



Accredited Laboratory

A2LA has accredited

PRECISION METROLOGY, INC.

Milwaukee, WI

for technical competence in the field of

Calibration

This laboratory is accredited in accordance with the recognized International Standard ISO/IEC 17025:2005 *General requirements for the competence of testing and calibration laboratories*. This laboratory also meets the requirements of ANSI/NCSLI Z540-1-1994 and R205 – Specific Requirements: Calibration Laboratory Accreditation Program. This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system (*refer to joint ISO-ILAC-IAF Communiqué dated 8 January 2009*).



Presented this 16th day of January 2017.

A handwritten signature in black ink, appearing to read "L. J. ...", positioned above a horizontal line.

President and CEO
For the Accreditation Council
Certificate Number 1078.01
Valid to July 31, 2018

For the calibrations to which this accreditation applies, please refer to the laboratory's Calibration Scope of Accreditation.



SCOPE OF ACCREDITATION TO ISO/IEC 17025:2005
& ANSI/NCSL Z540-1-1994

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CALIBRATION

Valid To: July 31, 2018

Certificate Number: 1078.01

In recognition of the successful completion of the A2LA evaluation process, accreditation is granted to this laboratory to perform the following calibrations^{1, 10}:

I. Acoustical Quantities

Parameter/Equipment	Range	CMC ^{2, 8} (±)	Comments
Sound Level Source	(85 to 140) dB	0.20 dB + 0.032 %	Piston phone, transducer
Measure (Meters)	(20 to 140) dB	0.32 dB	Sound level calibrator
Sound Level ³ Source/Measure (Meters)	(20 to 140) dB	0.60 dB	Sound level calibrator

II. Chemical

Parameter/Equipment	Range	CMC ^{2, 4} (±)	Comments
Conductivity Meters	10 µS/cm 100 µS/cm 1000 µS/cm 1400 µS/cm 10 000 µS/cm	0.68 µS/cm + 0.6R 1.2 µS/cm + 0.6R 4.5 µS/cm + 0.6R 6.9 µS/cm + 0.6R 55 µS/cm + 0.6R	Conductivity solutions

Parameter/Equipment	Range	CMC ² (±)	Comments
pH Meters ³	4 pH 7 pH 10 pH	0.014 pH 0.014 pH 0.014 pH	Standard buffers

III. Dimensional

Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
Angle Blocks	Up to 60°	$(0.36 + 1.1 * \theta / 20)$ arcsec,	Sine bar, gage blocks, gage amp & probe, Where θ = angle
Angle Plates ³	Up to 30 in	$(120 + 6H)$ μin	Gage amp. probe, indi-square and test indicator
Arbor – Straightness	Up to 24 in	$(35 + 9L)$ μin	Gage amp w/probe
Articulating Arm ³ (CMM) – Single Point Articulation Max Deviation 2sSPAT Effective Diameter Volumetric Max Deviation Range 2RMS	 (2 to 10.5) ft 1 in (25.4 mm) (16 to 36) in (52 to 76) in (16 to 36) in (52 to 76) in (16 to 76) in	 110 μin (2.8 μm) 22 μin (0.56 μm) 82 μin (2.1 μm) 60 μin + 7.5 μin/in 60 μin + 7.0 μin/in 85 μin + 11 μin/in 85 μin + 9.9 μin/in 0.98 μin/in	ASME B89.4.22-2004
Bench Center – Center Parallelism Base Flatness & Base Parallelism	 Up to 24 in Up to 24 in	 $(68 + 4L)$ μin $(62 + 2.5L)$ μin	Gage amp w/probe



Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
Bore Gages ³	Up to 12 in	22 μin or 0.6R (whichever is greater)	SIP302M
Box Parallels – Parallelism Squareness	5 in × 10 in × 10 in	(12 + 20H) μin (18 + 20H) μin	Gage amp w/probe, cylindrical square
Calipers ³ (Including Intertest, Oditest, Snap Jaw and other OD Calipers) – Resolution 0.0001 in Resolution 0.0005 in Resolution 0.001 in	Up to 2 in (2 to 12) in Up to 24 in (24 to 60) in Up to 30 in (30 to 100) in	78 μin 70 μin + 4 μin/in 450 μin 340 μin + 3.7 μin/in 840 μin 700 μin + 3.4 μin/in	Gage blocks
Chamfer Gages/Hole Gages ³	Up to 12 in	20 μin + 0.6R	Cylindrical rings
Clinometers and Inclinometers, and Electronic Levels	Up to 360°	0.18 arcseconds + 37 parts in 10 ⁶	Sine bar/gage blocks
CMMs – Imaging (Video CMMs/Vision Systems) ³ Length Measurements EUX, EUY, EUXY EUV EZ Squareness – ESQ Probing Performance PF2D, PFV2D	XY diagonal up to 36.5 in. Up to 24 in Up to 2 in. Up to 8 in (Z-axis) Up to 8 in (Z-axis) Diameter Measured: (0.012 to 0.12) in (0.12 to 0.4) in.	 (23 + 2.9L) μin (15 + 2.9L) μin (41 + 3.2L) μin (19 + 130L) μin 16 μin 25 μin	ISO 10360-7 (Unidirectional) Glass scales Glass scales Gage blocks Ballbar Test circles



Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
CMMs ³ –			
Length Error (E _L)	Up to 52 in	38 μin + 5.2 μin/in	ASME B89.4.1.10360.2
Repeatability Range (R ₀)	Up to 52 in	22 μin + 3 μin/in	
Length	Up to 114 in on each axis	38 μin + 5.2 μin/in	ASME B89.4.1.2000
Volume	Up to 36 in for shortest axis	82 μin + 13 μin/in	
Probing Analysis Bi-directional	Up to 30 in	2 μm (40 + 10L) μin	Ball bar Test probe
Coating Thickness Shims/Precision Shims	25 μin to 0.5 in	19 μin + 82 μin/in	Heidenhain-Certo CT 6001
Concentricity Gage	N/A	130 μin + 8 μin/in	Indicator, bench center
Cylindrical Plugs ³	Up to 4 in (4 to 8.5) in (8.5 to 20) in	4 μin + 5 μin/in 4 μin + 5.4 μin/in 5.2 μin + 5.5 μin/in	ULM, gage blocks
Cylindrical Rings ³	(0.1 to 8.5) in (8.5 to 18) in (18 to 36) in	(11 + 3.3D) μin (13 + 3.3 D) μin (50 + 3D) μin	ULM, gage blocks
Cylindrical Squares	Up to 12 in	(13 + 9H) μin	Gage amp w/probe; <i>H</i> is the height of the cylinder from the base in inches.
External Spline Gages ³ –			
Measurement Over Pins	Up to 8 in	(170 + 28D) μin	UMM
Circular Tooth Thickness	Up to 8 in Up to 8 in	(110 + 16L) μin	Optical comparator
Major Diameter	Up to 8 in	(28 + 12D) μin	UMM

Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
Fixed Gaging Screw Pitch Gages, Drill Gages, Taper Gages, Center Gages, Sheet and Wire Gages, Angle Gages	Up to 30 in Up to 30 in	(110 + 16L) μin (length measures) 54"	Measuring machine/optical comparator
Functional Gages	(Up to 30) in	(330 + 5.8L) μin	CMM
Gage Amplifier and Probe(s) ³ Single Probe Dual Probe	Up to 0.025 in Up to 0.002 in	8.9 μin 2.1 μin	Gage blocks Gage blocks
Gage Balls	Up to 4 in	(32 + 1.5D) μin	Universal measuring machine (UMM)
Gage Blocks	Up to 4 in (4 to 20) in	(3.1 + 3.2L) μin (3.3 + 3.2L) μin	Gage blocks and comparator
Height Gage ³	Up to 48 in	10 μin/in + 0.6R	Gage blocks
Height Measures ³	Up to 24 in	13 μin/in + 94 μin	Height gage
Indicators ³ – Dial & Test	Up to 4 in	35 μin or 0.6R (whichever is greater)	Indicator calibrator
Indicator Calibrator ³	Up to 4 in	12 μin + 0.6R	Gage blocks, amp w/probe
Laser Distance Meters	Up to 6.1 m	4.6 μm/m + 120 μm	ULM

Parameter/Equipment	Range	CMC ^{2, 4, 8} (\pm)	Comments
Length & Thickness Standards, Feeler Gages ³ –			
Steel	Up to 4 in (4 to 8.5) in (8.5 to 20) in (20 to 120) in	4 μ in + 5 μ in/in 4 μ in + 5.4 μ in/in 5.2 μ in + 5.5 μ in/in 3.7 μ in/in + 14 μ in	ULM, gage blocks ULM
Field Calibration	Up to 16 in	5 μ in + 14 μ in/in + 4 μ in/in/ $^{\circ}$ C	ULM, gage blocks, Relative to 20/ $^{\circ}$ C
Levels (Spirit, Bubble, Machinist) ³	Up to 96 in	5.1 arcseconds + 37 ppm	Surface plate and gage blocks
Linear Measurement of Machine Tools (ULMs) ³	Up to 20 ft	1.5 μ in/in + 0.58 μ in	Laser
Linear Scales/Reticles and Stage Micrometers –			
2D	Up to 12 in	(115 + 15L) μ in	Vision system
1D	Up to 30 in	11 μ in + 1.5 μ in/in	Gitterperioden interferometer
Micrometers ³ –			
Inside	Up to 294 in	12 μ in + 7 μ in /in + 0.2R	ULM, gage blocks or rings
Depth	Up to 12 in	18 μ in/in + 0.64R	
Tri-Bores	Up to 11 in	18 μ in/in + 0.7R	
Outside	Up to 42 in	18 μ in/in + 0.64R	
Groove	Up to 4 in	18 μ in/in + 0.64R	
Bench	Up to 42 in	18 μ in/in + 0.64R	
Thread (Screw, Thread, Pitch, Point)	Up to 4 in	18 μ in/in + 0.64R	
Microscopes ³ –			
Reticule Magnification	Up to 25 mm Up to 1000x	23 μ m 2.4 %	Stage micrometer

Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
Optical Comparator ³ – Linear Angle Magnification	Up to 12 in 0° to 360° 10x, 20x, 50x, 62.5x, 100x, 200x	0.0002 in 2' 0.00012 in	Glass scale Calibration sphere Calibration sphere
Optical Flats	Up to 8 in	2.8 μin	Reference flat and monochromatic light source
Parallels ³ – Steel Granite	1.5 in × 6 in 8 in × 48 in	(10 + 6L) μin (10 + 3.6L) μin	Gage amp w/probe; <i>L</i> is the distance between the parallel surfaces.
Pitch Micrometer Standards – Length Angle	Up to 12 in Up to 60°	(22 + 6L) μin 54"	UMM Vision system
Precision Diameter Tapes	Up to 48 in (48 to 96) in (96 to 780) in	200 μin + 4 μin/in 560 μin + 1.4 μin/in 0.0013 in + 6 μin/in	Setting discs, ULM
Profilometers ³	120 μin Ra	2.8 μin	Roughness specimen
Protractor – Digital and Mechanical ³	0° to 180°	0.0076°	Sine bar and gage blocks
Radius Gage	Up to 5 in	0.00015 in	Vision system
Riser Blocks and Stands	Up to 24 in	(13 + 8H) μin	Gage amplifier with probe

Parameter/Equipment	Range	CMC ^{2,4} (\pm)	Comments
Roundness (Test Circles)	(0.3 to 3.1) mm (3.1 to 10) mm	$(0.16 + 0.08D) \mu\text{m}$ $(0.53 + 0.006D) \mu\text{m}$	Imaging CMM
Roundness Testers ³ –			
Coning Error	Up to 16 in	11 μin	Test ball and riser cylinder
Axial Error	Up to 16 in	11 μin	Test ball
Radial Accuracy	Up to 16 in	11 μin	Test ball
Z-Axis straightness	(0.1 to 12) in	$(14 + 12H) \mu\text{in}$	Cylindrical square; In the CMC, H is the height of the cylinder from the base in inches.
Rules/Scales ³	Up to 100 in	$(86 + 16L) \mu\text{in}$	UMM
Sine Plates/Bars ³ –			
Flatness/Parallelism & Parallelism Cylinder to Base	Up to 20 in	50 μin	Gage amp w/probe, angle blocks and gage blocks
Angle Calibration Center of Rolls	0° to 90° Up to 20 in	0.00045° 16 $\mu\text{in/in}$	
Sand Sieves	20 μm to 125 mm	$(3.2 + 6.9L) \mu\text{m}$	ASTM E11, vision system
Snap Gages ³	Up to 20 in	$88 + 13L \mu\text{in}$	Box parallel with gage amp and probe
Squares ³ –			
Master	Up to 30 in	$(56 + 5H) \mu\text{in}$	Gage amp and probe
Granite	Up to 30 in	$(42 + 6H) \mu\text{in}$	Indi-square and test indicator
Steel	Up to 30 in	$(42 + 6H) \mu\text{in}$	Master square and gage blocks

Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
Straightness and Straight Edges ³	Up to 60 in	(10 + 14L) μin	Gage amplifier w/probe
Step Gages	Up to 50 in	6 μin + 3.9 μin/in	Gage amp and probe, gage blocks
Surface Plates ³ – Flatness	18 in x 24 in to 72 in x 144 in	8√D μin	Electronic levels D is the length of the plate diagonal in inches.
Repeatability	Up to 72 in x 144 in	34 μin	Repeat-o-meter
Surface Roughness ³	(15 to 150) μin Ra	3.4 μin	Verification of specimens per ASME B46.1 Type C using profilometers; Ra is the resolution of the profilometers in microinches.
Tape Measures ³	Up to 300 ft	12 μin + 53 μin/in	UMM
Tapered Plugs ³ – Simple Pitch Diameter	Up to 18 in	(100 + 12D) μin	Thread wires/UMM
Notch Height	Up to 18 in	13 μin/in + 94 μin	Height measuring machine
Tapered Rings ³ – Taper	Up to 18 in	400 μin	NPT master plug, UMM
Standoff and Thickness	Up to 18 in	120 μin	NPT master plug and height measuring machine
Functional Diameter	Up to 2 in	(300 + 8D) μin	

Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
Thread Plugs ³ – Simple Pitch Diameter Major Diameter	Up to 20 in Up to 4 in (4 to 8.5) in (8.5 to 20) in	82 μin + 6.8 μin/in 4 μin + 5 μin/in 4 μin + 5.4 μin/in 5.2 μin + 5.5 μin/in	3-wire method ULM, gage blocks
Thread Rings ³ – Simple Pitch Diameter Minor Diameter Functional Diameter	Up to 18 in Up to 2 in Up to 18 in	(140 + 9D) μin (70 + 13D) μin (100 + 8D) μin	UMM w/ set plug
Thread Wires	Up to 0.5 in	(8.5 + 7D) μin	UMM, gage blocks
Universal Measuring Machines ³ (UMMs) – English Metric	Up to 4 in (4 to 24) in Up to 100 mm	1.5 μin + 1.2 μin/in 1.3 μin + 1.8 μin/in 0.04 μm + 0.0015 μm/mm	Gage blocks
V-Blocks – Parallelism Side V Squareness	8 in × 8 in × 8 in 8 in × 8 in × 8 in 8 in × 8 in × 8 in	14 μin 20 μin (37 + 11H) μin	Gage amplifier w/probe Cylindrical square Cylindrical plug
Wire Crimpers ³ – Crimp Height Crimping Chamber Ratchet Inspection	Up to 00 gauge Up to 00 gauge Up to 00 gauge	0.0024 in (10 + 19D) μin 120 μin	Micrometer Pin; D is the diameter of the pin. Feeler gage

IV. Electrical – DC/Low Frequency

Parameter/Range	Frequency	CMC ^{2,7} (±)	Comments
AC Current – Generate & Measure ³			Max frequency up to 3 mA is 30 kHz. Fluke 5790A, 5700A/EP, A40s, standard resistors
10 µA to 20 A	10 Hz to 50 kHz ³	See Table IV.a ³	
(20 to 70) A (20 to 100) A	10 Hz 55 Hz 300 Hz 1 kHz 5 kHz	85 µA/A 0.013 % 0.012 % 0.012 % 0.036 %	Fluke 52120A, A40B-100, DMM
(20 to 80) A (20 to 50) A	6 kHz 10 kHz	0.039 % 0.092 %	
Measure Only ³ (100 to 1000) A	60 Hz	0.5 %	Current clamp-on meter
Generate Only–Turn Amps ³			
(20 to 120) A (120 to 6000) A	(50 to 400) Hz	0.055 % + 0.6 A 0.80 % - 1.6 A	Fluke 55120A w/ 52120-3k and 52120-6k coils
(20 to 120) A	1000 Hz	0.24 % + 0.24 A	
AC Current – 50 Turn Coils (Effective Current Transfer Ratio)	25 Turn Amps, 50 Hz, 400 Hz 500 Turn Amps, 50 Hz, 400 Hz 800 Turn Amps, 400 Hz 1000 Turn Amps, 50 Hz	0.11 % of ratio 0.12 % of ratio 0.14 % of ratio 0.14 % of ratio	Comparison to standard coil



TABLE IV.a AC Current Generate / Measure³ - CMCs

Current Range	10 Hz	20 Hz	40 Hz
(10 to 300) μ A	170 μ A/A + 0.03 nA	67 μ A/A + 0.03 nA	37 μ A/A + 0.03 nA
300 μ A to 3 mA	170 μ A/A + 0.3 nA	60 μ A/A + 0.3 nA	29 μ A/A + 0.3 nA
(3 to 10) mA	170 μ A/A + 1 nA	69 μ A/A + 1 nA	37 μ A/A + 1 nA
(10 to 20) mA	170 μ A/A + 2 nA	69 μ A/A + 2 nA	37 μ A/A + 2 nA
(20 to 30) mA	170 μ A/A + 3 nA	69 μ A/A + 3 nA	37 μ A/A + 3 nA
(30 to 50) mA	170 μ A/A + 5 nA	69 μ A/A + 5 nA	37 μ A/A + 5 nA
(50 to 100) mA	170 μ A/A + 60 nA	69 μ A/A + 60 nA	37 μ A/A + 60 nA
(100 to 200) mA	170 μ A/A + 120 nA	72 μ A/A + 120 nA	37 μ A/A + 120 nA
(200 to 300) mA	170 μ A/A + 180 nA	72 μ A/A + 180 nA	37 μ A/A + 180 nA
(300 to 500) mA	170 μ A/A + 300 nA	72 μ A/A + 300 nA	37 μ A/A + 300 nA
500 mA to 1 A	170 μ A/A + 6 μ A	72 μ A/A + 6 μ A	41 μ A/A + 6 μ A
(1 to 2) A	170 μ A/A + 12 μ A	75 μ A/A + 12 μ A	42 μ A/A + 12 μ A
(2 to 3) A	180 μ A/A + 18 μ A	81 μ A/A + 18 μ A	58 μ A/A + 18 μ A
(3 to 5) A	190 μ A/A + 30 μ A	85 μ A/A + 30 μ A	58 μ A/A + 30 μ A
(5 to 10) A	190 μ A/A + 60 μ A	100 μ A/A + 60 μ A	73 μ A/A + 60 μ A
(10 to 20) A	220 μ A/A + 12 μ A	130 μ A/A + 12 μ A	86 μ A/A + 12 μ A

TABLE IV.a (Cont'd) AC Current Generate / Measure³ - CMCs

Current Range	400 Hz	1 kHz	5 kHz
(10 to 300) μ A	37 μ A/A + 0.03 nA	37 μ A/A + 0.03 nA	46 μ A/A + 0.03 nA
300 μ A to 3 mA	29 μ A/A + 0.3 nA	30 μ A/A + 0.3 nA	30 μ A/A + 0.3 nA
(3 to 10) mA	35 μ A/A + 1 nA	35 μ A/A + 1 nA	36 μ A/A + 1 nA
(10 to 20) mA	35 μ A/A + 2 nA	35 μ A/A + 2 nA	36 μ A/A + 2 nA
(20 to 30) mA	35 μ A/A + 3 nA	35 μ A/A + 3 nA	36 μ A/A + 3 nA
(30 to 50) mA	35 μ A/A + 5 nA	35 μ A/A + 5 nA	36 μ A/A + 5 nA
(50 to 100) mA	35 μ A/A + 60 nA	35 μ A/A + 60 nA	36 μ A/A + 60 nA
(100 to 200) mA	35 μ A/A + 120 nA	35 μ A/A + 120 nA	36 μ A/A + 120 nA
(200 to 300) mA	35 μ A/A + 180 nA	35 μ A/A + 180 nA	36 μ A/A + 180 nA
(300 to 500) mA	35 μ A/A + 300 nA	35 μ A/A + 300 nA	36 μ A/A + 300 nA
500 mA to 1 A	39 μ A/A + 6 μ A	39 μ A/A + 6 μ A	40 μ A/A + 6 μ A
(1 to 2) A	40 μ A/A + 12 μ A	39 μ A/A + 12 μ A	40 μ A/A + 12 μ A
(2 to 3) A	56 μ A/A + 18 μ A	56 μ A/A + 18 μ A	56 μ A/A + 18 μ A
(3 to 5) A	56 μ A/A + 30 μ A	56 μ A/A + 30 μ A	56 μ A/A + 30 μ A
(5 to 10) A	72 μ A/A + 60 μ A	71 μ A/A + 60 μ A	72 μ A/A + 60 μ A
(10 to 20) A	85 μ A/A + 12 μ A	84 μ A/A + 12 μ A	85 μ A/A + 12 μ A



TABLE IV.a (Cont'd) AC Current Generate / Measure³ - CMCs

Current Range	10kHz	20kHz	50KHz
(10 to 300) μ A	46 μ A/A + 0.03 nA	62 μ A/A + 0.03 nA	79 μ A/A + 0.03 nA
300 μ A to 3 mA	30 μ A/A + 0.3 nA	45 μ A/A + 0.3 nA	48 μ A/A + 0.3 nA
(3 to 10) mA	36 μ A/A + 1 nA	36 μ A/A + 1 nA	60 μ A/A + 1 nA
(10 to 20) mA	36 μ A/A + 2 nA	36 μ A/A + 2 nA	63 μ A/A + 2 nA
(20 to 30) mA	36 μ A/A + 3 nA	36 μ A/A + 3 nA	63 μ A/A + 3 nA
(30 to 50) mA	36 μ A/A + 5 nA	36 μ A/A + 5 nA	63 μ A/A + 5 nA
(50 to 100) mA	36 μ A/A + 60 nA	39 μ A/A + 60 nA	68 μ A/A + 60 nA
(100 to 200) mA	36 μ A/A + 120 nA	39 μ A/A + 120 nA	68 μ A/A + 120 nA
(200 to 300) mA	36 μ A/A + 180 nA	39 μ A/A + 180 nA	72 μ A/A + 180 nA
(300 to 500) mA	36 μ A/A + 300 nA	39 μ A/A + 300 nA	72 μ A/A + 300 nA
500 mA to 1 A	40 μ A/A + 6 μ A	52 μ A/A + 6 μ A	110 μ A/A + 6 μ A
(1 to 2) A	40 μ A/A + 12 μ A	52 μ A/A + 12 μ A	110 μ A/A + 12 μ A
(2 to 3) A	56 μ A/A + 18 μ A	61 μ A/A + 18 μ A	120 μ A/A + 18 μ A
(3 to 5) A	56 μ A/A + 30 μ A	70 μ A/A + 30 μ A	160 μ A/A + 30 μ A
(5 to 10) A	72 μ A/A + 60 μ A	89 μ A/A + 60 μ A	130 μ A/A + 60 μ A
(10 to 20) A	85 μ A/A + 12 μ A	110 μ A/A + 12 μ A	150 μ A/A + 12 μ A

Parameter/Range	Frequency	CMC ^{2,6} (\pm)	Comments
AC Power ³ – Generate PF = 1			
(29 to 330) μ A (0.33 to 3.3) mA 3.3 mA to 3.3 A	(10 to 20) Hz 1 mV to 33 V	0.19 % 0.17 % 0.15 %	Fluke 5520A
(29 to 330) μ A (0.33 to 3.3) mA (3.3 to 330) mA 330 mA to 3 A	(20 to 45) Hz 1 mV to 33 V	0.15 % 0.11 % 0.080 % 0.15 %	
(29 to 330) μ A (0.33 to 3.3) mA (3.3 to 330) mA 330 mA to 1.1 A (1.1 to 3) A (3 to 11) A (11 to 20.5) A	(45 to 100) Hz 1 mV to 1020 V	0.13 % 0.088 % 0.041 % 0.052 % 0.054 % 0.065 % 0.12 %	



Parameter/Range	Frequency	CMC ^{2,6} (±)	Comments
AC Power ³ – Generate PF = 1 (cont)			
(29 to 330) μA (0.33 to 3.3) mA (3.3 to 33) mA (33 to 330) mA 330 mA to 1.1 A (1.1 to 3) A (3 to 11) A (3 to 20.5) A	100 Hz to 1 kHz 1 mV to 1020 V	0.13 % 0.088 % 0.041 % 0.041 % 0.052 % 0.054 % 0.095 % 0.14 %	Fluke 5520A
(29 to 330) μA (0.33 to 3.3) mA (3.3 to 33) mA (33 to 330) mA 330 mA to 1.1 A	(1 to 5) kHz 1 mV to 1020 V	0.28 % 0.17 % 0.070 % 0.092 % 0.54 %	
(1.1 to 3) A (3 to 11) A (11 to 20.5) A	(1 to 5) kHz 1 mV to 1020 V	0.26 % 2.4 % 2.4 %	
(29 to 330) μA (0.33 to 3.3) mA (3.3 to 33) mA (33 to 330) mA 330 mA to 1.1 A (1.1 to 3) A	(5 to 10) kHz 1 mV to 1020 V	0.67 % 0.40 % 0.17 % 0.18 % 2.3 % 2.1 %	
(29 to 330) μA (0.33 to 3.3) mA (3.3 to 330) mA	(10 to 30) kHz 1 mV to 330 V	1.3 % 0.79 % 0.32 %	



Parameter/Range	Frequency	CMC ^{2,7} (±)	Comments
AC Voltage – Measure & Generate ³			
(0.6 to 2.2) mV	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz (300 to 500) kHz 500 kHz to 1 MHz	0.14 % + 1.1 μV 0.062 % + 1.1 μV 0.040 % + 1.1 μV 0.067 % + 1.6 μV 0.097 % + 2.0 μV 0.19 % + 3.2 μV 0.19 % + 6.3 μV 0.31 % + 6.3 μV	Fluke 5790A, 5720A
(2.2 to 7) mV	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz (300 to 500) kHz 500 kHz to 1 MHz	0.068 % + 1.1 μV 0.032 % + 1.1 μV 0.021 % + 1.1 μV 0.034 % + 1.6 μV 0.049 % + 2.0 μV 0.096 % + 3.2 μV 0.11 % + 6.3 μV 0.19 % + 6.3 μV	
(7 to 22) mV	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz (300 to 500) kHz 500 kHz to 1 MHz	0.024 % + 1.1 μV 0.016 % + 1.1 μV 0.0096 % + 1.1 μV 0.018 % + 1.6 μV 0.026 % + 2.0 μV 0.066 % + 3.2 μV 0.074 % + 6.3 μV 0.14 % + 6.3 μV	
(22 to 70) mV	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz (300 to 500) kHz 500 kHz to 1 MHz	0.022 % + 1.2 μV 0.012 % + 1.2 μV 0.0071 % + 1.2 μV 0.012 % + 1.6 μV 0.025 % + 2.0 μV 0.048 % + 3.2 μV 0.063 % + 6.3 μV 0.096 % + 6.3 μV	
(70 to 220) mV	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz (300 to 500) kHz 500 kHz to 1 MHz	0.017 % + 1.2 μV 0.0076 % + 1.2 μV 0.0037 % + 1.2 μV 0.0058 % + 1.6 μV 0.013 % + 2.0 μV 0.022 % + 3.2 μV 0.031 % + 6.3 μV 0.079 % + 6.3 μV	



Parameter/Range	Frequency	CMC ^{2,7} (±)	Comments
AC Voltage – Measure & Generate ³ (cont)			
(220 to 700) mV	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz (300 to 500) kHz 500 kHz to 1 MHz	0.017 % + 1.2 µV 0.0061 % + 1.2 µV 0.0029 % + 1.2 µV 0.0046 % + 1.6 µV 0.0063 % + 2.0 µV 0.017 % + 4.3 µV 0.025 % + 6.3 µV 0.074 % + 6.3 µV	Fluke 5790A, 5720A
(0.7 to 2.2) V	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz (300 to 500) kHz 500 kHz to 1 MHz	0.018 % 0.0061 % 0.0022 % 0.004 % 0.0057 % 0.015 % 0.023 % 0.074 %	
(2.2 to 7) V	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz (300 to 500) kHz 500 kHz to 1 MHz	0.016 % 0.0054 % 0.0024 % 0.0041 % 0.0065 % 0.018 % 0.035 % 0.097 %	
(7 to 22) V	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz (300 to 500) kHz 500 kHz to 1 MHz	0.016 % 0.0057 % 0.0030 % 0.0039 % 0.0065 % 0.018 % 0.033 % 0.097 %	
(22 to 70) V	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz (300 to 500) kHz 500 kHz to 1 MHz	0.016 % 0.0058 % 0.0034 % 0.0050 % 0.0075 % 0.016 % 0.032 % 0.09 %	

Parameter/Range	Frequency	CMC ^{2,7} (±)	Comments
AC Voltage – Measure & Generate ³ (cont)			
(70 to 220) V*	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz (300 to 500) kHz	0.016 % 0.0058 % 0.0034 % 0.0056 % 0.0080 % 0.017 % 0.039 %	Fluke 5790A, 5720A * Subject to 2.2 x 10 ⁷ V-Hz limitation
(220 to 700) V	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz	0.016 % 0.0080 % 0.0038 % 0.011 % 0.040 %	Fluke 5790A, 5720A, 5725A
(700 to 1000) V**	(10 to 20) Hz (20 to 40) Hz 40 Hz to 20 kHz (20 to 50) kHz (50 to 100) kHz	0.016 % 0.0080 % 0.0036 % 0.011 % 0.040 %	** Measure only
AC High Voltage – Measure ³			
(1 to 5) kV (5 to 35) kV (35 to 75) kV	(50 to 60) Hz	0.2 % + 1 V 0.4 % + 65 V 0.4 % + 49 V	Vitretek 4700A
AC High Voltage – Generate ³			
(1 to 5) kV	60 Hz	0.24 % + 1 V	Assoc. res. 3565D



Parameter/Range	Frequency	CMC ^{2, 5} (±)	Comments
AC Voltage – Measure ³ ≤ 2 MHz			
(0 to 10) mV	(1 to 40) Hz 40 Hz to 1 kHz (1 to 20) kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz	0.023 % + 2 μV 0.018 % + 0.74 μV 0.026 % + 0.74 μV 0.069 % + 0.74 μV 0.34 % + 0.74 μV 2.7 % + 1.4 μV	Agilent/HP 3458A
(10 to 100) mV	(1 to 40) Hz 40 Hz to 1 kHz (1 to 20) kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz 300 kHz to 1 MHz (1 to 2) MHz	0.033 % + 2.7 μV 0.014 % + 1.4 μV 0.019 % + 1.4 μV 0.037 % + 1.4 μV 0.067 % + 1.4 μV 0.22 % + 6.7 μV 0.68 % + 6.7 μV 1.1 % + 6.7 μV	
(0.1 to 1) V	(1 to 40) Hz 40 Hz to 1 kHz (1 to 20) kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz 300 kHz to 1 MHz (1 to 2) MHz	0.0047 % + 27 μV 0.0047 % + 14 μV 0.0094 % + 14 μV 0.020 % + 14 μV 0.054 % + 14 μV 0.20 % + 67 μV 0.67 % + 67 μV 1.1 % + 67 μV	
(1 to 10) V	(1 to 40) Hz 40 Hz to 1 kHz (1 to 20) kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz 300 kHz to 1 MHz (1 to 2) MHz	0.0077 % + 0.27 mV 0.0062 % + 0.14 mV 0.0099 % + 0.14 mV 0.021 % + 0.14 mV 0.054 % + 0.14 mV 0.21 % + 0.67 mV 0.67 % + 0.67 mV 1.1 % + 0.67 mV	
(10 to 100) V	(1 to 40) Hz 40 Hz to 1 kHz (1 to 20) kHz (20 to 50) kHz (50 to 100) kHz (100 to 300) kHz 300 kHz to 1 MHz	0.025 % + 2.7 mV 0.016 % + 1.4 mV 0.014 % + 1.4 mV 0.025 % + 1.4 mV 0.082 % + 1.4 mV 0.27 % + 6.7 mV 1.1 % + 6.7 mV	
(100 to 700) V	(1 to 40) Hz 40 Hz to 1 kHz (1 to 20) kHz (20 to 50) kHz (50 to 100) kHz	0.033 % + 27 mV 0.027 % + 14 mV 0.041 % + 14 mV 0.081 % + 14 mV 0.21 % + 14 mV	

Parameter/Range	Frequency	CMC ^{2, 5, 7, 8} (±)	Comments
Capacitance – Measure ³ 1 pF 10 pF 100 pF to 1 μF (0.7 to 110) mF 10 pf to 0.1 F	1 kHz DC 12 Hz to 2 MHz	11 μF/F 13 μF/F 14 μF/F 0.012 % See Table IV.b	AH2500A 5700A w/ 3458A, charge method Quad tech 1689M, 7600
Capacitance – Generate ³ , Fixed Points 100 pF 0.001 μF 0.002 μF (0.01, 0.02, 0.05) μF (0.1, 0.5, 1) μF	100 Hz, 1 kHz	0.054 % 0.068 % 0.048 % 0.055 % 0.055 %	Standard capacitors

Table IV.b: CMC (in %) for Capacitance measured with 1689M and 7600 LCR Meter, Fixed Points

	10 pF	100 pF	1 nF	10 nF	100 nF	1 μF	10 μF	100 μF	0.001 F	0.01 F	0.1 F
12 Hz			3.1	5	1.5	0.79	0.93	0.14	0.11	0.46	4.5
20 Hz			1.9	3	0.63	0.48	0.49	0.11	0.11	0.76	
50 Hz		3.8	0.39	0.47	0.25	0.11	0.16	0.058	0.11	0.94	
100 Hz		1.4	0.16	0.21	0.15	0.047	0.067	0.047	0.16	1.4	
200 Hz		0.71	0.081	0.12	0.095	0.047	0.047	0.047	0.29	2.8	
500 Hz	1.9	0.2	0.035	0.042	0.058	0.035	0.035	0.058	0.48	4.4	
1 kHz	0.48	0.058	0.024	0.024	0.024	0.024	0.024	0.058	0.48	4.7	
2 kHz	0.71	0.081	0.047	0.035	0.035	0.041	0.035	0.17	1.2		
5 kHz	0.66	0.083	0.056	0.047	0.047	0.056	0.08	0.32	2.8		
10 kHz	0.42	0.07	0.056	0.055	0.055	0.06	0.11	0.6			
20 kHz	0.035	0.024	0.048	0.057	0.058	0.068	0.18	1.3			
50 kHz	0.024	0.024	0.066	0.066	0.07	0.11	0.46	4.1			
100 kHz	0.024	0.03	0.08	0.081	0.091	0.2	1.2				
200 kHz	0.27	0.11	0.11	0.12	0.15	0.46	3.7				
500 kHz	0.43	0.4	0.2	0.38	0.38	2.1					
1 MHz	0.36	0.35	0.35	0.41	1.1						
2 MHz	0.65	0.64	0.66	0.9	3.4						



Parameter/Equipment	Range	CMC ^{2, 7} (±)	Comments
DC Power ³ – Generate 33 mV to 1020 V	330 µA to 330 mA 330 mA to 3 A (3 to 20.5) A	0.068 % 0.07 % 0.12 %	Fluke 5520A
DC Current ³ – Generate and Measure	(0 to 100) nA (0.1 to 1) µA (1 to 10) µA (10 to 100) µA (0.1 to 1 mA (1 to 10) mA (10 to 100) mA (0.1 to 1) A (1 to 2) A (2 to 10) A (10 to 20) A (20 to 100) A (100 to 300) A (300 to 1000) A	30 µA/A + 0.27 nA 19 µA/A + 0.27 nA 17 µA/A + 0.067 nA 5.2 µA/A + 0.01 nA 4.9 µA/A + 0.1 nA 5.1 µA/A + 1 nA 5.6 µA/A + 60 nA 7.3 µA/A + 6 µA 8.9 µA/A + 12 µA 31 µA/A + 6 µA 31 µA/A + 12 µA 27 µA/A + 18 µA/°C 0.011 % + 18 µA/°C 0.077 % + 18 µA/°C	Fluke 3458A/HFL, current source, standard resistors/current shunts
Generate Only Turn Amps	(25 to 100) A (100 to 1500) A	0.09 % 0.52 %	Fluke 52120A w/52120-3k and 52120-6k coils
DC Voltage – Generate, Fixed Points	100 mV 1 V 10 V 19 V 100 V 1000 V	0.82 µV/V 0.63 µV/V 0.55 µV/V 1.1 µV/V 0.63 µV/V 0.82 µV/V	Fluke 732B, 752A, HP 34420A Fluke 732B, 752A, HP 34420A Fluke 732B Fluke 732B, 720A, 752A, HP 34420A Fluke 732B, 752A, HP 34420A Fluke 732B, 752A, HP 34420A

Parameter/Equipment	Range	CMC ^{2, 7, 8} (\pm)	Comments
DC Voltage – Generate	(0 to 220) mV 220 mV to 2.2 V (2.2 to 11) V (11 to 22) V (22 to 220) V (220 to 1100) V	5.6 μ V/V + 0.39 μ V 3.2 μ V/V + 0.63 mV 2.4 μ V/V + 2.4 μ V 2.4 μ V/V + 3.9 μ V 3.2 μ V/V + 39 μ V 4.8 μ V/V + 390 μ V	Fluke 5700A/EP
DC Voltage – Measure ³	Up to 100 mV 100 mV to 1 V (1 to 10) V (10 to 100) V (100 to 1000) V	3.0 μ V/V + 0.21 μ V 2.1 μ V/V + 0.21 μ V 2.1 μ V/V + 0.34 μ V 3.5 μ V/V + 21 μ V 3.7 μ V/V + 74 μ V	Agilent/HP 3458A
DC High Voltage – Measure ³	(1 to 6) kV (6 to 35) kV (35 to 100) kV	0.2 % + 1 V 0.4 % + 26 V 0.4 % + 140 V	VitreK 4700A
DC High Voltage – Generate ³	(1 to 6) kV	0.21 % + 1.1 V	Assoc. res. 3565D monitored with Vitrek 4700A
Edge Characteristics – Amplitude	(0 to 100) mV (0.1 to 1) V (1 to 10) V (10 to 100) V	3.0 μ V/V + 0.21 μ V 2.1 μ V/V + 0.21 μ V 2.1 μ V/V + 0.34 μ V 3.5 μ V/V + 21 μ V	Agilent/HP 3458A/HFL
Electrical Calibration of RTD Indicating Devices ³ – Pt 385, 100 Ω Pt 3926, 100 Ω	-200 $^{\circ}$ C to 0 $^{\circ}$ C 0 $^{\circ}$ C to 100 $^{\circ}$ C 100 $^{\circ}$ C to 300 $^{\circ}$ C 300 $^{\circ}$ C to 400 $^{\circ}$ C 400 $^{\circ}$ C to 630 $^{\circ}$ C 630 $^{\circ}$ C to 800 $^{\circ}$ C -200 $^{\circ}$ C to 0 $^{\circ}$ C 0 $^{\circ}$ C to 100 $^{\circ}$ C 100 $^{\circ}$ C to 300 $^{\circ}$ C 300 $^{\circ}$ C to 400 $^{\circ}$ C 400 $^{\circ}$ C to 630 $^{\circ}$ C	0.05 $^{\circ}$ C 0.07 $^{\circ}$ C 0.09 $^{\circ}$ C 0.1 $^{\circ}$ C 0.12 $^{\circ}$ C 0.14 $^{\circ}$ C 0.05 $^{\circ}$ C 0.07 $^{\circ}$ C 0.09 $^{\circ}$ C 0.1 $^{\circ}$ C 0.26 $^{\circ}$ C	Fluke 5520A



Parameter/Equipment	Range	CMC ^{2,7} (±)	Comments
Electrical Calibration of RTD Indicating Devices ³ (cont) –			
PtNi 385, 120 Ω	-80 °C to 100 °C 100 °C to 260 °C	0.08 °C 0.16 °C	Fluke 5520A
Pt 385, 200 Ω	-200 °C to 100 °C 100 °C to 260 °C 260 °C to 300 °C 300 °C to 400 °C 400 °C to 600 °C 600 °C to 630 °C	0.04 °C 0.05 °C 0.12 °C 0.13 °C 0.14 °C 0.16 °C	
Pt 385, 500 Ω	-200 °C to -80 °C -80 °C to 100 °C 100 °C to 260 °C 260 °C to 400 °C 400 °C to 600 °C 600 °C to 630 °C	0.04 °C 0.05 °C 0.06 °C 0.08 °C 0.09 °C 0.11 °C	
Pt 385, 1000 Ω	-200 °C to 0 °C 0 °C to 100 °C 100 °C to 260 °C 260 °C to 300 °C 300 °C to 600 °C 600 °C to 630 °C	0.03 °C 0.04 °C 0.05 °C 0.06 °C 0.07 °C 0.23 °C	
Pt 3916, 100 Ω	-200 °C to -190 °C -190 °C to -80 °C -80 °C to 0 °C 0 °C to 100 °C 100 °C to 260 °C 260 °C to 300 °C 300 °C to 400 °C 400 °C to 600 °C 600 °C to 630 °C	0.25 °C 0.04 °C 0.05 °C 0.06 °C 0.07 °C 0.08 °C 0.09 °C 0.10 °C 0.23 °C	



Parameter/Equipment	Range	CMC ² (±)	Comments
Electrical Calibration of Thermocouple Indicating Devices ³ –			
Type E	-250 °C to -100 °C -100 °C to -25 °C -25 °C to 350 °C 350 °C to 650 °C 650 °C to 1000 °C	0.5 °C 0.16 °C 0.14 °C 0.16 °C 0.21 °C	Fluke 5520A
Type J	-210 °C to -100 °C -100 °C to -30 °C -30 °C to 150 °C 150 °C to 760 °C 760 °C to 1200 °C	0.28 °C 0.16 °C 0.14 °C 0.17 °C 0.23 °C	
Type K	-200 °C to -100 °C -100 °C to -25 °C -25 °C to 120 °C 120 °C to 1000 °C 1000 °C to 1372 °C	0.34 °C 0.18 °C 0.16 °C 0.26 °C 0.40 °C	
Type S	0 °C to 250 °C 250 °C to 1000 °C 1000 °C to 1400 °C 1400 °C to 1767 °C	0.47 °C 0.36 °C 0.37 °C 0.46 °C	
Type T	-250 °C to -150 °C -150 °C to 0 °C 0 °C to 120 °C 120 °C to 400 °C	0.63 °C 0.24 °C 0.16 °C 0.14 °C	



Parameter/Range	Frequency	CMC ^{2, 8} (±)	Comments	
High Frequency Capacitance - Generate Fixed Points ³ –	1 pF	1 kHz	0.007 %	Agilent/HP 16380A series capacitors
		1 MHz	0.01 %	
		2 MHz	0.023 %	
		3 MHz	0.041 %	
		4 MHz	0.063 %	
		5 MHz	0.088 %	
		10 MHz	0.26 %	
		13 MHz	0.38 %	
	10 pF	1 kHz	62 parts in 10 ⁶	
		(1, 2) MHz	62 parts in 10 ⁶	
		3 MHz	64 parts in 10 ⁶	
		4 MHz	67 parts in 10 ⁶	
		5 MHz	72 parts in 10 ⁶	
		10 MHz	0.013 %	
		13 MHz	0.017 %	
	100 pF	1 kHz	61 parts in 10 ⁶	
		1 MHz	62 parts in 10 ⁶	
		2 MHz	68 parts in 10 ⁶	
		3 MHz	82 parts in 10 ⁶	
		4 MHz	0.01 %	
		5 MHz	0.014 %	
		10 MHz	0.034 %	
		13 MHz	0.049 %	
	1000 pF	1 kHz	63 parts in 10 ⁶	
		1 MHz	80 parts in 10 ⁶	
		2 MHz	0.016 %	
		3 MHz	0.028 %	
		4 MHz	0.046 %	
5 MHz		0.064 %		
10 MHz		0.2 %		
13 MHz		0.29 %		
0.01 μF	(0.12, 1, 10, 100) kHz	63 parts in 10 ⁶		
0.1 μF	(0.12, 1, 10, 100) kHz	63 parts in 10 ⁶		
1.0 μF	0.12 kHz	69 parts in 10 ⁶		
	(1, 10) kHz	63 parts in 10 ⁶		
	100 kHz	85 parts in 10 ⁶		



Parameter/Range	Frequency	CMC ^{2, 8} (±)	Comments
Inductance ³ – Measure (12 Hz to 2 MHz)	0.1 μH to 10 H	See Table IV.c	LCR meters
Generate – Fixed Points	100 μH (1, 5, 10, 100) mH (1, 2, 5) H	0.026 % 0.11 % 0.11 %	Standard inductors

Table IVc: Inductance Measure CMC (in %) measured with 1689M and 7600 LCR Meters

Freq.	0.1 μH	1 μH	10 μH	100 μH	1 mH	10 mH	100 mH	1 H	5 H	10 H
12 Hz						0.81	1.3	1.1	1.1	1.1
20 Hz					4.8	0.49	0.71	0.58	0.56	0.56
50 Hz					0.97	0.11	0.17	0.26	0.26	0.26
100 Hz				3.6	0.37	0.048	0.069	0.11	0.16	0.16
200 Hz				1.8	0.19	0.048	0.048	0.058	0.11	0.085
500 Hz			4.8	0.49	0.060	0.036	0.036	0.036	0.051	0.036
1 kHz			1.2	0.13	0.024	0.024	0.024	0.024	0.024	0.024
2 kHz			0.90	0.13	0.036	0.042	0.036	0.036	0.048	0.048
5 kHz		3.2	0.37	0.084	0.048	0.062	0.062	0.055	0.079	0.096
10 kHz		1.7	0.22	0.079	0.064	0.062	0.064	0.069	0.097	0.26
20 kHz		0.94	0.15	0.074	0.066	0.066	0.067	0.081	0.030	0.048
50 kHz	4.7	0.54	0.12	0.080	0.075	0.075	0.16	0.50	0.058	0.11
100 kHz	3.4	0.42	0.13	0.095	0.091	0.092	0.21	1.9	0.11	0.20
200 kHz	2.7	0.38	0.15	0.13	0.13	0.13	0.68	4.6		
500 kHz	2.4	0.44	0.25	0.23	0.46	0.50	1.9			
1 MHz	2.5	0.60	0.41	0.40	0.40	0.96				
2 MHz	2.7	0.92	0.75	0.73	0.76	4.3				

Parameter/Range	Frequency	CMC ² (±)	Comments
Phase – Generate 5 Vrms (Voltage Ratio = 1)	1 Hz to 1 kHz (1 to 6.25) kHz (6.25 to 50) kHz (50 to 200) kHz	6.6 m° 5.2 m° 13 m° 21 m°	Clark-Hess 5500-2 Ratio= ratio of the larger voltage divided by the smaller voltage
50 m to 100 Vrms	1 Hz to 1 kHz (1 to 6.25) kHz (6.25 to 50) kHz (50 to 200) kHz	(6.5 + (0.05 · Ratio))m° (11 + (0.1 · Ratio))m° (19 + (0.15 · Ratio))m° (41 + (0.4 · Ratio))m°	



Parameter/Range	Frequency	CMC ² (±)	Comments
Phase – Generate (cont) (100 to 120) Vrms	1 Hz to 1 kHz (1 to 6.25) kHz (6.25 to 50) kHz (50 to 200) kHz	$(15 + (0.1 \cdot \text{Ratio}))m^\circ$ $(21 + (0.2 \cdot \text{Ratio}))m^\circ$ $(31 + (0.3 \cdot \text{Ratio}))m^\circ$ $(81 + (1 \cdot \text{Ratio}))m^\circ$	Clark-Hess 5500-2 Ratio= ratio of the larger voltage divided by the smaller voltage
Phase – Measure (0.01 to 0.1) Vrms (0.1 to 120) Vrms	10 Hz to 10 kHz (10 to 50) kHz (50 to 100) kHz 10 Hz to 50 kHz (50 to 100) kHz	0.21° 0.36° 0.71° 0.054° 0.036°	KH 6620 phase meter
Oscilloscope Calibration ³ – Squarewave Signal 50 Ω at 1 kHz Source Squarewave Signal 1 MΩ at 1 kHz Source Leveled Sine Wave Flatness (relative to 50 kHz) Period	(1 to 110) mV 110 mV to 2.2 V (2.2 to 11) V (11 to 1100) V (1 to 110) mV 110 mV to 2.2 V (2.2 to 11) V (11 to 1100) V 50 kHz to 100 MHz (100 to 300) MHz (300 to 600) MHz (600 to 1100) MHz 1 ns to 20 ms 50 ms 100 ms 200 ms 500 ms 1 s 2 s 5 s	0.27 % + 42 μV 0.27 % + 130 μV 0.27 % + 1.2 mV 0.27 % + 12 mV 0.15 % + 42 μV 0.15 % + 130 μV 0.15 % + 1.2 mV 0.15 % + 12 mV 1.5 % + 110 μV 2 % + 110 μV 4 % + 110 μV 5 % + 110 μV 2.0 parts in 10 ⁶ 59 parts in 10 ⁶ 97 parts in 10 ⁶ 180 parts in 10 ⁶ 410 parts in 10 ⁶ 800 parts in 10 ⁶ 1600 parts in 10 ⁶ 3900 parts in 10 ⁶	Fluke 5520A/SC1100 scope option



Parameter/Range	Frequency	CMC ^{2, 8} (±)	Comments
Oscilloscope Calibration ³ – (cont)			
Rise Time – Generate	12.8 ps	3.9 ps	Tektronix 067-1338-00
Rise Time – Measure	> 5.4ps	5.4 ps	Tektronix TDS8000 with 80E03
Resistance – Generate, Fixed Points ³	100 μ Ω 1 m Ω 10 m Ω 0.1 Ω 1 Ω 10 Ω 100 Ω 1 k Ω 10 kΩ 19 kΩ 100 kΩ 1 MΩ 10 MΩ 100 MΩ 1 GΩ 10 GΩ 100 GΩ 1 TΩ 10 TΩ	29 μΩ/Ω 14 μΩ/Ω 9.5 μΩ/Ω 6.5 μΩ/Ω 4.6 μΩ/Ω 4.2 μΩ/Ω 2.3 μΩ/Ω 2.5 μΩ/Ω 1.6 μΩ/Ω 4.7 μΩ/Ω 3.3 μΩ/Ω 4.5 μΩ/Ω 9.0 μΩ/Ω 22 μΩ/Ω 22 μΩ/Ω 0.13 % 0.22 % 0.34 % 1.2 %	Norma 80 L&N 4222B L&N 4223B L&N resistors Fluke 742A, standard resistors IET high resistance standard
Resistance – Measure, DC	100 μΩ 100 μΩ to 1 mΩ (1 to 10) mΩ (10 to 100) mΩ (0.1 to 1) Ω (0 to 2) Ω (2 to 20) Ω (20 to 200) Ω 200 Ω to 2 kΩ (2 to 20) kΩ (20 to 200) kΩ 200 kW to 2 MΩ (2 to 20) MΩ (20 to 200) MΩ 200 MΩ to 2 GΩ (2 to 20) GΩ	85 μΩ/Ω + 0.48 nΩ 12 μΩ/Ω + 4.8 nΩ 9.2 μΩ/Ω + 4.8 nΩ 5.4 μΩ/Ω + 48 nΩ 2.6 μΩ/Ω + 0.48 μΩ 3.4 μΩ/Ω + 4.4 μΩ 2.1 μΩ/Ω + 15 μΩ 2.6 μΩ/Ω + 33 μΩ 2.5 μΩ/Ω + 0.33 mΩ 1.5 μΩ/Ω + 3.3 mΩ 2.3 μΩ/Ω + 33 mW 4.4 μΩ/Ω + 1.1 Ω 4.4 μΩ/Ω + 11 Ω 8.3 μΩ/Ω + 110 Ω 28 μΩ/Ω + 110 kΩ 0.21 % + 1.1 MΩ	Stable current source, 3458A/HFL, standard resistors Fluke 8508A and standard resistors



Parameter/Range	Frequency	CMC ^{2, 8} (±)	Comments
Resistance – Measure, DC (cont)	100 MΩ to 1 GΩ (1 to 10) GΩ (10 to 100) GΩ 100 GΩ to 1 TΩ (1 to 10) TΩ (10 to 100) TΩ	0.081 % 0.12 % 0.24 % 0.35 % 0.59 % 1.2 %	6500A
Resistance – Measure, AC	10 Hz to 2 MHz	See Table IV.d	LCR meters

Table IV.d: AC Resistance Measure CMC (in %) measured with LCR Meters

	0.1 Ω	1 Ω	10 Ω	100 Ω	1 kΩ	10 kΩ	100 kΩ	200 kΩ	500 kΩ	1 MΩ
12 Hz		0.60	0.11	0.11	0.11	0.11	0.11	1.7		
20 Hz		0.60	0.11	0.11	0.11	0.11	0.11	0.85	2.8	4.6
50 Hz	3.1	0.31	0.058	0.058	0.058	0.058	0.058	0.38	1.3	2.0
100 Hz	2.3	0.23	0.047	0.047	0.047	0.047	0.047	0.23	0.70	1.2
200 Hz	2.3	0.23	0.047	0.047	0.047	0.047	0.047	0.15	0.44	0.70
500 Hz	1.5	0.16	0.035	0.035	0.035	0.035	0.035	0.10	0.29	0.44
1 kHz	0.77	0.09	0.024	0.024	0.024	0.024	0.024	0.082	0.24	0.35
2 kHz	1.0	0.15	0.035	0.035	0.035	0.035	0.047	0.075	0.21	0.31
5 kHz	0.90	0.14	0.047	0.047	0.047	0.047	0.063	0.072	0.20	0.30
10 kHz	1.0	0.14	0.062	0.055	0.055	0.055	0.063	0.073	0.21	0.30
20 kHz	1.1	0.16	0.066	0.057	0.057	0.057	0.067	0.077	0.22	0.33
50 kHz	1.4	0.19	0.077	0.066	0.065	0.066	0.31	0.37	1.1	1.7
100 kHz	1.9	0.26	0.10	0.081	0.079	0.081	0.40	0.47	1.5	2.2
200 kHz	3.0	0.39	0.14	0.11	0.11	0.12	0.56	0.68	2.2	3.4
500 kHz		0.79	0.26	0.20	0.20	0.26	1.1	1.4	4.2	
1 MHz		1.5	0.45	0.35	0.35	0.70	1.9	2.4		
2 MHz		2.8	0.85	0.65	0.64	1.4	3.5	4.5		



V. Electrical – RF/Microwave

Parameter/Range	Frequency	CMC ^{2, 8} (±)	Comments
Amplitude Modulation ³ –			
AM Accuracy: (0.15 to 10) MHz 5 % to 40 % AM Depth	Rate: 50 Hz to 10 kHz Rate: 20 Hz to 10 kHz	2.3 % + 0.012 % AM 3.5 % + 0.012 % AM	Measuring receiver
40 % to 99 % AM Depth	Rate: 50 Hz to 10 kHz Rate: 20 Hz to 10 kHz	2.3% + 0.12 % AM 3.5 % + 0.12 % AM	
(10 to 1300) MHz 5 % to 40 % AM Depth	Rate: 50 Hz to 50 kHz Rate: 20 Hz to 100 kHz	1.2 % + 0.012 % AM 3.5 % + 0.012 % AM	
40 % to 99 % AM Depth	Rate: 50 Hz to 50 kHz Rate: 20 Hz to 100 kHz	1.2 % + 0.12 % AM 3.5 % + 0.12 % AM	
(1.3 to 26.5) GHz 5 % to 40 % AM Depth	Rate: 50 Hz to 50 kHz Rate: 20 Hz to 100 kHz	1.7 % + 0.012 % AM 3.5 % + 0.012 % AM	Measuring receiver, down converter and local oscillator
40 % to 99 % AM Depth	Rate: 50 Hz to 50 kHz Rate: 20 Hz to 100 kHz	1.7 % + 0.12 % AM 3.5 % + 0.12 % AM	
AM Distortion: 150 kHz to 1.3 GHz	< 50 % AM Depth 50 % to 95 % AM Depth	1.1 dB 2.1 dB	Measuring receiver and distortion analyzer
(1.3 to 26.5) GHz	< 50 % AM Depth 50 % to 95 % AM Depth	1.1 dB 2.1 dB	
AM Flatness: (0.01 to 26.5) GHz 20 % to 80 % AM Depth	Rate: 90 Hz to 10 kHz	0.31 %	Measuring receiver
Distortion Accuracy – Measure ³			
(0 to -70) dB	(2 to 20) Hz	0.43 dB	Low frequency signal analyzer
(-7 to -99.9) dB (-7 to -99.9) dB	20 Hz to 20 kHz (20 to 100) kHz	1.1 dB 2.1 dB	Distortion analyzer



Parameter/Range	Frequency	CMC ^{2, 8} (±)	Comments
<p>Frequency Modulation³ –</p> <p>FM Accuracy (0.15 to 10) MHz < 4 kHz FM peak Dev. < 40 kHz FM peak Dev.</p> <p>(10 to 1300) MHz < 400 kHz FM pk Dev.</p> <p>(1.3 to 26.5) GHz < 400 kHz FM pk Dev.</p> <p>FM Distortion 400 kHz to 10 MHz Rate: 20 Hz to 10 kHz</p> <p>10 MHz to 26.5 GHz Rate: 20 Hz to 100 kHz</p> <p>Residual FM Carrier Frequency (<i>f</i>) < 100 MHz (100 to 1300) MHz (1.3 to 6.2) GHz (6.2 to 12.4) GHz (12.4 to 18) GHz (18 to 26.5) GHz</p>	<p>Rate:</p> <p>20 Hz to 10 kHz 20 Hz to 10 kHz</p> <p>50 Hz to 100 kHz 20 Hz to 200 kHz</p> <p>50 Hz to 100 kHz 20 Hz to 200 kHz</p> <p>< 10 kHz FM Deviation</p> <p>< 100 kHz FM Deviation</p> <p>Bandwidth: 50 Hz to 3 kHz 50 Hz to 3 kHz 50 Hz to 3 kHz 50 Hz to 3 kHz 50 Hz to 3 kHz 50 Hz to 3 kHz</p>	<p>2.4 % + 1.2 Hz 2.4 % + 12 Hz</p> <p>1.3 % + 120 Hz 5.8 % + 240 Hz</p> <p>1.3 % + 120 Hz 5.8 % + 240 Hz</p> <p>0.15 %</p> <p>0.15 %</p> <p>1 Hz (rms) 0.4 Hz + (6 x 10⁻⁹) <i>f</i> 17 Hz 33 Hz 49 Hz 65 Hz</p>	<p>Measuring receiver</p> <p>Measuring receiver and distortion analyzer</p> <p>Measuring receiver</p>
<p>Phase Modulation³ –</p> <p>(0.15 to 10) MHz < 40 Radians (peak) < 400 Radians (peak)</p> <p>(10 to 1300) MHz < 4 Radians (peak) < 40 Radians (peak) < 400 Radians (peak)</p> <p>(1.3 to 26.5) GHz < 4 Radians (peak) < 40 Radians (peak) < 400 Radians (peak)</p>	<p>Rate: 200 Hz to 10 kHz</p> <p>Rate: 200 Hz to 20 kHz</p> <p>Rate: 200 Hz to 20 kHz</p>	<p>4.7 % + 0.012 rad 4.7 % + 0.12 rad</p> <p>3.8 % + 0.0012 rad 3.5 % + 0.012 rad 3.5 % + 0.12 rad</p> <p>3.7 % + 0.0012 rad 3.5 % + 0.012 rad 3.5 % + 0.12 rad</p>	<p>Measuring receiver</p> <p>Measuring receiver, down converter and local oscillator</p>



Parameter/Range	Frequency	CMC ^{2, 8} (\pm)	Comments
Range Calibration (Power Meters) ³ –			
Zero Set Instrument Accuracy	(0.03 to 10) mW 3 μ W 10 μ W 30 μ W (100, 300) μ W (1, 2) mW (10, 30, 100) mW	0.25 % + 6.2 nW 1.6 % 0.46 % 0.28 % 0.26 % 0.28 % 0.30 %	Range calibrator, Agilent 11683A or Agilent 8477A
RF Power Level ³ – Generate/Measure			
Absolute	0 dBm @ 50 MHz +35 to -127 dBm (1.3 to 26.5) GHz	0.11 dB + <i>M</i> See Table V.a	Signal generator, power splitter, attenuator, standard sensors, and power meter
Relative	+35 to -127 dBm 0.9 MHz to 26.5 GHz	See Table V.b	8902A, 11722A, 11792A, 11793A, E8244A
Relative (Power Sensor Calibration Factors)	100 kHz 300 kHz 1 MHz 3 MHz 10 MHz 30 MHz 100 MHz 300 MHz 500 MHz 1 GHz 2 GHz 3 GHz 4 GHz 5 GHz 6 GHz 7 GHz 8 GHz 9 GHz 10 GHz 11 GHz 12 GHz 13 GHz 14 GHz 15 GHz	0.75 % + <i>M</i> 0.51 % + <i>M</i> 0.46 % + <i>M</i> 0.46 % + <i>M</i> 0.43 % + <i>M</i> 0.43 % + <i>M</i> 0.52 % + <i>M</i> 0.61 % + <i>M</i> 0.61 % + <i>M</i> 0.65 % + <i>M</i> 0.76 % + <i>M</i> 0.92 % + <i>M</i> 1.0 % + <i>M</i> 1.1 % + <i>M</i> 1.1 % + <i>M</i> 1.1 % + <i>M</i> 1.1 % + <i>M</i> 1.2 % + <i>M</i> 1.3 % + <i>M</i> 1.2 % + <i>M</i> 1.2 % + <i>M</i> 1.2 % + <i>M</i> 1.2 % + <i>M</i> 1.3 % + <i>M</i>	Power sensors, splitters, meters UUT Mismatch uncertainty (<i>M</i>)

Parameter/Range	Frequency	CMC ^{2, 8} (±)	Comments
RF Power Level ³ – Generate (cont)			
Relative (Power Sensor Calibration Factors)	16 GHz	1.3 % + <i>M</i>	Power sensors, splitters, meters
	17 GHz	1.3 % + <i>M</i>	
	18 GHz	1.4 % + <i>M</i>	
	19 GHz	2.2 % + <i>M</i>	
	20 GHz	2.3 % + <i>M</i>	
	21 GHz	2.3 % + <i>M</i>	
	22 GHz	2.4 % + <i>M</i>	
	23 GHz	2.4 % + <i>M</i>	
	24 GHz	2.5 % + <i>M</i>	
	25 GHz	2.7 % + <i>M</i>	
	26 GHz	2.7 % + <i>M</i>	
	26.5 GHz	2.7 % + <i>M</i>	

Table V.a RF Power Source/Measure Absolute (CMC in dBm)

		FREQUENCY					
		100 MHz		1.3 GHz to	4 GHz to	8 GHz to	17 GHz to
		0.9 MHz to	to	4 GHz	8 GHz	17 GHz	26.5 GHz
		100 MHz	1.3 GHz				
POWER LEVEL	+ 35 dBm	0.14	0.14	0.18	---	--	--
	+ 20 dBm	0.14	0.14	0.18	0.25	0.32	0.47
	+10 dBm	0.12	0.13	0.13	0.15	0.18	0.23
	0 dBm	0.12	0.13	0.13	0.15	0.18	0.23
	-10 dBm	0.12	0.13	0.13	0.15	0.18	0.23
	-20 dBm	0.13	0.13	0.14	0.15	0.18	0.23
	-30 dBm	0.13	0.14	0.14	0.15	0.18	0.23
	-40 dBm	0.14	0.14	0.14	0.16	0.18	0.23
	-50 dBm	0.15	0.15	0.15	0.17	0.19	0.24
	-60 dBm	0.16	0.16	0.16	0.18	0.2	0.25
	-70 dBm	0.17	0.17	0.18	0.18	0.21	0.25
	-80 dBm	0.18	0.18	0.18	0.19	0.22	0.26
	-90 dBm	0.19	0.19	0.2	0.21	0.22	0.27
	-100 dBm	0.2	0.21	0.21	0.22	0.23	0.28
	-110 dBm	0.22	0.22	--	--	--	--
-120 dBm	0.3	0.3	--	--	--	--	
-127 dBm	0.32	0.32	--	--	--	--	



Table V.b RF Power Source/Measure Relative (CMC in dB)

		FREQUENCY					
		0.9 MHz to 100 MHz	100 MHz to 1.3 GHz	1.3 GHz to 4 GHz	4 GHz to 8 GHz	8 GHz to 17 GHz	17 GHz to 26.5 GHz
POWER LEVEL	+ 35 dBm	0.12	0.12	0.16	---	--	--
	+ 20 dBm	0.12	0.12	0.16	0.22	0.29	0.45
	+10 dBm	0.04	0.05	0.06	0.09	0.13	0.2
	0 dBm	0.04	0.05	0.06	0.09	0.13	0.2
	-10 dBm	0.04	0.05	0.06	0.09	0.13	0.2
	-20 dBm	0.05	0.06	0.07	0.09	0.13	0.2
	-30 dBm	0.06	0.07	0.07	0.1	0.13	0.2
	-40 dBm	0.07	0.08	0.08	0.11	0.14	0.2
	-50 dBm	0.09	0.1	0.1	0.12	0.15	0.21
	-60 dBm	0.11	0.11	0.11	0.13	0.16	0.22
	-70 dBm	0.12	0.12	0.13	0.14	0.17	0.22
	-80 dBm	0.13	0.13	0.14	0.15	0.18	0.23
	-90 dBm	0.15	0.15	0.16	0.17	0.19	0.24
	-100 dBm	0.16	0.17	0.17	0.18	0.2	0.25
	-110 dBm	0.18	0.18	--	--	--	--
-120 dBm	0.27	0.27	--	--	--	--	
-127 dBm	0.29	0.29	--	--	--	--	



Parameter/Equipment	Range	CMC ² (±)	Comments
S-Parameters³ – Reflection			
S11/22 Magnitude and Phase –			
3.5 mm – Magnitude	(1.5 to 26.5) GHz (0.01 to 1.0) lin	(± 0.012 to ± 0.040) lin	8510C Network analyzer 85052D, calibration kit, and 85053B verification kit
Phase	(0 to 0.01) lin (0.01 to 0.1) lin (0.01 to 0.5) lin (0.5 to 1) lin	(± 7.4 to ± 180) deg (± 0.095 to ± 20) deg (± 0.54 to ± 2.3) deg (± 0.50 to ± 1.1) deg	
Magnitude (0 to 1) lin	300 kHz to 1.3 GHz (1.3 to 3.0) GHz (3.0 to 6.0) GHz	(± 0.005 to ± 0.015) lin (± 0.008 to ± 0.02) lin (± 0.015 to ± 0.032) lin	
Phase (0 to 0.2) lin	300 kHz to 1.3 GHz (1.3 to 3.0) GHz (3.0 to 6.0) GHz	(± 180 to ± 2) deg (± 180 to ± 3) deg (± 180 to ± 4.5) deg	8753ES Network Analyzer
(0.2 to 1) lin	300 kHz to 1.3 GHz (1.3 to 3.0) GHz (3.0 to 6.0) GHz	(± 2 to ± 1) deg (± 3 to ± 1.5) deg (± 4.5 to ± 2) deg	
7 mm – Magnitude (0 to 1) lin	300 kHz to 1.3 GHz (1.3 to 3.0) GHz (3.0 to 6.0) GHz	(± 0.001 to ± 0.006) lin (± 0.001 to ± 0.01) lin (± 0.005 to ± 0.018) lin	
Phase (0 to 0.2) lin	300 kHz to 1.3 GHz (1.3 to 3.0) GHz (3.0 to 6.0) GHz	(± 180 to ± 1) deg (± 180 to ± 1.5) deg (± 180 to ± 2) deg	850431B calibration kit, 85029B verification kit
(0.2 to 1) lin	300 kHz to 1.3 GHz (1.3 to 3.0) GHz (3.0 to 6.0) GHz	(± 1 to ± 5) deg (± 1.5 to ± 0.5) deg (± 2 to ± 1) deg	
N-Type – Magnitude (0 to 1) lin	100 kHz to 0.3 GHz (0.3 to 1.3) GHz (1.3 to 3.0) GHz (3.0 to 6.0) GHz	0.0085 lin (± 0.005 to ± 0.018) lin (± 0.005 to ± 0.025) lin (± 0.01 to ± 0.05) lin	



Parameter/Equipment	Range	CMC ² (±)	Comments
S-Parameters³ – Reflection S₁₁/S₂₂ Magnitude and Phase (cont)– Phase (0 to 0.2) lin (0.2 to 1) lin	300 kHz to 1.3 GHz (1.3 to 3.0) GHz (3.0 to 6.0) GHz 300 kHz to 1.3 GHz (1.3 to 3.0) GHz (3.0 to 6.0) GHz	(± 180 to ± 1.5) deg (± 180 to ± 2) deg (± 180 to ± 4) deg (± 1.5 to ± 1) deg (± 2.0 to ± 1.5) deg (± 4 to ± 3) deg	3577A Spectrum analyzer B5032B verification kit
S-Parameters³ – Transmission S₁₂/S₂₁ Magnitude and Phase – 3.5 mm (0 to 20) dB (20 to 40) dB (10 to -90) dB 7 mm (10 to -90) dB N-Type (10 to -90) dB	(1.5 to 26.5) GHz (1.5 to 26.5) GHz 300 kHz to 1.3 GHz (1.3 to 3.0) GHz (3.0 to 6.0) GHz 300 kHz to 1.3 GHz (1.3 to 3.0) GHz (3.0 to 6.0) GHz 300 kHz to 1.3 GHz (1.3 to 3.0) GHz (3.0 to 6.0) GHz	(± 0.11 to ± 0.29) dB (± 1.2 to ± 12) deg (± 0.13 to ± 0.68) dB (± 1.5 to ± 19) deg (± 0.3 to ± 6.0) dB (± 0.25 to ± 80) deg (± 0.04 to ± 6.0) dB (± 0.35 to ± 90) deg (± 0.06 to ± 9.0) dB (± 0.67 to ± 180) deg (± 0.03 to ± 5.0) dB (± 0.26 to ± 80) deg (± 0.03 to ± 5.0) dB (± 0.26 to ± 90) deg (± 0.05 to ± 10) dB (± 0.54 to ± 180) deg (± 0.03 to ± 6.0) dB (± 0.2 to ± 80) deg (± 0.04 to ± 6.0) dB (± 0.44 to ± 90) deg (± 0.1 to ± 9.0) dB (± 0.67 to ± 90) deg	Network analyzer with S-parameter test set, calibration kit, and cables, system verification with verification kit (see reflection)



VI. Fluid Quantities

Parameter/Equipment	Range	CMC ^{2, 4, 8} (±)	Comments
Dynamic Viscosity ³	(0 to 100 000) cP	0.83 %	Standard viscosity fluids, PRT
Flow ³	2 sccm to 10 slm (10 to 1000) slm	0.26 % 0.51 %	Mass flow system
Hydrometers – Baume Lighter than Water (80.5 to 57) API (81 to 57) (57 to 10) API (57 to 10) Heavier than Water (0.72 to 21) API (10 to -11) (0.72 to 67)	Specific Gravity: 1.00 (0.66 to 0.75) (0.75 to 1) (1 to 1.17) (1 to 1.85)	 0.0058 % + 0.6R 0.0072 % + 0.6R 0.006 % + 0.6R 0.0058 % + 0.6R 0.0058 % + 0.6R	 Distilled water Petroleum based solutions Alcohol solutions Sulfuric acid and/or glycerine solutions Sulfuric acid solutions
Kinematic Viscosity ³	Zahn cups (1 to 5) Shell cups (1 to 6)	0.84 s + 0.24 % 0.84 s + 0.24 %	Temperature bath, viscosity oils, stopwatch
Volumetric Calibration	(0 to 200) mL 200 mL to 1 L (1 to 25) L	0.24 % + 130 nL 0.24 % + 9 µL 0.24 % + 900 µL	Gravimetric method



VII. Foundry-Industry Specific Calibrations

Parameter/Equipment	Range	CMC ^{2, 4, 8} (±)	Comments
AFS Clay Tester ⁹	300 s	0.42 s	Stopwatch
Mold Strength Tester ⁹	(0 to 50) psi	0.20 % + 0.6R	Mold strength tester and balances
Moisture Teller ⁹	(100 to 300) °F	2.0 °F	Temperature calibrator
Permmeter ⁹	25 perms 90 perms 160 perms	1.6 perms 5.3 perms 9.4 perms	Perm standard
Sand Rammer ⁹ (Compactability Tester)	(0.6 to 0.9) inches	0.0066 in + 0.6R	Impact rings with caliper
Sand Specimen Tube ³	2.0 in	0.0014 in	Bore gage
Sand (Green) Strength Machine ⁹	(0 to 500) psi	0.93 % + 0.82 psi	Master force proving gage
Welders ³	(1 to 750) V (1 to 750) A	1.0 % 1.0 %	Loadbank and DMM
Wet Tensile Tester ⁹ – Load Temperature Load Rate	0.449 N/cm ² (300 to 320) °F 0.05 N/cm ² /s	0.002 N/cm ² 0.70 °F 0.0017 N/cm ² /s	Dead weight Thermometer Stopwatch



VIII. Mechanical

Parameter/Equipment	Range	CMC ^{2, 4, 8} (±)	Comments
Accelerometers – Shear and Charge ³	(0.25 to 10) g (5 to 10 000) Hz	2.7 % 2.7 %	Accelerometer; <i>g</i> is the acceleration due to gravity.
Air Velocity	(100 to 4000) ft/min (4000 to 7400) ft/min	0.48 % + 5.5 ft/min 0.48 % + 40 ft/min	Flowkinetics manometer
Cable Tensiometers/ Wire Tension Meters	(0 to 1000) lb	1.1 lb + 0.6 <i>R</i>	Deadweights
Deadweight Testers – Piston and Cylinder Area Mass Performance Test (Cross-Float)	 (0 to 10 000) psi (100 to 5 000) g (50 to 10 000) psi	 (12 + 3 <i>D</i>) μin 3.0 mg + 0.0010 % 0.040 %	 UMM Class F weights and scales Pressure calibrator with transducer
Durometers ³ – Indenter Shape and Extension: Durometer Spring	Types A, B, C, D, E, O and DO Pressure foot orifice diameter Indenter extension length Cone angle Tip radius Indenter thickness Up to 45 N	 3.2 μm 3.2 μm 1 arcmin 3.2 μm 3.2 μm 36 mN	ASTM D2240 Gage blocks Vision system Durometer calibrator
Durometer Calibrator	Scales A, B, E, O and C, D, DO	0.20 %	Scale and CMM



Parameter/Equipment	Range	CMC ^{2, 4, 8} (\pm)	Comments
Dynamometer ³	(0 to 10 000) lbf	0.11 % + 0.6R	Load cells
Force Gages and Force Rings ³	(0 to 1500) lbf (>1500 to 10 000) lbf	0.0024 % + 0.007 lbf 0.60 % + 1.2 lbf	Deadweights Load cell
Indirect Verification of Brinell Hardness Testers at Test Condition(s) ³ – (3000, 1500, 500) kg	<u>10 mm/500 kg</u> (50 to 70) HBW (71 to 90) HBW (91 to 109) HBW <u>10 mm/1500 kg</u> (50 to 99) HBW (100 to 200) HBW (201 to 345) HBW <u>10 mm/3000 kg</u> (100 to 199) HBW (200 to 499) HBW (500 to 650) HBW	0.13 HBW 0.38 HBW 1.1 HBW 0.35 HBW 0.56 HBW 1.4 HBW 0.80 HBW 1.6 HBW 3.7 HBW	ASTM E10
Indirect Verification of Leeb Hardness Testers	Up to 800 HLD	7.4 HLD	Standard test block
Indirect Verification of Microindentation Hardness Testers (Knoop and Vickers) ³ –	Vickers, \leq 1 kg (100 to 240) HV (241 to 600) HV (600 to >650) HV Knoop, \leq 1 kg (100 to 250) HK (251 to 650) HK (650 to >650) HK	11 HV 11 HV 11 HV 5.3 HK 5.6 HK 5.2 HK	ASTM E384



Parameter/Equipment	Range	CMC ² (±)	Comments
Indirect Verification of Rockwell Hardness and Rockwell Superficial Hardness Testers ³	HRA: Low Mid High HRBW: Low Mid High HRC: Low Mid High HRE: Low Mid High HR15N: Low Mid High HR30N: Low Mid High HR45N: Low Mid High HR15T: Low Mid High HR30T: Low Mid High HR45T: Low Mid High	0.29 HRA 0.56 HRA 0.24 HRA 0.94 HRB 0.69 HRB 0.62 HRB 0.78 HRC 0.92 HRC 0.39 HRC 0.92 HRE 1.1 HRE 0.89 HRE 0.76 HR15N 0.75 HR15N 1.1 HR15N 0.55 HR30N 0.48 HR30N 0.46 HR30N 0.68 HR45N 0.72 HR45N 0.66 HR45N 0.79 HR15T 0.52 HR15T 0.61 HR15T 0.70 HR30T 0.61 HR30T 0.42 HR30T 0.98 HR45T 0.78 HR45T 0.81 HR45T	ASTM E18



Parameter/Equipment	Range	CMC ^{2, 4, 8} (\pm)	Comments
Load Cells	(0 to 500) lbf (500 to 2 000) lbf (2 to 5.5) klbf (5.5 to 10) klbf	0.034 % + 0.00044 lbf 0.036 % + 0.60 lbf 0.028 % + 1.9 lbf 0.028 % + 4.0 lbf	Dead weights, comparison to master load cell
Load Cells ³	(0 to 10 000) lbf	0.1 % + 0.002 lbf	Dead weights or comparison to master load cell
Mass	1 mg to 50 g (50 to 220) g (220 to 400) g 400 g to 1.2 kg (1.2 to 8.2) kg (8.2 to 30) kg	17 μ g 35 μ g 0.14 mg 3.7 mg 12 mg 0.11 g	By comparison
Mass ³	(2 to 30) kg	0.20 g	By comparison
Pressure/Vacuum Gauges ³	(-15 to 1000) psi Pneumatic (1000 to 5000) psi (5000 to 10 000) psi	0.005 psi + 0.012 % fs 0.32 psi + 0.026 % fs 1.8 psi + 0.026 % fs	Pressure calibrator Pressure transducers
Refractometers ³	(0 to 100) %	0.02 % + 0.6R	Standard solutions
Scales ³	(1 to 50) mg 51 mg to 10 g (11 to 50) g (51 to 300) g (301 to 1000) g (1 to 5) kg (5 to 30) kg	0.016 mg + 0.58R 0.03 mg + 0.58R 0.054 mg + 0.58R 0.24 mg + 0.58R 3.8 mg + 0.58R 11 mg + 0.58R 89 mg + 0.58R	Verification with mass standards

Parameter/Equipment	Range	CMC ^{2, 4, 8} (\pm)	Comments
Scales ³ (cont)	Up to 0.5 lb (0.5 to 1) lb (1 to 2) lb (2 to 5) lb (5 to 10) lb (10 to 20) lb (20 to 50) lb (50 to 100) lb (100 to 500) lb (500 to 1000) lb	0.000 0015 oz + 0.58R 0.000 0030 oz + 0.58R 0.000 011 oz + 0.58R 0.000 14 oz + 0.58R 0.000 34 oz + 0.58R 0.000 68 oz + 0.58R 0.000 93 oz + 0.58R 0.0043 oz + 0.58R 0.0086 oz + 0.58R 0.043 oz + 0.58R	Verification with mass standards
Scales – Proportional Testing ³	Up to 750 lb (750 to 1500) lb (1500 to 3000) lb (3000 to 4500) lb (4500 to 6000) lb	0.22 lb + 0.6R 0.28 lb + 0.6R 0.36 lb + 0.6R 0.42 lb + 0.6R 0.48 lb + 0.6R	Class F weights
Spring Testers ³ – Force Scale	(0 to 1000) lbf	0.02 % + 0.6R	Weights, load cells; R is the resolution of the force scale of the spring tester.
Deflection Accuracy	Up to 20 in	26 μ in + 0.6R	Gage blocks; R is the resolution of the deflection scale.
Tachometers ³ – Non-Contact	Up to 180 000 rpm	0.8R	Calibrator, LED
Contact	Up to 5000 rpm (5000 to 15 000) rpm	0.024 % + 1.4 rpm 0.032 % + 0.84 rpm	Tachometer calibrator
Tensile Testers ³	(0 to 30 000) lbf (30 000 to 50 000) lbf	0.4 % + 0.08 % fs 0.26 % + 0.02 % fs	Load cells
Torque Wrenches	Up to 1000 ft·lbf (1000 to 2000) ft·lbf Up to 120 in·lbf	0.18 % + 0.10 ft·lbf 0.062 % + 1.3 ft·lbf 0.32 % + 0.6R	Torque calibrator



Parameter/Equipment	Range	CMC ^{2, 4, 8} (±)	Comments
Torque – Calibration of Torque Meters and Sensors	(0.1 to 2000) ft·lbf	0.14 %	Weights
Torque Watches ³	(0.5 to 215) in·ozf	0.080 % + 0.52 in·ozf	Torque calibrator
Ultrasonic Thickness Testers ³	(0 to 10) in	(800 + 13L) μin	Standard thickness specimen

IX. Optical Quantities

Parameter/Equipment	Range	CMC ² (±)	Comments
Gloss Meters ³	20°	0.73 <i>GU</i>	Gloss standards; <i>GU</i> represents gloss units.
	60°, 85°	0.54 <i>GU</i>	

X. Thermodynamics

Parameter/Equipment	Range	CMC ^{2, 4} (±)	Comments
Dew Point	-20 °C to 60 °C	-0.44 °C + 0.6 <i>R</i>	Thunder Scientific humidity chamber
Industrial Platinum Resistance Thermometers	-30 °C to 75 °C 75 °C to 200 °C 200 °C to 250 °C 250 °C to 300 °C	0.024 °C 0.032 °C 0.041 °C 0.047 °C	SPRT, temperature bath, resistance bridge
Infrared Thermometers – Measuring Equipment ³	-15 °C to 120 °C 35 °C to 500 °C	0.6 °C + 0.6 <i>R</i> 0.8 °C + 0.6 <i>R</i>	Hart 9132 radiation source
	500 °C to 1100 °C	1.6 °C + 0.0043 °C/ °C	Isotech Pegasus 92R radiation source



Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
Liquid-in-Glass Thermometers and Temperature Measuring Devices	-30 °C to 150 °C 150 °C to 250 °C 250 °C to 300 °C	0.02 °C + 0.6R 0.03 °C + 0.6R 0.04 °C + 0.6R	Constant temperature bath, SPRT
Relative Humidity – Measure			
Hygrometer	(10 to 95) % RH	0.7 % RH + 0.6R	Humidity generator, Thunder Scientific 2500ST
Psychrometer	5 °C to 35 °C	0.1 °C + 0.84R	Comparison to SPRT in temp bath
Temperature – Measuring Equipment ³	-10 °C to 50 °C 50 °C to 650 °C	0.04 °C + 0.6R 0.045 °C + 0.6R	Dry-wells, PRT
Thermocouples and Thermocouple Wire	-80 °C to 650 °C	0.42 °C	Comparison to SPRT with Agilent 3458A

XI. Time & Frequency

Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
Frequency – Measuring Equipment & Measure	10 MHz 0.01 Hz to 200 kHz	3 parts in 10 ¹¹ 3 parts in 10 ¹¹ + 1.4 μHz + 0.58R	GPS Function generator, signal generator, frequency counter or spectrum analyzer with ext. GPS timebase



Parameter/Equipment	Range	CMC ² (\pm)	Comments
Stopwatches & Timers ³	10 s to 72 hr	28 ms + 18 μ s/s	Function generator, frequency counter
	(2 to 960) s	0.037 s/day	Timometer

¹ This laboratory offers commercial calibration service and field calibration service.

² Calibration and Measurement Capability Uncertainty (CMC) is the smallest uncertainty of measurement that a laboratory can achieve within its scope of accreditation when performing more or less routine calibrations of nearly ideal measurement standards or nearly ideal measuring equipment. CMCs represent expanded uncertainties expressed at approximately the 95 % level of confidence, usually using a coverage factor of $k = 2$. The actual measurement uncertainty of a specific calibration performed by the laboratory may be greater than the CMC due to the behavior of the customer's device and to influences from the circumstances of the specific calibration.

³ Field calibration service is available for this calibration and this laboratory meets A2LA R104 – *General Requirements: Accreditation of Field Testing and Field Calibration Laboratories* for these calibrations. Please note the actual measurement uncertainties achievable on a customer's site can normally be expected to be larger than the CMC found on the A2LA Scope. Allowance must be made for aspects such as the environment at the place of calibration and for other possible adverse effects such as those caused by transportation of the calibration equipment. The usual allowance for the actual uncertainty introduced by the item being calibrated, (e.g. resolution) must also be considered and this, on its own, could result in the actual measurement uncertainty achievable on a customer's site being larger than the CMC.

⁴ In the statement of CMC, L is the numerical value of the nominal length in inches; R is the resolution of the unit under test; D is the diameter in inches; H is the height of the unit under test (except where noted); and fs represents full scale. Ra is the numerical value of the nominal roughness of the surface measured in micrometer roughness, except where noted.

⁵ CMC for calibrations performed in the laboratory with the Agilent/HP 3458A/HFL is based upon 90-day specifications. CMC for calibrations performed field with the Agilent/HP 3458A is based upon 1-year specifications. The measurands stated are generated with the Agilent/HP 3458A. This capability is suitable for the calibration of the devices intended to measure the stated measurand in the ranges indicated. CMC are expressed as either a specific value that covers the full range or as a fraction of the reading plus a fixed floor specification. Unless otherwise noted, percentages are defined as percent of reading.

⁶ CMC for calibrations performed with the Fluke 5520A is based upon 1-year specifications. CMC for calibrations performed with the Fluke 5720A/EP is based upon 90-day specifications. The measurands stated are generated with the Fluke 5500, 5700 and 732B series of instruments. This capability is suitable for the calibration of the devices intended to measure the stated measurand in the ranges indicated. CMC are expressed as either a specific value that covers the full range or as a fraction of the reading plus a fixed floor specification. Unless otherwise noted, percentages are defined as percent of reading.



⁷ CMC for calibrations performed with the Fluke 5790A is based upon 1-year specifications. The measurands stated are generated with the Fluke 5700 series of instruments. This capability is suitable for the calibration of the devices intended to measure the stated measurand in the ranges indicated. CMCs are expressed as either a specific value that covers the full range or as a fraction of the reading plus a fixed floor specification. Unless otherwise noted, percentages are defined as percent of reading.

⁸ In the statement of CMC, the value is defined as the percentage of reading, unless otherwise noted.

⁹ This calibration is offered for “Field Service” only.

¹⁰ This accreditation covers calibrations performed at the main laboratory listed above, and the following satellite laboratory located at 2591 S. Oakwood Road, Oshkosh, WI 54904.

Satellite Location:

PRECISION METROLOGY, INC.
 2951 S. Oakwood Rd
 Oshkosh, WI 54904
 Carol Shipley Phone: 414 351 7420

CALIBRATION

I. Dimensional

Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
Bore Gages ³	Up to 12 in	10 µin/in + 0.6R	Gage blocks
Calipers ³ –			Gage blocks
Resolution 0.0001 in	Up to 2 in (2 to 12) in	78 µin 70 µin + 4 µin/in	
Resolution 0.0005 in	Up to 24 in (24 to 60) in	450 µin 340 µin + 3.7 µin/in	
Resolution 0.001 in	Up to 30 in (30 to 80) in	840 µin 700 µin + 3.4 µin/in	
Chamfer Gages/Hole Gages ³	Up to 12 in	(20 + 0.6R) µin	Cylindrical rings
Depth Gages	Up to 12 in	12 µin/in + 0.6R	Gage blocks



Parameter/Equipment	Range	CMC ^{2,4} (\pm)	Comments
Dial Indicator	Up to 0.5 in (0.5 to 8) in	12 $\mu\text{in/in} + 0.6R$ 12 $\mu\text{in/in} + 0.6R$	Indicator calibrator Gage blocks
Height Gage	Up to 36 in	15 $\mu\text{in/in} + 0.6R$	Reference stack
Intertest/Oditest Calipers	Up to 4 in	54 $\mu\text{in} + 0.6R$	Gage blocks
Micrometers ³ – Depth Groove	Up to 12 in Up to 4 in	20 $\mu\text{in/in} + 0.6R$ 18 $\mu\text{in/in} + 0.6R$	Gage blocks
Micrometer – OD Micrometers	Up to 42 in	12 $\mu\text{in/in} + 0.6R$	Gage blocks
Pin and Plug Gages	(0 to 1) in	6.7 $\mu\text{in/in} + 79 \mu\text{in}$	ULM
Test Indicator	Up to 0.5 in	0.0001 in	Indicator calibrator
Tri-Bore Micrometers	Up to 3 in	15 $\mu\text{in/in} + 0.6R$	Cylindrical rings

II. Mechanical

Parameter/Equipment	Range	CMC ^{2,4,5} (\pm)	Comments
Torque Wrenches	Up to 1000 in·lbf Up to 250 ft·lbf	0.6 % + 0.6R 0.6 % + 0.1 ft·lbf	Torque calibrator

¹ This laboratory offers commercial calibration service and field calibration service.

² Calibration and Measurement Capability Uncertainty (CMC) is the smallest uncertainty of measurement that a laboratory can achieve within its scope of accreditation when performing more or less routine calibrations of nearly ideal measurement standards or nearly ideal measuring equipment. CMCs represent expanded uncertainties expressed at approximately the 95 % level of confidence, usually using a coverage factor of $k = 2$. The actual measurement uncertainty of a specific calibration performed by the laboratory may be greater than the CMC due to the behavior of the customer's device and to influences from the

circumstances of the specific calibration.

³ Field calibration service is available for this calibration and this laboratory meets A2LA R104 – *General Requirements: Accreditation of Field Testing and Field Calibration Laboratories* for these calibrations. Please note the actual measurement uncertainties achievable on a customer's site can normally be expected to be larger than the CMC found on the A2LA Scope. Allowance must be made for aspects such as the environment at the place of calibration and for other possible adverse effects such as those caused by transportation of the calibration equipment. The usual allowance for the actual uncertainty introduced by the item being calibrated, (e.g. resolution) must also be considered and this, on its own, could result in the actual measurement uncertainty achievable on a customer's site being larger than the CMC.

⁴ In the statement of CMC, R is the resolution of the unit under test.

⁵ In the statement of CMC, the value is defined as the percentage of reading, unless otherwise noted.

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