# A Few Words From The microK Design Team

When we were tasked with designing the microK product in 2004, the brief was to produce a precision thermometer that measures at the sub-mK performance level and is simply the best in its class… the microK was to have the best performance (on all parameters!) and have the most comprehensive range of features. Two years on and with the microK in production, we look back on a project which has brought a lot of professional satisfaction to the team as we have pushed the performance boundaries (and ourselves) to achieve that goal. I thought it would be useful to set down some of the technical background to the microK instrument in order to shows what sets it apart.

Accuracy

Measurement uncertainty is a key parameter for any temperature metrologist. We wanted the accuracy of the microK to contribute the minimum uncertainty possible.

Other instrument working at or below 1mK uncertainty use either a DC (actually chopped DC) potentiometric measuring technique or are AC resistance bridges. We wanted the microK to work with thermocouples as well as PRTs and thermistors, so the AC bridge technique, with its excellent measuring performance, was not an option. One problem with DC instruments lies in the ADC – typically they use an integrating ADC whose linearity is fundamentally limited to a few ppm by dielectric absorption effects and the limitations of the analog circuits. The best commercially available integrating ADCs (produced by Thaler) have a linearity of 3ppm (very good, but not good enough for us) Some DC instruments use these ADCs and then 'linearize' the instrument in order to correct for the limitations of their ADC. But with our sights set on being the best, such an approach wasn't acceptable - so we decided to design our own ADC. The new ADC had to have a linearity of better than 0.5ppm since it is the "measurement engine" for any instrument and we were determined not to leave the microK 'underpowered'.

The ADC used in the microK is a unique adaptation of the established sigma-delta technique in which the analog signal is balanced again a modulated waveform that has only two states (a 1-bit DAC). A control loop controls this DAC and ensures that the average value of the modulated waveform equals that of the analogue signal. The average value of the modulated waveform, determined using digital-signal-processing (DSP), is the output from the ADC.
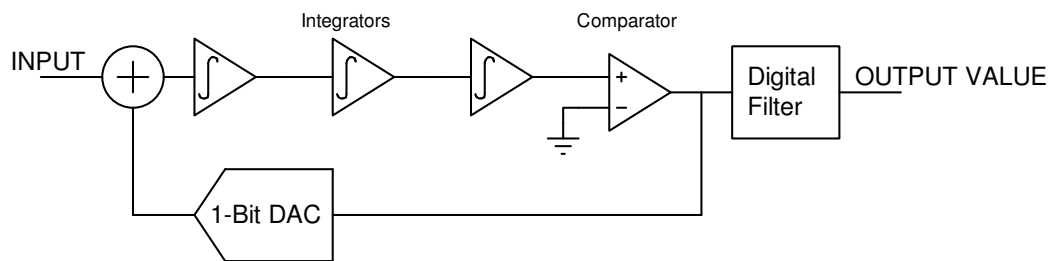
Conventional Sigma-Delta ADC

Sigma-delta ADCs are readily available as single integrated circuits and provide phenomenal resolution. However, their linearity is significantly more limited than their resolution and the converted signal is inevitably quite noisy (since they rely on taking a very noise, binary signal and filtering it heavily using DSP). The microK ADC is different in that it uses a 5-bit DAC in place of the 1-bit DAC in the control loop. This would not normally be feasible, since the DAC would 'carry' the full accuracy burden of the measurement. However, the microK ADC uses pulse-width-modulation (PWM) to generate the 5-bit signal thereby converting the analog signal requirement into one of timing. This in itself presented some interesting challenges; our sigma-delta control loop works at 100kHz in order to achieve our required 0.1s conversion time, so 0.5ppm corresponds to a timing accuracy of 5ps, or to put it in perspective, about the time it takes light/electrical signals to travel 1.5mm!. In actual fact we have been able to do better than our 0.5ppm target.

A fundamental benefit of the new ADC is its low noise. The 5-bit PWM DAC immediately reduces the noise by a factor of 32 compared with the conventional 1-bit sigma-delta approach. The new ADC therefore gave us exceptional linearity and extremely low noise… both of which are key to achieving low measurement uncertainty.
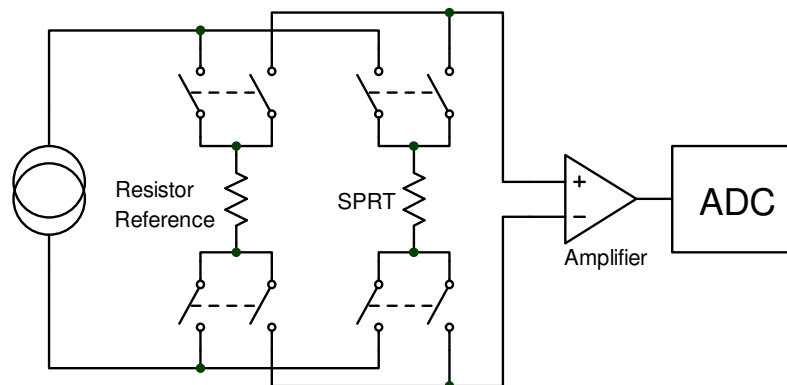
Stability

Traditionally, DC potentiometric instruments pass a common current through the device under test (DUT) and a reference resistor. A precision voltmeter is then switched between the two devices in order to measure the voltage across them and thereby determine the ratio of their resistance.
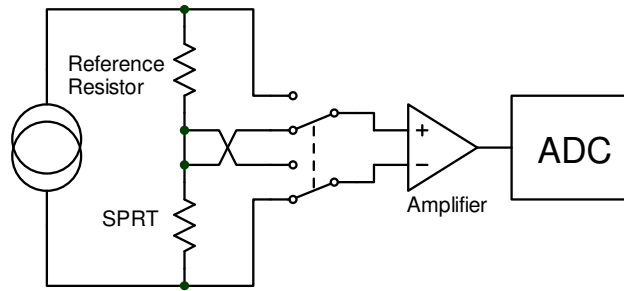
The problem with this approach is that the common-mode potential at the voltmeter input changes between the two measurements, which ultimately limits the measurement accuracy.

With the microK, we have taken an alternative approach. We have only one measurement 'position' into which we successively switch the DUT and reference resistor. There is then no change in common mode voltage between the measurements. Indeed the DUT and reference measurements are 'indistinguishable' from each other, save for the fact that they take place at different times. This "substitution" technique provides true zero drift (inherently stable).

Reliability

The sophisticated circuitry behind the microK's performance together with its unparalleled features mean that it is one of the most complex instruments of its type. Despite this, we wanted it to have the highest reliability and to have the shortest service/repair time.

Experience shows that electronic components themselves are very reliable. Considering their complexity, modern integrated circuits have amazing reliability… basically any integration at the silicon level provides the highest possible reliability. That is why we use a Field Programmable Gate Array (FPGA) containing 150,000 gates to perform the DSP that is at the core of the ADC's performance.

Poor reliability comes primarily from interconnections and contacts, particularly connector contacts (especially if they are not gold plated) and potentiometer wipers. That is why we banned potentiometers from the design and have just two ribbon cables (with gold plated contacts) to connect together all the PCBs in the microK. All other instruments operating at or below 1mK use relays for signal switching, which provide the primary failure source for these products. The microK uses the most modern semiconductor devices for its signal switching to lay claim to being the only 100% solid-state instrument of its type

The electronics use modern surface-mount technology (except for a few devices that are not available in surface mount). Component soldering is made by a machine process, which is typically and an order of magnitude more reliable than conventional hand-soldered joints. To maximise reliability, the microK circuit is realised on just four printed circuit boards any of which can be replaced in less than 10 minutes, so if a microK does require service it is a quick and easy process.

With this attention to detail in the implementation of the electronics, the microK offers extremely high reliability and low cost of ownership.

Quality –The No Compromise Approach

Throughout the project, we were faced with choices about the components to use and the circuits to employ. The design team presented the options to the wider management team at design reviews and invariably the decisions went in favour of the best performance rather than the lowest cost. We have, of course, tried throughout to avoid unnecessary cost but have spent the budget for the instrument's manufactured cost where it adds real value. That is why the microK has the best available zener references, the most stable reference resistors and a high resolution (640 x 480 full VGA) colour LCD with an industrial grade touch screen.

Tellurium Copper "Cable Pod"™ Connectors

Thermal EMFs (the EMFs generated at the junction between dissimilar metals) are a potential source of error when working at this precision. These can largely be eliminated when measuring resistance by reversing the current and averaging the measurements. That is okay for use with PRTs and thermistors, but of course is of no use when measuring temperature with thermocouples… the thermal EMFs need to be eliminated at source.

We wanted to use tellurium-copper (gold plated, of course) as the contact material, since this combines good mechanical properties with extremely low thermal EMFs against the copper terminations of a thermocouple. We also wanted the terminals to be able to accept any of the standard terminations, making it easy for users to connect any type of sensor. Whilst standard binding posts are available in tellurium-copper, we were looking for something

a little better than "standard". We settled on the Cable Pod™ connectors made by Eichmann for the hi-fi market as these accept 4mm plugs, spades or bare wires. They have other nice features, such as a clamping arrangement that doesn't rotate as you screw down the terminal, thereby protecting the wires from mechanical damage… their features and EMF performance are ideally suited to our desire to offer the best solution.

The historical dominance of AC resistance bridges in this market means that many PRTs have BNC terminations. For this reason, we set the separation of the terminals to ¾" (19mm) allowing standard adaptors to be used for connecting BNC terminated PRTs. We wanted to make the microK as easy to use as possible.

When measuring the voltage from a thermocouple, it is common practice to reverse the input terminations and repeat the measurement in order to detect and/or compensate for any thermal EMFs or offsets inherent to the voltmeter instrument and its terminals. In the microK, we automatically reverse the input connections immediately behind the input terminals. Since we do this with solid-state switching, this does not suffer from the limitations (extra thermal EMFs) associated with doing this using relays. The user can, of course, still reverse the connections manually to gain confidence in the instrument, but it is no longer necessary to achieve low measurement uncertainty.

Final Thoughts

This has been one of the most exciting and rewarding projects I have worked on. The design team are proud to be associated with this product and hope that customers will derive as much satisfaction from using the instrument as we have from designing it. We are, of course, very happy to hear from our customers and if you want to contact us with questions, comments or feedback, then please email us at microkteam@isotech.co.uk.

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