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APPLICATION NOTE 41

In Digital Sampling Metrology
What is the optimum ADC bit count?

Since the advent of digital measurement instrumentation where sampling and digital processing began to replace solely analogue designs, it has been understandably common for potential users to enquire about the specification of digitising devices. It follows that a question commonly asked of our engineers becomes: "what is the bit count of your ADC?"

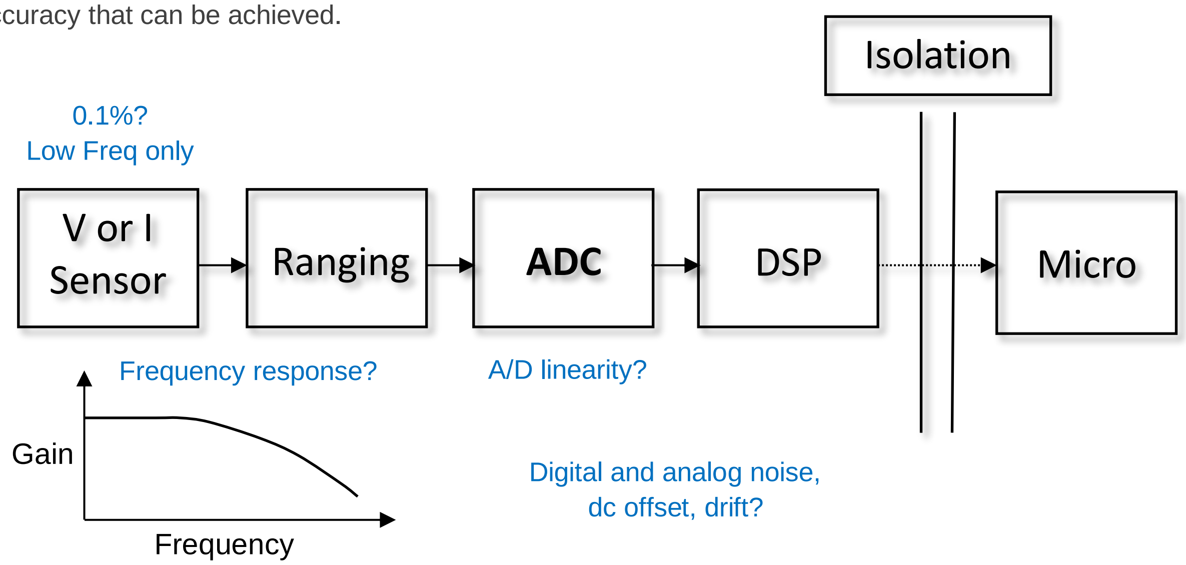
This appears at first a reasonable question, since basic digital theory tells us that more 'bits' will provide greater resolution, so people imagine that the number of bits must be a logical way to establish the limits of accuracy in a measurement instrument. The reality however is that this is usually a pointless question, because the ADC bit count of a measurement instrument tells you little about the true accuracy or meaningful resolution of any measurement device.

In this document we will explain not only why it is a pointless question, but why most of the those who ask it are prompted either by a marketing person, inclined to use an easy pseudo technical differentiator for sales purposes, or inexperienced engineers, unfamiliar with the complexities of instrumentation design beyond a rudimentary level.

What are the primary influences on measurement accuracy?

In a very simple digitising system with little or no signal conditioning and where the signal to be measured is applied directly to an ADC, then the real or effective quantization level (resolution), linearity, noise and no missing code specification will indicate the meaningful resolution and approximate accuracy.

However, in ALL precision power measurement instruments, the ADC is only part of a structure that requires many functional elements which dictate the analogue response and therefore also the accuracy that can be achieved.



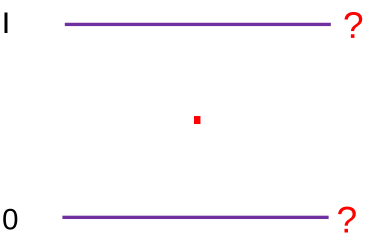
Even in a very basic measurement system as illustrated here, functions before an ADC will dominate the absolute accuracy. It should be recognised too, that critical functions of isolation, noise rejection and data processing after the ADC will also have a much greater impact on measurement performance than the ADC bit count.

Does the number of input bits dictate resolution?

The simple answer is no. There are a wide range of techniques that make the absolute number of sampling bits just one of many considerations when developing an optimum digitizing system.

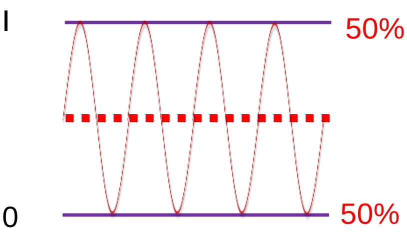
Consider for example the fact that for any cost/performance band, a low bit count ADC is commonly more linear than a high bit count ADC. This superior linearity is the reason that many high precision measurement instruments specifically use lower bit count ADC's combined with innovative sampling techniques to achieve higher resolution and accuracy than a high bit count ADC may achieve.

For illustration, let us consider how to measure a point that is between two available states and for simplicity, we can imagine a one bit system with two states that represent 0V and 10V:



In a 1 bit system, we know that an input to the ADC is read as either 0 (0V) or I (10V)
So it would seem that we could not 'resolve' a point between 0V or 10V, for example 5V indicated by the sample shown.

However, by using faster sampling and taking advantage of the fact that all ADC's have noise, or by adding 'jitter' to a system, we can identify any level between the available levels.



If we sample faster and use ADC noise or added jitter equivalent to 1 bit, we will force the applied signal to be in either the '0' or 'I' position for a proportion of samples equal to the absolute level between bits (quantisation levels).
So in this example where we have 50% of logic '0' samples and 50% of logic '1' samples, we know that the input is 5V

This principle can be used to resolve a signal point between bit levels of an ADC to almost limitless precision.

We should be clear that higher bit count ADC's do give the benefit of resolving a level with less samples and N4L always use multiple bit devices. However, the selected number of bits must be balanced with many other considerations of equal or greater importance, with linearity being the most obvious example. It must therefore be recognised that anyone who states or thinks high resolution can be achieved only with high bit count, is wrong.

What is the right way to find the accuracy of a measurement instrument?

In any field of precision metrology, a potential customer should be very wary of any supplier who tries to draw discussions about accuracy toward their ADC specification. A well-known phrase used in the world of accredited laboratories states: "in metrology, you should not trust what is claimed, only what is proven".

The right way to find the resolution and accuracy of any measurement instrument is to ask two simple questions:

Question 1 – What is your product measurement accuracy specification over the operating range you offer?

Question 2 – How do you prove it?

How should a supplier answer these two questions?

It should be easy, because any supplier will have a defined specification which should answer question 1 and question 2 is answered by a calibration certificate verifying measurement accuracy in accordance with that specification.

To illustrate this, we follow with some lines from the standard calibration certificate of a PPA5500 power analyzer from N4L:

```
Phase tests
      [------------ applied -------------]       phase 1 [--------- phase ---------]
                                         ranges           dev       spec     uncert
 OK:  55.00 Hz  220.00 V  1.0000 A +0.000°  7  5 -0.000° <-0.000°> [0.006°] {0.003°}
 OK:  55.00 Hz  220.00 V  1.0000 A +30.00°  7  5 +30.00° <+0.000°> [0.006°] {0.003°}
 OK:  55.00 Hz  220.00 V  1.0000 A +60.00°  7  5 +60.00° <+0.001°> [0.006°] {0.003°}
 OK:  55.00 Hz  220.00 V  1.0000 A +90.00°  7  5 +90.00° <+0.000°> [0.006°] {0.003°}

Verify power measurement at 220V 7A at 40-850Hz
      [------------- applied -------------]        [---- phase 1 ----] [---------- VA ---------] [---------- W ----------]
                                          ranges                            dev      spec     uncert     dev      spec     uncert
 OK:  40.00 Hz  1.5400kVA  1.5400kW +0.000°  7  6  1.5399kVA  1.5399kW <-0.00%> [0.13%] {0.016%} <-0.01%> [0.07%] {0.016%}
 OK:  55.00 Hz  1.5400kVA  1.5400kW +0.000°  7  6  1.5400kVA  1.5400kW <-0.00%> [0.13%] {0.013%} <+0.00%> [0.07%] {0.013%}
 OK:  150.0 Hz  1.5400kVA  1.5400kW +0.000°  7  6  1.5399kVA  1.5400kW <-0.00%> [0.13%] {0.016%} <+0.00%> [0.07%] {0.016%}
 OK:  400.0 Hz  1.5400kVA  1.5400kW +0.000°  7  6  1.5399kVA  1.5399kW <-0.01%> [0.14%] {0.016%} <-0.01%> [0.07%] {0.016%}
 OK:  850.0 Hz  1.5400kVA  1.5400kW +0.000°  7  6  1.5399kVA  1.5399kW <-0.00%> [0.14%] {0.016%} <-0.01%> [0.08%] {0.016%}

Verify power measurement at different phase angles at 220V 15A
      [------------- applied -------------]        [---- phase 1 ----] [---------- VA ---------] [---------- W ----------]
                                          ranges                            dev      spec     uncert     dev      spec     uncert
 OK:  55.00 Hz  3.3000kVA  3.3000kW +0.000°  7  7  3.3000kVA  3.3001kW <+0.00%> [0.15%] {0.013%} <+0.00%> [0.08%] {0.013%}
 OK:  55.00 Hz  3.3000kVA  2.8579kW -30.00°  7  7  3.3000kVA  2.8580kW <+0.00%> [0.15%] {0.013%} <+0.00%> [0.09%] {0.013%}
 OK:  55.00 Hz  3.3000kVA  2.3335kW +45.00°  7  7  3.3000kVA  2.3335kW <+0.00%> [0.15%] {0.013%} <+0.00%> [0.10%] {0.014%}
 OK:  55.00 Hz  3.3000kVA  1.6500kW -60.00°  7  7  3.3000kVA  1.6501kW <+0.00%> [0.15%] {0.013%} <+0.01%> [0.14%] {0.015%}

Verify low power measurements @ 0.5W at 230V 50Hz and 110V 60Hz
      [------------- applied -------------]        [---- phase 1 ----] [---------- VA ---------] [---------- W ----------]
                                          ranges                            dev      spec     uncert     dev      spec     uncert
 OK:  50.00 Hz  3.4500 VA  500.00mW -81.67°  7  1  3.4525 VA  500.90mW <+0.07%> [2.15%] {0.042%} <+0.18%> [0.41%] {0.051%}
 OK:  60.00 Hz  1.6500 VA  500.01mW -72.36°  7  1  1.6514 VA  499.52mW <+0.08%> [2.20%] {0.042%} <-0.10%> [0.30%] {0.044%}

Verify external inputs
      [------- applied -------]        [------- phase 1 --------]  [------ magnitude ------] [--------- phase ---------]
                               ranges  voltage       current         dev      spec    uncert    dev       spec      uncert
 OK:  55.00 Hz  1.2462 V 0.000°  9  9  1.2462 V  1.2462 A +0.000° <+0.00%> [0.10%] {0.024%} <+0.000°> [0.006°] {0.002°}
 OK:  400.0 Hz  1.4311 V 0.000°  9  9  1.4312 V  1.4312 A +0.000° <+0.01%> [0.09%] {0.023%} <+0.000°> [0.009°] {0.002°}
 OK:  8.000kHz  1.3681 V 0.000°  9  9  1.3682 V  1.3683 A +0.000° <+0.01%> [0.13%] {0.031%} <+0.000°> [0.085°] {0.002°}
 OK:  48.00kHz  1.3675 V 0.000°  9  9  1.3678 V  1.3678 A +0.000° <+0.02%> [0.29%] {0.054%} <+0.000°> [0.485°] {0.004°}
 OK:  220.0kHz  1.3654 V 0.000°  9  9  1.3667 V  1.3667 A -0.002° <+0.10%> [0.97%] {0.391%} <-0.002°> [2.205°] {0.013°}
 OK:  700.0kHz  1.3543 V 0.000°  9  9  1.3665 V  1.3669 A -0.027° <+0.93%> [2.89%] {0.442%} <-0.027°> [7.005°] {0.037°}
 OK:  1.200MHz  1.3174 V 0.000°  9  9  1.3299 V  1.3301 A -0.023° <+0.96%> [4.90%] {0.698%} <-0.023°> [12.01°] {0.062°}
 OK:  2.000MHz  1.2819 V 0.000°  9  9  1.2830 V  1.2828 A -0.011° <+0.08%> [8.10%] {1.125%} <-0.011°> [20.00°] {0.102°}
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It can be seen that power, power factor and low power verification over primary power frequencies plus voltage, current, and phase over the complete frequency range is proven with traceable uncertainty.

There is no greater assurance of good design than traceable evidence of compliance to a stated specification.

Conclusion

The accuracy or meaningful resolution of a precision measurement instrument cannot be derived from the number of bits in an ADC. It is therefore a pointless question.

Anyone wishing to establish the ability of a measurement instrument to meet its defined accuracy should ask instead, for traceable evidence of compliance to its published specification.