**Tipo de Documento**: Tutorial
**Soportado por NI**: Sí
**Fecha de Publicación**: 28-oct-2008

# Measuring Pressure with Pressure Sensors

### Visión General

This tutorial is part of the National Instruments Measurement Fundamentals series. Each tutorial in this series will teach you a specific topic of common measurement applications by explaining theoretical concepts and providing practical examples. This tutorial introduces and explains the concepts and techniques of measuring pressure with pressure sensors.

For more in-depth guidance on making pressure measurements, visit the how-to guide.

To find more information on the Measurement Fundamentals series, return to the NI Measurement Fundamentals Main Page.

### Contenido



### What is Pressure?

Pressure is defined as force per unit area that a fluid exerts on its surroundings.[1] For example, pressure, P, is a function of force, F, and area, A.

$$P = F/A$$

A container full of gas contains innumerable atoms and molecules that are constantly bouncing of its walls. The pressure would be the average force of these atoms and molecules on its walls per unit of area of the container. Moreover, pressure does not have to be measured along the wall of a container but rather can be measured as the force per unit area along any plane. Air pressure, for example, is a function of the weight of the air pushing down on Earth. Thus, as the altitude increases, pressure decreases. Similarly, as a scuba diver or submarine dives deeper into the ocean, the pressure increases.

The SI unit for pressure is the Pascal (N/m2), but other common units of pressure include pounds per square inch (PSI), atmospheres (atm), bars, inches of mercury (in Hg), and millimeters of mercury (mm Hg).

A pressure measurement can be described as either static or dynamic. The pressure in cases where no motion is occurring is referred to as *static* pressure. Examples of static pressure include the pressure of the air inside a balloon or water inside a basin. Often times, the motion of a fluid changes the force applied to its surroundings. Such a pressure measurement is known as dynamic pressure measurement. For example, the pressure inside a balloon or at the bottom of a water basin would change as air is let out of the balloon or as water is poured out of the basin.

*Head pressure*(or pressure head) measures the static pressure of a liquid in a tank or a pipe. Head pressure, P, is a function solely on the height, h, of the liquid and weight density, w, of the liquid being measured as shown in Figure 1 below.

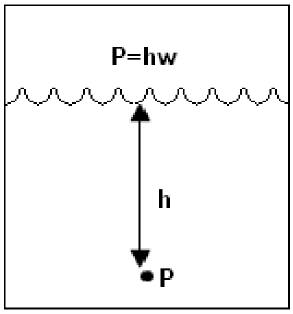



**Figure 1. Head Pressure Measurement**

The pressure on a scuba diver swimming in the ocean would be the diver's depth multiplied by weight of the ocean (64 pounds per cubic foot). A scuba diver diving 33 feet into the ocean would have 2112 pounds of water on every square foot of his body. The translates to 14.7 PSI. Interestingly enough, the atmospheric pressure of the air at sea level is also 14.7 PSI or 1 atm. Thus, 33 feet of water create as much pressure as 5 miles of air! The total pressure on a scuba diver 33 feet deep ocean would be the combined pressure caused by the weight of the air *and* the water and would be 29.4 PSI or 2 atm.

A pressure measurement can further be described by the type of measurement being performed. There are three types of pressure measurements: absolute, gauge, and differential. Absolute pressure measurement is measured relative to a vacuum as showing in Figure 2 below. Often times, the abbreviations PAA (Pascals Absolute) or PSIA (Pounds per Square Inch Absolute) are use to describe absolute pressure.

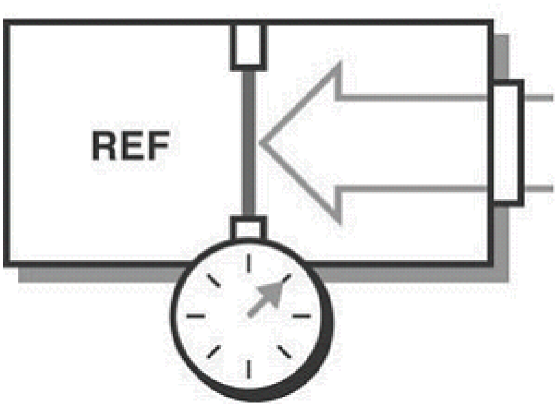



**Figure 2. Absolute Pressure Sensor [3]**

Gauge pressure is measured relative to ambient atmospheric pressure as shown in Figure 3. Similar to absolute pressure, the abbreviations PAG (Pascals Gauge) or PSIA (Pounds per Square Inch Gauge) are use to describe gauge pressure.

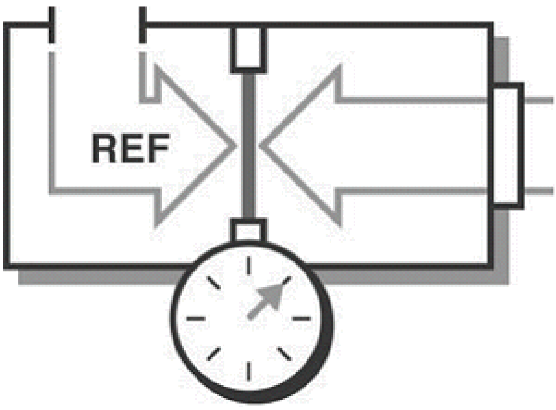



**Figure 3. Gauge Pressure Sensor [3]**

Differential pressure is similar to gauge pressure, but instead of measuring relative to ambient atmospheric pressure, differential measurements are taken with respect to a specific reference pressure as shown in Figure 4. Also, the abbreviations PAD (Pascals Differential) or PSID (Pounds per Square Inch Differential) are use to describe differential pressure.

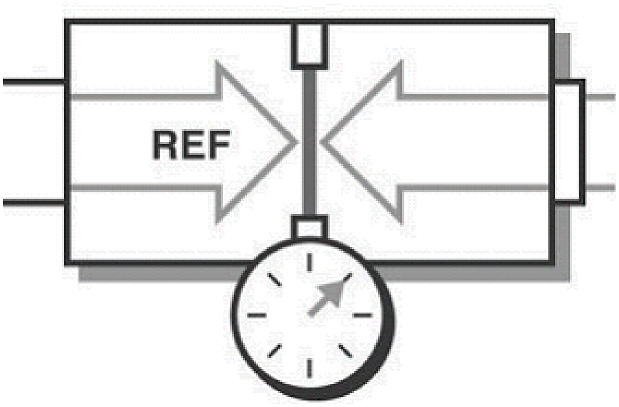



**Figure 4. Differential Pressure Sensor [3]**

**The Pressure Sensor**

Because of the great variety of conditions, ranges, and materials for which pressure must be measured, there are many different types of pressure sensor designs. Often pressure can be converted to some intermediate form, such as displacement. The sensor then converts this displacement into an electrical output such as voltage or current. The three most universal types of pressure transducers of this form are the strain gage, variable capacitance, and piezoelectric.

Of all the pressure sensors, Wheatstone bridge (strain based) sensors are the most common, offering solutions that meet varying accuracy, size, ruggedness, and cost constraints. Bridge sensors are used for high and low pressure applications, and can measure absolute, gauge, or differential pressure. All bridge sensors make use of a strain gage and a diaphragm as seen in Figure 4.

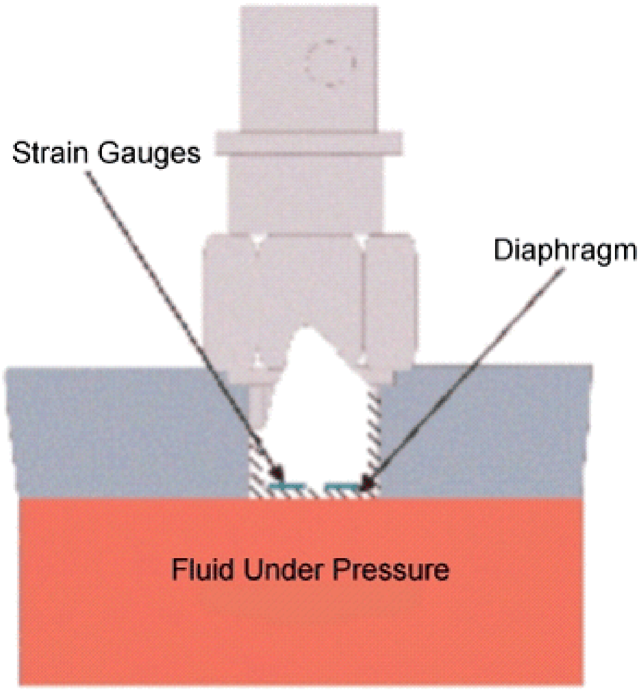



**Figure 4. Cross Section of a Typical Strain Gage Pressure Sensor [3]**

When a change in pressure causes the diaphragm to deflect, a corresponding change in resistance is induced on the strain gauge, which can be measured by a Data Acquisition (DAQ) System. These strain gauge pressure transducers come in several different varieties: the bonded strain gauge, the sputtered strain gauge, and the semiconductor strain gauge.

In the bonded strain gauge pressure sensor, a metal foil strain gauge is actually glued or bonded to the surface where strain is being measured. These bonded foil strain gauges (BFSG) have been the industry standard for years and are continually used because of their quick 1000 Hz response times to changes in pressure as well as their large -452°F to -525°F operating temperature.

Sputtered strain gauge manufacturers sputter deposit a layer of glass onto the diaphragm and then deposit a thing metal film strain gauge on to the transducer’s diaphragm. Sputtered strain gauge sensors actually from a molecular bond between the strain gauge element, the insulating later, and the sensing diaphragm. These gauges are most suitable for long-term use and harsh measurement conditions.

Integrated circuit manufacturers have developed composite pressure sensors that are particularly easy to use. These devices commonly employ a semiconductor diaphragm onto which a semiconductor strain gauge and temperature-compensation sensor have been grown. Appropriate signal conditioning is included in integrated circuit form, providing a dc voltage or current linearly proportional to pressure over a specified range.

The capacitance between two metals plates changes if the distance between these two plates changes. A variable capacitance pressure transducer, seen in Figure 5 below, measures the change in capacitance between a metal diaphragm and a fixed metal plate. These pressure transducers are generally very stable and linear, but are sensitive to high temperatures and are more complicated to setup than most pressure sensors.

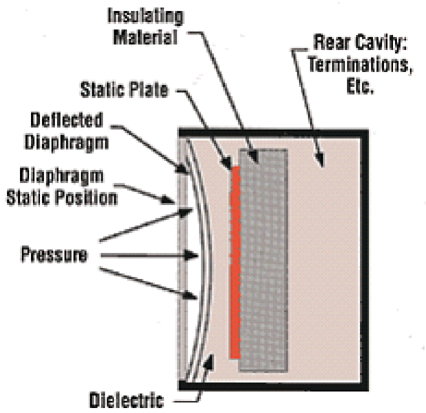



**Figure 5. Capacitance Pressure Transducer [4]**

Piezoelectric pressure transducer, as shown in Figure 6, take advantage of the electrical properties of naturally occurring crystals such as quartz. These crystals generate an electrical charge when they are strained. Piezoelectric pressure sensors do not require an external excitation source and are very rugged. The sensors however, do require charge amplification circuitry and very susceptible to shock and vibration.

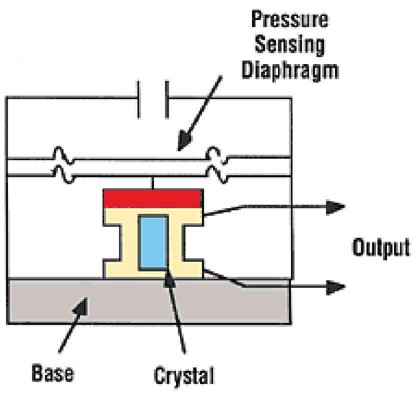



**Figure 6. Piezoelectric Pressure Transducer [4]**

A common cause of sensor failure in pressure measurement applications is dynamic impact, which results in sensor overload. A classic example of overloading a pressure sensor is known as the water hammer phenomenon. This occurs when a fast moving fluid is suddenly stopped by the closing of a valve. The fluid has momentum that is suddenly arrested, which causes a minute stretching of the vessel in which the fluid is constrained. This stretching generates a pressure spike that can damage a pressure sensor. To reduce the effects of “water hammer”, sensors are often mounted with a *snubber* between the sensor and the pressure line. A snubber is usually a mesh filter or sintered material that allows pressurized fluid through but does not allow large volumes of fluid through and therefore prevents pressure spikes in the event of water hammer. A snubber is a good choice to protect your sensor in certain applications, but in many tests the peak impact pressure is the region of interest. In such a case you would want to select a pressure sensor that does not include overprotection. [3]

**Pressure Measurement**

As described above, the natural output of a pressure transducer is a voltage. Most strain based pressure transducers will output a small mV voltage. This small signal requires several signal conditioning considerations that are discussed in the next section. Additionally, many pressure transducers will output a conditioned 0-5V signal or 4-20 mA current. Both of these outputs are linear across the working range of the transducer. For example both 0 V and 4 mA correspond to a 0 pressure measurement. Similarly, 5 volts and 20 mA correspond to the Full Scale Capacity or the maximum pressure the transducer can measure. The 0-5V and 4-20 mA signals can easily be measured by National Instruments Multi-function

Data Acquisition (DAQ) hardware.

See Also:
Data Acquistion (DAQ) Hardware

**Signal Conditioning for Pressure Sensors**

As with any other bridge based sensor, there are several signal conditioning considerations. To ensure accurate bridge measurements, it is important to consider the following:

- Bridge completion
- Excitation
- Remote sensing
- Amplification
- Filtering
- Offset
- Shunt Calibration

Each of these considerations are addressed thoroughly in the Measuring Strain with Strain Gauges tutorial linked below.

Once you have obtained a measurable voltage signal, that signal must be converted to actual units of pressure. Pressure sensors generally produce a linear response across their range of operation, so linearization is often unnecessary, but you will need some hardware or software to convert the voltage output of the sensor into a pressure measurement. The conversion formula you will use depends on the type of sensor you are using, and will be provided by the sensor manufacturer. A typical conversion formula will be a function of the excitation voltage, full scale capacity of the sensor, and a calibration factor.

$$\text{Pressure} = \left(\frac{C_{fs}}{V_{ex}}\right)\left(\frac{V_{meas}}{CF}\right), \text{ where}$$

$C_{fs}$ = Full Scale Capacity - the maximum pressure which the transducer should receive

$V_{ex}$ = Excitation Voltage - the recommended input voltage

$V_{meas}$ = Measured Voltage - the raw voltage returned by the sensor

$CF$ = Calibration Factor - the output of the transducer ,usually expressed in mV per input V

[+] Ampliar Imagen

For example, a pressure trandsducer with a full scale capacity of 10,000 PSI and a calibration factor of 3mv/V and given an excitation voltage of 10V DC produces a measured voltage of 15 mV, the measured pressure would be 5000 PSI.

After you have properly scaled your signal, it is necessary to obtain a proper rest position. Pressure sensors (whether absolute or gauge) have a certain level that is identified as the rest position, or reference position. The strain gauge should produce 0 volts at this position. Offset nulling circuitry adds or removes resistance from one of the legs of the strain gauge to achieve this "balanced" position. Offset nulling is critical to ensure the accuracy of your measurement and for best results should be performed in hardware rather than software.

See Also:
Measuring Strain with Strain Gauges

**DAQ Systems for Pressure Measurements**

**C Series Hardware for a Modular, Flexible System**

National Instruments C Series hardware for strain(bridge) based pressure sensors include two modules with varying specifications and several module carriers to create a flexible, modular system.  The NI 9237 module can measure quarter, half, and full-bridge sensors including pressure sensors.  The NI 9237 is a 4 channel module that samples at 24-bits of resolution and 50kS/s/ch for true simultaneous measurements.  Another C Series module for pressure measurement is the NI 9219 which also measures quarter, half, and full bridge sensors.  The NI 9219 has ch-ch isolation, 24-bit ADCs, and samples at 100S/s/ch.  In addition to bridge measurements, the NI 9219 is a universal module which means it can also measure thermocouples, RTDs, voltage, current, and resistance.  Both the NI 9237 and NI 9219 modules can power strain gages or pressure transducers and both are supported by the USB single module carrier, NI CompactDAQ chassis, and CompactRIO chassis for programming and data storage.

*USB CompactDAQ, CompactRIO, and C Series USB Carrier shown with modules*

Build your own system starting with a recommended bundle at the CompactDAQ Advisor:

Pressure/Strain Starter Set (includes software)

Model Pages:

NI 9237

NI 9219

NI CompactDAQ

NI CompactRIO

C Series Single Module Carrier

**Using SCXI with Pressure Measurements**

National Instruments SCXI is a signal conditioning system for PC-based data acquisition systems as shown in Figure 7. An SCXI system consists of a shielded chassis that houses a combination of signal conditioning input and output modules, which perform a variety of signal conditioning functions. You can connect many different types of sensors, including absolute and gauge pressure sensors, directly to SCXI modules. The SCXI system can operate as a front-end signal conditioning system for PC plug-in data acquisition (DAQ) devices (PCI and PCMCIA) or PXI DAQ modules.

*Product Info:*
The **NI SCXI-1520 8-Channel Universal Strain Gauge Input Module** has programmable excitation, gain, and filter settings

[+] Ampliar Imagen

**Figure 7. A Typical National Instruments SCXI System**

SCXI offers an excellent solution for measuring pressure. The SCXI-1520 universal strain-gauge module is ideal for taking strain based pressure measurements. It provides 8 simultaneous sampled analog input channels each with bridge completion, programmable excitation (0-10 V), remote excitation sensing, programmable gain amplification (1-1000), a programmable 4-pole Butterworth filter (10 Hz, 100 Hz, 1 kHz, 10kHz), offset nulling, and shunt calibration. The SCXI-1314 terminal block provides screw terminals for easy connections to your sensors. Additionally, the SCXI-1314T includes a built-in TEDS reader for Class II bridge-based smart TEDS sensors.

Recommended starter kit for Pressure SCXI DAQ System:

1. SCXI-1600 DAQ module
2. SCXI chassis
3. SCXI-1520 modules and SCXI-1314/SCXI-1314T terminal blocks
4. Refer to ni.com/sensors for recommended sensor vendors

For a customized solution, see the SCXI Advisor linked below.

**Using SC Series DAQ with Strain Based Pressure Sensors**

For high performance integrated DAQ and signal conditioning, the National Instruments PXI-4220 shown in Figure 8, part of the SC Series, provides an excellent measurement solution. SC Series DAQ offers up to 333 kS/s measurements with 16-bit resolution, and combines data acquisition and signal conditioning into one plug in board. The PXI-4220 is a 200 kS/s, 16 bit DAQ board with programmable excitation, gain, and 4-pole Butterworth filter. Each input channel of the PXI-4220 also includes a 9-pin D-Sub connector for easy connection to bridge sensors, and programmable shunt and null calibration circuitry. The PXI-4220 provides the perfect solution for dynamic pressure measurements with low channel counts.

*Product Info:*
The **NI PXI-4220** has dual 16-bit inputs for measuring strain gauges, load cells, and pressure sensors

**Figure 8. National Instruments PXI-4220**

Recommended starter kit for Pressure SC Series DAQ System:

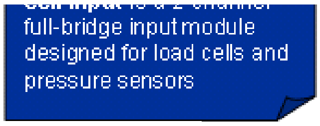
1. PXI chassis
2. PXI embedded controller
3. PXI-4220 modules
4. Refer to ni.com/sensors for recommended sensor vendors

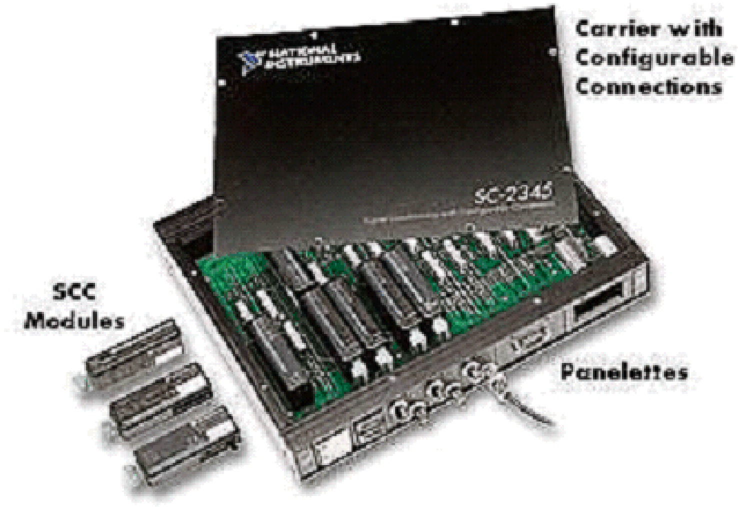
For a customized solution, see the PXI advisor linked below.

**Using SCC with Strain Based Pressure Sensors**

National Instruments SCC provides portable, modular signal conditioning for DAQ system as seen in Figure 9 below. The SCC series provides a great low channel count and low cost solution that directly interfaces to National Instruments M Series DAQ boards. SCC modules can condition a variety of analog I/O and digital I/O signals, including bridge sensors. SCC DAQ systems include an SC Series shielded carrier such as the SC-2345 or the SC-2350, SCC modules, a cable, and a DAQ device. The SC-2350 shielded carrier provides additional support for TEDS sensors.

*Product Info:*
The **NI SCC-SG24 Load Cell Input** is a 2-channel




[+] Ampliar Imagen

**Figure 9. National Instruments SCC Carrier and Modules**

The SCC-SG24 Load Cell Input module accepts up to two full-bridge inputs from load cells or pressure sensors. Each channel of the module includes an instrumentation amplifier, a 1.6 kHz lowpass filter, and a potentiometer for bridge offset nulling. Each SCC-SG24 module also includes a single 10 V excitation source.

Recommended Starter Kit for Pressure SCC DAQ System:

1. M Series DAQ board
2. SC-2345/SC-2350 module carrier
3. SCC-SG24 modules (1 per 2 pressure sensors)
4. Refer to ni.com/sensors for recommended sensor vendors

See Also:
Sensors - Affiliated Product Advisors
SCXI Product Advisor
PXI Product Advisor

**References**

[1] Johnson, Curtis D, “Pressure Principles” *Process Control Instrumentation Technology*, Prentice Hall PTB.
[2] Daytronic.com, “Strain Gauge Pressure Transducers”, http://www.daytronic.com/products/trans/t-presstrans.htm (current November 2003).
[3] Sensotec.com, “Honeywell Sensotec Frequently Asked Questions”, http://www.sensotec.com/pdf/FAQ_092003.pdf (current November 2003).
[4] Sensorsmag.com, "Pressure Measurement: Principles and Practice", http://www.sensorsmag.com/articles/0103/19/main.shtml (current January 2003).

For more tutorials, return to the NI Measurement Fundamentals Main Page.

**Comentarios del Lector | Enviar un comentario »**

Great!, this website is very useful for me. Thanks NI
- 18-may-2008

**Some Mistakes, or Maybe...**
"In the bonded strain gauge pressure sensor, ... as well as their large -452°F to -525°F operating temperature. " -525°F? "Sputtered strain gauge manufacturers sputter deposit a layer of glass onto the diaphragm ... Sputtered strain gauge

sensors actually from a molecular bond ..." I think the word "from" should be "form".
- *Li Chao, CUMT.* lc_crazy2000@hotmail.com - 28-jun-2007

**Small typo**
"Gauge pressure is measured relative to ambient atmospheric pressure as shown in Figure 3. Similar to absolute pressure, the abbreviations PAG (Pascals Gauge) or PSIA (Pounds per Square Inch Gauge) are use to describe gauge pressure." PSIA should be PSIG.
- *Dave Snyder, n/a.* dave-snyder@comcast.net - 14-dic-2006

**good**
this page sounds equally good for all...
- *shameem, aram.* shameemabdulkadar@yahoo.co.in - 23-may-2006

**this site is excellent.**
this web site was good for me because it gave me a rough description on my final year project that required me to study on pressure measurement system on a wind tunnel.thanks.
- bourgon_ville@yahoo.com - 19-dic-2005

**Quick note on "water hammer"**
In "Measuring Pressure with Pressure Sensors" you note: "A classic example of overloading a pressure sensor is known as the water hammer phenomenon. This occurs when a fast moving fluid is suddenly stopped by the closing of a valve. The fluid has momentum that is suddenly arrested, which causes a minute stretching of the vessel in which the fluid is constrained. This stretching generates a pressure spike that can damage a pressure sensor." Actually, when you suddenly stop liquid flowing through a long tube, a shockwave will form and propagate back through the tube transforming forward velocity into pressure as the liquid is shocked to a halt. The "pressure spike" detected is this shockwave. (There are probably many websites that can explain this better than I can.) The stretching of the vessel is secondary. It would be like explaining the "bang" you hear when you pop a balloon is due to the ripping of the rubber. Yes, the balloon rips, but really that's merely a secondary effect to the sudden release of pressurized gas which really generates the sound wave. I appreciate the large, high-quality technical resource base that NI provides its users (easily one of the top reasons many of us continue to use your products) and hope this helps you maintain your high standards.
- *Jeffrey Mach, Sierra Lobo, Inc..* jmach@mail.arc.nasa.gov - 24-ene-2005