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Eliminate RTD Self-Heating Errors

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Обе схемы и таблица саморазогрева даны отдельными GIF-файлами в той же дир.

Synchronous detection, long used in telecommunications because of performance potential, can now be effectively applied to sensor interface circuitry due to advances in low-cost ICs. This circuit *(see the figure)* employs a synchronous-detection scheme to measure the resistance of RTDs (resistance-temperature detectors) with self-heating errors of less than 0.001°C.

Conventional circuits require a large current through the sensor so that the smallest temperature change to be measured results in a voltage change larger than the total system noise, drift, and offset. For example, a 0.3-Ω/°C RTD with a 0.1% system resolution requirement and a system offset and drift of only 0.3 mV needs an excitation current in excess of 10 mA. The power dissipated in the RTD causes its temperature to rise above its ambient by:

$$\Delta T = (I^2 R_{RTD})\,\theta$$

where ΔT = the change in temperature due to internal power dissipation; I = excitation current; R_{RTD} = the value of the RTD in ohms; and θ = the self-heating effect in °C/mW.

In the previous example, upon power on, an RTD with θ = 0.05°C/mW, and a nominal value of 100 Ω at 0°C using a 10-mA excitation current will have a drift error of 0.5°C. That's due to the self-heating effect, which may take several minutes to settle *(see the table)*.

Waiting for the system to settle is pointless, because a self-heating-induced gain error remains. Drift errors can also be caused when the medium measured changes flow rate. This will cause a variation in the chill effect, which in turn will change ΔT.

Reducing the excitation current to 100 µA will, of course, effectively lower this self-heating error by 10,000. However, the transducer output will be reduced by 100 (to 0.385 µV per 0.01°C, for an RTD with α = 0.385 Ω/°C). (α is a measure of an RTD's resistance slope.)

That's well below the offset, noise, and drift of amplifying elements, effectively rendering the transducer output invisible.

In the synchronous technique, the RTD is excited by a 1-kHz ac waveform. The RTD's varying resistance then modulates this sine-wave carrier. The modulated waveform, which conveys information about the RTD value and hence sensed temperature, is demodulated using the same ac waveform as its reference. Because the demodulation process employs the same reference, uncorrelated perturbations like noise, offset, and drift can be distinguished and filtered out from variations caused by RTD modulation. In this application, the frequency stability and distortion of the nominal 1-kHz carrier aren't critical, because the same waveform is used for modulation and demodulation.

The circuit in the figure uses a 100-µA peak alternating current through the RTD to create an alternating voltage across it that's proportional to temperature. IC_{1b} (half of an AD706 precision op amp) supplies a reference voltage so that at some reference temperature, R_{T1} may be trimmed to yield a zero differential input voltage to the instrumentation amplifier, IC_2 (an AD620). IC_2 amplifies this differential voltage and R_G sets the gain of the instrumentation amplifier to 408. The output of IC_2 is then demodulated with a synchronous detector IC, IC_3. IC_3's output is low-pass filtered, removing all uncorrelated disturbances, such as noise, offset, and drift, while retaining a dc voltage that's proportional to the change in resistance of the RTD from its nominal value. IC_4 (a precision operational amplifier) provides a noninverting gain of 10. Potentiometer R_{T2} supplies the trim adjustment for gain accuracy.

The relationship between the RTD's resistance and the output voltage is then:

$$V_{out} = 2/\pi V_{pk}/10\text{ k}\Omega \times \Delta R_{RTD} \times G$$

where ΔR_{RTD} = the change in RTD resistance from nominal value; and G = total system gain.

For an RTD with α = 0.385 Ω/°C, the output scale then becomes 100 mV/°C of deviation from the reference temperature.

Update by Albert O'Grady

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When eliminating errors due to self-heating effects in RTD applications, the circuit shown in the updated figure is an enhanced version of the one in the original Idea For Design. Both solutions use a similar technique. The new circuit provides a digital-output representation of the temperature, however, while the original design offers an analog output that's proportional to temperature.

Typically, a digital output is more beneficial in terms of further processing to drive LCDs, for example, in conveying the measured value to the end user. The new circuit is a more integrated solution. It removes the majority of the signal conditioning previously required. This allows implementation on a smaller board area, and removes issues associated with noise and layout in systems that use many signal-conditioning components.

In temperature-measurement applications, dc excitation has generally been accepted as the normal method of exciting RTDs. The excitation current through the sensor must be large enough so that the smallest temperature change to be measured results in a voltage change that's larger than the system's noise, offset, and drift. The excitation currents required to overcome these errors are usually 1 mA or greater.

The power dissipated in the RTD causes its temperature to rise, introducing drift errors in the measurement and reducing system accuracy. For example, using a 1-mA dc-excitation source with a 1-kΩ RTD, which has a self-heating effect of 0.05°C/mW, results in a drift error of 0.5°C. Utilizing an ac-excitation source should reduce offset and drift effects, allowing excitation currents of much lower magnitude to be used in many applications. These lower-magnitude currents lessen the self-heating effects in the RTD and minimize the associated output errors.

Also eliminated with ac excitation are the errors that arise from parasitic thermocouples produced by differential metal connections (solder and copper track) within the circuit. The ac excitation is a form of synchronous detection in which the sensor is excited with an alternating excitation source. The analog-to-digital converter (ADC) then measures information in the same phase as that excitation source.

In the updated circuit, an AD7730 high-resolution sigma-delta converter is used for the ac-excited RTD measurement application. The converter is operated with split supplies, such that AV_{DD} and DV_{DD} are at separate potentials, as are AGND and DGND. The one stipulation with this arrangement is that AV_{DD} or DV_{DD} must not exceed the AGND by 5.5 V.

When operating with ±2.5-V analog supplies, the DV_{DD} must be restricted to +3 V with respect to digital ground. In the system, digital ground is the system ground. In this application, the ACX output from the AD7730 controls the reversing of the current. That output is with respect to the AV_{DD} and AGND supplies. When ACX is high, a current of 100 µA flows through the RTD in one direction. When it's low, that same current flows in the opposite direction through the RTD.

The switched-polarity current source is developed using op amps U1 and U2 in a standard voltage-to-current configuration. The AD7730 is configured for its ac-excitation mode and produces a square wave at its ACX output. During the conversion process, the ADC takes two conversion results, one on each phase of the ACX signal. It combines these to produce one data-output word representing the measured temperature.

DC-Induced Errors Are Revoved

Say the RTD output during phase one of the ACX signal is 10 mV and a 1-mV circuit-induced dc error exists due to parasitic thermocouples. The ADC then measures 11 mV. During the second phase, the excitation current is reversed and the ADC measures −10 mV from the RTD and again sees +1-mV dc error, giving an ADC output of −9 mV. These measurements are processed within the ADC (11 mV −(−9 mV)/2= 10 mV), thereby removing the dc-induced errors within the system. The use of ac excitation permits currents in the region of 100 µA to be effectively used in RTD applications, reducing self-heating effects substantially.

In the circuit shown, the resistance measurement is made with a ratiometric technique. Resistor values in the voltage-to-current converter don't affect system accuracy. As the exact value of the drive current isn't critical, a tolerance of around 1% is acceptable. So 100-ppm/°C resistors will suffice. Resistor R_{REF}, which develops the ADC reference, must be stable over temperature to prevent reference-induced errors in the measurement output.

In this circuit, temperature ranges from −200° to +200°C can be easily accommodated. Because very little rejection is offered at the chopping frequency, it's recommended that this frequency be selected at 57 Hz to provide rejection to both 50- and 60-Hz components. With that update rate of 57 Hz, resolutions of 16 bits p-p are achievable when using the AD7730 in its unipolar 0- to 20-mV range. With the AD7730L version used with the same operating conditions, peak-to-peak resolutions of 14.5 bits are achievable.

The AD7730 also offers RTD applications its immunity to both radiated electric fields and fast transient bursts (EFT). In a noisy environment, it's recommended to use it in chop mode. The chopper-stabilization techniques within the AD7730 eliminate offset and minimize offset drift. When the converter is operated in chop mode, the signal chain, including the first stage filter, is chopped. Overall drift performance drops to less than 5 nV/°C.

The AD7730 can be operated in the presence of electric fields (1 V/m to 3 V/m) from 30 MHz to 1 GHz. The offset remains flat across the frequency range. If chopping isn't incorporated, the offset performance degrades in the presence of an electric field and drifts with frequency. The following are the key advantages that the updated circuit offers over the original:

1. The integrated solution contains an on-chip programmable-gain amplifier, switching circuitry to control the ac current source, and processing power to handle the results from the ac excitation.
2. The new circuit provides the analog-to-digital function with all of the processing performed within the ADC. The AD7730 gives a digital representation of the measured temperature. This result can be further processed using the system microcontroller to drive LCD readouts, etc.
3. A peak-to-peak resolution of 16 bits is achievable, creating a data-acquisition system with high resolution and accuracy.
4. Minimal signal conditioning is required, so issues related to pc-board layout, noise, and decoupling are greatly reduced. The board area required for circuit implementation is also substantially smaller.
5. The total solution cost of the implementation is lower.

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