
Temperature Measurement

Types of Temperature devices

- Indicators
 - Contact probes
 - Non-contact probes
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Indicators

- Two primary types
 - Liquid expansion (Glass bulb) thermometers
 - Bi-metal thermometers



Glass Thermometers

■ Construction

- ❑ Glass tube with very small hollow in center
 - Sometimes shaped as an oval hole rather than round
- ❑ Large reservoir at both ends
- ❑ Evacuated and Sealed

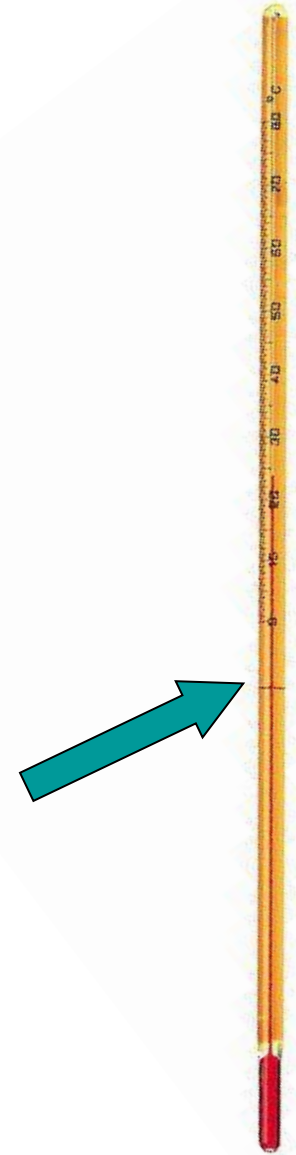
■ Liquid filled

- ❑ Used to be Mercury
 - Still available but less common
- ❑ Petrolate
- ❑ Alcohol based liquid
- ❑ Mineral oil
- ❑ Synthetic oil



Immersion depth

- Immersion depth on thermometers is critical to reduce error
 - Partial immersion
 - Most common
 - Immersion depth indicated by a line on thermometer
 - Total immersion
 - Less common but used in special conditions



How it works

- Liquid in the glass bulb expands with temperature
 - Expansion rate known and constant
- Liquid pushes up the thin tube
 - Amount of liquid going up tube is small compared to the amount in reservoir
- Scale marked on outside of tube
- Reservoir on end prevents pressure buildup inside tube as fluid rises and provides for “overflow” if pushed over scale.

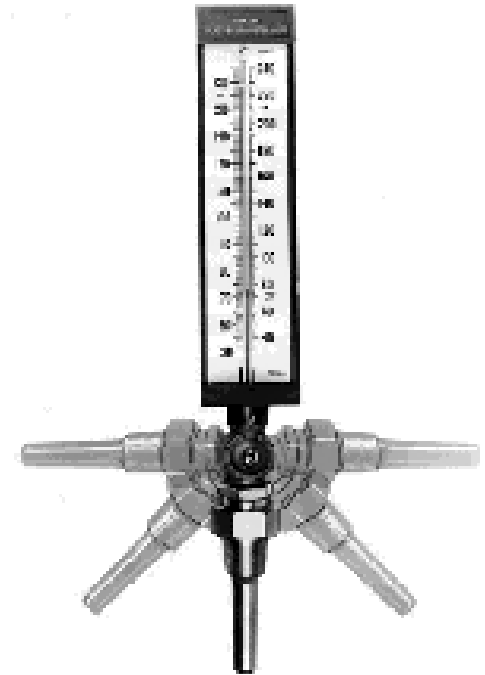


Error and problems

- Fragile!
 - Cant take a lot of pressure
 - Cant insert into high flow rate liquids without protection
- Insertion depth critical to calibration
 - Too deep or shallow causes error
- Temperature of extended portion can cause error.
 - Relies on small volume of tube to reduce this error

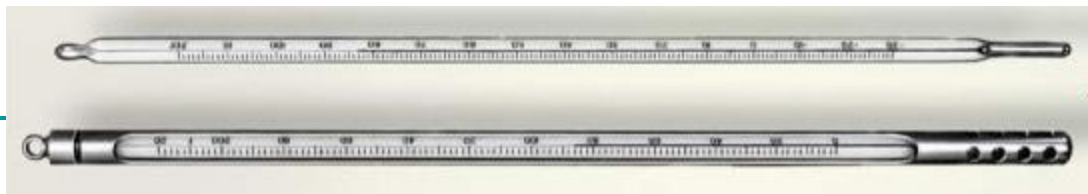
Industrial Thermometers

- Armored ends to prevent breakage
- Angle bases
 - ❑ Actual thermometer measures temperature of metal not fluid!
- Thermometer sleeves, encase in metal but still allow actual thermometer immersion in liquid.



CAT. NO. 141C

CAT. NO. 141G



In old days...

- Thermometer switches existed
 - Relied on the electrical conduction of mercury as a switch
 - Used on various control systems before electronic controllers existed
 - Specially thermometers existed that utilized unique tube designs to vary scale resolution at certain temperature ranges.
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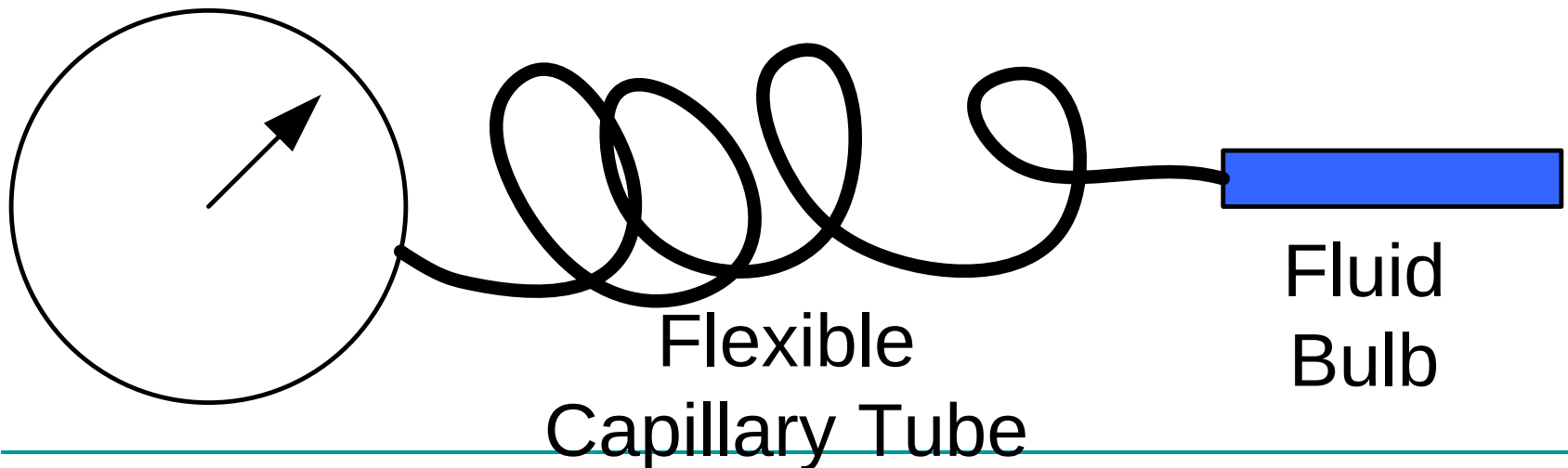
Expansion bulb thermometers

- Rely on the expansion of fluid to move a needle (or switch element) remotely.



Expansion bulb thermometers

- Used for remote readings
- Used in refrigeration switches
 - If you have a refrigerator, you have a variation on this!



Bi-Metal Thermometer

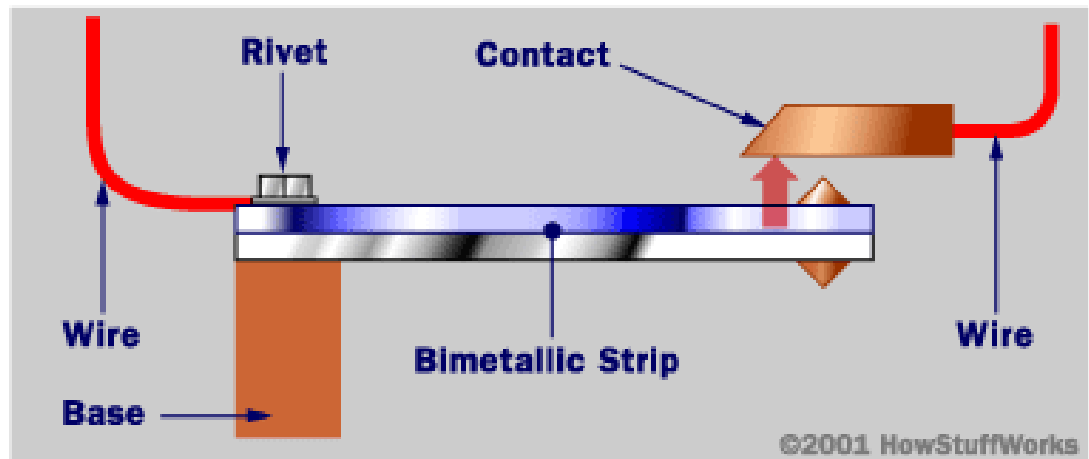
- Typically good for indicators and switches
- Not particularly accurate
- Good rugged indicators
- Inexpensive
- Very common in all kinds of processes and systems where “human viewable” indicators are needed.



How do they work?

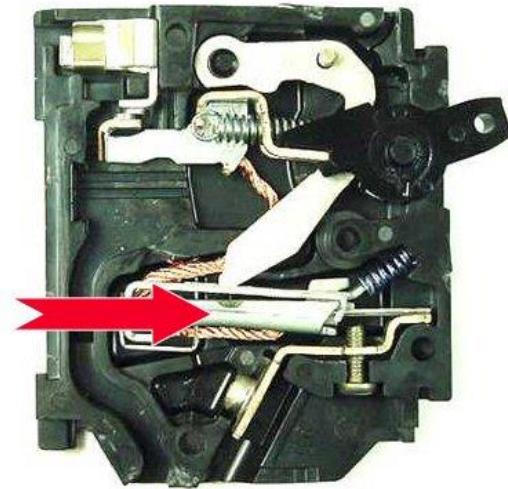
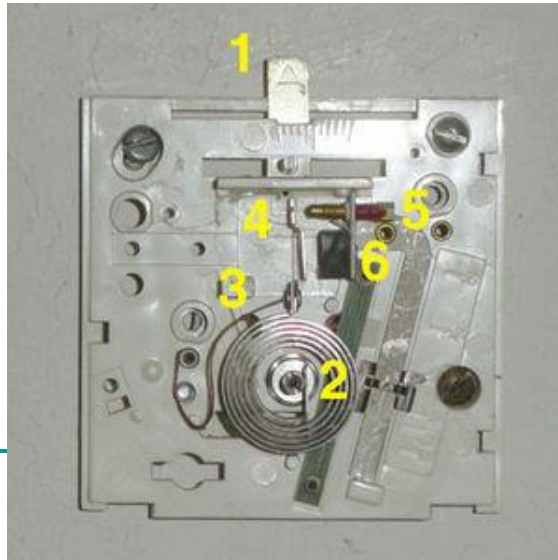
- Consists of two metallic materials laminated together.
- Each material has different coefficient of expansion.
- Different rates of expansion cause element to bend as it heats and cools

Simple Bi-metal switch



Other applications of Bi-Metal elements

- Thermometer uses a coil of Bi-Metal to twist gauge dial
- Other common uses for this technology:
 - Home thermostat
 - Electrical circuit breaker
 - Water heater thermostats



Here comes that new technology stuff!

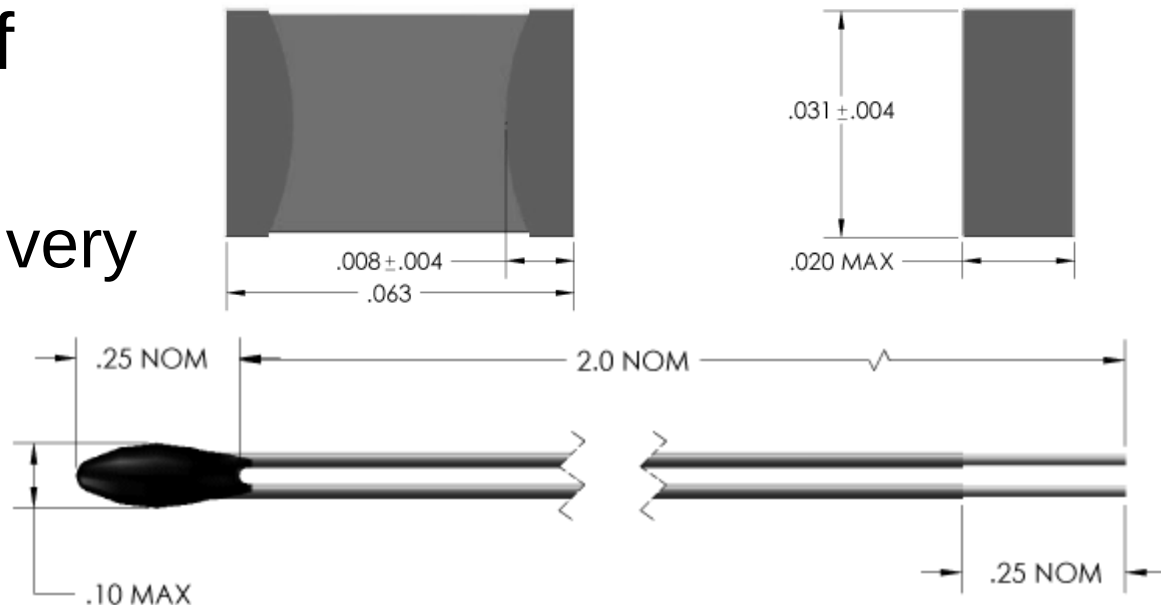
- Devices so far do not lend themselves to accurate recording of data for other uses.
 - New stuff, better stuff, new ways to do it...
 - Yep this stuff really is better... **IF** you use it right!
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Electronic Contact Probes and Devices

- Resistance Elements
 - Thermistor
 - RTD
 - Voltage Elements
 - Thermocouple
 - Semiconductor
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Thermistor

- Variable resistance element
- Resistance varies with Temperature
- Has a variety of package types
 - ❑ Actual element very tiny.

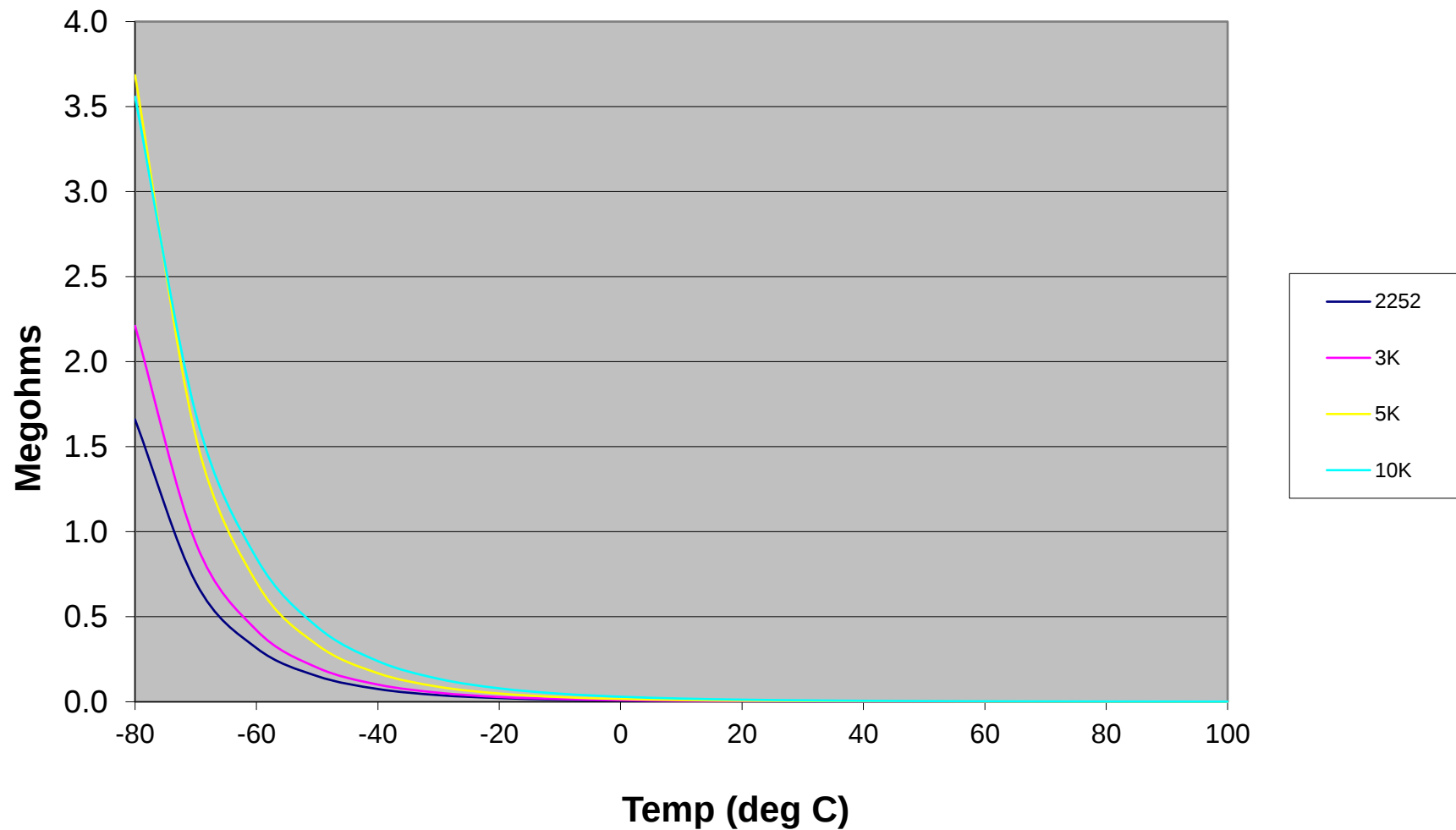


Thermistor

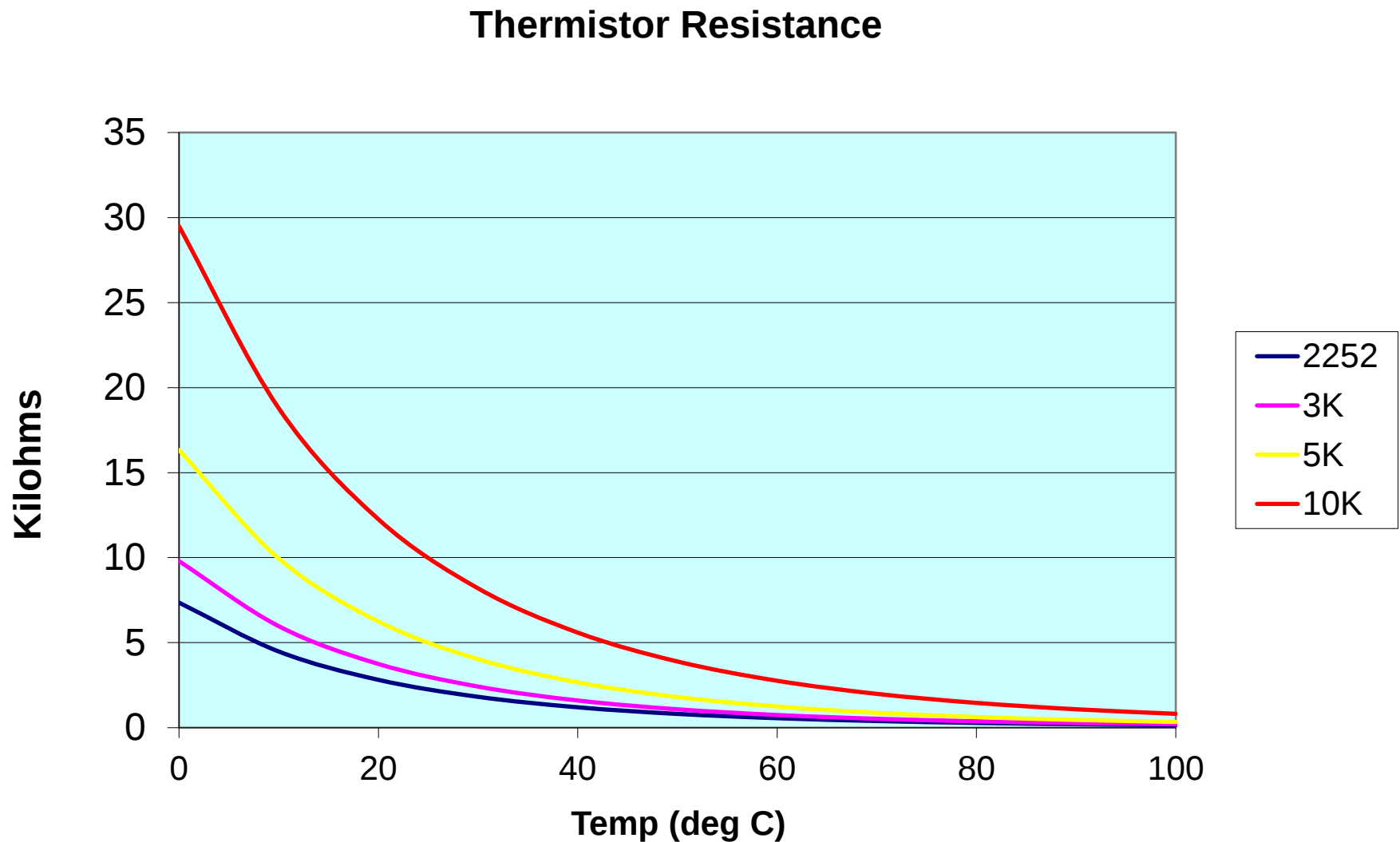
- Reasonably inexpensive
 - Elements run from around \$20 and up.
 - Resistance is inverse WRT temperature
 - Temp goes up resistance goes down
 - Extremely Non-linear
 - Thermistor value specified as resistance at 25°C
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Thermistor Plot

Thermistor Resistance



Thermistor Plot 0 – 100 C

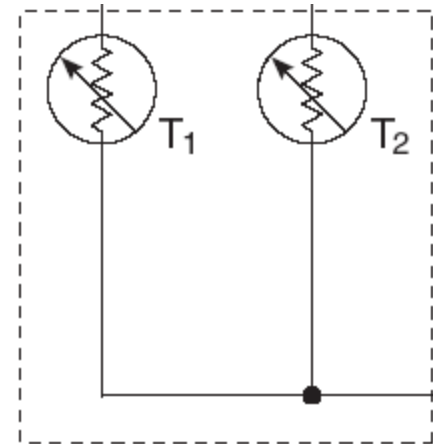


Reading the temperature

- Lookup in table
 - Calculate from formula
 - Typically requires multiple formulas covering different segments of the curve.
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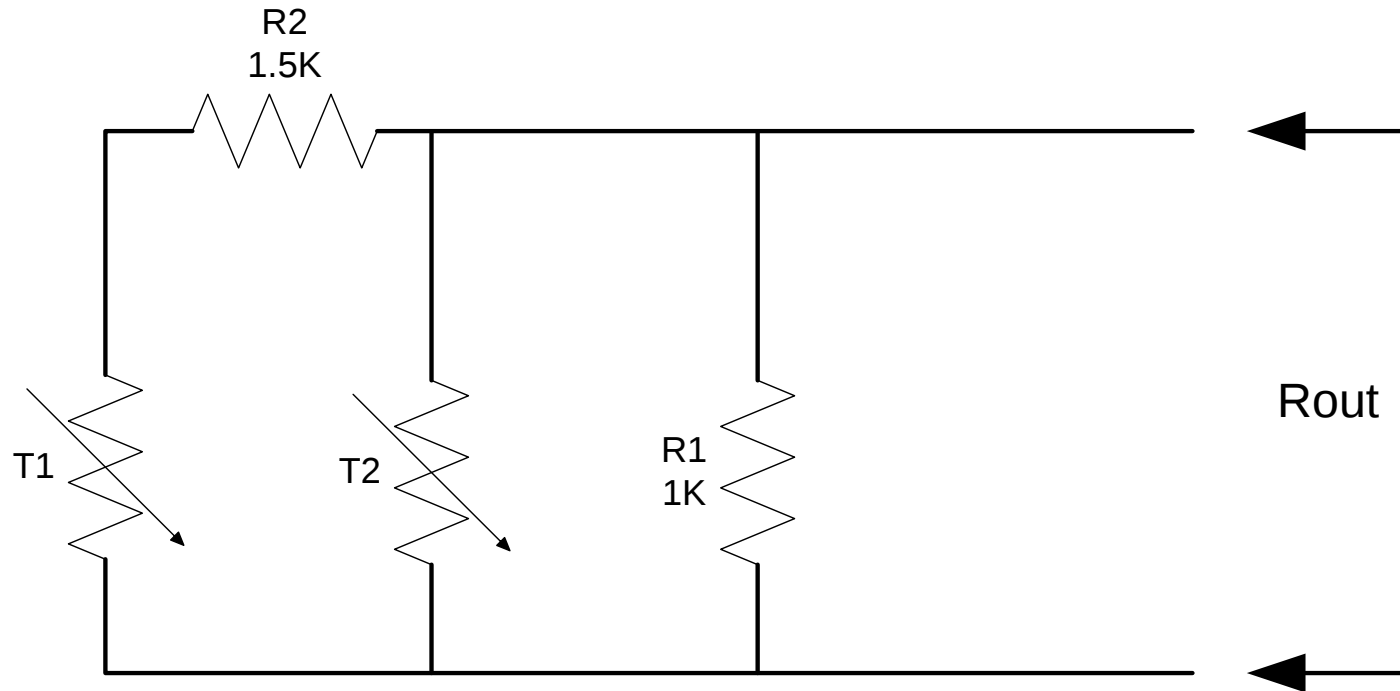
Linear Thermistor

- Built of two matched thermistors that act in concert to provide a linear (more or less) output.
- Typically linear over a fairly short temperature span

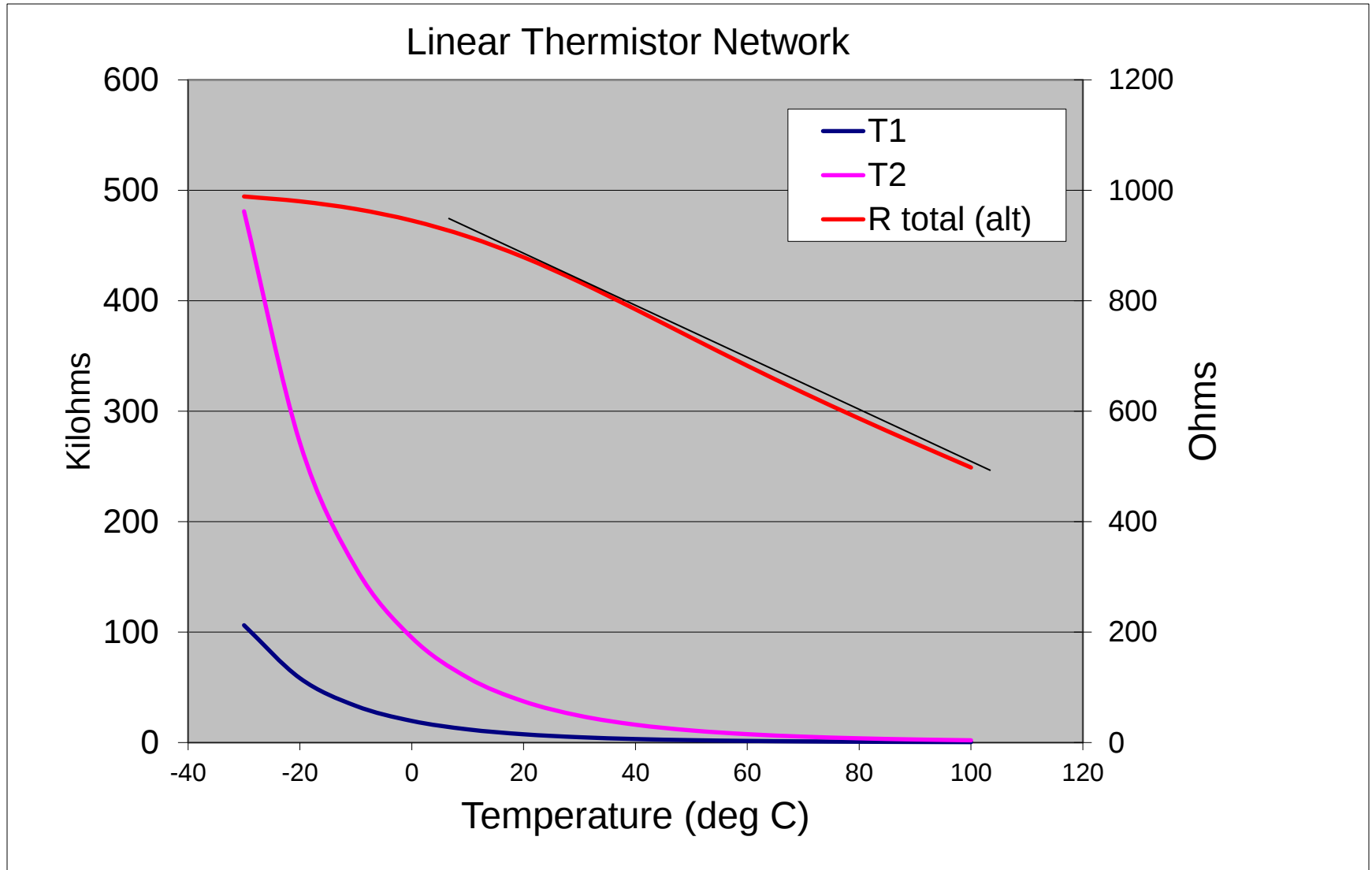


Linear Thermistor network

- Example of linear thermistor network



Plot of “linear” Thermistor set (Omega 44018)

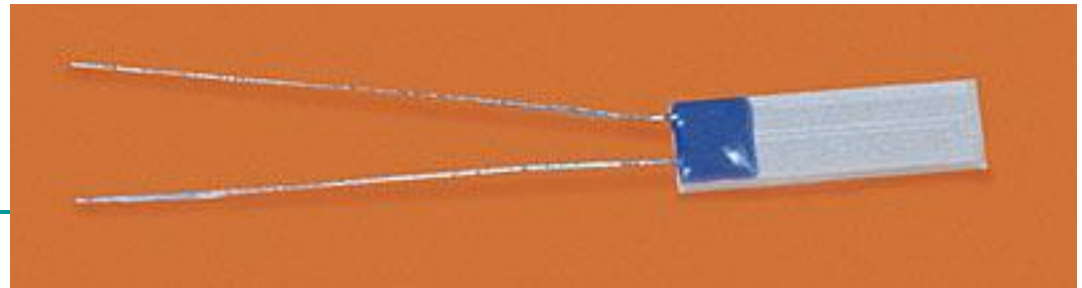


RTD

- Resistance Temperature Detector
 - The RTD is one of the most accurate temperature sensors. Not only does it provide good accuracy, it also provides excellent stability and repeatability.
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RTD

- Fine coiled wire wrapped around a ceramic or glass core
- Or film of metal on a ceramic backing



RTD

- EXTREEMLY Fragile
 - Generally installed into a metal sheath



- The RTD element is made from a pure material whose resistance at various temperatures has been documented
 - Rated by α ($\Omega/\Omega/^{\circ}\text{C}$ or $\%/^{\circ}\text{C}$)

RTD

- Materials used for RTD's
 - ❑ Platinum (most popular and accurate)
 - ❑ Nickel
 - ❑ Copper
 - ❑ Balco (rare)
 - ❑ Tungsten (rare)

Measuring resistance elements

- Remember back to measuring resistance with basic instrumentation!



- Flow current through element and measure current through and voltage across

Flow current through the element?

- Uh Oh.... Current through a resistance... sounds like a heater, doesn't it?
- YES! You must be very careful.
- This is known as self heating error
- Generally specified in $^{\circ}\text{C}/\text{mW}$ at some air flow
 - Typically in the range from .04 to .2 $^{\circ}\text{C}/\text{mW}$

Solution...

- Use as low a current as you can!

Strengths

- Values are very accurate and predictable
 - Wide range of styles
 - Relatively inexpensive
 - Starting at around \$50
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Weaknesses

- Very small change in resistance per degree
- Generally limited temperature range
 - -200 to around 850°C

Temperature from Resistance value

- IEC 751 standard temperature curve
 - $R_0 = 100 \, \Omega$ @ 0°C ($\alpha = .00385$)
 - Temperature curve calculation (0°C to 850°C)
- Coefficients
 - $A = 0.0039083$ $B = -5.775\text{e-}7$

$$T_R = \frac{-R_0 A + \sqrt{R_0^2 A^2 - 4R_0 B(R_0 - R_T)}}{2R_0 B}$$

Plug and chug

- $R_T = 220.57$ (Resistance at temp)
 - Coefficients
 - $A = 0.0039083$ $B = -5.775e-7$
- $R_0 = 100$ (Resistance at 0C)
- $Temp = 324.009^{\circ}C$

$$T_R = \frac{-R_0 A + \sqrt{R_0^2 A^2 - 4R_0 B(R_0 - R_T)}}{2R_0 B}$$

RTD resistance values

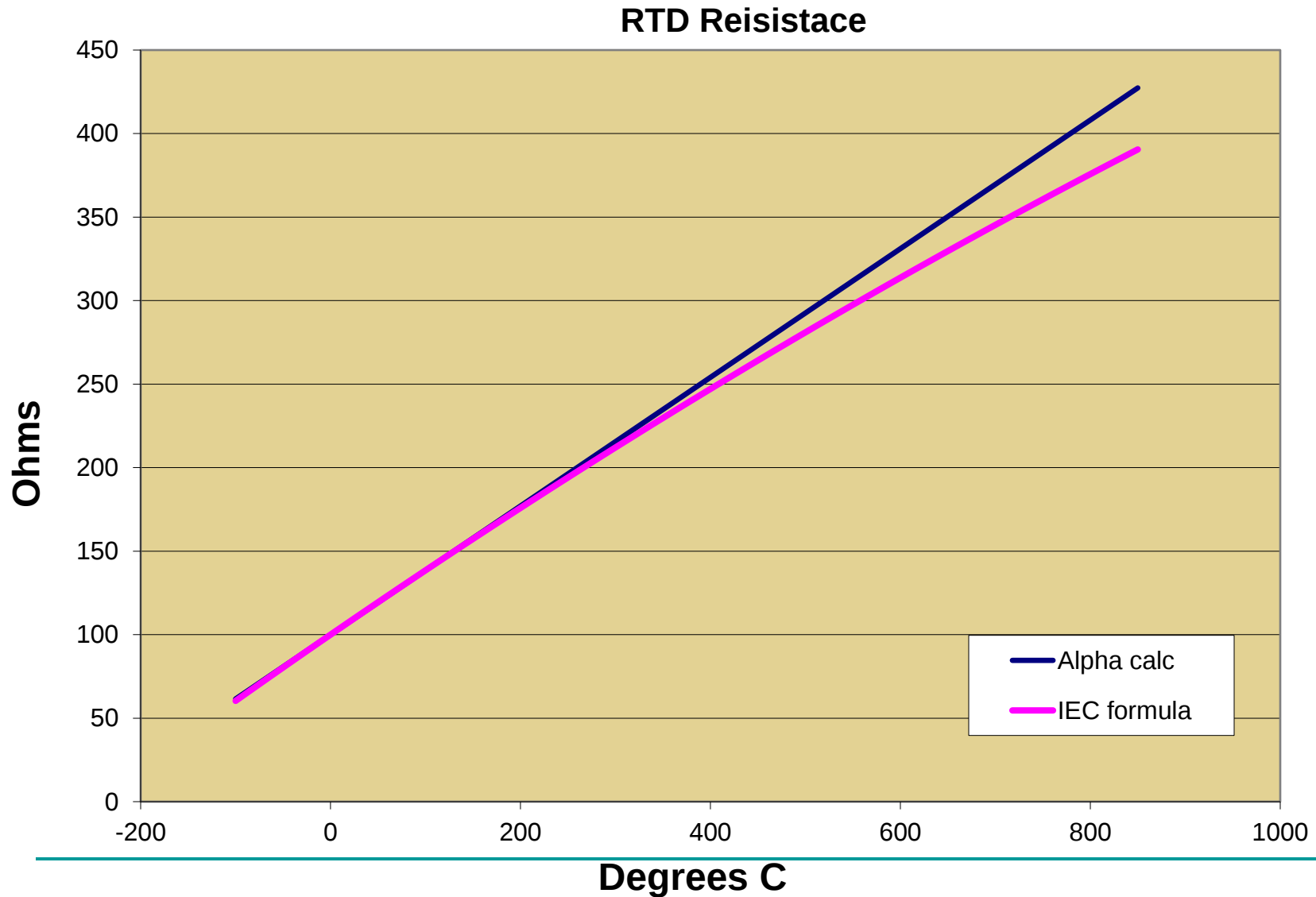


Table lookup

Reference Data

Resistance vs. Temperature Table for DIN-IEC-751 Platinum RTDs

Continued

100 Ohm With Temperature Coefficient of 0.00385

ITS-90 °C	0	1	2	3	4	5	6	7	8	9	ITS-90 °C
200	175.86	176.22	176.59	176.96	177.33	177.69	178.06	178.43	178.79	179.16	200
210	179.53	179.89	180.26	180.63	180.99	181.36	181.72	182.09	182.46	182.82	210
220	183.19	183.55	183.92	184.28	184.65	185.01	185.38	185.74	186.11	186.47	220
230	186.84	187.20	187.56	187.93	188.29	188.66	189.02	189.38	189.75	190.11	230
240	190.47	190.84	191.20	191.56	191.92	192.29	192.65	193.01	193.37	193.74	240
250	194.10	194.46	194.82	195.18	195.55	195.91	196.27	196.63	196.99	197.35	250
260	197.71	198.07	198.43	198.79	199.15	199.51	199.87	200.23	200.59	200.95	260
270	201.31	201.67	202.03	202.39	202.75	203.11	203.47	203.83	204.19	204.55	270
280	204.90	205.26	205.62	205.98	206.34	206.70	207.05	207.41	207.77	208.13	280
290	208.48	208.84	209.20	209.56	209.91	210.27	210.63	210.98	211.34	211.70	290
300	212.05	212.41	212.76	213.12	213.48	213.83	214.19	214.54	214.90	215.25	300
310	215.61	215.96	216.32	216.67	217.03	217.38	217.74	218.09	218.44	218.80	310
320	219.15	219.51	219.86	220.21	220.57	220.92	221.27	221.63	221.98	222.33	320
330	222.68	223.04	223.39	223.74	224.09	224.45	224.80	225.15	225.50	225.85	330
340	226.21	226.56	226.91	227.26	227.61	227.96	228.31	228.66	229.02	229.37	340
350	229.72	230.07	230.42	230.77	231.12	231.47	231.82	232.17	232.52	232.87	350
360	233.21	233.56	233.91	234.26	234.61	234.96	235.31	235.66	236.00	236.35	360
370	236.70	237.05	237.40	237.74	238.09	238.44	238.79	239.13	239.48	239.83	370
380	240.18	240.52	240.87	241.22	241.56	241.91	242.26	242.60	242.95	243.29	380
390	243.64	243.99	244.33	244.68	245.02	245.37	245.71	246.06	246.40	246.75	390
400	247.00	247.34	247.68	248.02	248.37	248.71	249.05	249.39	249.73	250.07	400

Voltage generating transducers

■ Thermocouple

- ❑ Created by junction of two dissimilar metals
- ❑ Generates small voltages in response to temperatures
- ❑ Called “thermo-electric” effect

■ Thermopile

- ❑ Specialized cell consisting of many thermo-electric elements wired in series.
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Thermocouple

- Not all metal combinations are useful
- Common materials
 - ❑ (J) Iron-Constantan [First industrial TC]
 - ❑ (T) Copper – Constantan
 - ❑ (K) Chromel – Alumel
 - ❑ (E) Chromel – Constantan

Thermocouple

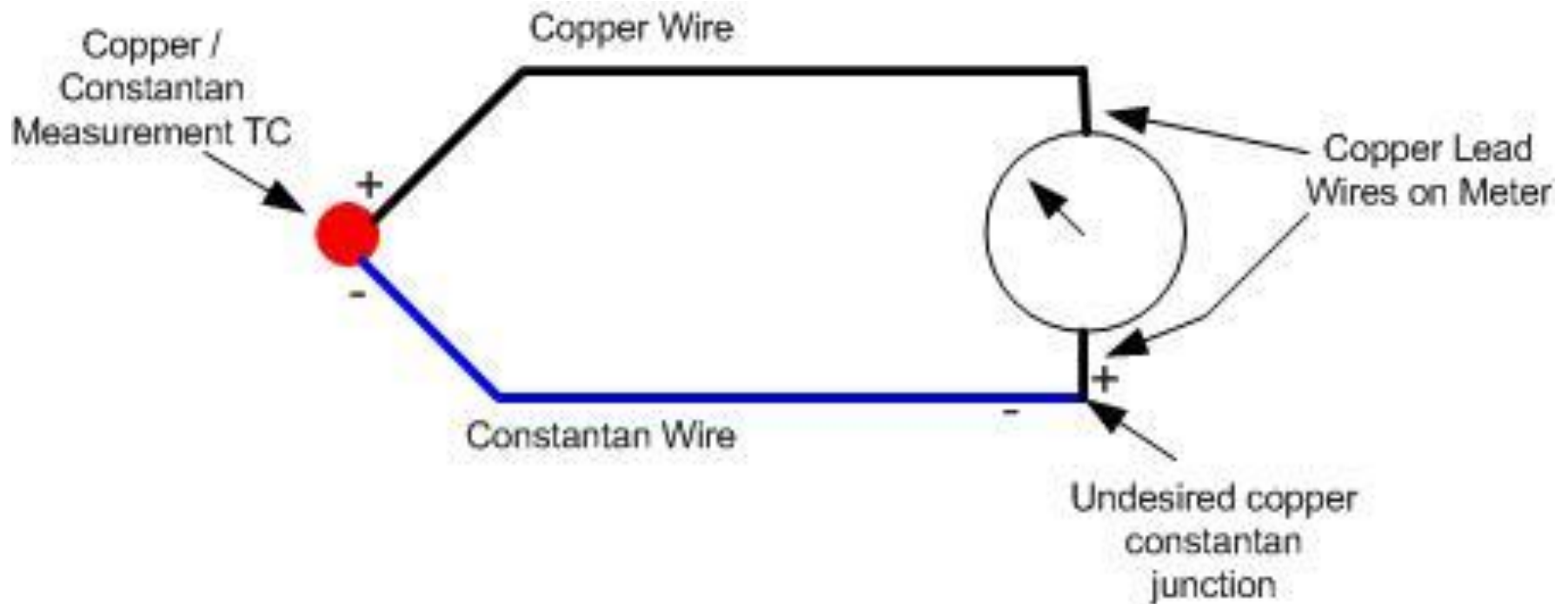
- High temperature and exotic types
 - ❑ R
 - ❑ N
 - ❑ S
 - ❑ T
 - ❑ Tungsten - Rhenium combinations
 - ❑ Tungsten – Gold combinations

Temperature ranges

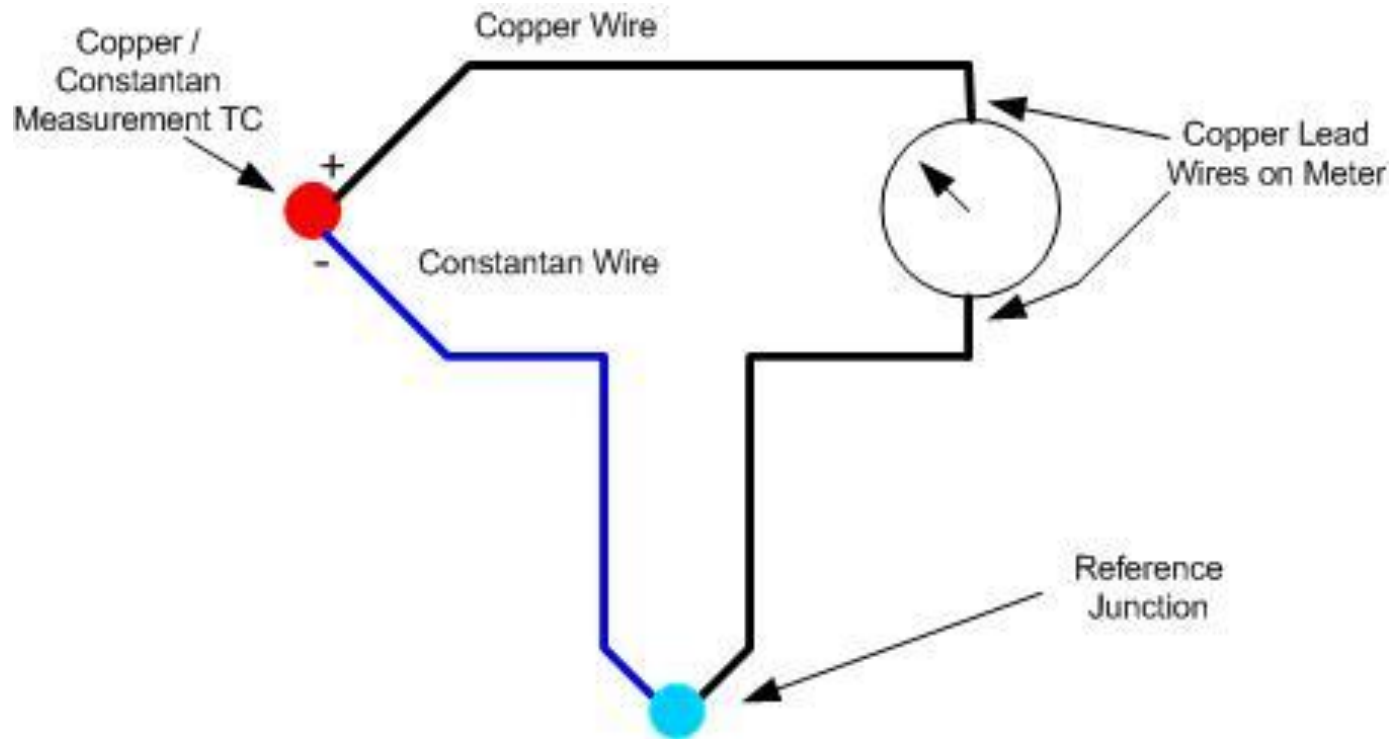
Type	Materials	Min temp	Max temp	Min°C	Max°C
J	Iron Constantan(Cu-Ni)	0°C	750°C	0 mV	42.281 mV
T	Copper Constantan(Cu-Ni)	-250°C	350°C	-6.18 mV	17.819 mV
K	Cromel (Ni-Cr) Alumel (Ni- Al)	-200°C	1250°C	-5.891 mV	50.644 mV
E	Cromel (Ni-Cr) Constantan(Cu-Ni)	-200°C	900°C	-8.825 mV	68.787 mV
N	Nicrosil (Ni-Cr-Si) NiSil (Ni-Si-Mg)	-260°C	1300°C	-4.336 mV	47.513 mV
S	Platinum-13% Rhodium Platinum	-50°C	1768°C	-0.236 mV	18.693 mV
B	Platinum-30% Rhodium Platinum-6% Rhodium	0°C	1820°C	0 mV	13.82 mV
C	Tungsten-5% Rhenium Tungsten-26% Rhenium	0°C	2320°C	0 mV	37.107 mV

Simple TC circuit

- Connect TC directly to Meter



Solution to unwanted junction

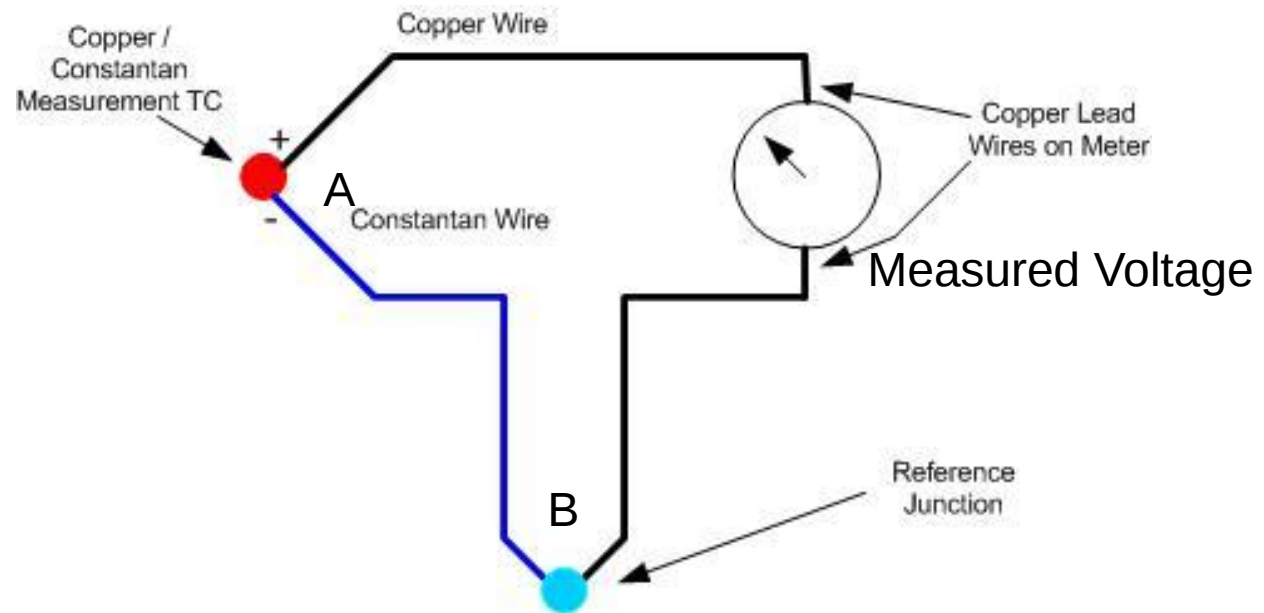


- Add a second type T junction to change wire type

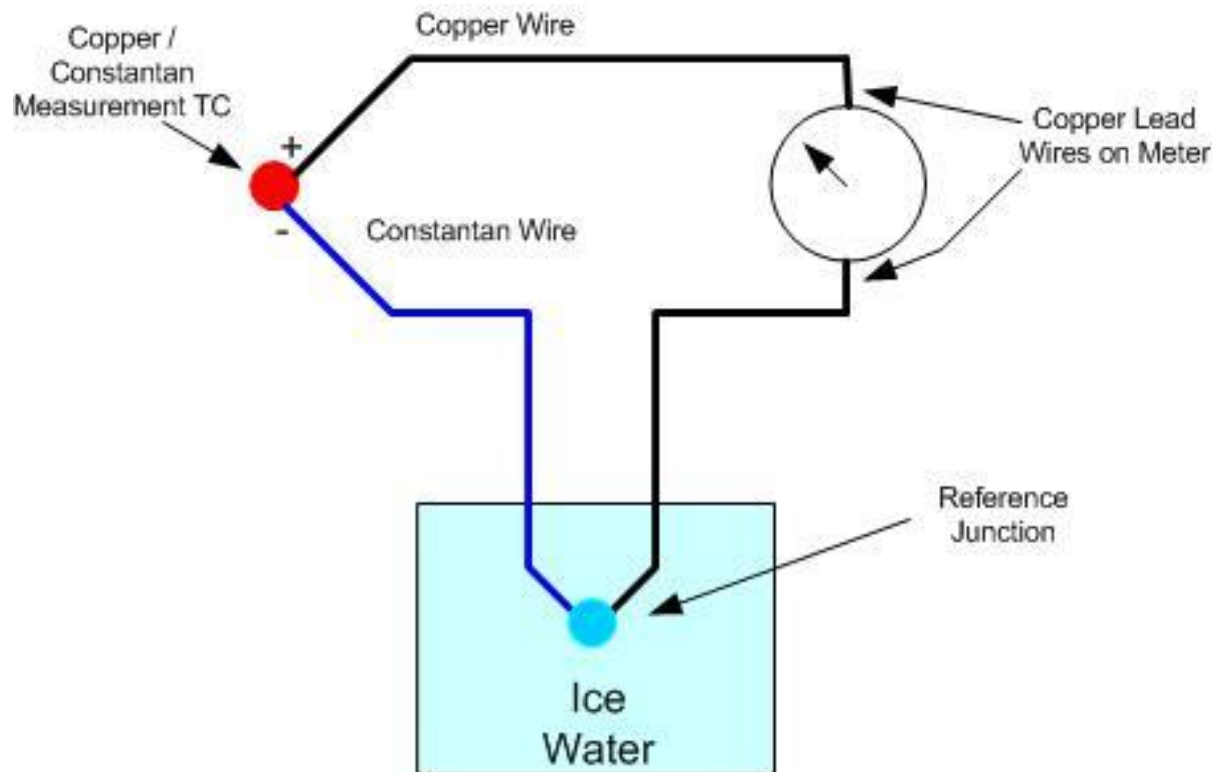
Turning the voltage into temperature

$$A \text{ volts} = \text{Measured volts} + B \text{ volts @ } x^{\circ}\text{C}$$

where x = reference junction temperature



Reference junction temperature



- Holding the reference junction at 0°C makes things easier because its always the same value.

Voltage to temperature conversion

- Lookup table
 - Each type has its own table
 - Calculation
 - Multiple coefficient polynomial
 - Different coefficients for different temperature ranges and TC types
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Lookup Table

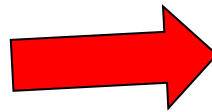
Thermoelectric Voltage in Millivolts

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C	°C	0	1	2	3	4	5	6	7	8	9	10	°C
-260	-6.258	-6.256	-6.255	-6.253	-6.251	-6.248	-6.245	-6.242	-6.239	-6.236	-6.232	-260	50	2.036	2.079	2.122	2.165	2.208	2.251	2.294	2.338	2.381	2.425	2.468	50
-250	-6.232	-6.228	-6.223	-6.219	-6.214	-6.209	-6.204	-6.198	-6.193	-6.187	-6.180	-250	60	2.468	2.512	2.556	2.600	2.643	2.687	2.732	2.776	2.820	2.864	2.909	60
-240	-6.180	-6.174	-6.167	-6.160	-6.153	-6.146	-6.138	-6.130	-6.122	-6.114	-6.105	-240	70	2.909	2.953	2.998	3.043	3.087	3.132	3.177	3.222	3.267	3.312	3.358	70
-230	-6.105	-6.096	-6.087	-6.078	-6.068	-6.059	-6.049	-6.038	-6.028	-6.017	-6.007	-230	80	3.358	3.403	3.448	3.494	3.539	3.585	3.631	3.677	3.722	3.768	3.814	80
-220	-6.007	-5.996	-5.985	-5.973	-5.962	-5.950	-5.938	-5.926	-5.914	-5.901	-5.888	-220	90	3.814	3.860	3.907	3.953	3.999	4.046	4.092	4.138	4.185	4.232	4.279	90
-210	-5.888	-5.876	-5.863	-5.850	-5.836	-5.823	-5.809	-5.795	-5.782	-5.767	-5.753	-210	100	4.279	4.325	4.372	4.419	4.466	4.513	4.561	4.608	4.655	4.702	4.750	100
-200	-5.753	-5.739	-5.724	-5.710	-5.695	-5.680	-5.665	-5.650	-5.634	-5.619	-5.603	-200	110	4.750	4.798	4.845	4.893	4.941	4.988	5.036	5.084	5.132	5.180	5.228	110
-190	-5.603	-5.587	-5.571	-5.555	-5.539	-5.523	-5.506	-5.489	-5.473	-5.456	-5.439	-190	120	5.228	5.277	5.325	5.373	5.422	5.470	5.519	5.567	5.616	5.665	5.714	120
-180	-5.439	-5.421	-5.404	-5.387	-5.369	-5.351	-5.334	-5.316	-5.297	-5.279	-5.261	-180	130	5.714	5.763	5.812	5.861	5.910	5.959	6.008	6.057	6.107	6.156	6.206	130
-170	-5.261	-5.242	-5.224	-5.205	-5.186	-5.167	-5.148	-5.128	-5.109	-5.089	-5.070	-170	140	6.206	6.255	6.305	6.355	6.404	6.454	6.504	6.554	6.604	6.654	6.704	140
-160	-5.070	-5.050	-5.030	-5.010	-4.989	-4.969	-4.949	-4.928	-4.907	-4.886	-4.865	-160	150	6.704	6.754	6.805	6.855	6.905	6.956	7.006	7.057	7.107	7.158	7.209	150
-150	-4.865	-4.844	-4.823	-4.802	-4.780	-4.759	-4.737	-4.715	-4.693	-4.671	-4.648	-150	160	7.209	7.260	7.310	7.361	7.412	7.463	7.515	7.566	7.617	7.668	7.720	160
-140	-4.648	-4.626	-4.604	-4.581	-4.558	-4.535	-4.512	-4.489	-4.466	-4.443	-4.419	-140	170	7.720	7.771	7.823	7.874	7.926	7.977	8.029	8.081	8.133	8.185	8.237	170
-130	-4.419	-4.395	-4.372	-4.348	-4.324	-4.300	-4.275	-4.251	-4.226	-4.202	-4.177	-130	180	8.237	8.289	8.341	8.393	8.445	8.497	8.550	8.602	8.654	8.707	8.759	180
-120	-4.177	-4.152	-4.127	-4.102	-4.077	-4.052	-4.026	-4.000	-3.975	-3.949	-3.923	-120	190	8.759	8.812	8.865	8.917	8.970	9.023	9.076	9.129	9.182	9.235	9.288	190
-110	-3.923	-3.897	-3.871	-3.844	-3.818	-3.791	-3.765	-3.738	-3.711	-3.684	-3.657	-110	200	9.288	9.341	9.395	9.448	9.501	9.555	9.608	9.662	9.715	9.769	9.822	200
-100	-3.657	-3.629	-3.602	-3.574	-3.547	-3.519	-3.491	-3.463	-3.435	-3.407	-3.379	-100	210	9.822	9.876	9.930	9.984	10.038	10.092	10.146	10.200	10.254	10.308	10.362	210
-90	-3.379	-3.350	-3.322	-3.293	-3.264	-3.235	-3.206	-3.177	-3.148	-3.118	-3.089	-90	220	10.362	10.417	10.471	10.525	10.580	10.634	10.689	10.743	10.798	10.853	10.907	220
-80	-3.089	-3.059	-3.030	-3.000	-2.970	-2.940	-2.910	-2.879	-2.849	-2.818	-2.788	-80	230	10.907	10.962	11.017	11.072	11.127	11.182	11.237	11.292	11.347	11.403	11.458	230
-70	-2.788	-2.757	-2.726	-2.695	-2.664	-2.633	-2.602	-2.571	-2.539	-2.507	-2.476	-70	240	11.458	11.513	11.569	11.624	11.680	11.735	11.791	11.846	11.902	11.958	12.013	240
-60	-2.476	-2.444	-2.412	-2.380	-2.348	-2.316	-2.283	-2.251	-2.218	-2.186	-2.153	-60	250	12.013	12.069	12.125	12.181	12.237	12.293	12.349	12.405	12.461	12.518	12.574	250
-50	-2.153	-2.120	-2.087	-2.054	-2.021	-1.987	-1.954	-1.920	-1.887	-1.853	-1.819	-50	260	12.574	12.630	12.687	12.743	12.799	12.856	12.912	12.969	13.026	13.082	13.139	260
-40	-1.819	-1.785	-1.751	-1.717	-1.683	-1.648	-1.614	-1.579	-1.545	-1.510	-1.475	-40	270	13.139	13.196	13.253	13.310	13.366	13.423	13.480	13.537	13.595	13.652	13.709	270
-30	-1.475	-1.440	-1.405	-1.370	-1.335	-1.299	-1.264	-1.228	-1.192	-1.157	-1.121	-30	280	13.709	13.766	13.823	13.881	13.938	13.995	14.053	14.110	14.168	14.226	14.283	280
-20	-1.121	-1.085	-1.049	-1.013	-0.976	-0.940	-0.904	-0.867	-0.830	-0.794	-0.757	-20	290	14.283	14.341	14.399	14.456	14.514	14.572	14.630	14.688	14.746	14.804	14.862	290
-10	-0.757	-0.720	-0.683	-0.646	-0.608	-0.571	-0.534	-0.496	-0.459	-0.421	-0.383	-10	300	14.862	14.920	14.978	15.036	15.095	15.153	15.211	15.270	15.328	15.386	15.445	300
0	-0.383	-0.345	-0.307	-0.269	-0.231	-0.193	-0.154	-0.116	-0.077	-0.039	0.000	0	310	15.445	15.503	15.562	15.621	15.679	15.738	15.797	15.856	15.914	15.973	16.032	310
10	0.000	0.039	0.078	0.117	0.156	0.195	0.234	0.273	0.312	0.352	0.391	10	320	16.032	16.091	16.150	16.209	16.268	16.327	16.387	16.446	16.505	16.564	16.624	320
20	0.391	0.431	0.470	0.510	0.549	0.589	0.629	0.669	0.709	0.749	0.790	20	330	16.624	16.683	16.742	16.802	16.861	16.921	16.980	17.040	17.100	17.159	17.219	330
30	0.790	0.830	0.870	0.911	0.951	0.992	1.033	1.074	1.114	1.155	1.196	30	340	17.219	17.279	17.339	17.399	17.458	17.518	17.578	17.638	17.698	17.759	17.819	340
40	1.196	1.238	1.279	1.320	1.362	1.403	1.445	1.486	1.528	1.570	1.612	40	350	17.819	17.879	17.939	17.999	18.060	18.120	18.180	18.241	18.301	18.362	18.422	350
°C	0	1	2	3	4	5	6	7	8	9	10	°C	°C	0	1	2	3	4	5	6	7	8	9	10	°C
													360	18.422	18.483	18.543	18.604	18.665	18.725	18.786	18.847	18.908	18.969	19.030	360
													370	19.030	19.091	19.152	19.213	19.274	19.335	19.396	19.457	19.518	19.579	19.641	370
													380	19.641	19.702	19.763	19.825	19.886	19.947	20.009	20.070	20.132	20.193	20.255	380
													390	20.255	20.317	20.378	20.440	20.502	20.563	20.625	20.687	20.748	20.810	20.872	390

Look up Reference junction voltage

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-260	-6.258	-6.256	-6.255	-6.253	-6.251	-6.248	-6.245	-6.242	-6.239	-6.236	-6.232	-260
-250	-6.232	-6.228	-6.223	-6.219	-6.214	-6.209	-6.204	-6.198	-6.193	-6.187	-6.180	-250
-240	-6.180	-6.174	-6.167	-6.160	-6.153	-6.146	-6.138	-6.130	-6.122	-6.114	-6.105	-240
-230	-6.105	-6.096	-6.087	-6.078	-6.068	-6.059	-6.049	-6.038	-6.028	-6.017	-6.007	-230
-220	-6.007	-5.996	-5.985	-5.973	-5.962	-5.950	-5.938	-5.926	-5.914	-5.901	-5.888	-220
-210	-5.888	-5.876	-5.863	-5.850	-5.836	-5.823	-5.809	-5.795	-5.782	-5.767	-5.753	-210
-200	-5.753	-5.739	-5.724	-5.710	-5.695	-5.680	-5.665	-5.650	-5.634	-5.619	-5.603	-200
-190	-5.603	-5.587	-5.571	-5.555	-5.539	-5.523	-5.506	-5.489	-5.473	-5.456	-5.439	-190
-180	-5.439	-5.421	-5.404	-5.387	-5.369	-5.351	-5.334	-5.316	-5.297	-5.279	-5.261	-180
-170	-5.261	-5.242	-5.224	-5.205	-5.186	-5.167	-5.148	-5.128	-5.109	-5.089	-5.070	-170
-160	-5.070	-5.050	-5.030	-5.010	-4.989	-4.969	-4.949	-4.928	-4.907	-4.886	-4.865	-160
-150	-4.865	-4.844	-4.823	-4.802	-4.780	-4.759	-4.737	-4.715	-4.693	-4.671	-4.648	-150
-140	-4.648	-4.626	-4.604	-4.581	-4.558	-4.535	-4.512	-4.489	-4.466	-4.443	-4.419	-140
-130	-4.419	-4.395	-4.372	-4.348	-4.324	-4.300	-4.275	-4.251	-4.226	-4.202	-4.177	-130
-120	-4.177	-4.152	-4.127	-4.102	-4.077	-4.052	-4.026	-4.000	-3.975	-3.949	-3.923	-120
-110	-3.923	-3.897	-3.871	-3.844	-3.818	-3.791	-3.765	-3.738	-3.711	-3.684	-3.657	-110
-100	-3.657	-3.629	-3.602	-3.574	-3.547	-3.519	-3.491	-3.463	-3.435	-3.407	-3.379	-100
-90	-3.379	-3.350	-3.322	-3.293	-3.264	-3.235	-3.206	-3.177	-3.148	-3.118	-3.089	-90
-80	-3.089	-3.059	-3.030	-3.000	-2.970	-2.940	-2.910	-2.879	-2.849	-2.818	-2.788	-80
-70	-2.788	-2.757	-2.726	-2.695	-2.664	-2.633	-2.602	-2.571	-2.539	-2.507	-2.476	-70
-60	-2.476	-2.444	-2.412	-2.380	-2.348	-2.316	-2.283	-2.251	-2.218	-2.186	-2.153	-60
-50	-2.153	-2.120	-2.087	-2.054	-2.021	-1.987	-1.954	-1.920	-1.887	-1.853	-1.819	-50
-40	-1.819	-1.785	-1.751	-1.717	-1.683	-1.648	-1.614	-1.579	-1.545	-1.510	-1.475	-40
-30	-1.475	-1.440	-1.405	-1.370	-1.335	-1.299	-1.264	-1.228	-1.192	-1.157	-1.121	-30
-20	-1.121	-1.085	-1.049	-1.013	-0.976	-0.940	-0.904	-0.867	-0.830	-0.794	-0.757	-20
-10	-0.757	-0.720	-0.683	-0.646	-0.608	-0.571	-0.534	-0.496	-0.459	-0.421	-0.383	-10
0	-0.383	-0.345	-0.307	-0.269	-0.231	-0.193	-0.154	-0.116	-0.077	-0.039	0.000	0
0	0.000	0.039	0.078	0.117	0.156	0.195	0.234	0.273	0.312	0.352	0.391	0
10	0.391	0.431	0.470	0.510	0.549	0.589	0.629	0.669	0.709	0.749	0.790	10
20	0.790	0.830	0.870	0.911	0.951	0.992	1.033	1.074	1.114	1.155	1.196	20
30	1.196	1.238	1.279	1.320	1.362	1.403	1.445	1.486	1.528	1.570	1.612	30
40	1.612	1.654	1.696	1.738	1.780	1.823	1.865	1.908	1.950	1.993	2.036	40
°C	0	1	2	3	4	5	6	7	8	9	10	°C

Look-up 0°C



Ohhh 0V

That's handy!

Next lookup voltage measured

- Lets assume a measured value of 6.945mV

- $6.945 + 0 = 6.945$

- 154-155°C

°C	0	1	2	3	4	5	6	7
50	2.036	2.079	2.122	2.165	2.208	2.251	2.294	2.337
60	2.468	2.512	2.556	2.600	2.643	2.687	2.732	2.775
70	2.909	2.953	2.998	3.043	3.087	3.132	3.177	3.221
80	3.358	3.403	3.448	3.494	3.539	3.585	3.631	3.676
90	3.814	3.860	3.907	3.953	3.999	4.046	4.092	4.138
100	4.279	4.325	4.372	4.419	4.466	4.513	4.561	4.607
110	4.750	4.798	4.845	4.893	4.941	4.988	5.036	5.083
120	5.228	5.277	5.325	5.373	5.422	5.470	5.519	5.566
130	5.714	5.763	5.812	5.861	5.910	5.959	6.008	6.056
140	6.206	6.255	6.305	6.355	6.404	6.454	6.504	6.553
150	6.704	6.754	6.805	6.855	6.905	6.956	7.006	7.056
160	7.209	7.260	7.310	7.361	7.412	7.463	7.515	7.566
170	7.720	7.771	7.823	7.874	7.926	7.977	8.029	8.080
180	8.237	8.289	8.341	8.393	8.445	8.497	8.550	8.601
190	8.759	8.812	8.865	8.917	8.970	9.023	9.076	9.127

Calculation by polynomial

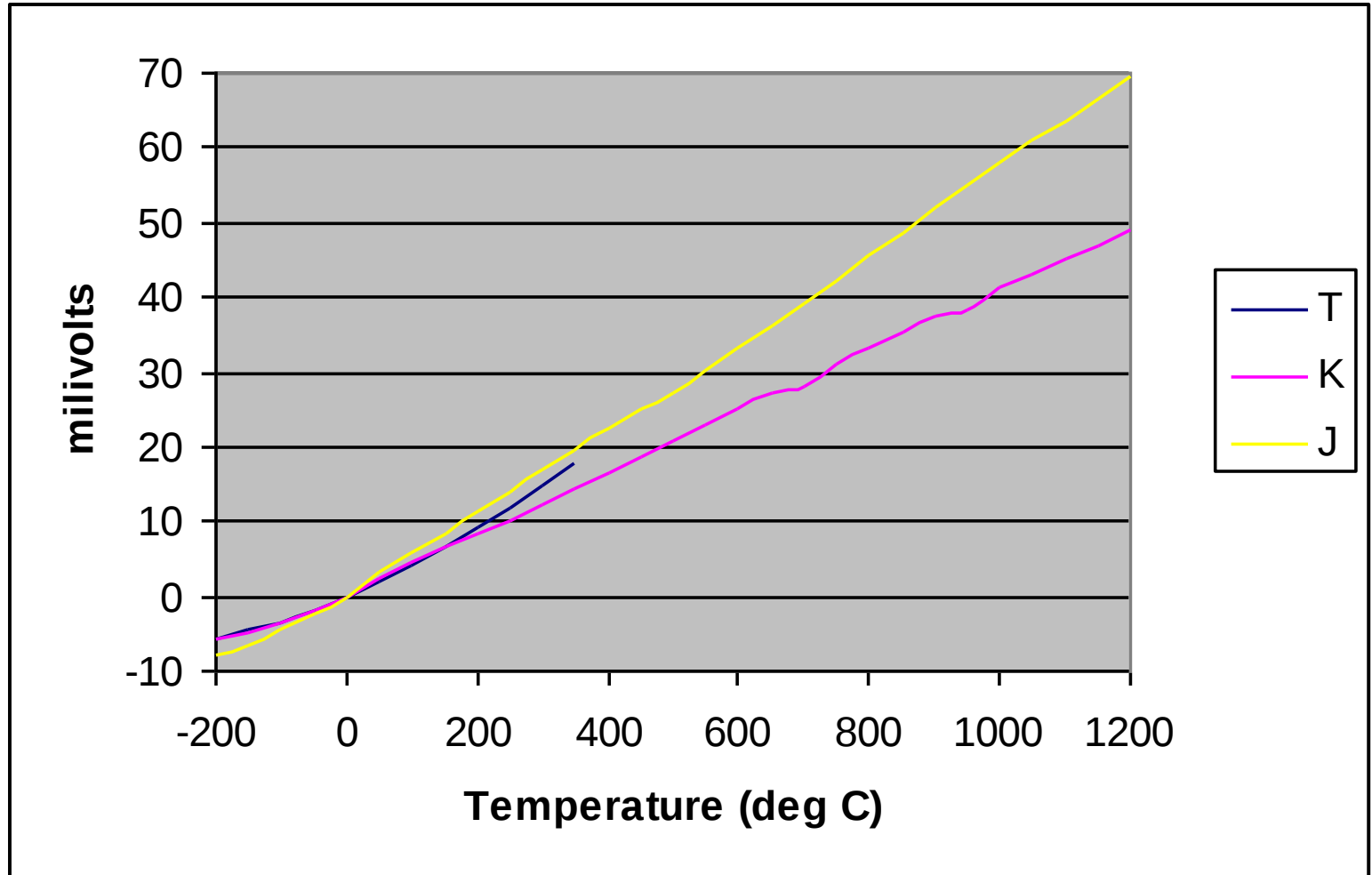
$$T = 0 + 2.5928E+01(6.945) + -7.602961E-01(6.945)^2 + 4.637791E-02(6.945)^3 + -2.165394E-03(6.945)^4 + 6.048144E-05(6.945)^5 + -7.293422E-07(6.945)^6$$

Is that ugly or what?

Generate a spreadsheet

	A	B	C	D	E	F
1						
2	E	6.945	mv in			
3			E^n	d_n* E^n		
4	d_0	0.0000000000E+00	0	0.0000000000E+00		
5	d_1	2.5928000000E+01	6.945	1.8006996000E+02		
6	d_2	-7.6029610000E-01	48.23303	-3.6671380799E+01		
7	d_3	4.6377910000E-02	334.9784	1.5535596168E+01		
8	d_4	-2.1653940000E-03	2326.425	-5.0376260882E+00		
9	d_5	6.0481440000E-05	16157.02	9.7719980825E-01		
10	d_6	-7.2934220000E-07	112210.5	-8.1839853478E-02		
11	d_7	0.0000000000E+00	779301.9	0.0000000000E+00		
12						
13			Temp Out	154.79		
14						
15			t_90 = d_0 + d_1*E + d_2*E^2 + ...			
16						

TC voltage vs Temperature



Lets look at the TC a bit more

- Different sizes and types
 - Wire sizes from .001" up to .032"
 - Wide array of probe sizes and end types
- Grounded / ungrounded ends

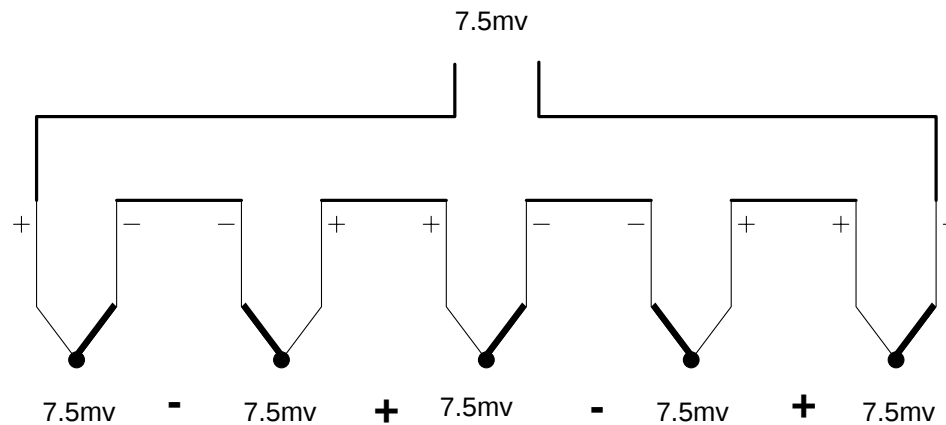


Accuracy

Type	Standard	SLE
J	2.2°C	1.1°C
	0.75%	0.4%
T	1°C	0.5°C
	0.75%	0.4%
K	2.2°C	1.1°C
	0.75%	0.4%
E	1.7°C	1°C
	0.5%	0.4%

Advantages

- Inexpensive
- Easy to make
- Can take extremely high temperatures (up to 4200°F)
- Can couple multiple TC's in series (reversed polarity) to “average” an area.

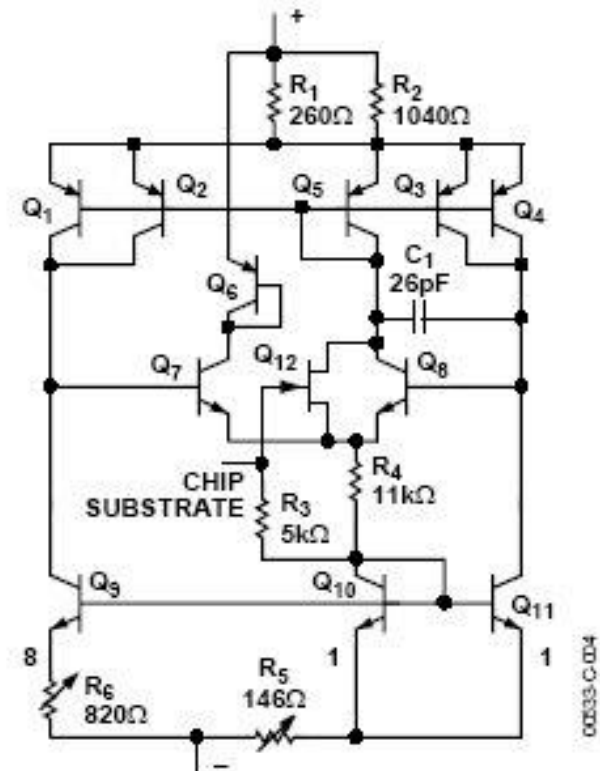
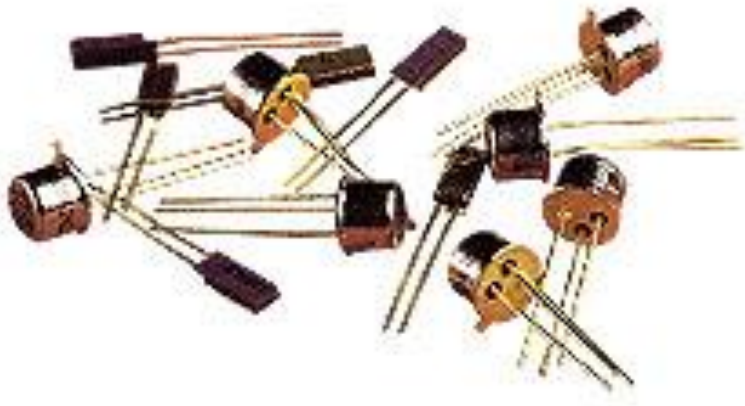


Disadvantages

- Calculation is difficult
 - Accuracy is only good for large temperature ranges
 - Output is non-linear
 - Signal levels are small and easily pick up noise
 - Need to filter makes them difficult for signals faster than about 20 Hz
 - Inadvertent current flows between grounded junctions can affect readings.
-

Semiconductor Probes

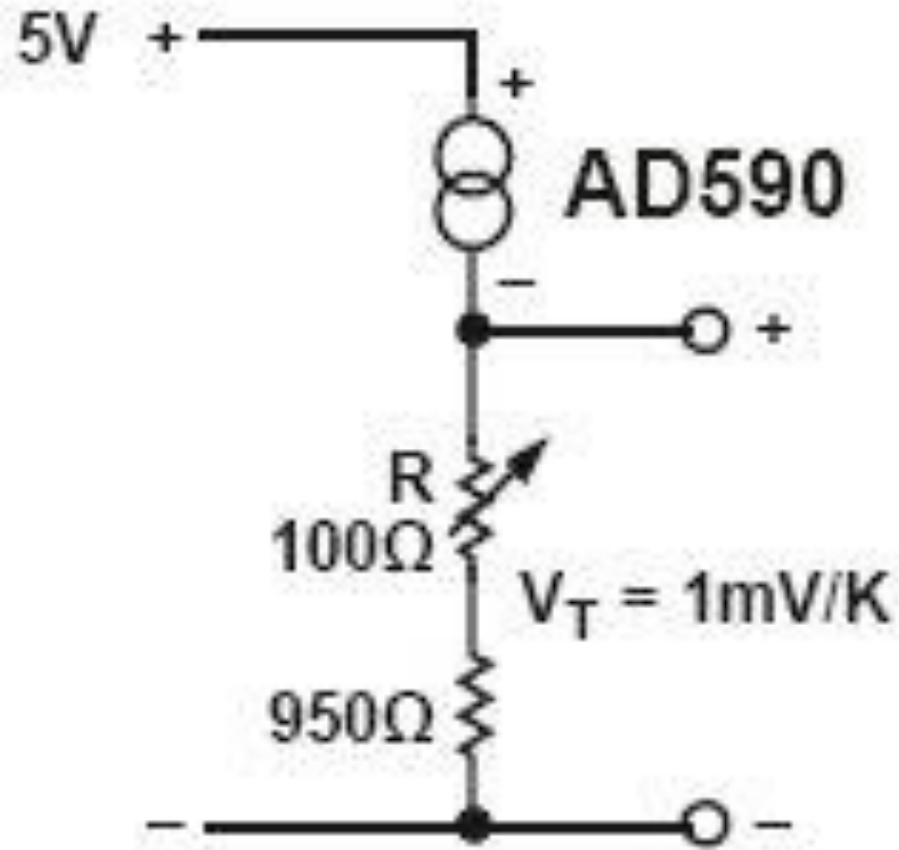
- Most common is an AD590
- Output is $1\mu\text{A per } ^\circ\text{K}$



AD590

- Temperature range -55°C to $+150^{\circ}\text{C}$
- Supply voltage $+4\text{V}$ to $+30\text{VDC}$
- Accuracy ranges from $\pm 5^{\circ}\text{C}$ to $\pm 0.5^{\circ}\text{C}$ depending on model
- VERY linear ($<1.5^{\circ}\text{C}$ over temp range)
- Price ranges from \$6.50 to \$65 depending on accuracy

How to use an AD590



Other semiconductor sensors

- National Semiconductor LM355
 - 10mV/°K
 - LM35
 - 10mV/°C
 - 250mV @ 25°C
 - LM334
 - 1μA /°C
 - Maxim MAX6612
 - 19.53mV/°C
 - -10°C to +125°C
 - \$0.67 ea
 - Surface Mount Package
-

Common Uses

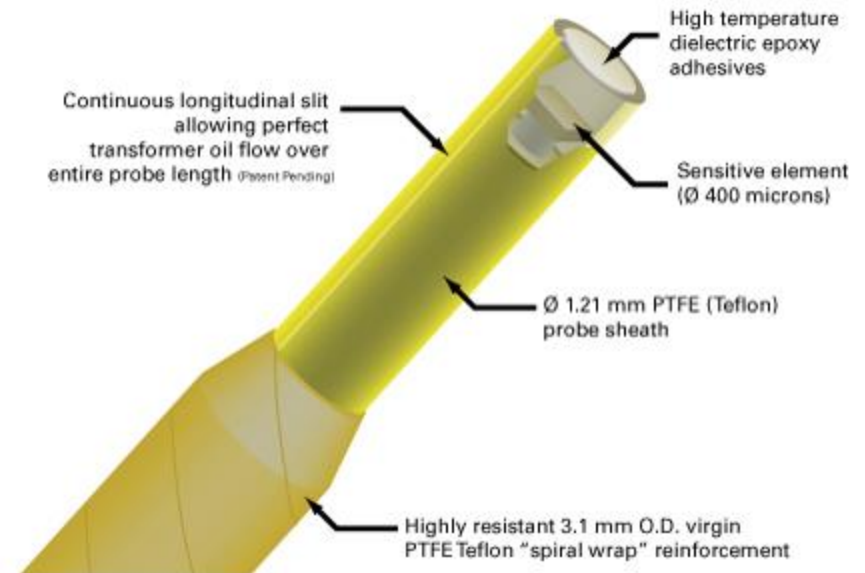
- Cold Junction compensation
 - Electronic circuit board / component temperature measuring (computer over temp)
 - Home thermometers and thermostats
-

Non-contact Probes

- Two categories
 - Single temperature readings
 - “Image” scanners
- All work on the same basic principle.
 - All “hot” surfaces emit radiation in the infrared range
 - These devices look at this radiation to determine temperature

Non-conductive laser probes

- Uses laser beam down a fiber optic cable
- Change in diffraction based on temperature
- Electrically non-conductive



Single reading units

- Handheld devices and probes
- Focus all the IR within the field onto a single detector effectively averaging the field.
- “emissivity” greatly affects the measured temperature.
 - a number between 0 and 1 that takes into account *wavelength, waveband, reflectivity, transmissivity, absorptivity, absorption coefficient etc.*

Single reading devices

- Reflections of other IR sources will affect readings
 - Sunlight
 - Arc Lamps
 - Halogen Lamps
 - The field is cone shaped, everything within the cone will be included in the measurement
-

Single point IR



Image field devices

- Display temperature as an image of different colors or gray scale
 - Different colors represent different temperatures
- Reading the temperature of a single point is difficult.
- Range in price from \$1000 and up....up...up

Fluke FlexCam R2 Infrared Camera

- Bottom line unit \$1000
- 8 calibrated color “ranges”
- Temperature range from -20°C to 100°C (-4°F to 212°F)
- Spectral Band: 8μm to 14μm
- Emissivity/Background Correction: Based on user input



Fluke FlexCam TiR3FT

- High end \$20,000
- Calibrated temperature range: -20°C to 100°C (-4°F to 212°F)
- High image quality
- Accuracy: $\pm^{\circ}\text{C}$ or 2%
- Emissivity correction: 0.1 to 1.0 (0.01 increments)



Transmitters

- Transmitters exist to change the signal from a TC, Thermistor, RTD to Voltage or Current
 - Current outputs in 0-20ma or 4-20ma
 - 4ma offset allows for “broken wire” detection
 - Current outputs are VERY noise immune
 - Lead length can be very long and lead resistance is NOT a factor (exception is VERY high lead resistances over a few hundred ohms)
 - Used heavily in industrial environments where signals need to be sent a long ways!
-

Transmitters

- Range in price from \$75 to over \$300
- Come in a variety of sizes and package styles



Newer technologies always coming out!

- Wireless TC transmitter (\$125)
- Battery operated for remote use (300' range)
- USB receiver can read 12 transmitters (\$225)



What would you use?

■ Application:

- ❑ Measuring a cryogenic application
 - ❑ -230 Deg C

 - ❑ Type T Thermo couple
 - ❑ Good down to -250 Deg C
-

What would you use?

■ Application:

- ❑ High volume (means low cost)
- ❑ 10 to 40 deg C
- ❑ Easily read by a computer
- ❑ Thermistor – Inexpensive, and easy to use over a short temperature span, even though it is very non-linear

What would you use?

■ Application:

- ❑ Measure average temperature of a fluid down the length of a long tube (prefer at least ten measurement points)
 - ❑ 150 Deg C
 - ❑ Type T thermocouples in series.
-

What would you use?

■ Application:

- ❑ Measure temperature in a reactor vessel
 - ❑ 450 Deg C +/- 2
 - ❑ Location is 1/4 mile from recording computer.

 - ❑ Type K Thermocouple with a transmitter
-

Questions?
