Thermal sensors

RTDs

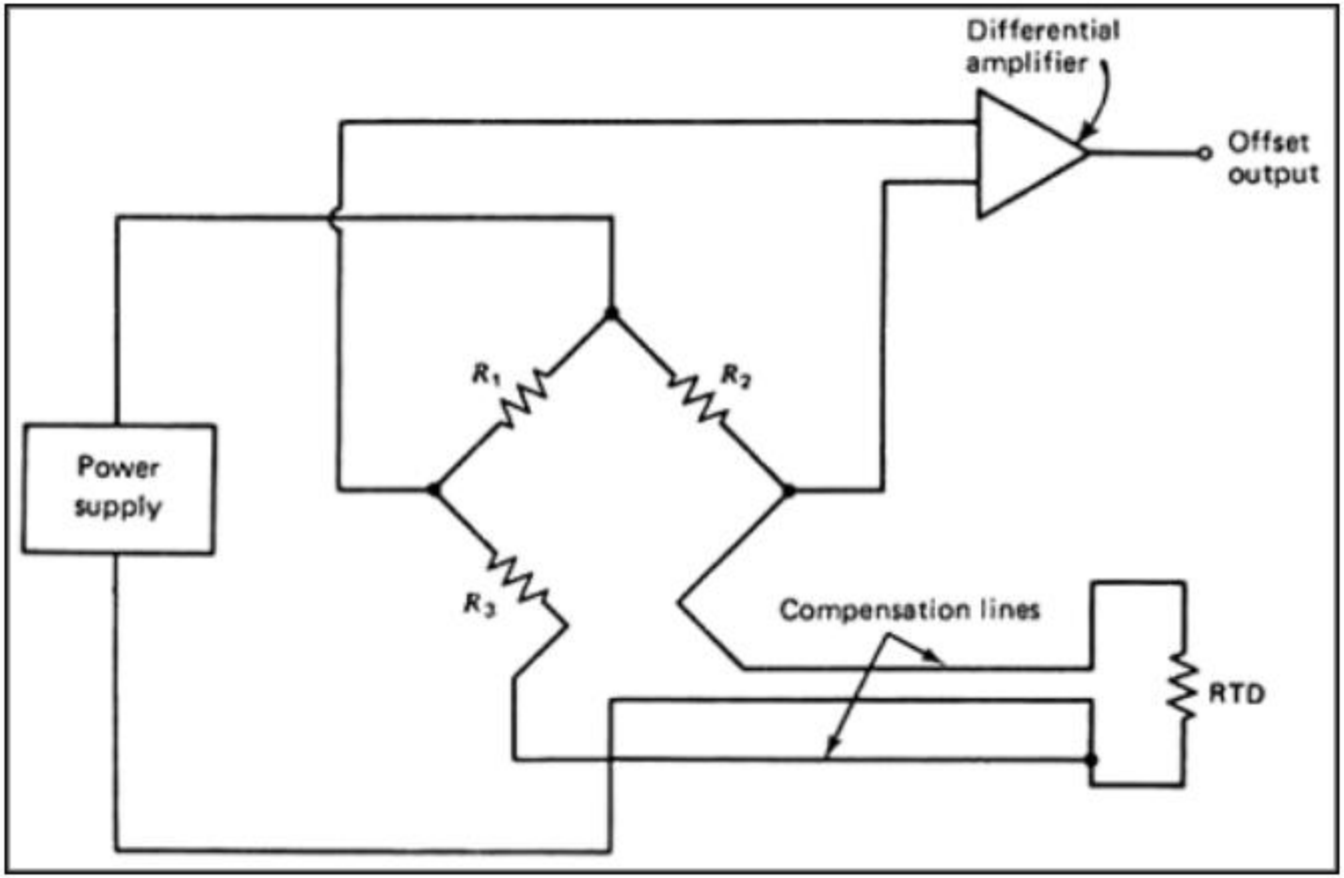
IST platinum temperature sensors provide solutions for extreme temperature applications. IST products are designed with the highest quality materials, allowing them to operate within a temperature range of -200°C to +1000°C. Standard DIN 60751 sensors are offered in class B (0.12%), class A (0.06%), 1/3 class B (0.04%), and higher accuracies upon request.

IST sensors are available in SMD and wired configurations, and in sizes ranging from 1.6mm to 10mm (L), and 0.8mm to 5.08mm (W). Standard sensors can be customized with a variety of wire material, length, and configurations with user defined attributes such as nominal resistance, TCR value, and tolerance class.

Benefits of Thin Film RTD

There are many options when considering contact temperature measurement, including thermocouples, thermistors, and RTDs (wire wound and thin film). While thermocouples can handle very high temperatures and thermistors are inexpensive, there are many advantages of RTDs. Some of these advantages include their accuracy, precision, long-term stability, and good hysteresis characteristics. Even beyond these, there are advantages of thin film RTDs over wire wound, including smaller dimensions, better response times, vibration resistance, and relative inexpensiveness. New advancements has even made thin film technology just as accurate as wire wound at higher temperatures ranges.

Signal Conditioning



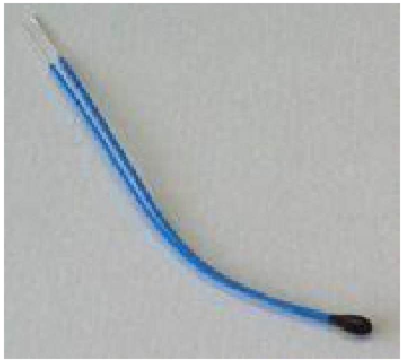
	Thermocouple	RTD	Thermistor	Integrated Silicon
Temperature Range	–270 to 1800°C	–250 to 900 °C	–100 to 450°C	-55 to 150°C
Sensitivity	10s of μV / °C	0.00385 Ω / Ω / °C (Platinum)	several Ω / Ω / °C	Based on technology that is -2mV/°C sensitive
Accuracy	±0.5°C	±0.01°C	±0.1°C	±1°C
Linearity	Requires at least a 4th order polynomial or equivalent look up table.	Requires at least a 2nd order polynomial or equivalent look up table.	Requires at least 3rd order polynomial or equivalent look up table.	At best within ±1°C. No linearization required.
Ruggedness	The larger gage wires of the thermocouple make this sensor more rugged. Additionally, the insulation materi-als that are used enhance the thermo-couple's sturdiness.	RTDs are susceptible to damage as a result of vibration. This is due to the fact that they typ-ically have 26 to 30 AWG leads which are prone to breakage.	The thermistor element is housed in a variety of ways, however, the most stable, hermetic Ther-mistors are enclosed in glass. Generally ther-mistors are more difficult to handle, but not affected by shock or vibration.	As rugged as any IC housed in a plastic pack-age such as dual-in-line or surface outline ICs.
Responsiveness in stirred oil	less than 1 Sec	1 to 10 Secs	1 to 5 Secs	4 to 60 Secs
Excitation	None Required	Current Source	Voltage Source	Typically Supply Voltage
Form of Output	Voltage	Resistance	Resistance	Voltage, Current, or Digital
Typical Size	Bead diameter = 5 x wire diameter	0.25 x 0.25 in.	0.1 x 0.1 in.	From TO-18 Transistors to Plastic DIP
Price	$1 to $50	$25 to $1000	$2 to $10	$1 to $10

Thermistors

thermistor is a type of resistor with resistance varying according to its temperature.

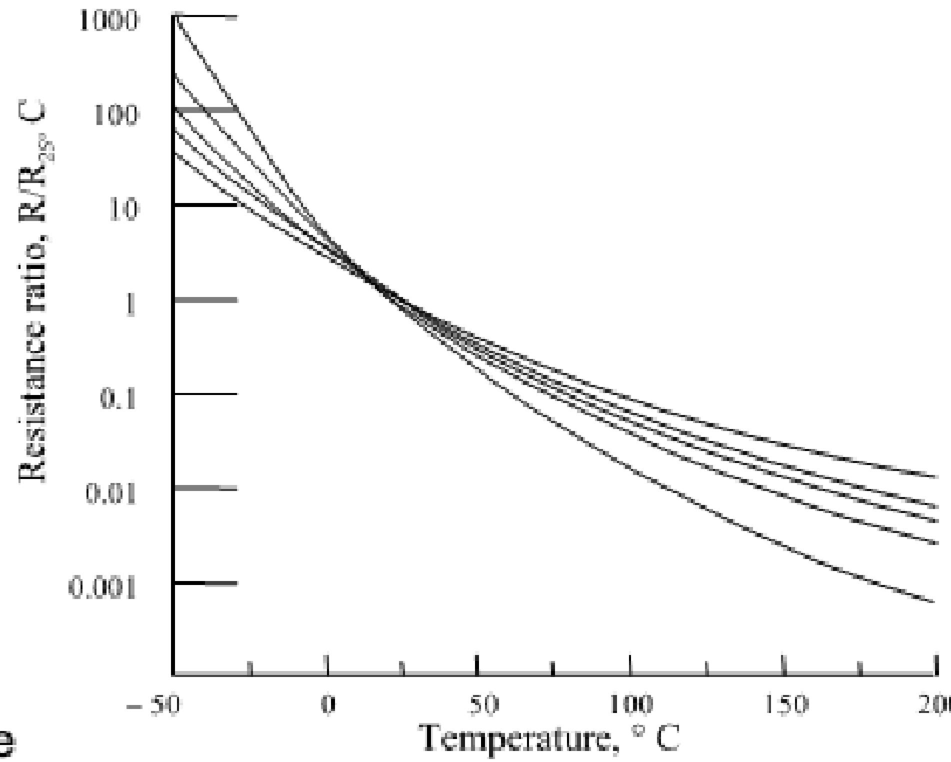
thermal and *resistor* = thermistor

- Many applications for thermistors: current-sensing, thermal protectors, self-regulating heaters.
- Biomedical applications: thermometers, flow sensing, breathing (nasal thermistor)
- All resistors have some temperature variation. Thermisors have large tempco (%change/ºC)
- material is generally a ceramic or polymer



Thermistor: sensitivity model

Typical thermistor zero-power resistance ratio-temperature characteristics for various materials.



Linear model:

$$\Delta R = k\Delta T$$

where

- ΔR = change in resistance
- ΔT = change in temperature
- k = first-order temperature coefficient of resistance

Linear model only works over small range

Nonlinear Relationship

Empirical Relationship between R and T (Kelvin)

$$R_t = R_0 \, e^{\beta \frac{T_0 - T}{T \, T_0}}$$

where

β = material constant for thermistor

T_0 = standard reference temperature

From this, we can calculate the temperature coefficient

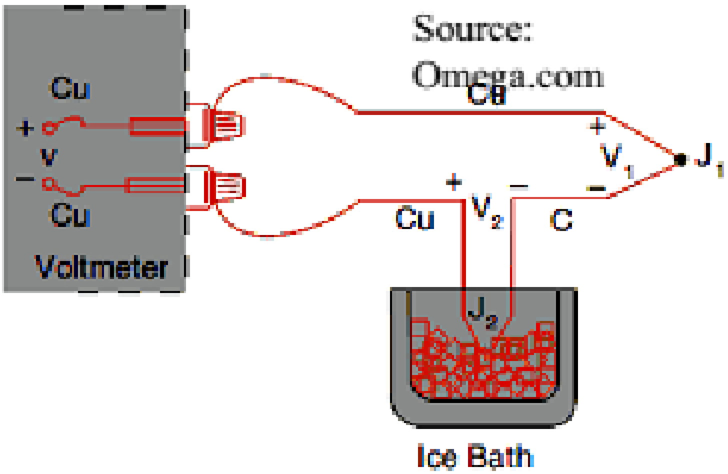
$$\alpha = \frac{1}{R_t} \frac{dR_t}{dT} = -\frac{\beta}{T^2} [\% / K]$$

In a given application, we need to consider the self-heating of the thermistor.

If the thermistor is exposed to air or fluid flow, then the cooling of the flow is important

Thermocouples

- Based on Seebeck effect: when a conductor (such as a metal) is subjected to a thermal gradient, it will generate a voltage.
- Thermocouples measure the temperature difference, not absolute temperature.
- Traditionally, one of the junctions—the cold junction—was maintained at a known (reference) temperature, while the other end was attached to a probe.
- Thermocouples are faster, smaller, more robust, more linear than thermistors



EXTERNAL REFERENCE JUNCTION
Figure 5

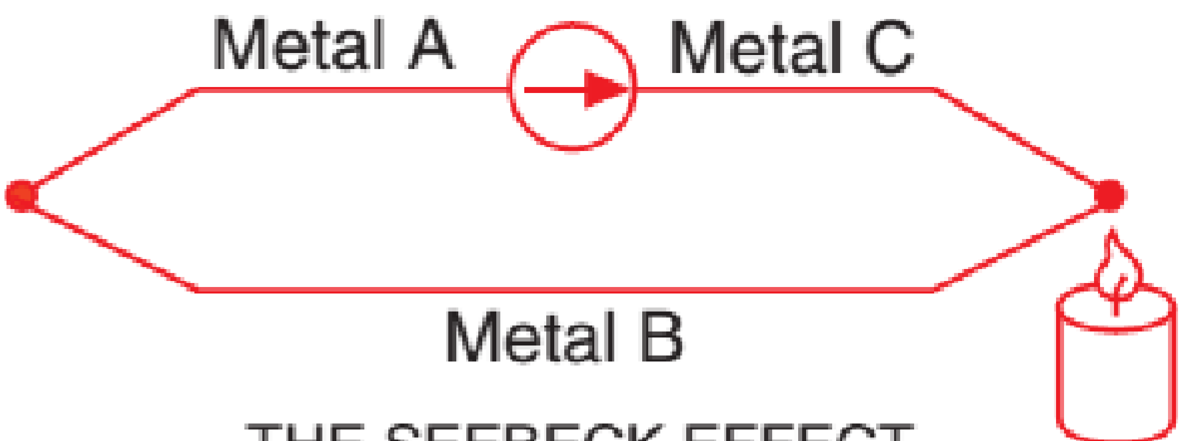
One way to determine the temperature of J_2 is to physically put the junction into an ice bath, forcing its temperature to be 0°C and establishing J_2 as the *Reference Junction*. Since both voltmeter terminal junctions are now copper-copper, they create no thermal emf and the reading *V* on the voltmeter is proportional to the temperature difference between J_1 and J_2.

Now the voltmeter reading is (see Figure 5):

$V = (V_1 - V_2) \cong \alpha(t_{J_1} - t_{J_2})$

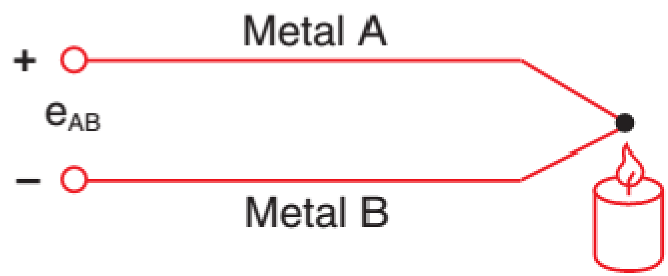
Thermocouple

When two wires composed of dissimilar metals are joined at both ends and one of the ends is heated, there is a continuous current which flows in the *thermoelectric* circuit. Thomas Seebeck made this discovery in 1821.



THE SEEBECK EFFECT

Seebeck Coefficient



e_{AB} = SEEBECK VOLTAGE

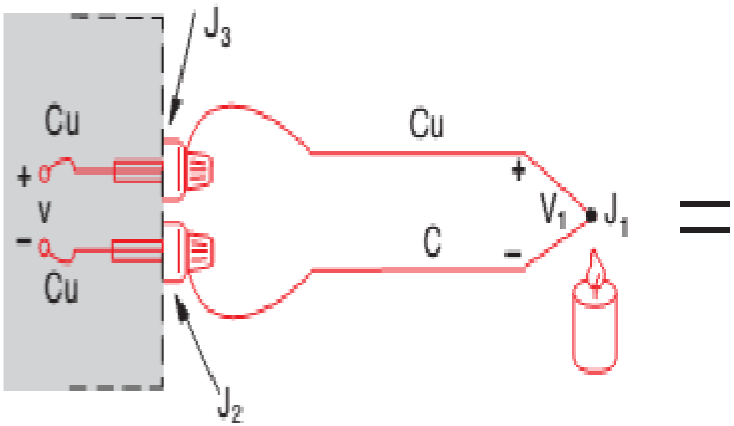
For small changes in temperature the Seebeck voltage is linearly proportional to temperature:

$$\Delta e_{AB} = \alpha \Delta T$$

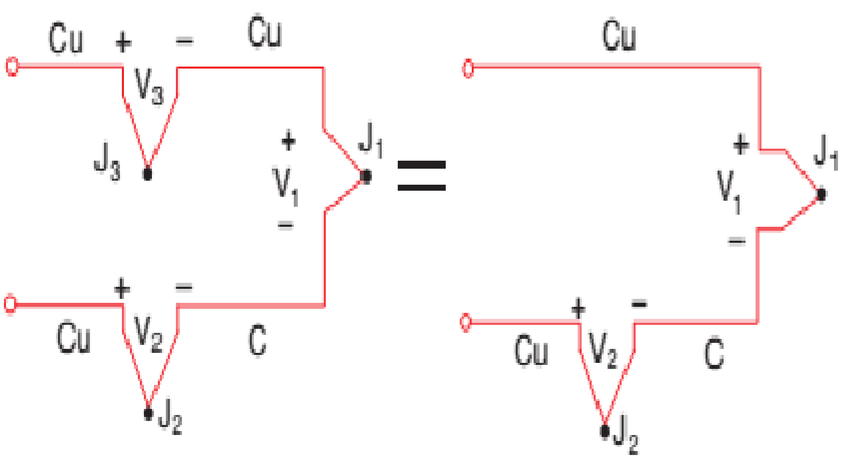
Where α, the Seebeck coefficient, is the constant of proportionality.

Measuring Thermocouple Voltage - We can't measure the Seebeck voltage directly because we must first connect a voltmeter to the thermocouple, and the voltmeter leads themselves create a new thermoelectric circuit.

Let's connect a voltmeter across a copper-constantan (Type T) thermocouple and look at the voltage output:



EQUIVALENT CIRCUITS



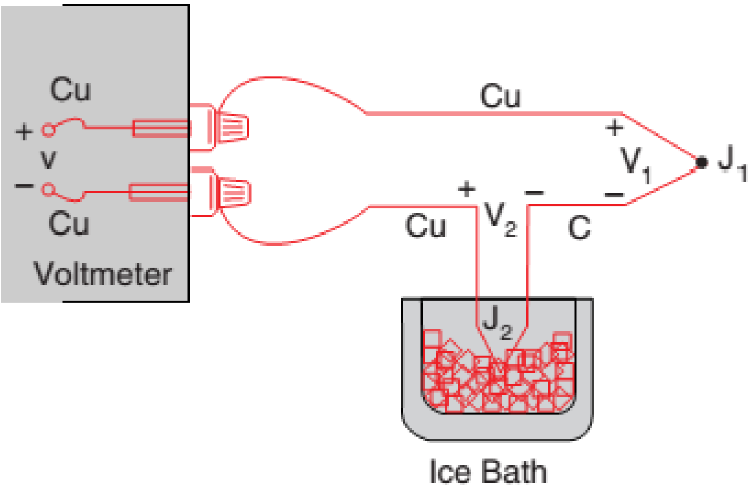
MEASURING JUNCTION VOLTAGE WITH A DVM

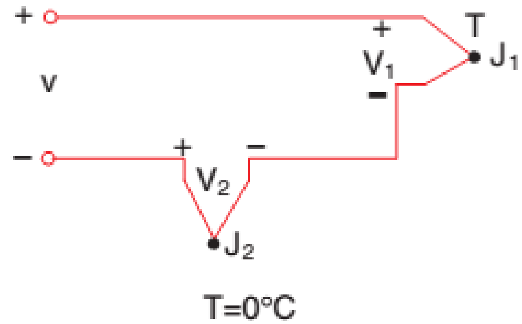
Constantan is a copper-nickel alloy usually consisting of 55% copper and 45% nickel.

We would like the voltmeter to read only V_1, but by connecting the voltmeter in an attempt to measure the output of Junction J_1, we have created two more metallic junctions: J_2 and J_3. Since J_3 is a copper-to-copper junction, it creates no thermal EMF ($V_3 = 0$), but J_2 is a copper-to-constantan junction which will add an EMF (V_2) in opposition to V_1. The resultant voltmeter reading V will be proportional to the temperature difference between J_1 and J_2. This says that we can't find the temperature at J_1 unless we first find the temperature of J_2.

Constantan is a copper-nickel alloy

The Reference Junction





$V = (V_1 - V_2) \cong \alpha(t_{J_1} - t_{J_2})$

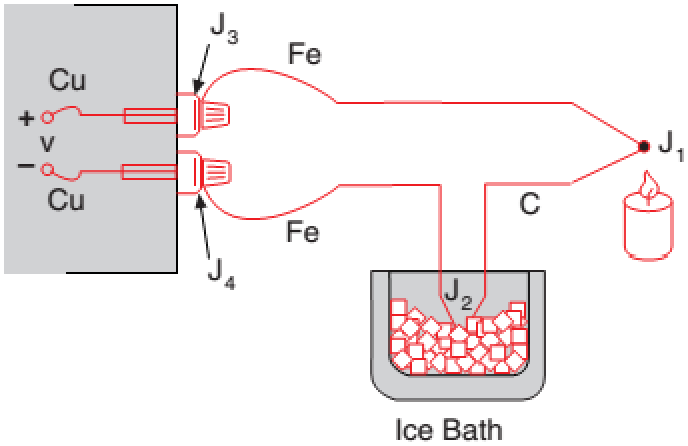
If we specify T_{J_1} in degrees Celsius:

$T_{J_1}\,(^{\circ}C) + 273.15 = t_{J_1}$

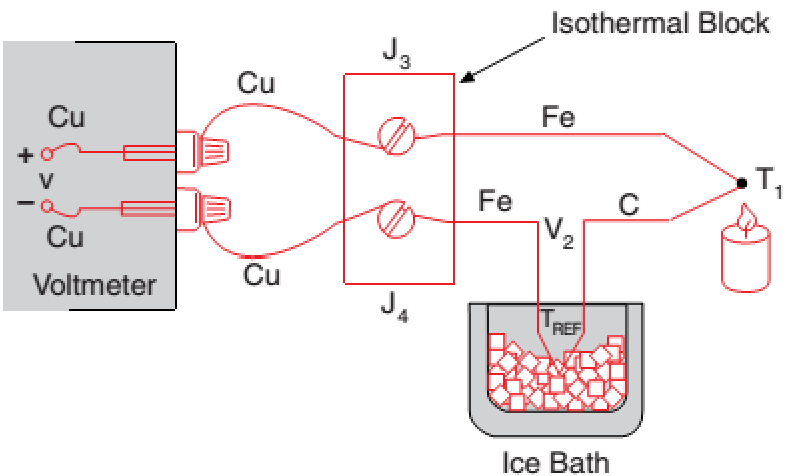
then V becomes:

$$V = V_1 - V_2 = \alpha\,[(T_{J_1} + 273.15) - (T_{J_2} + 273.15)]$$
$$= \alpha\,(T_{J_1} - T_{J_2}) = \alpha\,(T_{J_1} - 0)$$

$V = \alpha T_{J_1}$



IRON-CONSTANTAN COUPLE

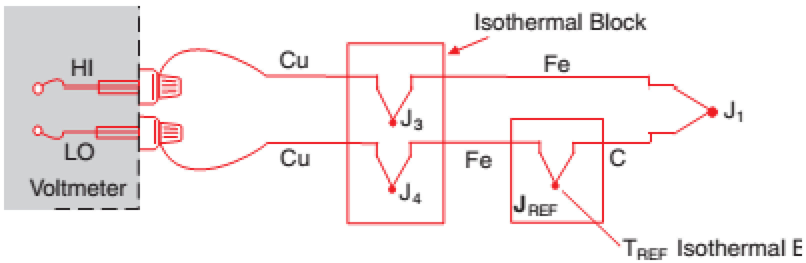


REMOVING JUNCTIONS FROM DVM TERMINALS

The isothermal block is an electrical insulator but a good heat conductor, and it serves to hold J_3 and J_4 at the same temperature. The absolute block temperature is unimportant because the two Cu-Fe junctions act in opposition. We still have

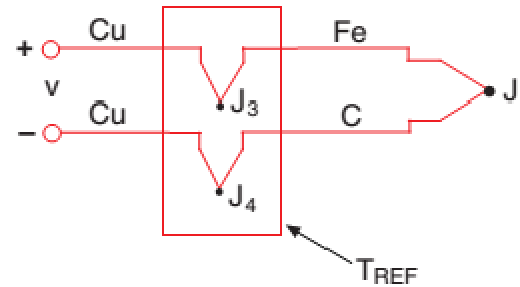
$$V = \alpha (T_1 - T_{REF})$$

Let's replace the ice bath with another isothermal block



ELIMINATING THE ICE BATH

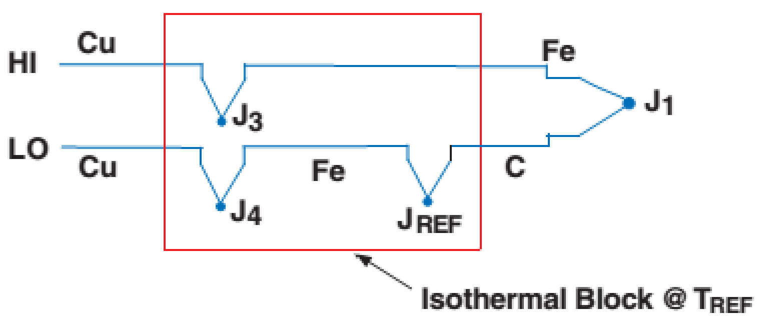
This is a useful conclusion, as it completely eliminates the need for the iron (Fe) wire in the LO lead:



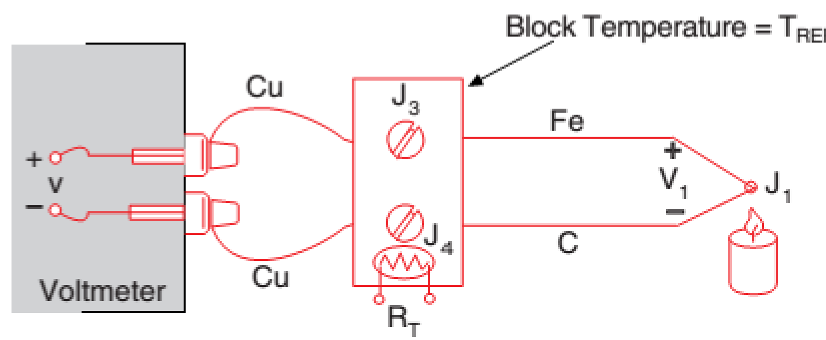
EQUIVALENT CIRCUIT

The new block is at Reference Temperature T_{REF}, and because J_3 and J_4 are still at the same temperature, we can again show that

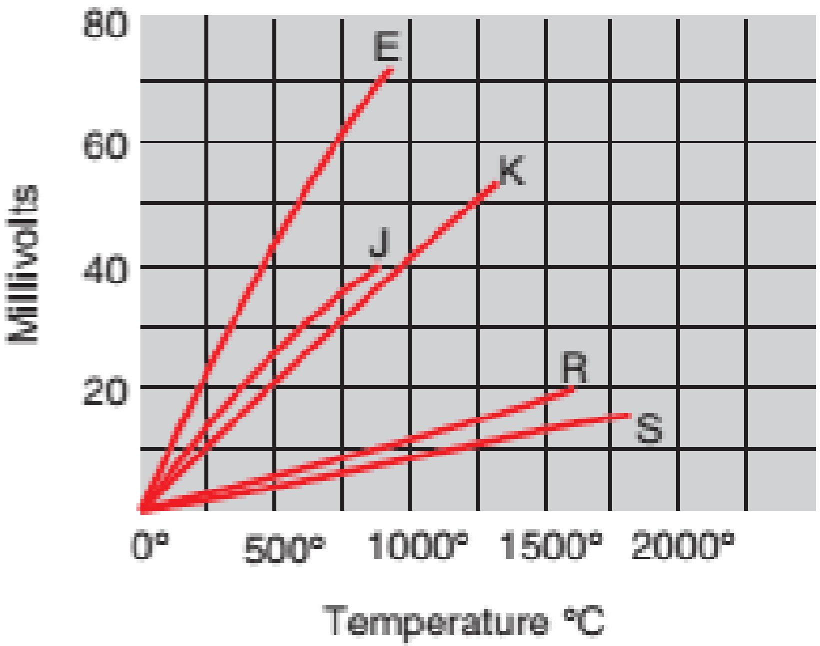
$$V = \alpha (T_1 - T_{REF})$$



JOINING THE ISOTHERMAL BLOCKS



EXTERNAL REFERENCE JUNCTION-NO ICE BATH



Type	Metals (+ / −)
E	Chromel vs. Constantan
J	Iron vs. Constantan
K	Chromel vs. Alumel
R	Platinum vs. Platinum 13% Rhodium
S	Platinum vs. Platinum 10% Rhodium
T	Copper vs. Constantan

THERMOCOUPLE TEMPERATURE vs. VOLTAGE GRAPH

Example

- Type J thermocouple is to be used in measurement system that must provide an output of 2V at 200C. A solid state sensor system will be used to provide reference temperature compensation. The sensor has output voltage varies as 8mV/C. Develop the system.

Solution

- J thermocouple with 0 reference will output 10.75mv @200C.
- Overall gain=2/10.75mv=185.5
- (8mV/C)/(50mV/C)=160 times larger than TC.
- 185.5/160=1.159 extra amplification is needed.
- $V_{out} = 1.159[160V_{TC} + V_c]$

Semiconductor Temperature Sensors

- Modern semiconductor temperature sensors offer high accuracy and high linearity over an operating range of about –55°C to +150°C. Internal amplifiers can scale the output to convenient values, such as 10mV/°C. They are also useful in cold-junction-compensation circuits for wide temperature range thermocouples

Semiconductor Temperature Sensors

- All semiconductor temperature sensors make use of the relationship between a bipolar junction transistor's (BJT) base-emitter voltage to its collector current:

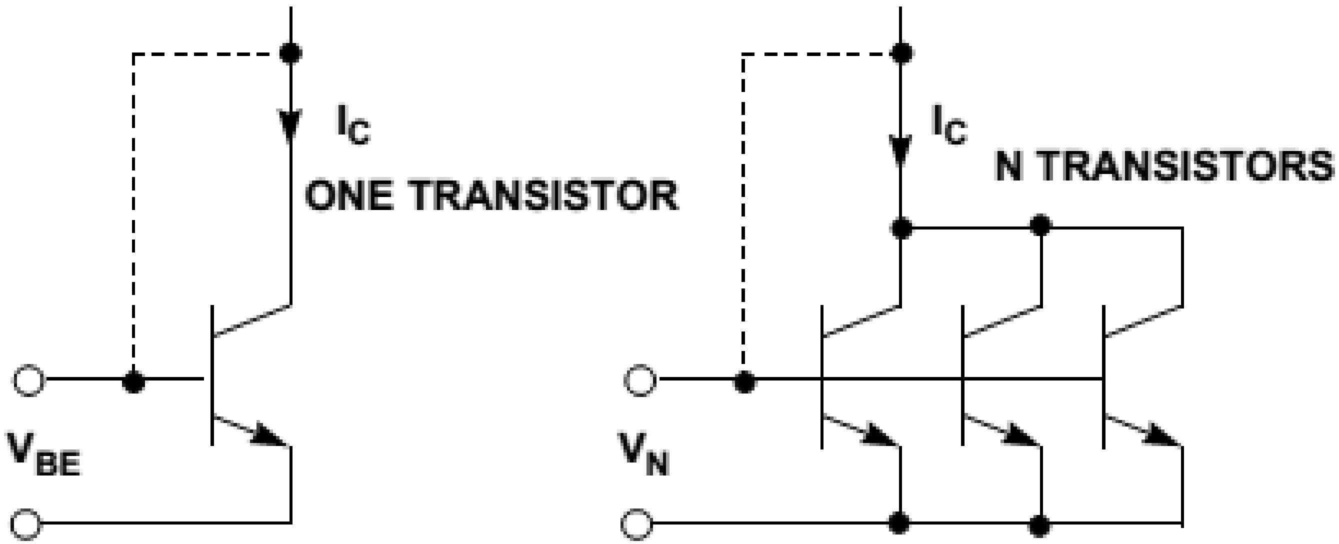
$$V_{BE} = \frac{kT}{q} \ln\left(\frac{I_c}{I_s}\right)$$

where k is Boltzmann's constant, T is the absolute temperature, q is the charge of an electron, and Is is a current related to the geometry and the temperature of the transistors.

If we take N transistors identical to the first and allow the total current Ic to be shared equally among them, we find that the new base-emitter voltage is given by the equation

$$V_N = \frac{kT}{q} \ln\left(\frac{I_c}{N \cdot I_s}\right)$$

BASIC RELATIONSHIPS FOR SEMICONDUCTOR TEMPERATURE SENSORS



$$V_{BE} = \frac{kT}{q}\ln\left(\frac{I_C}{I_S}\right)$$

$$V_N = \frac{kT}{q}\ln\left(\frac{I_C}{N \cdot I_S}\right)$$

$$\Delta V_{BE} = V_{BE} - V_N = \frac{kT}{q}\ln(N)$$

INDEPENDENT OF I_C, I_S

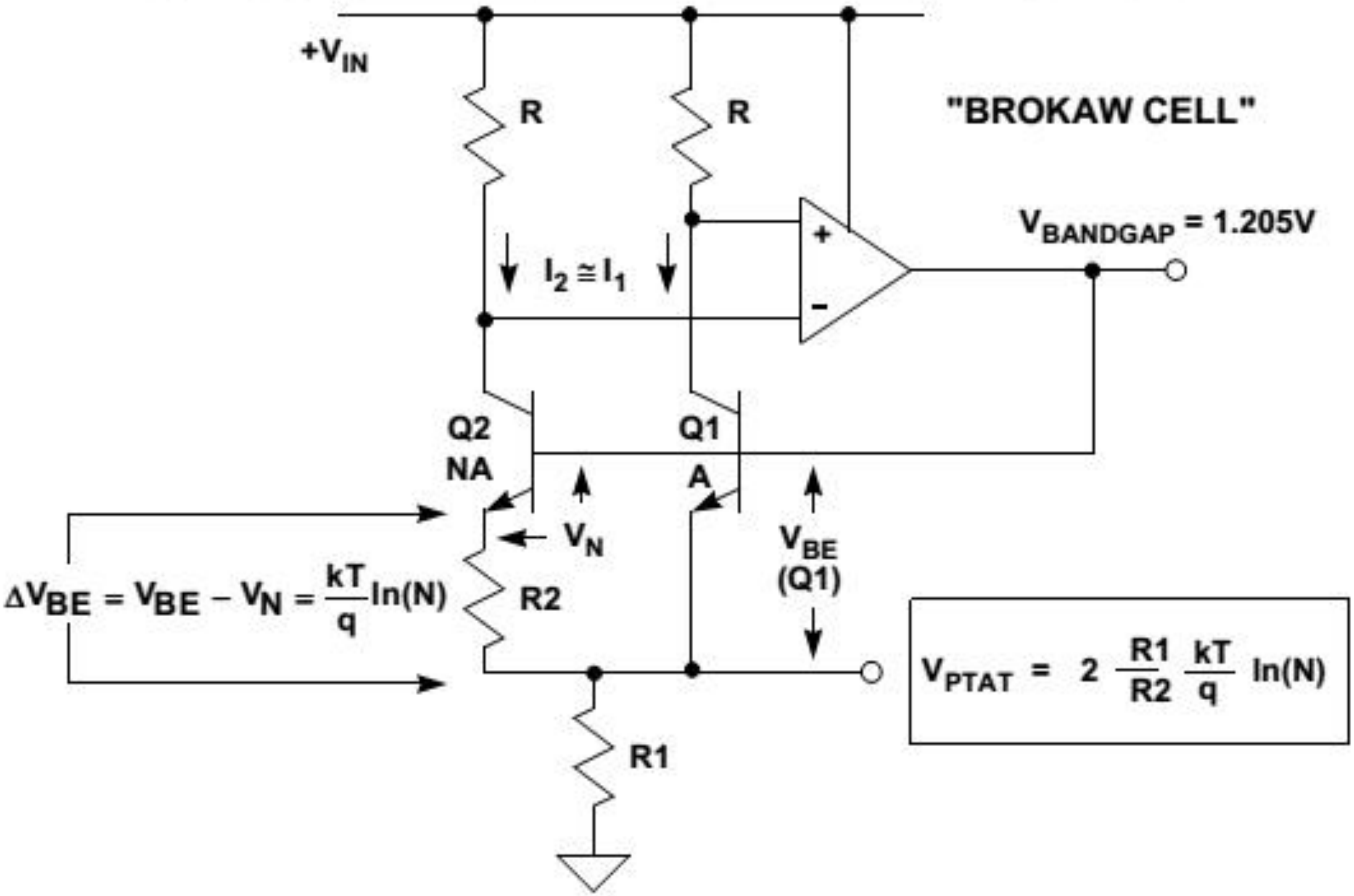
$$\Delta V_{BE} = V_{BE} - V_N = \frac{kT}{q} \ln\left(\frac{I_c}{I_s}\right) - \frac{kT}{q} \ln\left(\frac{I_c}{N \cdot I_s}\right)$$

$$\Delta V_{BE} = V_{BE} - V_N = \frac{kT}{q}\left[\ln\left(\frac{I_c}{I_s}\right) - \ln\left(\frac{I_c}{N \cdot I_s}\right)\right]$$

$$\Delta V_{BE} = V_{BE} - V_N = \frac{kT}{q} \ln\left[\left(\frac{I_c}{I_s}\right) \Big/ \left(\frac{I_c}{N \cdot I_s}\right)\right] = \frac{kT}{q} \ln(N)$$

$$V_{PTAT} = \frac{2R1\left(V_{BE} - V_N\right)}{R2} = 2\frac{R1}{R2}\frac{kT}{q}\ln(N).$$

CLASSIC BANDGAP TEMPERATURE SENSOR



Integrated Temperature Sensor– LM35 as Example–

- You can measure temperature more accurately than a using a thermistor.
- The sensor circuitry is sealed and not subject to oxidation, etc.
- The LM35 generates a higher output voltage than thermocouples and may not require that the output voltage be amplified.
- The scale factor is .01V/ºC

- The LM35 does not require any external calibration or trimming and maintains an accuracy of +/-0.4 ºC at room temperature and +/- 0.8 ºC over a range of 0 ºC to +100 ºC.

Electrical Connections

- V_c = 4 to 30V
- 5v or 12 v are typical values used.
- R_a can range from 80 KΩ to 600 KΩ , but most just use 80 KΩ.
- Temperature (ºC) = Vout * (100 ºC/V)