# RTD Circuits

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## Introduction

The abbreviation, RTD, refers to a resistor that has a predictable increase in resistance with temperature. There are a variety of interpretations of RTD – Resistance Thermometer Device, Resistance Temperature Detector, etc. All refer to the same part. The most common RTD is made of pure Platinum wire and has a resistance of 100.0 ohms at 0 C. RTDs are known by their resistance at 0 C. At lower temperatures the change in resistance with temperature is fairly constant at about 0.39 ohms per C. At higher temperatures the change becomes less and non-linear correction is needed – that is beyond the scope of this note. For simplicity we will consider the device to be linear. Other values of RTD 0 C resistances are available from a few tens of ohms to ten thousand ohms. A 10K RTD would have a resistance change per C of 39 ohms. Copper wire can also be used as an RTD and has similar characteristics to Platinum up to around 100 C. Above that temperature Copper tends to degrade and also has a more non-linear response. As an example, if the resistance of a 100 ohm RTD was 130 ohms then the temperature would be (130 – 100) / 0.39 = 77 C.

An RTD is normally operated with a small constant current (typically between about 100 uA and 1 mA for a 100 ohm device) so that the response is linear. The current must be small enough so that heating effects are negligibly small. The voltage across the RTD is then the voltage at 0 C resulting from the constant current times the 0 C resistance plus the change in resistance times the constant current. This is not unlike a semiconductor diode characteristic except that the slope is positive instead of negative. RTD processing involves scaling the change in resistance to a change in voltage (often 10 mV / C) and removing the 0 C offset. There are a variety of circuits to do this.

RTDs are often located a distance (perhaps many tens of feet) from the processing electronics. The resistance of the connecting wires adds to that of the RTD and is an error term. The 4-wire Kelvin connection eliminates the error. A modified 3-wire Kelvin connection is most commonly used. Two methods for doing this are illustrated in the following examples.

## Circuit 1

The RTD processing circuit in Figure 1 illustrates a simplistic method based on simple circuits that students should know. Although the circuit works fine, it uses a lot of parts. Subsequent circuits will use more advanced concepts and fewer parts. This circuit is excellent for students to use as a learning exercise.

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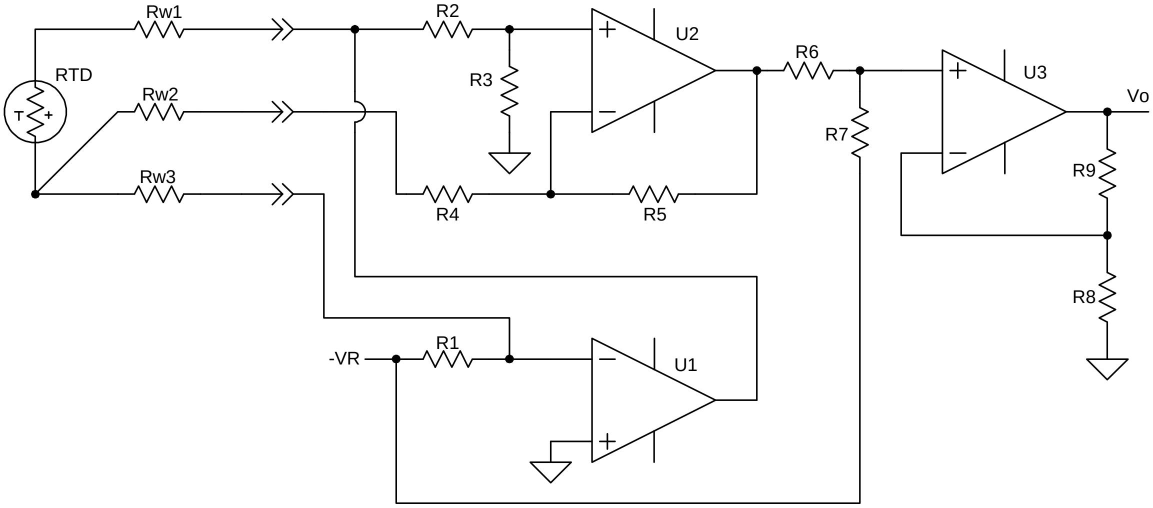


Circuit 1

The circuit requires a negative reference voltage (typically -1.25, -2.50, -5.00, or -10.00). U1 is an inverting amplifier with the RTD in the feedback path. The constant current through the RTD is the voltage reference divided by R1. This current is typically in the range of 100 uA to 1 mA for a 100 ohm RTD. For this example we will use VR = -5.00 volts and R1 = 10K so that the constant current through a 100 ohm RTD is 500 uA. All of the Rw wire resistances are identical – the numbers are an aid in discussing a particular resistance. The current through the RTD passes through Rw1 and Rw3. There is no current (technically, it is negligibly small) in Rw2. The voltage at the R2 input is the sum of the RTD voltage and the voltage drop across two connecting wires in series. The voltage at the R4 input is the voltage drop across Rw3. All we need to do is to subtract twice the voltage at the R4 input from the voltage at the R2 input and the effect of voltage drop in the wires connecting the RTD will vanish at the output of U2. We need for R5/R4 to be two but this will make the non-inverting gain equal to three and we need that gain to be one. Thus, we include a voltage divider, R2 and R3, that has a transfer gain of one-third so that the net non-inverting gain of U2 is one and its output voltage is the voltage across the RTD. One set of resistors that will accomplish this is R2 = 200K, R3 = 100K, R4 = 100K, and R5 = 200K.

The next step is to remove the offset voltage at 0 C and this is done with the voltage divider formed by R6 and R7. At 0 C the output of U2 is the constant current multiplied by the RTD resistance – 500 uA * 100 ohms = 0.05 volts. The desired voltage at the non-inverting input to U3 is zero volts. We can choose R6 to be any convenient value – we will choose 1K and the current through R6 will be 0.05 / 1K = 50 uA. R7 will have (0 - -VR) or 5 volts across it and should conduct 50 uA. R7 calculates to be 100K.

The last step is to determine R8 and R9 for the desired output scale factor – we want 10 mV / C. The 100 RTD will increase by 0.39 ohms per C which becomes 195 uV / C when multiplied by the 500 uA constant current. The voltage division by R6 and R7 reduces this to 193.07 uV / C. Thus, the non-inverting gain of U3 must be 0.01 /

0.00019307 = 51.795. This means that R9/R8 = 50.795. We could choose R8 = 1K and then R9 will be 50.795K.

## Homework problems

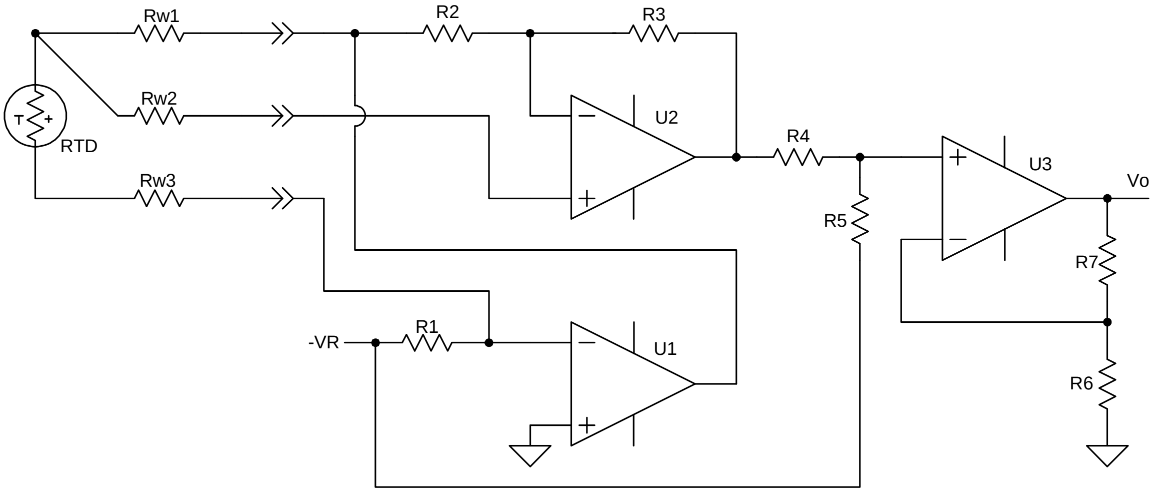
1. Rework the example with R1 modified so that the constant current is 1 mA.

2. Rework problem 1 with the reference voltage changed to -1.25 volts. Try the other common reference voltages too.

3. For a test you would be given the RTD value, VR, and probably R2 through R5. You would also be given either R6 or R7 and either R8 or R9 and the desired output scale factor. Your job would be to calculate the value of the resistors not given.

## Circuit 2

Circuit 2 is the same concept as that of circuit 1 except that the reference wire on the RTD is to the high side rather than to the ground side. Although using the ground side seems more intuitive, the circuitry for processing the high side is simpler. That is typical for a lot of circuits – the obvious method takes more parts and a non obvious approach works the same but with fewer parts. As before, all of the Rw resistances are identical – the numbers are only so that a specific resistance can be discussed.



Circuit 2

Note that the RTD system is in the feedback of U1 and that the current is VR / R1. This current would typically be in the range of 100 uA to 1 mA for a 100 ohm RTD. The voltage at the output of U1 is VRTD + 2*Vw (the current is through Rw1 and Rw3). The voltage at the non-inverting input to U2 is VRTD + Vw (there is no current through

Rw2). R2 and R3 are the same value (perhaps 10K). The output of U2 is then 2*(VRTD + Vw) – (VRTD + 2*Vw) = VRTD. For this example we will use a 100 ohm RTD and VR = -5.00 volts, and R1 = 10K so that the constant current is 500 uA. The student should carefully work the math regarding U2 to fully understand the process.

The next step is to remove the offset voltage at 0 C and this is done with the voltage divider formed by R4 and R5. At 0 C the output of U2 is the constant current multiplied by the RTD resistance – 500 uA * 100 ohms = 0.05 volts. The desired voltage at the non-inverting input to U3 is zero volts. We can choose R4 to be any convenient value – we will choose 1K and the current through R5 will be 0.05 / 1K = 50 uA. R5 will have (0 - -VR) or 5 volts across it and should conduct 50 uA. R5 calculates to be 100K.

The last step is to determine R6 and R7 for the desired output scale factor – we want 10 mV / C. The 100 RTD will increase by 0.39 ohms per C which becomes 195 uV / C when multiplied by the 500 uA constant current. The voltage division by R4 and R5 reduces this to 193.07 uV / C. Thus, the non-inverting gain of U3 must be 0.01 / 0.00019307 = 51.795. This means that R7/R6 = 50.795. We could choose R6 = 1K and then R7 will be 50.795K.

## Homework problems

1. Rework the example for VR = 1.25, 2.50, and 10.00 volts. Also, change the output scale factor for one of the problems to 50 mV /C. For all cases, calculate R1 for a constant current of 1.0 mA.

2. For a test you would be given VR, the desired constant current, either R2 or R3, either R6 or R4, and the desired output scale factor. You would have to calculate R1 and the resistors not provided.

## Circuit 3

The circuit in Figure 3 is much simpler than the previous two although it requires a 4-wire Kelvin connection. It is the result of really thinking about the simplest method to accomplish what is desired. All Rw resistances are equal – the numbers are an aid to refer to a particular resistance. Typical values for Rw range from less than one ohm for short cables to several ohms for long cables. Point L on the RTD is held at virtual ground by feedback from U1. There is current through Rw4 but no current through Rw3 – thus no voltage drop. The current is the reference voltage (typically 5.00) across the sum of R1 and Rw4 and is typically in the 100 uA to 1 mA range for 100 ohm RTDs. Feedback current from U1 is through Rw2 and the RTD. Thus, ignoring a tiny voltage drop across RW1, the voltage across R3 is the RTD voltage – and this is a negative voltage because of the inverting amplifier. R2 is calculated to sum current into the virtual ground of U2 so that there is no feedback current through R4 when the RTD is at 0 C. R4 is calculated to provide the desired output scale factor.

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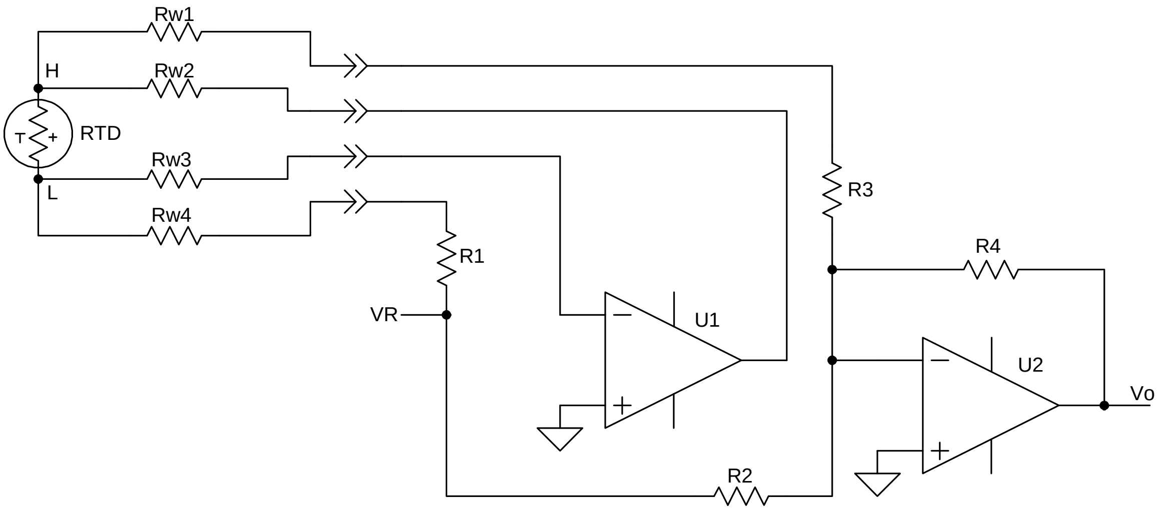

Figure 3:

As an example, If VR is 5.00 volts and R1 is 10K then the current is 500 uA and the voltage across the RTD is then -500 uA*(100 + 0.39*T) or -0.05 - 0.000195*T volts. If we desire the output voltage of U2 to be 10 mV / C then the inverting gain must be 0.01 / 0.000195 = 51.28. We could choose R3 to be 1 K and calculate R4 to be 51.28K. R2 is used to eliminate the 0.05 volt offset at the output of U1. At 0 C the voltage across R3 is 0.05 volts and the current is 50 uA. We need the current through R2 to be 50 uA so that the current through R4 is zero. R2 computes to be 100K.

**Homework problems**

1. Rework the example for an output scale factor of 5 mV/C.

2. Rework the example if the RTD was 10K. Calculate R1 so that the voltage across the RTD at 0 C is 1.00 volts and use an output scale factor of 100 mV / C.

3. For a test you would be given the reference voltage and either R3 or R4 and you would have to calculate the other, and R1 (for a specified constant current), and R2. The output scale factor might be different from 10 mV/ C. The RTD might be different from 100 ohms.