Schedule to
CERTIFICATE OF ACCREDITATION

Callaghan Innovation **Client Number 8**
Measurement Standards Laboratory of New Zealand

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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

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5.86	Voltage Standards and Current Standards
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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 Mark Clarkson	5.41, 5.42, 5.43, 5.44
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 Annette Koo	5.68, 5.69
Dr Tim Lawson	5.82, 5.86, 5.88, 5.89
Dr Jeremy Lovell-Smith	5.35
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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 Cheng Yang	5.89, 5.91
Mr Yang Yenn Tan	5.65
Mr Chris Young	5.01, 5.02, 5.05, 5.11, 5.12, 5.14

Callaghan Innovation
Metrology & Calibration Laboratory
SCOPE OF ACCREDITATION

Accreditation Number 1

The uncertainty of a Calibration and Measurement Capability (CMC) is expressed as an expanded uncertainty corresponding to a level of confidence of 95 % [Note1].

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

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

Measurand	Conditions	CMC Uncertainty
Mean diameter	0.5 mm to 25 mm	Q(130, 1.4*L*) nm, *L* in mm
Mean diameter	25 mm to 300 mm	Q(95, 1.8*L*) nm, *L* in mm

Setting ring gauges by comparison with gauge blocks

Measurand	Conditions	CMC Uncertainty
Mean diameter	1 mm to 300 mm	Q(95, 1.8*L*) nm, *L* in mm

Where $Q(a, b) = \sqrt{a^2 + b^2}$

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

Measurand	Conditions	CMC Uncertainty
Lobster tail gauges	52 mm to 100 mm	0.01 mm

(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

Measurand	Conditions	CMC Uncertainty
	10 mm to 700 mm	Q(0.1, 0.55*L*) µm, *L* in m

5.02 Jigs, Fixtures, Cutting Tools and Components

3D measurements using a calibrated Legex 574 CMM

Measurand	Conditions	CMC Uncertainty
Error of indicated size	0.001 mm to 750 mm	(0.28 + *L*/1000) µm, *L* in mm

Angle measurements derived from length measurements

Measurand	Conditions	CMC Uncertainty
Angle	7×10^{-6} radians to 6.28 radians	7×10^{-7} radians

Measurement of components/objects on Profile Projector

	Error of indicated size	up to 200 mm x 200 mm	Q(0.76, 12.6*L*) 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, 0.018*R*) µm, *R* in µm

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

Parallelism 0 µm to 10 µm	Range of diameters 10 mm to 35 mm	0.08 µm
Flatness 0 µm to 2.5 µm	Range of diameters 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, 7.1*L*) 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, 0.15*L*) nm, *L* in mm
By comparison	0.1 mm to 103 mm	Q(36, 1.4*L*) nm, *L* in mm

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

(b) Length bars and accessories

Measurement of central length and variation in length

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

	100 mm to 300 mm		Q(91, 1.3*L*) nm, *L* in mm
	Measurement of variation in length		Q(34, 0.35*L*) 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, 8.2*L*) 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, 10.5*L*) µm, *L* in m

Surveyor levelling rods

	0.5 m to 3 m		Q(10, 10*L*) 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, 0.6×10^{-3}*L*) mm, *L* in m

5.12 Precision Measuring Instruments

(a) Length measuring machines

Electronic distance measuring machines (EDMs)

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

(b) Other stabilised lasers

Absolute frequency	473 612 GHz	0.2 MHz

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 40 µg
1 kg to 10 kg	1.1 x 10^{-7}
10 kg to 20 kg	1.6 x 10^{-7}
20 kg to 300 kg	1.5 x 10^{-6}
300 kg to 500 kg	10 g to 16 g

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

(b) Examination of other types of volumetric apparatus

0.002 L to 50 L	0.01 %

5.32 Density

(a) Density of solids

1400 kg/m^3 to 3000 kg/m^3	1.0 x 10^{-5}
7800 kg/m^3 to 8200 kg/m^3	1.5 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

$(-70 \le t_f < 0)$ °C	0.2 °C to 0.06 °C
$(0 \le t_d < 40)$ °C	0.06 °C
$(40 \le t_d \le 70)$ °C	0.06 °C to 0.12 °C

Relative humidity hygrometers

Measurand	Conditions	CMC uncertainty
$(10 \le h \le 98)$ %rh	$(0 \le t \le 70)$ °C	0.006h %rh
$(1 \le h < 10)$ %rh	$(0 \le t \le 70)$ °C	0.06 %rh
$(10 \le h \le 98)$ %rh	$(-55 \le t < 0)$ °C	$(0.006 – 0.00022t)h$ %rh

Air temperature

$(-55 \le t \le 70)$ °C	0.05 °C

Humidity generators (including chambers)

CMCs as per 5.35 (a)

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}

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110 kPa to 130 kPa	2.0 x 10^{-5}

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	00 mPa to 160 mPa, increasing linearly
8 kPa to 550 kPa	2 x 10^{-5}
550 to 11000 kPa	6 x 10^{-5}

Gauge pressure – liquid medium

0.1 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)

5.44 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	2×10^{-5}
550 kPa to 7000 kPa	6×10^{-5}

Gauge pressure – gas medium

-96 kPa to 8 kPa	0.0031 kPa
8 kPa to 90 kPa	2×10^{-5}
90 kPa to 110 kPa	1×10^{-5}
110 kPa to 550 kPa	2×10^{-5}
550 to 11000 kPa	6×10^{-5}

Absolute pressure – liquid medium

0.3 MPa to 17 MPa	($1 \times 10^{-4} + 6.6 \times 10^{-5}p$) MPa ($p$ in MPa)
17 MPa to 280 MPa	($6.6 \times 10^{-5}p + 7 \times 10^{-7}p^2$) MPa ($p$ in MPa)

Gauge pressure – liquid medium

0.2 MPa to 17 MPa	($1 \times 10^{-4} + 6.6 \times 10^{-5}p$) MPa ($p$ in MPa)
17 MPa to 280 MPa	($6.6 \times 10^{-5}p + 7 \times 10^{-7}p^2$) 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

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

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

-190 °C to 0 °C	(2.4 - 0.005*t*) mK, *t* in °C
0 °C to 200 °C	(2.4 + 0.008*t*) 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 %

(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 $\mu W.cm^{-2}$ to 5000 $\mu W.cm^{-2}$

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 $\mu J.cm^{-2}$

	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

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 $\mu W.nm^{-1}$ to 10 $\mu W.nm^{-1}$ and corresponding irradiance levels using appropriate apertures. For spectral power levels below 0.1 $\mu W.nm^{-1}$ 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 %

(e) Illuminance

0.005 lux to 30000 lux		2.3 %

(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	$0.000087.10^{0.8.OD}$
		OD = 0 to 2	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

(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

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(b)	Luminous reflectance	
	General materials	5 % of value
(c)	Colour transmitted, x, y, Y or L*a*b*	
	In x and y Luminous transmittance Y for (0.1 < Y < 1)	0.005 5 % of value
(d)	Colour of surfaces, x, y, Y or L*a*b*	
	In x and y Luminance factor Y for (0.1 < Y < 1)	0.003 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 (Current ≤ 100 mA)	0.2 μΩ/Ω
	1 Ω to 10 kΩ (Power dissipation ≤ 10 mW)	0.12 μΩ/Ω
	10 mΩ to 1000 mΩ (Current ≤ 1A)	25 μΩ/Ω
	0.1 mΩ to 1000 mΩ (Current = 1 A to 875 A)	63 $R^{-0.35}$ μΩ/Ω, *R* in mΩ values range from 141 μΩ/Ω to 6 μΩ/Ω
	0.01 MΩ to 1 MΩ (Applied voltages = 5 V to 100 V)	0.7 μΩ/Ω
	0.001 GΩ to 1 GΩ (Applied voltages = 5 V to 100 V)	(0.7 + 27 *R* – 20 R^3) μΩ/Ω, *R* in GΩ, values range from 0.7 μΩ/Ω to 8 μΩ/Ω
	1 MΩ to 5 TΩ (Applied voltages = 100 V to 1000 V)	(35 + 6.9 x 10^{-11} R^2 + 9.4 μΩ/Ω x $10^{-4}R$) μΩ/Ω, *R* in MΩ, values range from 35 μΩ/Ω to 6460 μΩ/Ω
	0 MΩ to 1 MΩ (frequency, *f* = 40 Hz to 2 kHz)	(2000/*f* + 19 *R*) μΩ, *f* in Hz, *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 (Input voltage ≤ 1100 V, output voltage ≥ 1 V)	0.4 x 10^{-6}
	0 kV to 50 kV	3 mV/V
(c)	DC shunts	
	0.1 mΩ to 1 Ω (Applied current 1 A to 875 A) (Applied voltage 10 mV to 1 V)	63 $R^{-0.35}$ μΩ/Ω, *R* in mΩ values range from 141 μΩ/Ω to 6 μΩ/Ω
(d)	AC shunts	
	0 Ω to 100 Ω (frequency, *f* = 40 Hz to 2 kHz)	(2000/*f* + 19*R*) μΩ, *f* in Hz, *R* in Ω, values range from 1 μΩ to 1900 μΩ
	0.2 A to 100 A (frequency, *f* = 47 Hz to 75 Hz)	25 μΩ/Ω
5.84	**Capacitors**	
(a)	Precision capacitors	
	0 μF to 100 μF (frequency, *f* = 40 Hz to 2 kHz)	(0.2/*f* + 22C) pF, *f* in Hz, *C* in μF, values range from 0.0001 pF to 2200 pF
Dissipation factor	0 to 0.2 (frequency, *f* = 40 Hz to 2 kHz) (capacitance, *C* = 0.5 pF to 100 μF)	(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)	(0.2/f + 14L) µH, f in Hz L in H, values range from 0.0001 µH to 1400 µH
Equivalent series resistance	0 Ω to 1 MΩ (frequency, f = 40 Hz to 2 kHz)	(2000/f + 19R) µΩ, f in Hz, R in Ω, values range from 1 µΩ to 19 Ω

(d) Current transformers: protection and measurement

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	-36 crad to 36 crad	0.0010 crad to 0.18 crad

(frequency, f = 50 Hz; secondary currents 1 A, 5 A)

5.86 Voltage Standards and Current Standards

(b) Electronic emf reference devices

1 V	0.1 µV
1.018 V	0.1 µV
10 V	1.5 µV

5.87 Transfer Instruments (AC/DC)

0.002 V to 0.6 V	11 µV/V to 321 µV/V
> 0.6 V to 6 V	6 µV/V to 77 µV/V
> 6 V to 1000 V	9 µV/V to 76 µV/V
(frequency, f = 10 Hz to 1 MHz)	
1 V and 3 V (frequency, f = 1 MHz to 100 MHz)	0.16 mV/V to 2.6 mV/V
0.1 mA to 0.01 A (frequency, f = 40 Hz to 2 kHz)	15 µA/A to 38 µA/A
0.01 A to 20 A (frequency, f = 40 Hz to 100 kHz)	15 µA/A to 70 µA/A

5.88 Calibrators for Instrumentation

(a) DC voltage

0 V to 12 V	(0.05 + 0.15U) µV, U in V, values range from 0.05 µV

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		to 1.85 µV
	12 V to 1100 V	0.5 µV/V
(b)	AC voltage	
	0.5 V to 250 V (frequency, f = 40 Hz to 75 Hz)	19 µV/V
	1 V and 3 V (frequency, f = 1 MHz to 100 MHz)	0.3 mV/V to 8 mV/V
(c)	DC current	
	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 1000 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)	35 µA/A to 170 µA/A
	0.01 A to 100 A (frequency, f = 47 Hz to 75 Hz)	25 µA/A
(e)	Resistance	
	0 Ω to 10 Ω	40 µΩ
	0.01 kΩ to 1 MΩ	3 µΩ/Ω
	1 MΩ to 100 MΩ	(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	0.05 µV
	0.001 V to 12 V	(0.05 + 0.15 U) µV, U in V, values range from 0.05 µV

	12 V to 1100 V	to 1.85 µV 0.5 µV/V
(b)	AC voltmeters	
	0.002 V to 1000 V (frequency, *f* = 10 Hz to 1 MHz)	9 µV/V to 862 µV/V
	1 V and 3 V (frequency, *f* = 1 MHz to 100 MHz)	0.3 mV/V to 8 mV/V
(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

(h) Power factor meters

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

(i) Ohmmeters

0.1 mΩ to 1000 mΩ (applied current 875 A to 1 A)	$63R^{-0.35}$ µΩ/Ω, R in mΩ, values range from 141 µΩ/Ω to 6 µΩ/Ω
0.1 Ω to 1 Ω (applied current ≤100 mA)	0.2 µΩ/Ω
1 Ω to 10 kΩ	0.12 µΩ/Ω
10 kΩ to 1 GΩ	$(1 + 27R - 20R^3)$ µΩ/Ω, R in GΩ, values range from 1 µΩ/Ω to 8 µΩ/Ω
1 GΩ to 100 GΩ	$(-0.07R^2 + 22R - 15)$ µΩ/Ω, R in GΩ, values range from 6.9 µΩ/Ω to 1485 µΩ/Ω
100 GΩ to 1200 GΩ	$(1300R + 2.2R)$ µΩ/Ω, R in GΩ, values range from 1520 µΩ/Ω to 3940 µΩ/Ω

(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)

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	0 Ω to 1 MΩ		(2000/*f* + 19*R*) μΩ, *f* in Hz, *R* in Ω, values range from 1 μΩ to 19 Ω
	0 μF 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 H to 1 H		(0.2/*f* + 14*L*) μH, *f* in Hz, *L* in H, values range from 0.0001 μH to 14 μH

(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*) μΩ, *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

1 Hz to 40 GHz	1×10^{-10}
0.001 Hz to 1 Hz (period)	1 ns

(c) Counters

	1 Hz to 40 GHz 0.001 Hz to 1 Hz (period)	1 x 10^{-10} 1 ns
(d)	Time interval meters	
	10 ns to 86400 s	2 ns or 0.27 ps/s, whichever is greatest
(g)	Frequency standards	
	100 kHz to 10 MHz 0.001 Hz to 1 Hz (period)	2 x 10^{-13} 1 ns

5.92 Waveform

(a)	Frequency characteristics	
	1 Hz to 20 MHz 0.001 Hz to 1 Hz (period)	1 in 10^{-10} 1 ns
(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 µs to 1.00 x 10^6 µs	Q(2 ns, 0.05T), T in s
Pulse amplitude (pulse length > 200 µs)	(10 mV, 100 mV, 1 V, 10 V)	
	0 V to 10 V	(30 µV+ 100Va + 420Vr), applied voltage Va in V, voltmeter range Vr in V, values range from 34.2 µV to 5230 µV
(c)	Timing characteristics	
	10 ns to 100 s (time difference)	2 ns

5.93 Signal Sources

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(a)	Frequency characteristics	
	1 Hz to 20 MHz 0.001 Hz to 1 Hz (period)	1×10^{-10} 1 ns
(b)	Output characteristics	
	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 µs)	(10 mV, 100 mV, 1 V, 10 V)	
	0 V to 10 V	(30 µV + 100*Va* + 420*Vr*) applied voltage *Va* in V, voltmeter range *Vr* in V, values range from 34.2 µV to 5230 µV
Pulse risetime (T > 5 ns)	(10 mV to 10 V)	
	0.005 µs to 1.00×10^6 µs	Q(2 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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