

# *Metrology Services*

## **Capabilities**



**Northrop Grumman Metrology Standards Lab  
Redondo Beach, CA**

**[www.st.northropgrumman.com/emc](http://www.st.northropgrumman.com/emc)**

## ***Metrology Services***

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Northrop Grumman provides advanced technology products and services for the automotive, space and defense and information technology markets worldwide.

Located in Redondo Beach, California, Northrop Grumman's Space Technology produces, integrates and tests electronic space payloads; produces advanced microelectronics integrated circuits and modules for telecommunications; develops advanced space instruments and builds commercial and military lasers.

The 24,000 square feet Metrology Standards Lab and Test Equipment Management Center have supported internal technology for more than 35 years, developing an extensive range of capabilities.

Metrology Services were first offered outside the company in 1988 to extend internal capabilities as a resource to companies requiring additional calibration support. On-site calibration is available upon request.

## ***Services & Specialized Consulting***

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- **Calibration & Repair**
- **Special Measurements:**
  - RF/millimeter wave development, phase noise evaluations, fiber optics, laser power
- **Metrology Engineering Consulting:**
  - Characterization and Validation
  - Phase Noise
  - Multimeter Wave
  - Software development (HP VEE, Visual Basic)
- **Customized Training Programs:**
  - Metrology Fundamentals, Calibration & Repair, HP VEE
- **Measurement and Test Development:**
  - Methodologies, System Design, Automation and Procedures
- **Calibration, Procedures and Systems for ISO 9001, 2 or 3 – Section 4.11**
  - Metrology Training for Calibration Technicians
    - Uncertainty, Environmental and Interval Analysis, Measurement Technique, Dimensional, Physical, DC/Low Frequency and RF/Microwave Develop calibration and recall system
    - Review and generate calibration procedures, including DOIs, SOPs
- **Managing Test Equipment**
  - Consulting offered to help you attain superior financial returns on your investment in technology assets
    - Assessment of processes from Acquisitions thru Disposal, with follow-on Strategies and Training of key personnel
    - Optional Software tools

**TYPICAL INSTRUMENTATION SERVICED**

<p><b>ADAPTER</b> COAXIAL TO COAXIAL WAVEGUIDE TO COAXIAL WAVEGUIDE TO WAVEGUIDE</p> <p><b>AIR LINE</b> COAXIAL</p> <p><b>AMPLIFIER</b> CHARGE DATA GENERAL PURPOSE LOCK-IN OPERATIONAL POWER PULSE</p> <p><b>ANALYZER</b> GAS MOISTURE OXYGEN</p> <p><b>ANALYZER (ELECTRONIC)</b> DATACOMM, DIGITAL DISTORTION NETWORK SPECTRUM WAVE</p> <p><b>ANEMOMETER</b> THERMAL VANE</p> <p><b>ATTENUATOR</b> FIXED VARIABLE</p> <p><b>BALANCE</b> ANALYTICAL LABORATORY TOP LOADING</p> <p><b>BATH (CONSTANT TEMP)</b> LIQUID</p> <p><b>BEND</b> WAVEGUIDE</p> <p><b>BIAS NETWORK</b> MICROWAVE</p> <p><b>BLOCK</b> GAGE, ANGLE SET GAGE, SET MAGNETIC VEE</p> <p><b>BRIDGE</b> CAPACITANCE CONDUCTIVITY IMPEDANCE INDUCTANCE</p>	<p><b>BRIDGE</b> RESISTANCE TEMPERATURE, OHMS READING</p> <p><b>CALIBRATOR</b> FLOW, GAS PRESSURE, DEAD WEIGHT</p> <p><b>CALIBRATOR (ELECTRONIC)</b> ATTENUATOR AUDIO/MICROPHONE OHMS POWER METER</p> <p><b>CALIBRATOR (VOLTS/AMPS)</b> AC CURRENT AC VOLTAGE DC CURRENT DC VOLTAGE</p> <p><b>CALORIMETER</b> LASER</p> <p><b>CAPACITOR</b> DECADE FIXED VARIABLE</p> <p><b>CENTRIFUGE</b></p> <p><b>CHAMBER</b> FREEZER FURNACE OVEN TEMPERATURE TEMPERATURE/HUMIDITY</p> <p><b>CONTROLLER (ELECTRONIC)</b> TEMPERATURE</p> <p><b>CONVERTER (SIGNAL)</b> AC/DC TO LOGARITHMIC ANALOG TO DIGITAL DIGITAL TO ANALOG FREQUENCY TO VOLTAGE VOLTAGE-TO-FREQUENCY VOLTAGE, THERMAL</p> <p><b>COUNTER (ELECTRONIC)</b> AUTOMATIC COMPUTING FREQUENCY UNIVERSAL PRESET REVERSIBLE TIME INTERVAL TOTALIZER</p> <p><b>COUPLER</b> DIRECTIONAL HYBRID</p>	<p><b>DATA ACQUISITION SYSTEM</b></p> <p><b>DELAY LINE</b> FIXED VARIABLE</p> <p><b>DENSITOMETER</b> OPTICAL</p> <p><b>DETECTOR</b> LEAK MICROWAVE</p> <p><b>DISPLAY</b> DIGITAL, MODULAR</p> <p><b>DIVIDER</b> POWER, MICROWAVE</p> <p><b>DIVIDER, DC/AC</b> VOLTAGE</p> <p><b>DIVIDER, AC VOLTAGE</b> RATIO TRANSFORMER</p> <p><b>DOSIMETER</b> NUCLEAR</p> <p><b>FILTER</b> BAND PASS, FIXED BAND PASS, VARIABLE BAND REJECT, FIXED BAND REJECT, VARIABLE HIGH PASS LOW PASS MULTIFUNCTION NOTCH</p> <p><b>FLOW MEASUREMENT</b> FLOWMETER, GAS</p> <p><b>GAGE (DIMENSIONAL)</b> HEIGHT CYLINDRICAL PLUG</p> <p><b>GAGE (ELECTRONIC)</b> VACUUM</p> <p><b>GAGE (INDICATOR TYPE)</b> FORCE PRESSURE PRESSURE, ABSOLUTE PRESSURE, COMPOUND PRESSURE, DIFFERENTIAL PRESSURE, GAS PRESSURE, LIQUID VACUUM</p> <p><b>GAGE/CONTROLLER (ELEC)</b> VACUUM, ANALOG VACUUM, DIGITAL</p>
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<p><b>GENERATOR (ELECTRONIC)</b>            DELAY            FREQUENCY STANDARD            FREQUENCY SYNTHESIZER            FUNCTION            TIME MARK            NOISE            NOISE SOURCE            OSCILLATOR            POWER PULSE            POWER SIGNAL            PULSE            RATE            SIGNAL            SQUARE WAVE            SWEEP            WORD/DATA</p> <p><b>HYGROMETER</b>            DEW POINT            DIRECT READING</p> <p><b>INDICATOR (ELECTRONIC)</b>            LINEAR            DISPLACEMENT            PRESSURE, ANALOG            STRAIN            TRANSDUCER, UNIVERSAL</p> <p><b>INDUCTOR</b>            DECADE            FIXED</p> <p><b>ISOLATOR</b>            MICROWAVE</p> <p><b>LEAK</b>            FIXED RATE</p> <p><b>LOAD (ELECTRONIC)</b>            ACTIVE</p> <p><b>MANOMETER</b>            ANALOG            DIGITAL            FLUID</p> <p><b>MEASURING SYSTEM</b>            COORDINATE</p> <p><b>METER</b>            FIELD INTENSITY            FREQUENCY GAS, WET TEST            GAUSS            ILLUMINANCE/FOOT CANDLE            LASER POWER            MODULATION FM/AM            NOISE FIGURE            NULL</p>	<p><b>METER</b>            PEAK MEMORY VOLTMETER            PH            PHASE            POWER            SOUND LEVEL            STANDING WAVE RATIO (SWR)            WATT</p> <p><b>METER (RCL)</b>            CAPACITANCE            IMPEDANCE            IMPEDANCE, VECTOR            INDUCTANCE            Q</p> <p><b>METER (VOA)</b>            AMMETER, AC            AMMETER, AC/DC            AMMETER, DC            ELECTROMETER            MULTIMETER            OHMMETER            VOLT, DIGITAL, PANEL DC            VOLTMETER, AC            VOLTMETER, AC/RF            VOLTMETER, DC            VOLTMETER, DIFFERENTIAL AC/DC            VOLTMETER, DIFFERENTIAL DC            VOLTMETER, DIGITAL AC/DC            VOLTMETER, DIGITAL DC            VOLTMETER, TRUE RMS            VOLTMETER, VECTOR</p> <p><b>MICROMETER</b>            BORE/HOLE SET            DEPTH            INSIDE            OUTSIDE</p> <p><b>MICROPHONE</b></p> <p><b>MICROSCOPE</b>            BINOCULAR            MEASURING            METALLOGRAPH            METALLURGICAL            STEREO</p> <p><b>MISMATCH</b>            MICROWAVE</p> <p><b>MIXER (ELECTRONIC)</b></p> <p><b>MONITOR</b>            RADIATION, NUCLEAR            PARTICLE COUNTER</p> <p><b>MULTIPLIER</b>            FREQUENCY</p>	<p><b>OPTICAL</b>            AUTOCOLLIMATOR            CATHETOMETER            CLINOMETER            COM PARATOR            FLAT</p> <p><b>OSCILLOSCOPE</b>            DIGITAL STORAGE            DISPLAY UNIT            DISPLAY UNIT, STORAGE            DUAL BEAM            GENERAL PURPOSE            SAMPLING            STORAGE</p> <p><b>OSCILLOSCOPE ACCESSORY</b>            CALIBRATOR, AMPLITUDE            UNINTERRUPTIBLE (UPS)            NORMALIZER            PLUG-IN, COUNTER            PLUG-IN, DIFFERENTIAL            PLUG-IN, DMM            PLUG-IN, DUAL TRACE            PLUG-IN, FOUR TRACE            PLUG-IN, LOGIC ANALYZER            PLUG-IN, SAMPLING            PLUG-IN, SAMPLING SWEEP            PLUG-IN, SAMPLING/TDR            PLUG-IN, SINGLE TRACE            PLUG-IN SPECTRUM ANALYZER            PLUG-IN, SWEPT FREQUENCY            PLUG-IN, TIME BASE            SAMPLING HEAD            TRIGGER COUNTDOWN</p> <p><b>PHASE SHIFTER</b>            MICROWAVE</p> <p><b>PHOTOMETER</b>            OPTICAL</p> <p><b>PLATE</b>            ANGLE            SINE            SURFACE</p> <p><b>POTENTIOMETER</b>            PRECISION            TEMPERATURE            DIRECT READING</p> <p><b>POWER</b>            INVERTER</p>
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<p><b>POWER SUPPLY</b> AC DC COMPUTER CONTROLLED DC CURRENT REGULATED DC GENERAL PURPOSE DC PRECISION KLYSTRON MODULAR PLATING PULSE, CURRENT REGULATOR, VOLTAGE, AC UNINTERRUPTIBLE (UPS)</p> <p><b>PRESS</b> LABORATORY</p> <p><b>PROBE</b> CURRENT VOLTAGE</p> <p><b>PYROMETER</b> INFARED OPTICAL</p> <p><b>RADIOMETER</b> OPTICAL</p> <p><b>RADIOMETER ACCESSORY</b> DETECTOR</p> <p><b>RATEMETER</b> NUCLEAR</p> <p><b>RECORDER</b> ANALOG TAPE DIGITAL PRINTER OSCILLOGRAPH (LIGHT BEAM) OSCILLOGRAPHIC STRIP CHART XY</p> <p><b>RECORDER (ENVIRONMENTAL)</b> HYGRO-THERMOGRAPH TEMPERATURE</p> <p><b>RECORDER/CONTROLLER</b> TEMPERATURE</p> <p><b>REFERENCE JUNCTION</b> TEMPERATURE</p> <p><b>REGULATOR</b> PRESSURE</p> <p><b>RESISTOR</b> DECADE FIXED VARIABLE</p> <p><b>ROTARY JOINTS</b> MICROWAVE</p>	<p><b>SCALE</b> PRECISION</p> <p><b>SECTION</b> WAVEGUIDE</p> <p><b>SHORT SHUNT</b> <b>SLOTTED LINE</b> MICROWAVE SOURCE BLACKBODY INFARED</p> <p><b>SOURCE</b> BLACKBODY INFARED</p> <p><b>SPECTROPHOTOMETER</b> SQUARE CYLINDRICAL</p> <p><b>STANDARD</b> MAGNET</p> <p><b>STROBOSCOPE</b> INDICATOR, ANALOG</p> <p><b>SURVEY METER</b> NUCLEAR</p> <p><b>SWITCH</b></p> <p><b>SYCHRO/RESOLVER</b> STANDARD</p> <p><b>TABLE</b> ROTARY</p> <p><b>TEE</b> MICROWAVE HYBRID</p> <p><b>TELEMETRY</b> RECEIVER</p> <p><b>TELEMETRY ACCESSORY</b> CHANNEL SELECTOR DEMODULATOR, PHASE DISCRIMINATOR SYNCHRONIZER, BIT TUNER VCO</p> <p><b>TERMINATION</b> POWER</p> <p><b>TESTER</b> HARDNESS TENSILE/COMPRESSION TORQUE</p>	<p><b>TESTER (ELECTRONIC)</b> CURVE TRACER EDDY CURRENT</p> <p><b>TESTER (ELECTRONIC)</b> ERROR RATE, COMMUNICATION INSULATION LOGIC CIRCUIT ANALYZER LOGIC PROBE SEMICONDUCTOR TRANSMISSION LINE</p> <p><b>THERMOMETER</b> DIAL GAGE DIGITAL GLASS INDICATOR, ANALOG PROBE, RESISTANCE TEMP PROBE, THERMOCOUPLE</p> <p><b>TIME CODE</b> GENERATOR/TRANSLATOR TRANSLATOR</p> <p><b>TIMER</b> ELECTRONIC</p> <p><b>TORQUE</b> WRENCH/GAGE</p> <p><b>TRANSDUCER</b> ACCELEROMETER DISPLACEMENT, ANGULAR DISPLACEMENT, LINEAR EXTENSOMETER LOAD CELL PRESSURE TORQUE</p> <p><b>TRANSFORMER</b> CURRENT ISOLATION MATCHING VARIABLE</p> <p><b>TRANSITION</b> WAVEGUIDE TO WAVEGUIDE</p> <p><b>TUNER</b> MICROWAVE</p> <p><b>WEIGHT SET</b></p>
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## ***Measurement Capabilities, Ranges & Uncertainties***

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### ***Notes***

- Northrop Grumman is ISO-9001 certified. Measurements and calibrations are performed in compliance with ANSI/NCSL Z540, NASA NHB-5300.4 and MIL-STD-45662-A.
- Measurements and calibrations are directly traceable to NIST (National Institute of Standards and Technology) or other recognized National Standards.
- The ***Uncertainty Values*** listed are for standard calibrations and are intended as a reference only. Actual uncertainties may vary and lower uncertainty values can be achieved in most disciplines upon request.

**DC/LOW FREQUENCY**

<b>Discipline</b>	<b>Nominal Value or Range</b>	<b>Uncertainty</b>
<b>AC VOLTAGE</b>	10 mV 10 Hz – 100 kHz	0.05 %
	100 mV 10 Hz – 40 Hz	0.03 %
	40 Hz – 20 kHz	0.005 %
	20 kHz – 300 kHz	0.03 %
	300 kHz – 1MHz	0.04 %
	1 V 10 Hz – 20 Hz	0.02 %
	20 Hz – 40 Hz	0.003 %
	40 Hz- 100 Hz	0.002 %
	100 Hz – 20 kHz	0.002 %
	20 kHz – 100 kHz	0.005 %
	100 kHz – 1 MHz	0.013 %
	10 V 10 Hz – 20 Hz	0.02 %
	40 Hz – 100 Hz	0.003 %
	100 Hz – 20 kHz	0.002 %
	20 kHz – 100 kHz	0.005 %
	100 kHz – 1MHz	0.013 %
	100 V 10 Hz – 20 Hz	0.02 %
	40 Hz – 20 kHz	0.003 %
	50 kHz – 100 kHz	0.007 %
	300 kHz	0.013 %
	1000 V 10 Hz – 20 Hz	0.02 %
	40 Hz – 20 kHz	0.003 %
	50 kHz – 100 kHz	0.007 %

**DC/LOW FREQUENCY**

<b>Discipline</b>	<b>Nominal Value or Range</b>	<b>Uncertainty</b>	
<b>AC CURRENT</b>	0.01 A 1 kHz, 10 kHz	0.005 %	
	0.02 A 1 kHz, 10 kHz	0.005 %	
	0.03 A 1 kHz, 10 kHz	0.005 %	
	0.05 A 1 kHz, 10 kHz	0.005 %	
	0.1 A 1 kHz, 10 kHz	0.005 %	
	0.2 A 1 kHz, 10 kHz	0.005 %	
	0.3 A 1 kHz, 10 kHz	0.005 %	
	0.5 A 1 kHz, 10 kHz	0.005 %	
	1.0 A 1 kHz, 10 kHz	0.005 %	
	2.0 A 1 kHz, 10 kHz	0.005 %	
	3.0 A 1 kHz, 10 kHz	0.005 %	
	5.0 A 1 kHz, 10 kHz	0.005 %	
	10.0 A 1 kHz, 20 kHz	0.01 %	
	20 A 1 kHz, 10 kHz	0.01 %	
	<b>AC VOLTAGE</b>	0 – 350V at 1 kHz	1 ppm

**DC/LOW FREQUENCY**

<b>Discipline</b>	<b>Nominal Value or Range</b>	<b>Uncertainty</b>
<b>CAPACITANCE</b>	1 pF @ 1 kHz	0.0003 %
	10 pF @ 1 kHz	0.0002 %
	100 pF @ 1 kHz	0.0002 %
	1000 pF @ 1 kHz	0.0005 %
	0.01 $\mu$ F @ 1 kHz	0.05 %
	0.1 $\mu$ F @ 1 kHz	0.05 %
	1.0 $\mu$ F @ 1 kHz	0.053 %
	10 $\mu$ F @ 1 kHz	0.25 %
	Steps of 10 $\mu$ f @ 1 kHz	.25% per step
	<b>INDUCTANCE</b>	10 $\mu$ H @ 100 Hz & 1 kHz
1 mH @ 100 Hz & 1 kHz		0.02 %, 0.05 %
10 mH @ 100 Hz & 1 kHz		0.02 %
100 mH @ 100 Hz & 1 kHz		0.02 %
1 H @ 100 Hz & 1 kHz		0.02 %, 0.05 %
10 H @ 100 Hz & 1 kHz		0.02 %, 0.2 %
<b>RESISTANCE</b>	10 $\mu\Omega$ – 100 $\mu\Omega$	10 ppm
	100 $\mu\Omega$ – 1 m $\Omega$	1.3 ppm
	1 m $\Omega$ – 10 m $\Omega$	1 ppm
	10 m $\Omega$ – 100 m $\Omega$	0.6 ppm
	1 $\Omega$	0.16 ppm
	1 $\Omega$ – 10 $\Omega$	0.2 ppm
	10 $\Omega$ – 100 $\Omega$	0.3 ppm
	100 $\Omega$ – 1 k $\Omega$	0.4 ppm
	10 k $\Omega$	0.25 ppm
	10 k $\Omega$ – 100 k $\Omega$	0.3 ppm
	100 k $\Omega$ – 1 M $\Omega$	2 ppm
	1 M $\Omega$ – 10 M $\Omega$	5 ppm
	10 M $\Omega$ – 100 M $\Omega$	350 ppm
	100 M $\Omega$ – 1 G $\Omega$	500 ppm
	1 G $\Omega$ – 10 G $\Omega$	700 ppm
	10 G $\Omega$ – 100 G $\Omega$	1000 ppm
100 G $\Omega$ – 1 T $\Omega$	2000 ppm	
1 T $\Omega$ – 10 T $\Omega$	3000 ppm	

**DC/LOW FREQUENCY**

<b>Discipline</b>	<b>Nominal Value or Range</b>	<b>Uncertainty</b>
<b>PHASE</b>	0° - 360° @ 400 Hz	0.005°
	0° - 360° @ 50kHz	0.005°
<b>FREQUENCY RESPONSE</b>	0.2 V	
	1.0 – 1 MHz	0.05 %
	10 MHz	0.1 %
	30 MHz	0.2 %
	100 MHz	1.0 %
	1.0 V, 3.0 V	
	0.03 – 1 MHz	0.05 %
	2 – 10 MHz	0.1 %
	20 – 30 MHz	0.2 %
	40 MHz	0.4 %
	60 MHz	0.6 %
	80 MHz	0.8 %
	100 MHz	1 %
	<b>RISETIME</b>	≤ 14.7 pS
<b>DC VOLT</b>	10 V	0.3 ppm
	1 V	0.5 ppm
	1 μV	10 %
	10 μV	1.0 %
	100 μV	0.1 %
	1 mV	0.01 %
	10 mV	10 ppm
	100 mV	0.8 ppm
	100 V	0.5 ppm
	1000 V	0.8 ppm
	2000 V	0.02 %
	30000 V	0.02 %
50000 V	0.02 %	
<b>DC CURRENT</b>	2 pA	1 %
	20 pA	0.5 %
	200 pA	0.3 %
	2nA – 20 nA	0.07 %
	200 nA	0.04 %
	2 μA – 20 μA	0.03 %
	100 μA – 1A	0.00065 %
	1 A – 10 A	0.005 %
	10A – 100A	0.005 %

**RF/MICROWAVE**

<b>Discipline</b>	<b>Range</b>	<b>* Frequency</b>	<b>Measurement Uncertainty</b>
<b>ATTENUATION</b>			
Fixed Coaxial	0 – 50dB	0.01 – 50 GHz	±(.05 dB + .3 % dB value)
Variable Coaxial	0 – 100 dB 0 – 100 dB	30 MHz 0.01 – 67 GHz	± 0.01 – ±0.15 dB ±(.03 per 10 dB or .3 % dB value) whichever is greater
Fixed Waveguide	0 – 100dB 0 – 50 dB 0 – 50 dB	2.6 – 12.4 GHz 12.4 – 18.0 GHz 18.0 – 110.0 GHz	±(.05 dB + .3 % dB value) ±(.05 dB + .3 % dB value) ±(.05 dB + .3 % dB value)
Variable Waveguide	0 – 100dB 0 – 50 dB 0 – 50 dB	2.6 – 8.2 GHz 8.2 – 18.0 GHz 18.0 – 110.0 GHz	±(.03 per 10 dB or .3 % dB value) whichever is greater ±(.03 per 10 dB or .3 % dB value) whichever is greater ±(.03 per 10 dB or .3 % dB value) whichever is greater
<b>RF POWER</b>			
Thermistors	0 dBm	2 – 18 GHz	±(0.25% – 1.5 %)
Thermocouple & Diode Sensors	0 dBm	2 – 18 GHz	±(0.40% – 1.5 %)
Coaxial	* 0.01 – 100 mW	0.001 – 67.0 GHz	±(1.5 – 6.0 %)
Waveguide	* 0.01 – 100 mW * 0.01 – 100 mW * 0.01 – 100 mW	8.2 – 50.0 GHz 50.0 – 75.0 GHz 75 – 110 GHz	±(2.0 – 4.5 %) ±(4.0 – 6.0 %) ±(6.0 – 8.0 %)
* <i>Other power levels are available upon request</i>			



**RF MICROWAVE**

Discipline	Range	Measurement Uncertainty
<p><b>NETWORK ANALYSIS</b> All 4 S-Parameters Magnitude &amp; Phase</p>	<p>300 kHz – 110 GHz</p>	<p>Dependent on system used</p>
<p><b>FREQUENCY</b> Cesium Primary Frequency Standard</p>	<p>10 MHz, 5 MHz, 1 MHz, 100 KHz outputs</p>	<p><math>\pm 5 \times 10^{-13}</math></p>
<p><b>TIME</b> Relative with respect to GPS</p>	<p>1 pps output</p>	<p><math>\pm 30</math> n Sec RMS</p>

**PHYSICAL**

Discipline	Range	Measurement Uncertainty
<b>FLOW GAS</b>	50 – 50,000 scc/min	± 01.15 % of reading (k=2)
<b>VISCOSITY</b>	Up to 1000 mm <sup>2</sup> /s 1000 – 10,000 mm <sup>2</sup> /s Greater than 10,000 mm <sup>2</sup> /s	0.29% of actual viscosity 0.38% of actual viscosity 0.44% of actual viscosity
<b>MASS</b>	1 mg – 50 mg 100 mg – 500 mg 1 g – 50 g 100 g – 1 kg 5 kg – 30 kg	± 0.002 mg ± 0.005 mg ± 0.010 mg ± 0.050 mg ± 1 ppm
<b>FORCE</b>		
Deadweights	Up to 300 lbf	± 0.097% of full scale*
Load Cells	0 – 60,000 lbf	± 0.1% of full scale* (k=2)
<b>TORQUE</b>		
Transducers	Up to 1000 ft lb	± .025% of Full Scale
Wrenches/Screwdrivers	5 – 50 in oz 5 – 50 in lb 40 – 400 in lb 100 – 1000 in lb 25 – 250 ft lb 60 – 600 ft lb	± 0.5 % of reading ± 0.25 % of reading ± 0.25 % of reading ± 0.25 % of reading ± 0.25 % of reading ± 0.25 % of reading

*\* The combined system uncertainty includes uncertainty as calculated in accordance with ASTM E 74, drift due to temperature variations, drift over time, and indicator uncertainty.*

**PHYSICAL**

Discipline	Range	Measurement Uncertainty
<b>VIBRATION</b>	100 Hz, (2 pk g) 20 Hz to <100 Hz, (2 pk g) >100 Hz to 2000 Hz, (2 pk g) >2000 Hz to 10,000 Hz, (2 pk g)	± 1.6% (k=2) ± 2.1% (k=2) ± 1.9% (k=2) ± 2.9% (k=2)
<b>PRESSURE</b>		
Portable Pressure Calibrator	0 – 0.8 in H2O 0 – 8 in H2O	± 0.1% of reading + 1 digit ± 0.1% of reading + 1 digit
Capacitance Manometer	0.001 – 4 Torr 4 – 1000 Torr	± 0.004 Torr ± 0.1% of reading
Pneumatic Piston Gage	0.2 – 25 psi 25 – 1000 psi 1000 – 10000 psi	± 0.0015% of reading ± 0.005% of reading ± 0.01% of reading
Hydraulic Piston Gage	0 – 1000 psi 1000 – 15,000 psi	± 0.011% of reading ± 0.06% of reading
Absolute (Ps) Differential (Qc)	0.5 – 32 in Hg 0.5 – 100 in Hg	0.003% of FS + 0.005% of reading 0.003% of FS + 0.005% of reading
<b>VACUUM</b>	1 E-7 – 1 E-4 Torr	± 4.0% of reading (k=2)
<b>LEAK</b>		
Standard Leak Artifact	1 E-7 std cc/s 1 E-8 std cc/s 1 E-9 std cc/s	± 10.1% of reading (k=2) ± 10.0% of reading (k=2) ± 10.4% of reading (k=2)

**PHYSICAL**

Discipline	Range	Measurement Uncertainty
<b>TEMPERATURE</b> Bath Calibration Blackbody Source Electrical Substitution LN2 Comparison Calibrator	-60 – 400° C 50 – 1100° C -270 – 2300° C -196° C	± 0.005° C ± 0.5° C ± 0.02% ±0.005°C
<b>HUMIDITY</b> Dewpoint Relative Humidity	-80 - + 20° C 20 – 90% RH	± 0.2° C ± 0.5% RH
<b>GAS ANALYZERS</b> Oxygen Analyzers	8, 90, 100, 500 ppm 10%, 15%, 20%	± 2% of reading ± 2% of range
<b>AIR VELOCITY</b> Thermal Anemometers  Vane Anemometers	50 – 250 ft/min 250 – 1500 ft/min 1500 – 6000 ft/min  50 – 4000 ft/min	± (2% reading + 2 ft) ± (2% reading + 5 ft) ± (1% reading + 15 ft)  ± (1% reading + 1 ft)
<b>pH</b>	4, 7, and 10 pH	± 0.024 pH (k=2)
<b>CONDUCTIVITY</b>	1,000 – 10,000 & 100,000µS/cm	± 2% at 25° C
<b>NUCLEAR RADIATION</b> Gamma Radiation	0.21 – 1500 milliroentgens/hr	± 5.0% of reading

**DIMENSIONAL**

Discipline	Range	Measurement Uncertainty
<b>LENGTH</b>		
Gage Blocks	<0.250 in 0.250 – 4.000 in 5.000 – 20.000 in	$\pm 3.4\mu$ in $\pm 2.2$ in $\pm 0.93$ ppm $5\mu$ in 1 ppm
Cylindrical Ring Gages	0.10 – 6 in	$10\mu$ in $\pm 1$ ppm
Cylindrical Plug Gages	0.01 – 6 in	$5\mu$ in $\pm 1$ ppm
Outside Micrometers	0.5 – 20 in (any inch)	$\pm 0.00005$ in
Inside Micrometers	0.1 – 6 in (any inch)	$\pm 0.0001$ in
Vernier Gages	0.01 – 36 in (any inch)	$\pm 0.0001$ in
Measuring Microscopes	0.01 – 3.0 in (Glass scale)	$\pm 0.0001$ in
Coordinating Measuring Machines	Scales to 17 in Ball Bar Test	$\pm 0.00001$ in $\pm 1.7$ ppm $\pm 0.0001$ in
Thread Plug & Set Gages	4 – 80 pitch	$\pm 0.00005$ in
Thread Wires	4 – 80 pitch	$\pm 10.8\mu$ in
Scales (metal)	Up to 12 ft	$\pm 0.0003$ in / ft
<b>SURFACE ROUGHNESS</b>		
Surface Roughness Systems	0.000001 – 0.0001 in Ra 0.0001 – 0.001 in Ra	$\pm 0.000001$ in Ra $\pm 0.000004$ in Ra
Surface Roughness Standards	0.000001 – 0.0001 in Ra 0.0001 – 0.001 in Ra	$\pm 3.4\%$ $\pm 3.4\%$
<b>ROUNDNESS</b>		
Cylindrical Squares	0.5 – 6 in	$\pm 11.6\mu$ in
<b>FLATNESS</b>		
Optical Flats	All Standard Sizes (Plano-Interferometer)	$\pm 0.63\mu$
Surface Plates Plate/Anvils	All Standard Sizes All via Electronic Height Gage and AA Surface Plate	0.000060 in / ft $\pm 0.00005$ in
<b>OPTICAL-DIMENSIONAL</b>		
Theodolites	0 – 360 degrees	$\pm 2$ arcsec
Jig Transits	0 – 360 degrees	$\pm 5$ arcsec

**DIMENSIONAL**

Discipline	Range	Measurement Uncertainty
<b>ANGLE</b>		
Angle Gage Blocks	1 sec – 45 degrees	± 0.54 arcsec
Rotary Tables	0 – 360 degrees	± 0.63 arcsec
Autocollimators	0 – 20 arcmin	± 0.2 % of reading
Levels	0 – 20 arcsec	± 0.5 arcsec
Sine Bars	0 – 20 arcmin	± 0.5 arcsec
Optical Cubes	90 degrees	± 1.6 arcsec
12 Sided Optical Polygons	0 – 360 degrees	± 0.5 arcsec
<b>HARDNESS</b>		
Rockwell Hardness	0.1 – 100 pts Rc	± 1.0 -2.0 pts Rc *
Testers	(B, C, E, N, & T Scales)	varies with test specimen
* Traceable to NIST via Force, rate of application and depth. (Wilson Test Specimens)		

**ELECTRO-OPTICS/FIBER OPTICS**

<b>Discipline</b>	<b>Range</b>	<b>Measurement Uncertainty</b>
<b>LASER POWER</b>		
Laser Power Meter	632.8 nm	± 1.09%
Laser Power Meter (Electrical Substitution)	10 $\mu$ W – 3 mW Flat Response 1 mW – 50 W	± 0.5%
<b>SPECTRAL RESPONSIVITY</b>		
	200nm	± 6.0%
	205nm - 215nm	± 4.0%
	220nm – 260nm	± 1.2%
	265nm – 345nm	± 1.1%
	350nm – 380nm	± 0.50%
	385nm – 450nm	± 0.35%
	455nm – 950nm	± 0.20%
	955nm – 1000nm	± 0.78%
	1005nm – 1050nm	± 1.50%
	1055nm – 1100nm	± 2.5%
<b>PHOTOGRAPHIC STEP TABLET</b>		
Optical Density	0.05 OD – 4.3 OD	± 0.02 O.D. or ± 1.1%
<b>DENSITOMETERS</b>		
Optical Density	0.05 OD – 4.3 OD	± 0.02 O.D. or ± 1.1%
<b>NEUTRAL DENSITY FILTERS</b>		
Optical Density	0.01 OD – 10.0 OD	± 0.005 OD
<b>COLOR FILTERS / INTERFERENCE</b>		
Transmission	300nm – 1700nm	See Spectral Irradiance
<b>PHOTOMETRY</b>		
Illuminance (footcandle)	0.5 fc - 4000 fc	± 1.45%
Illuminance (Lux)	5 Lux - 43000 Lux	± 1.45%
Luminance (footlambert)	1 fl - 500 fl	± 1.52%
Luminance (cd/m <sup>2</sup> )	3.426 cd/m <sup>2</sup> - 1700 cd/m <sup>2</sup>	± 1.52%
<b>COLORIMETRY</b>		
Chromaticity coordinates	432nm - 647nm	± 1.0 nm
<b>ULTRA-VIOLET (UVA)</b>		
Irradiance, 365nm	1 $\mu$ W/cm <sup>2</sup> - 28 mW/cm <sup>2</sup>	± 1.94%

**ELECTRO-OPTICS/FIBER OPTICS**

<b>Discipline</b>	<b>Range</b>	<b>Measurement Uncertainty</b>
<b>SPECTRAL IRRADIANCE</b>	300nm – 500nm	± 1.83%
	500nm – 750nm	± 1.56%
	750nm – 1100nm	± 2.05%
	1100nm – 1500nm	± 1.89%
	1500nm – 1700nm	± 2.26%
<b>FIBER OPTIC</b>		
F/O Power Meter		
Accuracy	FP 860 nm,	± 1.23%
Single Mode, Multi-Mode	-5 – -50dBm	
	FP 1303nm,	± 1.18%
	-5 – -50dBm	
	FP 1545nm,	± 1.17%
	-5 – -50dBm	
	DFB 1450nm – 1550nm,	± 1.17%
	+3 – -50dBm	
F/O Laser Source		
Output Power	600nm – 1550nm	± 1.18%
Single Mode, Multi-Mode	+10 – -50dBm	
Wavelength Accuracy	600nm – 700nm	± 0.16%
	700nm – 1650nm	± 0.0003%
F/O Attenuator		
Accuracy	0dB – -60dB	± 0.01dB
(see power meter wavelengths)		
Insertion Loss	0dB – -60dB	± 0.08dB
Repeatability	0dB – -60dB	± 0.008dB
F/O Optical / Electrical Converter		(Call for specific capability)
Power monitor	1303nm	± 1.18%
Pulse Width	1300nm	≤ 40ps
F/O Optical Spectrum Analyzer		
Wavelength	632.8nm	Natural Physical Constant
	860nm, 1450 – 1550nm	± 0.0003%
Amplitude	632.8nm / 860nm, 1450 – 1550nm	± 1.18%
<b>GLOSS / REFLECTANCE</b>		
Specular Gloss	1.5 GU – 30.3 GU	± 2 GU
	6.9 GU – 40.7 GU	± 2 GU
	85.8 GU – 99.3 GU	± 1 GU
<b>ACCOUSTICS</b>		
Sound Level Meter (type0,1,2)		
A,B,C,Lin weighting Accuracy	110dB	ANSI S1.6-1967, ± 0.11 dB
(125Hz – 2000Hz)		
Linearity	-80 dB – 130 dB	± 0.11 dB
Sound Pressure Level Calibrators		
Sound Pressure Level	-80 dB – 130 dB	± 0.11 dB
Frequency	125Hz – 2000Hz	± 0.01%
Distortion (THD)	-80 – 0 dB (.01 to 100%)	± 1.0 dB

**SPECIAL ENGINEERING CAPABILITIES**

<b>PHASE NOISE</b>	
Automated Phase Noise	Fully automated Phase Noise measurements are performed using the HP/Agilent E5504 system supplemented by the HP/Agilent 8566B. The HP/Agilent E5504 covers the base band ranges: 0.01 Hz to 100 MHz. The HP/Agilent 8566B is used to extend the base band range to 800 MHz.
Two Oscillator Technique	RF frequency is limited by the availability of a reference oscillator. The HP/Agilent 8663A/70427A is used at RF frequencies to 26.5 GHz. Capability is enhanced if better reference oscillators are provided. State-of-the-art 5 MHz oscillators are available offering – 128 dBc/Hz at 1 Hz Fourier frequency.
Single Oscillator	Variations of the Single Oscillator (FM Discriminator) can measure at RF frequencies from 200 MHz to the millimeter wave, waveguide bands.

***\* Measurement uncertainties for special measurements shown vary with test and/or test configuration.***

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