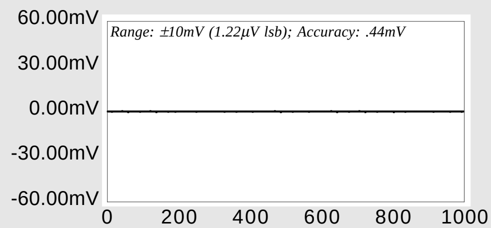
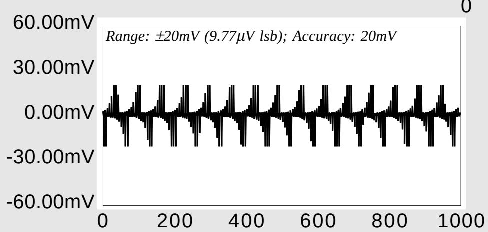
Data Acquisition Hardware Comparison

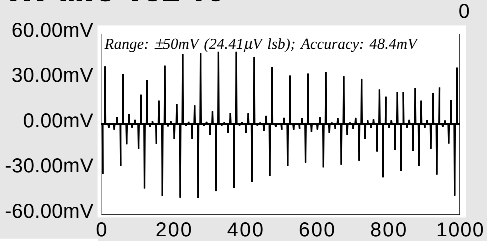
GW Instruments
***instruNet* 100**



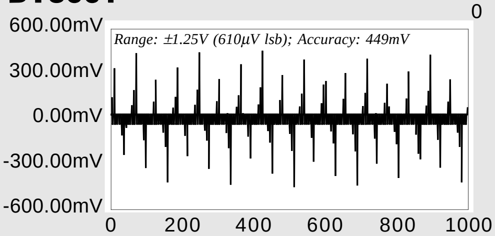
Keithley Metrabyte
DAS-1800ST



National Instruments
AT-MIO-16E-10



Data Translation
DT3001



Special Report By
GW Instruments, Inc.

Introduction

Data acquisition hardware from four leading manufacturers was tested for Voltage measurement accuracy; including systems from GW Instruments, National Instruments, Data Translation, and Metrabyte; as illustrated to the right. This report contains the results of those tests. The tests were performed with the manufacturer's breakout and cables, a ≥ 5.5 digit DVM, a function generator and a small battery operated voltage source. The tests were simple in nature, and can easily be reproduced in one's own laboratory. The hardware components from each manufacturer provide similar features (e.g. 16se/8di analog inputs, several analog outputs, 8 digital I/O) and cost approximately the same (e.g. $1300 USD list price). The results shown are typical, and may vary a little depending on the specific system in use.

What Is "Accuracy"?

Webster defines "Accuracy" as "the degree of conformity of a measure to its true value". A voltage measurement system can therefore be characterized by two numbers, its Accuracy and its Measurement Speed. Accuracy is simply the worst case difference between the applied voltage (i.e. to the screw terminals at the breakout) and the measured voltage (i.e. the value returned by the computer). To measure accuracy in this study, we applied a known voltage, digitized 1000 points, and then reported the ±Voltage Accuracy as the maximum error incurred between the Applied and Measured voltage. In a sense, this can be viewed as a typical Voltage measurement accuracy at 25°C. This value was then documented in terms of ±milliVolt Accuracy, % Full Scale Range Accuray (%FSR), and Effective Bits. For example, if 0Volts is applied to the screw terminals with a ±100mV range, 1000 points are digitized, and the maximum error of a point is -180uV, then the worst case error at 25°C would be ±.18mV, .18% FSR, and 9.1 Effective Bits $\{9.1 = \log_2(100mV/.18mV)\}$.

How Does this Relate to Manufacturer Specifications?

Most data acquisition hardware manufacturers do not specify overall accuracy values. Sensor manufacturers do it (e.g. "this thermocouple is accurate to ±3°C") and volt meter manufacturers do it (e.g. "this DVM is accurate to ±10uV on the ±200mV scale"), yet data

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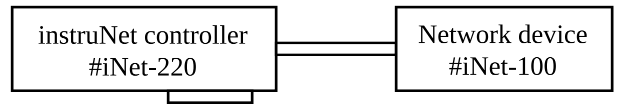
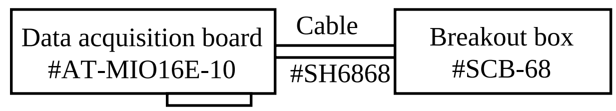


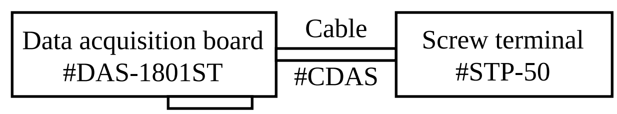
Computer: Macintosh Quadra 650/System 7.3D0
Software: SuperScope II v2.0, instruNet 0.9 (68k)

National Instruments



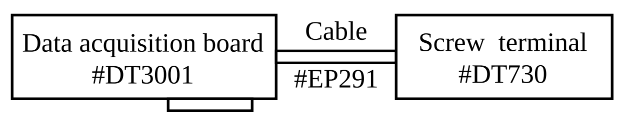
Computer: Daewoo 8mb 486 DX2/66 , Win 3.1, DOS 6.22
Software: Visual Basic 3.0, NI-DAQ 4.8.0

Keithley Metrabyte



Computer: Daewoo 8mb 486 DX2/66 , Win 3.1, DOS 6.22
Software: Visual Basic 3.0, ASO-1800 for Windows 4.10

Data Translation



Computer: Daewoo 8mb 486 DX2/66 , Win 3.1, DOS 6.22
Software: Visual Basic 3.0, DT300X v. 02.20

The above figures illustrate the four data acquisition systems tested in this study.

acquisition hardware manufacturers have historically avoided the issue. Instead, they report things like maximum offset error, gain error, non-linearity, crosstalk, and noise. They imply that all you need to do is add up these component errors and that's your accuracy. Notice that they don't add up the numbers for you. Why is that? It turns out that the actual errors in a typical data acquisition scenario are different than the sum of the typically specified component parts, since they do not include components such as manufacturer cable to breakout effects, overvoltage recovery time, slew rate limitations while digitizing multiple channels, and multiplexer current pumping -- all which effect Accuracy in a real life situation. This report documents Accuracies measured in 9 real life scenarios.

CROSSTALK TEST

Data acquisition accuracy is often limited by cross talk between analog (and possibly digital) signals within a multiwire cable that routes signals from sensors to a typical data acquisition system. Maxwell's Equations say that a changing voltage in 1 wire creates a magnetic field around that wire, and a changing magnetic field around an adjacent wire induces a changing current, which creates a voltage offset when pumped through resistance. Subsequently, sharp transitions from one wire (e.g. digital switching), inductively couple 10mV to 500mV spikes to all other signals in the cable[2]. This is especially bad when a portion of a ±5V range signal is coupling into a ±10mV signal.

How to Reproduce This Test

Place the data acquisition system in differential input mode, attach a signal generator (e.g. 5KHz ±5V square wave) to the 1st and 3rd channels, and short the 2nd channel to ground (possibly via R_{source}), as shown in Figure 1. Simultaneously digitize 1Kpts/ch from the three channels at ≥30Ks/sec, or the highest sample rate the system supports, and then view the 2nd channel on the computer monitor. It should be a flat 0V, yet artifacts from the function generator are likely to appear. Notice the different effects of sine and square wave signals at different frequencies, as well as different values of R_{source} and different gain settings for the 2nd channel.

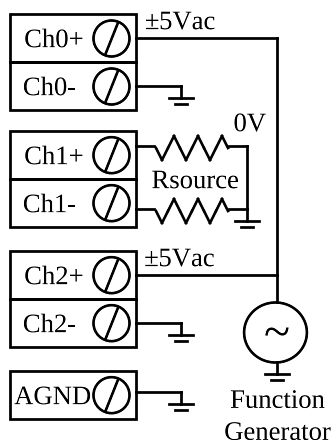
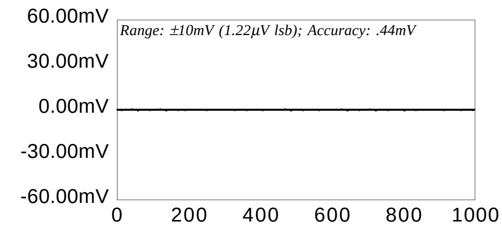


Figure 1 Crosstalk Test

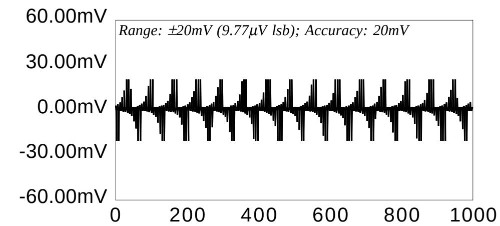
Test Results of 4 Systems

The table below summarizes the results of the Crosstalk Test with four leading systems. The NI, MBC and DT systems exhibited significant crosstalk, whereas the instruNet system did better, primarily because the instruNet "breakout" box contains the analog electronics, and therefore analog signals are never placed in a multiwire cable. The instruNet strategy is to place the a/d converter next to the sensor, 3 to 30 feet from the computer, instead of inside the computer where digital noise is rampant and cabling to the computer is problematic.

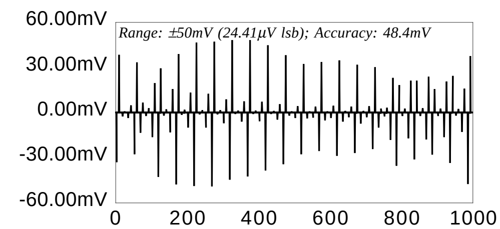
GW Instruments *instruNet* 100



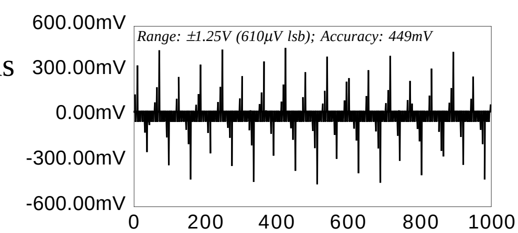
Metrabyte DAS-1800ST



National Inst. AT-MIO-16E-10



Data Translation DT3001



The above graphs show the digitized signal from the 2nd channel (which should be 0V) when 3 channels are simultaneously digitized at 30Ks/sec/ch[1]. 0Volts is applied to the 2nd channel via a 10KΩ resistor; while a 5KHz[1] ±5V square wave is applied to the 2 neighboring channels.

		GWI iNet100				MBC DAS-1801ST				NI AT-MIO-16E-10				DT DT3001			
Rs	Offender	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits
0	5V Square	±5V	1.16	0.02%	12.07	±5V	19.5	0.39%	8.00	±5V	2.44	0.05%	11.00	±10V	14.65	0.15%	9.41
0	5V Sin		1.15	0.02%	12.09		2.44	0.05%	11.00		0.00	0.00%	12.00		0	0.00%	12.00
10k	5V Square		1.89	0.04%	11.37		695	13.90%	2.85		58.60	1.17%	6.41		478	4.78%	4.39
10k	5V Sin		1.15	0.02%	12.09		239	4.78%	4.39		4.88	0.10%	10.00		48.83	0.49%	7.68
0	5V Square	±10mV	0.09	0.91%	6.78	±20mV	1.07	5.35%	4.22	±50mV	3.10	6.20%	4.01	±1.25V	7.32	0.59%	7.42
0	5V Sin		0.07	0.71%	7.14		0.08	0.39%	8.00		0.15	0.29%	8.42		0.61	0.05%	11.00
10k	5V Square		0.44	4.40%	4.51		20	100.00%	0.00		48.39	96.78%	0.05		449	35.92%	1.48
10k	5V Sin		0.07	0.70%	7.16		19.65	98.25%	0.03		3.56	7.12%	3.81		48.21	3.86%	4.70

[1] The sample rate for the instruNet system is 16.7Ks/sec/ch and the offending signal frequency is 2.7kHz. [2] One can easily see this by applying a square wave to wires #1 and #2 in a multiwire cable (via a function generator), attaching wires #10 to #11 at the same end of the cable, and then monitoring wires #2 and #11 (w.r.t. #1) at the other end of the cable with a 2channel oscilloscope. Trigger on wire #2 and then view the induced ±10mV to ±500mV spike on wire #11 (e.g. with AC couple and 20mV/division oscilloscope settings).

Differential Input Wiring Test

In the case of a Voltmeter, if you attach the two input leads together, the meter reads 0V. In the case of a data acquisition system, this sometimes works, yet sometimes it does not if careful steps had not been taken in the design of the front end of the system. In these cases, sensors measured in differential mode can drift or oscillate if external resistors are not added from each input terminal to ground. These external resistors provide a trickle of current to the internal instrumentation amplifier inputs; however, in some cases, they do not work well since the multiplexers pump current when they switch, and the applied circuit may not absorb this current particularly well. In other words, some systems do not do a good job of providing the benefits of differential inputs, since the differential wiring becomes problematic in a hurry. The Differential Input Wiring Test tests the ability of a data acquisition system to accurately measure a differential signal that is floating with respect to system ground, as shown in figure 2.

How to Reproduce This Test

Place the data acquisition system in differential mode and connect the 1st channel (+) input to the 1st channel (-) input, as shown in figure 2. Do not attach either of these inputs to ground. Digitize 1K points from the first channel at 30Ks/sec and view the results on the computer screen. The first channel should be a flat 0V. Digitize several times to observe the effects of current that might be pumped out the input terminals. Look for oscillations and unstable readings. Try this test at different gains.

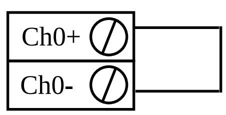
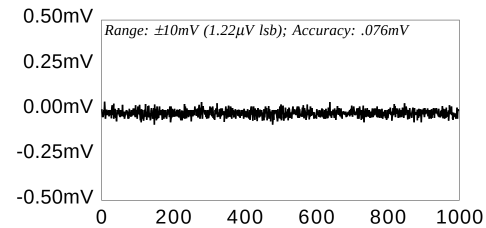


Figure 2 Differential Input Wiring Test

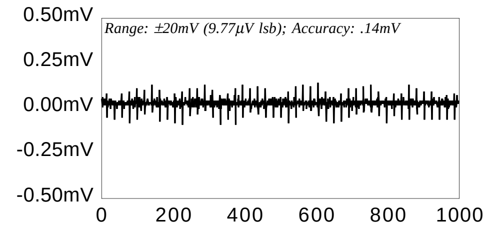
Test Results of 4 Systems

The table below summarizes the results of the Differential Input Wiring Test with four leading data acquisition systems. The NI and DT systems did not handle the floating differential input well; whereas the MBC and instruNet systems incurred no problems.

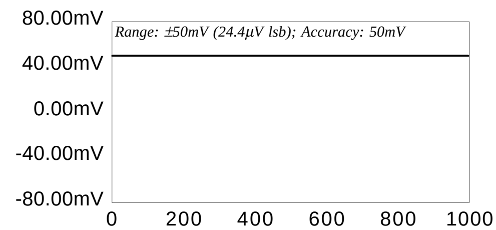
GW Instruments *instruNet* 100



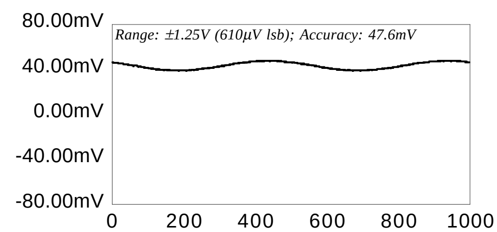
Metrabyte DAS-1800ST



National Inst. AT-MIO-16E-10



Data Translation DT3001



This test reflects the need, or lack thereof, of external resistors to ground when measuring signals in differential mode that are floating w.r.t. system ground. The above graphs show the 30Ks/sec digitization of the 1st channel, who's positive and negative inputs are connected together (i.e. 0V is applied differentially). The digitized waveform should be a flat line at 0V. MBC and instruNet do well; whereas NI and DT incur problems with floating inputs.

GWI iNet100				MBC DAS-1801ST				NI AT-MIO-16E-10				DT DT3001			
Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits
±5V	1.26	0.03%	11.95	±5V	2.44	0.05%	11.00	±5V	5.00V	100%	0.00	±10V	48.88	0.49%	7.68
±80mV	0.11	0.14%	9.51	±100mV	0.19	0.19%	9.04	±100mV	100.00	100%	0.00	±1.25V	47.61	3.81%	4.71
±10mV	0.08	0.76%	7.04	±20mV	0.14	0.68%	7.19	±50mV	50.00	100%	0.00				

Overvoltage Recovery Test

Each channel of a voltage measurement system has a designated signal input range (e.g. ±5V, ±100mV); however, the signal applied to a channel sometimes exceeds this range (e.g. an extraneous spike occurs). In most cases, the measurement system reports the measured voltage at the bound (e.g. apply 10V to a ±5V input and the computer sees it as 5V), which is fair since the designated range is real and must be respected. Yet it is also desirable that the overvoltage condition in one channel not effect other channels. That is, accuracy should be maintained in other channels if one channel incurs an overvoltage spike. Some systems maintain this accuracy, whereas others do not. Maintaining accuracy requires careful analog design. The Overvoltage Recovery Test tests a systems ability to insulate other channels if one channel incurs an overvoltage.

How to Reproduce This Test

Place the data acquisition system in differential input mode and set the gain on the 1st and 3rd channels to 1. Set the gain on the 2nd channel to a higher gain (e.g. 50, 100 if possible). Connect a DC voltage source to the 1st and 3rd channels as shown in figure 3. Set the voltage source to a value higher than the range of the system without exceeding the specified overvoltage protection limit (e.g. if the full scale range is ±5V, and it is overvoltage protected to ±25V, then set the voltage source to 20V but not much higher). Then digitize from all three channels at a high sample rate (e.g. 30Ks/sec) and view the 2nd channel on your computer screen -- it should show a flat 0V[3]. Try this test at different gains and different sample rates.

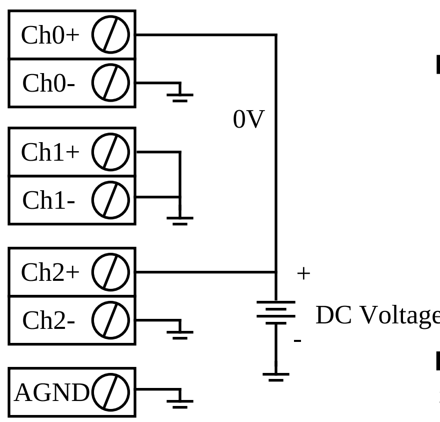
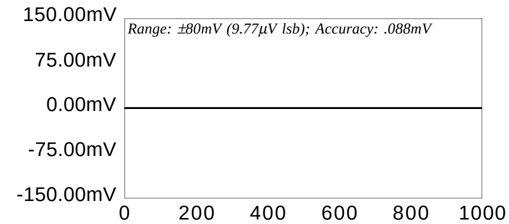


Figure 3 Overvoltage Recovery Test

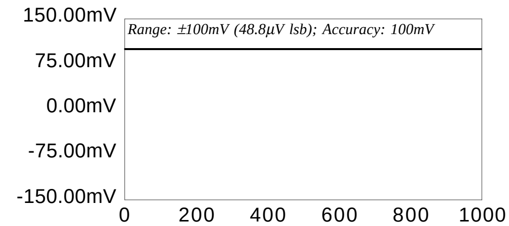
Test Results of 4 Systems

The table below summarizes the results of the Overvoltage Recovery Test with four leading data acquisition systems. instruNet handled the overvoltage scenario well; whereas the other systems incurred problems. This is because the instruNet system includes signal conditioning amplifiers at each voltage input channel; whereas the other systems route the input directly to the internal multiplexers. The instruNet signal conditioning amplifiers enable the instruNet inputs to directly connect to popular sensors such as thermocouples, RTD's, and strain gauges.

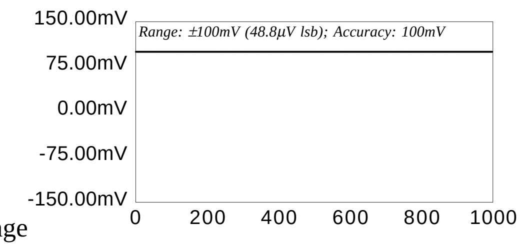
GW Instruments *instruNet* 100



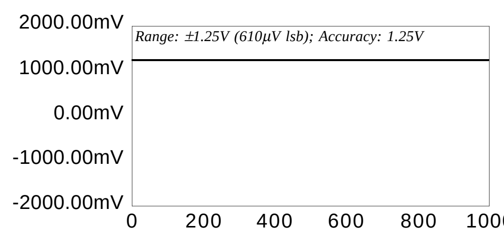
Metrabyte DAS-1800ST



National Inst. AT-MIO-16E-10



Data Translation DT3001



This test reflects the effects on other channels when one channel is overvoltaged. The above graphs show the 2nd channel (it should be 0V) when 3 channels are simultaneously digitized at 30Ks/sec/ch[3]. The 2nd channel has been grounded, whereas the 1st and 3rd channels have been overvoltaged. The instruNet system handles the overvoltage nicely, whereas the other systems do not.

GWI iNet100				MBC DAS-1801ST				NI AT-MIO-16E-10				DT DT3001			
Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits
±80mV	0.09	0.11%	9.81	±100mV	100	100%	0.00	±100mV	100.00	100%	0.00	±1.25V	1250	100%	0.00

[3] The sample rate for the instruNet system is 16.7Ks/sec/ch; whereas the sample rate for the other systems is 30Ks/sec/ch.

Common Mode Rejection Test

Voltage measurement systems often provide 2 input terminals for the purpose of measuring a voltage between these terminals, independent of a common signal that has been added to both. This is commonly referred to as "differential input" and is advantageous in cases where a noise signal (e.g. 60Hz) has been added to both wires. The amount of rejection of the common mode signal is referred to as common mode rejection, and is often described in terms of a dB attenuation quantity (of the common signal) at a specified frequency. Often, the rejection degrades at 20dB for each 10-fold increase in the common mode signal's frequency. For example, a system might provide common mode rejection of 100dB at 100Hz, yet only 20dB at 1MHz. In other words, common mode rejection is helpful at rejecting common low frequency noise (e.g. 60Hz), yet not useful at rejecting fast digital noise.

How to Reproduce This Test

Place the data acquisition system in differential input mode, set the gain of the 1st channel to 1, and connect a signal generator to the 1st channel high and low inputs as shown in figure 4. Set the function generator to output a ±5V 60Hz sine wave. Digitize 1K points at 30Ks/sec from the 1st channel, and then view the results on the computer screen. The 1st channel should read a flat zero volts since the voltage between the two inputs is 0V. Try this test again, with sine waves varying in frequency from 10Hz to half the sample rate.

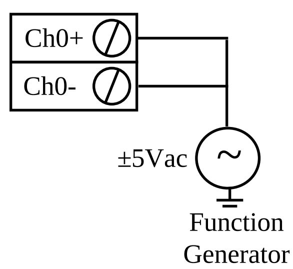
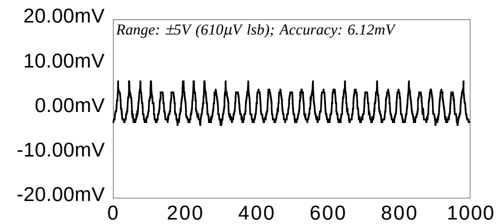


Figure 4 CMR Test

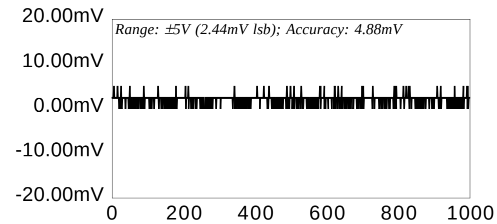
Test Results of 4 Systems

The table below summarizes the results of the CMR Test with four leading data acquisition systems. All four systems rejected the common mode sine wave nicely at 60Hz and showed a little leakage at 1KHz. In general, all systems did well. The instruNet system offers a further advantage by providing programmable analog low pass filters on each channel to further reject high common mode input frequencies.

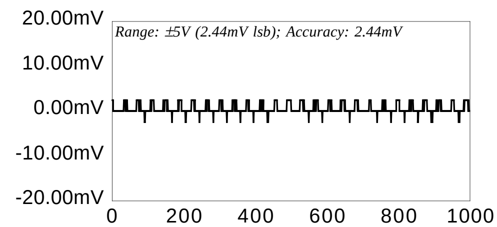
GW Instruments *instruNet* 100



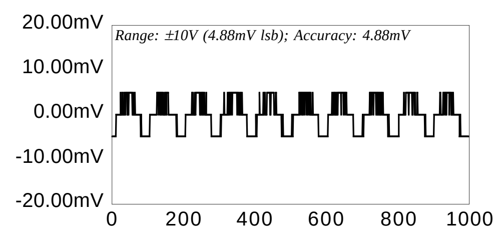
Metrabyte DAS-1800ST



National Inst. AT-MIO-16E-10



Data Translation DT3001



This test shows the amount of common mode signal that has leaked into the shorted differential input channel. The above graphs show the 30Ks/sec digitization of the 1st channel, which should be a flat 0V, yet instead shows a portion of the common mode 1KHz sine wave.

		GWI iNet100				MBC DAS-1801ST				NI AT-MIO-16E-10				DT DT3001			
Offending Frequency	Range	±mV Accuracy	%FSR Accuracy	CMR	Effective Bits	±mV Accuracy	%FSR Accuracy	CMR	Effective Bits	±mV Accuracy	%FSR Accuracy	CMR	Effective Bits	±mV Accuracy	%FSR Accuracy	CMR	Effective Bits
60 Hz	±5V -	1.18	0.02%	-72.54	12.05	4.88	0.10%	-60.21	10.00	0.00	0.00%	-72.20	12.00	0.00	0.00%	-72.20	12.00
1 kHz	±10V	6.12	0.12%	-58.24	9.67	4.88	0.10%	-60.21	10.00	2.44	0.05%	-66.23	11.00	4.88	0.05%	-60.21	10.00

MULTIPLEXER CURRENT PUMP TEST

Data acquisition systems sometimes pump current out the input terminals when the internal multiplexers switch channels. This can add spikes to the input signal, which can cause havoc if the signal is also routed to another measurement system in parallel. In some cases, the current is pumped into stray (or not so stray) capacitance to ground, and is discharged through the source resistance -- which causes a voltage offset to be added to the signal. In summary, with some signal sources, multiplexer current pumping can destroy accuracy; especially when working with small voltages, high source resistances, and sensors that contain capacitance to ground (e.g. a sensor that has an R•C low pass filter at its output). The best way to observe the effects of multiplexer current pumping is to digitize 0Volts from an R•C circuit tied to ground, while also digitizing a voltage source on other channels.

How to Reproduce This Test

Place the data acquisition system in single-ended input mode, set the gain of the first three channels to 1, connect a DC voltage source to the 1st and 3rd channels, and connect the 2nd channel to ground through a Resistor-Capacitor circuit as shown in figure 5. A battery operated voltage source (e.g. 4.5V derived from three D-Cells in series) works best since it offers low noise and no ground loops. Digitize 1K points per channel from the first 3 channels at 30Ks/sec/ch and view the 2nd channel on the computer screen -- it should show a flat zero volts[4]. Try this test at different gains.

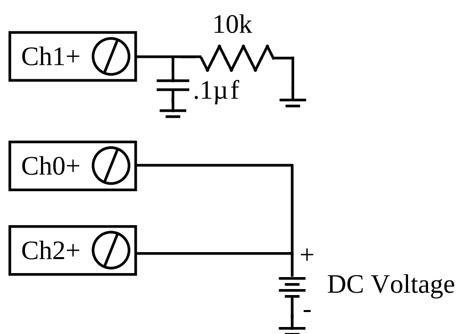
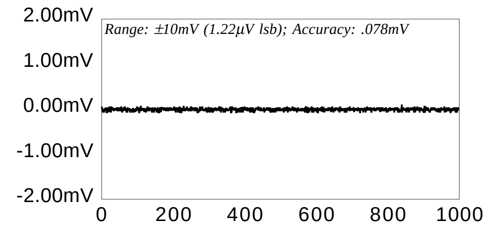


Figure 5 Multiplexer Current Pump Test

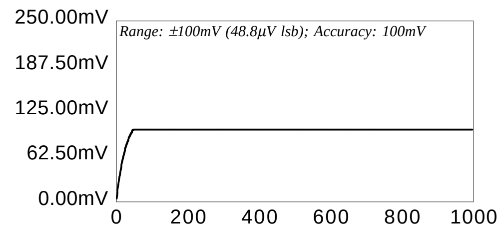
Test Results of 4 Systems

The table below summarizes the results of the Multiplexer Current Pump Test with four leading systems. The instruNet system did well since its voltage input terminals drive signal conditioning amplifiers (which do not pump current), instead of multiplexers. On the other hand, the MBC and DT systems incurred significant problems due to current pumping.

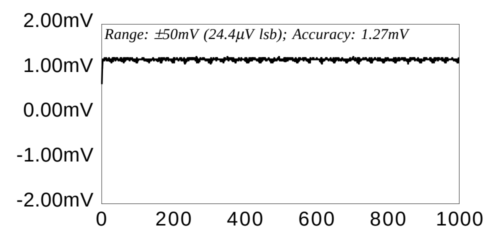
GW Instruments *instruNet* 100



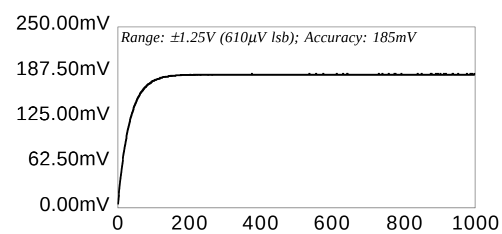
Metrabyte DAS-1800ST



National Inst. AT-MIO-16E-10



Data Translation DT3001



This test reflects the effect of current pumped out of switching multiplexers. The above graphs show the 2nd channel (it should be 0V) when 3 channels are simultaneously digitized at 30Ks/sec/ch[4]. The 2nd channel has been grounded through an resistor and capacitor in parallel, whereas the 1st and 3rd channels have been connected to 4.5V. Notice how the MBC and DT accuracy degraded significantly due to current pumping.

	GWI iNet100				MBC DAS-1801ST				NI AT-MIO-16E-10				DT DT3001			
Range	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits
±5V	±5V	1.15	0.02%	12.09	±5V	124	2.48%	5.33	±5V	2.44	0.05%	11.00	±10V	185	1.85%	5.76
±80mV	±50mV	0.08	0.16%	9.32	±100mV	100	100%	0.00	±50mV	1.27	2.54%	5.30	±1.25V	185	15%	2.76

[4] The sample rate used with the instruNet system was 16.7Ks/sec/ch.

Source Resistance Test

A voltage source is often modeled as an ideal voltage source in series with a resistor, where the resistor value is referred to as the "Source Resistance", as shown in figure 6. This resistance limits the ability of the source to drive a load. Some sources have a high resistance whereas others are low. For example, a 1000Ω RTD (i.e. which provides a 1KΩ source resistance) has less drive capability than a 1Ω thermocouple. The accuracy of a voltage measurement system is sometimes effected by this source resistance. In the Source Resistance Test, we apply a constant voltage with 0Ω, 1KΩ and 10KΩ source resistances, and measure the resulting Accuracy in each case.

How to Reproduce This Test

Place the data acquisition system in single-ended input mode and set the gain of the 1st channel to 1. Connect a DC voltage to the 1st channel, via a resistor, as shown in figure 6. It is best to use batteries for this voltage source to minimize the affects of noise and ground loops. The test results shown were acquired using a 4.5V source created with three 1.5V D-cell batteries. Measure the voltage source with an accurate voltmeter. Digitize 1K points from the 1st channel at 30Ks/sec and view the results on the computer screen. The 1st channel should be a flat line at the voltmeter measured Voltage. Try this test with different source resistances.

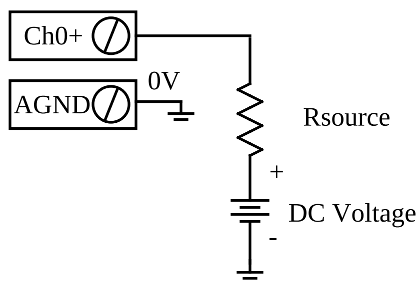


Figure 6 Source Resistance Test

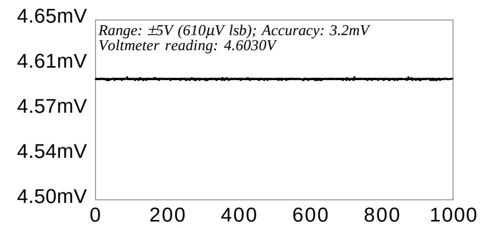
Test Results of 4 Systems

The table below summarizes the results of the Source Resistance Test. The NI system exhibited no loss of accuracy as the value of R_{source} increased due to NI's high 100GΩ input impedance; whereas the other systems saw a little degradation with 10KΩ R_{source}. This is due to the error caused by the voltage divider relationship between the input resistance and source resistance:

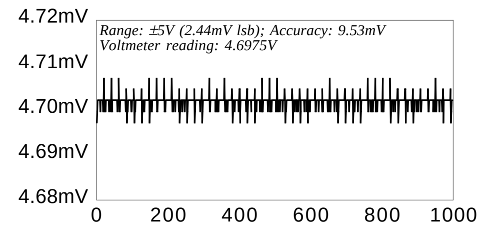
$$\text{gainFromResistors} = R_{inputImpedance} / (R_{source} + R_{inputImpedance})$$

For example, if R_{source} is 10KΩ and $R_{inputImpedance}$ is 22MΩ, then the voltage read by the measurement system will be .9995 {=22M/(22M+10K)} times that of the actual voltage (i.e. a 0.05% error).

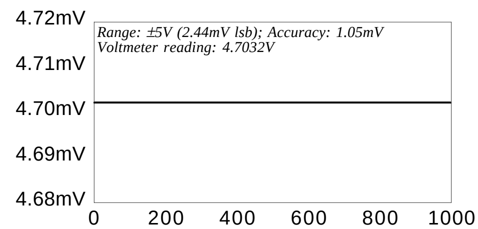
GW Instruments *instruNet* 100



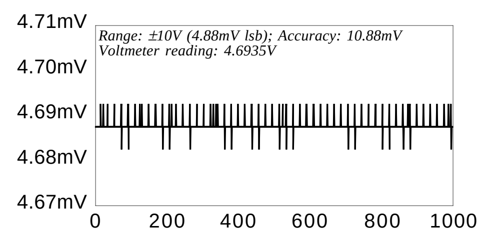
Metrabyte DAS-1800ST



National Inst. AT-MIO-16E-10



Data Translation DT3001



This test reflects the effects of different source resistances. The above graphs show the 30Ks/sec digitization of the 1st channel, which is connected to a voltage source via a 10KΩ resistor. The digitized waveform should be a flat line at the voltage source level, which is noted at the top of each graph.

	GWI iNet100			MBC DAS-1801ST			NI AT-MIO-16E-10			DT DT3001		
Rsource	±mV Accuracy	%FSR Accuracy	Effective Bits	±mV Accuracy	%FSR Accuracy	Effective Bits	±mV Accuracy	%FSR Accuracy	Effective Bits	±mV Accuracy	%FSR Accuracy	Effective Bits
0	0.76	0.02%	12.68	6.59	0.13%	9.57	1.35	0.03%	12.00	6.50	0.07%	10.59
1k	0.76	0.02%	12.68	4.64	0.09%	10.07	0.29	0.01%	12.00	6.20	0.06%	10.66
10k	3.21	0.06%	10.61	9.53	0.19%	9.04	1.05	0.02%	12.00	10.88	0.11%	9.84

System Noise Test

All voltage measurement systems internally include a noise signal that is added to the measured input signal. This is sometimes referred to as "System Noise" or "Background Noise"; and is caused by things like internal operation amplifiers, internal resistors, digital switching that couples into the voltage measurement circuitry, 60Hz that couples into the breakout to measurement system cable, and computer radiation that couples into the measurement signal path. This background noise is added to every voltage measurement channel, and therefore limits the maximum possible accuracy. One can easily measure the System Noise by grounding an input channel and digitizing this channel at a fast rate, and at different gains.

How to Reproduce This Test

Place the data acquisition system in single-ended input mode and set the gain on the 1st channel to 1. Connect the 1st channel to ground as shown in figure 7. Place the breakout and breakout-cable as far away as possible from noisy electrical sources such as 110V cables, disk drives and computer monitors. Then digitize 1K points from the 1st channel at 30Ks/sec and view the results on your computer screen. The 1st channel should read a flat 0V. Try this test at different gains.

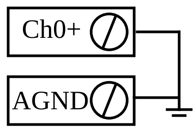
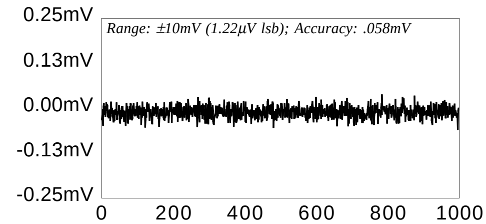


Figure 7 System Noise Test

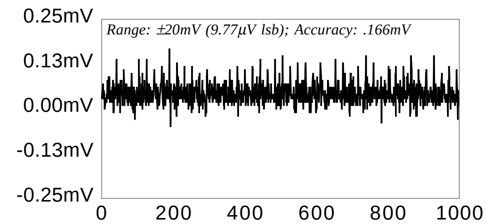
Test Results of 4 Systems

The table below summarizes the results of the System Noise Test with four leading data acquisition systems. The NI system is quieter than the MBC and DT systems due to its shielded breakout box, shielded breakout-cable, and outstanding printed circuit board ground plane shielding techniques. The instruNet system is also very quiet since its analog electronics (e.g. a/d converter, multiplexer, amplifiers) are housed in the breakout box itself, and this breakout box does not contain a noisy processor. The instruNet system also has the advantage of software selectable analog low-pass filters at each input channel -- which can be used to filter out high frequency noise that enters the system.

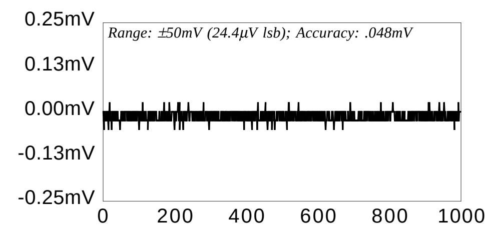
GW Instruments *instruNet* 100



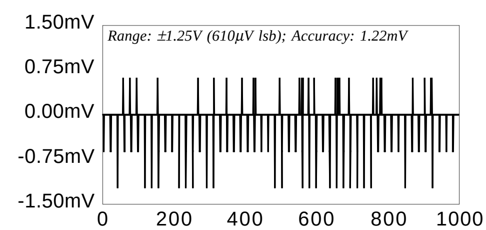
Metrabyte DAS-1800ST



National Inst. AT-MIO-16E-10



Data Translation DT3001



This test shows the amount of internal system noise added to every input signal. The above graphs show the 30Ks/sec digitization of the 1st channel at a high gain, which should be a flat 0V.

GWI iNet100				MBC DAS-1801ST				NI AT-MIO-16E-10				DT DT3001			
Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits
±5V	1.22	0.02%	12.00	±5V	4.88	0.10%	10.00	±5V	0.00	0.00%	12.00	±10V	0	0.00%	12.00
±600mV	0.29	0.06%	11.01	±500mV	1.46	0.29%	8.42	±500mV	0.00	0.00%	12.00	±2.5V	1.22	0.05%	11.00
±80mV	0.09	0.09%	9.88	±100mV	0.39	0.39%	8.00	±100mV	0.05	0.05%	11.00	±1.25V	1.22	0.10%	10.00
±10mV	0.06	0.29%	7.43	±20mV	0.16	0.80%	6.97	±50mV	0.05	0.10%	10.00				

Amplifier Gain•Bandwidth Test

Data acquisition accuracy is often limited by the ability of the data acquisition system to quickly switch from one channel to another when digitizing multiple channels. This is often limited by the gain-bandwidth performance of the internal amplifier between the a/d converter and the multiplexer. For example, if the gain-bandwidth product of this amplifier is 15MHz and a channel's gain is set to 100, then the bandwidth of the amplifier is .15MHz at that gain (.15 = 15/100), which settles in 14µs to a 5uV accuracy after transitioning 5Volts:

bandwidth = $1/*(2\pi T_c)$ = .15MHz
therefore: timecontant = T_c = 1.06us

settling time = T_c * ln (step/accuracy)
= 14µs = 1.06µs * ln (5V / 5uV)

We can observe this by digitizing 2 channels, one with a high input voltage at a gain of 1, and the other with a 0V input at a high gain.

How to Reproduce This Test

Place the data acquisition system in single-ended input mode, connect a DC voltage (e.g. a battery) to the 1st channel, and short the 2nd channel to analog ground, as shown in figure 8. This study used three 1.5V D-cell batteries in series to produce a 4.5V source. Digitize 1Kpts/ch from the first two channels at a sample rate of 30Ks/sec/ch[5] (or the maximum rate the system supports) and view the results on the computer screen. The 2nd channel should be a flat 0V. Try this test at different 2nd channel gains and sample rates. The best way to observe the Gain•Bandwidth limitation is to run the system at its fastest possible sample rate while the 2nd channel is set to its highest possible gain.

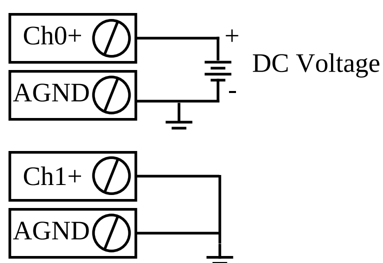
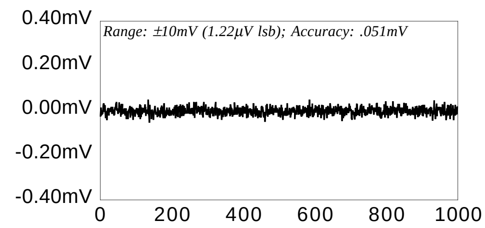


Figure 8 Amplifier Gain•Bandwidth Test

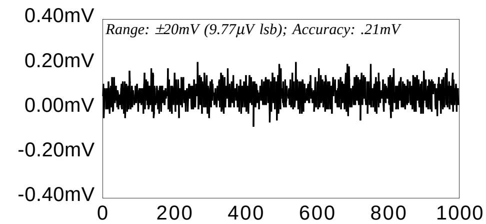
Test Results of 4 Systems

The table below summarizes the results of the Amplifier Gain•Bandwidth Test with four leading data acquisition systems. Generally, the results shown here are very similar to the results in the System Noise test, which does the same thing yet does not switch the multiplexer. This means that the amplifiers in all 4 systems had time to settle after switching -- good job industry!

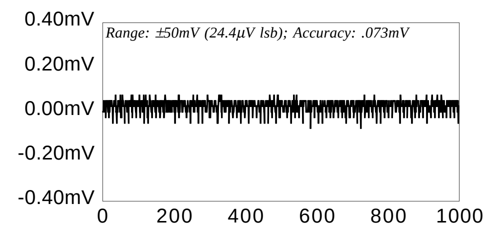
GW Instruments *instruNet* 100



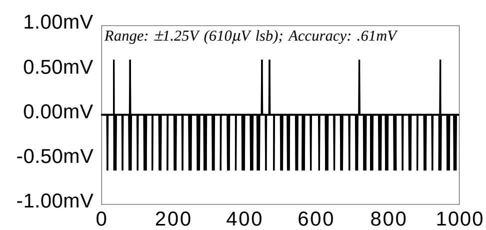
Metrabyte DAS-1800ST



National Inst. AT-MIO-16E-10



Data Translation DT3001



This test reflects the gain-bandwidth limitation of the high gain amplifier within the data acquisition system. The above graphs show the digitized signal from the 2nd channel (which should be 0V) when 2 channels are simultaneously digitized at a sample rate of 30Ks/sec/ch[5]. 0Volts is applied to the 2nd channel while 4.5V is applied to the 1st channel.

GWI iNet100				MBC DAS-1801ST				NI AT-MIO-16E-10				DT DT3001			
Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits
±5V	1.76	0.04%	11.47	±5V	2.44	0.05%	11.00	±5V	0.00	100.00%	12.00	±10V	4.88	0.05%	11.00
±80mV	0.11	0.14%	9.51	±100mV	0.59	0.59%	7.41	±100mV	0.05	0.05%	11.00	±2.5V	1.22	0.05%	11.00
±10mV	0.05	0.50%	7.64	±20mV	0.21	1.05%	6.57	±50mV	0.07	0.15%	9.42	±1.25V	0.61	0.05%	11.00

[5] The sample rate used with the *instruNet* system was 20.8Ks/sec/ch; whereas the sample rate used with the Metrabyte system was 25Ks/sec/ch.

Gain Error Test

Data acquisition systems often include an error, called the "gain" error, that is proportional to the measured voltage:

$$\text{measuredVoltage} = \text{actualVoltage} * \text{gainError}$$

Gain errors are often caused by internal resistors that drift with time and/or temperature. These resistors are used to set the gain of the internal amplifiers, and when they drift, the gain of the amplifiers drift as well. Gain errors can also be induced by internal reference voltage drift and amplifier non-linearities. Some systems automatically calibrate out most gain errors on power-up. Other systems try to use resistors and references that drift little with temperature and time. To measure the gain error, we look at the accuracy with a DC input voltage close to the maximum of the voltage input range.

How to Reproduce This Test

Place the data acquisition system in single-ended input mode, and connect a voltage source to the 1st channel as shown in figure 9. A battery voltage source works best since it is noise free and does not induce ground loops.

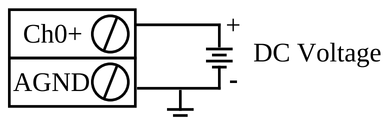
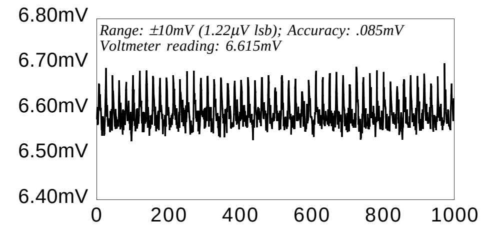


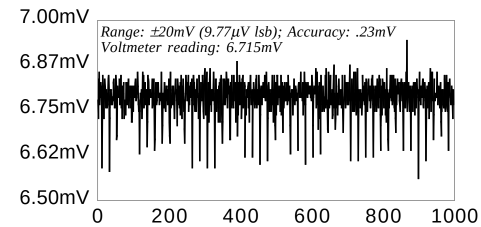
Figure 9 Gain Error Test

Apply voltages close to the maximum of each range (e.g. apply 45mV to a 50mV range input) and accurately measure it with a DVM. Digitize 1K points from the first channel at 30Ks/sec/ch and view the results on the computer screen. The 1st channel should be a flat line at the same voltage read by the DVM. Try this test at other gain settings and other voltage settings, making sure not to exceed the maximum allowed voltage.

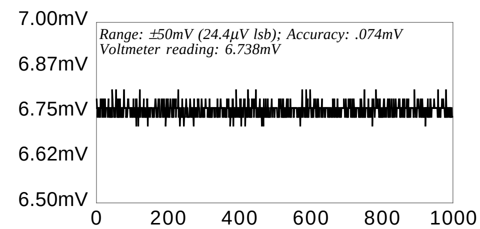
GW Instruments *instruNet* 100



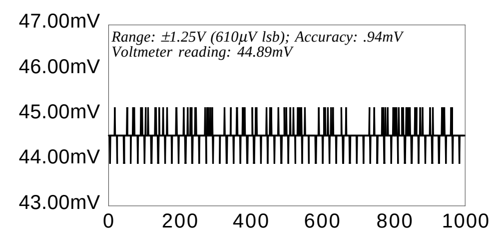
Metrabyte DAS-1800ST



National Inst. AT-MIO-16E-10



Data Translation DT3001



Test Results of 4 Systems

The table below summarizes the measured Accuracies of 4 leading systems when running the Gain Error test. Notice the MBC and DT systems showed some weakness. This is because they rely on potentiometers to calibrate out gain and offset errors at the factory, instead of autocalibration techniques performed on power-up. This means MBC and DT are more vulnerable to temperature change between factory calibration and actual usage. If we had tested the MBC and DT systems at 35°C instead of 25°C, we would have seen more inaccuracy.

This test reflects the gain error within the data acquisition system. The above graphs show the 30Ks/sec digitization of the 1st channel, which is attached to a DC voltage source. The digitized waveform should be a flat line at the voltage source level, which is measured with a 6digit DVM. The "Accuracy" is the maximum difference between the data acquisition measured and DVM measured voltage.

GWI iNet100				MBC DAS-1801ST				NI AT-MIO-16E-10				DT DT3001			
Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits	Range	±mV Accuracy	%FSR Accuracy	Effective Bits
±5V	1.32	0.03%	11.89	±5V	7.09	0.14%	9.46	±5V	0.04	0.00%	12.00	±10V	7.00	0.07%	10.48
±80mV	0.17	0.21%	8.90	±100mV	0.49	0.49%	7.67	±100mV	0.08	0.08%	10.34	±1.25V	0.94	0.08%	10.37
±10mV	0.09	0.85%	6.88	±20mV	0.23	1.14%	6.45	±50mV	0.07	0.15%	10.41				

The tests in this study were performed by GW Instruments. The results are accurate and fair to the best of GWI's knowledge and were performed in good faith. The results may vary a little from system to system, yet should not vary by more than 1 or 2 LSB, or ±30%, which ever is greater. Keep in mind that if 4.701V is applied to a 5mV LSB system, and it reads 4.700V, then the measured "Accuracy" is reported as ±1mV, yet could easily have been between 0 and 5mV depending on how the applied voltage happened to relate to the internal quantized levels; therefore, measured Accuracy numbers in many cases are only reproducible to ±1LSB. Additionally, measured accuracy can vary ±30% or so depending on the specific system in use (due to variations of internal components), the computer used for testing (each computer model radiates internal EMF differently), and the surrounding electrical environment. We ran all tests with only one data acquisition board installed in the computer at a time since we found that neighboring boards occasionally induced digital noise. Additionally, we ran all tests with 110V cables as far away as possible from the breakout and breakout cable to minimize the effects of 60Hz pickup. Also, since each system provides different gain options, we set the gains as close as possible in each test. The boards chosen were systems recommended to us by their manufacturer as their latest technology in the $1000 to $1500 price range.

In some cases, this study uses a system in a way that is not recommended by the manufacturer. In these cases, this study is not recommending that the system be used in this way, or disputing the manufacturer, yet only showing what happens when the system is used accordingly. For example, Data Translation does not recommend that its differential inputs be wired to a sensor that is floating with respect to system ground, yet in the Differential Input Wiring test, the 4 systems were wired in that way to demonstrate what happens in that configuration.

The accuracy performance with each system does vary a little with system temperature. This is due to properties of internal components that change with temperature. The Data Translation and Metrabyte systems are especially vulnerable to temperature change due to their lack of power-on calibration that subtracts out errors due to temperature drift.

In all tests, instruNet channel switching was set to Fast.

The products tested in this study were designed by the following leading manufacturers of data acquisition hardware:

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