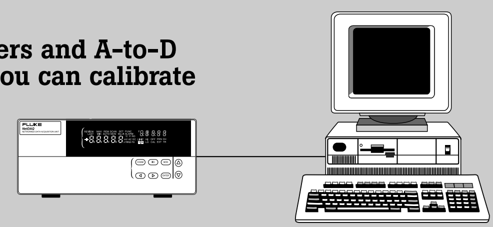
FLUKE®

Measurement Uncertainty and Traceability of PC-Based Data Acquisition Systems

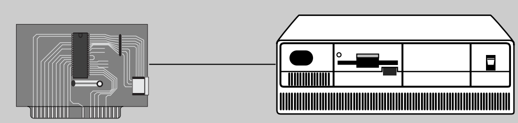
Technical Data

How do you calibrate it?

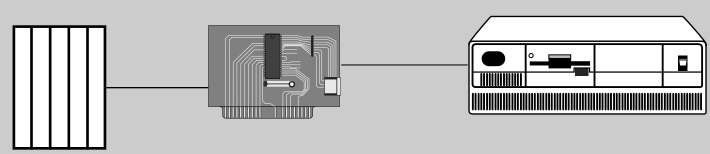
With signal conditioners and A-to-D in same "front-end" you can calibrate with any PC.



With plug-in boards that contain signal conditioners and A-to-D, you can calibrate it, but only in its designated PC.



With plug-in board and external signal conditioners you must calibrate the whole system at the same time.



Calibration and measurement uncertainty problems are often associated with PC-based data acquisition equipment both PC plug-in boards and external front-end chassis. Often with PC-based instrumentation systems, the measurement hardware is calibrated with one PC, then moved back to its "host" PC for actual operation. For the plug-in card, this procedure creates a situation where traceability cannot be reliably maintained due to the uncharacterized condition (inside the host PC) in which the measurements are made. A case can further be made that even if the measurement hardware is calibrated while situated in its host PC, noise conditions experienced during actual operation will not be the same as those experienced during its calibration simply because different software is running on the computer, changing the ways in which the memory and video hardware are used. This again poses the problem of measurement uncertainty that may only ultimately be solved through utilizing measurement devices external to the PC posessing known and controlled measurement environments. Ultimately, it is up to the user to decide how important these issues are in his application.

Background

There was a time when data acquisition was something you did by having a person with a clipboard and pen record the readings from panel meters. Unfortunately, this wasn't handy when you needed to record data every 10 minutes during an overnight test. Also, people make errors when performing this kind of repetitive work.

Things improved about 20 years ago, but even then data acquisition came in only two types:

- Data loggers, which measured the data and printed it on a "grocery tape."
- A rack of equipment under computer control.

The data logger was limited in that it didn't necessarily get the data into your computer for analysis and report generation.

The rack of equipment under computer control usually required you to spend time writing custom software to control all the instruments via IEEE-488 to make it do what you needed.

Today's choices

More recently, the range of choices has increased. The ready availability of desktop computers (PCs) makes it possible to acquire data with a peripheral device connected to the computer. This provides three further possible choices:

- Do you use an external front-end chassis that connects to your PC with a cable or wireless link?
- Do you use a PC board which can be plugged into an expansion slot on the motherboard of your PC?
- Do you use PCMCIA cards which plug into a slot on your laptop computer?

External chassis-based instruments are typically sold on the basis of accuracy, measurement integrity in hostile settings, and the ability to locate the measurement box near the sensors. External chassis-based instruments also tend to be higher priced and limited in speed by their communication link.

Plug-in boards and PCMCIA cards are typically sold on the basis of low cost and high measurement speed, with less attention given to environmental considerations and measurement integrity. Many of the items that enable them to be inexpensive, e.g. using the PC chassis and power supply, mean that they don't have control over key elements that determine measurement data integrity, such as power supply voltage and ripple, RFI and temperature rise.

Resolution and measurement uncertainty

Perhaps your data acquisition task can be satisfied with a digitizer with 12 (or fewer) bits of resolution and input signals in the range of ± 10V dc. If so, you can be pretty casual about how you handle the measurement environment. Since a 12 bit A-to-D converter resolves roughly one part in 4000 and runs off a 5V power supply, it never has to deal with anything smaller than (approximately) 1 mV. While a millivolt is not big, it isn't really small either. However, don't make the mistake of assuming that your system will be accurate to ±0.025% just because the A-to-D converter is. Twelve bit systems are typically accurate to about ±0.1% because there is usually much more error in the signal conditioning, which must deal with much smaller signals ahead of the converter than in the converter itself; we'll get to that later.

Things get trickier if you use a 16 bit A-to-D converter and are measuring thermocouples or low-level sensors. Sixteen bit A-to-D converters must resolve steps that are about 100 microvolts, which is at least 10 times more difficult than the 1 mV resolution of a 12 bit A-to-D converter. The payoff is that 16 bit systems can be made accurate to ±0.01% if the signal conditioning is good enough.

Interpreting accuracy specifications

The two accuracy specification tables below illustrate some interesting differences.

The first table describes the accuracy of two voltage ranges on a measurement front-end from a traditional T&M instrument manufacturer. The accuracy numbers describe the maximum error you will encounter when using the instrument at ambient temperatures between 18°C and 28°C for a stated period of time after calibration. It also tells you that your measurement resolution will be.

The second table describes the accuracy of a PC plug-in card from a typical manufacturer. Notice that most of the accuracy numbers are typical, not maximum. If you dig further, you may find that the maximums are frequently 10 times the typical. The operating temperature specification of "0°C to 70°C" for the PC plug-in card looks impressive, but doesn't bear any relation to the accuracy figures. It simply means that the card will work in that temperature range. Most PC's do not share the operating temperature range of 0°C to 70°C, making this specification even less helpful. If you want to know over what temperature range the card will deliver its specified accuracy or what your PC's measurement resolution will be on the different ranges, you are on your own.

Conclusion

In order to make your decision, you must look at how complete and detailed a specification is. Sometimes they require reading between the lines. As a general rule, a specification from an instrument manufacturer will be more complete because their customers expect it. A specification for a PC plug-in board often reflects the fact that low price is the primary selling feature of the product.

Specifications for a front-end with traceable accuracy

DC Voltage			Accuracy[1] ±(% input + V)		
Range	Resolution		slow		fast
	slow	fast	90 day	1 year	1 year
300 mV	10 µV	100 µV	.026% + 20 µV	.031% + 20 µV	.047% + .2 mV
3V	100 µV	1 mV	.028% + 2 mV	.033% + 2 mV	.05% + .2 mV

[1] Total instrument accuracy for 1 year following calibration (unless otherwise specified). Ambient operation temperature 18°C–28°C. Includes A/D errors, initial calibration error and power line variations. Relative humidity up to 90% non-condensing.

PC plug-in card specifications

Input ranges	±5V or ±3.2768V full scale (jumper selectable)
Input gains	1, 10, 100 (software selectable)
Accuracy gain=1 gain=10 gain=100	±.01% of full scale ±.05% typ ±.05% typ
Input offset	Gain=1, 10 ±1LSB Gain=100 ±10 µV
Operating temp	0 to 70°C or F
Humidity	0 to 95% non-condensing

Going a step farther, if you want to measure a thermocouple with 0.1 degree resolution you need circuitry that amplifies the signal so you can resolve a 4 μV step. These low-level signals are extremely susceptible to noise and other sources of contamination, such as ground loops. It is much harder to maintain signal integrity in these sensitive circuits, called 'signal conditioners,' than it is to accurately digitize the high level signal that comes out of them. Without these circuits, you can't get a useful signal from your sensor into your A-to-D converter.

Signal conditioners

It's easy to think of your PC plug-in card or external chassis as simply digitizing whatever is connected to its inputs. In practice, there's more to it than that. Of course there's an A-to-D converter, but there's also signal conditioning circuitry that amplifies small signals, attenuates large signals, changes AC volts to DC volts, turns resistance into DC volts and generally turns the signals from your sensors into something the A-to-D converter can measure.

In order to calibrate your equipment, you must calibrate both the A-to-D converter and the signal conditioners. Further, in order to know that your calibration is valid in your application, you must ensure that both the digitizer (the A-to-D converter) and the signal conditioners see the same pertinent operating conditions in the application as they saw during calibration. Because all of the signal conditioners (and much of the A-to-D converter) is composed of analog circuitry, they are susceptible to numerous sources of error and interference to which digital circuits are largely immune.

Possible sources of error and interference

The accuracy of analog circuits is susceptible to change with power supply voltage, electromagnetic interference, (EMI) drift with time and changes in temperature, among other things.

External chassis, "front end" instruments that communicate with a PC by means of a cable or wireless link can be characterized and specified for a range of power line voltages, EMI in the operating environment, drift with time and variations in ambient temperature. You have the opportunity, through equipment manuals or product brochures, to compare the conditions for which their accuracy is specified with the conditions that your application imposes and determine whether they will meet your needs.

Of course, not all manufacturers provide this information, but some do. You can generally tell where the manufacturer stands by seeing if their product brochure specifies compliance with FCC class A or B (US standards) for radiated and conducted EMI. If the product doesn't emit excessive EMI, it indicates that considerable care went into the design, and it probably has good immunity to EMI, too. Do they specify an ability to maintain accuracy over a range of power line voltage? Is the accuracy specificied for a useful span of time and over a reasonable ambient temperature range? If these things are not specified, you don't really know what will happen in your actual applications. For example, what will happen when someone uses a walkie-talkie or cellular phone near the equipment or when the building temperature fluctuates while you are running an overnight test?

The situation is less clear with a PC plug-in board. Does it have an accuracy specification that includes time and temperature effects? Is it calibrated before it is shipped? Is its accuracy affected by the power supply voltage of the PC? Do you know if it was calibrated in a PC with the same power supply voltage as yours? Does the power supply voltage of your PC change with power line variations? Is the board designed to tolerate the EMI and the temperature rise inside the average PC? What if your PC is worse than average: how can you tell? Assuming that your PC is pretty average, you may still wonder whether the board will work in the expansion slot that is available. For instance, the expansion slot next to the video interface probably encounters much more EMI than other slots. Certainly, moving the PC plug-in card from one computer to another with a different configuration should raise questions about its calibration. Even moving around the cards in the same PC is somewhat suspect.

The point is that sometimes it's hard to know just what you're getting.

In order to decide which set of criteria matters most to you, ask yourself the following question:

How important is your data?

All of this discussion must be tempered by some consideration for the relative importance of the data that you hope to collect with this system.

If you are collecting some experimental data in a situation where you can confirm your results by other means and the results are not critical to how you do your job, you may not need to worry much about accuracy. You may only be looking for a general indication of what's happening rather than an accurate measurement. In this case, if the data proves to be less than accurate it probably isn't a problem. Perhaps the experiment or test you're doing is easy to reproduce, so questionable results can be clarified by repeating the test.

In the middle of the spectrum, if you are making a measurement that will go into a report to a customer, you need to know that the data is accurate within acceptable limits. If you are making measurements that are used to certify that your end product meets its requirements, you need to know that the data is accurate. If you are researching a theory of how some phenomena interact, you need to know that what you measure is a change in the phenomena rather than a change in the measurement hardware. In this case, if the data is less accurate than expected it will cause embarrassment but may not be catastrophic.

The extreme case, requiring the highest data integrity, arises when you are collecting data to certify that your product or process meets regulatory or contractual requirements. In this case, you must know that the data is accurate and you must be able to prove it to someone else. Proving it to someone else usually requires the ability to demonstrate 'traceability' of the system accuracy to some recognized standards laboratory, such as National Institute of Standards and Technology (NIST) in the US. In this case, a lack of traceable, accurate data may result in a forced recall of your product or other unpleasant legal actions. If the experiment would be expensive or difficult to rerun, you need to know that your data will be good the first time.

The underlying question can be broken into three parts:

- Will the data acquisition hardware and software provide data that is accurate enough to meet the needs of the application?
- Must it continue to do so for a significant length of time? i.e. must it be calibrated and maintained?
- Would your test be expensive to repeat, or will you need to prove the integrity of your data to anyone else?

If the answer is 'yes' to more than one of these questions, a measurement peripheral in an external chassis may do a better job than a PC plug-in board.

Conclusion

Just about everyone asks the following three questions when chosing measurement equipment for use with their PC:

- Does the equipment meet your performance requirements for accuracy, measurement speed and signal conditioning flexibility?
- Is suitable application software available to let you gather your data, analyze and manipulate it as needed?
- Does the cost of ownership fit within your budget?

Asking three additional questions will help ensure the best equipment selection:

- Who is the end user of your data? What are their expectations regarding accuracy and traceability? (Are they minimal or are they strict?)
- Does the manufacturer provide documentation that enables you to know what traceable accuracy the equipment delivers in your application setting?
- Is there a documented calibration strategy for the equipment (including the signal conditioning) that will enable you to maintain it at the required level of accuracy?

It requires planning and understanding of the application to answer the last three questions.

That planning and understanding frequently saves trouble later. When a data acquisition user understands the last three questions, he or she frequently selects measurement peripherals in external chassis rather than plug-in boards.

Data Acquisition Tools
Portable • Wireless • Networked

Fluke measurement specification philosophy

The accuracy specifications for the Hydra and NetDAQ instruments are calculated conservatively so that they include three standard deviations from the nominal value: this is referred to as 3-Sigma. Greater than 99.7% of the instruments produced will perform within the error limits. Rigorous screening and testing procedures catch and correct the 3 out of 1000 instruments which would have fallen outside their published specifications. Many other products use a "root-sum-square" scheme, or only specify the error band within one standard deviation (1-Sigma) of nominal. This method produces a specification that appears to be more accurate, but the resulting "typical" specifications correctly characterize only ~66% of the instruments produced. This method is kind of like knowing how accurate "most of the instruments" will be. Our 3-Sigma specifications tell you how accurate ALL of the instruments will be.

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