

## **Digiquartz® Pressure Instrumentation**

### **Background**

Paroscientific is the leader in the field of high-accuracy pressure measurement.

The company was founded in 1972 by Jerome M. Paros after a decade of research on digital force sensors. Application of this technology to the pressure instrumentation field resulted in transducers of the highest quality and superior performance.

Precision comparable to the best primary standards is achieved through the use of a special quartz crystal resonator whose frequency of oscillation varies with pressure-induced stress. A quartz crystal temperature signal is provided to thermally compensate the calculated pressure and achieve high accuracy over a wide range of temperatures.

### **Digiquartz® Pressure Instrumentation**

Paroscientific manufactures and sells a complete line of high-precision pressure instrumentation. Resolution of up to one part-per-billion of full scale and typical accuracy of 0.01% of full scale are achieved even under difficult environmental conditions. Other desirable characteristics include high reliability, low power consumption, and excellent long-term stability.

Over 30 full scale pressure ranges are available - from a fraction of an atmosphere to thousands of atmospheres (+/-2 psig to 40,000 psia). Absolute and gauge transducers have been packaged in a variety of configurations including intelligent transmitters, depth sensors, laboratory and portable standards, meteorological measurement systems and water level systems. Intelligent electronics have two-way digital interfaces that allow the user to adjust sample rates, resolution, engineering units and other operational parameters.

The Digiquartz® products are successfully used in such diverse fields as metrology, oceanography, meteorology, process control, aerospace, energy exploration and laboratory instrumentation.

### **Advantages of Digital Technology**

The use of digital pressure transducers has grown dramatically with the trend towards digital data-acquisition and control systems. Inherently digital sensors such as frequency output devices have been combined with microprocessor based systems to provide unparalleled accuracy and performance, even under extreme environmental conditions. The design and performance requirements of these advanced transducers include:

1. Digital output
2. Accuracy comparable to primary standards
3. Highly reliable and simple design
4. Insensitivity to environmental factors
5. Minimum size, weight and power consumption
6. Ease and utility of readout

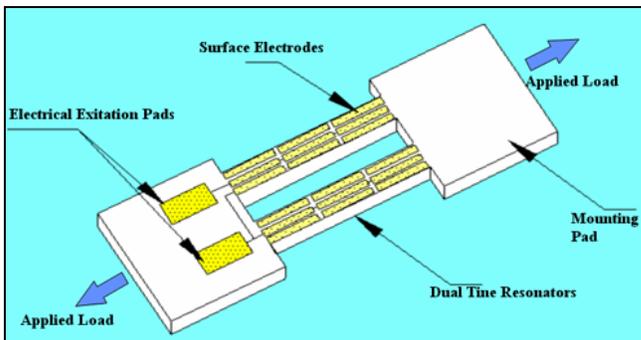
True digital sensors have a great advantage in resolution and accuracy over traditional analog devices because more precise measurements can be made in the time domain. Digital-type signals are also less susceptible to interference, easier to transmit over long distances, and readily interface to counter-timers, telemetry and digital computer systems.

### Digiquartz® Pressure Sensing Technology

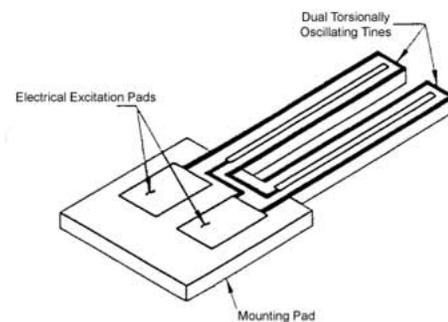
Accuracy, stability, and reliable performance under difficult environmental conditions are the key performance requirement for precision pressure instrumentation. Accuracy and stability are required to ensure data quality. Instrumentation reliability directly affects network data integrity as well as operating costs.

The superior performance of the Digiquartz instruments is achieved through the use of a precision quartz crystal resonator whose frequency of oscillation varies with pressure-induced stress. Quartz crystals were chosen for the sensing elements because of their remarkable repeatability, low hysteresis, and excellent stability. The resonant frequency outputs are maintained and detected with oscillator electronics similar to those used in precision clocks and counters.

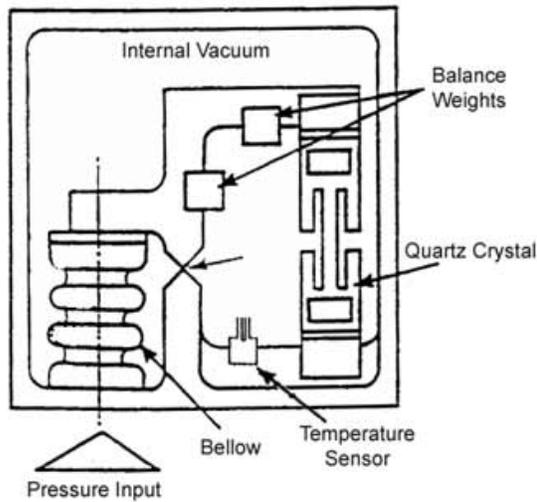
Flexurally-vibrating, single or dual beam, load-sensitive resonators have been developed. The double-ended tuning fork consists of two identical beams driven piezoelectrically in 180° phase opposition such that very little energy is transmitted to the mounting pads. The high-Q resonant frequency, like tuning a violin string, is a function of the applied load: increasing with tension and decreasing with compressive forces. The digital temperature sensor consists of piezoelectrically-driven, torsionally-oscillating tines whose resonant frequency is a function of temperature. Its output is used to thermally compensate the calculated pressure and achieve high accuracy over a wide range of temperatures.



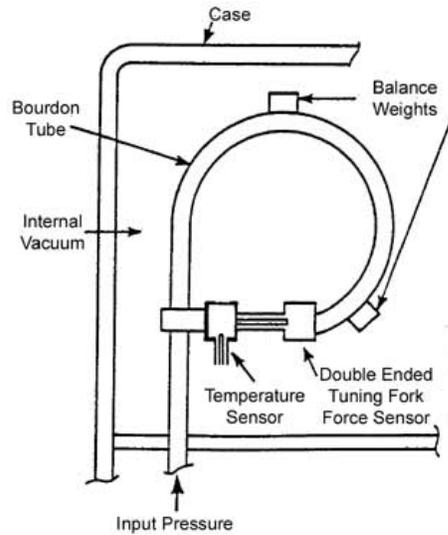
**Force-Sensing Quartz Crystal**



**Temperature-Sensing Quartz Crystal**



**Digiquartz® Low Pressure Sensor**



**Digiquartz® High Pressure Sensor**

Pressure transducer mechanisms employ bellows or Bourdon tubes as the pressure-to-load generators. Pressure acts on the effective area of the bellows to generate a force and torque about the pivot and compressively stress the resonator. The change in frequency of the quartz crystal oscillator is a measure of the applied pressure. Similarly, pressure applied to the Bourdon tube generates an uncoiling force that applies tension to the quartz crystal. Temperature sensitive crystals are used for thermal compensation. The mechanisms are acceleration compensated with balance weights to reduce the effects of orientation sensitivity. The transducers are hermetically sealed and evacuated to eliminate air damping and maximize the Q of the resonators. The internal vacuum also serves as an excellent reference for the absolute pressure transducer configurations.

Microprocessor-based intelligent electronics are available with highly stable TCXO counter-timer circuitry to measure transducer frequency or period outputs, and to store the linearization and thermal compensation algorithm, calibration coefficients, and command and control software that process the outputs in a variety of digital formats.

Paroscientific Intelligent Transmitters consist of a Digiquartz® Pressure Transducer and a digital interface board in an integral package. Commands and data requests are sent via two-way RS-232 or RS-485 serial interfaces. Digital outputs are provided directly in engineering units with typical accuracy of 0.01% over a wide temperature range. Output pressure is fully thermally compensated using a quartz crystal temperature signal. All intelligent transmitters are preprogrammed with calibration coefficients.

Dual RS-232 and RS-485 interfaces allow complete remote configuration and control of all operating parameters, including resolution, sample rate, choice of engineering units, integration time, and sampling requests. The commands include: Single sample and send, synchronized sample and hold, continuous sample and send, and special burst sampling modes. Starting with firmware revision R5.10 (M3.0, MET4/4A) or later it is now possible to achieve parts-per-billion resolution. This feature is also enabled by software command. When disabled, the sensor is backward compatible and works in the standard mode with typical parts-per-million resolution. Nano-resolution is achieved by sub-sampling pressure at

a much higher rate (typically 8 kHz) and applying digital signal processing techniques using an IIR (infinite impulse response) filter.

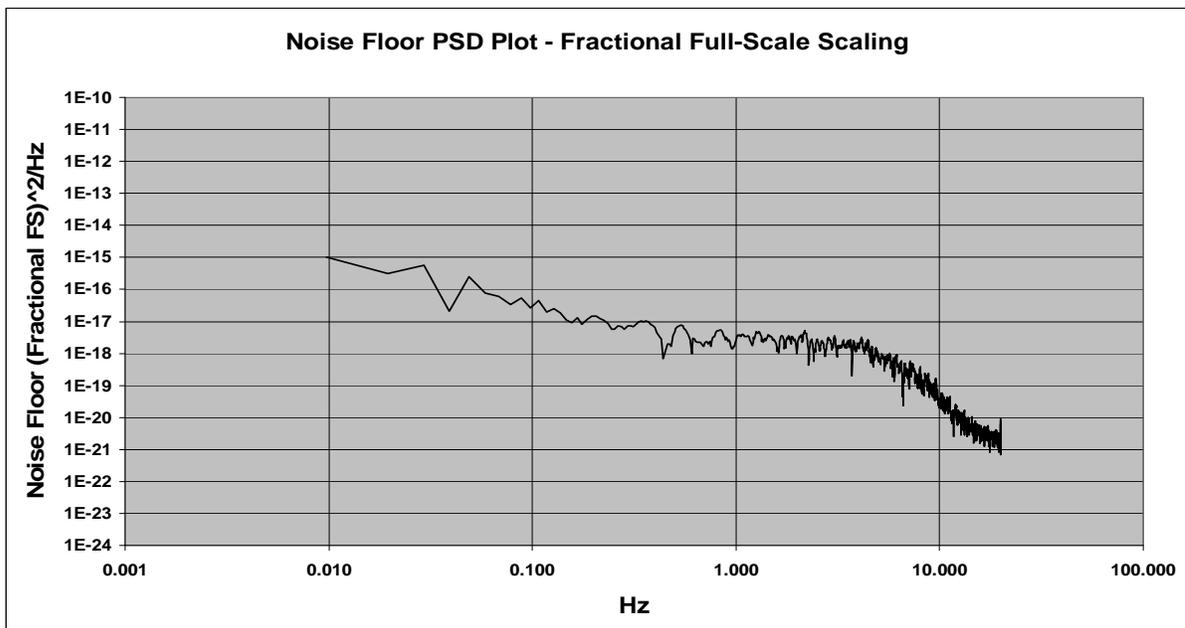
Additional features include support for serial loop and multi-drop networking, user-selectable baud rates up to 115,200 baud, synchronization of measurements with time-based integration, 2 or 4 wire RS-485 with transmission distances greater than 1 kilometer, improved high-speed continuous pressure measurements, a power management “sleep” mode, data formatting features, and unit identification commands.

## Performance

Digiquartz® products are the highest resolution, lowest noise, and most accurate instruments available today. The transducers are based on the inherently digital, highly stable, vibrating quartz crystal technology developed by Paroscientific over the last four decades. They are designed and tested to deliver outstanding performance even under difficult field conditions. Although many applications require both high resolution and accuracy, short-term measurements generally benefit from our high pressure sensitivity while longer term measurements need our accuracy, stability, and insensitivity to environmental errors.

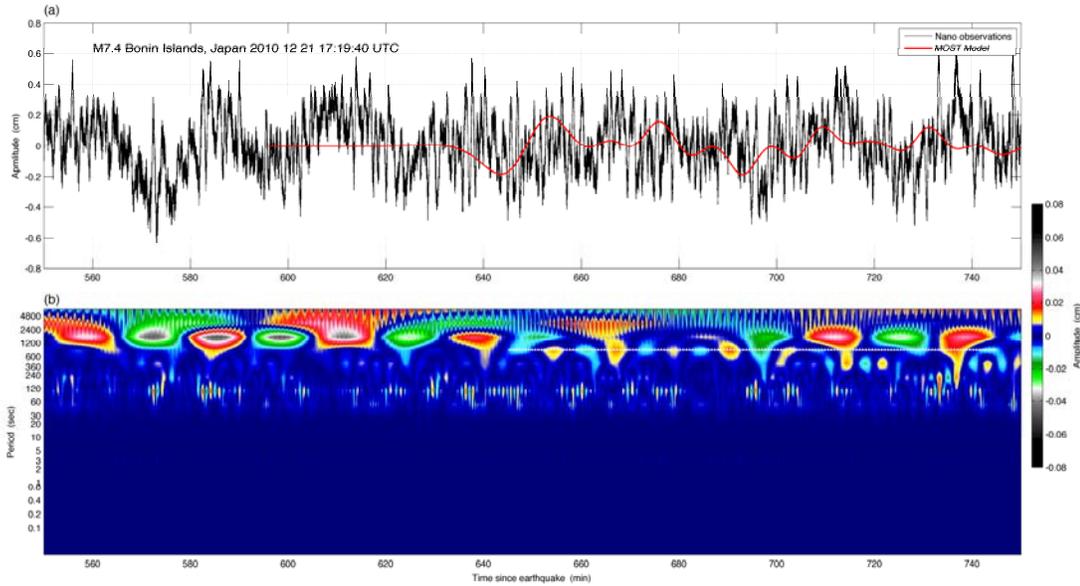
### a. High Resolution

With a sensor of inadequate resolution, real signals can be obscured by noise, or sensor noise can be interpreted as real signals. Paroscientific transducer mechanisms, oscillator circuits, and digital interfaces are carefully designed for ultra-high resolution. Nano-Resolution, (parts-per-billion sensitivity) is available with all Paroscientific intelligent products. The noise floor of Quartz Crystal Sensors is shown below for an isolated quartz crystal.



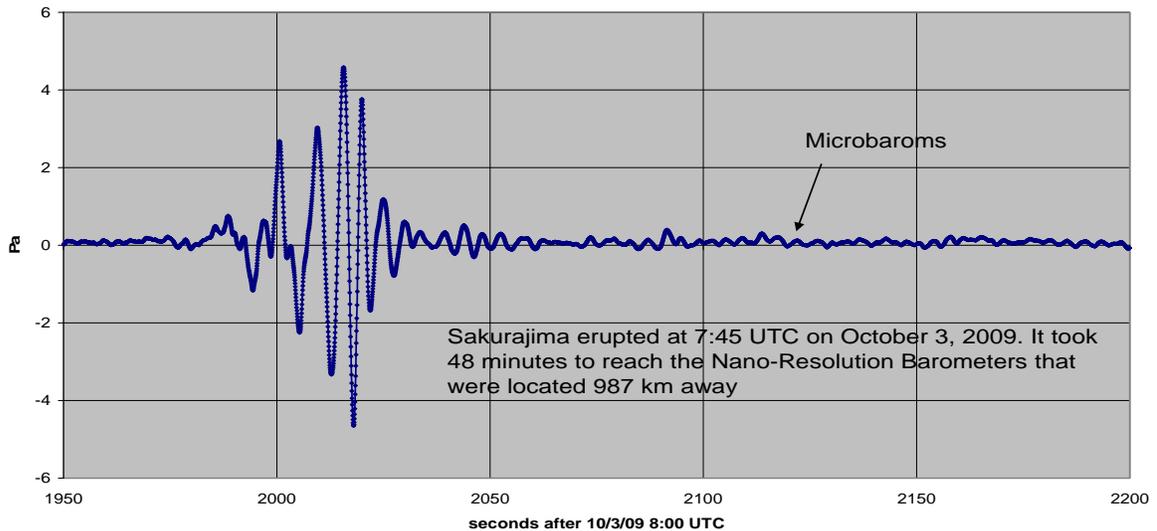
Applications where it is important to measure extremely small pressure changes include tsunami detection in the ocean and land-based infrasound detection of tsunamis, severe weather, volcanic eruptions, avalanches, wind shear, wake-turbulence, and bolides. Examples of high resolution measurements using high-range absolute sensors follow.

A micro-tsunami was recorded by the nano-resolution pressure sensor on December 21, 2010 (M7.4 Bonin Island earthquake). Using wavelet analysis, a spectrogram was computed for the tsunami (see Figure 6). The cutoff period for tide removal is 1 hour, using Butterworth filters. Note the color scale in the plot was set to emphasize the tsunami, so the high frequency components are muted. The red line in the upper panel is the modeled tsunami amplitude time series. The tsunami appears from 645-745 minutes (indicated by white dashed line) with a period of about 14 minutes. The maximum tsunami amplitude is about 0.2 cm.



On 3 October 2009, an eruption of Sakurajima Volcano generated infrasound signals that were measured 987 km away at a nuclear test monitoring site. Note that ocean-generated microbarom signals with amplitudes of 0.1 Pa were measured with a sensitivity of 0.0003 Pa before and after the eruption.

**Sakurajima Eruption 10/3/09 7:45 UTC**  
**Station IS30 S/N 111244 Bandwidth 0.05 - 1.4 Hz**



On April 20, 2010 the Space Shuttle re-entered the atmosphere over Vancouver Island in British Columbia, Canada. Figure 9 above shows the pressure signal measured from a location in West Seattle, approximately 150 miles away. The pressure change shown is the typical N-Wave that is generated from supersonic flight

**Space Shuttle Infrasonic Pressure Signature**  
 Measured with Paroscientific Nano-Resolution Barometers  
 West Seattle, WA USA--Location: 47 34 44 N 122 22 47 W

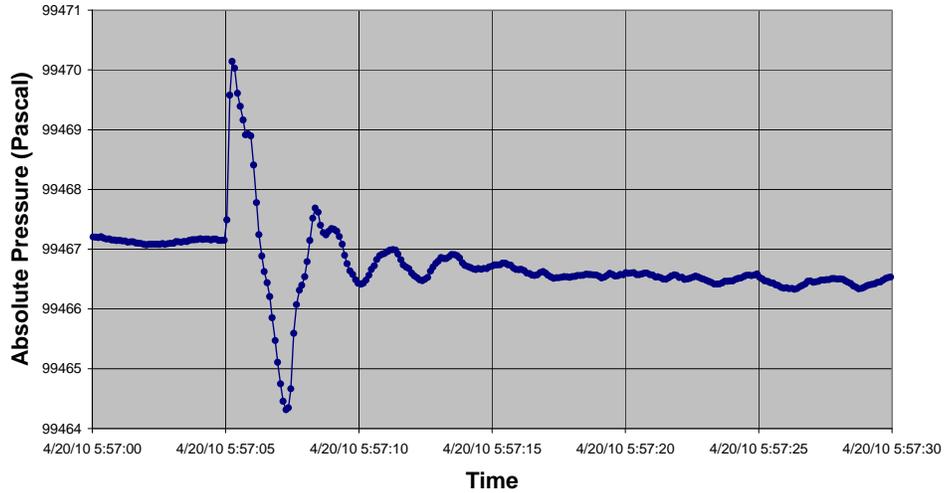
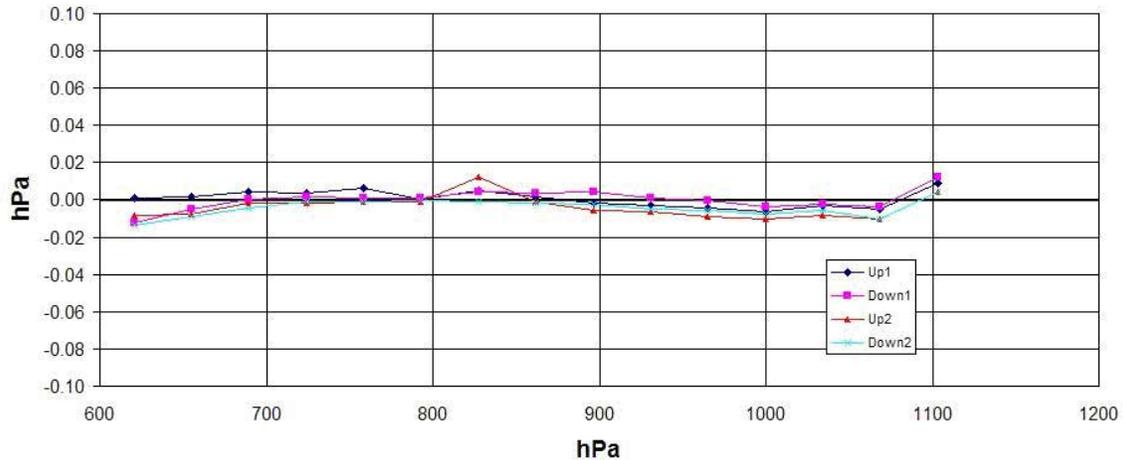


Figure 9

b. Static Error Band

Typical accuracy of Digiquartz® Instruments is 0.01% of full scale or better. Accuracy relative to the primary standard includes resolution, hysteresis, non-repeatability and non-conformance. Digiquartz® Instruments are calibrated across a wide operating temperature and accuracy does not degrade as temperature changes.

**Static Error Band**  
 (Including Repeatability, Hysteresis, Conformance)

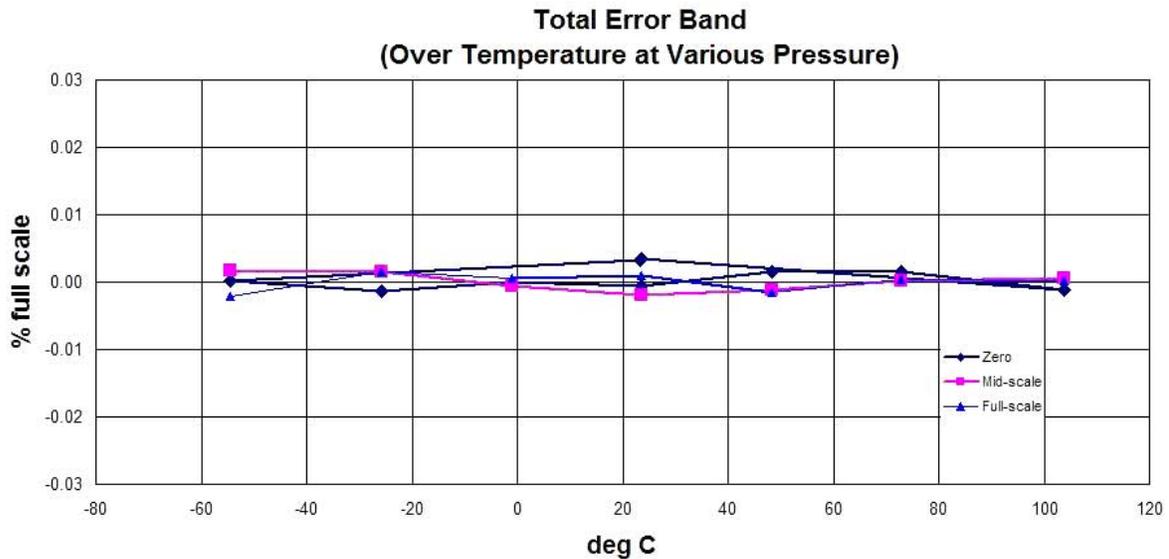


Typical static error band for Digiquartz® Instruments is achieved after meticulous testing and calibration. Calibration is performed by applying known pressure from primary standards to manifolds of transducers mounted in temperature chambers. Two frequency (or period) output signals are sent from each transducer. Pressure is measured with a force-sensitive quartz crystal whose output period changes with applied load. A second period output comes from a quartz crystal temperature sensor used for thermal compensation. The manifold of transducer signals are multiplexed, measured, and the data fit to derive coefficients for the standard equation that characterizes the transducers. The calibration coefficients are provided with each transducer and the indicated pressure (calculated) will agree with the “true” applied pressure with a typical accuracy of 0.01 percent of transducer full scale over the full operational range of pressure and temperatures. Digiquartz® Intelligent Transmitters store the calibration coefficients in non-volatile EEPROM to provide fully temperature-compensated and linearized outputs on the bi-directional RS-232 and RS-485 interfaces.

c. Environmentally Rugged and Reliable

Digiquartz® Instruments are carefully calibrated and temperature-compensated over a broad temperature range. They are also designed to survive extremes of shock and vibration with accurate, reliable measurements. Paroscientific transducers have been used in a variety of applications from deep space probes to ocean bottom deployments.

All Digiquartz transducers have an internal quartz temperature sensor whose output is used to thermally compensate the calculated pressure and achieve high accuracy over a wide range of temperatures.



**Temperature Conformance of a Typical Digiquartz® Instrument**

The temperature conformance plot above shows the closeness of the indicated pressure to the applied pressure at different temperatures over the full operational range of pressures and temperatures.

d. Low Cost of Ownership

Digiquartz® products provide a low total-cost-of-ownership. The long-term stability of Digiquartz® products reduces recalibration intervals and operational costs. Ease of use reduces the need for extensive training. Reliable operation eliminates excessive product purchases, repair costs and loss of revenues due to process interruptions.

**Quality Assurance and Test**

Paroscientific, Inc., maintains a Quality Management System that is certified to the requirements of the ISO 9001 International Quality Standard. All calibrations performed at Paroscientific, Inc. are traceable to the National Institute of Standards and Technology (NIST) Our quality system and commitment to excellence ensure our customers of outstanding products and services.

**Facilities**

The Paroscientific Inc. headquarters and manufacturing facility are located in an award-winning building in Redmond, Washington USA. This facility contains all of the sophisticated manufacturing and test equipment necessary to produce the world's most accurate pressure instrumentation including electron-beam, laser, resistance and pulsed TIG welders, vacuum deposition machines, mass spectrometer leak detectors, specialized quartz crystal and pressure transducer fabrication and test stations, high-vacuum evacuation and bake-out equipment, environmental test chambers, primary standards, and automated test stands.



Paroscientific Facility in Redmond, WA



Weld Room (TIG, Laser, Electron)



Manufacturing Area



Calibration Laboratory

## **Warranties, Service and Support**

Paroscientific Inc. provides world-class products, service and quality. We offer a 5-year limited warranty on all of our pressure transducers including a 3-year stability warranty on all barometric products and a free 2-year zero adjustment with a calibration certificate traceable to NIST on all absolute pressure instruments (<1000 psia).

Product and application support including technical reports and free software are available on our web site at [www.paroscientific.com](http://www.paroscientific.com). Paroscientific sells direct in the USA and world-wide through the International Representative Network listed on our web site. Please contact us at [support@paroscientific.com](mailto:support@paroscientific.com) or call us at (425) 883-8700 for our **Personal Pressure Search Engine Support**.

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