has been dedicated to helping industries stay competitive and sustainable. Over the years, ITRI has nurtured more than 260 companies, including well-known global semiconductor leaders such as TSMC and UMC. Meanwhile, it has cultivated over 140 CEOs in the local high-tech industry. ITRI has played a vital role in Taiwan's economic growth as it shifted the industry from a labor-intensive business into a value-added, technology-driven one.

Organization Chart of ITRI

Center for Measurement Standards (CMS) was founded by ITRI in 1985 to carry out the Weight and Measures Calibration project of the Ministry of Economic Affairs (MOEA). In 1987, MOEA designated the established laboratory as "National Measurement Laboratory" (NML). The initial intended mission of CMS was to establish and maintain the national measurement standards. From the experiences and capacities built of the primary standards techniques conforming to the world’s metrology society, CMS expands R&D scope to instrumentation and sensing, smart sensing, medical device evaluation, and energy and environment metrology. The core technologies of these fields are developed to help the industry gaining the international market competition with advanced technology and quality assurance. There are 7 divisions in CMS. The businesses of NML are operated by the Measurement Standards & Technology and the Measurement Standards & Legal Metrology two primary divisions. Currently there are 9 staffs working for Acoustics, Ultrasound and Vibration metrology.



Organization Chart of CMS

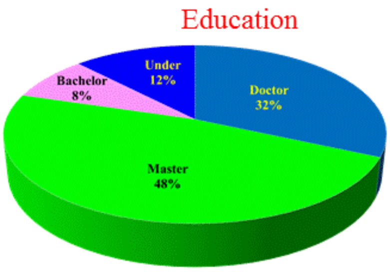
National Measurement Laboratory (NML)

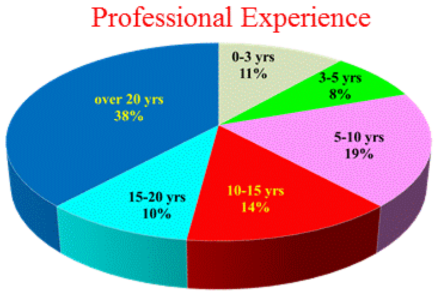
- **Missions of NML**

The National Measurement Laboratory (NML) of Taiwan was established in 1987, and soon began providing measurement services to government agencies and the private sector. To maintain high level of confidence in measurement standards, NML actively participates in the intercomparison programs conducted by the BIPM and regional metrology organizations. So far, NML has established primary standards, such as the quantum Hall resistance system for resistance measurement and the iodine stabilized He-Ne laser for dimension enhancing the reliability and traceability of the national measurement systems. NML has also established national measurement standards in the fields of electricity, magnetics, microwave, luminous intensity, temperature, humidity, chemistry, vibration, acoustics, dimension, mass, force, pressure, vacuum, and flow. The well-established national standards provide extensive calibration services for the industry.

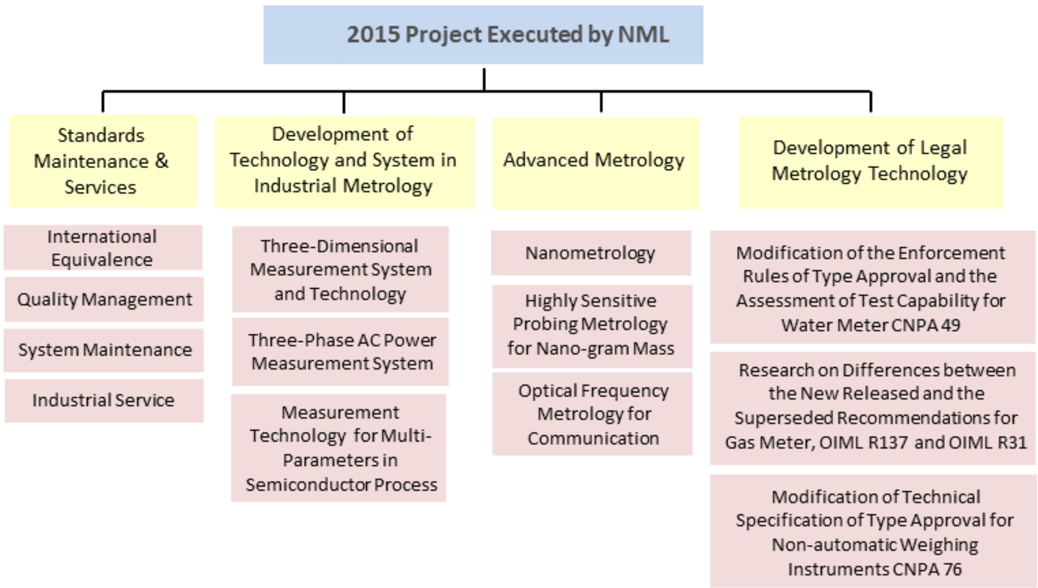
To support the hi-tech industry development, NML are devoted to advanced research projects such as absolute distance measurement using optical frequency comb, advanced material metrology, new primary electricity standards ensuring precise measurement of electricity consumption, 3D measurement system & technology for upgrading machine tool industry, and primary measurement standards of greenhouse gases of carbon-containing gas emission for future green energy industry. In addition, standards for flat panel display and inspection technology also have been established. The testing services are opened for the industry.

- **Human Resource of NML**





- **Major Projects at NML**



- **Quality System**

The quality system of NML conforms to ISO/IEC 17025:2005 for calibration laboratory. The reassessment in AUV was held in Oct., 2010 by the Taiwan Accreditation Foundation (TAF). Assessors were experts from NMIJ (Japan) and KRISS (South Korea). The Certificate of Accreditation, with certificate number of N0001 will be renewed in coming 2016.

Acoustics Ultrasound and Vibration Metrology at NML/CMS

The Acoustics, Ultrasound and Vibration Laboratory (AUVL) provides traceability of sound pressure and acceleration standards and relative calibration services for domestic industry. A variety of measurement systems were established and grouped into dynamics measurement in NML/CMS. The provided calibration services include pressure sensitivity level for 1" and 1/2" microphones, sound level measurement for pistonphone and sound calibrator, sound pressure response level for sound level meter and the voltage sensitivity, charge sensitivity and shock sensitivity for acceleration measuring chain. In addition to the developments of calibration systems, the AUVL also devotes its efforts into advanced dynamics metrology research such as error motion of rotating shaft/axis, balancing evaluation for cooling fan.

In additional to the calibration capability of accelerometers, charge amplifier and vibration meters, the AUVL is also well equipped with the modal analysis for structural vibrations and enhancement techniques, the experimental analysis and control techniques of floor vibrations for factory buildings, and the monitoring, analysis and preventing techniques of environmental vibrations, and rotor rotating unbalanced and roundout measurement of rotor under spinning test. Also the AUVL serves the monitoring and fault diagnostics of mechanical equipment, performance verification of vibration isolators, and precision measurement of floor vibrations, etc. Furthermore, the advanced technology in non-contact precision measurement is under developing at the moment.

In AUVL, The calibration service of microphone, sound calibrators, and sound level meters in acoustics field helps to support the high precision measurement application for noise control in production facilities, transportation, and environmental concerns. The laboratory has also developed core technologies in performance test of standard microphones and sound sources, frequency response test of microphones, directionality characteristics of sound-level meters, absorption coefficients and impedance measurement of sound-absorbing materials, performance test and the design service for the anechoic chambers, and wind turbine noise measurement technique, the sound insulation and reverberation time measurement of building or construction, and audio performance test of public addressing system and audio device, etc.

In the ultrasound metrology, AUVL has included the capabilities of the frequency response characteristics, the sound pressure level and the directionality of ultrasonic probe; for underwater acoustics, the hydrophone sensitivity, the output power, and intensity measurements. Also, the AUVL have established the ability on ultrasonic scanning technique for structure crack and defect inspection.

Calibration and Measurement Capabilities (CMCs)

Since 2006, the calibration and measurement capabilities (CMCs) in the area of acoustics, ultrasound and vibration (AUV) have been published in BIPM's key comparison database (KCDB) and latest revised on January, 2012. It declares that AUVL's CMC's have gained international recognition and associated availability of offering measurement service worldwide. Nowadays, there are 39 items listed on the CMC table for AUVL.

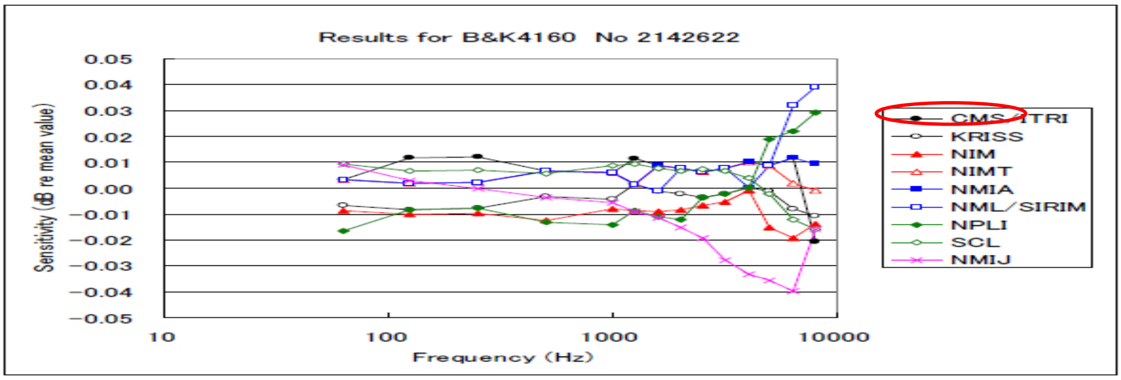
International Comparisons

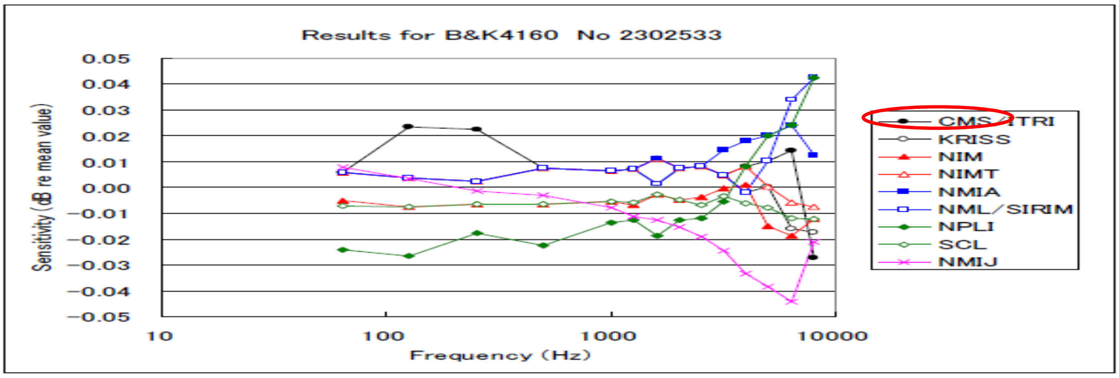
CMS has actively initiated or participated in the following comparisons and pilot studies conducted by RMO .

Code	Date	Title	Status
APMP.AUV.A-K1	2004~2005	Pressure sensitivity of one inch laboratory standard microphone – 63 Hz to 8 kHz	
APMP.AUV.A-K3	2006~2007	Pressure sensitivity of half inch laboratory standard microphone – 31.5 Hz to 25 kHz	
APMP.AUV.A-S1	2008~2010	Sound pressure level of a multi-frequency sound calibrator – 31.5 Hz to 16 kHz	
APMP.AUV.V-K1	1996~1997	Vibration acceleration	coordinator
APMP.AUV.V-K1.1	2010	Vibration acceleration	
APMP.AUV.V-K3	2010~2011	Vibration acceleration (Low frequency)	
APMP.AUV.V-P1	2013~2014	Shock acceleration(Low intensity)	
	2015	Bilateral comparison between CMS/ITRI and NIM; Free field sensitivity of laboratory standard microphone – 1 kHz to 25 kHz	Pilot

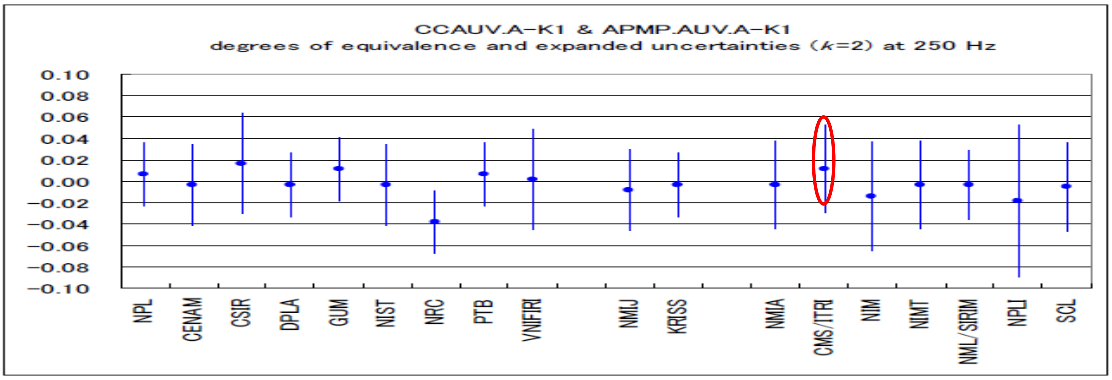
Some published results of key and supplementary comparisons in recent ten years are shown as follows.

APMP.AUV.A-K1 (2004~2005)

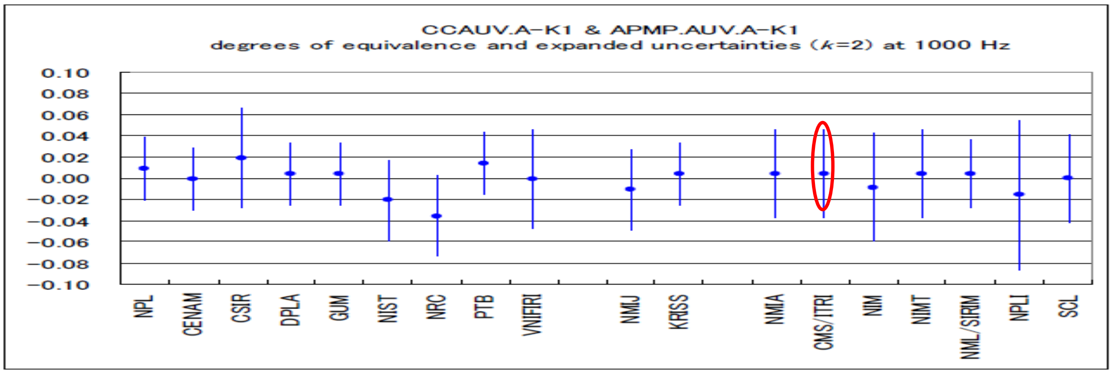




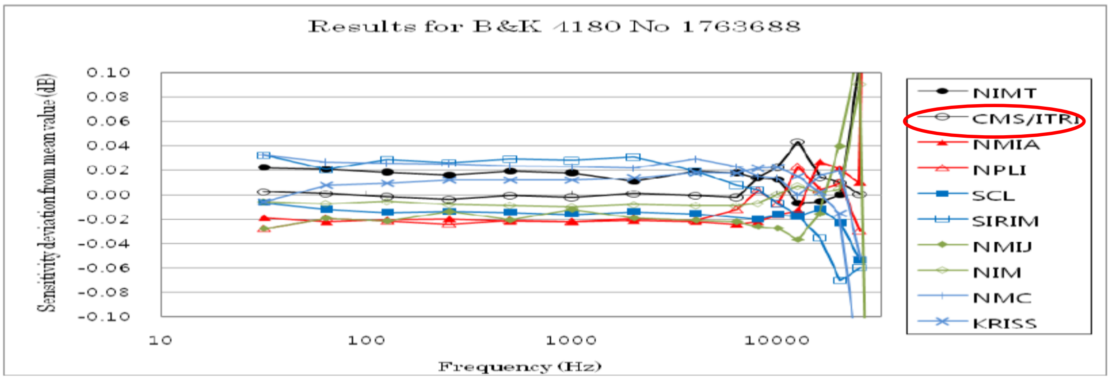
CCAUV.A-K1&APMP.AUV.A-K1(250 Hz)

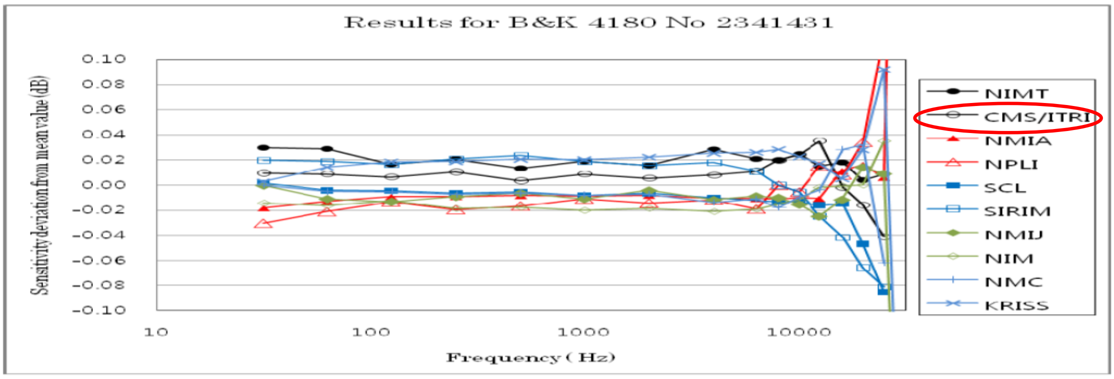


CCAUV.A-K1&APMP.AUV.A-K1(1 kHz)

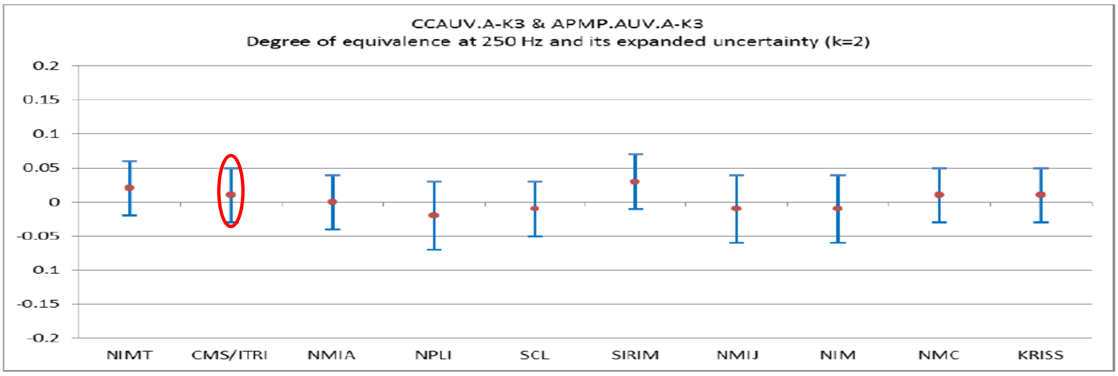


APMP.AUV.A-K3 (2006~2007)

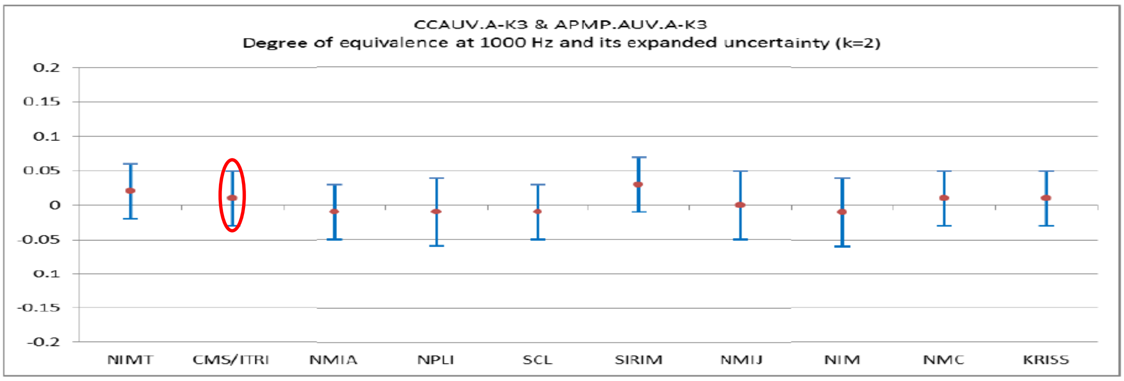




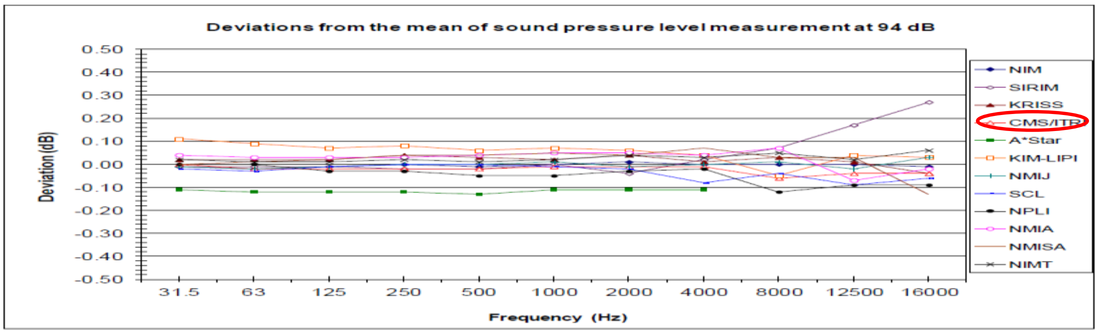
CCAUV.A-K3&APMP.AUV.A-K3(250 Hz)

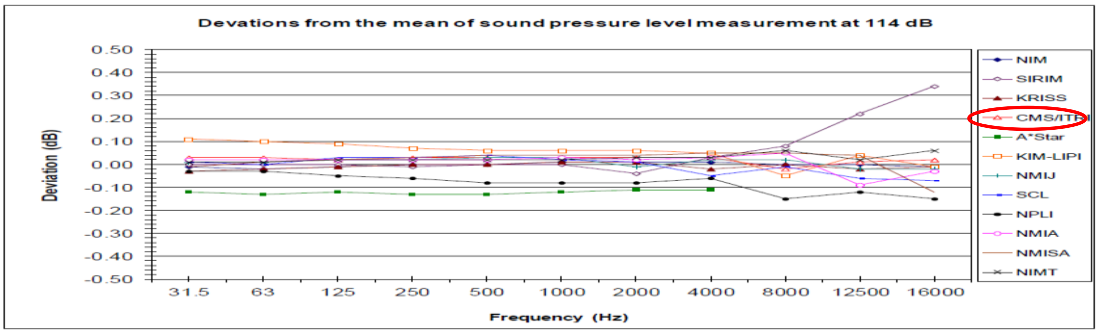


CCAUV.A-K3&APMP.AUV.A-K3(1 kHz)

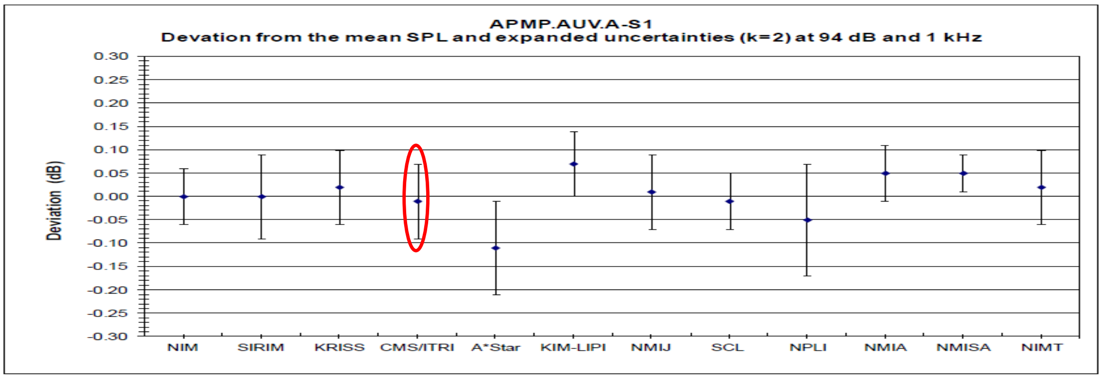


APMP.AUV.A-S1 (2008~2010)

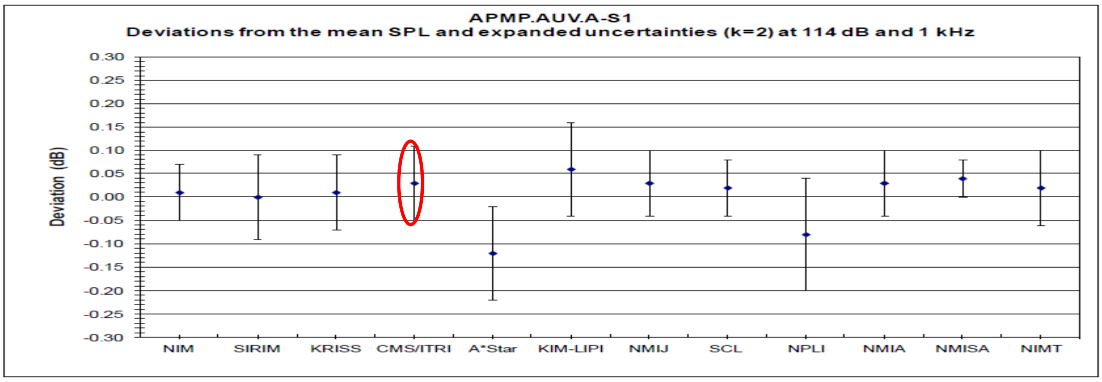




APMP.AUV.A-S1 (at 94 dB and 1 kHz)



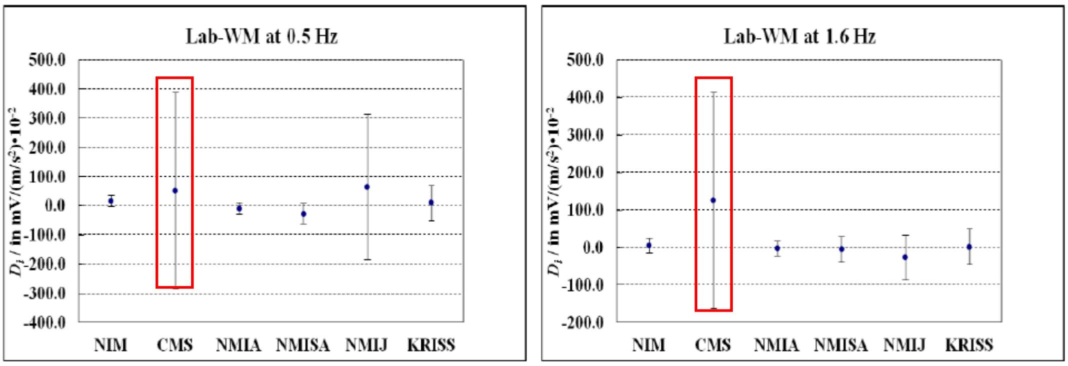
APMP.AUV.A-S1 (at 114 dB and 1 kHz)



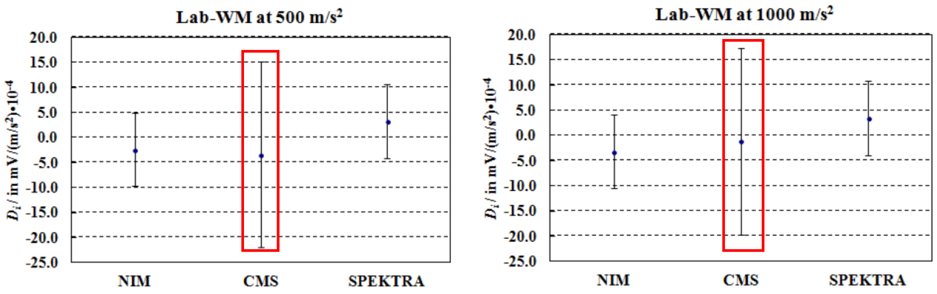
DoE between the participants of APMP.V-K1.1 and those of CCAUV.V-K1 for the BB transducer at 160 Hz

160 Hz	CMS/ITRI		NIMT		NMC, A*STAR	
$i \rightarrow$	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
$j \downarrow$	in pC/(m/s²)·10⁻⁴		in pC/(m/s²)·10⁻⁴		in pC/(m/s²)·10⁻⁴	
PTB	-1.6	4.0	1.7	5.2	1.7	6.5
BNM-CEST	-1.0	7.4	2.3	8.1	2.3	9.0
CSIRO-NML	-2.0	5.4	1.3	6.3	1.3	7.5
CMI	-2.0	7.0	1.3	7.7	1.3	8.7
CSIR-NML	-2.0	7.4	1.3	8.1	1.3	9.0
CENAM	-2.0	7.4	1.3	8.1	1.3	9.0
NRC	-0.5	5.4	2.8	6.3	2.8	7.5
KRISS	-3.1	5.9	0.2	6.8	0.2	7.9
NMIJ	-2.0	6.7	1.3	7.5	1.3	8.5
VNIIM	0.2	6.3	3.5	7.2	3.5	8.2
NIST	-3.0	5.4	0.3	6.3	0.3	7.5
NMi-VSL	-2.0	5.7	1.3	6.7	1.3	7.7

DoE for horizontial voltage sensitivity of SE-1021at 0.5 Hz and 1.6 Hz



DoE. for voltage sensitivity under monopole shock excitation at 500 m/s^2, 3.0 ms and 1000 m/s^2, 2.0 ms



Research Projects

The research scope of the Acoustics, Ultrasound and Vibration Laboratory (AUVL) mainly covers in the fields of vibration, acoustics and ultrasound metrology. The projects executed by the AUVL in recent years are described as follows.

- Primary shock calibration using laser interferometry
- Electromagnetic impact hammer for accelerometer shock calibration
- Development of standard uniaxial eccentricity spindle for balancing machine
- Spinning test technique for rotor roundout and unbalancing
- Development of small sized reference sound source
- Acoustics comfortable index for residential space
- Microphone reciprocity calibration technique in free-field conditions
- Non-Contact vibration measurement technique

Measurement Facilities

Some measurement facilities of Acoustics and Vibration Measurement Laboratory in CMS are described as follows.

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Microphone Pressure-Field Sensitivity Calibration System - Reciprocity Method

- The system is to provide calibration of the sound pressure sensitivity for one-inch or half-inch condenser microphone. The suitable calibration ranges are compliant to IEC 61094-1 LS1P of one-inch condenser microphone (Frequency range: 20 Hz to 10 kHz) and IEC 61094-1 LS2aP and LS2F of half-inch condenser microphone (Frequency range: 20 Hz to 20 kHz).

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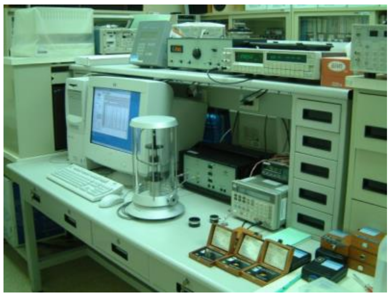

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Microphone pressure sensitivity calibration system - single and multi-frequency comparison method

- By comparing the output voltage of the calibrated item to that from the standard one with known sensitivity, then the sensitivity of calibrated item is calculated. The system is to provide calibration of the sound pressure sensitivity at 250 Hz of one inch and half inch condenser microphone and pressure sensitivity calibration at frequency range 20 Hz to 20 kHz of half-inch condenser microphone.

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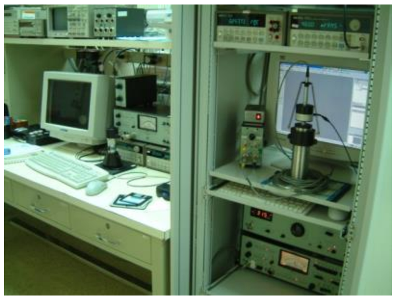

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Sound calibrator and sound level meter calibration system - Comparison method and Insert voltage technique

- The comparison method is by using a sound calibrator with known sound pressure level (SPL) as reference standard, comparing the output voltage of the reference standard to that of the device under test to obtain the ratio. Then the SPL of device under test can be calculated. The suitable measurement ranges are: Sound calibrator (1000 Hz) sound pressure level (90 to 120) dB re 20 µPa, and Piston phone (250 Hz) sound pressure level (90 to 130) dB re 20 µPa.
- The insert voltage method is by using a microphone with known sound pressure sensitivity as reference standard, and it is applied to find the open-circuit voltage output of microphone, by comparing the sensitivity of the

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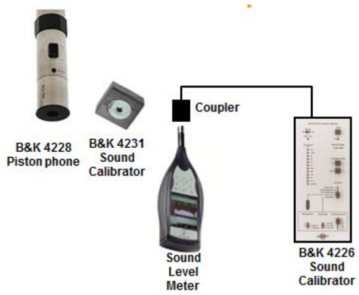

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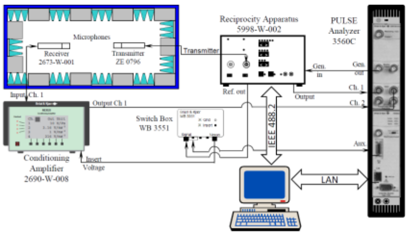
<tr><td>microphone with the measured insert voltage. Then the SPL of device under test can be calculated. The system can be used to calibrate sound calibrators, including pistonphone, for one inch or half- inch microphone. The suitable range is sound pressure level (90~130) dB re 20 μPa, and the frequency range is from 31.5 Hz to 16 kHz.</td><td></td></tr>
<tr><td>Microphone Free-Field Sensitivity Calibration System - Reciprocity Method
▪ A free-field reciprocity method for calibration of the free-field sensitivity of microphone ranges at frequency from 1 kHz to 20 kHz for laboratory standard microphone. The calibration system along with its specific technique is supporting the microphone calibration needed for noise measurement of the consumer electronics product and the sound power level measurement in free-field condition.</td><td>

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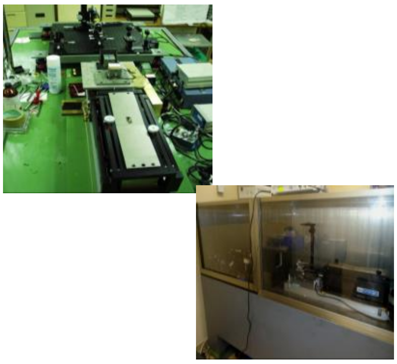
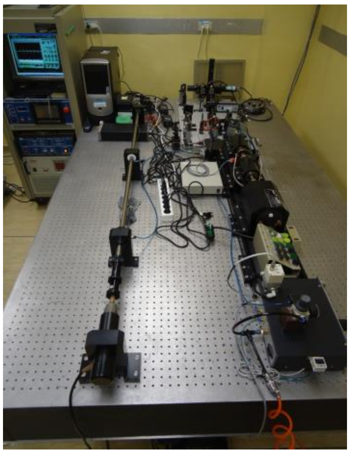
<tr><td>Primary accelerometer calibration
▪ The laser interferometers based primary accelerometer calibration system is capable of performing low uncertainty accelerometer calibrations while maintaining and realizing highest acceleration standard in Taiwan. The fringe counting and the sine approximation method both are in the frequency range from 50 Hz to 10 kHz.</td><td></td></tr>
<tr><td>Secondary accelerometer calibration
▪ In comparison method, the sensitivity of sensor under test (SUT) is measured by mounting in a back-to-back arrangement with a standard reference accelerometer. This calibration system is to provide calibration of the accelerometers and vibrometers for most of the industry and research application in the frequency range from 50 Hz to 7 kHz.</td><td></td></tr>
</table>

Comparison typed shock calibration system ▪ Utilizing the drop machine, the shock accelerometer is calibrated by comparing to a reference transducer with acceleration range from 1000 m/s^2 to 10000 m/s^2. Relative Expanded Uncertainties 2.1 % is provided with acceleration range from 1000 m/s^2 to 10000 m/s^2. The system is to provide the measurement traceability of the drop test and reliability test for the consumer electronics product manufactured in Taiwan.	
Low Frequency Vibration Calibration System ▪ The accelerometer sensitivity on low frequency calibration system is in compliance to ISO 16063-11, taking data by laser interferometer fringe counting method to calibrate the sensitivity of accelerometer. The measurement frequency range is from 0.4 Hz to 100 Hz with acceleration 1 m/s^2 to 5 m/s^2.	
Primary low shock calibration system ▪ The primary calibration system for shock acceleration is established by referring to ISO 16063-13. The rigid collision is from the electromagnetic excitation which hits the airborne hammer first and then the movement passes to the anvil. The displacement of accelerometer can be calculated by interference signals from the modified Michelson and Mach–Zehnder interferometer. At present the acceleration capability of primary shock calibration system is from 200 m/s^2 to 10000 m/s^2, with the shock pulse duration time less than 3 ms.	

Technical Services

- **Acoustics, Vibration measurement/Calibration Service**

Quantity and Item	Instrument type or Method	Measurand Level or Range	Relative Expanded Uncertainty
Accelerometer voltage sensitivity	ISO 16063-11 interferometry by fringe-counting method	0.4 Hz to 0.7 Hz 0.8 Hz to 2 Hz 3.15 Hz to 100 Hz 50 Hz to 700 Hz	2.8 % 2.5 % 0.6 % 0.5 %
Accelerometer voltage sensitivity	ISO 16063-11 interferometry by sine-approximation method	50 Hz to 1.5 kHz 3 kHz to 5 kHz 8 kHz to 10 kHz	0.5 % 1.0 % 1.8 %
Accelerometer voltage sensitivity	Comparison ,ISO 16063-21	0.8 Hz to 2 Hz 3.15 Hz to 100 Hz 50 Hz, 100 Hz 160 Hz to 600 Hz 700 Hz to 7 kHz	3.0 % 1.3 % 2.8 % 3.7 % 3.5 %
Accelerometer charge sensitivity	Comparison ,ISO 16063-21	100 Hz, 160 Hz	2.8 %
Acceleration shock sensitivity	Comparison ,ISO 16063-21	**Shock duration** 0.3 ms to 3.0 ms **Voltage sensitivity** 1000 m/s^2 to 6000 m/s^2 8000 m/s^2 to 10000 m/s^2	 2.1 % 2.6 %
Acceleration shock sensitivity	ISO 16063-13 Laser interferometry	**Shock duration** 0.3 ms to 3.0 ms **Voltage sensitivity** 200 m/s^2 to 10000 m/s^2 **Charge sensitivity** 200 m/s^2 to 10000 m/s^2	 1.0 % 1.0 %
Vibration meter	Instrument calibration technique for vibration meter - comparison method	**Acceleration** 3.15 Hz to 50 Hz 50 Hz to 5 kHz **Velocity**: 3.15 Hz to 50 Hz 50 Hz to 2 kHz **Displacement** 3.15 Hz to 50 Hz 50 Hz to 200 Hz	 1.9 % 1.1 % 2.2 % 1.6 % 2.2 % 2.0 %
Charge Amplifier	Instrument calibration technique for charge amplifier	10 Hz to 10 kHz	0.13 %
Microphone Pressure sensitivity level	IEC 61094-2:2009	**LS1P** 20 Hz to 25 Hz 31.5 Hz to 4 kHz 5 kHz to 10 kHz **LS2P** 20 Hz to 25 Hz 31.5 Hz to 40 Hz 50 Hz to 8 kHz 10 kHz to 20 kHz	 0.06 dB re 1 V/Pa 0.05 dB re 1 V/Pa 0.07 dB re 1 V/Pa 0.08 dB re 1 V/Pa 0.06 dB re 1 V/Pa 0.05 dB re 1 V/Pa 0.11 dB re 1 V/Pa

Microphone pressure sensitivity level	IEC 61094-5: 2001	250 Hz (fulfilling IEC 61094-1LS,IEC 61094-4 WS) 20 Hz to 40 Hz 50 Hz to 8 kHz 10 kHz to 20 kHz (IEC 61094-1LS2,IEC 61094-4 WS2)	0.08 dB re 1 V/Pa 0.12 dB re 1 V/Pa 0.08 dB re 1 V/Pa 0.16 dB re 1 V/Pa
Pistonphone Sound pressure level	Sound pressure level by insert voltage	sound pressure level: (90 to 130) dB re 20 μPa Microphone type: LS1P and LS2P 250 Hz 1 kHz	 0.08 dB re 20 μPa 0.12 dB re 20μPa
	Sound pressure level by comparison method	sound pressure level: (90 to 130) dB re 20 μPa Microphone type: LS1P and LS2P 250 Hz	 0.14 dB re 20 μPa
Sound calibrator Sound pressure level	Instrument calibration technique for sound calibrator - insert-voltage technique	**multi-frequency sound calibrator:** sound pressure level: (90 to 120) dB re 20 μPa Microphone type: LS2P 31.5 Hz 63 Hz to 8 kHz 12.5 kHz to 16 kHz	 0.10 dB re 20 μPa 0.08 dB re 20 μPa 0.14 dB re 20 μPa
Sound pressure response level on sound level meter	Sequential comparison	31.5 Hz 63 Hz to 1 kHz 2 kHz to 4 kHz 8 kHz 12.5 kHz 16 kHz	0.3 dB re 20 μPa 0.2 dB re 20 μPa 0.3 dB re 20 μPa 0.4 dB re 20 μPa 0.5 dB re 20 μPa 0.6 dB re 20 μPa

- **Related Measurement and Technical Consulting Service**

The AUVL in CMS not only maintains high level of confidence in measurement standards but also helps industries and government agencies laying down proper regulations to create suitable environment for better dwelling and living einviroment. Thus, CMS has very close links to the industries and can provide consulting services like:

1. Consultancy services for establishment of calibration systems for accelerometers, vibrometers, charge amplifiers and its quality system.
2. Vibration tests, analysis, and improvement for mechanical components
3. Functionality tests for vibration testing euipments
4. Measurement of micro vibrations, monitoring and analysis of environmental vibrations
5. Seismometer and vibration monitoring system functionality and validation test
6. Stress analysis for structural dynamics, module testing, and finite element analysis
7. Calibration techniques transfer for microphones, sound pressure calibrators, and sound-level meters
8. Development test stand and test service for sound absorption/insulation characteristics of materials
9. Development test technique and test service for audio performance of electro-acoustic devices
10. Emitted noise (sound power, sound pressure) measurements, sound quality evaluation and noise reduction
11. Designing and performance testing service for audiometric booths/ hearing test rooms, hemi-anechoic/anechoic rooms, studio rooms
12. Factory/ working area noise monitoring and reduction strategy
13. Building acoustics evaluation service
14. Audio equipments test and measurement

Participation in International Standardization Committees

APMP-Asia Pacific Metrology Programme : member

- Technical Committee for Acoustic Ultrasound Vibration

IMEKO TC22 : member

Selected Publications (2011~2015)

Journal Papers

1. Jiun-Kai Chen et al., "Study of High Shock on Calibration Technology", Measurement Information (2011).
2. Jung-En Hsiao et al., "Study of the Method for Free-Field Sensitivity Calibration of Standard Microphone", Measurement Information (2011).
3. Shu-Fen Kuo et al., "Measurement Technique for the Free-Field Response of a Sound Level Meter", Measurement Information (2011).
4. Yu-Chung Huang et al., "The set up of primary calibration system for shock acceleration in NML", Measurement (2012).
5. Shu-Fen Kuo et al., "Discuss on the regional comparison for the multi-frequency sound calibrator", Measurement Information (2012).
6. Yu-Chung Huang et al., "Study on the feasibility of shock calibration comparison with different shock exciters using laser interferometry", Journal of Applied Sound and Vibration (2013).
7. Jung-En Hsiao et al., "Evaluation on the acoustics center for laboratory standard microphone", Measurement Information (2013).
8. Shu-Fen Kuo et al., "The measurement technique of materials sound insulation using the acoustic impendence tube method", Measurement Information (2013).
9. Tsung-Hsien Tu et al., "Sound Environment Prediction for working office", Measurement Information (2013).
10. Tsung-Hsien Tu., "Review on the Speech Recognition Technique", Measurement Information (2013).
11. Jung-En Hsiao et al., "Non-Contact Measurement for Fan Blade Dynamic Runout System Introduction", Measurement Information (2013).
12. Yu-Chung Huang et al., "Report On Regional Supplementary Comparison APMP.AUV.A-S1", Metrologia (2014)
13. Tsung Hsien Tu et al., "Anthropometry of external auditory canal by non-contactable measurement", Applied Ergonomics (2015)

Conference Papers

1. Shu-Fen Kuo et al., "Research on Measurement Technique for the Free-Field Response of a Sound Level Meter", Acoustics on Conference (2011)
2. Sheng-Hang Wang et al., "International comparison of NML primary low frequency vibration calibration system", The 20st National Conference on Chinese Society of Sound and Vibration (2012)
3. Jiun-Kai Chen et al., "The key comparison feasibility evaluation between low shock and high shock acceleration calibration system", IMEKO World Congress (2012)
4. Jung-En Hsiao et al., "Preliminary Study for Microphone Free-field Sensitivity Calibration by Reciprocity Method", Cross-Strait Conference on Measurement and Inspection Technologies (2013)

5. Pei-Yao Yu et al., "The theory applicable to vibration calibration of accelerometer by laser interferometry", The 21st National Conference on Chinese Society of Sound and Vibration, (2013).
6. Sheng-Hang Wang et al., "Study of effects for low frequency accelerometer calibration", The 21st National Conference on Chinese Society of Sound and Vibration, (2013).
7. Jung-En Hsiao et al., "The works for microphone free-field sensitivity calibration by reciprocity method", InterNoise (2013).
8. Kuang-Yih Tsuei et al., "Research on calibration technology for reference sound source", InterNoise (2013).
9. Pei-Yao Yu et al., "The dynamic characteristics test and simulation of isolated foundation", The 22nd National Conference on Chinese Society of Sound and Vibration (2014).
10. Sheng-Hang Wang et al., "Study of Piezoelectric Vibrating Exciter", The 22nd National Conference on Chinese Society of Sound and Vibration, (2014).
11. Tsung-Hsien Tu et al., "Anthropometry of External Auditory Canal by Non-contactable Measurement", Inter Noise (2014).
12. Tsung-Hsien Tu et al., "Systemic simulation for the wind turbine noise propagation", Conference on Taiwan Wind Energy Association, (2014)
13. Yu-Chung Huang, et al., "The Inter-Comparison of Vibration and Shock Accelerometer for Industry Traceability", Cross-Strait Conference on Measurement and Inspection Technologies (2014).
14. Pei-Yao Yu, "Investigation on exciter transverse motion and its effect on accelerometer calibration uncertainty", The 23rd National Conference on Chinese Society of Sound and Vibration (2015).
15. Sheng-Hang Wang et al., "Precision Spindle Dynamic Error Motion Measurement Technology", The 23rd National Conference on Chinese Society of Sound and Vibration (2015).
16. Tsung-Hsien Tu, et al., "The Setup and Performance Evaluation of Accelerometer Comparison Calibration System in NML Taiwan", IMEKO XXI World Congress (2015).