Resistance Temperature Detectors (RTDs)

Chapter 8

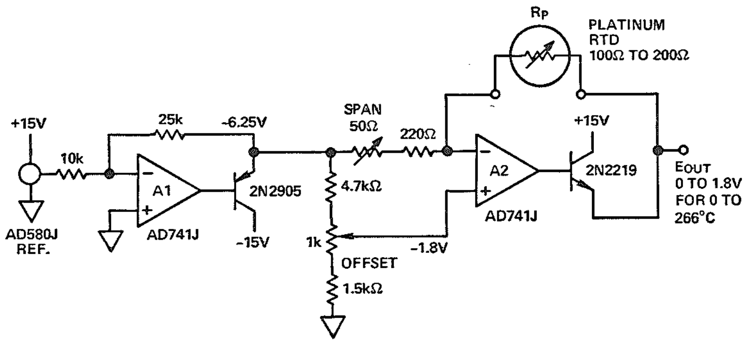
The resistance change in RTDs caused by temperature (see Chapter 1) is sensed in two ways, either directly, as a change in voltage across a current-driven resistor, or by the output of a resistance bridge. The most-frequently used RTD is platinum; though it is expensive, its properties are stable and predictable. At the end of this chapter, abbreviated ready-reference tables provide the resistance and incremental temperature coefficients for a 100Ω (0°C) platinum resistor.

SIMPLE OP-AMP INTERFACE

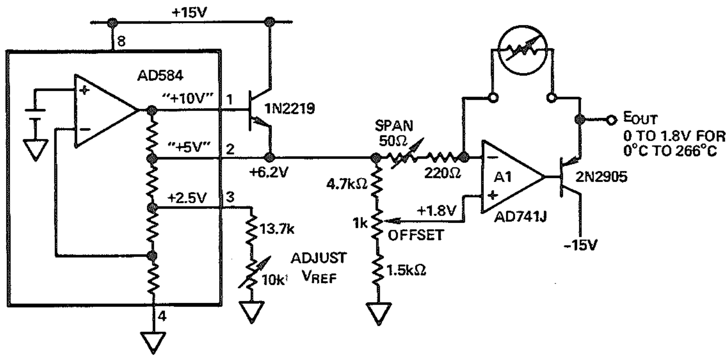
Figure 8-1 shows a 100Ω RTD connected to perform temperature measurements in the range 0°C to 266°C, using simple, low-cost circuitry. The RTD is connected in the feedback path of an operational amplifier (A2); the 18mA excitation current is established by the net voltage across the input resistor. The 2.5V output of the AD580 reference IC (version a) is amplified to the 6.25V level (which permits a 6.2V zener diode to be used optionally, if sufficient current is provided). An excellent option is to replace the AD580 and AD741J by an AD584 adjustable multi-reference, set for 6.2V output at the external 2N2219 booster's emitter (b). Reference and output polarities are reversed.

The 1kΩ pot and the 50Ω variable resistor provide offset and span adjustments to set the output to 0V at 0°C and 1.8V at 266°C (first 1.8V span, then 0V offset). The scale is somewhat arbitrary, determined, in the case of the circuit shown here, by the voltage range required by the circuitry fed by this circuit.

The RTD's resistance varies from 100Ω to 200Ω over the temperature range. Best-straight-line linearity is to within about ±1.3°C.



a. Low-cost fixed reference and op amp



b. Boosted adjustable reference

Figure 8-1. Simple interface for RTD

USING A SIGNAL-CONDITIONER

In Figure 8-2, a Model 2B31 signal conditioner provides complete signal conditioning for temperature in the range −100°C to +600°C, using a YSI-Sostman four-wire, 100Ω platinum RTD (PT139AX).

The signal conditioner, functioning as a high-impedance current source, provides 1mA of excitation; the output voltage sensitivity is thus 1mV/Ω—about 350μV/°C. Because the device has four leads, one pair for excitation and the other for voltage pickoff, errors due to voltage drops are minimized.

The offset terminal of the signal conditioner allows the reference level to be shifted, and the span terminals provide for gain adjustment. In the example shown, the offset and span can be adjusted

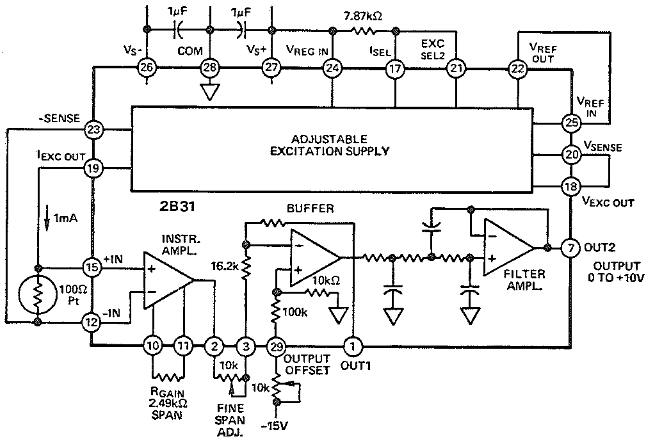


Figure 8-2. Platinum RTD in current-excited temperature measurement using 2B31 signal conditioner

for 0 to 10V output over the temperature range being measured. Measurement resolution and repeatability are ±0.1°C.

BRIDGE CONFIGURATION USING 3-WIRE RTD

As noted earlier, a bridge configuration is particularly useful for providing offset in interfacing to a platinum RTD, so that small, fractional sensor resistance changes can be detected stably and accurately.

In the configuration of Figure 8-3, an RTD is used as the active

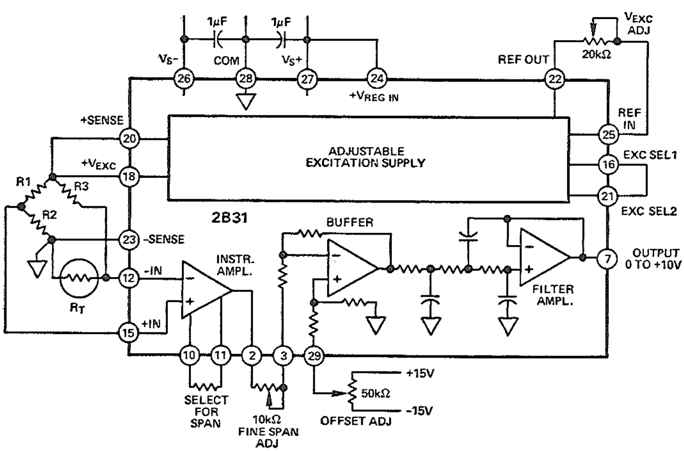


Figure 8-3. Platinum RTD measurement using resistance bridge

leg of a bridge. Lead compensation is employed to maintain high measurement accuracy when the lead lengths are so long that thermal gradients along the RTD leg may cause changes in line resistance.

The two completion resistors, R1 and R2, should have good ratio tracking (±5ppm/°C) to minimize bridge error due to drift. The resistor in series with the platinum sensor, R3, must have high absolute stability. The offset and span are adjustable independently, and the voltage excitation provided by the 2B31 can be adjusted for the best compromise between sensitivity (higher voltage) and stability (avoiding self-heating–lower voltage).

LINEARIZING RTD CIRCUITS

As tables 1 and 2–at the end of the chapter–show, platinum RTD's have a departure from linearity that is quite large compared to their resolution, stability, and repeatability. For example, over the range 0° to 558°C (100 to 300 ohms), the nonlinearity bow approaches 13°C (calibrated end points).

There are a number of ways to considerably improve the linearity of responses having a bow-shaped error curve. Since they have been discussed earlier, and are of universal applicability, the reader who is interested in this topic should consult Figures 5-9 and 5-11, and the associated text. They show how to linearize the output of bridges, using feedback around the bridge drive (in the former case) and analog multipliers (latter), *adjustably*, to permit correction for nonlinearity due to both the bridge and the sensor.

CURRENT TRANSMITTERS FOR RTD OUTPUTS

For process measurements, where temperature information must be communicated via a 4-to-20mA current loop, the voltage output of the signal conditioner is used to drive a voltage-to-current converter, such as the 2B20. In Figure 8-4, the output of a 2B31 provides the input to a 2B20, which can drive a loop with maximum resistance of 950Ω at +24V supply, within the specifications, and an absolute maximum load of 1.35kΩ, with a 32V supply.

In this application, ISA Standard 50.1, for Type 3, Class L and U, non-isolated current-loop transmitters, is met. If isolation is desired, the 2B22 V/I converter may be used.

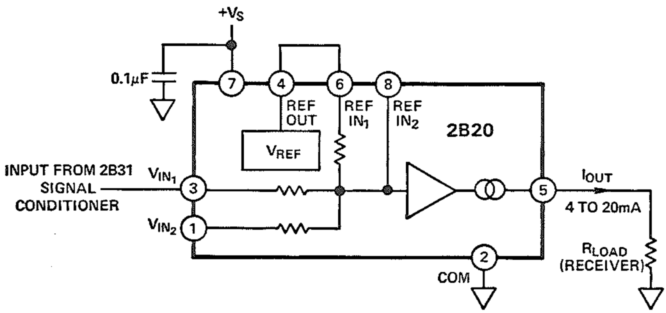


Figure 8-4. Current transmitter connection diagram

RTD-BASED PRECISION CONTROLLER

Figure 8-5 is a circuit that was developed to keep a small oven in a spacecraft at a temperature of 200°C ±0.1°C for *five years* under varying environmental conditions. A platinum RTD in a 3.5kΩ bridge circuit has a resistance of 3.5kΩ at 200°C. Any change in temperature will produce an unbalance voltage, which is amplified (A1), filtered (A2), and applied as a modulating signal to an oscillator (A3), which drives a resistance heater via a power FET.

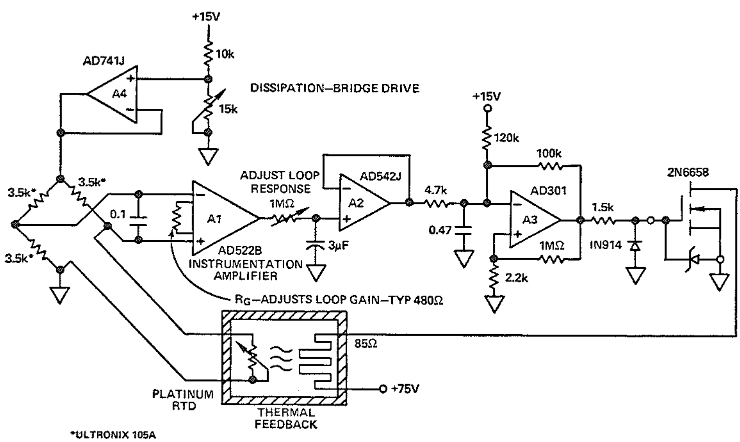


Figure 8-5. RTD-based precision temperature controller

The bridge drive is adjusted for the best compromise between output level (sensitivity) and dissipation (errors due to self-heating). Amplification is provided with low drift (2μV/°C max) by the AD522B, which also provides high common-mode rejection. The resistor in series with the platinum sensor must have high stability, because it is the resistance reference for the sensor; the other two resistors in the bridge need only be well-matched and tracking, and in close proximity to one another.

The 0.1μF capacitor at the input of the AD522 filters out noise spikes picked up at the front end from the hash generated by the switching circuitry. Additional filtering is provided by the RC at the input of A2; it also serves as the dominant pole in the feedback loop.

The output of A2 biases a pulse-width-frequency modulator. The more negative the output of A2, the greater the average power furnished to the 85Ω heater. When the output of A2 is positive, signifying that the temperature is high, the output of A3 is driven negative, turning the FET off and biasing A3 via the positive-feedback divider. If the output of A3 goes negative enough to bring the negative input of A3 below the threshold at the positive input, the output switches positive, applying power to the heater. The positive output also switches the input threshold positive and charges the 0.47μF capacitor, at a rate determined by the net current supplied to the capacitor via the 4.7kΩ, 100kΩ, and 120kΩ resistors (the more negative the output of A2, the slower the rate). When the capacitor's voltage crosses the threshold, the output of A3 switches negative, changing the polarity of the current through the 100kΩ resistor, turning off the power, and causing the capacitor to charge negatively. The cycle repeats; as the oven heats and the output of A3 becomes less negative, the ratio of time off to time on increases.

The modulated high-speed switching provides the benefits of continuously controlled temperature without perceptible temperature variations due to the discontinuous application of power; at the same time, the switched mode of power delivery provides efficient operation, essential for the application. The stability of temperature in the oven, with time and ambient change, is due to the stability of the bridge components and the amplifier.

MULTI-CHANNEL RTD THERMOMETER

The AD2037 is a 6-channel scanning* 3 1/2-digit integrating digital

*Its digital properties (display and scanning scheme) are the same as those of the AD2036, described in relation to Figure 7-10.

panel meter with a floating input system. In its simplest application, it can be used to monitor continuously millivolt-level voltages at six different points within a piece of equipment or a system. The basic full-scale range is 1.999V, but to make it easy to obtain offsets and other values of gain, it has a built-in operational amplifier, with a nominal gain of ten and all active terminals available. Thus, a full-scale range of 199.9mV is available, by simple jumpering.

In the application shown in Figure 8-6, the AD2037 is used to read temperature in the range 0° to 199.9°C, as measured by several 100Ω platinum RTD's, with repeatability and precision to within 0.1°C.

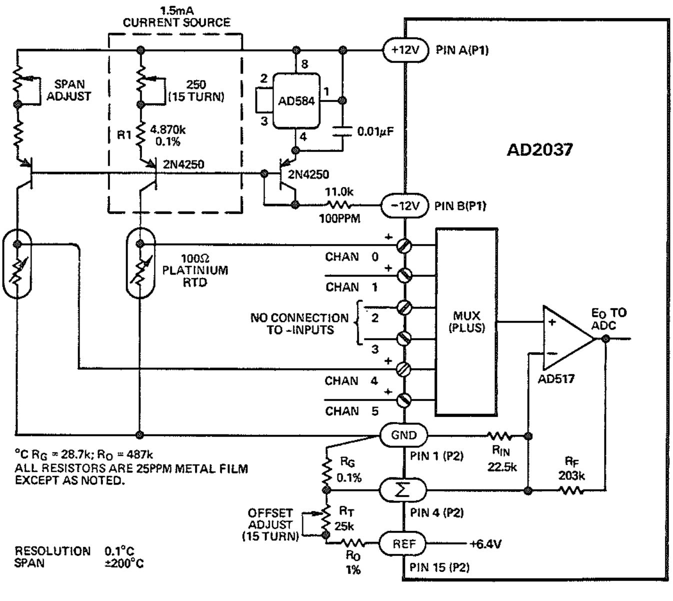


Figure 8–6. Application of the AD2037 with platinum RTD's

In this application, individual 1.5mA currents are applied to each device, and the voltages developed across them are multiplexed, applied to an amplifier, converted to digital, and displayed. The amplifier provides offset and gain so that the meter reads directly in °C.

The 1.5mA constant-current sources consist of 2N4250 transistors, 4.87kΩ resistors, and 250Ω rheostat-connected potentiometers to set the exact full-scale span. The reference for the excitation currents is provided by the AD584 multiple-reference IC, connected as a current source, in series with a 2N4250 and an 11kΩ resistor.

The resistance values shown are calculated for the proper relationship to obtain a full-scale reading of 199.9 to correspond to 199.9°C. The calculation process is described here to help you calculate values for different spans and resolutions.

Since the full-scale change of the RTD is from 100Ω to 175.84Ω from 0°C to 200°C, the span of resistance change for readings from 0° to 199.9°C is 75.75Ω. With an excitation current of 1.5mA, this corresponds to a voltage change of 113.625mV; therefore, the amplifier gain, for 1.999V full scale, must be 17.59.

The initial resistance of 100Ω at 0°C will produce an output of 100Ω X 1.5mA X 17.59 = 2.6385V, which must be offset by an added constant. The added constant is applied from the internal 6.4V reference, using an attenuation of –2.6385/6.4 = –0.41227. Since the nominal feedback resistance is 203kΩ, the input resistance must be 492.4kΩ. This value is achieved with a fixed resistance, R_O = 487kΩ, and a 25kΩ pot, R_T, to allow it to be trimmed.

To obtain the correct amount of gain for the 200°C span, a resistance, R_G, must be connected from the summing point to common, with resistance value to satisfy the relationship:

$$G = 17.59 = 1 + \frac{203}{22.5} + \frac{203}{492.4} + \frac{203}{R_G}$$

The nominal value of R_G is thus 28.37kΩ. The exact sensitivity of each channel, at a specific value of temperature, is set by the 250Ω pot in series with the emitter of each 2N4250.

Since the meter is bipolar, it will read negative values corresponding to temperatures less than 0°C. However, because of the nonlinearity of the platinum resistor, they will not be normalized to the 0 to -200°C range. At –200°C negative full-scale, the resistance is 18.53Ω; thus ΔR for that range is 81.47Ω, compared to 75.84Ω for +200°C full scale. Because the maximum reading occurs at a ΔR of 75.84Ω, the lowest temperature that can be read is nominally –186.7°C, which corresponds to 24.20Ω, for a reading of -199.9.

PLATINUM RESISTANCE TABLES

The following tables present, in compact form, data on the response of platinum RTD's to temperature, based on the resistance of a 100Ω device.

Table 1 lists, at 50°C intervals, the resistance (R_T), incremental resistance-temperature-coefficient, ($\Delta R/\Delta T|_T$), and the relative-resistance temperature-coefficient, $\left(\frac{\Delta R}{R_T}/\Delta T\right)$, from −200°C to +800°C.

PLATINUM RTD RESPONSE*

TABLE 1. RESISTANCE vs. TEMPERATURE

TEMP °C	RESISTANCE (ohms – or millivolts per milliampere of excitation)	INCREMENTAL RESISTANCE TEMPCO ΔΩ/Δ°C (100Ω@0°C)	RELATIVE RESISTANCE TEMPCO ΔΩ/Ω/Δ°C [%/°C]
-200	18.53	0.421	2.27
-150	39.65	0.416	1.05
-100	60.20	0.406	0.67
-50	80.25	0.396	0.49
0	100.00	0.391	0.39
+ 50	119.40	0.385	0.322
+100	138.50	0.379	0.274
+150	157.32	0.374	0.238
+200	175.84	0.368	0.209
+250	194.08	0.362	0.187
+300	212.03	0.356	0.168
+350	229.69	0.350	0.152
+400	247.06	0.344	0.139
+450	264.14	0.338	0.128
+500	280.93	0.332	0.118
+550	297.43	0.327	0.110
+600	313.65	0.322	0.103
+650	329.57	0.316	0.096
+700	345.21	0.310	0.090
+750	360.55	0.304	0.084
+800	375.61	0.298	0.079

TABLE 2. TEMPERATURE vs. RESISTANCE (R_O = 100.0Ω)

RESISTANCE (ohms – or millivolts per milliampere of excitation)	TEMPERATURE °C
20	-197.55
40	-149.17
60	-100.49
80	- 50.63
100	0.00
120	+ 51.56
140	+103.98
160	+157.19
180	+211.33
200	+266.39
220	+322.46
240	+379.57
260	+437.79
280	+497.21
300	+557.85
320	+619.84
340	+683.26.
360	+748.19

*Summarized from The Omega 1979 Temperature Measurement Handbook, Omega Engineering, Inc., Stamford Connecticut 06907

In Table 2 are listed, at 20Ω intervals, the temperatures corresponding to given values of resistance. For 1mA excitation, the resistance column can be interpreted as millivolts of output. This table is especially useful in developing linearization circuitry, and in calibration.

Although the increments are relatively large, the relationship for platinum is sufficiently well-behaved that interpolation is easy, and surprisingly accurate, even with simple linear interpolation. The incremental resistance figures can be used for higher-order interpolation, as well as for sensitivity assessments.