



SCOPE OF ACCREDITATION TO ISO/IEC 17025:2017
& ANSI/NCSL Z540-1-1994

PRECISION METROLOGY, INC.¹⁰
7350 North Teutonia Avenue
Milwaukee, WI 53209
Dainna Lowrance Phone: 414 351 7420

CALIBRATION

Valid To: January 31, 2021

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	(1 to 10) μS/cm (50 to 100) μS/cm (1000 to 1413) μS/cm (5 to 100) ms/cm (150 to 200) ms/cm	0.34 μS/cm 0.96 μS/cm 5.5 μS/cm 750 μS/cm 1.5 mS/cm	Conductivity solutions

Parameter/Equipment	Range	CMC ² (±)	Comments
pH Meters ³	4 pH 7 pH 10 pH	0.011 pH 0.011 pH 0.012 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 48 in	65 μ in or (12 μ in/in + 30 μ in), whichever is greater	Gage amp. probe, indi-square and test indicator
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 μ in (2.8 μ m) 22 μ in (0.56 μ m) 82 μ in (2.1 μ m) 60 μ in + 7.5 μ in/in 60 μ in + 7.0 μ in/in 85 μ in + 11 μ in/in 85 μ in + 9.9 μ in/in 0.98 μ in/in	ASME B89.4.22-2004
Bench Center – Center Parallelism Base Flatness & Base Parallelism	 Up to 24 in Up to 24 in	 (68 + 4L) μ in (62 + 2.5L) μ in	Gage amp w/probe

Parameter/Equipment	Range	CMC ^{2,4} (\pm)	Comments
Bore Gages ³	Up to 12 in	22 μ in or 0.6R (whichever is greater)	SIP302M
Box Parallels – Parallelism Squareness	5 in \times 10 in \times 10 in 5 in \times 10 in \times 10 in	28 μ in 12 μ in/in + 38 μ in	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 μ in 70 μ in + 4 μ in/in 450 μ in 340 μ in + 3.7 μ in/in 840 μ in 700 μ in + 3.4 μ in/in	Gage blocks
Chamfer Gages/Hole Gages ³	Up to 12 in	20 μ in + 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) μ in (15 + 2.9L) μ in (41 + 3.2L) μ in (19 + 130L) μ in 16 μ in 25 μ in	ISO 10360-7 (Unidirectional) Glass scales Glass scales Gage blocks Ballbar Test circles

Parameter/Equipment	Range	CMC ^{2,4} (\pm)	Comments
CMMs ³ – Length Error (E _L) Repeatability Range (R ₀)	Up to 52 in Up to 52 in	38 μ in + 5.2 μ in/in 22 μ in + 3 μ in/in	ASME B89.4.1.10360.2, ISO 10360-2
Coating Thickness Shims/Precision Shims	25 μ in to 0.5 in	19 μ in + 82 μ in/in	ULM
Concentricity Gage	N/A	130 μ in + 8 μ in/in	Indicator, bench center
Cylindrical Plugs ³	Up to 4 in (4 to 20) in	4 μ in + 5 μ in/in 4 μ in + 5.4 μ in/in	ULM, gage blocks
Cylindrical Rings ³	(0.1 to 4) in (4 to 8.5) in (8.5 to 18) in (18 to 36) 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 50 μ in + 3 μ in/in	ULM, gage blocks
External Spline Gages ³ – Measurement Over Pins Circular Tooth Thickness Major Diameter	Up to 8 in Up to 8 in Up to 8 in	(170 + 28D) μ in (110 + 16L) μ in (28 + 12D) μ in	ULM Vision system ULM
Fixed Gaging – Screw Pitch Gages, Drill Gages, Taper Gages, Center Gages, Sheet and Wire Gages, Angle Gages, Radius Gage, Functional Gages	Up to 30 in Up to 30 in Up to 360 degrees	(110 + 16L) μ in (length measures) (330 + 5.8L) μ in 54"	Optical comparator, vision system, hand tools, hand gages CMM Vision system

Parameter/Equipment	Range	CMC ^{2,4} (\pm)	Comments
Gage Amplifier and Probe(s) ³ Single Probe Dual Probe	Up to 0.025 in Up to 0.002 in	8.9 μ in 2.1 μ in	Gage blocks Gage blocks
Gage Balls	Up to 4 in	(32 + 1.5D) μ in	Universal length machine (ULM)
Gage Blocks	Up to 4 in (4 to 20) in	(3.1 + 3.2L) μ in (3.3 + 3.2L) μ in	Gage blocks and comparator
Height Gage ³	Up to 48 in	10 μ in/in + 0.6R	Gage blocks
Height Measures ³	Up to 24 in	13 μ in/in + 94 μ in	Height gage
Indicators ³ – Dial & Test, LVDTs	Up to 4 in	35 μ in or 0.6R (whichever is greater)	Indicator calibrator
Indicator Calibrator ³	Up to 4 in	12 μ in + 0.6R	Gage blocks, amp w/probe
Laser Distance Meters	Up to 6.1 m	4.6 μ m/m + 120 μ m	ULM

Parameter/Equipment	Range	CMC ^{2,4,8} (±)	Comments
Length & Thickness Standards, Feeler Gages ³ –			
Steel	Up to 4 in (4 to 20) in (20 to 120) in	4 μin + 5 μin/in 4 μin + 5.4 μin/in 3.7 μin/in + 14 μin	ULM, gage blocks
Field Calibration	Up to 16 in	5 μin + 14 μin/in + 4 μin/in/°C	ULM, gage blocks, Relative to 20/°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 Scales ³	Up to 20 ft	1.5 μin/in + 0.58 μin	Laser
Linear Scales/Reticles and Stage Micrometers –			
2D	Up to 12 in	(115 + 15L) μin	Vision system
1D	Up to 30 in	11 μin + 1.5 μin/in	Gitterperioden interferometer
Micrometers ³ –			
Inside	Up to 294 in	12 μin + 7 μin /in + 0.2R	ULM, gage blocks or rings
Depth	Up to 12 in	18 μin/in + 0.64R	
Tri-Bores	Up to 11 in	18 μin/in + 0.7R	
Outside	Up to 42 in	18 μin/in + 0.64R	
Groove	Up to 4 in	18 μin/in + 0.64R	
Bench	Up to 42 in	18 μin/in + 0.64R	
Thread (Screw, Thread, Pitch, Point)	Up to 4 in	18 μin/in + 0.64R	
Microscopes ³ –			
Reticule Magnification	Up to 25 mm Up to 1000x	23 μm 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	0.000 2 in 2’ 0.000 12 in	Glass scale Calibration sphere Calibration sphere
Optical Flats – Flatness Parallelism ¹¹	Up to 8 in Up to 1.5 in diameter and 1 in thickness	3.4 µin 3.1 µin	Reference flat and monochromatic light source Gage block comparator
Parallels ³ – Parallelism	Up to 72 in	1 µin/in + 20 µin	Gage amp w/probe
Pitch Micrometer Standards – Length Angle	Up to 12 in Up to 60°	(22 + 6L) µin 54”	UMM Vision system
Precision Diameter Tapes	Up to 38 in (38 to 54) in (54 to 780) in	1.3 µin/in + 280 µin 7.5 µin/in + 250 µin 1.4 µin/in + 430 µin	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
Riser Blocks and Stands	Up to 24 in	2 µin/in + 23 µin	Gage amplifier w/probe

Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
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) μin	Cylindrical square; In the CMC, <i>H</i> is the height of the cylinder from the base in inches.
Sine Plates/Bars ³ –			
Flatness/Parallelism & Parallelism Cylinder to Base	Up to 20 in	53 μin	Gage amp w/probe, angle blocks and gage blocks
Angle Calibration Center of Rolls	0° to 90°	0.00045° (1.6 arcsec, 16 μin/in)	
	Up to 20 in	17 μin/in (1.8 arcsec)	
Sand Sieves	20 μm to 125 mm	(3.2 + 6.9L) μm	ASTM E11, vision system
Snap Gages ³ –			
Parallelism	Up to 20 in	97 μin	Box parallel with gage amp and probe
Linear Accuracy	Up to 20 in	13 μin/in + 49 μin	
Squares ³ –			
Master Squares (Class A Grade)	Up to 48 in	51 μin or (7 μin/in + 21 μin), whichever is greater	Indi-square and test indicator, gage amp and probe, gage locks
Granite, Steel, Cylindrical	Up to 48 in	65 μin or (12 μin/in + 30 μin), whichever is greater	

Parameter/Equipment	Range	CMC ^{2,4} (\pm)	Comments
Straightness and Straight Edges ³	Up to 72 in	1 $\mu\text{in/in}$ + 19 μin	Gage amplifier w/probe
Step Gages, Step Bars, Reference Stacks	Up to 50 in	6 μin + 3.9 $\mu\text{in/in}$	Gage amp and probe, gage blocks
Surface Plates ³ – Flatness	18 in x 24 in to 72 in x 144 in	8 \sqrt{D} μin	Electronic levels <i>D</i> 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) $\mu\text{in Ra}$	3.4 μin	Verification of specimens per ASME B46.1
Tape Measures, Rulers ³	Up to 10 ft (10 to 300) ft	1200 μin + 2.1 $\mu\text{in/in}$ 220 μin + 6.8 $\mu\text{in/in}$	ULM
Tapered Plugs ³ – Simple Pitch Diameter	Up to 18 in	(100 + 12 <i>D</i>) μin	Thread wires/UMM
Notch Height	Up to 18 in	13 $\mu\text{in/in}$ + 94 μin	Height measuring machine
Tapered Rings ³ – Taper	Up to 18 in	400 μin	NPT master plug, ULM
Standoff and Thickness	Up to 18 in	120 μin	NPT master plug and height measuring machine
Functional Diameter	Up to 2 in	(300 + 8 <i>D</i>) μin	

Parameter/Equipment	Range	CMC ^{2,4} (\pm)	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 μ in + 6.8 μ in/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-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) μ in (70 + 13D) μ in (100 + 8D) μ in	ULM w/ set plug
Thread Wires	Up to 0.5 in	(8.5 + 7D) μ in	ULM, gage blocks
Universal Length Machines ³ (ULMs)	Up to 4 in (4 to 24) in	1.5 μ in + 1.2 μ in/in 1.3 μ in + 1.8 μ in/in	Gage blocks, force gage, optical flat, monochromatic light source
V-Blocks – Parallelism Side V Parallelism Squareness	8 in \times 8 in \times 8 in 8 in \times 8 in \times 8 in 8 in \times 8 in \times 8 in	28 μ in 1 μ in/in + 28 μ in 9.7 μ in/in + 48 μ in	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) μ in 120 μ in	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.
10 µA to 20 A	10 Hz to 50 kHz ³	See Table IV.a	Fluke 5790A, 5700A/EP, A40s, standard resistors
(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

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) 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	0.14 % + 1.1 μV	Fluke 5790A, 5720A
		(20 to 40) Hz	0.062 % + 1.1 μV	
		40 Hz to 20 kHz	0.040 % + 1.1 μV	
		(20 to 50) kHz	0.067 % + 1.6 μV	
		(50 to 100) kHz	0.097 % + 2.0 μV	
		(100 to 300) kHz	0.19 % + 3.2 μV	
		(300 to 500) kHz	0.19 % + 6.3 μV	
	500 kHz to 1 MHz	0.31 % + 6.3 μV		
	(2.2 to 7) mV	(10 to 20) Hz	0.068 % + 1.1 μV	
		(20 to 40) Hz	0.032 % + 1.1 μV	
		40 Hz to 20 kHz	0.021 % + 1.1 μV	
		(20 to 50) kHz	0.034 % + 1.6 μV	
		(50 to 100) kHz	0.049 % + 2.0 μV	
		(100 to 300) kHz	0.096 % + 3.2 μV	
		(300 to 500) kHz	0.11 % + 6.3 μV	
	500 kHz to 1 MHz	0.19 % + 6.3 μV		
	(7 to 22) mV	(10 to 20) Hz	0.024 % + 1.1 μV	
		(20 to 40) Hz	0.016 % + 1.1 μV	
		40 Hz to 20 kHz	0.0096 % + 1.1 μV	
		(20 to 50) kHz	0.018 % + 1.6 μV	
		(50 to 100) kHz	0.026 % + 2.0 μV	
		(100 to 300) kHz	0.066 % + 3.2 μV	
		(300 to 500) kHz	0.074 % + 6.3 μV	
	500 kHz to 1 MHz	0.14 % + 6.3 μV		
	(22 to 70) mV	(10 to 20) Hz	0.022 % + 1.2 μV	
		(20 to 40) Hz	0.012 % + 1.2 μV	
		40 Hz to 20 kHz	0.0071 % + 1.2 μV	
		(20 to 50) kHz	0.012 % + 1.6 μV	
		(50 to 100) kHz	0.025 % + 2.0 μV	
		(100 to 300) kHz	0.048 % + 3.2 μV	
(300 to 500) kHz		0.063 % + 6.3 μV		
500 kHz to 1 MHz	0.096 % + 6.3 μV			
(70 to 220) mV	(10 to 20) Hz	0.017 % + 1.2 μV		
	(20 to 40) Hz	0.0076 % + 1.2 μV		
	40 Hz to 20 kHz	0.0037 % + 1.2 μV		
	(20 to 50) kHz	0.0058 % + 1.6 μV		
	(50 to 100) kHz	0.013 % + 2.0 μV		
	(100 to 300) kHz	0.022 % + 3.2 μV		
	(300 to 500) kHz	0.031 % + 6.3 μV		
500 kHz to 1 MHz	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	Vitrek 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	Vitretek 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 to 0) $^{\circ}$ C (0 to 100) $^{\circ}$ C (100 to 300) $^{\circ}$ C (300 to 400) $^{\circ}$ C (400 to 630) $^{\circ}$ C (630 to 800) $^{\circ}$ C (-200 to 0) $^{\circ}$ C (0 to 100) $^{\circ}$ C (100 to 300) $^{\circ}$ C (300 to 400) $^{\circ}$ C (400 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 to 100) °C (100 to 260) °C	0.08 °C 0.16 °C	Fluke 5520A
Pt 385, 200 Ω	(-200 to 100) °C (100 to 260) °C (260 to 300) °C (300 to 400) °C (400 to 600) °C (600 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 to -80) °C (-80 to 100) °C (100 to 260) °C (260 to 400) °C (400 to 600) °C (600 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 to 0) °C (0 to 100) °C (100 to 260) °C (260 to 300) °C (300 to 600) °C (600 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 to -190) °C (-190 to -80) °C (-80 to 0) °C (0 to 100) °C (100 to 260) °C (260 to 300) °C (300 to 400) °C (400 to 600) °C (600 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 to -100) °C (-100 to -25) °C (-25 to 350) °C (350 to 650) °C (650 to 1000) °C	0.5 °C 0.16 °C 0.14 °C 0.16 °C 0.21 °C	Fluke 5520A
Type J	(-210 to -100) °C (-100 to -30) °C (-30 to 150) °C (150 to 760) °C (760 to 1200) °C	0.28 °C 0.16 °C 0.14 °C 0.17 °C 0.23 °C	
Type K	(-200 to -100) °C (-100 to -25) °C (-25 to 120) °C (120 to 1000) °C (1000 to 1372) °C	0.34 °C 0.18 °C 0.16 °C 0.26 °C 0.40 °C	
Type S	(0 to 250) °C (250 to 1000) °C (1000 to 1400) °C (1400 to 1767) °C	0.47 °C 0.36 °C 0.37 °C 0.46 °C	
Type T	(-250 to -150) °C (-150 to 0) °C (0 to 120) °C (120 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 · Ratio)) m° (21 + (0.2 · Ratio)) m° (31 + (0.3 · Ratio)) m° (81 + (1 · Ratio)) m°	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 μΩ 1 mΩ 10 mΩ 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 μ Ω/Ω + 0.48 nΩ 12 μΩ/Ω + 4.8 nΩ 9.2 μ Ω/Ω + 4.8 nΩ 5.4 μ Ω/Ω + 48 nΩ 2.6 μ Ω/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	1.1 dB 2.1 dB	Measuring receiver and distortion analyzer
(1.3 to 26.5) GHz	< 50 % AM Depth 50 % to 95 % AM	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
Frequency Modulation ³ –			
FM Accuracy (0.15 to 10) MHz < 4 kHz FM peak Dev. < 40 kHz FM peak Dev.	Rate: 20 Hz to 10 kHz 20 Hz to 10 kHz	2.4 % + 1.2 Hz 2.4 % + 12 Hz	Measuring receiver
(10 to 1300) MHz < 400 kHz FM pk Dev.	50 Hz to 100 kHz 20 Hz to 200 kHz	1.3 % + 120 Hz 5.8 % + 240 Hz	
(1.3 to 26.5) GHz < 400 kHz FM pk Dev.	50 Hz to 100 kHz 20 Hz to 200 kHz	1.3 % + 120 Hz 5.8 % + 240 Hz	Measuring receiver and distortion analyzer
<u>β (0 to 0.5)</u> Rate: (1 to 3) Hz Peak Dev: 1 Hz to 1.3 GHz	1 Hz to 2.6 GHz	1.6 %	89441A
Rate: 3 Hz to 6.7 GHz Peak Dev: 3 Hz to 6.7 GHz	3 Hz to 13.2 GHz	1.6 %	E4445A
<u>β 0.5 to 2</u> Rate: (1 to 3) Hz Peak Dev: 1 Hz to 1.3 GHz	1 Hz to 2.6 GHz	2.1 %	89441A
Rate: 3 Hz to 6.7 GHz Peak Dev: 3 Hz to 6.7 GHz	3 Hz to 13.2 GHz	1.9 %	E4445A
<u>β 2 to 10</u> Rate: 1 Hz to 3 Hz Peak Dev: 1 Hz to 1.3 GHz	1 Hz to 2.6 GHz	1.2 %	89441A
Rate: 3 Hz to 6.7 GHz Peak Dev: 3 Hz to 6.7 GHz	3 Hz to 13.2 GHz	1.1 %	E4445A

Parameter/Range	Frequency	CMC ^{2,8} (±)	Comments
Frequency Modulation ³ – (cont)			
<u>β 10 to 100</u> Rate: 1 Hz to 3 Hz Peak Dev: 1 Hz to 1.3 GHz	1 Hz to 2.6 GHz	0.39 %	89441A
Rate: 3 Hz to 6.7 GHz Peak Dev: 3 Hz to 6.7 GHz	3 Hz to 13.2 GHz	0.36 %	E4445A
<u>β 100 to 200</u> Rate: 1 Hz to 3 Hz Peak Dev: 1 Hz to 1.3 GHz	1 Hz to 2.6 GHz	0.09 %	89441A
Rate: 3 Hz to 6.7 GHz Peak Dev: 3 Hz to 6.7 GHz	3 Hz to 13.2 GHz	0.09 %	E4445A
<u>β 200 to 500</u> Rate: 1 Hz to 13 MHz Peak Dev: 1 Hz to 1.3 GHz	1 Hz to 2.6 GHz	0.24 %	89441A
Rate: 1 Hz to 7 MHz Peak Dev: 1 Hz to 700 MHz	(2.6 to 18) GHz	0.24 %	89441A w/ mixer
<u>β 500 to 5000</u> Rate: 1 Hz to 13 MHz Peak Dev: 1 Hz to 1.3 GHz	1 Hz to 2.6 GHz	0.14 %	89441A
Rate: 1 Hz to 7 MHz Peak Dev: 1 Hz to 700 MHz	(2.6 to 18) GHz	0.14 %	89441A w/ mixer
<u>β 5000 to 6 000 000</u> Rate: 1 Hz to 13 MHz Peak Dev: 1 Hz to 1.3 GHz	1 Hz to 2.6 GHz	0.03 %	89441A
Rate: 1 Hz to 7 MHz Peak Dev: 1 Hz to 700 MHz	(2.6 to 18) GHz	0.034 %	89441A w/ mixer

Parameter/Range	Frequency	CMC ^{2, 8} (\pm)	Comments
Frequency Modulation ³ – (cont) FM Distortion 400 kHz to 10 MHz Rate: 20 Hz to 10 kHz 10 MHz to 26.5 GHz Rate: 20 Hz to 100 kHz 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	< 10 kHz FM Deviation < 100 kHz FM Deviation 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	0.15 % 0.15 % 1 Hz (rms) 0.4 Hz + (6 x 10 ⁻⁹) <i>f</i> 17 Hz 33 Hz 49 Hz 65 Hz	Measuring receiver
Single Sideband Phase Noise – Measure CF = 5 MHz <u>Offset</u> 20 Hz 1 kHz 20 kHz 100 kHz 1 MHz 5 MHz CF = 225 MHz <u>Offset</u> 20 Hz 1 kHz 20 kHz 100 kHz 1 MHz 10 MHz	Range -110 dBc/Hz -126 dBc/Hz -131 dBc/Hz -133 dBc/Hz -139 dBc/Hz -140 dBc/Hz -101 dBc/Hz -114 dBc/Hz -139 dBc/Hz -140 dBc/Hz -146 dBc/Hz -148 dBc/Hz	1.6 dB 1.3 dB 1.0 dB 1.3 dB 1.3 dB 1.4 dB 1.3 dB 1.0 dB 1.0 dB 1.1 dB 1.4 dB 1.4 dB	Agilent E8251A Agilent E4408B HP 89441A w/PMSSBPNMS

Parameter/Range	Frequency	CMC ^{2,8} (±)	Comments
Single Sideband Phase Noise – Measure (cont)			
CF = 1 GHz			
<u>Offset</u>			
20 Hz	-89 dBc/Hz	1.6 dB	Agilent E8251A Agilent E4408B HP 89441A w/PMSSBPNMS
1 kHz	-101 dBc/Hz	1.0 dB	
20 kHz	-131 dBc/Hz	0.9 dB	
100 kHz	-134 dBc/Hz	1.1 dB	
1 MHz	-145 dBc/Hz	1.4 dB	
10 MHz	-147 dBc/Hz	1.4 dB	
CF = 5 GHz			
<u>Offset</u>			
20 Hz	-76 dBc/Hz	1.9 dB	
1 kHz	-88 dBc/Hz	1.4 dB	
20 kHz	-118 dBc/Hz	0.9 dB	
100 kHz	-119 dBc/Hz	1.0 dB	
1 MHz	-143 dBc/Hz	1.4 dB	
10 MHz	-149 dBc/Hz	2.0 dB	
CF = 9.6 GHz			
<u>Offset</u>			
20 Hz	-70 dBc/Hz	1.1 dB	
1 kHz	-82 dBc/Hz	1.2 dB	
20 kHz	-113 dBc/Hz	0.9 dB	
100 kHz	-116 dBc/Hz	1.0 dB	
1 MHz	-141 dBc/Hz	1.9 dB	
10 MHz	-144 dBc/Hz	3.0 dB	
CF = 15 GHz			
<u>Offset</u>			
20 Hz	-66 dBc/Hz	1.8 dB	
1 kHz	-77 dBc/Hz	1.2 dB	
20 kHz	-108 dBc/Hz	1.0 dB	
100 kHz	-110 dBc/Hz	1.0 dB	
1 MHz	-136 dBc/Hz	1.5 dB	
10 MHz	-145 dBc/Hz	3.5 dB	

Parameter/Range	Frequency	CMC ^{2,8} (\pm)	Comments
Single Sideband Phase Noise – Measure (cont) CF = 18 GHz <u>Offset</u> 20 Hz 1 kHz 20 kHz 100 kHz 1 MHz 10 MHz	 -64 dBc/Hz -76 dBc/Hz -107 dBc/Hz -109 dBc/Hz -136 dBc/Hz -142 dBc/Hz	 1.5 dB 1.4 dB 0.9 dB 1.0 dB 1.6 dB 3.0 dB	 Agilent E8251A Agilent E4408B HP 89441A w/PMSSBPNMS
Phase Modulation ³ – (0.15 to 10) MHz < 40 Radians (peak) < 400 Radians (peak) (10 to 1300) MHz < 4 Radians (peak) < 40 Radians (peak) < 400 Radians (peak) (1.3 to 26.5) GHz < 4 Radians (peak) < 40 Radians (peak) < 400 Radians (peak)	 Rate: 200 Hz to 10 kHz Rate: 200 Hz to 20 kHz Rate: 200 Hz to 20 kHz	 4.7 % + 0.012 rad 4.7 % + 0.12 rad 3.8 % + 0.0012 rad 3.5 % + 0.012 rad 3.5 % + 0.12 rad 3.7 % + 0.0012 rad 3.5 % + 0.012 rad 3.5 % + 0.12 rad	 Measuring receiver Measuring receiver, down converter and local oscillator
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

Parameter/Range	Frequency	CMC ^{2, 8} (\pm)	Comments
RF Power Level ³ – Generate/Measure			
Absolute	0 dBm @ 50 MHz	0.11 dB + <i>M</i>	Signal generator, power splitter, attenuator, standard sensors, and power meter
	+35 to -127 dBm (1.3 to 26.5) GHz	See Table V.a	
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	0.75 % + <i>M</i>	Power sensors, splitters, meters
	300 kHz	0.51 % + <i>M</i>	
	1 MHz	0.46 % + <i>M</i>	UUT Mismatch uncertainty (<i>M</i>)
	3 MHz	0.46 % + <i>M</i>	
	10 MHz	0.43 % + <i>M</i>	
	30 MHz	0.43 % + <i>M</i>	
	100 MHz	0.52 % + <i>M</i>	
	300 MHz	0.61 % + <i>M</i>	
	500 MHz	0.61 % + <i>M</i>	
	1 GHz	0.65 % + <i>M</i>	
	2 GHz	0.76 % + <i>M</i>	
	3 GHz	0.92 % + <i>M</i>	
	4 GHz	1.0 % + <i>M</i>	
	5 GHz	1.1 % + <i>M</i>	
	6 GHz	1.1 % + <i>M</i>	
	7 GHz	1.1 % + <i>M</i>	
	8 GHz	1.1 % + <i>M</i>	
	9 GHz	1.2 % + <i>M</i>	
	10 GHz	1.3 % + <i>M</i>	
	11 GHz	1.2 % + <i>M</i>	
	12 GHz	1.2 % + <i>M</i>	
	13 GHz	1.2 % + <i>M</i>	
	14 GHz	1.2 % + <i>M</i>	
	15 GHz	1.3 % + <i>M</i>	
	16 GHz	1.3 % + <i>M</i>	
	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	4 GHz to 8 GHz	8 GHz to 17 GHz	17 GHz to 26.5 GHz
		0.9 MHz to 100 MHz	to 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	100 MHz	1.3 GHz	4 GHz	8 GHz	17 GHz
		to 100 MHz	to 1.3 GHz	to 4 GHz	to 8 GHz	to 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-Parameters ³ – Reflection S ₁₁ /S ₂₂ Magnitude and Phase –			
3.5 mm – Magnitude	300 kHz to 26.5 GHz (0 to 1.0) lin	(± 0.008 to ± 0.062) lin	8510C or 8753ES Network analyzer, 85052D calibration kit
Phase	300 kHz to 26.5 GHz (0 to 0.01) lin (0.01 to 0.40) lin (0.40 to 1.0) lin	(± 53 to ± 180) deg (± 1.3 to ± 7.3) deg (± 0.9 to ± 1.8) deg	
7 mm – Magnitude	300 kHz to 6 GHz (0 to 1.0) lin	(± 0.002 to ± 0.009) lin	8753ES Network Analyzer, 85031B calibration kit
Phase	(0 to 0.01) lin (0.01 to 1.0) lin	(± 1.2 to ± 31) deg (± 0.2 to ± 1.7) deg	
N-Type – Magnitude	300 kHz to 18 GHz (0 to 1.0) lin	(± 0.003 to ± 0.04) lin	8510C or 8753ES Network analyzer, 85054D or 85032B calibration kit
Phase	(0 to 0.01) lin (0.01 to 1.0) lin	(± 1.9 to ± 180) deg (± 0.5 to ± 6) deg	
S-Parameters ³ – Transmission S ₁₂ /S ₂₁			
3.5 mm – Magnitude	300 kHz to 26.5 GHz (10 to -70) dB	(± 0.018 to ± 0.95) dB	8510C or 8753ES Network analyzer, 85052D calibration kit
	300 kHz to 6 GHz (-70 to -90) dB	(± 1.2 to ± 6.6) dB	
Phase	300 kHz to 26.5 GHz (10 to 0) dB (0 to -50) dB (-50 to -70) dB	(± 0.20 to ± 6.5) deg (± 0.20 to ± 1.3) deg (± 1.3 to ± 6.7) deg	
	300 kHz to 6 GHz (-70 to -90) dB	(± 8.3 to ± 180) deg	

Parameter/Equipment	Range	CMC ² (±)	Comments
S-Parameters ³ – Transmission S ¹² /S ²¹ (cont)			
7 mm – Magnitude	300 kHz to 6 GHz (10 to -50) dB (-50 to -70) dB (-70 to -90) dB	(± 0.02 to ± 0.71) dB (± 0.16 to ± 0.95) dB (± 1.2 to ± 6.6) dB	8753ES Network Analyzer
Phase	(10 to 0) dB (0 to -50) dB (-50 to -70) dB (-70 to -90) dB	(± 5.4 to ± 6.5) deg (± 0.14 to ± 1.3) deg (± 1.3 to ± 6.7) deg (± 8.3 to ± 180) deg	
N-Type – Magnitude	300 kHz to 18 GHz (10 to -70) dB	(± 0.02 to ± 1.1) dB	8510C or 8753ES Network analyzer, 85054D or 85032B calibration kit
	300 kHz to 6 GHz (-70 to -90) dB	(± 1.2 to ± 6.6) dB	
Phase	300 kHz to 18 GHz (10 to -50) dB (-50 to -70) dB	(± 0.16 to ± 1.3) deg (± 1.3 to ± 180) deg	
	300 kHz to 6 GHz (-70 to -90) dB	(± 1.3 to ± 180) deg	

VI. Fluid Quantities

Parameter/Equipment	Range	CMC ^{2,4,8} (±)	Comments
Viscosity ³ – Dynamic (Meter) Kinematic (Cups)	(0 to 100 000) cP (0 to 100 000) cP	0.83 % 0.24 % + 0.84 s	Standard viscosity fluids, PRT, stopwatch
Flow ³	2 sccm to 650 slm	0.26 %	Mass flow system

Parameter/Equipment	Range	CMC ^{2,4,8} (±)	Comments
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
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} (\pm)	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 50) 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	(5 to 2000) Hz (2 to 10) kHz	2.0 % 2.7 %	Reference accelerometer, back-to-back comparison method
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 + 0.6R	Deadweights
Durometers ³ – Indenter Shape and Extension: Durometer Spring Display Linearity	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 (0.001 to 0.2) in	 3.2 μm 3.2 μm 1 arcmin 3.2 μm 3.2 μm 36 mN 37 μin or 0.6R, whichever is greater	ASTM D2240 Gage blocks Vision system Durometer calibrator Gage blocks
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
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	ASTM A956 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:		ASTM E18
	Low	0.29 HRA	
	Mid	0.56 HRA	
	High	0.24 HRA	
	HRBW:		
	Low	0.94 HRB	
	Mid	0.69 HRB	
	High	0.62 HRB	
	HRC:		
	Low	0.78 HRC	
	Mid	0.92 HRC	
	High	0.39 HRC	
	HRE:		
Low	0.92 HRE		
Mid	1.1 HRE		
High	0.89 HRE		
HR15N:			
Low	0.76 HR15N		
Mid	0.75 HR15N		
High	1.1 HR15N		
HR30N:			
Low	0.55 HR30N		
Mid	0.48 HR30N		
High	0.46 HR30N		
HR45N:			
Low	0.68 HR45N		
Mid	0.72 HR45N		
High	0.66 HR45N		
HR15T:			
Low	0.79 HR15T		
Mid	0.52 HR15T		
High	0.61 HR15T		
HR30T:			
Low	0.70 HR30T		
Mid	0.61 HR30T		
High	0.42 HR30T		
HR45T:			
Low	0.98 HR45T		
Mid	0.78 HR45T		
High	0.81 HR45T		



Parameter/Equipment	Range	CMC ^{2, 4, 8} (±)	Comments
Load Cells & Transducers – Load Cells, Force Gauges, Force Rings, and Dynamometers	(0 to 3325) lbf (up to 2 000) lbf (2 to 5.5) klbf (5.5 to 10) klbf (10 to 50) klbf	0.01 % 0.036 % + 0.60 lbf 0.028 % + 1.9 lbf 0.028 % + 4.0 lbf 0.21 % + 19 lbf	Dead weights, 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 µg 35 µg 0.14 mg 3.7 mg 12 mg 0.11 g	Mass comparison by substitution
Pressure/Vacuum Gauges & Transducers ³	To 1 inH ₂ O (>1 to 5) inH ₂ O (>5 to 10) inH ₂ O (>10 to 100) inH ₂ O (>100 to 400) inH ₂ O (-15 to 15) psig (>15 to 88) psig (>88 to 350) psig (> 350 to 1000) psig (>1000 to 1485) psig (>1485 to 3000) psig (>3000 to 6000) psig (>6000 to 10 000) psig To 30 psia (>30 to 200) psia (>200 to 1000) psia (>1000 to 1500) psia	0.0006 inH ₂ O 0.0031 inH ₂ O 0.0061 inH ₂ O 0.0016 % + 0.0058 inH ₂ O 0.0015 % + 0.0015 inH ₂ O 0.0069 % + 0.0023 psig 0.0005 % + 0.0051 psig 0.0052 % + 0.0008 psig 0.0152 % + 0.0091 psig 0.15 psig 0.004 % + 0.242 psig 0.0007 % + 0.656 psig 0.0038 % + 0.745 psig 0.0065 % + 0.0015 psia 0.0083 % + 0.0066 psia 0.0152 % + 0.0077 psia 0.15 psia	Pressure calibrators and sensors
Barometric	(10 to 17) psig	0.0007 % + 0.0015 psia	
Refractometers ³	(0 to 100) %	0.02 % + 0.6R	Standard solutions

Parameter/Equipment	Range	CMC ^{2, 4, 8} (\pm)	Comments
Scales and Balances ³	(1 to 50) mg	0.016 mg + 0.58R	Mass standards
	51 mg to 10 g	0.03 mg + 0.58R	
(11 to 50) g	0.054 mg + 0.58R		
(51 to 300) g	0.24 mg + 0.58R		
(301 to 1000) g	3.8 mg + 0.58R		
(1 to 5) kg	11 mg + 0.58R		
(5 to 30) kg	89 mg + 0.58R		
Up to 0.5 lb	0.000 0015 oz + 0.58R		
(0.5 to 1) lb	0.000 0030 oz + 0.58R		
(1 to 2) lb	0.000 011 oz + 0.58R		
(2 to 5) lb	0.000 14 oz + 0.58R		
(5 to 10) lb	0.000 34 oz + 0.58R		
(10 to 20) lb	0.000 68 oz + 0.58R		
(20 to 50) lb	0.000 93 oz + 0.58R		
(50 to 100) lb	0.0043 oz + 0.58R		
(100 to 500) lb	0.0086 oz + 0.58R		
(500 to 1000) lb	0.043 oz + 0.58R		
Proportional Calibrations	Up to 750 lb	0.22 lb + 0.6R	Class F weights
	(750 to 1500) lb	0.28 lb + 0.6R	
	(1500 to 3000) lb	0.36 lb + 0.6R	
	(3000 to 4500) lb	0.42 lb + 0.6R	
	(4500 to 6000) lb	0.48 lb + 0.6R	
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
Torque Wrenches, Watches, and Indicators	Up to 1.5 in·lbf >1.5 to 10 in·lbf >10 to 100 in·lbf >100 to 145 in·lbf >145 to 3000 in·lbf >3000 to 24 000 in·lbf	0.0076 in·lbf 0.17 % + 0.013 in·lbf 0.25 % + 0.008 in·lbf 0.38 in·lbf 0.28 % + 0.0058 in·lbf 0.25 % + 3 in·lbf	Torque calibrator
Testers and Transducers	Up to 2000 ft·lbf	0.05 %	Weights, loading arms
Ultrasonic Thickness Testers ³	(0 to 10) in	(800 + 13L) μ in	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 to 60) °C	-0.44 °C + 0.6 <i>R</i>	Thunder Scientific humidity chamber
Infrared Thermometers – Measuring Equipment ³	(-15 to 120) °C	0.6 °C + 0.6 <i>R</i>	Hart 9132 radiation source
	(35 to 500) °C	0.8 °C + 0.6 <i>R</i>	
	(500 to 1100) °C	1.6 °C + 0.0043 °C/ °C	Isotech Pegasus 92R radiation source
Temperature Measuring Equipment– Indicators, RTD's, Thermocouples ³	(-40 to 650) °C	0.013 % rdg +0.0028 °C or 0.011 °C (Whichever is greater)	Temperature source, SPRT
	-80 °C fixed point		
	(650 to 1000) °C	0.011 % rdg +0.45 °C	
Relative Humidity – Measure			
Hygrometers	(10 to 30) % RH	0.59 % RH	Humidity generator, Thunder Scientific 2500ST
	(30 to 60) % RH	0.60 % RH	
	(60 to 90) % RH	0.63 % RH	
Psychrometers	(5 to 35) °C	0.1 °C + 0.84 <i>R</i>	Comparison to SPRT in temp bath

XI. Time & Frequency

Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
Frequency – Measuring Equipment & Measure	10 MHz	3 parts in 10 ¹¹	GPS
	0.01 Hz to 200 kHz	3 parts in 10 ¹¹ + 1.4 μHz + 0.58R	Function generator, signal generator, frequency counter or spectrum analyzer with ext. GPS timebase
Stopwatches & Timers ³	10 s to 72 hr	28 ms + 18 μs/s	Function generator, frequency counter
	(2 to 960) s	0.037 s/day	Timometer

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	21 μin/in + 0.6R (whichever is greater)	SIP302M



Parameter/Equipment	Range	CMC ^{2,4} (±)	Comments
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 + 0.6R) μin	Cylindrical rings
Indicators ³ – Dial & Test, LVDTs	Up to 4 in	35 μin or 0.6R (whichever is greater)	Indicator calibrator
Height Gage ³	Up to 48 in	10 μin/in + 0.6R	Gage blocks
Micrometers ³ – Inside Depth Tri-Bores Outside Groove Bench Thread (Screw, Thread, Pitch, Point)	Up to 294 in Up to 12 in Up to 11 in Up to 42 in Up to 4 in Up to 42 in Up to 4 in	12 μin + 7 μin /in + 0.2R 18 μin/in + 0.64R 18 μin/in + 0.7R 18 μin/in + 0.64R 18 μin/in + 0.64R 18 μin/in + 0.64R 18 μin/in + 0.64R	ULM, gage blocks, rings
Pin and Plug Gages	(0 to 1) in	6.7 μin/in + 79 μin	ULM

II. Mechanical

Parameter/Equipment	Range	CMC ^{2, 4} (\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, 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; the value is defined as the percentage of reading, unless otherwise 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.

¹¹ Parallelism measurements apply only to optical parallels; calibrated for flatness and parallelism.



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 17025:2017 *General requirements for the competence of testing and calibration laboratories*. This laboratory also meets the requirements of ANSI/NCSL 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 April 2017*).



Presented this 26th day of June 2019.

A blue ink signature of the Vice President of Accreditation Services.

Vice President, Accreditation Services
For the Accreditation Council
Certificate Number 1078.01
Valid to January 31, 2021

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