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

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

ITRI Southern Region Campus
ITRI Central Region Campus
Biomedical Technology and Device Research Laboratories
Green Energy and Environment Research Laboratories
Material and Chemical Research Laboratories
Mechanical and Systems Research Laboratories
Information and Communications Research Laboratories
Electronics and Optoelectronics Research Laboratories
Center for Measurement Standards
Display Technology Center
Service Systems Technology Center
Industrial Economics and Knowledge Center
Knowledge-based Economy and Competitiveness Center
Computational Intelligence Technology Center
Machine Tools Technology Center

ITRI College
Technology Transfer Center
Commercialization and Industry Service Center
ITRI International Center
Office of Strategy and R&D Planning
Office of Marketing Communications

Administrative Service
Accounting Resource Center
IT Service and Development Center
Human Resources Office

Industrial Technology Investment Corporation

Center for Measurement Standards
# About CMS/ITRI (Founded on August 1985)

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

Total staff: 277

NML
Total staff: 123
Average Exp: 15.3 years

Education

Professional Experience

- Bachelor: 10 (8%)
- Under 15: 12%
- Master: 59 (48%)
- Doctor: 39 (32%)

- 0-3 yrs: 14 (11%)
- 3-5 yrs: 10 (8%)
- 5-10 yrs: 23 (19%)
- 10-15 yrs: 17 (14%)
- Over 20 yrs: 47 (38%)

Planning & Promotion Division
Instrumentation & Sensing Technology Development
Energy & Environment Metrology Division
Medical Device Evaluation Division

General Director
Measurement Standards & Technology Division
Measurement Standards & Legal Metrology Division
Advanced Micro Sensor Division
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
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
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• International Activity
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• Conclusion
A/V standards

Traceability Hierarchy of V/A Laboratory in NML

NML Primary

Length Std.  Mass Std.  Time Std.  Electrical Std.

Low Frequency Vibration System
- Fringe Counting

Primary Shock Calibration System
- Phase

Vibration Laser Calibration System
- FC, Sine Approx.

Microphone Free-field Sensitivity Calibration System
- Reciprocity

Microphone Pressure Sensitivity Calibration System
- Reciprocity

Comparison

Low Frequency Vibration System
- Comparison

Shock Calibration System
- Comparison

Vibration Calibration System
- Comparison

Microphone Calibration System
- Comparison

Sound Calibrator Calibration System
- Comparison


Present

Secondary Labs. & End Users

Low Frequency Accelerometers
Vibrometers

Shock Accelerometers/
Vibrometers

Accelerometers
Vibrometers
Vibration calibrator

Microphone
Sound Level Meter
Noise dosimeter

Pistonphone
Sound Calibrator
Artificial ear
Audio meter
**Primary Accelerometer Calibration**

**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: $k = 2$

Air Bearing Shaker
PCB 396C11
V02 Secondary Accelerometer Calibration

B&K 4812 Shaker

<table>
<thead>
<tr>
<th>Frequency</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Hz to 1.5 kHz</td>
<td>1.4 %</td>
</tr>
<tr>
<td>1.5 kHz to 5 kHz</td>
<td>1.9 %</td>
</tr>
<tr>
<td>5 kHz to 7 kHz</td>
<td>2.4 %</td>
</tr>
</tbody>
</table>

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
---|---

#### Measurement Frequency Range

The measurement frequency range is from 0.4 Hz to 100 Hz with acceleration 1 m/s² to 5 m/s².

#### Calibration for Accelerometer

<table>
<thead>
<tr>
<th>Item</th>
<th>Range</th>
<th>Relative Expanded uncertainty</th>
<th>Coverage factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerometer</td>
<td>0.8 Hz to 2 Hz</td>
<td>2.8 %</td>
<td>k = 2</td>
</tr>
<tr>
<td></td>
<td>3.15 Hz to 100 Hz</td>
<td>1.3 %</td>
<td>k = 2</td>
</tr>
<tr>
<td>Accelerometer</td>
<td>0.4 Hz to 0.7 Hz</td>
<td>2.8 %</td>
<td>k = 2</td>
</tr>
<tr>
<td></td>
<td>0.8 Hz to 2 Hz</td>
<td>2.5 %</td>
<td>k = 2</td>
</tr>
<tr>
<td></td>
<td>3.15 Hz to 100 Hz</td>
<td>0.6 %</td>
<td>k = 2</td>
</tr>
</tbody>
</table>
V06 Primary Low Shock Calibration

**Shock machine**

**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)

**Duration time**: < 3.0 ms

<table>
<thead>
<tr>
<th>Item</th>
<th>Range</th>
<th>Relative Expanded uncertainty</th>
<th>Coverage factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerometer</td>
<td>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</td>
<td>1.0 %</td>
<td>k ≈ 1.96</td>
</tr>
</tbody>
</table>
V03 Comparison Shock Calibration

**ENDEVCO 2965C**

<table>
<thead>
<tr>
<th>Item</th>
<th>Range</th>
<th>Relative Expanded uncertainty</th>
<th>Coverage factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerometer</td>
<td>1 km/s², 2 km/s², 3 km/s², 4 km/s², 6 km/s²</td>
<td>2.1 %</td>
<td>k = 1.97</td>
</tr>
<tr>
<td></td>
<td>8 km/s², 10 km/s²</td>
<td>2.6 %</td>
<td>k = 1.97</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Item</th>
<th>Range</th>
<th>Expanded uncertainty</th>
<th>Coverage factor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Microphone</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LS1P</td>
<td>20 Hz to 25 Hz</td>
<td>0.06 dB</td>
<td>$k \approx 2$</td>
</tr>
<tr>
<td></td>
<td>31.5 Hz to 4 kHz</td>
<td>0.05 dB</td>
<td>$k \approx 2$</td>
</tr>
<tr>
<td></td>
<td>5 kHz to 10 kHz</td>
<td>0.07 dB</td>
<td>$k \approx 2$</td>
</tr>
<tr>
<td>LS2P</td>
<td>20 Hz to 25 Hz</td>
<td>0.08 dB</td>
<td>$k \approx 2$</td>
</tr>
<tr>
<td></td>
<td>31.5 Hz to 40 Hz</td>
<td>0.06 dB</td>
<td>$k \approx 2$</td>
</tr>
<tr>
<td></td>
<td>50 Hz to 8 kHz</td>
<td>0.05 dB</td>
<td>$k \approx 2$</td>
</tr>
<tr>
<td></td>
<td>10 kHz to 20 kHz</td>
<td>0.11 dB</td>
<td>$k \approx 2$</td>
</tr>
</tbody>
</table>
A02 Microphone Pressure Sensitivity Calibration – Single / Multi-Frequency Comparison Method

Range: 20 Hz to 20 kHz

<table>
<thead>
<tr>
<th>Item</th>
<th>Range</th>
<th>Expanded uncertainty</th>
<th>Coverage factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microphone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LS2, WS2</td>
<td>20 Hz to 40 Hz</td>
<td>0.12 dB</td>
<td>( k \approx 2 )</td>
</tr>
<tr>
<td></td>
<td>50 Hz to 8 kHz</td>
<td>0.08 dB</td>
<td>( k \approx 2 )</td>
</tr>
<tr>
<td></td>
<td>10 kHz to 20 kHz</td>
<td>0.16 dB</td>
<td>( k \approx 2 )</td>
</tr>
<tr>
<td>Microphone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LS, WS</td>
<td>250 Hz</td>
<td>0.08 dB</td>
<td>( k \approx 2 )</td>
</tr>
</tbody>
</table>
# A03 Sound Calibrator and Sound Level Meter Calibration - Comparison Method

**Range:** 31.5 Hz to 16 kHz

**90 dB to 130 dB**

<table>
<thead>
<tr>
<th>Items calibrated</th>
<th>Frequency range</th>
<th>Expanded uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound Calibrator</td>
<td>1 kHz</td>
<td>0.14 dB</td>
</tr>
<tr>
<td></td>
<td>250 Hz</td>
<td>0.14 dB</td>
</tr>
<tr>
<td>Piston-phone</td>
<td>31.5 Hz</td>
<td>0.3 dB</td>
</tr>
<tr>
<td></td>
<td>63 Hz to 1 kHz</td>
<td>0.2 dB</td>
</tr>
<tr>
<td>Sound level meter</td>
<td>2 kHz to 4 kHz</td>
<td>0.3 dB</td>
</tr>
<tr>
<td></td>
<td>8 kHz</td>
<td>0.4 dB</td>
</tr>
<tr>
<td></td>
<td>12.5 kHz</td>
<td>0.5 dB</td>
</tr>
<tr>
<td></td>
<td>16 kHz</td>
<td>0.6 dB</td>
</tr>
</tbody>
</table>

**B&K 4226 Sound Calibrator**

**B&K 4231 Sound Calibrator**

**B&K 4228 Piston phone**

**Coupler**

**Sound Level Meter**

**Notes:**
- The table above summarizes the frequency range and expanded uncertainty for the calibrated items.
- The expanded uncertainty values are provided for each frequency range to ensure accurate calibration results.

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**Image Description:**
- The image shows a workspace with various sound calibration equipment, including a sound calibrator and a sound level meter, set up for calibration purposes.
# A03 Sound Calibrator Calibration – Insert Voltage

Range: 31.5 Hz to 16 kHz  
90 dB to 130 dB

<table>
<thead>
<tr>
<th>Items calibrated</th>
<th>Frequency range</th>
<th>Expanded uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound Calibrator Piston-phone</td>
<td>31.5 Hz</td>
<td>0.10 dB</td>
</tr>
<tr>
<td>Multi-frequency sound calibrator</td>
<td>63 Hz to 8 kHz</td>
<td>0.08 dB</td>
</tr>
<tr>
<td></td>
<td>12.5 kHz to 16 kHz</td>
<td>0.14 dB</td>
</tr>
</tbody>
</table>
A04 Microphone Free-Field Sensitivity Calibration - Reciprocity Method

Horizontally disposed by CMS/ITRI

Vertically disposed by NIM

Range: 1 kHz Hz to 20 kHz

Bilateral comparison between CMS/ITRI and NIM

<table>
<thead>
<tr>
<th>Item</th>
<th>Range</th>
<th>Expanded uncertainty</th>
<th>Coverage factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS2P</td>
<td>1 kHz to 10 kHz</td>
<td>0.30 dB</td>
<td>$k \approx 2$</td>
</tr>
<tr>
<td></td>
<td>12.5 kHz to 16 kHz</td>
<td>0.15 dB</td>
<td>$k \approx 2$</td>
</tr>
<tr>
<td></td>
<td>20 kHz</td>
<td>0.30 dB</td>
<td>$k \approx 2$</td>
</tr>
</tbody>
</table>
• Introduction of CMS/ITRI & AUVL
• Measurement Facilities & Calibration Service
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• International Activity
• Publications
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

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)

Modal analysis
Reference Sound Source Calibration

50 Hz to 20 kHz

1. ISO 6926, Acoustics – Requirements for the performance and calibration of reference sound sources used for the determination of sound power levels, 2000.
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
Wind Turbine Induce Noise Measurement

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

Elementary School
Penghu island
500 km from Taiwan
• Introduction of CMS & AUVL
• Measurement Facilities & Calibration Service
• Metrology application to Industry Project
• **International Activity**
• Publications
• Conclusion
International Activities

Hosted 2013 APMP Meeting

APMP TCAUV members
## International Activities

### Comparison

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

Computation 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)

Results for B&K 1180 No 1763688

Frequency (Hz)

Sensitivity deviation from mean value (dB)

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

Degree of equivalence at 250 Hz and its expanded uncertainty (k=2)
### 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**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>CMS/ITRI</th>
<th>NIMT</th>
<th>NMC, A*STAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>160 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$i$</td>
<td>$D_y$</td>
<td>$U_y$</td>
<td>$D_y$</td>
</tr>
<tr>
<td>$j$</td>
<td>in pC/(m/s$^2$)$\cdot10^4$</td>
<td>in pC/(m/s$^2$)$\cdot10^4$</td>
<td>in pC/(m/s$^2$)$\cdot10^4$</td>
</tr>
<tr>
<td>PTB</td>
<td>-1.6</td>
<td>4.0</td>
<td>1.7</td>
</tr>
<tr>
<td>BNM-CEST</td>
<td>-1.0</td>
<td>7.4</td>
<td>2.3</td>
</tr>
<tr>
<td>CSIRO-NML</td>
<td>-2.0</td>
<td>5.4</td>
<td>1.3</td>
</tr>
<tr>
<td>CMI</td>
<td>-2.0</td>
<td>7.0</td>
<td>1.3</td>
</tr>
<tr>
<td>CSIR-NML</td>
<td>-2.0</td>
<td>7.4</td>
<td>1.3</td>
</tr>
<tr>
<td>CENAM</td>
<td>-2.0</td>
<td>7.4</td>
<td>1.3</td>
</tr>
<tr>
<td>NRC</td>
<td>-0.5</td>
<td>5.4</td>
<td>2.8</td>
</tr>
<tr>
<td>KRISS</td>
<td>-3.1</td>
<td>5.9</td>
<td>0.2</td>
</tr>
<tr>
<td>NMIJ</td>
<td>-2.0</td>
<td>6.7</td>
<td>1.3</td>
</tr>
<tr>
<td>VNIIM</td>
<td>0.2</td>
<td>6.3</td>
<td>3.5</td>
</tr>
<tr>
<td>NIST</td>
<td>-3.0</td>
<td>5.4</td>
<td>0.3</td>
</tr>
<tr>
<td>NMi-VSL</td>
<td>-2.0</td>
<td>5.7</td>
<td>1.3</td>
</tr>
</tbody>
</table>

DoE for horizontal voltage sensitivity of SE-1021 at 0.5 Hz and 1.6 Hz
International Activities

Pilot Study Results

DoE. for voltage sensitivity under monopole shock excitation at 500 m/s², 3.0 ms and 1000 m/s², 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
Conference Papers
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