工業技術研究院
Industrial Technology Research Institute

國家度量衡標準實驗室
NATIONAL MEASUREMENT LABORATORY R.O.C.

Measurements for Transport
-- Some Examples in Taiwan

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EXAMPLES

1. Taiwan High Speed Rail
- **vibration analysis**
- **magnetic field and RF EM field**

2. Taoyuan airport MRT System
- **noise**

3. Highways and Expressways
- **LED Lighting**

Example 1 – Taiwan High Speed Rail

1.1 Vibration of Pole and Viaduct Induced by High Speed Train

Taiwan High Speed Rail (THSR)

Map of Taiwan High Speed Rail Line.

- The line opened for service on 5 January 2007
- THSR is a high-speed rail line that runs approximately 345 km along the west coast of Taiwan
- Trains running at a top speed of 300 km/h
- There are 12 operational Stations now
- About 120,000 ridership per day
- Electrification AC 25 kV, 60 Hz catenary

Civil Works of THSR

viaducts

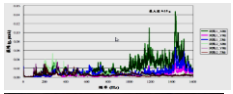
- Most part of the line is carried on superstructures.
- About 251 km or 73 % of the line runs on viaducts.
- About 61 km or 18 % of the line is in tunnels.
- About 33 km or 9 % of lines is mound.

tunnel

mound

Why and What to measure

Earthquake monitoring on post and bridge



Clarify relation between electric switch and vibration

Ground, Post and Bridge Dynamic Behavior

Viaduct and Pole Vibration Evaluation

Electric Switch Vibration

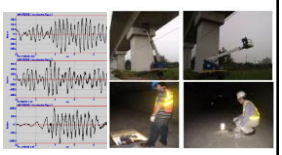
Transportation Safety

Steel Bridge and Turnout Vibration

Bridge and Train Vibration

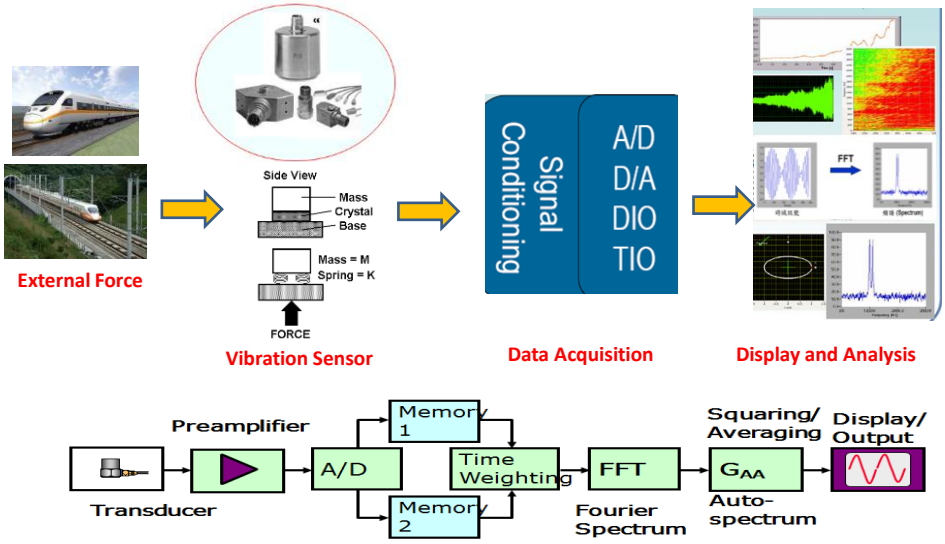
Verify the resonance of viaduct and pole

Clarify dynamical signal between steel structure and turnout



Clarify relation between bridge structure and train vibration

Measurement Principle and Process



Selection of Sensors for Measurement

- The swing vibration of an electric power wire is in low frequency range which is less than 20 Hz.
- Wheel-rail vibration induced by the high speed train is a broadband and in high frequency range which is higher than 500 Hz.

suitable for viaduct and pole vibration measurement

- Sensitivity: (± 5%) 1 V/g
- Frequency Range: (± 5%) 0.5 Hz to 2000 Hz
- Resonance frequency : 12 kHz

suitable for micro-vibration measurement

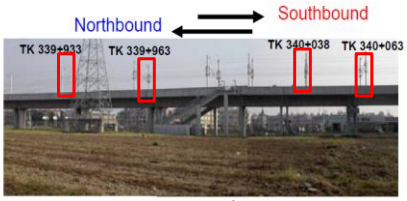
- Sensitivity: (± 5%) 10 V/g
- Frequency Range: (± 5%) 0.5 Hz to 450 Hz
- Resonance frequency : 780 Hz

Vibration Measurement for Viaduct and Pole

◆ Measurement locations

Locations include 4 eastern poles and viaducts which are located at TK 339+933, TK339+963, TK340+038 andTK340+063.

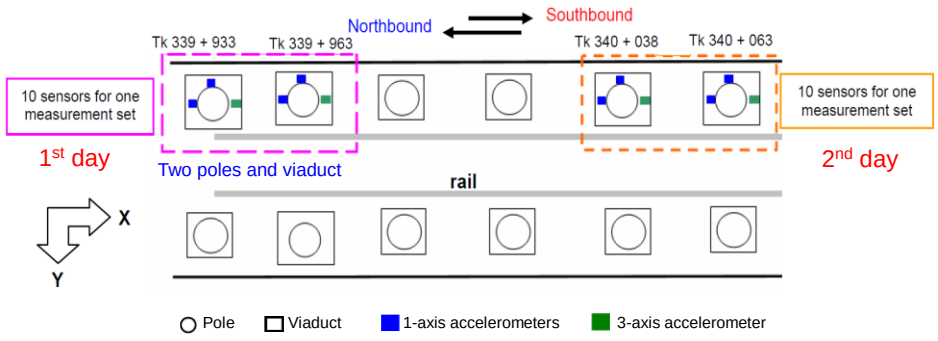
TK340 curved section



Measurement locations

Vibration Measurement for Viaduct and Pole

◆ Measurement directions and sensors arrangement



- 10 sensors for simultaneous vibration measurement of two poles and viaduct.
- X-direction of vibration measurement is parallel to the direction of rail.
- Y-direction is perpendicular to the rail.

Vibration Measurement for Viaduct and Pole

◆ Measurement Time

Measurement time is from 08:00 A.M. to 10:00 P.M. 19 trains ran southbound or northbound at 3 different speeds.

◆ Measurement procedures

Sensors mounting (2 sets, 6 3-dir vibr. sensors) on the viaduct Cable connection to system

Sensors fastened (2 sets, 4 X/Y-dir vibr. sensors) on poles /Cable connection to system

System connection with B&K Pulse frequency analyzer

Power on vibration measurement system

Parameters setup: sampling rate: 1600

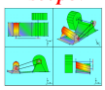
On-site signal verification test: vibration calibrator at 6.3 Hz

Start "Record" function on B&K analyzer for a long time record

Data storage

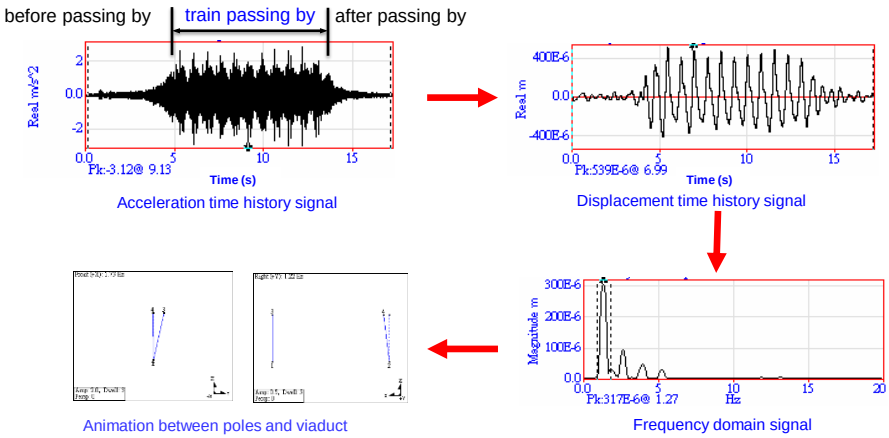
Analysis on Me'scope software

ME'scopeVES™



Vibration Measurement for Viaduct and Pole

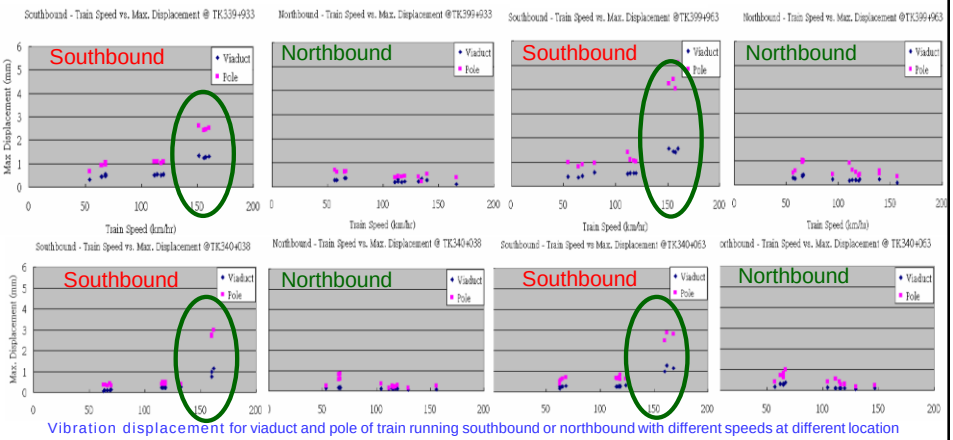
◆ Measurement and Analysis Methods



- Maximum displacement of viaducts and poles is obtained from the time domain data.
- The dominant frequencies can also be obtained from the frequency domain.
- Animated vibration mode is simulated between viaducts and poles.

Measurement Results

- Vibration measurement results for trains passing with different speeds



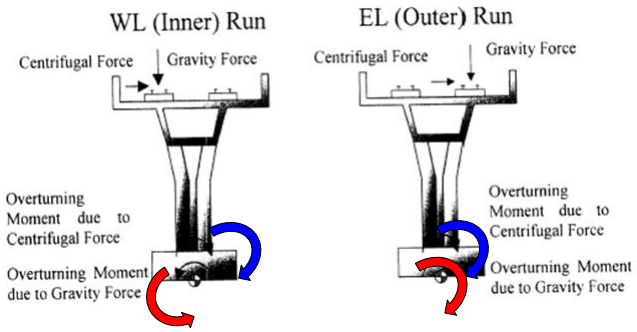
Vibration displacement for viaduct and pole of train running southbound or northbound with different speeds at different location

- Poles' vibration is 2 to 4 times higher than viaduct's vibration.
- Vibration of trains running southbound is higher running northbound especially at speed of 150 km/hr to 170 km/hr.

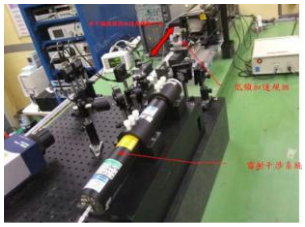
Comments for the Results

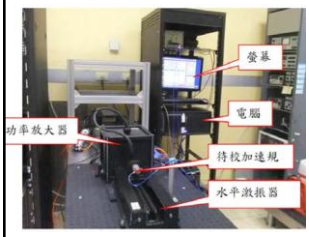
- Vibration from southbound trains is higher than northbound.

- TK340 is a curved section, a moment and higher vibration are generated on the viaduct by the weight of the train and its centrifugal force.



NML provides metrological traceability





SI Unit
Voltage (V), Length(m), Time(s)

Calibration: Wavelength, Voltage

ISO 16063-11
Instrument Calibration Technique for Low Frequency Accelerometer

Input: Wavelength
Measurement: $\hat{u}$, $\hat{a}$
Output: S_r

Standard low-frequency accelerometers
Voltage sensitivity (S_r)
Frequency range: 0.1 Hz to 160 Hz

Input: S_r
Measurement: V_r, V_u
Output: S_u

Low frequency accelerometers
Voltage sensitivity (S_u)
Frequency range: 0.5 Hz to 160 Hz

Input: Su
Measurement: V
Output: a

Vibrometer
Vibration acceleration (a)
Frequency range: 3.15 Hz to 70 Hz

SI Unit
Voltage (V), Length (m), Time (s)

Sine Approximation Method

Primary Calibration System (V04)

$S_r = \frac{\hat{u}}{\hat{a}}$

S_r : Reference accelerometer sensitivity [V/(m/s^2)]
$\hat{u}$: Reference accelerometer output voltage [V]
$\hat{a}$: Laser interferometer acceleration [(m/s^2)]

Comparison Calibration System (V04)

$S_u = \frac{V_u}{V_r} \times S_r$

S_r : Reference accelerometer sensitivity [V/(m/s^2)]
V_r : Reference accelerometer output voltage [V]
S_u : SUT accelerometer sensitivity [V/(m/s^2)]
V_u : SUT accelerometer output voltage [V]

Vibration measurement

$a = \frac{V}{S_u}$

a : Measured acceleration [m/s^2]
V : Accelerometer output voltage [V]
S_u : Accelerometer sensitivity [V/(m/s^2)]

Example 1 – Taiwan High Speed Rail

1.2 Exposure Assessment of ELF Magnetic Field and RF EM Field Radiated from Railway Facilities

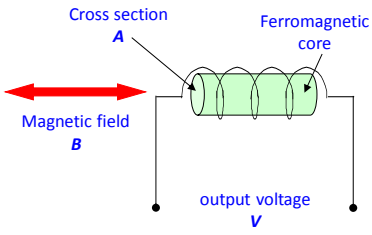
Measuring ELF Magnetic Field by Gauss meter

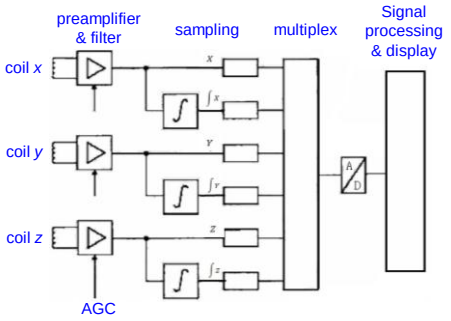
(Extremely Low Frequency)

- The ELF magnetic field is measured by a **search coil magnetometer**, also known as a **Gauss meter**, based on an inductive coil. An isotropic magnetic field sensor is configured by three orthogonal inductive coils.
- The inductive coil is based on Faraday's law of induction. The temporal variation of the **magnetic flux** Φ through a ***N*** turns circuit will induce a **voltage** ***V*** which follows:

$$V = -N\frac{\partial \Phi}{\partial t} \quad \Rightarrow \quad V = -N \cdot A\frac{\partial B}{\partial t}$$

by assuming that the **magnetic field** ***B*** is homogeneous over a section ***A***.





Configuration of an isotropic Gauss meter

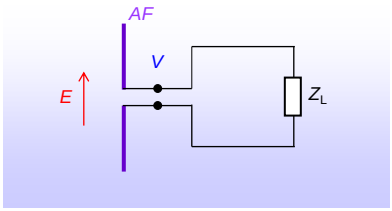
Measuring RF Electromagnetic Field by Antenna

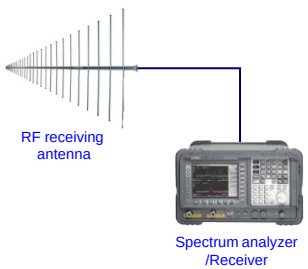
(Radio Frequency)

- An **antenna** is a device which converts electric power into radio waves, and vice versa. In transmission, a radio transmitter supplies an electric current oscillating at radio frequency to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves. In reception, an antenna intercepts some of the power of an electromagnetic and produces a voltage at its terminals, that is applied to a receiver to be amplified.
- The **electric field strength** ***E*** (V/m) can be determined by the **induced voltage** ***V*** (V) across the terminals of an antenna and the **antenna factor** ***AF*** (1/m) of this antenna:

$$E = AF \cdot V, \text{ or } E = AF + V \text{ in decibel unit.}$$

if the impedance of the receiver is matched with the antenna impedance, $Z_L = Z_{ant}$



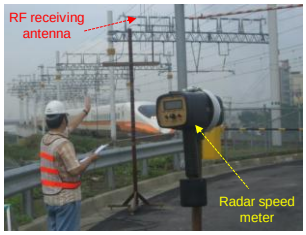


RF Field Beside the THSR Railway

(Radio Frequency)

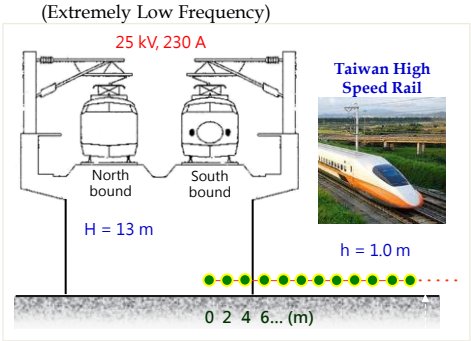
Why and What to Measure

- To ensure the safety of public who lives nearby the railway facilities, measurements on the **RF** electromagnetic field and **ELF** magnetic field radiated from railway facilities were carried out.
- **Reference standard**: **EN 50121-2 (2000,** now 2015**)** " Railway applications – Electromagnetic compatibility – Part 2:Emission of the whole railway system to the outside world "
- Measure the RF electromagnetic field beside the railway tracks when the train is passing through in acceleration/deceleration conditions.

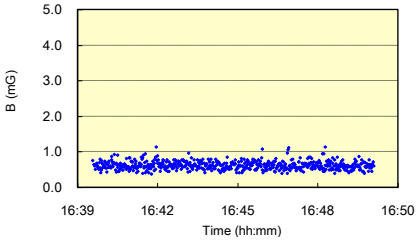


ELF Field Distribution under THSR Power Lines

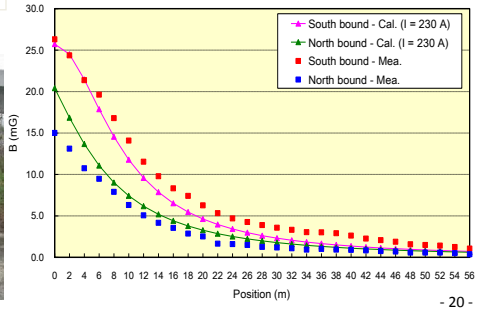
(Extremely Low Frequency)



- **No train passing by**



- **With train pass through**

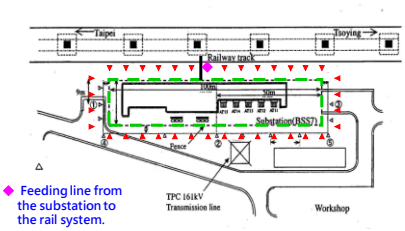


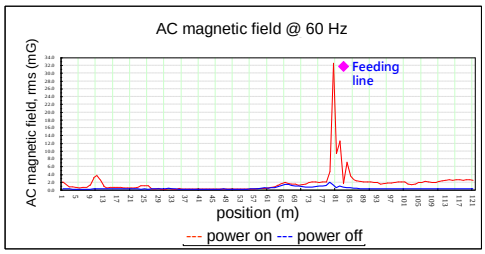
- **Test instrument: Gauss meters**

ELF Field Around THSR Substation

(Extremely Low Frequency)

❖ **Measurement of the ELF magnetic field around the substation of the THSR by a Gauss meter.**

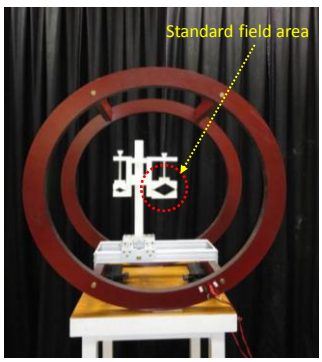




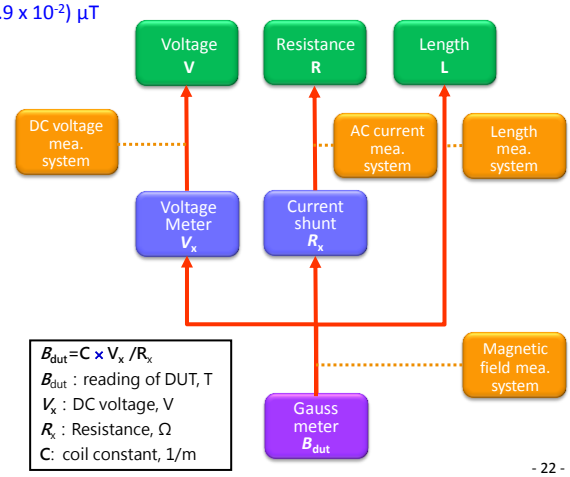
NML provides metrological traceability

❖ The standard **AC magnetic flux density** is generated by Helmholtz coils and is traceable to **voltage, resistance,** and **length** standards.

❖ The calibration capability of our **AC magnetic field measurement system** :
Frequency range: 50 Hz to 1 kHz
Field range: 0.5 μT to 50 μT
Expanded uncertainty: (1.6 x 10^{-3} to 9.9 x 10^{-2}) μT
(k = 2.16, 95 % confidence level)



AC Helmhaltz coils

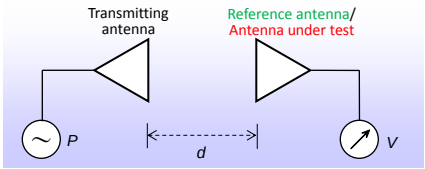


B_{dut}=C × V_x /R_x
B_{dut} : reading of DUT, T
V_x : DC voltage, V
R_x : Resistance, Ω
C: coil constant, 1/m

NML provides metrological traceability

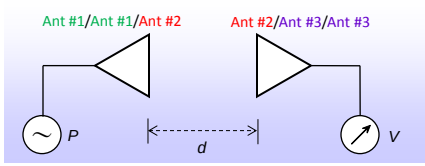
❖ **Reference antenna method** (substitution method):

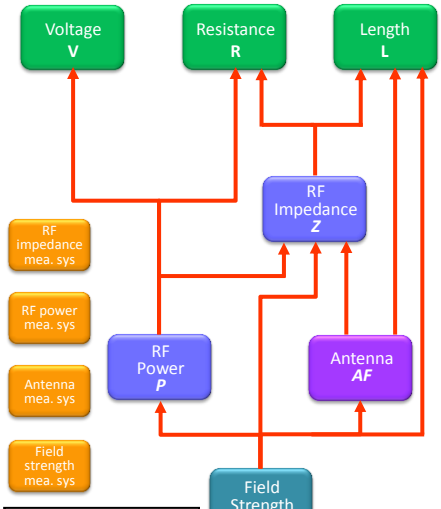
$$E = AF_{ref} + V_{ref} = AF_{aut} + V_{aut}$$



❖ **Three antenna method**:

$$SA_1 = AF_1 + AF_2 + 48.92 - 20\cdot\log(f_{MHz}) - E_d$$
$$SA_2 = AF_1 + AF_3 + 48.92 - 20\cdot\log(f_{MHz}) - E_d$$
$$SA_3 = AF_2 + AF_3 + 48.92 - 20\cdot\log(f_{MHz}) - E_d$$
$$\Rightarrow AF_1, AF_2, AF_3$$



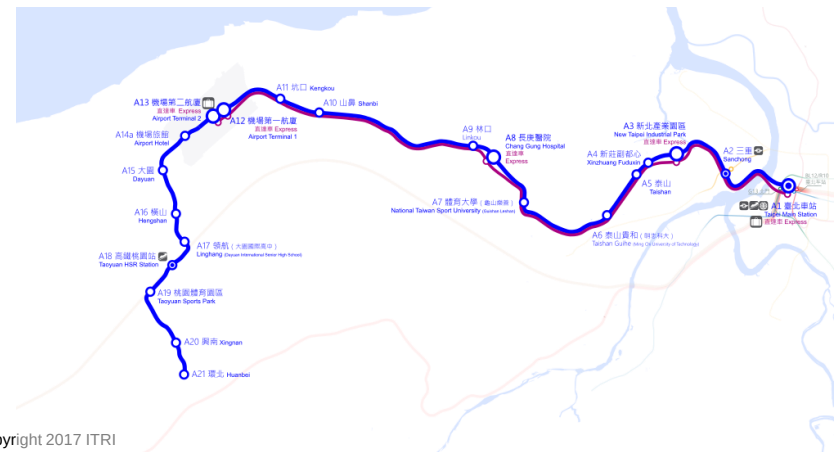


E=*AF*× *V*
E : electric field, V/m
V : induced voltage, V
AF : antenna factor, 1/m

Example 2 – Taoyuan airport MRT System

Noise measurements

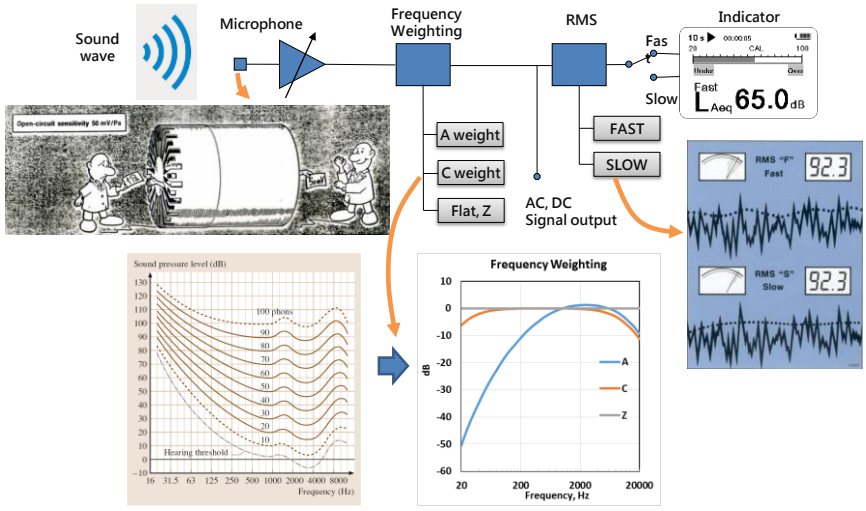
Total distance：53.1 km (21 stations)



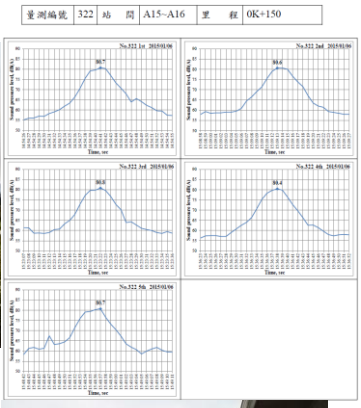
Why and What to Measure

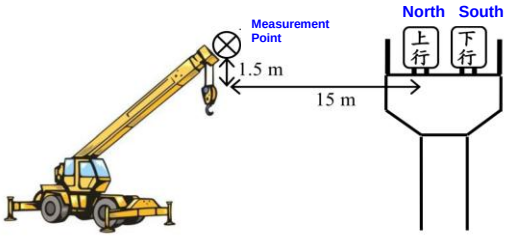
- The induced noise by MRT should be less than 83 dB(A) with the train speed 90 km/h
- Every 50 m interval should set one point to measure noise of viaduct induced by MRT
- Measure the max. noise when the MRT pass by and take 5 trains noise data for averaging

Measurement Principle and Process

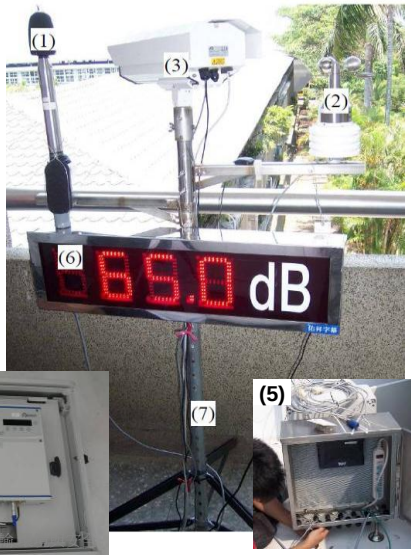


Noise Measurement



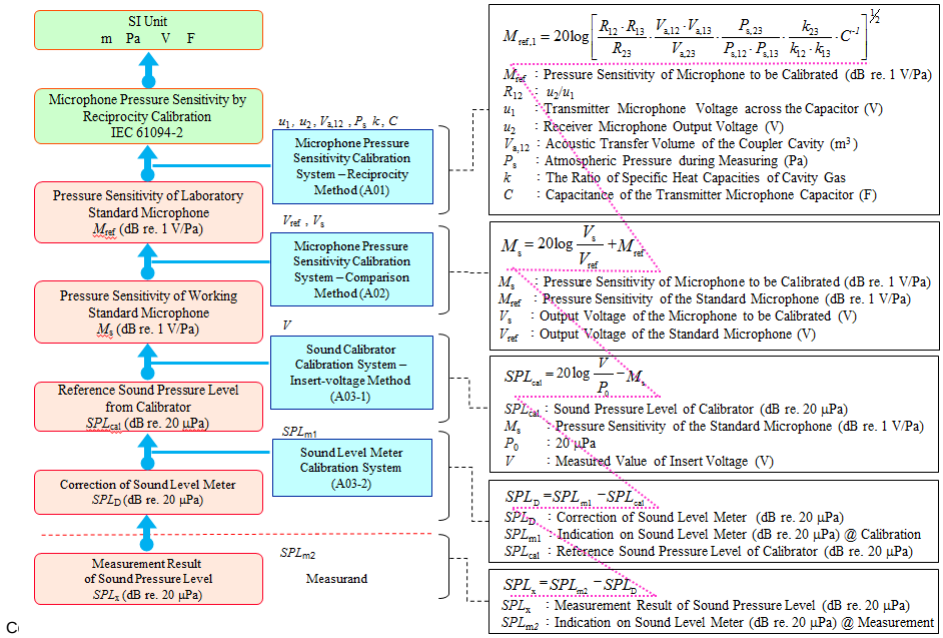


Noise monitoring system at school for transports



(1) Microphone (2)Weather monitoring Set (3)Camera (4)Central Controller (5)Cables (6)Noise display (7)Support frame

NML provides metrological traceability



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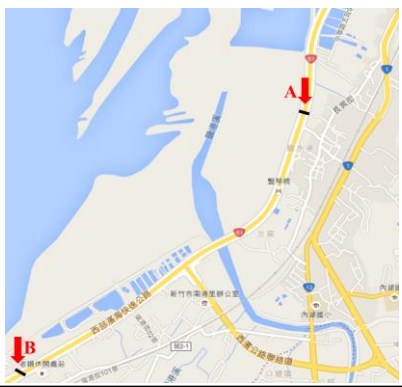
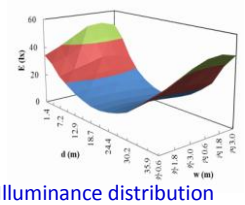
Example 3 – Highways and Expressways

LED Lighting on Expressway

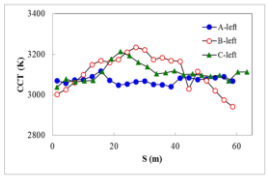


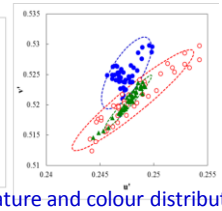
Why and What to Measure

CNS: On site measurement of the luminance of road and tunnel lighting (draft)
CIE 140: Road Lighting Calculations
CIE 194: On Site Measurement of the Photometric Properties of Road and Tunnel Lighting



Illuminance distribution





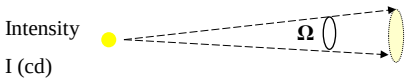
Correlated Colour Temperature and colour distribution

Nightjar Force (work at nights)

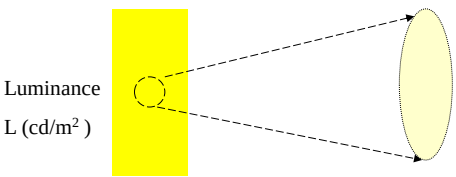
Spectral irradiance and illuminance measurement system

Image Luminance Measurement Device

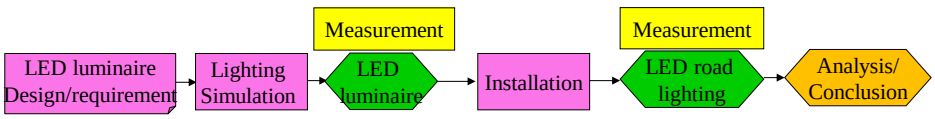
Measurement Principle and Process



$$I = E \cdot d^2$$



$$E = \frac{\pi r_s^2 L}{d^2} = \pi L \cdot \frac{r_s^2}{d^2}$$



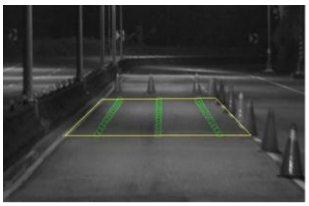
Measuring Parameters and Instruments

illuminance distribution, average illuminance, overall uniformity
luminance distribution, average luminance, overall uniformity, longitudinal uniformity, TI (Threshold Increment)
CCT distribution, Color dispersion, CRI (Color Rendering Index)
6 000 h maintenance

√ √ √

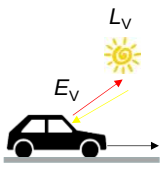
Illuminance meter

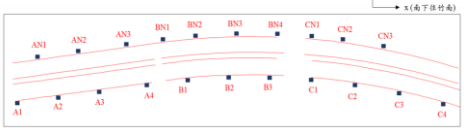
luminance meter



Road surface image

Glare and Flicker Measurement on Expressway

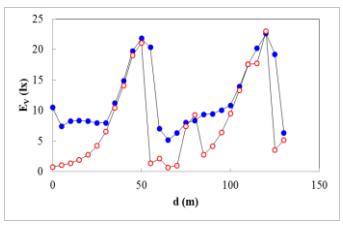




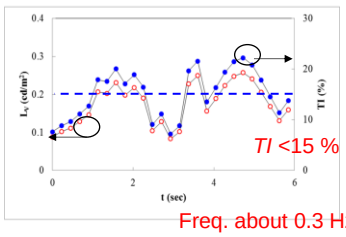
Vertical illuminance (E_V), Veiling luminance (L_V) and Threshold Increment (TI)

$$L_{Vi} = 0.003 \cdot E_{Vi}/\theta_i{}^2$$

$$TI_i = 65 \cdot L_{Vi}/L_{ave}{}^{0.8}$$



Vertical illuminance

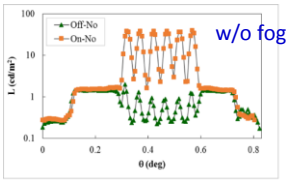


TI <15 %

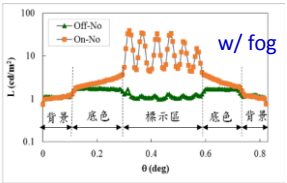
Freq. about 0.3 Hz

L_V vs. TI (at 80 km/h)

Road Lighting Field @ ITRI S. Campus



w/o fog



w/ fog

LED lamp | High Pressure Sodium lamp | Metal Halide lamp

Standard Development for Outdoor Lighting

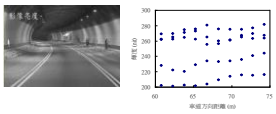
Tunnel lighting measurement

LED flicker measurement

Light pollution measurement

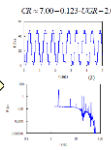
Comfortable and health lighting standard

- **CIE194-on site measurement of the photometric properties of road and tunnel lighting**
- **CIE140-road lighting calculations**
- **Glare Rating Measurement by Image Luminance Measuring Device reportership (CIE JTC7)**



Flicker measurement for SSL

- **JEITA, IEC, IESNA**
- **Flicker measurement standard reportership (CIE Div.2)**
- **New index -Comfort rating**

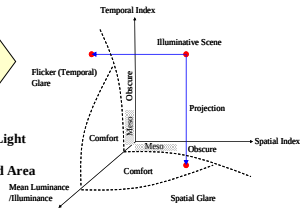


Comfort rating (average) < 5.2
Comfort rating (instant) < 4.0
LPFI = 0.31
UGR (average) > 13.2
UGR (instant) > 19.0

(LPFI :low pass filter intensity)

Light pollution

- **CIE, IESNA, IEC**
- **TC 5-28: Guide on the Limitation of the Effects of Obtrusive Light**
- **Illuminance, luminance, glare, flicker…**

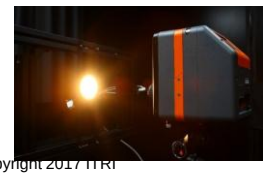


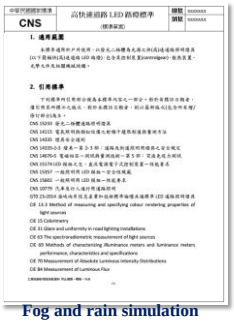
- **CIE 150-2003:Guide on the Limitation of the Effects of Obtrusive Light from Outdoor Lighting Installations**
- **CIE 112-1994:Glare Evaluation System for Use within Outdoor and Area Lighting**
- **CIE 117-1995:Discomfort Glare in Interior Lighting**

CNS: LED Road Lighting Standard for Expressways

Established a unique simulation and test field to develop national standard of LED road lighting for highways and expressways in Taiwan

LED road lighting measurement system



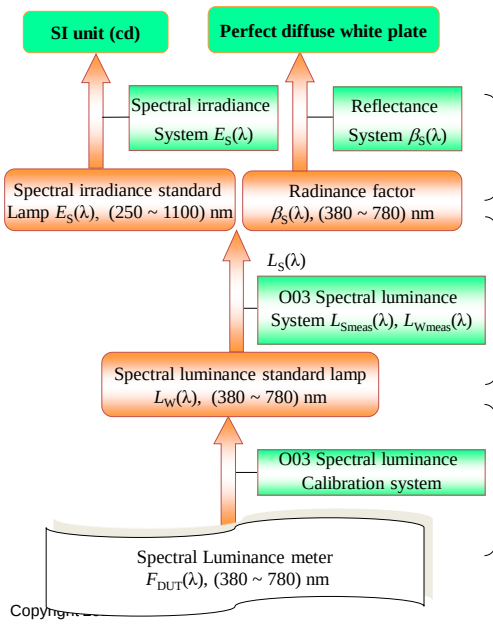


Exp. way LED road lighting demonstration field

Fog and rain simulation experiment for LED road lighting

LED road lighting experiment and testing field

NML provides metrological traceability



$$L_S(\lambda) = \frac{E_S(\lambda) \times \beta_S(\lambda)}{\pi}$$

$L_S(\lambda)$: Spectral luminance standard W/(m² · sr · nm)
$E_S(\lambda)$: Spectral irradiance standard W/(m² · nm)
$\beta_S(\lambda)$: Radiance factor
λ : Wavelength

$$F_1(\lambda) = \frac{L_S(\lambda)}{L_{Smeas}(\lambda)} \quad (1)$$

$$L_W(\lambda) = F_1(\lambda) L_{Wmeas}(\lambda) \quad (2)$$

$L_S(\lambda)$: Spectral luminance standard W/(m² · sr · nm)
$L_{Smeas}(\lambda)$: Spectral luminance value by standard meter W/(m² · sr · nm)
$F_1(\lambda)$: Correction factor of Spectral luminance meter
$L_W(\lambda)$: Spectral luminance of standard lamp W/(m² · sr · nm)
$L_{Wmeas}(\lambda)$: Spectral luminance of working standard lamp W/(m² · sr · nm)

$$F_{DUT}(\lambda) = \frac{L_W(\lambda)}{L_{DUTmeas.}(\lambda)}$$

$F_{DUT}(\lambda)$: Correction factor by DUT
$L_W(\lambda)$: Spectral luminance of standard lamp W/(m² · sr · nm)
$L_{DUTmeas.}(\lambda)$: Spectral luminance of DUT W/(m² · sr · nm)

Summary

- Celebrating WMD-2017 and NML-30
- Measurements support transport for moving ourselves, food, clothes, goods, and raw materials.
- NML provides metrological traceability and helps drafting national/international standards

Thank You

for Your Attention