An Introduction to RTD Processing

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Introduction

This paper discusses the techniques for creating a voltage proportional to temperature using what is known as an RTD (Resistance Temperature Detector also known as a Resistance Thermometer Device). The most common material used is platinum because it has a very predictable positive temperature coefficient over a wide temperature range and is very inert to many hostile environments.

Because the resistance of an RTD is a function of temperature, the specified resistance in a data sheet is always that at 0 C. Thus, a standard 100 ohm (by far the most common) RTD has a resistance of 100.00 ohms at 0 C. There are several other standard values that range from around 10 ohms to 10,000 ohms.

Table 1 shows the temperature coefficient for platinum in general and the resistance of a 100 ohm RTD as a function of temperature. Note that the temperature coefficient decreases with temperature thus the RTD has a non-linear response.

Temperature	**Temperature Coefficient**	**100 Ω RTD Resistance**
-100 C	4100 ppm/C	60.26 ohms
0	3850	100.00
100	3800	138.50
200	3700	175.84
300	3600	212.02
400	3500	247.04
500	3400	280.98
600	3200	313.71
700	3100	345.28
800	3000	375.70

Table 1: Data from platinum RTD tables at omega.com

Measurement Concept

The basic concept is to apply a constant current to the RTD and the resulting voltage across it is directly proportional to the resistance. Then the offset voltage (because of the resistance at 0 C) is subtracted and gain is applied to scale the voltage to a common value of 10 millivolts per degree C. Other commonly used scale factors are 5 and 2 millivolts per degree C which are often used if very high temperatures are going to be measured and instrumented with a low voltage A/D converter.

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The linear process just described works well for temperatures up to about 200 C. For higher accuracy, non-linear correction is required and modern practice is to perform that using a microcomputer.

Constant Current

In all cases it is very important that the constant current be small enough so that I^2R heating of the RTD only causes a small error. This error increases with temperature so calculations need to be performed at the highest temperature of interest. A general guide is to choose the current to be no more than would cause a power dissipation of one milliwatt at the highest temperature. However, if the RTD is very small physically, then the power level may have to be reduced. For a typical 100 ohm RTDs a reasonable maximum current is 1 milliampere. Figure 1 shows a basic current source. A stable voltage reference of 5.00 volts is used and an analysis of the circuit reveals that the voltage across the 4.99K resistor is always 5.00 volts thus making a current of 1 mA through the external impedance, Rx, provided it is not too large. For best results the indicated pairs of resistors should be matched to within a tenth of a percent. The I_O and V_O are connected to the following circuits. Note that V_O is the buffered voltage across the external resistance.

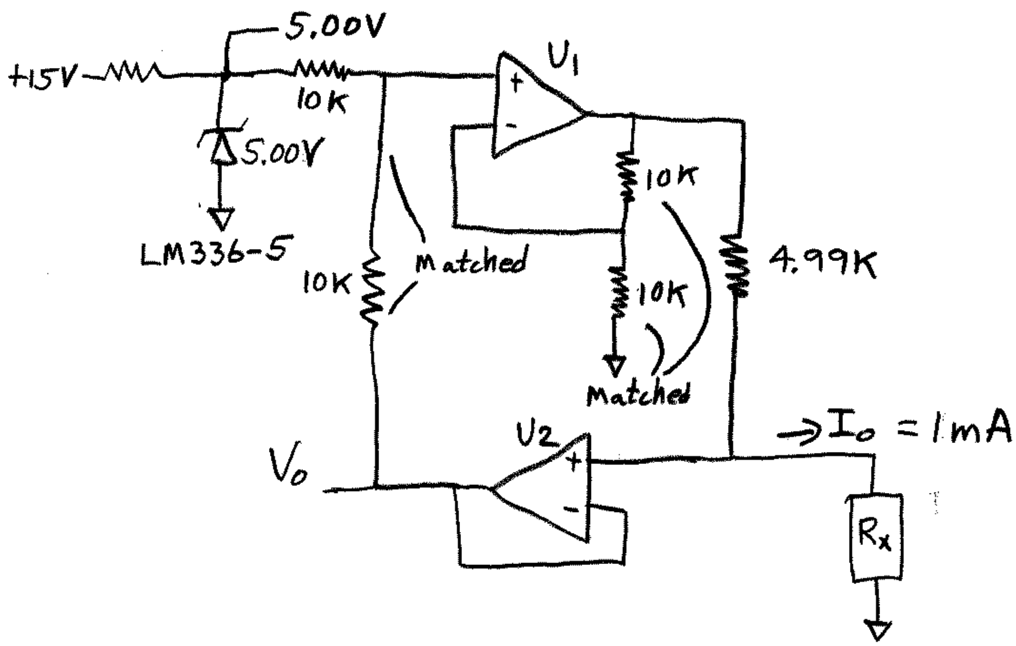

Figure 1: Constant Current Source

Circuits

Figure 2 shows a very simple circuit that is fine if the wire length to the RTD is short such that there is negligible voltage drop. The network around U3 enables subtraction of the 0 C offset voltage and scaling to an output voltage of 10 mV/C. Observe that the circuit is cast so that R2 (including the trim potentiometer) controls the output offset and has little effect on the gain and that R3 (including the trim potentiometer) strongly affects the gain with no effect on the output offset – an example of what is known as orthogonal adjustments (the student should explore and understand this in order to be able to apply the technique on an engineering job). Calibration would consist of placing the RTD in an ice bath for a 0 C reference and tweaking R2 so that the output voltage is 0.000 volts. Then the RTD would be placed in a known temperature environment and R3 would be tweaked for the properly scaled output voltage. The process might be repeated for refinement as there is a small interaction between R2 and R3 concerning the gain. If the temperature signal is sent to a computer then the modern approach is to store calibration factors in a data table rather than using use potentiometers in the circuit.

Classic design calls for first calculating the theoretical values for R2 and R3. Then the series combination of a metal film resistor (because of its precision, temperature stability and low drift) and potentiometer is used to achieve the required value for calibration. The adjustment range is chosen considering the accumulative tolerances in the system and rounding up a small amount – in this example this might be as small as +-3 percent but perhaps as high as five. The goal is the smallest adjustment range that will handle all cases. Excessive adjustment range makes it harder to set the potentiometers to the necessary values and results in the higher temperature coefficient of the potentiometer being a larger portion of the total – a bad practice. The component values shown in Figure 2 are an example. The closest standard 1% values for R2 and R3 are used based on the potentiometers being in the nominal center or half resistance position. The calculated value for R2 (including the pot) is 19.231K. So the actual chosen value of R2 is a standard 18.7K after subtracting 500 ohms (half the pot resistance). The calculated value for R3 (including the pot) is 408.5 ohms. So the actual chosen value of R3 is a standard 383 ohms after subtracting 25 ohms (half the pot resistance).

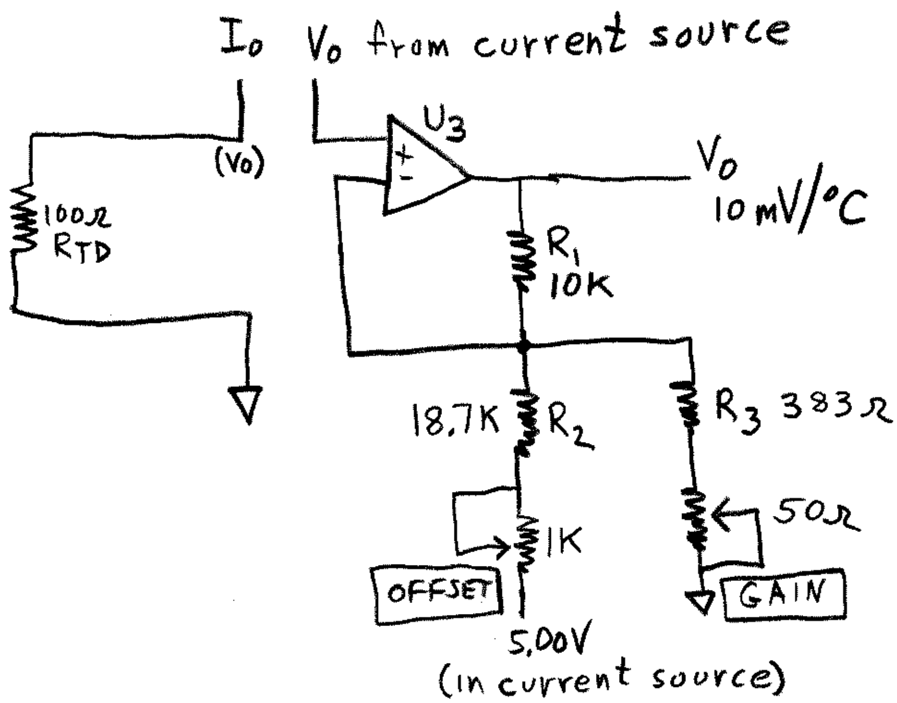

Figure 2: Simple RTD Processor

Four wire circuit (Kelvin connection)

When sensing the resistance of an RTD it is important to exclude the resistance of the connecting wires and connector contact resistance as these are error terms. Figure 3 illustrates the problem and solution if the RTD is located considerable distance from the processing electronics. In this case the resistance of the connecting wires adds to that of the RTD and causes an error if the measurement were made using the outer set of wires. The error is eliminated by using what is known as a Kelvin connection (credited to William Thompson who received the honorary title of Lord Kelvin). Note that there is zero current in the inner set of wires and thus no voltage drop. The input voltage to the instrumentation amplifier is exactly that across the RTD independent of how long the wires are. Rg and V_{OFFSET} are adjusted for the desired output scale factor and zero as before.

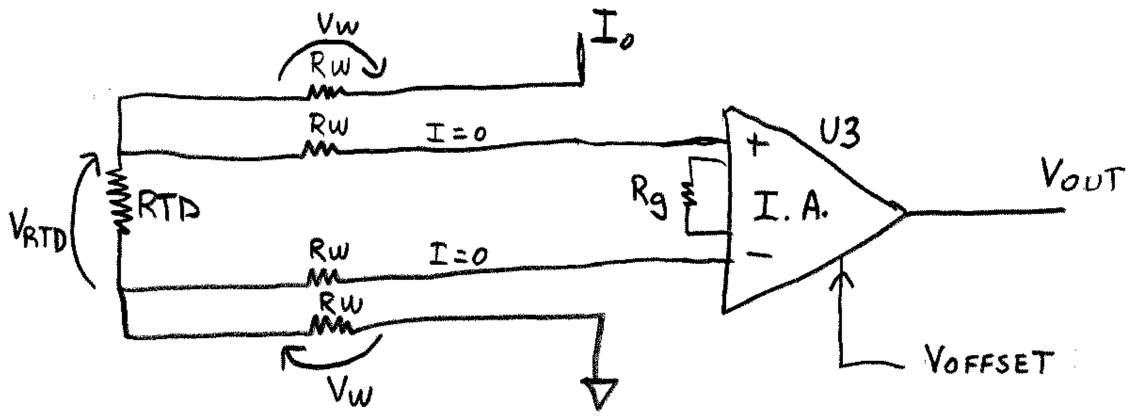

Figure 3: Kelvin connection to eliminate wiring voltage drop errors

Three-wire circuit (intuitive)

The Kelvin connection requires four wires. Good engineering practice is to minimize the number of required wires. A circuit is shown in Figure 4 that reduces the number of wires to the absolute minimum possible – three. This circuit is the first and more intuitive of two ways to accomplish this. In operation U4 measures the voltage drop across the return current wire and multiplies that by four for an output of $4*V_W$. U3 has a non-inverting gain of two on the sum of the RTD voltage and the total wire drop voltage (four times that of one wire) for a partial output of $2*V_{RTD} + 4*V_W$. The inverting gain of one connection to U4 subtracts $4*V_W$ leaving a net output voltage on U3 of $2*V_{RTD}$. A similar circuit to Figure 2 then performs scaling and offset – note that the required gain is half since the output of U3 is twice the RTD voltage.

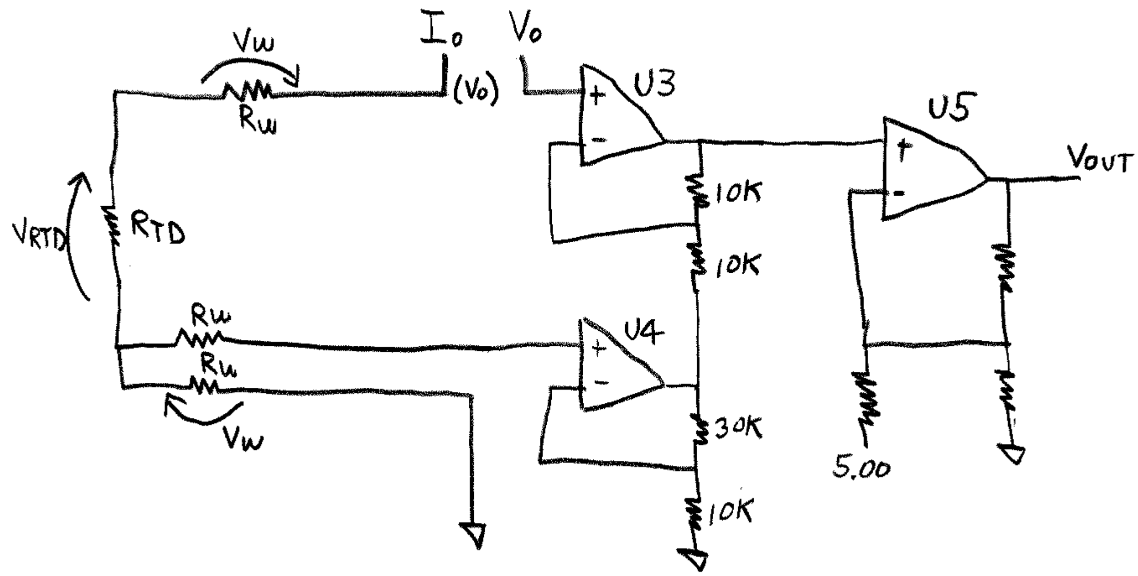

Figure 4: Three-wire Connection

Three-wire circuit (clever version)

The circuit in Figure 5 is less intuitive than that of Figure 4 but works similarly and with fewer parts! Good engineering practice is to minimize the number of required parts. A general statement is that the intuitive approach is rarely the optimum approach. A common trap for engineers is to stop thinking once an intuitive approach is found. Good engineering requires attacking the intuitive approach from various angles to determine what improvements can be made. In operation, U3 has a non-inverting gain of two for the signal comprised of V_{RTD} + V_W and an inverting gain of one for the signal comprised of V_{RTD} + 2*V_W. The net output of U1 is just VRTD independent of the voltage dropped across the wire.

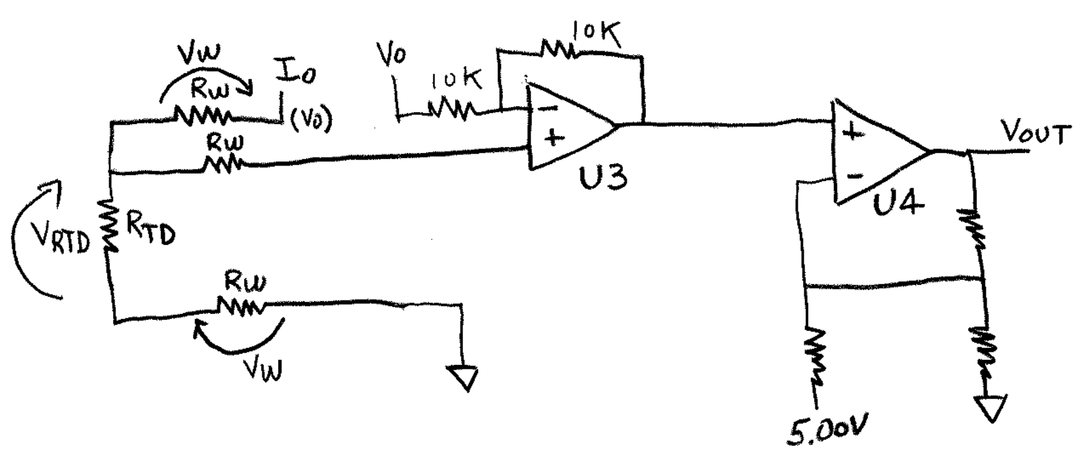

Figure 5: Advanced Three-Wire Circuit

It is left as an exercise for the student to explore whether it is possible or practical to combine the functions of U4 into U3. This concept should always be explored. The results can vary as follows.

- It may not be possible to do at all.

- It may be possible but the circuit is very impractical requiring odd value resistors and may have high interaction between calibration adjustments. Strong interactions make the circuit very difficult to calibrate as considerable iteration is required. Ideally, adjustments are orthogonal meaning they have zero interaction. In many practical circuits there may be some small interaction.

- It may be readily possible with some clever thought to combine functions and with little or no inconvenience of odd component values or interactive adjustments.