工業技術研究院
Industrial Technology
Research Institute

CCAUV/15-48

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

Center for Measurement Standards (CMS) / ITRI

Yu-Chung HUANG

2015/11/27

Outline

- Introduction of CMS/ITRI & AUVL
- Measurement Facilities & Calibration Service
- Metrology application to Industry Project
- International Activity
- Publications
- Conclusion

About ITRI (Founded in 1973)

A not-for-profit, non-government R&D organization

8.1.2015

Total Staff: 5,561

Ph.D.：	1,310
Master：	3,030
Bachelor：	1,221
Alumni：	23,538

Total Patents

23,101

Startups & Spinoffs(2014)

260

Industry Services(2014)

Provided Services：15,086

Transferred Technologies：626

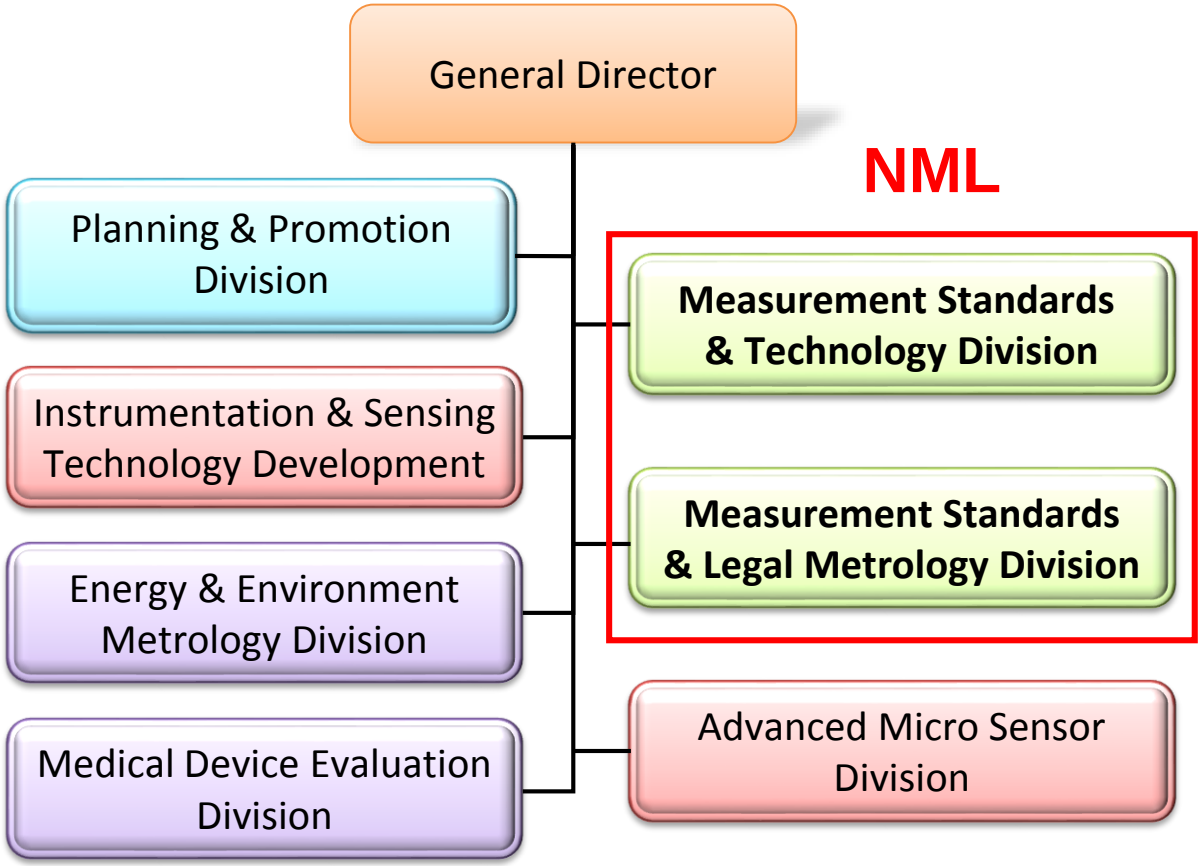
Organization

About CMS/ITRI (Founded on August 1985)

1987	Open House of NML
1994	Entry to and as a founding member of APMP
1985	Acquire ISO 9001 QA certificate
2002	Accepted as an associate member of CGPM
2003	Entry to BIPM-KCDB CMCs (Appendix C) reviewed by BIPM/JCRB; EM quantity being the first getting approved
2015	28th Anniversary of CMS-NML

Organization of CMS/ITRI

Total staff: 277

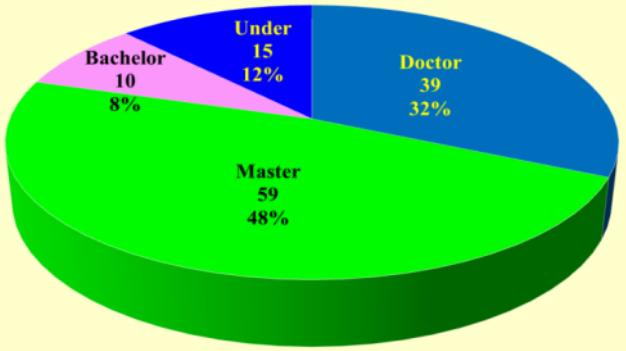


NML

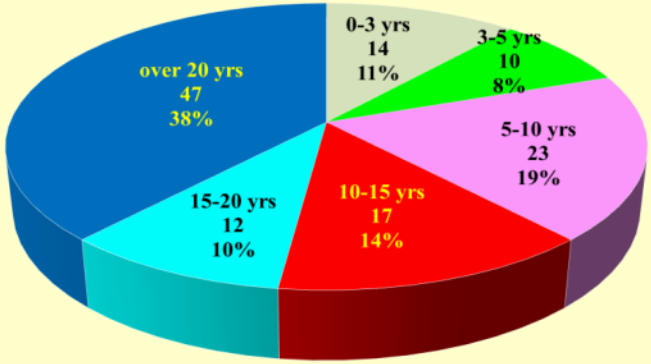
Total staff: 123

Average Exp: 15.3 years

Education



Professional Experience



CMCs

Calibration and Measurement Capabilities

Acoustics, Ultrasound and Vibration, Chinese TAIPEI, CMS (Center for Measurement Standards)

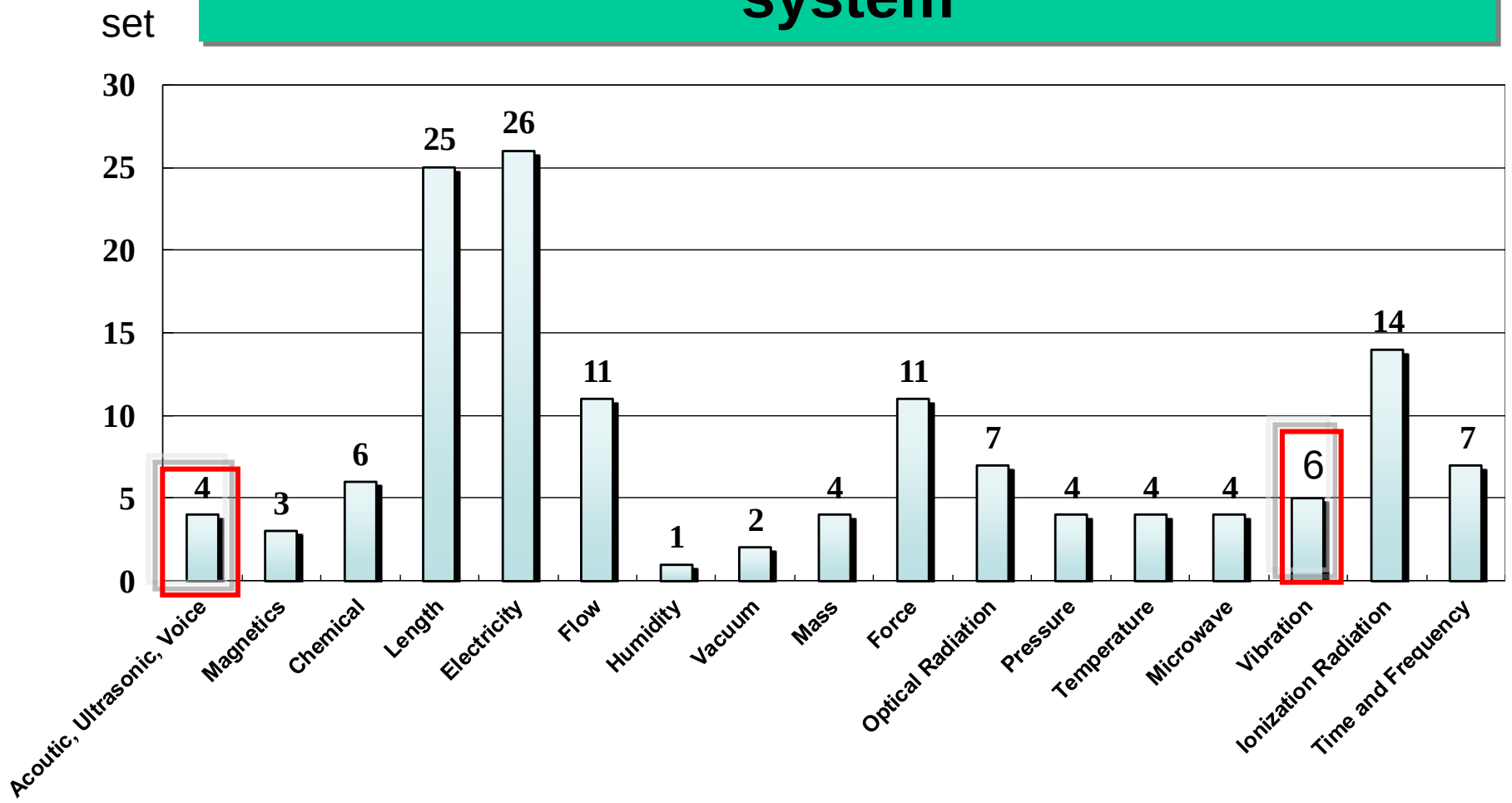
KCDB

Calibration or Measurement Service			Measurand Level or Range			Measurement Conditions/Independent Variable		Expanded Uncertainty						
Quantity	Instrument or Artifact: Measurand	Instrument Type or Method	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of Confidence	Is the expanded uncertainty a relative one?	NMI Service Identifier	Comments
Pressure sensitivity level	Measurement microphone type: IEC 61094-1 LS1P	IEC 61094-2:2009			dB (reference: 1 V/Pa)	Frequency	20 Hz to 25 Hz	0.06	dB	2	95%	No	A-01	Approved on 12 January 2012
Pressure sensitivity level	Measurement				dB									ed on 12 ry 2012
Pressure sensitivity level														ed on 12 ry 2012
Pressure sensitivity level														ed on 12 ry 2012
Pressure sensitivity level														ed on 12 ry 2012
Pressure sensitivity level														ed on 12 ry 2012
Pressure sensitivity level														ed on 12 ry 2012
Pressure sensitivity level	IEC 61094-4 WS2				1 V/Pa)									ed on 12 ry 2012
Pressure sensitivity level	Measurement microphone type: IEC 61094-1 LS2, IEC 61094-4 WS2	IEC 61094-5:2001			dB (reference: 1 V/Pa)	Frequency	31.5 Hz to 40 Hz	0.12	dB	2	95%	No	A-02	Approved on 12 January 2012
Pressure sensitivity level	Measurement microphone type: IEC 61094-1 LS2, IEC 61094-4 WS2	IEC 61094-5:2001			dB (reference: 1 V/Pa)	Frequency	50 Hz to 8 kHz	0.08	dB	2	95%	No	A-02	Approved on 12 January 2012
Pressure sensitivity level	Measurement microphone type: IEC 61094-1 LS2, IEC 61094-4 WS2	IEC 61094-5:2001			dB (reference: 1 V/Pa)	Frequency	10 kHz to 20 kHz	0.16	dB	2	95%	No	A-02	Approved on 12 January 2012
Pressure sensitivity level	Measurement microphone type: IEC 61094-1 LS and IEC 61094-4 WS	IEC 61094-5:2001			dB (reference: 1 V/Pa)	Frequency	250 Hz	0.08	dB	2	95%	No	A-02	Approved on 12 January 2012

- Since 2006, the CMCs of CMS-AUV have been incorporated in KCDB.
- In 2015, there are 39 items were listed on the BIPM website.

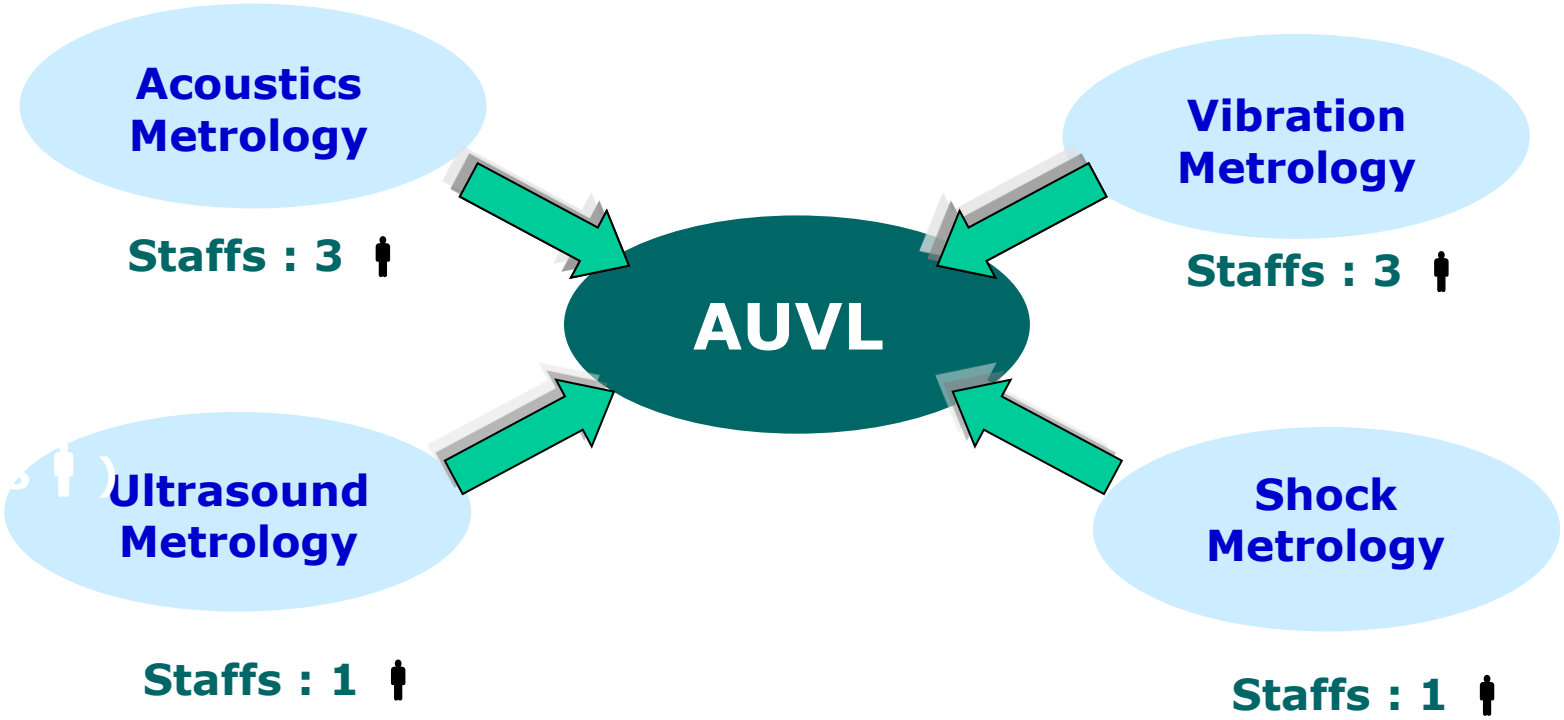
Measurement Capabilities of CMS

Total: 17 fields / 139 sets of measurement system



Acoustics Ultrasound and Vibration measurement Lab.

- The Acoustics, Ultrasound and Vibration Laboratory (AUVL) provides traceability of sound pressure, acceleration standards and relative calibration services for domestic industry in TAIWAN.
- There are 10 measurement systems in AUVL.



- Introduction of CMS/ITRI & AUVL
- **Measurement Facilities & Calibration Service**
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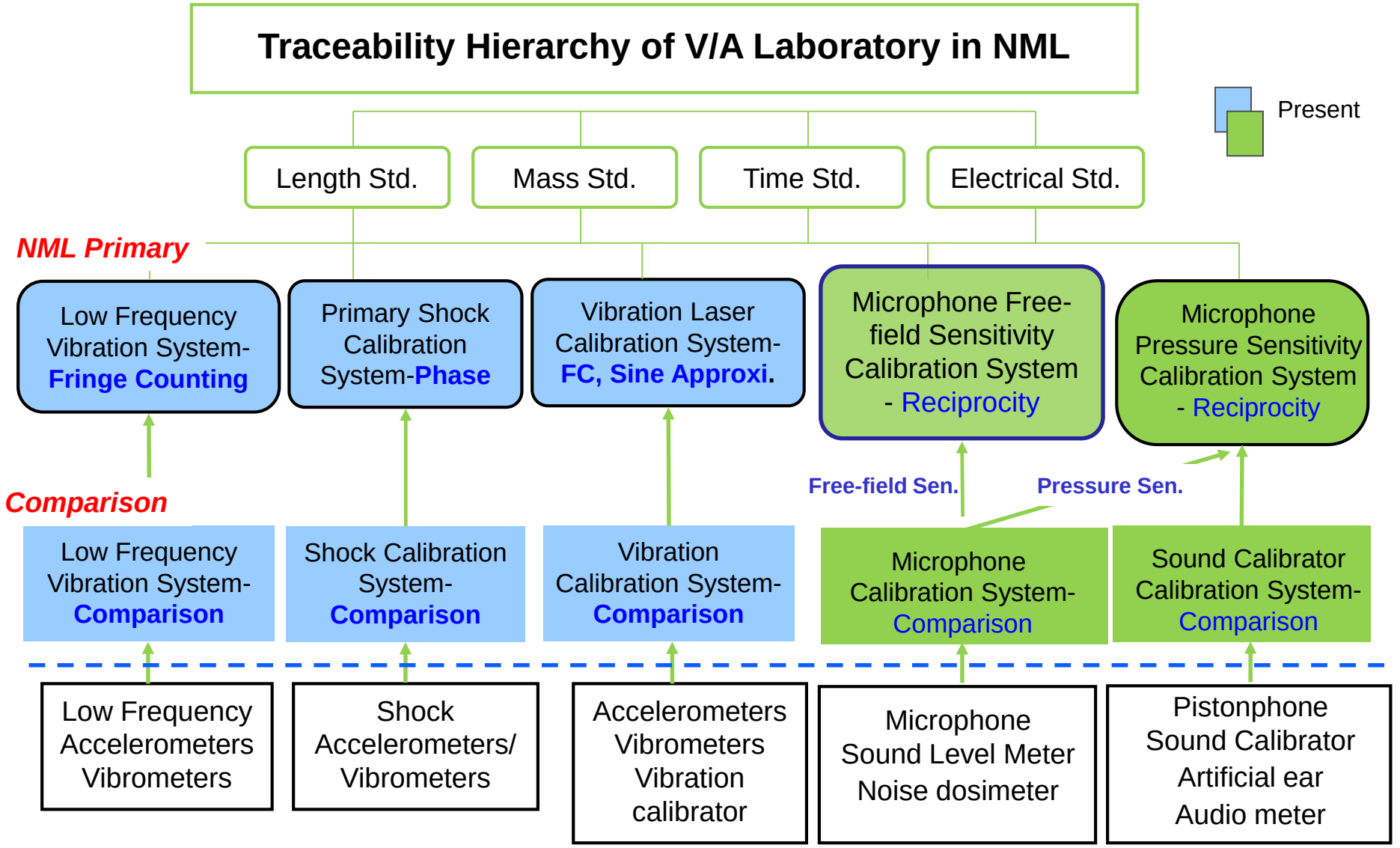
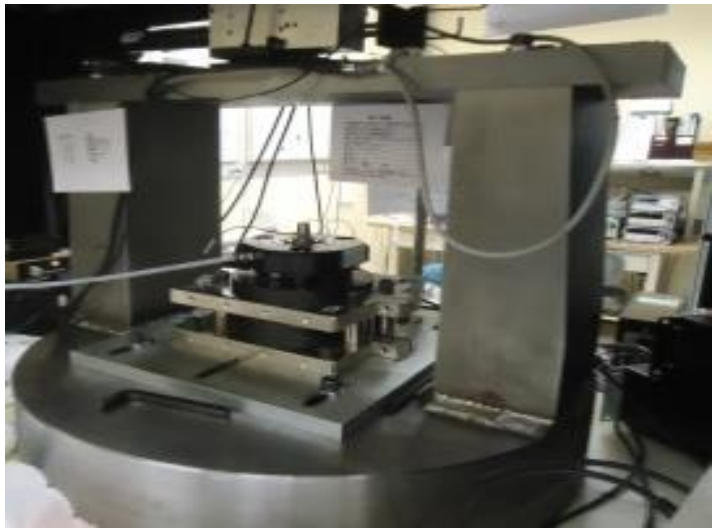
A/V standards



V01 Primary Accelerometer Calibration



APMP.AUV.V-K1
APMP.AUV.V-K1.1

Air Bearing Shaker
PCB 396C11

Sine-Approximation Method

Range : 50 Hz - 10000 Hz

Relative Expanded uncertainty:

50 Hz - 1500 Hz : 0.5 %

3000 Hz - 5000 Hz : 1.0 %

6000 Hz - 10000 Hz : 1.8 %

Coverage factor : k =2

Fringe-Counting Method

Range : 50 Hz - 700 Hz.

Relative Expanded uncertainty: 0.5 %

Coverage factor : k =2

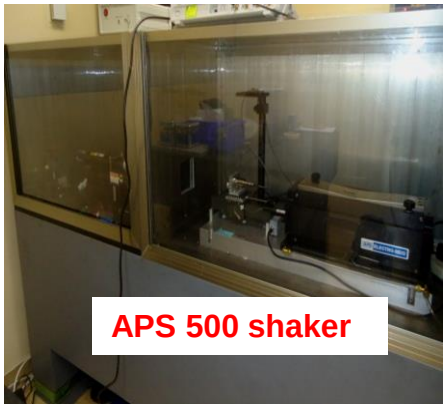
V02 Secondary Accelerometer Calibration

B&K 4812 Shaker

Frequency	U
50 Hz to 1.5 kHz	1.4 %
1.5 kHz to 5 kHz	1.9 %
5 kHz to 7 kHz	2.4 %

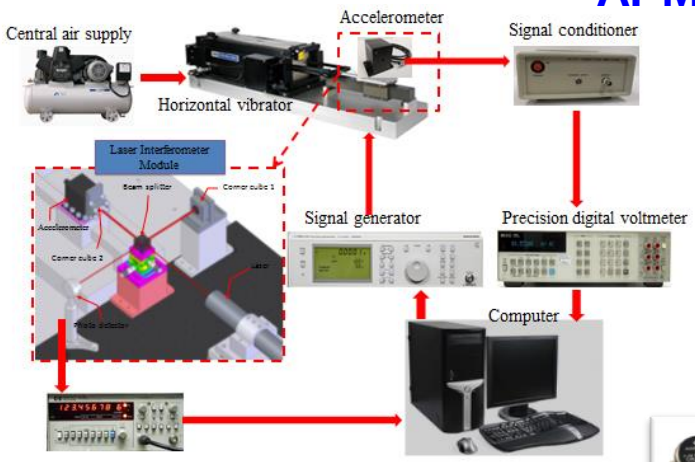
This calibration system is to provide calibration of the accelerometers and vibration meters for most of the industry and research in Taiwan.

V04 Low Frequency Vibration Calibration



Comparison method Fringe counting method

APMP.AUV.V-S1

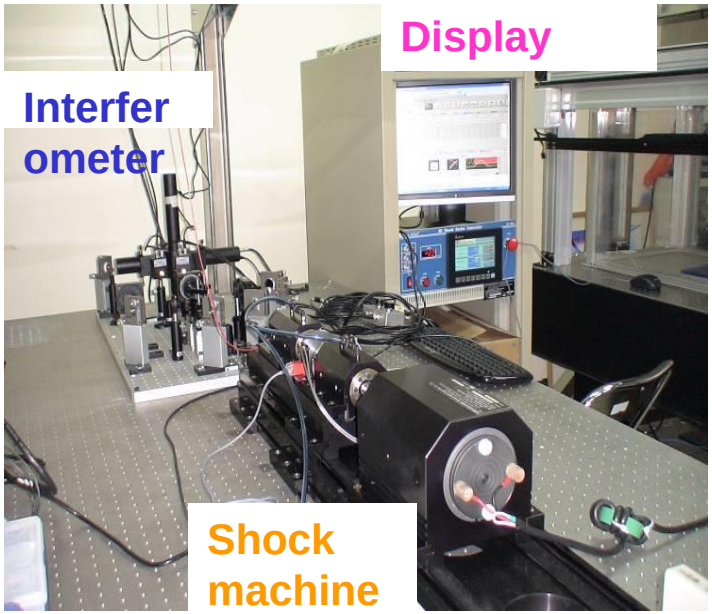


Item	Range	Relative Expanded uncertainty	Coverage factor
Accelerometer	0.8 Hz to 2 Hz	2.8 %	k ≅ 2
	3.15 Hz to 100 Hz	1.3 %	k ≅ 2

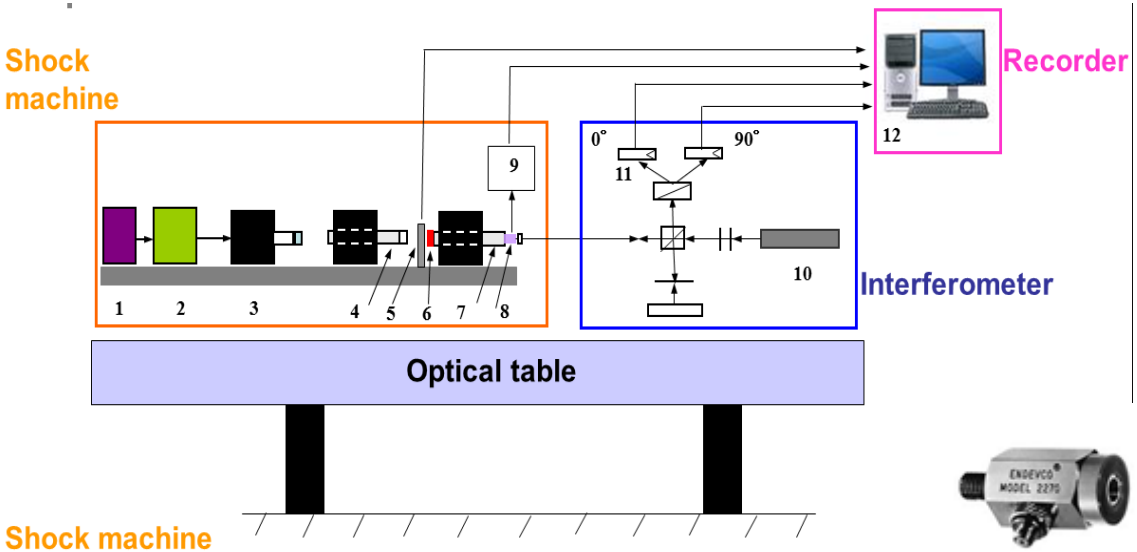
Item	Range	Relative Expanded uncertainty	Coverage factor
Accelerometer	0.4 Hz to 0.7 Hz	2.8 %	$k \cong 2$
	0.8 Hz to 0.2 Hz	2.5 %	$k \cong 2$
	3.15 Hz to 100 Hz	0.6 %	$k \cong 2$

The measurement frequency range is from 0.4 Hz to 100 Hz with acceleration 1 m/s^2 to 5 m/s^2.

V06 Primary Low Shock Calibration



APMP.AUV.V-P1



Shock machine

1. Controller 2. Programmable DC supply 3. High speed electromagnetic hammer
4. Airborne hammer 5.Trigger unit 6. PU rubber 7. Airborne anvil 8. Accelerometer 9. Charge amplifier

Interferometer

10. Laser 11. Light detectors

Recorder

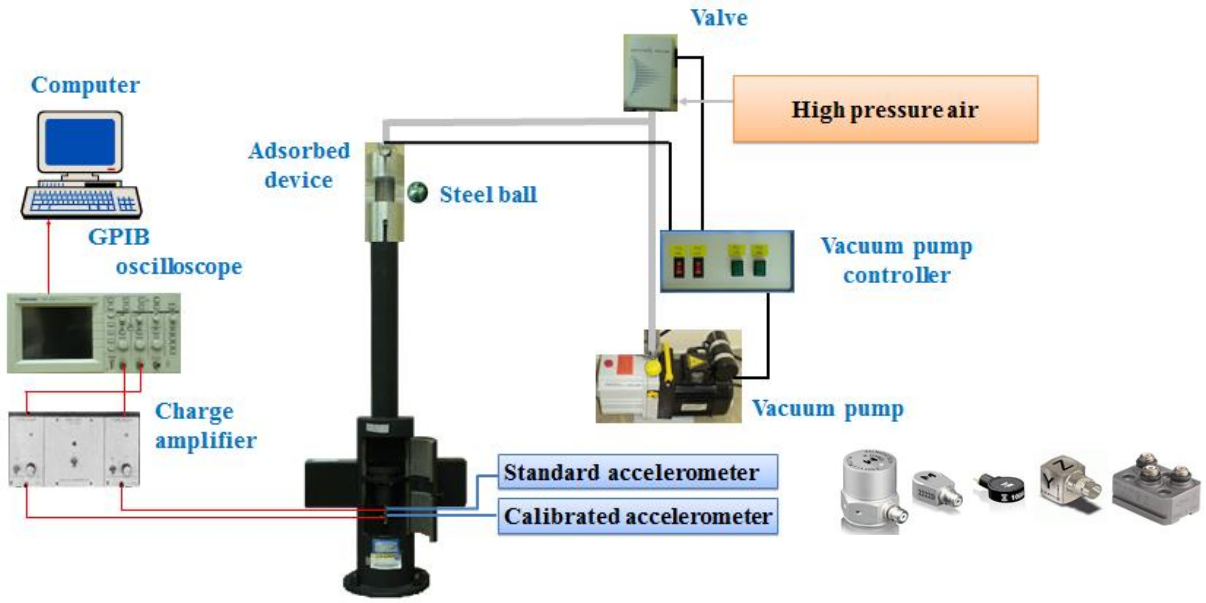
12.Digital scope： NI 5124 -50 MHz 12 bit (Quadrature Interferometer signal)
NI 5922 -10 MHz 16 bit (Accelerometer output Voltage)

Item	Range	Relative Expanded uncertainty	Coverage factor
Accelerometer	0.2 km/s², 1 km/s², 2 km/s², 3 km/s², 4 km/s², 5 km/s², 6 km/s², 8 km/s², 10 km/s²	1.0 %	$k \cong 1.96$

Duration time :

< 3.0 ms

V03 Comparison Shock Calibration

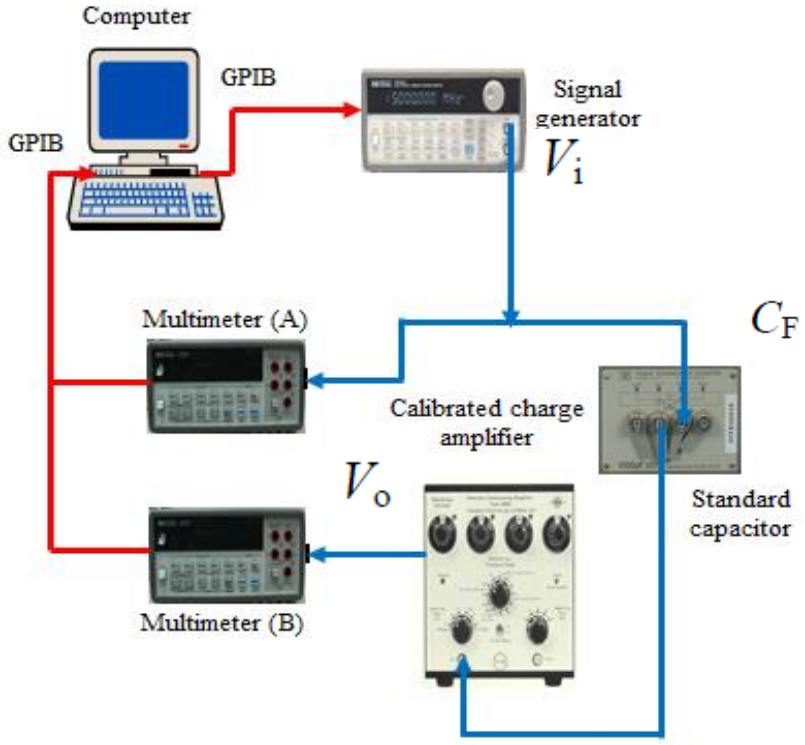


Range : 980 m/s^2 to 9800 m/s^2

Item	Range	Relative Expanded uncertainty	Coverage factor
Acceler ometer	1 km/s^2, 2 km/s^2, 3 km/s^2, 4 km/s^2, 6 km/s^2	2.1 %	k = 1.97
	8 km/s^2, 10 km/s^2	2.6 %	k = 1.97

The system is to provide the measurement traceability of the drop test and reliability test for the consumer electronics product manufactured in Taiwan.

Charge Amplifier Calibration



$$A = \frac{V_o}{V_i C_F}$$

A : the sensitivity of the calibrated charge amplifier (mV/pC)

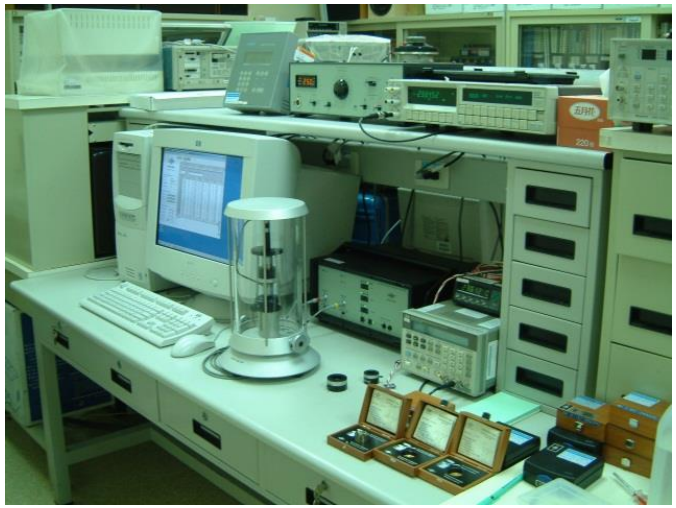
C_F: the standard capacitance (pF)

V_i: the output voltage of the signal generator (V)

V_o: the output voltage of the calibrated charge amplifier (V)

Charge Amplifier Calibration
Range : 10 Hz - 10 kHz.
Relative Expanded uncertainty:
0.22 % ~ 0.64 %.
Coverage factor : k =2

A01 Microphone Pressure Field Sensitivity Calibration - Reciprocity Method



Range : 20 Hz to 20 kHz

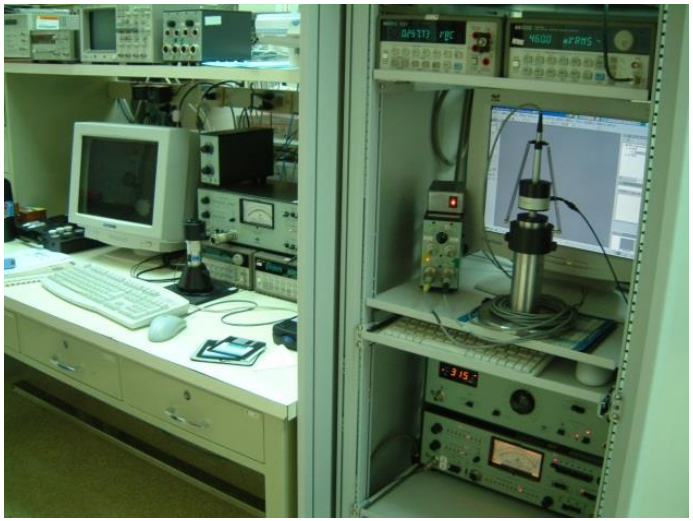
APMP.AUV.A-K1
APMP.AUV.A-K3

Items Calibrated:

Fulfilling IEC 61094-1 LS1P, LS2aP and LS2F Laboratory Standard Condenser Microphone

Item	Range		Expanded uncertainty	Coverage factor
Microphone	LS1P	20 Hz to 25 Hz	0.06 dB	$k \cong 2$
		31.5 Hz to 4 kHz	0.05 dB	$k \cong 2$
		5 kHz to 10 kHz	0.07 dB	$k \cong 2$
	LS2P	20 Hz to 25 Hz	0.08 dB	$k \cong 2$
		31.5 Hz to 40 Hz	0.06 dB	$k \cong 2$
		50 Hz to 8 kHz	0.05 dB	$k \cong 2$
		10 kHz to 20 kHz	0.11 dB	$k \cong 2$

A02 Microphone Pressure Sensitivity Calibration – Single / Multi-Frequency Comparison Method



Range : 20 Hz to 20 kHz

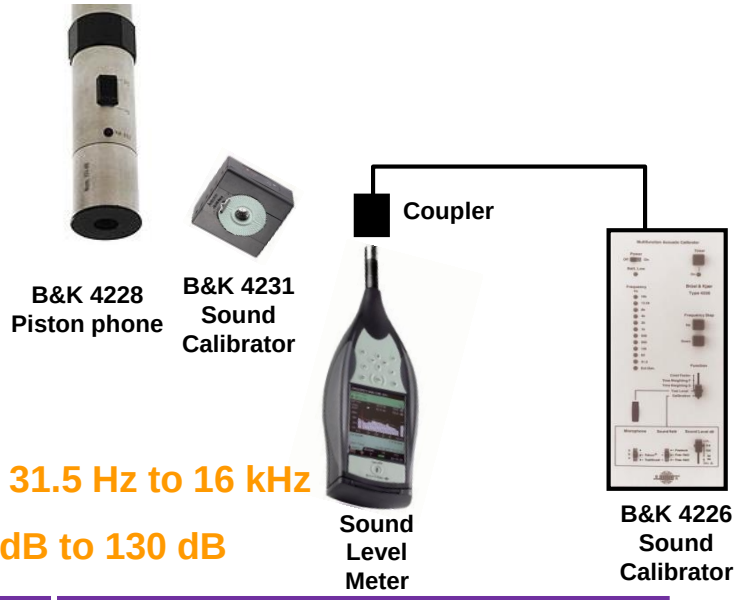
Items Calibrated:

Fulfilling IEC 61094-1 LS, IEC 61094-4 WS

Item	Range		Expanded uncertainty	Coverage factor
Microphone	LS2, WS2	20 Hz to 40 Hz	0.12 dB	$k \cong 2$
		50 Hz to 8 kHz	0.08 dB	$k \cong 2$
		10 kHz to 20 kHz	0.16 dB	$k \cong 2$

Item	Range		Expanded uncertainty	Coverage factor
Microphone	LS, WS	250 Hz	0.08 dB	$k \cong 2$

A03 Sound Calibrator and Sound Level Meter Calibration - Comparison Method



Range : 31.5 Hz to 16 kHz

90 dB to 130 dB

Items calibrated	Frequency range	Expanded uncertainty
Sound Calibrator	1 kHz	0.14 dB
Piston-phone	250 Hz	0.14 dB
Sound level meter	31.5 Hz	0.3 dB
	63 Hz to 1 kHz	0.2 dB
	2 kHz to 4 kHz	0.3 dB
	8 kHz	0.4 dB
	12.5 kHz	0.5 dB
	16 kHz	0.6 dB

A03 Sound Calibrator Calibration – Insert Voltage

APMP.AUV.A-S1

Range : 31.5 Hz to 16 kHz

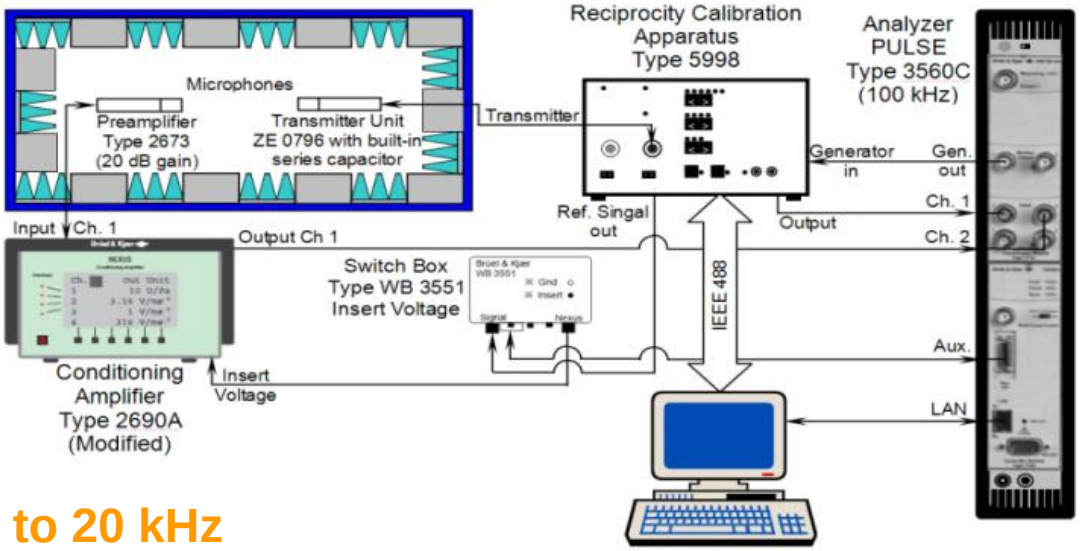
90 dB to 130 dB

Items calibrated	Frequency range	Expanded uncertainty	
Sound Calibrator Piston-phone Multi-frequency sound calibrator	31.5 Hz	LS2P	0.10 dB
		WS2P	0.16 dB
	63 Hz to 8 kHz	LS1P/LS2P	0.08 dB
		WS1P/WS2P	0.12 dB
	12.5 kHz to 16 kHz	LS2P	0.14 dB
		WS2P	0.18 dB

A04 Microphone Free-Field Sensitivity Calibration - Reciprocity Method

Vertically disposed by NIM

Horizontally disposed by CMS/ITRI



Range : 1 kHz Hz to 20 kHz

Bilateral comparison between CMS/ITRI and NIM

Item	Range	Expanded uncertainty	Coverage factor
LS2P	1 kHz to 10 kHz	0.30 dB	$k \cong 2$
	12.5 kHz to 16 kHz	0.15 dB	$k \cong 2$
	20 kHz	0.30 dB	$k \cong 2$

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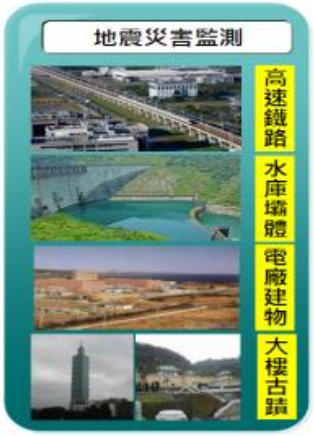
Seismometer Verification

Sites of seismometer
In Taiwan

Ji Ji earthquake (1999)

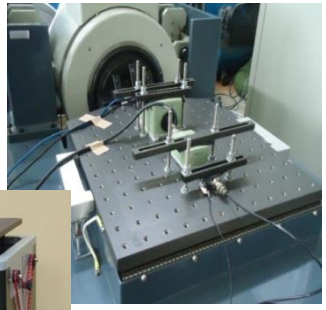


monitoring of earthquake

different type seismometer

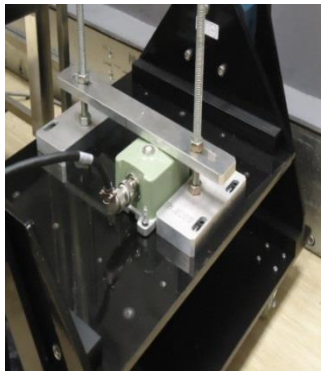
Vertical

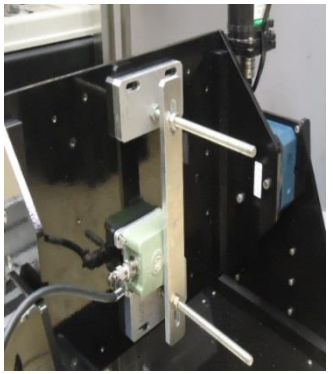
Shaker



Horizontal
Shaker

Dynamic verification



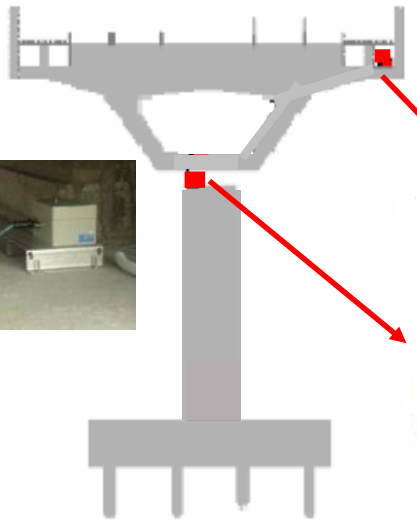


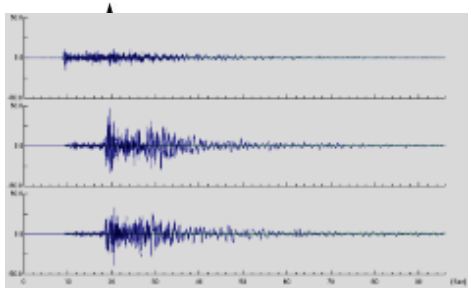
Tilt testing (different tilt angle)

Static verification

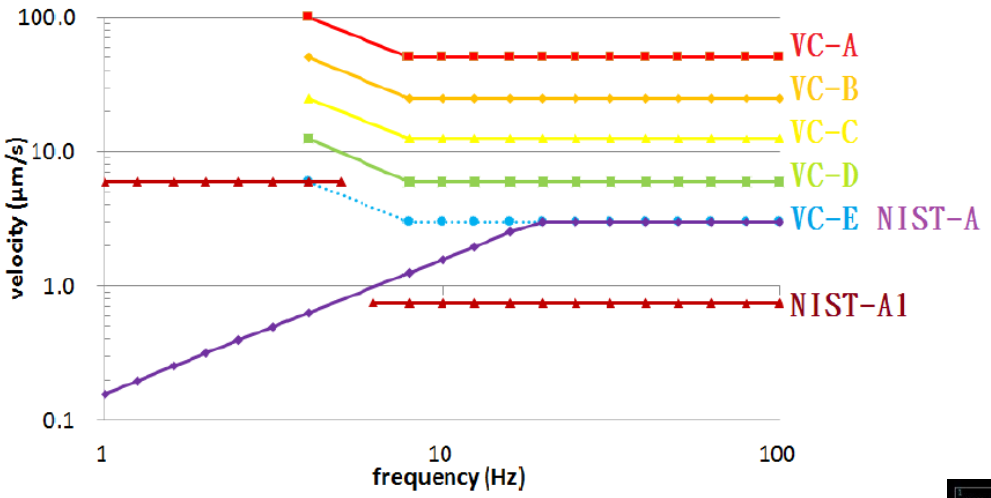
Earthquake monitoring for High Speed Train

- Record 48 months earthquake events data
- Compare the earthquake value between peer (Slave) and bridge (Master)
- Verify the amplification of the structure



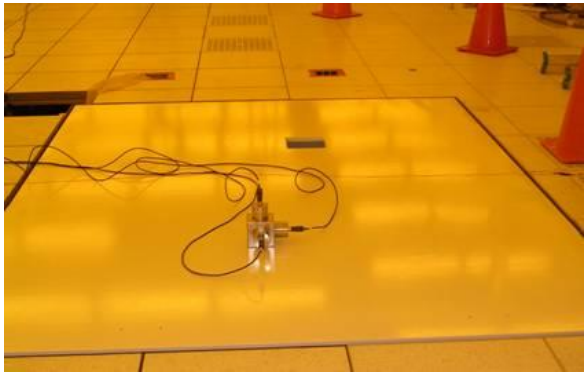


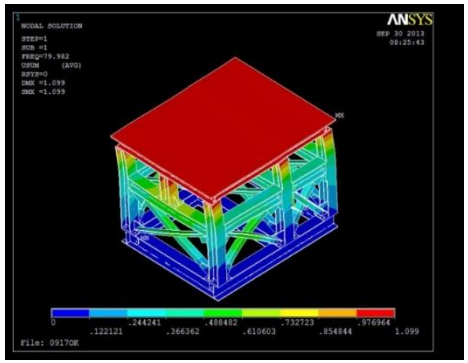
Foundation Micro-Vibration Measurement



VC-A to VC-E vibration criteria

(C.G. Gordon, 1999, "Generic Vibration Criteria for Vibration-Sensitive Equipment", Proceedings of International Society for Optical Engineering)



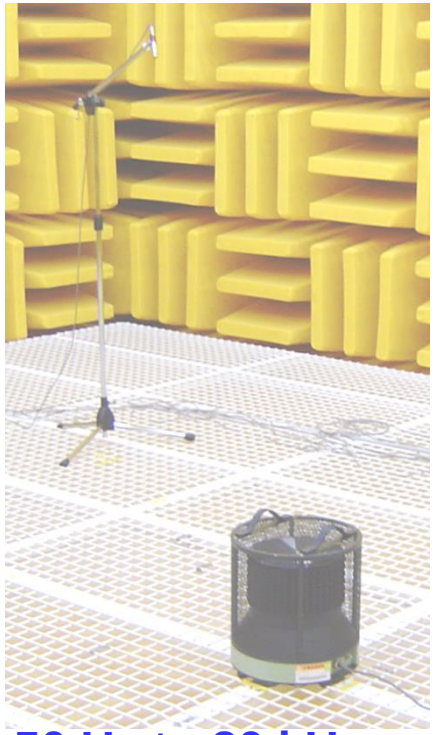


Modal analysis

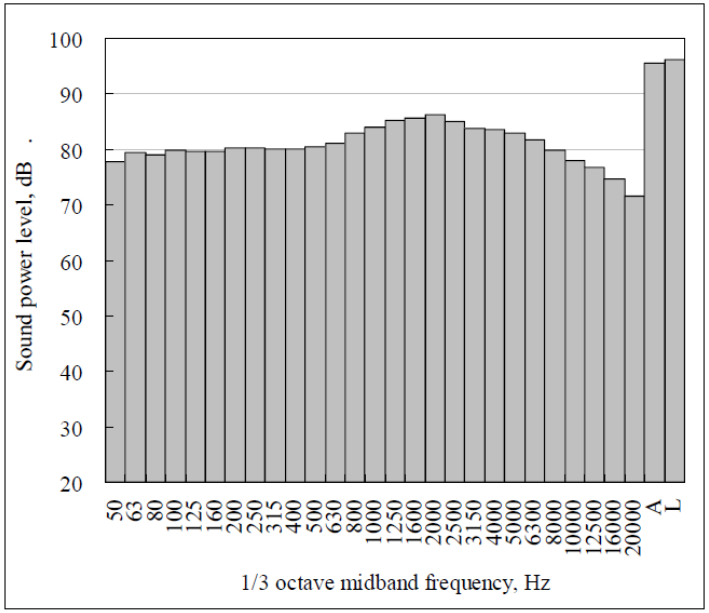
High sensitivity accelerometer is required

1. Voltage Sensitivity：10.0V/g
2. Frequency range(±5 %)：0.1 Hz~200 Hz
3. Measurement range：± 0.5 g pk
4. Resolution(Broadband)：1 μg(0.2 μg)

Reference Sound Source Calibration



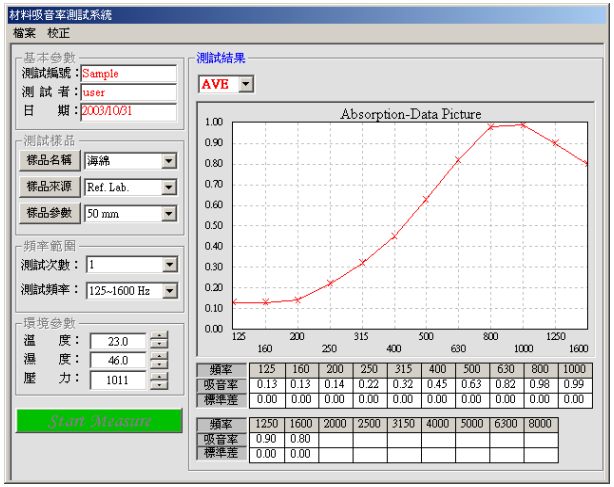
50 Hz to 20 kHz



1/3 octave midband frequency (Hz)	Sound power level (dB re 1 pW)	Expanded uncertainty (dB re 1 pW)
50	77.7	2.5
63	79.4	1.5
80	78.9	1.4
100	79.7	0.9
125	79.5	0.8
160	79.6	0.8
200	80.1	0.7
250	80.2	0.7
315	79.9	0.7
400	80.0	0.7
500	80.3	0.7
630	81.0	0.7
800	82.8	0.7
1000	83.8	0.7
1250	85.0	0.7
1600	85.5	0.7
2000	86.2	0.7
2500	84.8	0.7
3150	83.6	0.7
4000	83.5	0.7
5000	82.8	0.7
6300	81.6	0.8
8000	79.8	0.8
10000	77.9	0.8
12500	76.7	0.9
16000	74.7	1.1
20000	71.5	1.4
A-weighted	95.4	0.7
Linear	96.0	0.7

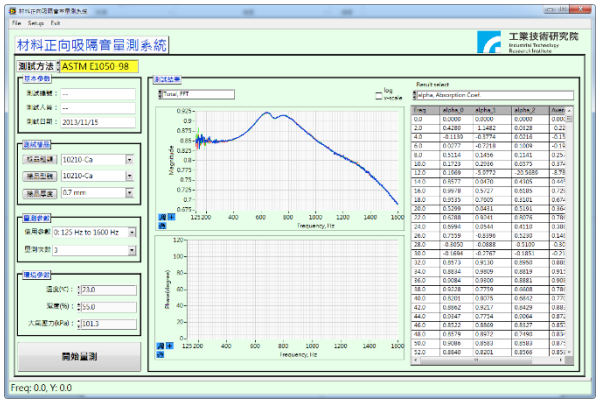
1. ISO 6926, Acoustics – Requirements for the performance and calibration of reference sound sources used for the determination of sound power levels, 2000.
2. ISO 3745, Acoustics – Determination of sound power levels of noise sources using sound pressure – Precision methods for anechoic and hemi-anechoic rooms, 2003.
3. ISO/IEC Guide 98-3, Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement, 2008.

Acoustics Material Testing



ASTM E1050-98

Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones, and a Digital Frequency Analysis System.



ASTM E2611-09

Standard Test Method for Measurement of Normal Incidence Sound Transmission of Acoustical Materials Based on the Transfer Matrix Method.

Wind Turbine Induce Noise Measurement

Penghu island
500 km from Taiwan

P1,P2,P4 for Sound Power Rated
Floor Board for eliminating the wind noise

P5,P6,P7 for Sound Propagation
Height at human ear for simulating the receiver perception

R:22 m

H:46 m

Wind Direction

P2

60^0

60^0

P1

68 m

R_1:82.1 m

P4

P5

168 m

R_5:174.2 m

P6

R_6:362.9 m

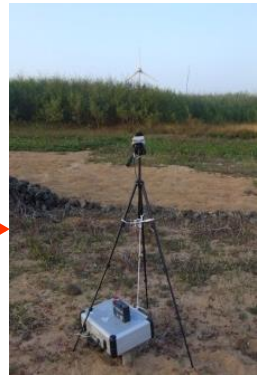
360 m

R_7:564.9 m

P7

563 m

Elementary School



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International Activities

◎ Hosted 2013 APMP Meeting

APMP TCAUV members

International Activities

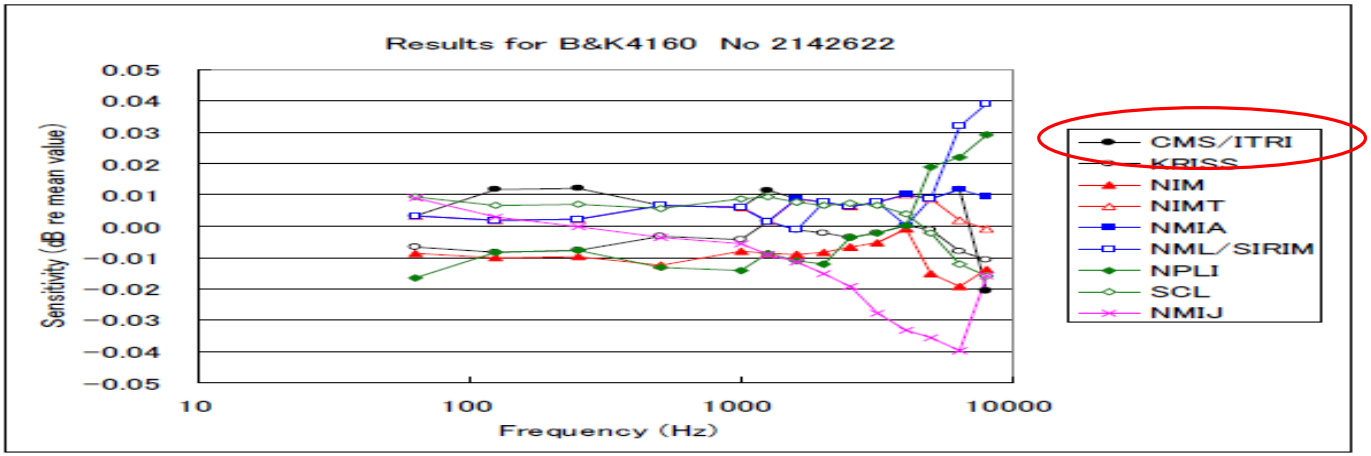
◎ Comparison

Code	Date	Title	
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

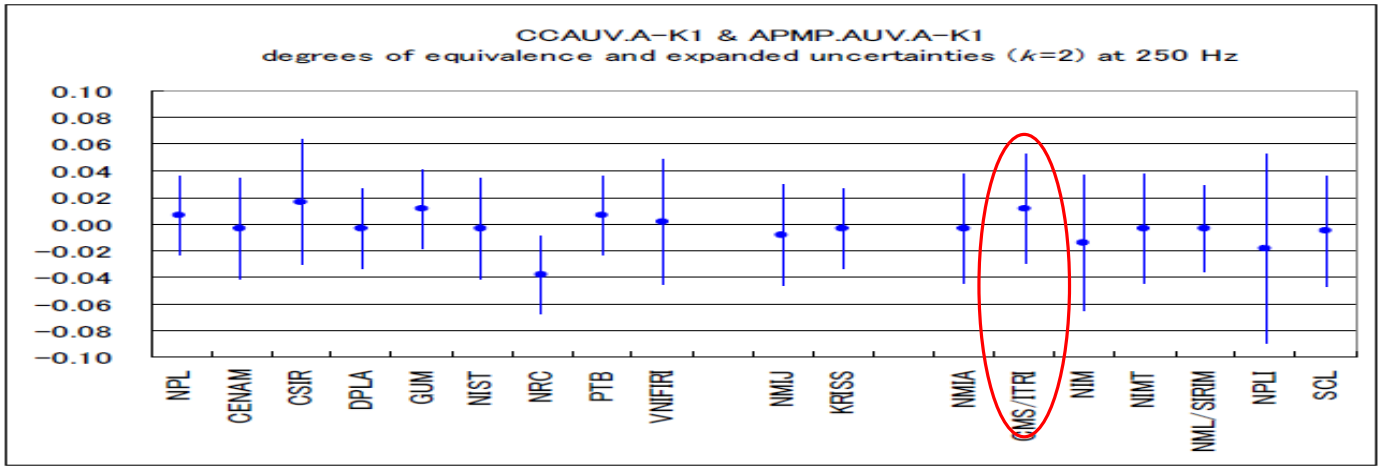
International Activities

◎ Comparison Results

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



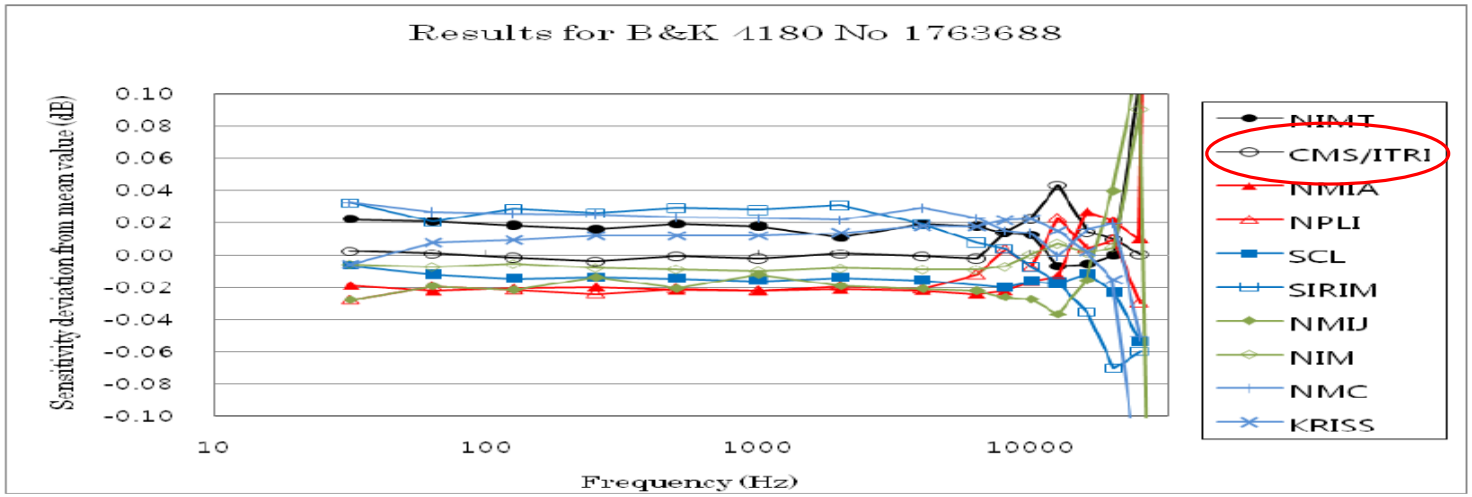
CCAUV.A-K1&APMP.AUV.A-K1(250 Hz)



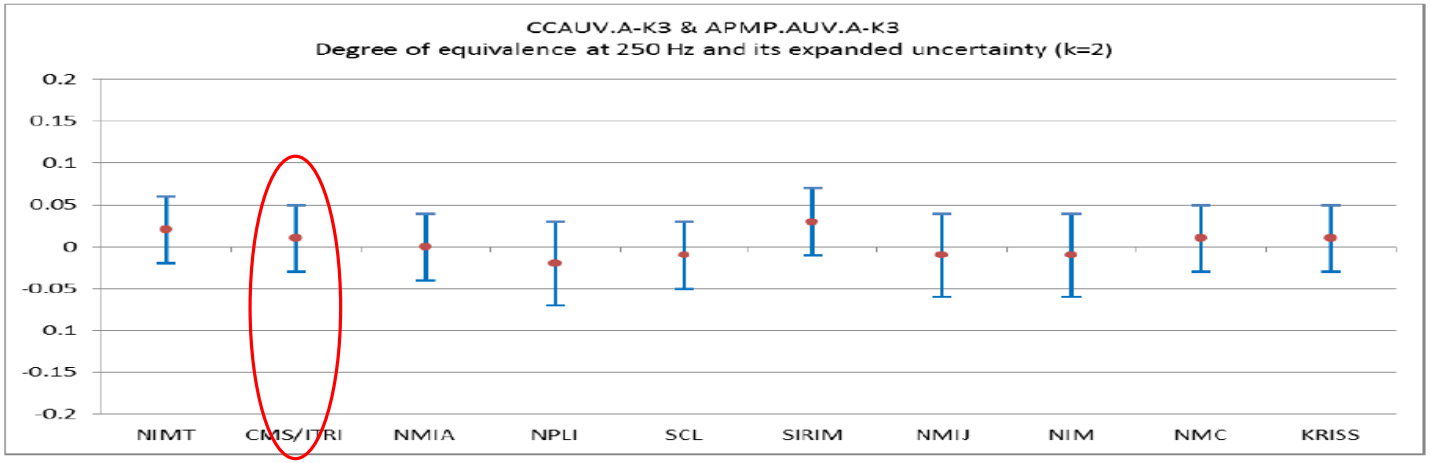
International Activities

◎ Comparison Results

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



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



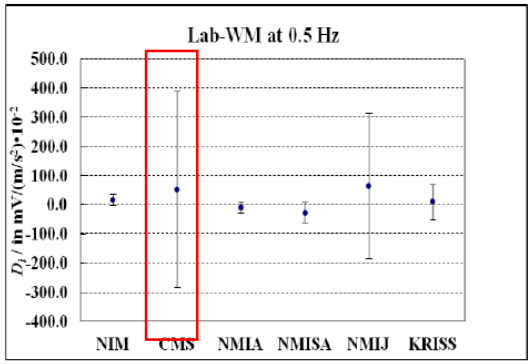
International Activities

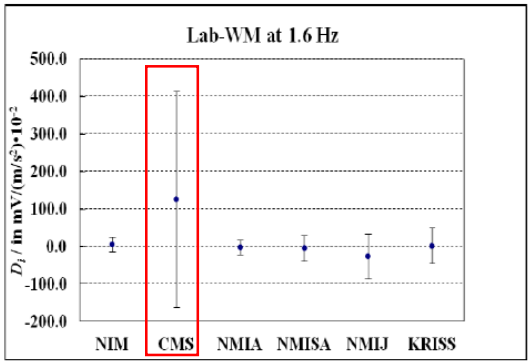
DoE between the participants of APMP.V-K1.1 and those of CCAUV.V-K1 for the BB transducer at 160 Hz

◎ Comparison Results

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/s^2)·10^{-4}		in pC/(m/s^2)·10^{-4}		in pC/(m/s^2)·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 horizontal voltage sensitivity of SE-1021at 0.5 Hz and 1.6 Hz

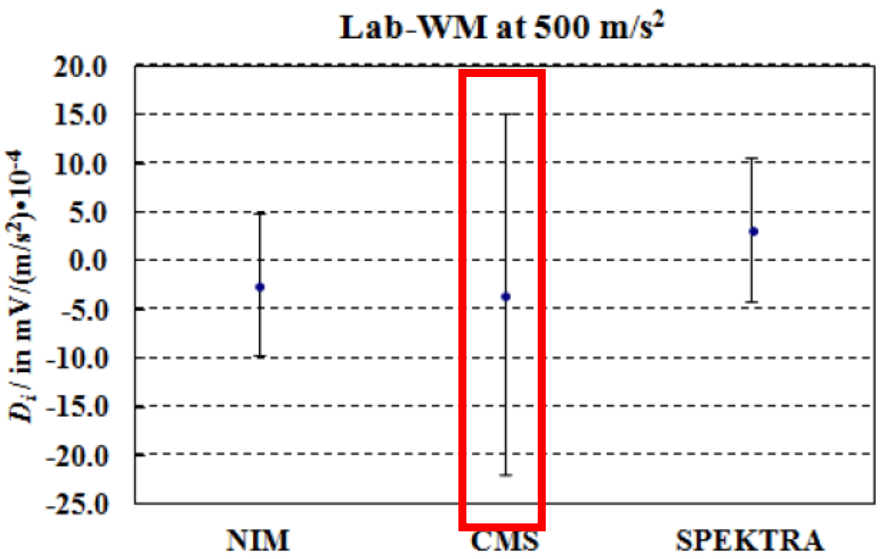


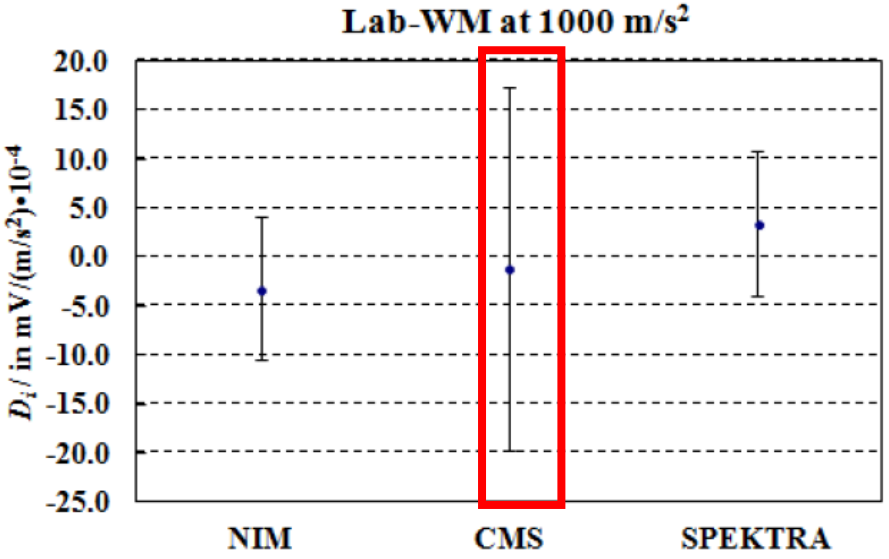


International Activities

◎ Pilot Study Results

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





International Activities

Participation in International Standardization Committees

- **APMP-Asia Pacific Metrology Programme: TCAUV**
  - ➢ **Technical Committee for Acoustics, Ultrasound and Vibration**

- **IMEKO TC22 : member.**

As APMP TCAUV_Inter_RMO reviewer

- **NMI LNE, France , NMI: CEM, Spain**

As Technical Peer reviewer

- **NMIA (2015.04) , NIM(2015.10)**

Invited speaker

- **2014 APMP TCAUV DEC workshop**
- **2015 APMP TCAUV TCI Workshop**

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)

Selected Publications(2011~2015)

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).

Conclusions

CMS is not only the organization to maintain high level of confidence in measurement standards and provide services to Taiwan's industries, but also a member of international metrology society. We are willing to have more contributions to this society.

Thank you for your attention.

http://www.nml.org.tw/index.asp