



Callaghan Innovation

Measurement Standards Laboratory of New Zealand

Client Number 8

PO Box 31310, Lower Hutt, 5040
69 Gracefield Road, Gracefield, Lower Hutt, 5010

Telephone 04 931-3000

www.measurement.govt.nz

Authorised Representative

Mr Neil Swift
Senior Research Scientist and Quality Manager

Programme

Metrology & Calibration Laboratory

Accreditation Number 1


Initial Accreditation Date 30 July 2004

Conformance Standard

ISO/IEC 17025:2017
General requirements for the competence of testing and calibration laboratories

Laboratory Services Summary

- 5.01 Engineers' Limit Gauges
- 5.02 Jigs, Fixtures, Cutting Tools and Components
- 5.05 Geometric Form
- 5.11 Working Standards of Length and Angle
- 5.12 Precision Measuring Instruments
- 5.14 Laser Frequency
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- 5.35 Hygrometry
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- 5.42 Differential Pressure Measuring Devices (including Manometers)
- 5.43 Pressure Gauge Calibrators and Pressure Balances
- 5.44 Pressure and Vacuum
- 5.61 Temperature Measuring Equipment
- 5.65 Photometers and Radiometers
- 5.66 Lamps, LEDs, Lasers and Other Light Sources
- 5.67 Colour of Light Sources and Colorimeters
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- 5.84 Capacitors
- 5.85 Inductors and Transformers

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CERTIFICATE OF ACCREDITATION



5.86	Voltage Standards and Current Standards
5.87	Transfer Instruments (AC/DC)
5.88	Calibrators for Instrumentation
5.89	Indicating Instruments and Recording Instruments
5.90	Bridges, Potentiometers and Test Sets
5.91	Time and Frequency
5.92	Waveform
5.93	Signal Sources

Key Technical Personnel

Dr Laurie Christian	5.82, 5.85, 5.86, 5.87, 5.88, 5.89, 5.90, 5.92, 5.93
Dr Adam Dunford	5.91, 5.92, 5.93
Dr Murray Early	5.82, 5.86, 5.87, 5.88, 5.89, 5.90, 5.92, 5.93
Dr Lucy Forde	5.05, 5.11, 5.12, 5.14
Dr Rebecca Hawke	5.21
Ms Eleanor Howick	5.01, 5.02, 5.05, 5.11, 5.12, 5.14
Mr Keith Jones	5.82, 5.84, 5.85, 5.86, 5.87, 5.88, 5.89, 5.90, 5.92, 5.93
Dr Tim Lawson	5.82, 5.86, 5.88, 5.89
Dr Jeremy Lovell-Smith	5.35
Dr Peter McDowall	5.41, 5.42, 5.43, 5.44
Dr Ellie Molloy	5.61, 5.68, 5.69
Mr Greg Reid	5.21, 5.31, 5.32
Dr Peter Saunders	5.61, 5.82, 5.90
Mr Ben Sherson	5.35
Dr Francois Shindo	5.65, 5.66, 5.67
Mr Tom Stewart	5.82, 5.84, 5.85, 5.88, 5.89, 5.90
Mr Neil Swift	5.05, 5.65, 5.66, 5.67, 5.68, 5.69
Mr Yang Yenn Tan	5.65
Mr Cheng Yang	5.89, 5.91
Mr Chris Young	5.01, 5.02, 5.05, 5.11, 5.12, 5.14

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The uncertainty of a Calibration and Measurement Capability (CMC) is expressed as an expanded uncertainty corresponding to a level of confidence of 95 % ^{Note 1}.

Measurement results are traceable to the International System of Units (SI)

Calibrations are generally performed at the premises of the accredited laboratory, although some may be carried out in the field and some at customer premises.

Measurand	Conditions	CMC Uncertainty
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5.01 Engineers' Limit Gauges

(a) Plain plug, ring and gap gauges. Taper plug and ring gauges.

Setting plug gauges by comparison with gauge blocks

Mean diameter	0.5 mm to 25 mm	Q(130, 1.4L) nm, L in mm
Mean diameter	25 mm to 300 mm	Q(95, 1.8L) nm, L in mm

Setting ring gauges by comparison with gauge blocks

Mean diameter	1 mm to 300 mm	Q(95, 1.8L) nm, L in mm
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Where $Q(a,b) = \sqrt{a^2 + b^2}$

(e) Position and receiver gauges involving both linear and angular measurements.

Lobster tail gauges	52 mm to 100 mm	0.01 mm
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(g) Other gauges involving measurements similar to those under (a) and including depth gauges, height gauges and gauges involving plane coordinated position of holes and spigots.

Step gauge face spacing by comparison with end standards on CMM

10 mm to 700 mm	Q(0.1, 0.55L) μ m, L in m
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5.02 Jigs, Fixtures, Cutting Tools and Components

3D measurements using a calibrated Legex 574 CMM

Error of indicated size	0.001 mm to 750 mm	(0.28 + L/1000) μ m, L in mm
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Angle measurements derived from length measurements

Angle	7 x 10 ⁻⁶ radians to 6.28 radians	7 x 10 ⁻⁷ radians
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Measurement of components/objects on Profile Projector

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Error of indicated size up to 200 mm x 200 mm Q(0.76, 12.6L) μm , L in m

5.05 Geometric Form

(b) Roundness

Variability in roundness Range of diameters

0 μm to 400 μm 1 mm to 300 mm Q(0.025, 0.018R) μm , R in μm

(d) Flatness of Optical Flat, Parallelism, Wedge Angle of Optical Wedge or Flat

Parallelism Range of diameters
0 μm to 10 μm 10 mm to 35 mm 0.08 μm

Flatness Range of diameters
0 μm to 2.5 μm 10 mm to 35 mm 0.06 μm

Flatness of optical flats by Interferometry

Up to 150 mm diameter 22 nm
Up to 250 mm diameter 33 nm

(h) Parallelism

Levelling of dynamic weigh station sites by measurement of deviation from a horizontal plane (calibration carried out on site)

Deviation in height Horizontal range
1.8 m to 60 m Q(41, 7.1L) μm , L in m is the horizontal distance to staff

5.11 Working Standards of Length and Angle

(a) Gauge blocks and accessories

Measurement of central length

By interferometry 0.1 mm to 103 mm Q(17, 0.15L) nm, L in mm
By comparison 0.1 mm to 103 mm Q(36, 1.4L) nm, L in mm

Measurement of variation in length Q(30, 0.35L) nm, L in mm

(b) Length bars and accessories

Measurement of central length and variation in length

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Long gauge blocks by comparison with gauge blocks using the Horizontal Federal

100 mm to 300 mm Q(91, 1.3L) nm, L in mm

Measurement of variation in length Q(34, 0.35L) nm, L in mm

Long gauge blocks by comparison with gauge blocks using the Legex CMM

100 mm to 750 mm (0.28 + L/1000) µm, with L in mm

(f) Precision linear scales

Engineer or machinist scale-line spacing

0.1 m to 4 m Q(10, 8.2L) µm, L in m

(h) Precision graticules including stage micrometers and haemocytometer counting chambers

0.01 mm to 200 mm Q(0.76, 12.6L) µm, L in m

(i) Surveying tapes and petroleum dip tapes

0.5 mm to 50 m Q(10, 10.5L) µm, L in m

Surveyor levelling rods

0.5 m to 3 m Q(10, 10L) µm, L in m

(k) Angle gauges and precision polygons

Angles derived from measurements defined in 5.11 (a)

Angle gauges 0.05 minutes to 10 minutes 1.6×10^{-7} radians

Angles derived from measurements defined in 5.02

Angle gauges 10 minutes to 90 degrees 7×10^{-7} radians

(n) Geodetic baselines (calibrations carried out on site)

Interval distances 0.19 m to 1500 m Q(0.3, $0.6 \times 10^{-3}L$) mm, L in m

5.12 Precision Measuring Instruments

(a) Length measuring machines

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Electronic distance measuring machines (EDMs)

Error of indicated displacement	0.19 m to 206 m	$Q(0.13, 7 \times 10^{-4}L)$ mm, L in m
Error of indicated frequency	5 MHz to 100 MHz	$0.16 \times 10^{-6}L \times \text{frequency}$
Error of prism constant		0.26 mm

5.14 Laser Frequency

(a) Stabilised lasers of the mise en pratique

Absolute frequency	473 612 GHz	25 kHz
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(b) Other stabilised lasers

Absolute frequency	473 612 GHz	0.2 MHz
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5.21 Masses

- (a) Examination of laboratory standards of mass
- (b) Examination of industrial standards of mass
- (c) Determination of the mass of solid objects

1 mg to 100 mg	0.4 µg to 0.7 µg
0.1 g to 1 g	0.7 µg to 1.6 µg
1 g to 10 g	1.6 µg to 4 µg
10 g to 100 g	4 µg to 8 µg
0.1 kg to 1 kg	8 µg to 57 µg
1 kg to 10 kg	1.1×10^{-7}
10 kg to 20 kg	6.0×10^{-7}
20 kg to 50 kg	8.8×10^{-7}

5.31 Volumetric Equipment

(a) Examination of laboratory volumetric glassware including examination for compliance with the Class A or Class B requirements of the relevant national or international standards

0.02 mL to 2 mL	0.0002 mL
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(b) Examination of other types of volumetric apparatus

0.002 L to 50 L	0.01 %
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5.32 Density

CMCs valid in the temperature range 17 °C to 23 °C

(a)	Density of solids		
	1400 kg/m ³ to 3000 kg/m ³ for mass 200 g to 400 g		1.0 x 10 ⁻⁵
	7800 kg/m ³ to 8200 kg/m ³ for mass 1 kg		2.0 x 10 ⁻⁵
(b)	Density of liquids		
	600 kg/m ³ to 2000 kg/m ³		2.0 x 10 ⁻⁵

5.35 Hygrometry

(a) Humidity measuring devices

Where t_d = dew-point temperature (units °C), t_f = frost-point temperature (units °C), t = air temperature (units °C) and h = relative humidity (units %rh)

Dew point hygrometers

$(-60 \leq t_f < -55) \text{ } ^\circ\text{C}$		0.33 °C
$(-55 \leq t_f < 0) \text{ } ^\circ\text{C}$		0.17 °C to 0.06 °C
$(0 \leq t_d < 40) \text{ } ^\circ\text{C}$		0.06 °C
$(40 \leq t_d \leq 70) \text{ } ^\circ\text{C}$		0.06 °C to 0.12 °C

Relative humidity hygrometers

$(10 \leq h \leq 98) \text{ } \%rh$	$(0 \leq t \leq 70) \text{ } ^\circ\text{C}$	0.006h %rh
$(1 \leq h < 10) \text{ } \%rh$	$(0 \leq t \leq 70) \text{ } ^\circ\text{C}$	0.06 %rh
$(10 \leq h \leq 98) \text{ } \%rh$	$(-55 \leq t < 0) \text{ } ^\circ\text{C}$	$(0.006 - 0.00022t)h \text{ } \%rh$

Air temperature

$(-55 \leq t \leq 70) \text{ } ^\circ\text{C}$	0.05 °C
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5.41 Barometric indicators or transducers

Aneroid barometers (including digital barometers)

50 kPa to 90 kPa	2.0 x 10 ⁻⁵
90 kPa to 110 kPa	1.0 x 10 ⁻⁵
110 kPa to 130 kPa	2.0 x 10 ⁻⁵

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5.42 Differential Pressure Measuring Devices (including Manometers)

- (a) Diaphragm types
- (b) Liquid column types, inclined and vertical
- (c) Transducers and transmitters
- (d) Other types

1 Pa to 10000 Pa (6 x 10⁻³ + 4.5 x 10⁻⁵ p)
Pa, p in Pa

5.43 Pressure Gauge Calibrators and Pressure Balances

Absolute pressure – gas medium

8 kPa to 550 kPa 2 x 10⁻⁵
550 kPa to 7000 kPa 6 x 10⁻⁵

Gauge pressure – gas medium

-100 kPa to -10 kPa 7 x 10⁻⁵
-10 kPa to -1 kPa 200 mPa to 100 mPa,
decreasing linearly
1 kPa to 8 kPa 100 mPa to 160 mPa,
increasing linearly
8 kPa to 550 kPa 2 x 10⁻⁵
550 to 11000 kPa 6 x 10⁻⁵

5.44 Pressure and Vacuum

- (a) Pressure gauges
- (b) Vacuum gauges
- (c) Pressure transducers
- (d) Pressure recorders

Absolute pressure – gas medium

8 kPa to 90 kPa 2 x 10⁻⁵
90 kPa to 110 kPa 1 x 10⁻⁵
110 kPa to 550 kPa 2 x 10⁻⁵
550 kPa to 7000 kPa 6 x 10⁻⁵

Gauge pressure – gas medium

-96 kPa to 8 kPa 0.0031 kPa
8 kPa to 90 kPa 2 x 10⁻⁵
90 kPa to 110 kPa 1 x 10⁻⁵
110 kPa to 550 kPa 2 x 10⁻⁵

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550 to 11000 kPa	6 x 10 ⁻⁵
Absolute pressure – liquid medium	
0.3 MPa to 17 MPa	(1 x 10 ⁻⁴ + 6.6 x 10 ⁻⁵ p) MPa (p in MPa)
17 MPa to 280 MPa	(6.6 x 10 ⁻⁵ p + 7 x 10 ⁻⁷ p ²) MPa (p in MPa)
Gauge pressure – liquid medium	
0.2 MPa to 17 MPa	(1 x 10 ⁻⁴ + 6.6 x 10 ⁻⁵ p) MPa (p in MPa)
17 MPa to 280 MPa	(6.6 x 10 ⁻⁵ p + 7 x 10 ⁻⁷ p ²) MPa (p in MPa)
5.61 Temperature Measuring Equipment (including temperature calibration of electronic and glass thermometers)	
(a) Rare metal thermocouples	
0 °C to 962 °C	0.026 °C
962 °C to 1100 °C	0.22 °C
(b) Base metal thermocouples	
0 °C to 1100 °C	1.6 °C
(c) Platinum (and other metallic) resistance thermometers	
Contact thermometers, including Standard PRTs at the following fixed points	
Argon triple point (-189.3442 °C)	1 mK
Mercury triple point (-38.8344 °C)	0.4 mK
Water triple point (0.01 °C)	0.1 mK
Gallium melting point (29.7646 °C)	0.19 mK
Indium freezing point (156.5985 °C)	0.56 mK
Tin freezing point (231.928 °C)	0.85 mK
Zinc freezing point 419.527 °C)	1.9 mK
Aluminium freezing point (660.323 °C)	10 mK
Silver freezing point (961.78 °C)	20 mK
(j) Radiation thermometers	
Direct reading, single spot radiation thermometers and thermal imagers	
-40 °C to 50 °C	(0.205 – 0.002t) °C, t in °C

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50 °C to 200 °C	(0.123 – 0.00036t) °C, t in °C
200 °C to 500 °C	(-0.029 + 0.0004t) °C, t in °C
500 °C to 1100 °C	(0.106 + 0.00013t) °C, t in °C

(p) Other direct reading temperature measuring systems, including Industrial PRTs

-190 °C to 0 °C	(2.4 - 0.005t) mK, t in °C
0 °C to 200 °C	(2.4 + 0.008t) mK, t in °C
200 °C to 550 °C	(4.0 + 0.03(t – 200)) mK, t in °C

5.65 Photometers and Radiometers

(a) Photometers

10 lux to 3000 lux	0.38 %
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(b) Illuminance meters

0.005 lux to 10 lux	1.9 %
10 lux to 3000 lux	0.54 %
3000 lux to 30000 lux	2.3 %

(c) Luminance meters

0.5 cd/m ² to 800 cd/m ²	1.6 %
800 cd/m ² to 27000 cd/m ²	7 %
27000 cd/m ² to 33000 cd/m ²	11 %

(d) UV meters

For Irradiance levels of 1 µW.cm⁻² to 5000 µW.cm⁻²

240 nm to 270 nm	5 %
270 nm to 310 nm	2.3 %
310 nm to 380 nm	2.5 %

For radiant exposure levels greater than 1.3 µJ.cm⁻²

240 nm to 270 nm	20 % to 5 %, decreases with exposure time
270 nm to 310 nm	19 % to 2.3 %, decreases with exposure time
310 nm to 380 nm	19 % to 2.5 %, decreases with exposure time

(g) Laser power meters

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Laser lines from 450 nm to 500 nm	0.45 % to 0.23 %, decreases linearly with wavelength
Laser lines from 500 nm to 550 nm	0.23 % to 0.15 %, decreases linearly with wavelength
Laser lines from 550 nm to <650 nm	0.15 %
Laser lines from 650 nm to 750 nm	0.17 %
Laser lines from 750 nm to 800 nm	0.19 %

(h) Detector spectral responsivity measurement

Discrete wavelengths

Laser lines from 450 nm to 500 nm	0.45 % to 0.23 %, decreases linearly with wavelength
Laser lines from 500 nm to 550 nm	0.23 % to 0.15 %, decreases linearly with wavelength
Laser lines from 550 nm to <650 nm	0.15 %
Laser lines from 650 nm to 750 nm	0.17 %
Laser lines from 750 nm to 800 nm	0.19 %

The below CMCs are for spectral power levels of 0.1 $\mu\text{W}\cdot\text{nm}^{-1}$ to 10 $\mu\text{W}\cdot\text{nm}^{-1}$ and corresponding irradiance levels using appropriate apertures. For spectral power levels below 0.1 $\mu\text{W}\cdot\text{nm}^{-1}$ uncertainties will increase.

240 nm to <300 nm	1.4 %
300 nm to <340 nm	0.98 %
340 nm to 360 nm	1.02 % to 0.98 %, decreases linearly with wavelength
360 nm to 380 nm	0.98 %
380 nm to 450 nm	0.98% to 0.45%, decreases linearly with wavelength
450 nm to 800 nm	Same as for discrete wavelengths – see 5.65 (g)
800 nm to 950 nm	0.19% to 0.33%, increases linearly with wavelength

5.66 Lamps, LEDs, Lasers and Other Light Sources

Calibrations within 5.66 may be offered in the field as well as in the laboratory. An increase in uncertainty due to environmental conditions and other influence variables present in the field may need to be applied.

(a) Lamps: Luminous intensity

10 cd to 5000 cd	0.48 %
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(e) Illuminance

0.005 lux to 30000 lux	2.3 %
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- (f) General sources: Spectral irradiance
- | | | |
|------------------|---|----------------|
| 250 nm to 350 nm | 0.0001 W/(m ² .nm) to 0.5 W/(m ² .nm) | 2.6 % to 1.6 % |
| 350 nm to 850 nm | 0.001 W/(m ² .nm) to 0.5 W/(m ² .nm) | 1.6 % to 1.4 % |
- (h) Photoluminescent materials
- | | | |
|-----------------------------|--|--|
| from 0.5 mcd/m ² | | 0.5 mcd/m ² or 15 %, whichever is greater |
|-----------------------------|--|--|

5.67 Colour of Light Sources and Colorimeters

Calibrations within 5.67 may be offered in the field as well as in the laboratory. An increase in uncertainty due to environmental conditions and other influence variables present in the field may need to be applied.

- (a) General sources:
- | | | |
|---|--|---|
| Colour emitted in CIE x, y colour space | | 0.0005 to 0.005 in x and y, varies with measurand |
| Colour emitted in CIE u, v colour space | | 0.0007 in u and v |
- (d) Lamps:
- | | | |
|--|--|------|
| Correlated colour temperature 2700 K to 3000 K | | 20 K |
|--|--|------|

5.68 Optical Properties of Materials: Spectral

- (a) Regular transmittance (T) and optical density or absorbance (OD)

Bandwidth 1 nm to 3 nm

240 nm to 380 nm	T = 0.0001 to 0.01 T = 0.01 to 1.0	0.0002.T ^{0.2} 0.005.T
380 nm to 1000 nm	T = 0.0001 to 1.0	0.0007.T ^{0.65}
240 nm to 380 nm	OD = 2 to 4 OD = 0 to 2	0.000087.10 ^{0.8.OD} 0.0022
380 nm to 1000 nm	OD = 0 to 4	0.00031.10 ^{0.35.OD}

- (b) Wavelength calibration filters

240 nm to 800 nm		0.13 nm
800 nm to 1100 nm		0.13 nm to 0.25 nm

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(c)	Diffuse transmittance		
	240 nm to 400 nm		0.005 to 0.0002 or 5 % of value whichever is greater
	400 nm to 1000 nm		0.0002 or 5 % of value whichever is greater
	Haze measurements		
	0.1 % to 100 %		2 % of value or 0.1 % absolute, whichever is greater
(d)	Diffuse reflectance in 0/d and 6/d geometries		
	360 nm to 1000 nm	0.016 to 0.9	0.008 to 0.0036, varies with wavelength
	360 nm to 1000 nm	0.9 to 1.0	0.4 % of value
(e)	Specular reflectance at normal incidence		
	240 nm to 800 nm	0.05 to 1	1 % of value
(f)	Bidirectional reflectance distribution factor and bidirectional radiance factor		
	In plane geometries only, 0.001 sr ⁻¹ to 2500 sr ⁻¹		
	360 nm to 400 nm		1.5 % of value
	400 nm to 700 nm		0.5 % of value
	700 nm to 820 nm		1.5 % of value

Representative CMCs are for 0°:45° geometry and white spectralon only. Measurement uncertainty varies with scattering geometry, radiance factor and angular dependence of scattering properties of materials.

5.69 Optical Properties of Materials: Spectrally integrated

(a)	Luminous transmittance		
	Spectrally flat materials		0.3 % of value
	General materials		5 % of value
(b)	Luminous reflectance		
	General materials		5 % of value
(c)	Colour transmitted, x, y, Y or L*a*b*		
	In x and y		0.005
	Luminous transmittance Y for (0.1 < Y < 1)		5 % of value
(d)	Colour of surfaces, x, y, Y or L*a*b*		

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In x and y 0.003
Luminance factor Y for (0.1 < Y < 1) 5 % of value

(e) Retroreflectors: CIL value

Coefficient of luminous intensity 5 %

5.82 Resistors, Resistance Boxes and Potential Dividers

(a) Precision resistors, resistance boxes and conductance boxes

0.1 Ω to 1 Ω 0.2 μΩ/Ω
(Current ≤ 100 mA)

1 Ω to 10 kΩ 0.12 μΩ/Ω
(Power dissipation ≤ 10 mW)

10 mΩ to 1000 mΩ 25 μΩ/Ω
(Current ≤ 1A)

0.1 mΩ to 1000 mΩ 63 R^{-0.35} μΩ/Ω, R in mΩ
(Current = 1 A to 875 A) values range from 141 μΩ/Ω to 6 μΩ/Ω

0.01 MΩ to 1 MΩ 0.7 μΩ/Ω
(Applied voltages = 5 V to 100 V)

0.001 GΩ to 1 GΩ (0.7 + 27 R – 20 R³) μΩ/Ω, R
(Applied voltages = 5 V to 100 V) in GΩ, values range from 0.7 μΩ/Ω to 8 μΩ/Ω

1 MΩ to 5 TΩ (35 + 6.9 x 10⁻¹¹ R² + 9.4 μΩ/Ω
(Applied voltages = 100 V to 1000 V) x 10⁻⁴R) μΩ/Ω, R in MΩ, values range from 35 μΩ/Ω to 6460 μΩ/Ω

0 MΩ to 1 MΩ (2000/f + 19 R) μΩ, f in Hz,
(frequency, f = 40 Hz to 2 kHz) R in Ω, values range from 1 μΩ to 19 Ω

(b) Volt ratio boxes and potential dividers

1 V/V to 1000 V/V 0.4 x 10⁻⁶
(Input voltage ≤ 1100 V, output voltage ≥ 1 V)

0 kV to 50 kV 3 mV/V

(c) DC shunts

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| (d) AC shunts

0.1 mΩ to 1 Ω
(Applied current 1 A to 875 A)
(Applied voltage 10 mV to 1 V)

0 Ω to 100 Ω
(frequency, $f = 40$ Hz to 2 kHz)

0.2 A to 100 A
(frequency, $f = 47$ Hz to 75 Hz) | 63 $R^{0.35}$ μΩ/Ω, R in mΩ
values range from 141 μΩ/Ω
to 6 μΩ/Ω

(2000/ f + 19 R) μΩ, f in Hz,
R in Ω, values range from 1 μΩ
to 1900 μΩ

25 μΩ/Ω |
|--|---|

5.84 Capacitors

- | | |
|---|--|
| (a) Precision capacitors

0 μF to 100 μF
(frequency, $f = 40$ Hz to 2 kHz)

Dissipation factor
0 to 0.2

(frequency, $f = 40$ Hz to 2 kHz)
(capacitance, $C = 0.5$ pF to 100 μF) | (0.2/ f + 22 C) pF, f in Hz,
C in μF, values range from
0.0001 pF to 2200 pF

(0.000027 + 0.00027/ C) pF,
C in pF
values range from 0.00057 to
0.000027 |
| (c) Capacitance potential dividers

1 kV rms to 35 kV rms
(frequency, $f = 50$ Hz to 3 kHz) | 1 mV/V |

5.85 Inductors and Transformers

- | | |
|---|--|
| (a) Inductors, self and mutual

0 H to 100 H
(frequency, $f = 40$ Hz to 2 kHz)

Equivalent series resistance
0 Ω to 1 MΩ
(frequency, $f = 40$ Hz to 2 kHz) | (0.2/ f + 14 L) μH, f in Hz
L in H, values range from
0.0001 μH to 1400 μH

(2000/ f + 19 R) μΩ, f in Hz,
R in Ω, values range from 1 μΩ
to 19 Ω |
| (d) Current transformers: protection and measurement | |

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Primary currents 1 A to 4000 A, ratios 0.2 A/A to 4000 A/A

Ratio error	-25 % to 25 %	0.0010 % to 0.13 %
Phase error (frequency, $f = 50$ Hz; secondary currents 1 A, 5 A)	-36 crad to 36 crad	0.0010 crad to 0.18 crad

5.86 Voltage Standards and Current Standards

(b) Electronic emf reference devices

1 V	0.1 μ V
1.018 V	0.1 μ V
10 V	1.5 μ V

5.87 Transfer Instruments (AC/DC)

0.002 V to 0.6 V	11 μ V/V to 321 μ V/V
> 0.6 V to 6 V	6 μ V/V to 77 μ V/V
> 6 V to 1000 V (frequency, $f = 10$ Hz to 1 MHz)	9 μ V/V to 76 μ V/V

1 V and 3 V (frequency, $f = 1$ MHz to 100 MHz)	0.16 mV/V to 2.6 mV/V
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0.1 mA to 0.01 A (frequency, $f = 40$ Hz to 2 kHz)	15 μ A/A to 38 μ A/A
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0.01 A to 20 A (frequency, $f = 40$ Hz to 100 kHz)	15 μ A/A to 70 μ A/A
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5.88 Calibrators for Instrumentation

(a) DC voltage

0 V to 12 V	(0.05 + 0.15U) μ V, U in V, values range from 0.05 μ V to 1.85 μ V
12 V to 1100 V	

(b) AC voltage

0.5 V to 250 V (frequency, $f = 40$ Hz to 75 Hz)	19 μ V/V
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1 V and 3 V (frequency, $f = 1$ MHz to 100 MHz)	0.3 mV/V to 8 mV/V
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(c)	DC current	10 pA to 10 µA 10 µA to 1 A 1 A to 20 A 20 A to 1000 A	values range from 5 µA/A to 560 µA/A 5 µA/A $5 I^{0.43}$ µA/A, I in A, values range from 5 µA/A to 18µA/A $5 I^{0.43}$ µA/A, I in A, values range from 18 µA/A to 97 µA/A
(d)	AC current	0.1 mA to 2 A (frequency, $f = 40$ Hz to 2 kHz) 0.01 A to 100 A (frequency, $f = 47$ Hz to 75 Hz)	35 µA/A to 170 µA/A 25 µA/A
(e)	Resistance	0 Ω to 10 Ω 0.01 kΩ to 1 MΩ 1 MΩ to 100 MΩ	40 µΩ 3 µΩ/Ω $(2 + R^{0.8})$ µΩ/Ω, R in MΩ, values range from 3 µΩ/Ω to 42 µΩ/Ω
(f)	AC power sources	Same as 5.89 (e) and (f)	

5.89 Indicating Instruments and Recording Instruments

(a)	DC voltmeters	0 V to 0.001 V 0.001 V to 12 V 12 V to 1100 V	0.05 µV $(0.05 + 0.15 U)$ µV, U in V, values range from 0.05 µV to 1.85 µV 0.5 µV/V
(b)	AC voltmeters	0.002 V to 1000 V (frequency, $f = 10$ Hz to 1 MHz) 1 V and 3 V (frequency, $f = 1$ MHz to 100 MHz)	9 µV/V to 862 µV/V 0.3 mV/V to 8 mV/V

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(c) DC ammeters

10 pA to 10 µA	values range from 5 µA/A to 560 µA/A
10 µA to 1 A	5 µA/A
1 A to 20 A	5 I ^{0.43} µA/A, I in A, values range from 5 µA/A to 18µA/A
20 A to 875 A	5 I ^{0.43} µA/A, I in A, values range from 18 µA/A to 92 µA/A

(d) AC ammeters

0.1 mA to 2 A (frequency, f = 40 Hz to 2 kHz)	60 µA/A to 140 µA/A
0.2 A to 100 A (frequency, f = 47 Hz to 75 Hz)	25 µA/A

(e) Wattmeters

Conditions

Voltage 30 V to 500 V, frequency 40 Hz to 60 Hz, and PF 1 to 0, inductive or capacitive

Current

0.01 A to 0.02 A	28 µW/VA
0.02 A to 0.2 A	15 µW/VA
0.2 A to 200 A	10 µW/VA

(f) Varmeters

Conditions

Voltage 30 V to 500 V, frequency 40 Hz to 60 Hz, and QF 1 to 0, inductive or capacitive

Current

0.01 A to 0.02 A	28 µVar/VA
0.02 A to 0.2 A	15 µVar/VA
0.2 A to 200 A	10 µVar/VA

(g) Phase angle indicators (source or meter)

Conditions

Current 0.01 A to 100 A, frequency 45 Hz to 75 Hz, Voltage 0.7 V to 7 V, 42 V to 240 V

-3.14 rad to 3.14 rad	40 µrad
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(h) Power factor meters

Same conditions, CMC range and uncertainties as 5.89 (g)

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(i) Ohmmeters

0.1 mΩ to 1000 mΩ
(applied current 875 A to 1 A)
0.1 Ω to 1 Ω
(applied current ≤100 mA)
1 Ω to 10 kΩ
10 kΩ to 1 GΩ

1 GΩ to 100 GΩ

100 GΩ to 1200 GΩ

$63R^{0.35} \mu\Omega/\Omega$, R in mΩ, values range from 141 $\mu\Omega/\Omega$ to 6 $\mu\Omega/\Omega$
0.2 $\mu\Omega/\Omega$

0.12 $\mu\Omega/\Omega$
 $(1 + 27R - 20R^3) \mu\Omega/\Omega$, R in GΩ, values range from 1 $\mu\Omega/\Omega$ to 8 $\mu\Omega/\Omega$
 $(-0.07R^2 + 22R - 15) \mu\Omega/\Omega$, R in GΩ, values range from 6.9 $\mu\Omega/\Omega$ to 1485 $\mu\Omega/\Omega$
 $(1300R + 2.2R) \mu\Omega/\Omega$, R in GΩ, values range from 1520 $\mu\Omega/\Omega$ to 3940 $\mu\Omega/\Omega$

(k) Galvanometers and null detectors

Same CMC range and uncertainties from 5.89 (a)

(l) Energy meters

Same as 5.89 (e) and (f)

5.90 Bridges, Potentiometers and Test Sets

(a) DC bridges

Same as 5.89 (i)

(b) DC potentiometers

Same as 5.89 (a)

(c) AC bridges (frequency, $f = 40$ Hz to 2 kHz)

0 Ω to 1 MΩ

0 μF to 100 μF

0 H to 1 H

$(2000/f + 19R) \mu\Omega$, f in Hz, R in Ω, values range from 1 $\mu\Omega$ to 19 Ω
 $(0.2/f + 22C) \text{ pF}$, f in Hz, C in μF, values range from 0.0001 pF to 2200 pF
 $(0.2/f + 14L) \mu\text{H}$, f in Hz, L in H, values range from 0.0001 μH to 14 μH

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(f) Current transformer testing sets

Ratio/Phase
(frequencies in the range 45 Hz to 65 Hz)

Ratio error	± (0 to 0.002)	5.0×10^{-7} to 1.0×10^{-6}
Ratio error	± (0.002 to 0.02)	2.0×10^{-6} to 8.0×10^{-6}
Ratio error	± (0.02 to 0.2)	2.0×10^{-5} to 8.0×10^{-5}
Phase error	± 0 rad to 0.002 rad	5.0×10^{-7} rad to 1.0×10^{-6} rad
Phase error	± 0.002 rad to 0.02 rad	5.0×10^{-6} rad to 9.0×10^{-6} rad
Phase error	± 0.02 rad to 0.2 rad	5.0×10^{-5} rad to 9.0×10^{-5} rad

(g) Voltage transformer testing sets

Same as 5.90 (f)

AC and DC bridges for thermometry

Resistance 0 Ω to 400 Ω (frequency, $f =$ DC to 100 Hz)		$(6 + 0.3 R) \mu\Omega$, R in Ω, values range from 6 μΩ to 126 μΩ
Resistance ratio 0 Ω/Ω to 13 Ω/Ω (frequency, $f =$ DC to 100 Hz)		2.6×10^{-8}

5.91 Time and Frequency

Time and frequency CMC uncertainties relate only to the reference measuring systems. These uncertainties do not contain any contribution from the instrument under calibration.

(a) Frequency meters

(c) Counters

1 Hz to 120 MHz		$(7 \times 10^{-13}f + 5 \times 10^{-8})$ Hz, f in Hz
120 MHz to 350 MHz		$(2 \times 10^{-9}f + 5 \times 10^{-8})$ Hz, f in Hz
350 MHz to 40 GHz		$(2 \times 10^{-9}f + 5 \times 10^{-5})$ Hz, f in Hz
10 ns to 1000 s (period)	Rise time: <50 ns for 5 V	$(7 \times 10^{-13}t + 2 \times 10^{-10})$ s, t in s

(d) Time interval meters

10 ns to 86400 s	Rise time: <50 ns for 5 V	$(7 \times 10^{-13}t + 5 \times 10^{-10})$ s, t in s
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(g) Frequency standards

100 kHz to 10 MHz		2×10^{-13}
10 ns to 1000 s (period)	Rise time: <50 ns for 5 V	$(7 \times 10^{-13}t + 2 \times 10^{-10})$ s, t in s

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(h) Time measurement

Time scale difference – local clock vs UTC(MSL)
-1 s to 1 s

2 ns

Time scale difference – local clock vs UTC
-1 s to 1 s

10 ns

5.92 Waveform

(a) Frequency characteristics

1 Hz to 120 MHz
10 ns to 1000 s (period) Rise time: <50 ns for 5 V

$(7 \times 10^{-13}f + 5 \times 10^{-8})$ Hz, f in Hz
 $(7 \times 10^{-13}t + 2 \times 10^{-10})$ s, t in s

(b) Input characteristics

1 V and 3 V
(frequency, $f = 1$ MHz to 100 MHz)

0.16 mV/V to 2.6 mV/V

Pulse risetime ($T > 5$ ns)
(10 mV to 10 V)

0.005 μ s to 1.00×10^6 μ s

$Q(2 \text{ ns}, 0.05T)$, T in s

Pulse amplitude (pulse length > 200 μ s)
(10 mV, 100 mV, 1 V, 10 V)

0 V to 10 V

$(30 \mu\text{V} + 100V_a + 420V_r)$,
applied voltage V_a in V,
voltmeter range V_r in V, values
range from 34.2 μ V to 5230 μ V

(c) Timing characteristics

10 ns to 100 s
(time difference)

2 ns

5.93 Signal Sources

(a) Frequency characteristics

1 Hz to 120 MHz
10 ns to 1000 s (period) Rise time: <50 ns for 5 V

$(7 \times 10^{-13}f + 5 \times 10^{-8})$ Hz, f in Hz
 $(7 \times 10^{-13}t + 2 \times 10^{-10})$ s, t in s

(b) Output characteristics

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1 V and 3 V
 (frequency, $f = 1$ MHz to 100 MHz)

0.16 mV/V to 2.6 mV/V

Pulse amplitude (pulse length > 200 μ s)
 (10 mV, 100 mV, 1 V, 10 V)

0 V to 10 V

($30 \mu\text{V} + 100 V_a + 420 V_r$)
 applied voltage V_a in V,
 voltmeter range V_r in V, values
 range from 34.2 μ V to 5230 μ V

Pulse risetime ($T > 5$ ns)
 (10 mV to 10 V)

0.005 μ s to $1.00 \times 10^6 \mu$ s

$Q(2 \text{ ns}, 0.05T)$, T in s

Note 1:

A CMC anticipates the performance of a best available device. Measurement uncertainties achieved for specific calibrations may be greater than CMC uncertainties, but a laboratory may not report measurement uncertainties lower than those in its CMCs. Please contact the laboratory to discuss your specific requirements.

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