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READERS SOLVE DESIGN PROBLEMS

Platinum-RTD-based circuit provides high performance with few components

Jordan Dimitrov, Toronto, ON, Canada

The standard way of using an RTD (resistance-temperature-detector) sensor is to include it in a bridge followed by a differential amplifier. The problem is that two nonlinearities—one from the sensor and another from the bridge—affect the transfer function. Some approaches are available that attempt to avoid the problem, but they tend to be bulky and expensive (references 1, 2, and 3). An alternative circuit proposes adding only one extra resistor to the differential amplifier but provides neither design guidelines nor results (Reference 4). This Design Idea fills the gap. Although circuit analysis is somewhat complex, performance is good, and the circuit uses few components.

Besides the platinum RTD, R_{θ} , the circuit features only six precision resistors, an op amp, and a voltage reference (Figure 1). R_4 , the extra resistor for the differential amplifier, delivers

additional current to the sensor that relates to the temperature you are measuring. With proper design, the circuit can provide good linearity and stability over a wide range of input temperatures. The output voltage, V_O , depends on circuit components in the following way:

$$V_O = V_{REF} \times \frac{Y_1}{Y_2} \times \frac{R_{\theta}(Y_0 + Y_2 - Y_3 - Y_4) - 1}{R_{\theta}[Y_1 + Y_3 - R_2 Y_4(Y_0 + Y_1)] + 1}$$

where $Y_1 = 1/R_1$ and $I=0$ to 4.

For positive temperatures, a second-degree polynomial of the following form can approximate RTD characteristics:

$$R_{\theta} = R_0(1 + \alpha \times \theta + \beta \times \theta^2),$$

where R_0 is sensor resistance at 0°C, α and β are coefficients, and θ is the measured temperature.

After replacing the second equation

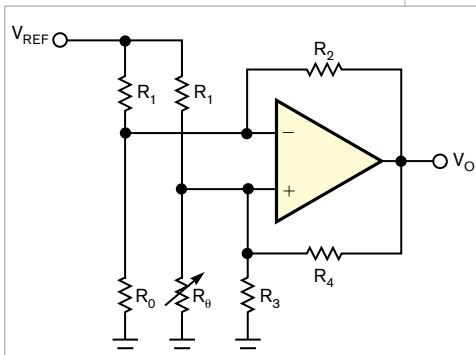


Figure 1 This generic RTD circuit needs few components.

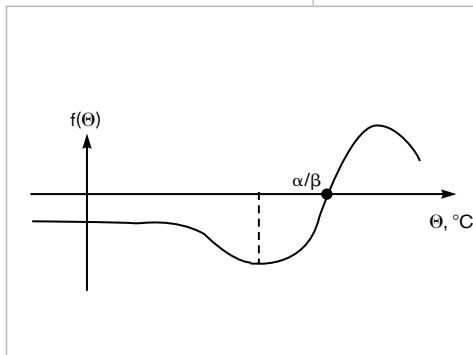


Figure 2 The general shape of function $f(\theta)$ varies with temperature.

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in the first and doing some rearrangements, you get:

$$V_O = \frac{\theta - B}{\theta^2 - B\theta - C} \times K \times \theta = f(\theta)K\theta,$$

where B, C, and K are constants and $f(\theta)$ is a function of temperature. Figure 2 shows the general shape of $f(\theta)$. The output voltage depends linearly on temperature when $f(\theta)$ is as close

as possible to a constant. This situation is most true around the minimum point of $f(\theta)$.

Some additional relations provide that the output voltage is 0V at temperature 0°C, the conversion coefficient is 10 mV/°C, the minimum of function $f(\theta)$ is in the middle of the measurement span, and

the current through R_{θ} causes negligible self-heating of the sensor.

Figure 3 shows the circuit that meets these requirements. The sensor is a DIN-IEC 751 platinum RTD. Microsoft (www.microsoft.com) Excel software fits 13 points of 0 to 600°C in steps of 50° from the RTD's calibration table. The spreadsheet software determined R_0 to have a value of 100Ω, α to have a value of $3.908 \times 10^{-3} \text{C}^{-1}$, and β to have a value of $-5.801 \times 10^{-7} \text{C}^{-2}$ with an R^2 factor of one.

All the circuit's resistors have tolerances of 0.02%, and the temperature

TABLE 1 EXPERIMENTAL RESULTS

Measurement range	-100 to +600°C
Nominal sensitivity	10 mV/°C
Basic accuracy (nonlinearity)	Well below ±1°C
Ambient-temperature effect	0.05°C/10°C
Power-supply effect	0.1°C/V
Cable effect (three-lead connection)	0.7°C/Ω
Power-supply range	±12 to ±18V
Consumption (600°C input)	9 and -3 mA
Operating temperature	-40 to +85°C

coefficient is 50 ppm/°C. You can use two trimming potentiometers, V_{R1} and V_{R2} , to independently adjust zero and span readings. You should perform span

adjustment at 550°C to match the magnitudes of the positive and the negative errors. You can also extend the temperature range to start from -100°C instead of 0°C without exceeding the basic nonlinearity. The three-lead connection to the sensor significantly reduces the influence of connection-cable resistance, R_C , on accuracy.

Table 1 shows the results of evaluating this circuit's performance with a calibrated, precision-decade resistance and a calibrated, 4.5-digit multimeter with readings at ambient temperatures of 24 and 68°C; power supplies of ±12, ±15, and ±18V; and cable resistances of 0 and 5Ω. **EDN**

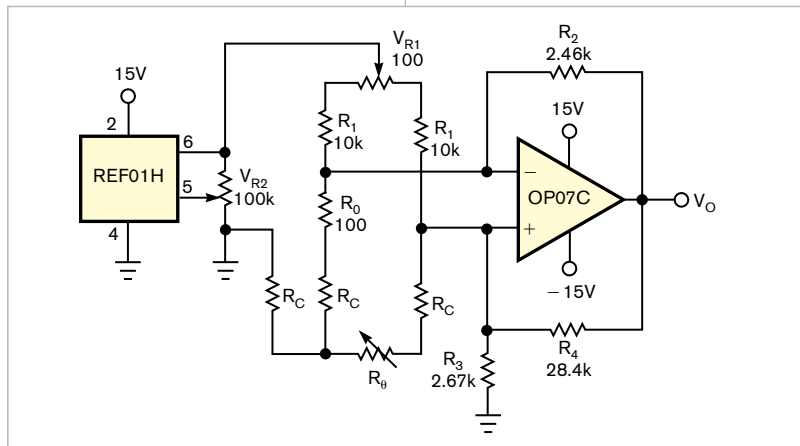


Figure 3 The full circuit needs trimming potentiometers V_{R1} and V_{R2} to adjust zero and span, respectively, and a three-lead cable for sensor connection. R_C is the cable's resistance.

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Proportional-ac-power controller doles out whole cycles of ac line

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In industrial and process control, it is often necessary to accurately control the temperature of a process. You control most heating elements using the "bang-bang" method—turning the power to them on and off at a predetermined setpoint. The temperature of the heated substance constantly hunts back and forth around the setpoint. You can achieve much

greater temperature precision using proportional power control. With this method, the controller monitors the temperature, proportionally varying the heater power to keep the temperature as close as possible to the setpoint. A PID (proportional-integral-derivative) control loop usually accomplishes this function. Varying the ac power to the heating element in a linear-proportion-

al manner is neither easy nor simple.

This Design Idea borrows from the delta-sigma-modulator concept. The controller sends cycles of the ac line to the load as the delta-sigma modulator determines. For example, when the input-control voltage is 15% of full-scale, only 15 of 100 ac cycles arrive at the load. Likewise, at 85%, 85 of 100 arrive (Figure 1). The control-voltage-input stage, IC_{1A} , is an inverting amplifier with a gain of negative one. This stage makes the control-voltage range over the positive side of 0V. In this example, the control-voltage input ranges from 0 to 2V full-scale. The control

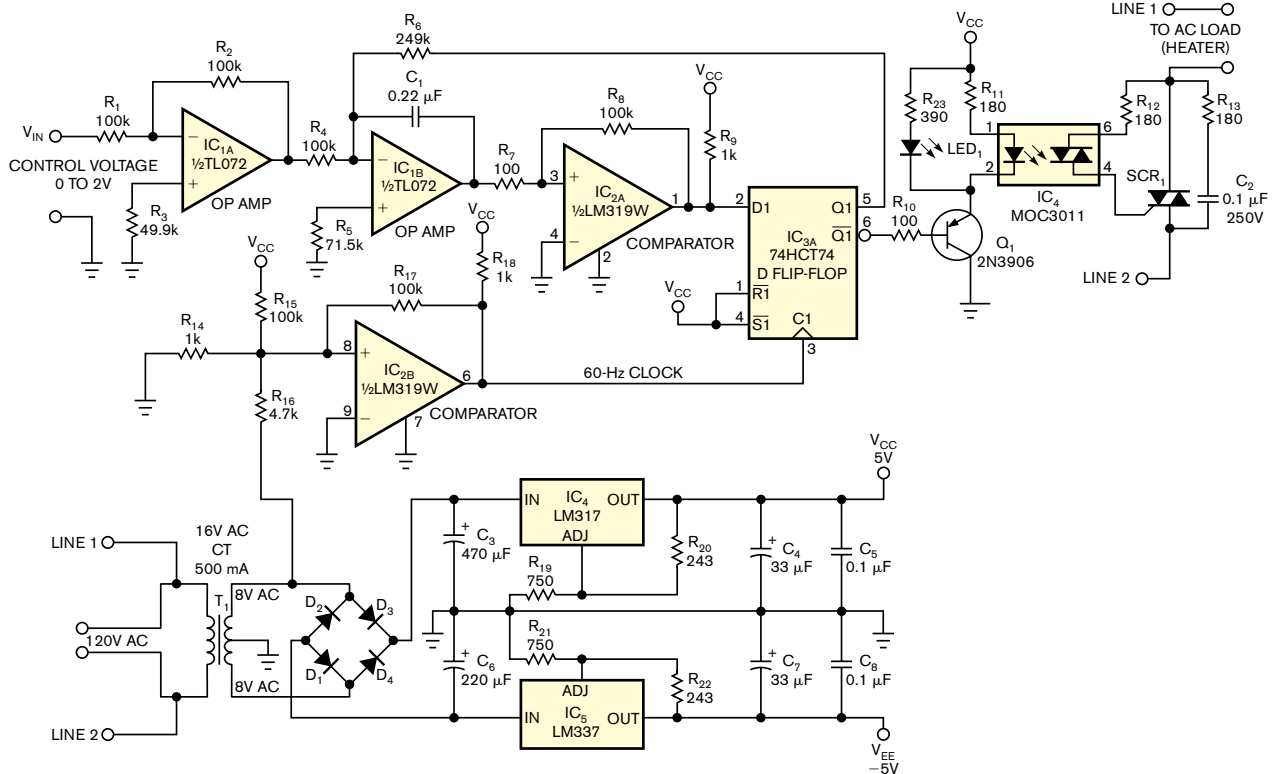


Figure 1 This ac controller borrows from a sigma-delta converter to output a number of whole cycles of ac-line power according to an input-control voltage.

voltage's input impedance is 100 kΩ.

The next stage, IC_{1B}, is an integrator. The integrator output ramps either up or down depending on the polarity of the input current. The speed at which it ramps depends on the magnitude of the input current. The integrator is the heart of the delta-sigma modulator. It forces a balance, on the average, between the control-voltage current in R₄ and the feedback current in R₆. In other words, the duty cycle of the output of IC_{3A}, a CMOS D-type flip-flop, must match the control-voltage percentage of full-scale.

Comparator IC_{2A} detects whether the integrator's output is positive, thus requiring more feedback current, or negative, thus requiring less feedback to maintain the balance. The output of the comparator switches between 0 and 5V. The flip-flop latches the comparator's decision on the next rising edge of the 60-Hz clock.

PNP transistor Q₁ and optoisolated SCR (silicon-controlled rectifier) IC₄ drive load-switching SCR₁ into conduction whenever the flip-flop provides feedback current to the integrator. Indicator LED₁ lights when the load SCR is on. The secondary of transformer T₁ detects the zero crossings of the ac-power line; these crossings provide the 60-Hz clock. The output of comparator

IF YOU TURN OFF THE SCR TOO LATE, ITS SELF-LATCHING NATURE MAY CAUSE IT TO STAY ON FOR AN EXTRA HALF-CYCLE WHEN IT SHOULD HAVE BEEN OFF.

IC_{2B} switches high during the positive half-cycles of the ac line and low during the negative half-cycles. Resistor R₁₅ provides a small positive bias, causing the edges of the 60-Hz clock to occur slightly early—which is better than late in this case. If you turn off the SCR too late, its self-latching nature may cause it to stay on for an extra half-cycle when it should have been off.

Both comparators IC_{2A} and IC_{2B} use a small amount of hysteresis to promote fast, clean switching. The remaining components generate the regulated 5 and -5V power supplies. Transformer T₁ and optoisolator IC₄ provide isolation from the ac-power line.

This Design Idea works well for an application such as a spa-heater control but does not work for light-dimming or motor-speed control because the output power is pulsating in nature. You can easily adapt the design for 240V-ac or 50-Hz operation. **EDN**

Extend monolithic programmable-resistor-adjustment range with active negative resistance

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A variety of solid-state, in-circuit-programmable replacements exist for the traditional electromechanical trimmer potentiometer. These replacements have many obvious advantages, such as automatic adjustability, miniaturization, and immunity to vibration. But these

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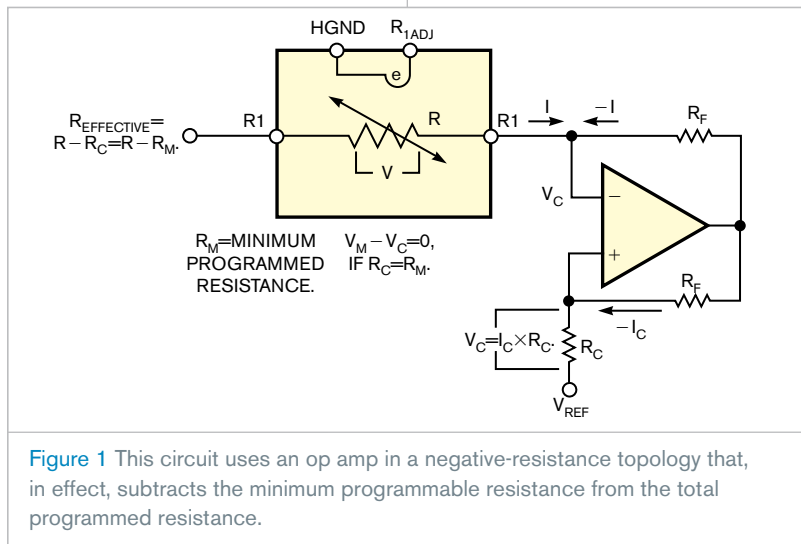


Figure 1 This circuit uses an op amp in a negative-resistance topology that, in effect, subtracts the minimum programmable resistance from the total programmed resistance.

devices, unlike humble mechanical potentiometers, have relatively large minimum programmable resistance. Although you can adjust a typical trimming potentiometer down to a fraction of 1Ω , solid-state-potentiometer substitutes usually bottom out at 10s, 100s, or even 1000s of ohms. This limitation can sometimes be problematic and frequently precludes use of the solid-state option in some design applications.

The Rejutor family of devices, which Microbridge (www.mbridgetech.com) recently introduced, provides an extreme example of this effect. You can program a typical Rejutor over only a narrow span of 30%. For example, you can program a $10\text{-k}\Omega$ Rejutor to no lower than $7\text{ k}\Omega$, imposing a serious and obvious obstacle to general-purpose application of these devices. **Figure 1** suggests a generally applicable workaround that works not only with Rejutors, but also with all adjustable resistances. It uses an op amp in a negative-resistance topology that, in effect, subtracts R_{MIN} (minimum programmable resistance) from the total programmed resistance. **EDN**

1-Wire network controls remote SPI peripherals

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Many 1-Wire-compatible peripherals are available, but, for those that lack the 1-Wire capability, the circuit in **Figure 1**, pg 80, illustrates one way to implement it. The example controls a remote LED display by the 1-Wire network through an SPI (serial-peripheral-interface)-compatible display controller.

To produce the three-wire SPI that a MAX7221 display controller requires for the \overline{CS} (chip-select), DIN (serial-data), and CLK (clock) signals, the 1-Wire network serially addresses three DS2405 1-Wire switches. The first switch directly creates \overline{CS} ; the second switch directly creates DIN; and the third switch, aided by three

exclusive-OR gates, creates CLK.

The edge detector and one-shot IC_{4A} , IC_{4B} , and IC_{4C} combine the outputs of IC_2 and IC_3 —Data 1 and Data 0—to create a clock signal for the SPI. This one-shot clock-generation circuit improves the data rate by requiring only a single 1-Wire transaction per SPI bit, instead of the three transactions—data, clock low, and clock high—that would be necessary if you directly use the IC_3 output as a clock signal.

To transmit data to the SPI inputs, first set the output of IC_1 low. Then, transmit the data bits using the following rules: If the current data bit differs from the previous bit, set IC_2 's Data 1

output accordingly. If the current data bit is the same as the previous bit, toggle IC_3 's Data 0 output. The circuit automatically generates a clock pulse each time and requires only one 1-Wire command for each data bit sent. When data transmission is complete, send a final 1-Wire command to set the IC_1 output high.

This circuit allows a 1-Wire network to control a remote temperature display, but similar techniques can provide an interface to I²C (inter-integrated-circuit)-compatible devices and to other SPI peripherals, such as ADCs and DACs. You can also produce a bi-directional-data capability by adding a fourth DS2405. Note that the SPI data rate and updates to the peripheral are relatively slow, but speed is not an issue for many remote-monitoring applications. **EDN**

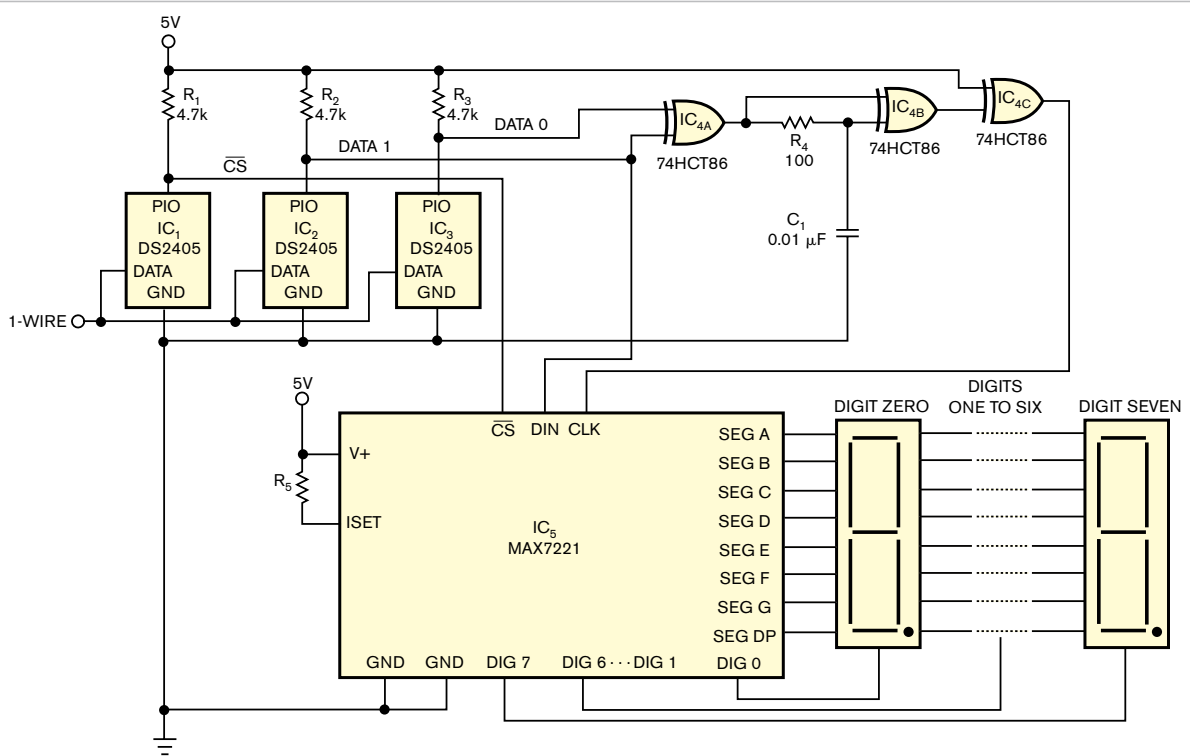


Figure 1 Three 1-Wire switches—IC₁, IC₂, IC₃; three XOR gates, IC₄; and the associated components enable a 1-Wire network to control this display through the SPI peripheral IC₅.