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Data Acquisition/Distributed Instrumentation: Isolating Circuits To Prevent Common-Mode Isolation Problems

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In all measurement and data acquisition systems, the test engineer must avoid or minimize problems associated with common mode voltage and related common mode currents, which compromise test accuracy and may pose a system reliability problem. Common mode voltage is an in-phase signal or voltage that appears simultaneously on both input terminals of a measurement instrument or data acquisition device. Common mode voltage can cause common mode current (or noise current) flow through ground loops in measurement systems that have multiple grounding locations. Any noise currents that appear between the low input and chassis ground of the measurement device may be a problem.

Additional ways in which common mode voltage can cause problems are:

- Common mode voltage can offset the signal being measured by an amount that exceeds the full scale range of the instrument input.
- Common mode voltage can exceed the maximum overvoltage rating of the measurement device front end, which may damage circuit components.
- Common mode overvoltage can cause barrier breakdown and put test personnel at risk of electrical shock, particularly when they handle back-end equipment and cables where they expect low potentials associated with solid-state devices.
- Common mode voltage can create what appears to be a noisy measurement, even if the signal is stable.

With regard to offset, the maximum common mode voltage rating of the measurement device is the difference between the maximum magnitude of the signal you are trying to measure and the full scale range of the input. For

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example, if you have a 10V full scale range and need to measure signals with a maximum level of 6V, the input can tolerate any common mode voltage less than 4V and still make the measurement.

Common Mode Voltage Isolation

If your application has the possibility of a common mode voltage, then you probably need isolation circuitry on the front end of the instrument. Typical applications are those requiring accurate measurements where the sensors or transducers are located on equipment operating at high voltage (compared, for example, to voltages found in many solid state devices.) A concrete example is a thermocouple used to measure the temperature of windings in an AC motor, which could be operating at 440V or higher. It is possible for the thermocouple to come in contact with high voltage inside the motor; when that happens, the high potential will appear at the input of the measurement instrument.

Isolation is absolutely required when (a) the common mode voltage exceeds the full scale range of the measurement device input or (b) any time a measurement involves the connection of the instrument to a human body (for safety reasons.) As long as common mode voltage does not exceed the barrier rating of the input, isolation circuitry ensures that no connection exists between the instrument ground and that of the signal source. In other words, the signal can float above ground at a level defined by the isolation barrier rating.

Comparison of Isolation Designs

Ideally, a measurement device should have built-in isolation circuitry. However, since many measurement devices do not offer internal isolation, the isolation is often accomplished in external signal conditioning devices. In the past, both internal and external designs provided rather bulky solutions. In PC-based data acquisition system boards and instruments, the level of isolation has been limited by available space. The external approach avoids internal space problems but has other shortcomings.

Frequently, the external isolation approach uses B series signal conditioning modules (3B, 5B, etc.) Typically, these modules are installed on a motherboard, in a backplane or on a separate chassis. Accuracy associated with 5B series signal conditioning is relatively low by today’s measurement standards, commonly 0.1% at best. In addition, isolators like the 5B series are not designed to maintain a low common mode current, a shortcoming that can result in substantial measurement errors. Also, using 5B modules can be expensive because of all their attendant connection paraphernalia.

Benchtop instruments typically offer internal isolation and do not have the board space and accuracy limitations of a data acquisition system or instrument card. Such instruments can provide high precision measurements at resolutions that meet the requirements of the most demanding applications. However, benchtop instruments need substantial space and typically cannot be used in distributed measurement applications.

Benchtop instruments can employ isolation circuitry with a rating of several hundred volts or higher. For example, most of Keithley's Series 2000 digital multimeters can accommodate 1500V from the inputs to earth ground. Still, if an application requires small size and a limited number of measurements, a benchtop instrument often is too large and expensive.

Related isolation problems perplexing users and developers of test and process systems include:

- Bulky equipment, often requiring 19″ rack mounting
- Environmentally hardened (and expensive) hardware for plant applications
- Measurements compromised by electrical noise induced into signal cables
- Separate and costly coaxial cabling to cut down on electrical noise
- Low accuracy in home-grown solutions using PLCs and data acquisition systems
- Costly, cumbersome adapters for incompatible interfaces

Keithley's SmartLink Instrument Solution

Keithley solved the size and cost problem with its SmartLink® miniaturized instruments, which can be located close to sensors in virtually any kind measurement environment. When the SmartLink instruments were first introduced, their small size (approx. 1″ × 1¼″ × 6½″) was an impediment to providing internal isolation. To maintain the miniature form factor and yet provide common-mode voltage and common-mode current protection, Keithley engineers had to take a new and innovative approach to isolation circuit design (patent pending.)

The new design accomplishes the same high levels of isolation found in some benchtop instruments and does it in a fraction of the space previously required. For example, in Keithley's new SmartLink isolated DC volts and Ohms measurement instruments, the isolation specifications are ±400V measurement inputs, 800V channel-to-channel, and 1500V front-to-back. Simultaneously, this module offers 16–20 bit measurement resolution, which equates to as little as 26 ppm. Even if an application does not require such high precision, the related stability and the resulting long calibration cycle can be a substantial benefit.

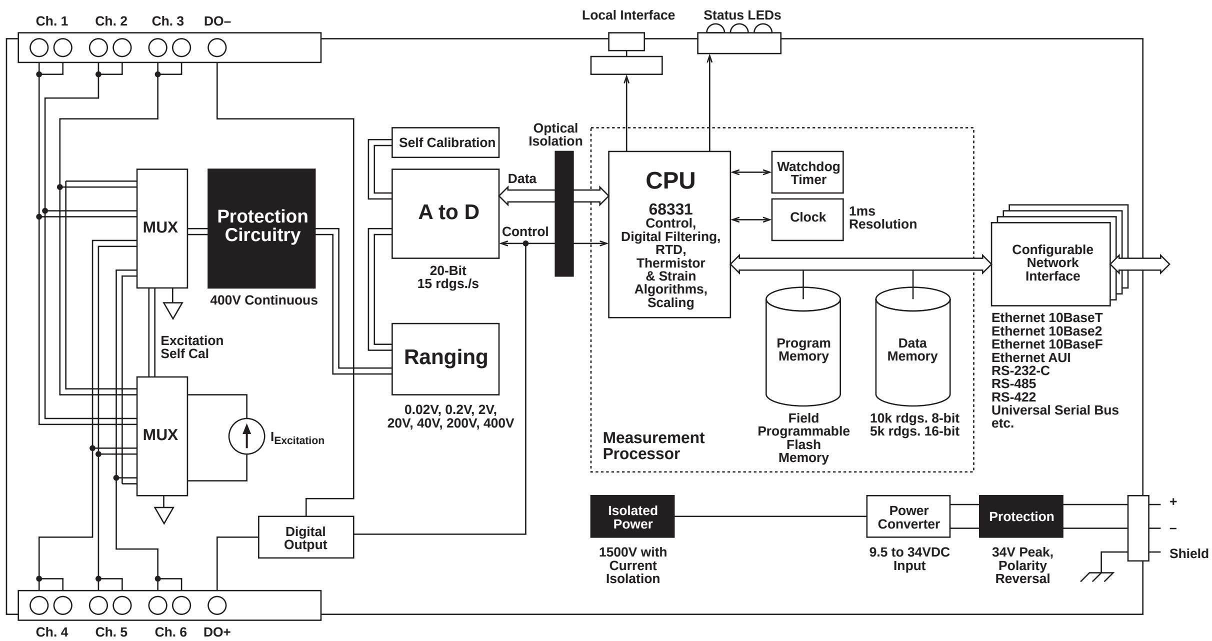

Figure 1 SmartLink instruments offer 400V continuous protection circuitry, optical isolation between the A/D converter and CPU, 1500V with current isolation, and 34V peak polarity reversal protection.

Voltage level (barrier) isolation is only half of the story. Keithley not only achieves 1500V of barrier isolation, but its new circuit design also minimizes common mode current and avoids noise from internal power sources that supply the isolation circuitry. This is unprecedented functionality in a space as small as that available on a SmartLink miniaturized instrument.

Getting the Best of Both Worlds—Small Size and Effective Isolation

Appreciating this accomplishment requires an explanation of common mode current and common mode noise problems associated with isolation circuit design, and how these problems relate to size constraints. Although the new SmartLink instruments use many isolation concepts found in bulkier designs, innovative miniaturization techniques and careful component selection results in a much smaller form factor, while providing superior common mode current rejection.

Conventional isolation designs often make use of optically coupled relays to create a voltage barrier. This type of design can provide good voltage isolation, but is rather bulky and may present other problems. For example, other considerations include:

- Isolation circuitry input impedance
- Noise currents and spikes originating in power sources that supply the isolation devices
- Common mode and leakage currents that flow to ground

Keithley's new design has optically coupled solid-state switches utilizing CMOS technology. However, CMOS transistors have substantial capacitance and may have leakage problems in their off state. These characteristics can lead to crosstalk between channels and present a low impedance input to incoming signals. Such problems cause measurement errors and inaccuracies. Keithley's new isolation design overcomes these problems by using special circuit techniques that makes solid-state switches function as well as electromechanical relays in terms of circuit characteristics mentioned above. Typically, the resulting input impedance has a shunt resistance greater than $10^9\Omega$ and less than 500pF capacitance, which virtually eliminates the problem of channel-to-channel cross talk, a major source of system errors.

The new design also overcomes voltage rating problems often associated with CMOS devices. Keithley handles this by cascading the solid-state switches to achieve 1500V front-to-back isolation on each channel, as well as ±400V inputs and 800V channel-to-channel isolation. Input multiplexing circuits used in SmartLink instruments are also protected with the same type of design.

To avoid noise and common mode currents, Keithley employs low leakage devices in power supplies and uses specially wound transformers designed to meet key specifications. A compact size is made possible by using the smallest solid-state devices and transformers available and by utilizing small-pitch surface mount technology.

User Benefits

The resulting channel-to-channel noise isolation and high level of common mode noise/current isolation provide high quality measurements in the smallest form factor available. The SmartLink instrument is so small it can be located only inches away from demanding signals and sensors. This minimizes lead length errors and induced electrical noise. The voltage barrier isolation provides greater equipment protection, while compact size offers greater system reliability through a significant reduction in hardware and cabling costs compared to external isolation solutions.

Keithley's implementation of its miniaturized isolation design is innovative, but the basic concept is simple. This produces a highly reliable solution. The end result is that signal integrity is improved and lab-grade measurements are a reality in factory and field environments.

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