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# APPLICATION NOTE 37

## Do I need a power analyzer or can I use a DAQ card instead?

In recent years, many educational courses have been somewhat forced into simplifying the complicated field of data acquisition and precision measurement. Such courses are under pressure to include a vast breadth of content in a short period. This is especially true ever since the emergence of digital micro controllers – a subject which is now included within many electronics courses, reducing the time to cover precision measurement and analog fundamentals. As such, the finer details of precision measurement are not fully appreciated during the early years of many an engineer's career. It is also reasonable for engineers to continue through our careers under the same assumptions taught during education. This application note is intended to cover the less known aspects of a specific sector of precision measurement – power analysis, whereby the pitfalls of such simplified assumptions are discussed.

> *"In reality, sample rate and bit resolution are not at the top of the priority list for a precision instrumentation designer"*

As an example, education may have taught us that a higher "bit count" Analogue to Digital converter and faster sample rates will give better, more accurate results - this just is not always the case, there are many other factors causing inaccuracy which exhibit a much greater influence on performance.

In reality, sample rate and bit resolution are in fact not at the top of the priority list for a precision instrumentation designer. This is not to say that bit count and sample rate do not matter, they do. Yet, the errors introduced within precision power measurement are not dominated by the number of bits and the sample rates used. Errors in precision power analysis are dominated by the analogue effects present right at the front end of a precision measurement input, the analogue signal conditioning circuitry connected to the test sample.

The mantra for hardware engineers at N4L is "If you put rubbish in, you will get rubbish out". The relevance of this is that no matter how fast you sample, no matter how high the resolution of your digitized signal, if the information passing from the analogue stage of the signal chain to the digital stage is not representative of the signal being measured, then high resolution ADC's and fast sample rates cannot help you – the system will simply digitise bad data. Calibration can only get you so far, it is imperative to feed good data into the system.

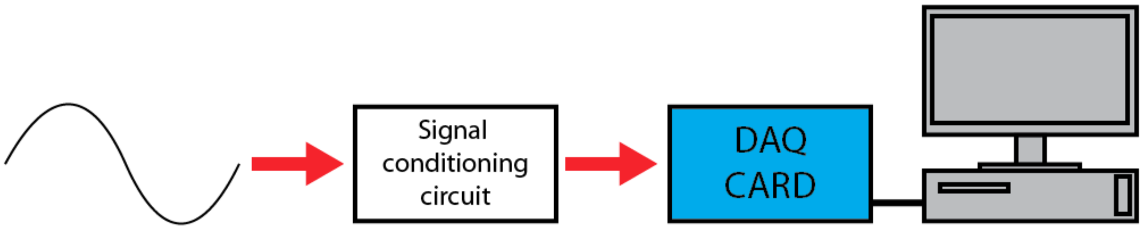


Fig.1

**What is a DAQ card?**

A DAQ (Data Acquisition) card is a multipurpose sampling system, commonly featuring multiple low voltage inputs. Fig.1 illustrates the position of the DAQ card within a typical signal chain, it resides between the signal conditioning circuitry and a PC.

This arrangement poses a significant problem for any precision measurement system using a DAQ based signal chain, as it is within the signal conditioning circuitry where most problems will occur, the DAQ card is further down the signal chain and does not affect the front end analogue performance.

A key issue is that the signal conditioning circuitry will function independent of the DAQ card, so there is no communication between the two and it will merely provide the following somewhat rigid functionality within a power measurement system listed below;

1. Isolation
2. Attenuation/Gain (normally a single stage, ***not*** actively adjustable during a real-time measurement)
3. Current/voltage signal conditioning to match DAQ input range

One may think this is all that is required and in simple terms, a DAQ based signal chain requires only the following functions;

*"in a DAQ based signal chain, it is the signal conditioning circuitry where the main problems will occur"*

**Voltage input:** Isolation of high voltage and attenuation of a differential signal down to a suitable level so that the DAQ card can digitise it and thus, the signal chain is complete.

**Current input:** Isolation of a current shunt resistor (or similar) and rejection of common mode voltage, so that the DAQ card receives an isolated and differential signal that can be digitised.

Sounds simple? Yes, but for reasons this document will explain, most signal chains will fail to achieve remotely acceptable results in the majority of applications for which a DAQ based power measurement system is likely to be used. Noisy, distorted or non-unity power factor applications are not accurately resolved by such simple signal conditioning and a DAQ card is unlikely to overcome this.

**DAQ card typical features:**

- Multiple input channels, 2~60
- Non-isolated
- Single range
- Low CMRR <80dB
- Sample rates 10ks/s~1Ms/s typical (Multiplexed)
- Input voltage max <10V

- Data is multiplexed between channels

**DAQ Issue #1 – The requirement for isolation**

If a DAQ based voltage measurement chain is required to measure the voltage waveforms being generated by a PWM inverter drive, a phase to phase measurement will be required. Thus, channel to channel isolation is needed to facilitate connection across the phases, eg L1~L2.

This isolation will usually be provided in the form of a differential probe, exhibiting a single range (100:1, 1000:1 etc.).

*"the differential probe will introduce phase shift to the measurement, the exact level of phase shift is unknown without extensive investigation"*

Firstly, even good differential probes exhibit a nominal accuracy of 1%, this is a significant source of error in magnitude alone and will affect measurements at all power factors. Good power analysers typically exhibit accuracies better than 0.1%, even with low cost solutions. Top of the range N4L analysers exhibit 0.01% reading errors.

Secondly, the differential probe will introduce phase shift to the measurement – the exact level of phase shift is unknown without extensive investigation. As power (Watts) is dependent upon the Power Factor (cos(θ)), any phase shift introduced by an attenuator is detrimental to the Watts accuracy of the system. This influence is greater at lower power factors.

**DAQ Issue #2 – The problems associated with single range inputs**

While voltage levels during a test may well be reasonably stable (although this is often not the case), current levels will most certainly not be. As such, it is vitally important for any high precision measurement system to select a suitable range to match the incoming signal. The closer a range can be to the peak of an incoming waveform (without clipping), the lower the range errors will be.

For example;

A 10V, 16bit DAQ based current measurement system is connected to a 10mOhm shunt resistor with a maximum burden capacity of 4W, where the shunt is capable of working with up to 20Arms current.

$$Power\ dissipation\ in\ shunt\ (watts) = I^2R = 20^2 * 0.01 = 4W$$

The voltage drop across the 10mOhm current shunt at 20Arms would be 0.2V

The 16 bit 10V input of the DAQ card achieve a maximum resolution of;

$$resolution = \frac{10}{2^{16}} = 152uV$$

However, it is noteworthy that this figure does not consider noise or the non-linearity (with respect to input magnitude and input frequency) of the DAQ card – which will be significantly higher than that of a dedicated power analyzer.

A 152uV drop across a 0.01Ω resistance is 15.2mA. Thus, the full scale (20A) range error can be calculated as;

$$range\ error\ (\%) = \left(\frac{0.0152}{20}\right) * 100 = 0.08\%$$

This does not seem too bad; it is however important to consider that there is only one range in this system. No matter whether the system is analysing a 20A signal or a 200mA signal, the 0.08% resolution (quantisation) error is based upon the 20A full scale range.

This error could be more accurately determined as the “full scale quantisation error”. When the input current is not close to the maximum current carrying capacity of the shunt, the measurement error will become larger.

As an example, if the input signal is 200mA, the 0.08% full scale error will contribute the same 15.2mA quantisation error to the reading.

As a percentage, this equates to;

$$resolution\ error\ w.r.t\ 200mA\ input\ signal = \frac{0.0152}{0.2} * 100 = 7.6\%$$

This is significant and highlights a major drawback of systems that do not have an active ranging system.

**Active ranging system? What do you mean?**

An active ranging system is one which can react to changes in the measured input signal during a measurement, re-ranging according to the peak of the incoming waveform and thus reducing range (quantisation) errors. This requires real-time communication between the analogue input circuitry and main CPU card, an active ranging system can change range almost instantaneously as the input signal changes in magnitude. The real-time communication between analogue channel and the main CPU is high speed and ensures a suitable range is always selected for a particular input signal, this minimises range errors and optimises accuracy of the signal chain.

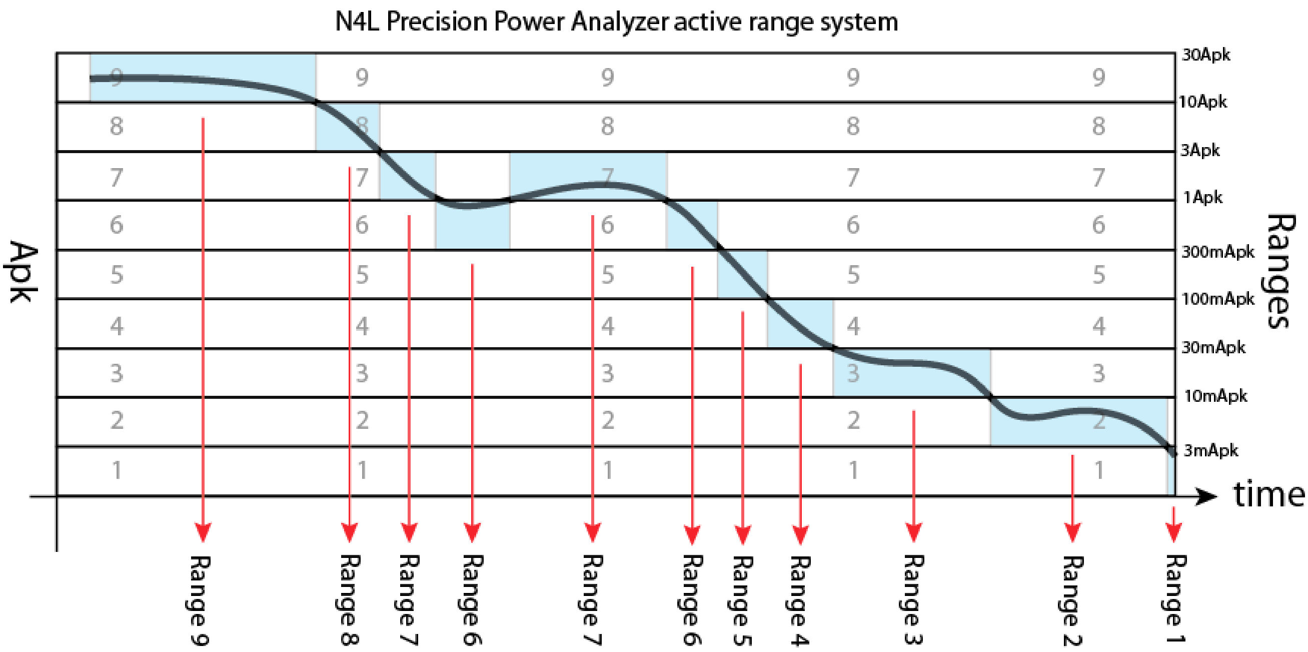


Fig.2

Fig.2 illustrates how an active ranging system reacts to a changing input signal, dynamically adjusting its range as the input signal changes in magnitude.

The active range is highlighted in blue in Fig.2, it should be clear to the reader that the resolution error is reduced as the range is lowered.

As an example of the benefits of this system, consider a 14-bit ADC based active ranging system with the ranges illustrated in Fig.2 above, the shunt resistance remains at 0.01Ω, the ADC has a full-scale range of +/-3Vpk. Even though the resolution of the ADC is lower than in the previous example, the resolution error of the measurement is lower in almost all cases.

$$resolution = \frac{3}{2^{14}} = 183uV$$

$$\frac{183uV}{3V} = 0.006\%\ of\ range$$

When monitoring a 200mArms input signal, the active ranging system on an N4L power analyzer would automatically select the 300mApk range.

Thus, the actual current error due to quantisation becomes:

$$error\ (A) = 0.006\% * 0.3 = \ 18uA$$

$$resolution\ error\ w.r.t\ 200mA\ input\ signal\ (active\ range, 300mApk) = \frac{0.000018}{0.2} * 100$$
$$= 0.009\%$$

It should be clear from these examples why an active range system is essential for high precision dynamic measurements.

The assumption of many engineers that a higher resolution ADC will provide greater accuracy is not always true – especially for power analysis. Ranging, linearity, jitter, analogue errors and many other factors play a role determining the accuracy of a system and low resolution ADC's can often be a better choice than high resolution equivalents. A detailed review of ADC resolution is covered in a separate application note, "ADC bit resolution – is higher always better?"

**DAQ Issue #3 – Multiplexing**

Most DAQ cards on the market share their sample rate between channels, this is a result of the DAQ card sequentially sampling each channel individually before moving onto the next channel – ie. Multiplexing.

Is this a problem?

Absolutely, yes, it is a rather big problem for power measurements A power analyser needs to sample the voltage and the current waveforms of every channel in the system simultaneously to accurately determine the phase shift between voltage/current channels as well as magnitude measurements between voltage-voltage channels. If the input channels of an analyzer are not simultaneously sampled, it is inevitable that phase to phase RMS measurements as well as Watts measurements will be affected. A phase to phase Voltage RMS measurement is used as an example below.

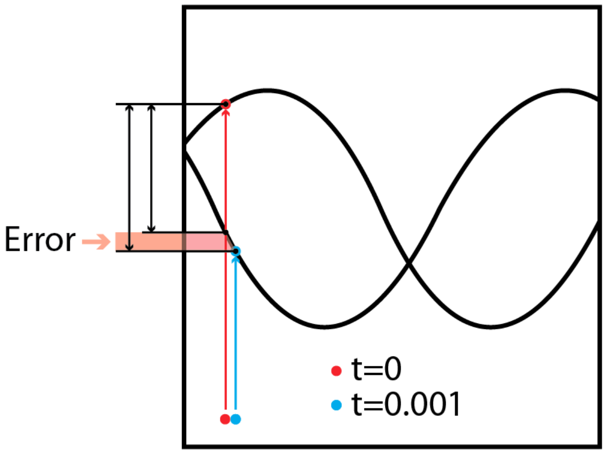


Fig.3 – Multiplexed phase-phase Vrms measurements cause errors

Fig.3 illustrates the errors caused by multiplexed sampling techniques, as implemented within typical DAQ card measurement systems due to the time delta between the sample at t=0 and t=0.001.

The sample by sample phase to phase readings will be incorrect when utilising a multiplexed DAQ card to acquire the raw data for power measurement. All N4L power analyzers sample the raw analogue signals present on all input channels simultaneously, this requires a signal chain capable of collecting raw samples in parallel – not a trivial task when sampling in the MHz region at a resolution of 14 bit.

N4L have developed a dedicated signal chain able to simultaneously sample 12 analogue channels (6x voltage and 6x current) plus the necessary torque and speed inputs required for any application. The management and acquisition of samples is handled by a combination of an FPGA and a DSP, with proprietary isolation techniques.

**DAQ Issue #4 – Traceability, what traceability?**

A power analyser should not only provide accurate measurements; it should also be able to prove those measurements against a traceable reference.

Unless a precision measurement device has been verified against a traceable reference with applicable uncertainties calculated, the measurement or specification of such a device cannot be relied upon. Accuracy "by design" is not enough, any precision analysis system should be traceable back to a primary ISO17025 reference.

**Uncertainty? Is this simply the accuracy of the calibrator?**

It is not as simple as that, while a more accurate calibrator will help to determine the uncertainty of any calibration process, you must also know;

1) The uncertainty of the calibrator
2) The repeatability of the measurement of the analyzer under calibration
3) The resolution of the result of the analyzer under calibration

Fig. 4 (Example Calibration setup for the PPA4500 Power Analyzer and Fluke 6105A)

**Uncertainty = Calibration Uncertainty + Resolution of Analyzer + Repeatability of Analyzer**

It is item 2 in this list that will prove most difficult for a DAQ based system as the process of determining the repeatability is extensive. Multiple tests must be made over long periods of time to determine the repeatability of a calibration system coupled with a calibrator. It is the combination of the two, plus the interconnecting hardware that is important. The accuracy of any precision measurement device must include repeatability performance of the calibrated instrument, the process of determining repeatability is not trivial.

*“The accuracy of any precision measurement device must include repeatability performance of the calibrated instrument, the process of determining repeatability is not trivial.”*

While it is not impossible to carry out all three of these steps, by the time this process has been completed, the cost of investment in time required would cover the purchase of a dedicated power analyser many times over. If one were to carry out full uncertainty calculation, it is very likely that once uncertainty is calculated, the analogue challenges discussed in this article will become apparent and the economic case for developing a DAQ based, accurate and ***traceable*** power measurement system soon become untenable.

**DAQ Issue #5 – True real time processing, with no-gap**

A requirement often overlooked within the power measurement industry is true real time processing with no-gap, even by many dedicated power analyser manufacturers. True real time processing involves a signal chain which acquires, processes and disposes of samples “on-the-fly”. This negates the requirement to buffer samples and thus also eliminates any need for a sample buffer, as buffering samples at the data rates required will soon fill up any available system memory.

**Why is this important?**

Imagine a PWM driven electric motor rotating at 0.1Hz that requires cycle-by-cycle analysis of power. Both a “buffer based” acquisition system (such as a DAQ based system) and a true real time no-gap system (such as the N4L power analyzers) need to acquire enough samples to encapsulate one entire cycle (10 seconds of data points on every channel, at 2Ms/s this is a total of 240 million samples for a 6-phase system).

Within a true real time, no-gap signal chain, the length of the acquisition window (10 seconds in this case) is of no concern to system memory as the samples will be processed on-the-fly. After processing, the computed answers are accumulated within memory and the raw samples are disposed of. Thus, the memory only requires enough space to hold a handful of accumulated values, such as integrated watts, until the end of the acquisition window - only kB’s, not Gb’s of memory space.

A memory buffer based signal chain handles samples in a different way, instead of processing the individual samples on-the-fly they are stored in memory (buffered). This is a problem as memory depth is always finite and eventually it will run out.

Not only that, by storing instead of processing the samples on the fly, once the acquisition window is complete there will be a huge amount of signal processing required to turn the buffer full of raw samples into Vrms, Irms, Watts, reactive power, active power and so on. The greater the number of samples requiring processing, more time will be required to complete these tasks and hence there will need to be a delay in sampling between completion of one window and the beginning of the next.

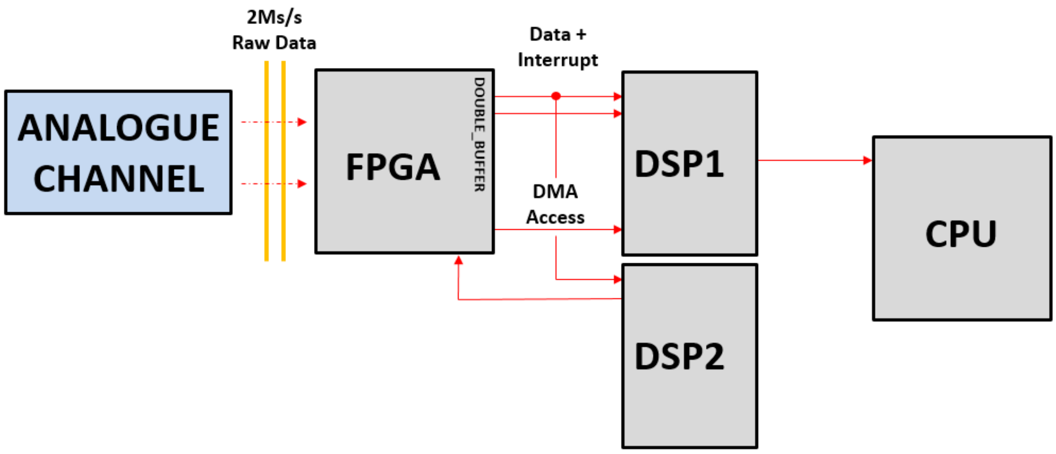


Fig. 5 – N4L's Dual DSP/FPGA real time no-gap signal chain (simplified)

In situations where the acquisition window needs to cover a long time period, buffer based instruments have significant limitations:

1. Reduce sample rate – Not ideal as this will reduce the Nyquist bandwidth
2. Increase memory size – Expensive, also causes larger gaps between windows as more mathematics must be performed on a greater number of samples in between windows. This fixes one problem and creates a bigger one.

Neither of the above options are ideal and will result in poorer measurement performance, measurement of power will be significantly restricted unless true real time gapless analysis is performed.

A "true no-gap" analyser should be able to maintain constant sample rate no matter whether the acquisition window is of short or long duration.

## Final thoughts

DAQ acquisition systems are extremely versatile and can provide key measurements within a vast array of applications and this application note should not be construed as stating any different. However, while DAQ systems solve a significant number of problems within the test and measurement industry, they do not provide answers in situations where precision power measurement is a prime concern.

With this in mind, high precision metrology requires dedicated analogue and digital circuitry along with an interconnecting communication backbone between the two, provided by dedicated topologies such as the dual FPGA/DSP physical layer within N4L power analyzers.

It is only dedicated power measurement signal chains that can provide the performance required by and expected of the industry. Such high demands require real-time no-gap analysis, traceable accuracies and repeatability only possible with a dedicated "end-to-end" measurement system.

It should also be noted that power analyzers such as N4L's will have endured years of development including a vast amount of work being afforded to the validation of the measurement system to traceable standards. N4L have spent a significant amount of effort developing dedicated ISO17025 traceable calibration systems to verify performance throughout the entire frequency range. This work behind the scenes is not immediately obvious, yet it is vitally important to any serious power measurement.