# Tallinn University of Technology

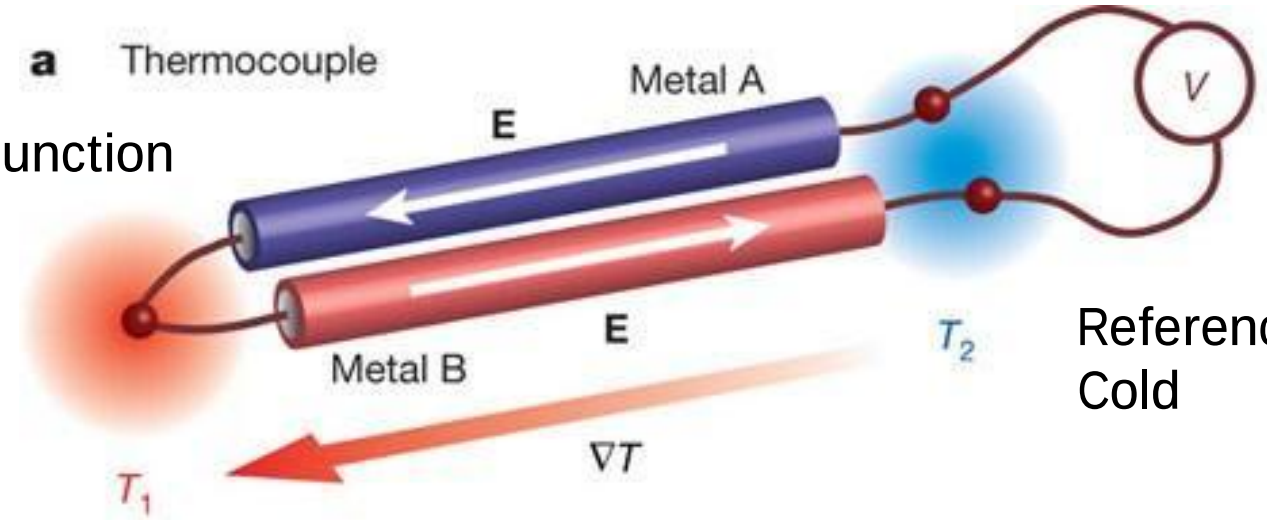
## Department of Thermal Engineering

# Thermocouple

Lecturer: Andrei Dedov

# Principle of operation

Measuring junction
Hot



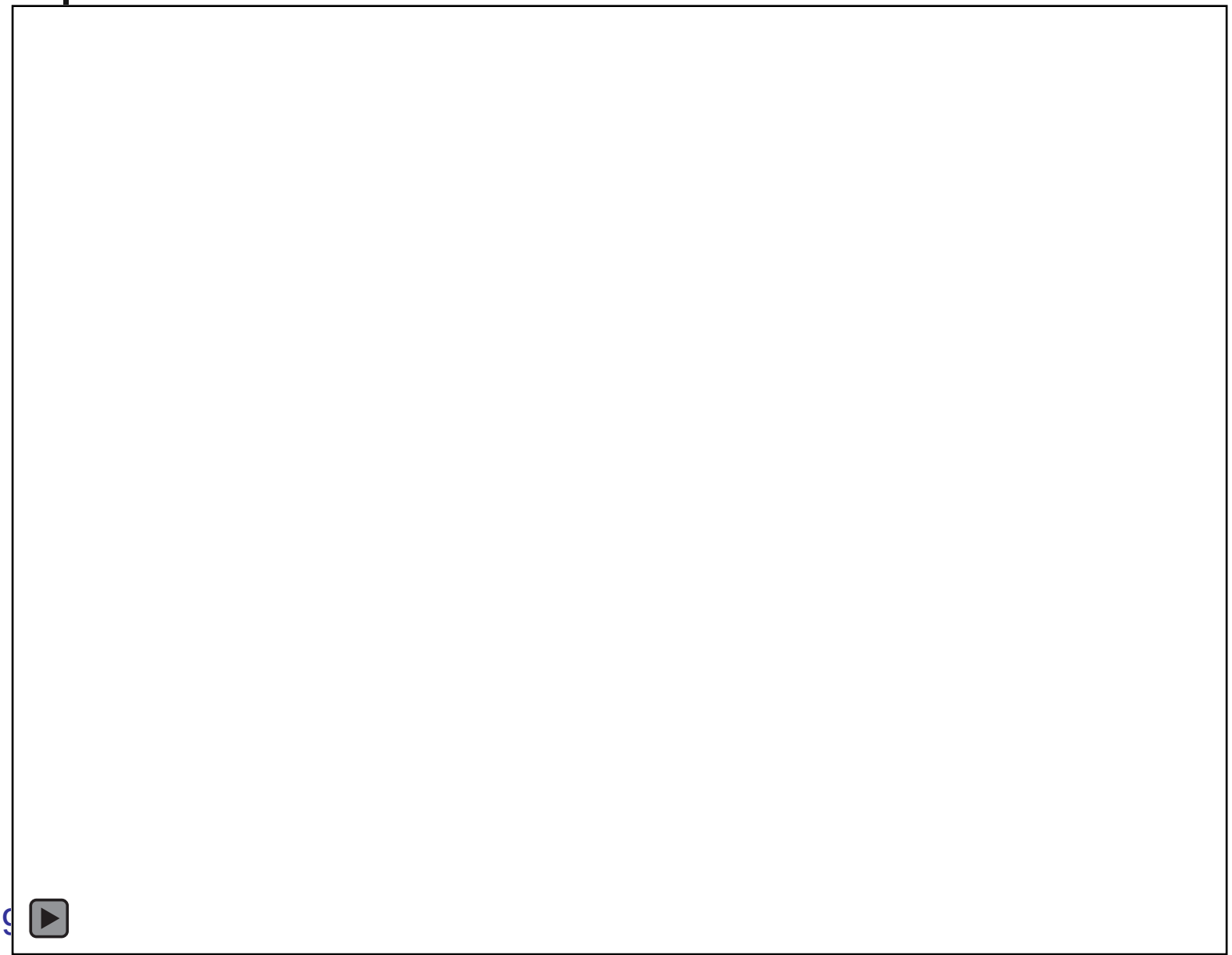

Reference junction
Cold

Seebeck effect

If the junctions of two dissimilar conductors are maintained at different temperatures, the emf is generated in the circuit. The value of emf depends on used materials and temperature difference in the junctions.

# Seebeck effect

# Peltier’ effect



| ANSI Code | ANSI MC 96.1 Colour Coding | | Alloy Combination | | Comments Environment Bare Wire | Maximum T/C Grade Temp. Range | EMF (mV) Over Max. Temp. Range | IEC 584-3 Colour Coding | | IEC Code |
|---|---|---|---|---|---|---|---|---|---|---|
| | Thermocouple Grade | Extension Grade | + Lead | – Lead | | | | Thermocouple Grade | Intrinsically Safe | |
| J |  |  | IRON Fe (magnetic) | CONSTANTAN COPPER-NICKEL Cu-Ni | Reducing, Vacuum, Inert. Limited Use in Oxidising at High Temperatures. Not Recommended for Low Temperatures. | –210 to 1200°C –346 to 2193°F | –8.095 to 69.553 |  |  | J |
| K |  |  | CHROME NICKEL-CHROMIUM Ni-Cr | NICKEL-ALUMINUM Ni-Al (magnetic) | Clean Oxidising and Inert. Limited Use in Vacuum or Reducing. Wide Temperature Range, Most Popular Calibration | –270 to 1372°C –454 to 2501°F | –6.458 to 54.886 |  |  | K |
| T |  |  | COPPER Cu | CONSTANTAN COPPER-NICKEL Cu–Ni | Mild Oxidising, Reducing Vacuum or Inert. Good Where Moisture Is Present. Low Temperature & Cryogenic Applications | –270 to 400°C –454 to 752°F | –6.258 to 20.872 |  |  | T |
| E |  |  | CHROME NICKEL-CHROMIUM Ni-Cr | CONSTANTAN COPPER-NICKEL Cu-Ni | Oxidising or Inert. Limited Use in Vacuum or Reducing. Highest EMF Change Per Degree | –270 to 1000°C –454 to 1832°F | –9.835 to 76.373 |  |  | E |
| N |  |  | NICROSIL Ni-Cr-Si | NISIL Ni-Si-Mg | Alternative to Type K. More Stable at High Temps | –270 to 1300°C –450 to 2372°F | –4.345 to 47.513 |  |  | N |
| R | NONE ESTABLISHED |  | PLATINUM-13% RHODIUM Pt-13% Rh | PLATINUM Pt | Oxidising or Inert. Do Not Insert in Metal Tubes. Beware of Contamination. High Temperature | –50 to 1768°C –58 to 3214°F | –0.226 to 21.101 |  |  | R |
| S | NONE ESTABLISHED |  | PLATINUM-10% RHODIUM Pt-10% Rh | PLATINUM Pt | Oxidising or Inert. Do Not Insert in Metal Tubes. Beware of Contamination. High Temperature | –50 to 1768°C –58 to 3214°F | –0.236 to 18.693 |  |  | S |
| U | NONE ESTABLISHED |  | COPPER Cu | COPPER-LOW NICKEL Cu-Ni | Extension Grade Connecting Wire for R & S Thermocouples, Also Known as RX & SX Extension Wire. | | |  |  | U |
| B | NONE ESTABLISHED |  | PLATINUM-30% RHODIUM Pt-30% Rh | PLATINUM-6% RHODIUM Pt-6% Rh | Oxidising or Inert. Do Not Insert in Metal Tubes. Beware of Contamination. High Temp. Common Use in Glass Industry | 0 to 1820°C 32 to 3308°F | 0 to 13.820 |  |  | B |
| G* (W) | NONE ESTABLISHED |  | TUNGSTEN W | TUNGSTEN-26% RHENIUM W-26% Re | Vacuum, Inert, Hydrogen. Beware of Embrittlement. Not Practical Below 399°C (750°F). Not for Oxidising Atmosphere | 0 to 2320°C 32 to 4208°F | 0 to 38.564 | NO STANDARD USE ANSI COLOUR CODE | | G (W) |
| C* (W5) | NONE ESTABLISHED |  | TUNGSTEN-5% RHENIUM W-5% Re | TUNGSTEN-26% RHENIUM W-26% Re | Vacuum, Inert, Hydrogen. Beware of Embrittlement. Not Practical Below 399°C (750°F) Not for Oxidising Atmosphere | 0 to 2320°C 32 to 4208°F | 0 to 37.066 | NO STANDARD USE ANSI COLOUR CODE | | C (W5) |
| D* (W3) | NONE ESTABLISHED |  | TUNGSTEN-3% RHENIUM W-3% Re | TUNGSTEN-25% RHENIUM W-25% Re | Vacuum, Inert, Hydrogen. Beware of Embrittlement. Not Practical Below 399°C (750°F)–Not for Oxidising Atmosphere | 0 to 2320°C 32 to 4208°F | 0 to 39.506 | NO STANDARD USE ANSI COLOUR CODE | | D (W3) |

# Relationship between emf and *t* °C

# Reference table

**MAXIMUM TEMPERATURE RANGE**

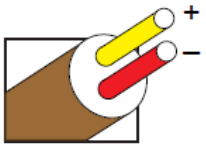
**Thermocouple Grade**
– 328 to 2282°F
– 200 to 1250°C

**Extension Grade**
32 to 392°F
0 to 200°C

**LIMITS OF ERROR**
(whichever is greater)
**Standard:** 2.2°C or 0.75% Above 0°C
2.2°C or 2.0% Below 0°C
**Special:** 1.1°C or 0.4%

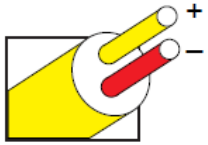
**COMMENTS, BARE WIRE ENVIRONMENT:**
Clean Oxidizing and Inert; Limited Use in Vacuum or Reducing; Wide Temperature Range; Most Popular Calibration

**TEMPERATURE IN DEGREES °C**
**REFERENCE JUNCTION AT 0°C**




Thermocouple Grade

**Nickel-Chromium**
**vs.**
**Nickel-Aluminum**




Extension Grade

## Revised Thermocouple Reference Tables

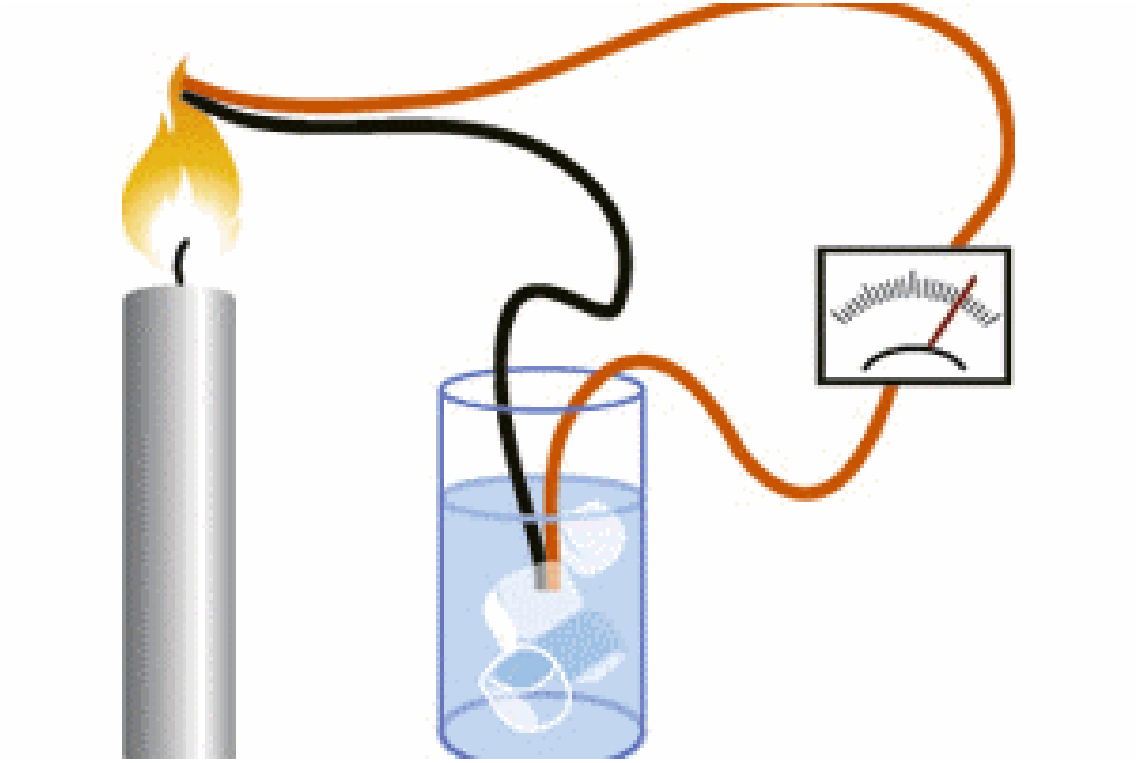
**TYPE K**
Reference Tables
N.I.S.T. Monograph 175
Revised to ITS-90

Thermoelectric Voltage in Millivolts

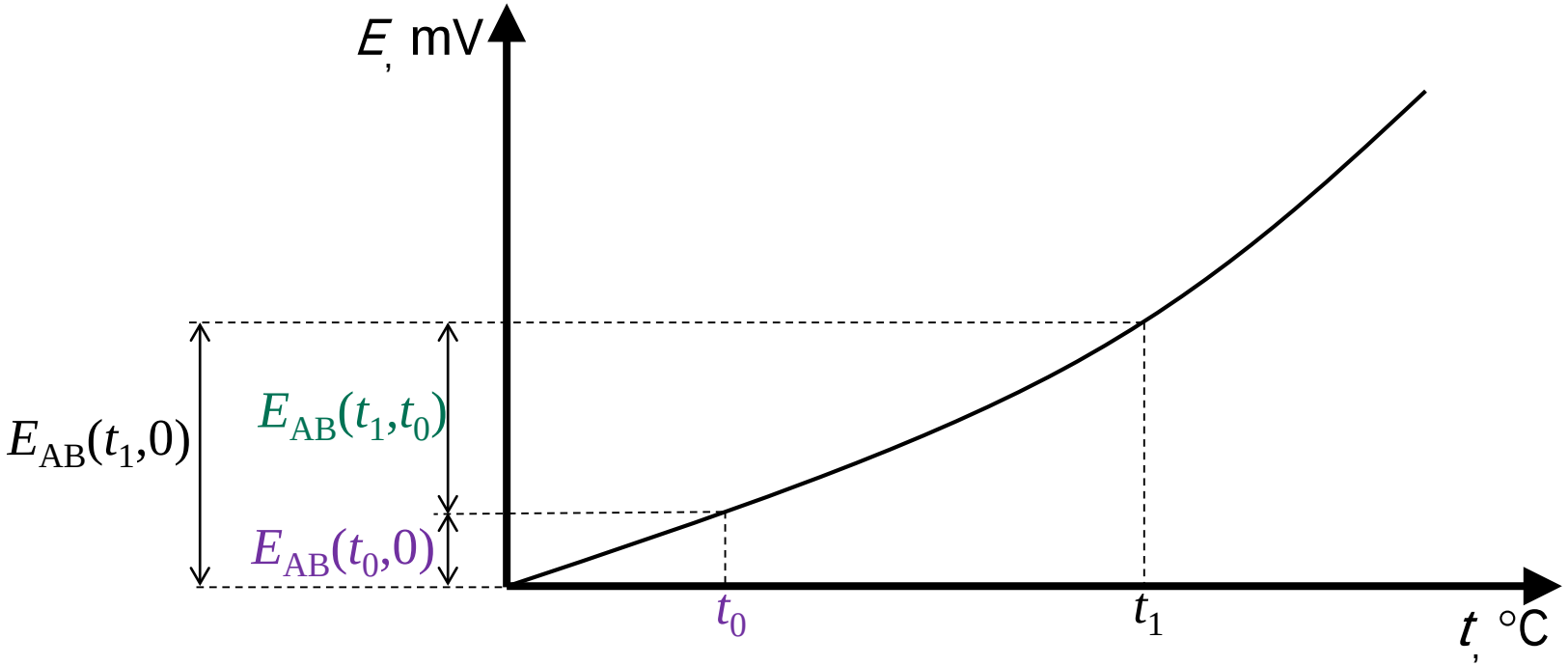
| °C | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 0 | °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -260 | -6.458 | -6.457 | -6.456 | -6.455 | -6.453 | -6.452 | -6.450 | -6.448 | -6.446 | -6.444 | -6.441 | -260 |
| -250 | -6.441 | -6.438 | -6.435 | -6.432 | -6.429 | -6.425 | -6.421 | -6.417 | -6.413 | -6.408 | -6.404 | -250 |
| -240 | -6.404 | -6.399 | -6.393 | -6.388 | -6.382 | -6.377 | -6.370 | -6.364 | -6.358 | -6.351 | -6.344 | -240 |
| -230 | -6.344 | -6.337 | -6.329 | -6.322 | -6.314 | -6.306 | -6.297 | -6.289 | -6.280 | -6.271 | -6.262 | -230 |
| -220 | -6.262 | -6.252 | -6.243 | -6.233 | -6.223 | -6.213 | -6.202 | -6.192 | -6.181 | -6.170 | -6.158 | -220 |
| -210 | -6.158 | -6.147 | -6.135 | -6.123 | -6.111 | -6.099 | -6.087 | -6.074 | -6.061 | -6.048 | -6.035 | -210 |
| -200 | -6.035 | -6.021 | -6.007 | -5.994 | -5.980 | -5.965 | -5.951 | -5.936 | -5.922 | -5.907 | -5.891 | -200 |
| -190 | -5.891 | -5.876 | -5.861 | -5.845 | -5.829 | -5.813 | -5.797 | -5.780 | -5.763 | -5.747 | -5.730 | -190 |
| -180 | -5.730 | -5.713 | -5.695 | -5.678 | -5.660 | -5.642 | -5.624 | -5.606 | -5.588 | -5.569 | -5.550 | -180 |
| -170 | -5.550 | -5.531 | -5.512 | -5.493 | -5.474 | -5.454 | -5.435 | -5.415 | -5.395 | -5.374 | -5.354 | -170 |
| -160 | -5.354 | -5.333 | -5.313 | -5.292 | -5.271 | -5.250 | -5.228 | -5.207 | -5.185 | -5.163 | -5.141 | -160 |
| -150 | -5.141 | -5.119 | -5.097 | -5.074 | -5.052 | -5.029 | -5.006 | -4.983 | -4.960 | -4.936 | -4.913 | -150 |
| -140 | -4.913 | -4.889 | -4.865 | -4.841 | -4.817 | -4.793 | -4.768 | -4.744 | -4.719 | -4.694 | -4.669 | -140 |
| -130 | -4.669 | -4.644 | -4.618 | -4.593 | -4.567 | -4.542 | -4.516 | -4.490 | -4.463 | -4.437 | -4.411 | -130 |
| -120 | -4.411 | -4.384 | -4.357 | -4.330 | -4.303 | -4.276 | -4.249 | -4.221 | -4.194 | -4.166 | -4.138 | -120 |
| -110 | -4.138 | -4.110 | -4.082 | -4.054 | -4.025 | -3.997 | -3.968 | -3.939 | -3.911 | -3.882 | -3.852 | -110 |
| -100 | -3.852 | -3.823 | -3.794 | -3.764 | -3.734 | -3.705 | -3.675 | -3.645 | -3.614 | -3.584 | -3.554 | -100 |
| -90 | -3.554 | -3.523 | -3.492 | -3.462 | -3.431 | -3.400 | -3.368 | -3.337 | -3.306 | -3.274 | -3.243 | -90 |
| -80 | -3.243 | -3.211 | -3.179 | -3.147 | -3.115 | -3.083 | -3.050 | -3.018 | -2.986 | -2.953 | -2.920 | -80 |
| -70 | -2.920 | -2.887 | -2.854 | -2.821 | -2.788 | -2.755 | -2.721 | -2.688 | -2.654 | -2.620 | -2.587 | -70 |
| -60 | -2.587 | -2.553 | -2.519 | -2.485 | -2.450 | -2.416 | -2.382 | -2.347 | -2.312 | -2.278 | -2.243 | -60 |
| -50 | -2.243 | -2.208 | -2.173 | -2.138 | -2.103 | -2.067 | -2.032 | -1.996 | -1.961 | -1.925 | -1.889 | -50 |
| -40 | -1.889 | -1.854 | -1.818 | -1.782 | -1.745 | -1.709 | -1.673 | -1.637 | -1.600 | -1.564 | -1.527 | -40 |
| -30 | -1.527 | -1.490 | -1.453 | -1.417 | -1.380 | -1.343 | -1.305 | -1.268 | -1.231 | -1.194 | -1.156 | -30 |
| -20 | -1.156 | -1.119 | -1.081 | -1.043 | -1.006 | -0.968 | -0.930 | -0.892 | -0.854 | -0.816 | -0.778 | -20 |
| -10 | -0.778 | -0.739 | -0.701 | -0.663 | -0.624 | -0.586 | -0.547 | -0.508 | -0.470 | -0.431 | -0.392 | -10 |
| 0 | -0.392 | -0.353 | -0.314 | -0.275 | -0.236 | -0.197 | -0.157 | -0.118 | -0.079 | -0.039 | 0.000 | 0 |

| °C | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 250 | 10.153 | 10.194 | 10.235 | 10.276 | 10.316 | 10.357 | 10.398 | 10.439 | 10.480 | 10.520 | 10.561 | 250 |
| 260 | 10.561 | 10.602 | 10.643 | 10.684 | 10.725 | 10.766 | 10.807 | 10.848 | 10.889 | 10.930 | 10.971 | 260 |
| 270 | 10.971 | 11.012 | 11.053 | 11.094 | 11.135 | 11.176 | 11.217 | 11.259 | 11.300 | 11.341 | 11.382 | 270 |
| 280 | 11.382 | 11.423 | 11.465 | 11.506 | 11.547 | 11.588 | 11.630 | 11.671 | 11.712 | 11.753 | 11.795 | 280 |
| 290 | 11.795 | 11.836 | 11.877 | 11.919 | 11.960 | 12.001 | 12.043 | 12.084 | 12.126 | 12.167 | 12.209 | 290 |
| 300 | 12.209 | 12.250 | 12.291 | 12.333 | 12.374 | 12.416 | 12.457 | 12.499 | 12.540 | 12.582 | 12.624 | 300 |
| 310 | 12.624 | 12.665 | 12.707 | 12.748 | 12.790 | 12.831 | 12.873 | 12.915 | 12.956 | 12.998 | 13.040 | 310 |
| 320 | 13.040 | 13.081 | 13.123 | 13.165 | 13.206 | 13.248 | 13.290 | 13.331 | 13.373 | 13.415 | 13.457 | 320 |
| 330 | 13.457 | 13.498 | 13.540 | 13.582 | 13.624 | 13.665 | 13.707 | 13.749 | 13.791 | 13.833 | 13.874 | 330 |
| 340 | 13.874 | 13.916 | 13.958 | 14.000 | 14.042 | 14.084 | 14.126 | 14.167 | 14.209 | 14.251 | 14.293 | 340 |
| 350 | 14.293 | 14.335 | 14.377 | 14.419 | 14.461 | 14.503 | 14.545 | 14.587 | 14.629 | 14.671 | 14.713 | 350 |
| 360 | 14.713 | 14.755 | 14.797 | 14.839 | 14.881 | 14.923 | 14.965 | 15.007 | 15.049 | 15.091 | 15.133 | 360 |
| 370 | 15.133 | 15.175 | 15.217 | 15.259 | 15.301 | 15.343 | 15.385 | 15.427 | 15.469 | 15.511 | 15.554 | 370 |
| 380 | 15.554 | 15.596 | 15.638 | 15.680 | 15.722 | 15.764 | 15.806 | 15.849 | 15.891 | 15.933 | 15.975 | 380 |
| 390 | 15.975 | 16.017 | 16.059 | 16.102 | 16.144 | 16.186 | 16.228 | 16.270 | 16.313 | 16.355 | 16.397 | 390 |
| 400 | 16.397 | 16.439 | 16.482 | 16.524 | 16.566 | 16.608 | 16.651 | 16.693 | 16.735 | 16.778 | 16.820 | 400 |
| 410 | 16.820 | 16.862 | 16.904 | 16.947 | 16.989 | 17.031 | 17.074 | 17.116 | 17.158 | 17.201 | 17.243 | 410 |
| 420 | 17.243 | 17.285 | 17.328 | 17.370 | 17.413 | 17.455 | 17.497 | 17.540 | 17.582 | 17.624 | 17.667 | 420 |
| 430 | 17.667 | 17.709 | 17.752 | 17.794 | 17.837 | 17.879 | 17.921 | 17.964 | 18.006 | 18.049 | 18.091 | 430 |
| 440 | 18.091 | 18.134 | 18.176 | 18.218 | 18.261 | 18.303 | 18.346 | 18.388 | 18.431 | 18.473 | 18.516 | 440 |
| 450 | 18.516 | 18.558 | 18.601 | 18.643 | 18.686 | 18.728 | 18.771 | 18.813 | 18.856 | 18.898 | 18.941 | 450 |
| 460 | 18.941 | 18.983 | 19.026 | 19.068 | 19.111 | 19.154 | 19.196 | 19.239 | 19.281 | 19.324 | 19.366 | 460 |
| 470 | 19.366 | 19.409 | 19.451 | 19.494 | 19.537 | 19.579 | 19.622 | 19.664 | 19.707 | 19.750 | 19.792 | 470 |
| 480 | 19.792 | 19.835 | 19.877 | 19.920 | 19.962 | 20.005 | 20.048 | 20.090 | 20.133 | 20.175 | 20.218 | 480 |
| 490 | 20.218 | 20.261 | 20.303 | 20.346 | 20.389 | 20.431 | 20.474 | 20.516 | 20.559 | 20.602 | 20.644 | 490 |
| 500 | 20.644 | 20.687 | 20.730 | 20.772 | 20.815 | 20.857 | 20.900 | 20.943 | 20.985 | 21.028 | 21.071 | 500 |
| 510 | 21.071 | 21.113 | 21.156 | 21.199 | 21.241 | 21.284 | 21.326 | 21.369 | 21.412 | 21.454 | 21.497 | 510 |
| 520 | 21.497 | 21.540 | 21.582 | 21.625 | 21.668 | 21.710 | 21.753 | 21.796 | 21.838 | 21.881 | 21.924 | 520 |
| 530 | 21.924 | 21.966 | 22.009 | 22.052 | 22.094 | 22.137 | 22.179 | 22.222 | 22.265 | 22.307 | 22.350 | 530 |
| 540 | 22.350 | 22.393 | 22.435 | 22.478 | 22.521 | 22.563 | 22.606 | 22.649 | 22.691 | 22.734 | 22.776 | 540 |

# Compensation of reference junction



# Compensation of reference junction



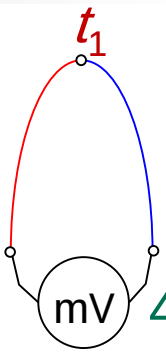

$$E_{AB}(t_1,0) = E_{AB}(t_1,t_0) + E_{AB}(t_0,0)$$

Readings (mV) Reference junction

# Compensation of reference junction

**TYPE S**
Reference Tables
N.I.S.T. Monograph 175
Revised to ITS-90

| °C | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.000 | 0.005 | 0.011 | 0.016 | 0.022 | 0.027 | 0.033 | 0.038 | 0.044 | 0.050 | 0.055 | 0 |
| 10 | 0.055 | 0.061 | 0.067 | 0.072 | 0.078 | 0.084 | 0.090 | 0.095 | 0.101 | 0.107 | 0.113 | 10 |
| 20 | 0.113 | 0.119 | 0.125 | 0.131 | 0.137 | 0.143 | 0.149 | 0.155 | 0.161 | 0.167 | 0.173 | 20 |
| 30 | 0.173 | 0.179 | 0.185 | 0.191 | 0.197 | 0.204 | 0.210 | 0.216 | 0.222 | 0.229 | 0.235 | 30 |
| 40 | 0.235 | 0.241 | 0.248 | 0.254 | 0.260 | 0.267 | 0.273 | 0.280 | 0.286 | 0.292 | 0.299 | 40 |
| 450 | 3.742 | 3.752 | 3.762 | 3.771 | 3.781 | 3.791 | 3.801 | 3.810 | 3.820 | 3.830 | 3.840 | 450 |
| 460 | 3.840 | 3.850 | 3.859 | 3.869 | 3.879 | 3.889 | 3.898 | 3.908 | 3.918 | 3.928 | 3.938 | 460 |
| 470 | 3.938 | 3.947 | 3.957 | 3.967 | 3.977 | 3.987 | 3.997 | 4.006 | 4.016 | 4.026 | 4.036 | 470 |
| 480 | 4.036 | 4.046 | 4.056 | 4.065 | 4.075 | 4.085 | 4.095 | 4.105 | 4.115 | 4.125 | 4.134 | 480 |
| 490 | 4.134 | 4.144 | 4.154 | 4.164 | 4.174 | 4.184 | 4.194 | 4.204 | 4.213 | 4.223 | 4.233 | 490 |
| 500 | 4.233 | 4.243 | 4.253 | 4.263 | 4.273 | 4.283 | 4.293 | 4.303 | 4.313 | 4.323 | 4.332 | 500 |
| 510 | 4.332 | 4.342 | 4.352 | 4.362 | 4.372 | 4.382 | 4.392 | 4.402 | 4.412 | 4.422 | 4.432 | 510 |
| 520 | 4.432 | 4.442 | 4.452 | 4.462 | 4.472 | 4.482 | 4.492 | 4.502 | 4.512 | 4.522 | 4.532 | 520 |
| 530 | 4.532 | 4.542 | 4.552 | 4.562 | 4.572 | 4.582 | 4.592 | 4.602 | 4.612 | 4.622 | 4.632 | 530 |
| 540 | 4.632 | 4.642 | 4.652 | 4.662 | 4.672 | 4.682 | 4.692 | 4.702 | 4.712 | 4.722 | 4.732 | 540 |
| °C | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | °C |




$E_{AB}(t_1, t_0)$ = 4,17 mV

$E_{AB}(t_0, 0)$ = 0,113 mV

$E_{AB}(t_1, 0) = E_{AB}(t_1, t_0) + E_{AB}(t_0, 0)$

$E_{AB}(t_1, 0)$ = 4,17 + 0,113 =
= 4,283 mV

$t_1$ = 505 °C

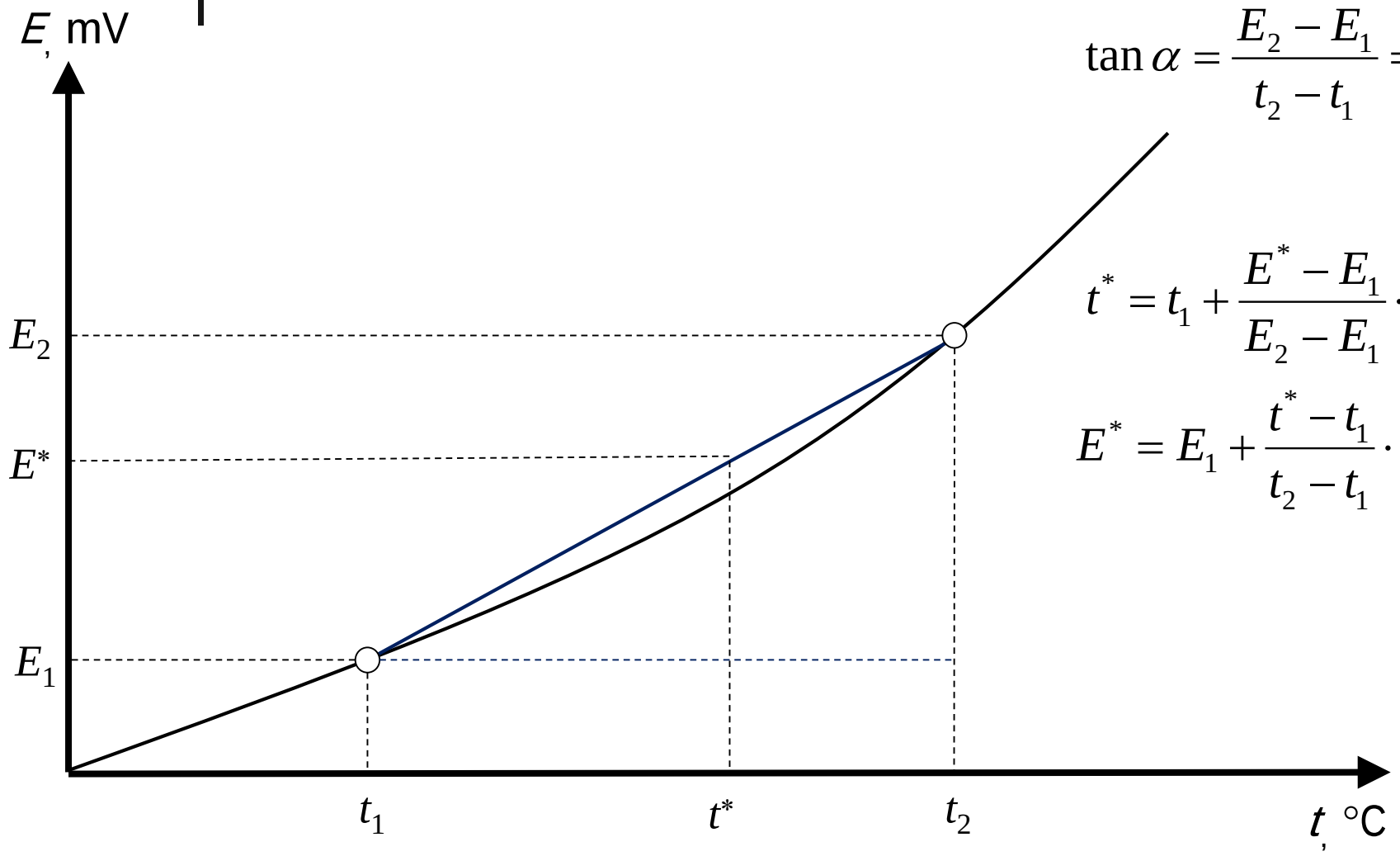
# Reference table

| Cold junction temp., $t_0$, °C | Therm.voltage, $E_{mV}$, mV | Cold junction, $E_0$, mV | Therm.voltage, $E_0 + E_{mV}$, mV | Temperature, t, °C |
|---|---|---|---|---|
| 15 | 2,462 | 0,597 | 3,059 | 75 |
| 24 | 4,693 | 0,960 | 5,653 | 138 |
| 28 | 5,016 | 1,122 | 6,138 | 150 |

TYPE K
Reference Tables
N.I.S.T. Monograph 175
Revised to ITS-90

| °C | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.000 | 0.039 | 0.079 | 0.119 | 0.158 | 0.198 | 0.238 | 0.277 | 0.317 | 0.357 | 0.397 | 0 |
| 10 | 0.397 | 0.437 | 0.477 | 0.517 | 0.557 | 0.597 | 0.637 | 0.677 | 0.718 | 0.758 | 0.798 | 10 |
| 20 | 0.798 | 0.838 | 0.879 | 0.919 | 0.960 | 1.000 | 1.041 | 1.081 | 1.122 | 1.163 | 1.203 | 20 |
| 30 | 1.203 | 1.244 | 1.285 | 1.326 | 1.366 | 1.407 | 1.448 | 1.489 | 1.530 | 1.571 | 1.612 | 30 |
| 40 | 1.612 | 1.653 | 1.694 | 1.735 | 1.776 | 1.817 | 1.858 | 1.899 | 1.941 | 1.982 | 2.023 | 40 |
| 50 | 2.023 | 2.064 | 2.106 | 2.147 | 2.188 | 2.230 | 2.271 | 2.312 | 2.354 | 2.395 | 2.436 | 50 |
| 60 | 2.436 | 2.478 | 2.519 | 2.561 | 2.602 | 2.644 | 2.685 | 2.727 | 2.768 | 2.810 | 2.851 | 60 |
| 70 | 2.851 | 2.893 | 2.934 | 2.976 | 3.017 | 3.059 | 3.100 | 3.142 | 3.184 | 3.225 | 3.267 | 70 |
| 80 | 3.267 | 3.308 | 3.350 | 3.391 | 3.433 | 3.474 | 3.516 | 3.557 | 3.599 | 3.640 | 3.682 | 80 |
| 90 | 3.682 | 3.723 | 3.765 | 3.806 | 3.848 | 3.889 | 3.931 | 3.972 | 4.013 | 4.055 | 4.096 | 90 |
| 100 | 4.096 | 4.138 | 4.179 | 4.220 | 4.262 | 4.303 | 4.344 | 4.385 | 4.427 | 4.468 | 4.509 | 100 |
| 110 | 4.509 | 4.550 | 4.591 | 4.633 | 4.674 | 4.715 | 4.756 | 4.797 | 4.838 | 4.879 | 4.920 | 110 |
| 120 | 4.920 | 4.961 | 5.002 | 5.043 | 5.084 | 5.124 | 5.165 | 5.206 | 5.247 | 5.288 | 5.328 | 120 |
| 130 | 5.328 | 5.369 | 5.410 | 5.450 | 5.491 | 5.532 | 5.572 | 5.613 | 5.653 | 5.694 | 5.735 | 130 |
| 140 | 5.735 | 5.775 | 5.815 | 5.856 | 5.896 | 5.937 | 5.977 | 6.017 | 6.058 | 6.098 | 6.138 | 140 |

# Interpolation




$$\tan\alpha = \frac{E_2 - E_1}{t_2 - t_1} = \frac{E^* - E_1}{t^* - t_1}$$

$$t^* = t_1 + \frac{E^* - E_1}{E_2 - E_1} \cdot (t_2 - t_1)$$

$$E^* = E_1 + \frac{t^* - t_1}{t_2 - t_1} \cdot (E_2 - E_1)$$

# Interpolation

$t^* = 24{,}2\ °C \qquad E^* = ?$

| °C | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.000 | 0.005 | 0.011 | 0.016 | 0.022 | 0.027 | 0.033 | 0.038 | 0.044 | 0.050 | 0.055 | 0 |
| 10 | 0.055 | 0.061 | 0.067 | 0.072 | 0.078 | 0.084 | 0.090 | 0.095 | 0.101 | 0.107 | 0.113 | 10 |
| 20 | 0.113 | 0.119 | 0.125 | 0.131 | 0.137 | 0.143 | 0.149 | 0.155 | 0.161 | 0.167 | 0.173 | 20 |
| 30 | 0.173 | 0.179 | 0.185 | 0.191 | 0.197 | 0.204 | 0.210 | 0.216 | 0.222 | 0.229 | 0.235 | 30 |
| 40 | 0.235 | 0.241 | 0.248 | 0.254 | 0.260 | 0.267 | 0.273 | 0.280 | 0.286 | 0.292 | 0.299 | 40 |

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$$E^* = 0{,}137 + E_x$$

$$E_x\ \text{mV} \rightarrow (24{,}2 - 24)\ °C$$

$$(0{,}143 - 0{,}137)\ \text{mV} \rightarrow (25 - 24)\ °C$$

$$E^* = 0{,}137 + \frac{24{,}2 - 24}{25 - 24} \cdot (0{,}143 - 0{,}137) = 0{,}1382 \quad \text{mV}$$

$$E^* = E_1 + \frac{t^* - t_1}{t_2 - t_1} \cdot (E_2 - E_1)$$

# Interpolation

$E^* = 4{,}275$ mV  $t^* = ?$

| °C | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 4.233 | 4.243 | 4.253 | 4.263 | 4.273 | 4.283 | 4.293 | 4.303 | 4.313 | 4.323 | 4.332 | 500 |
| 510 | 4.332 | 4.342 | 4.352 | 4.362 | 4.372 | 4.382 | 4.392 | 4.402 | 4.412 | 4.422 | 4.432 | 510 |
| 520 | 4.432 | 4.442 | 4.452 | 4.462 | 4.472 | 4.482 | 4.492 | 4.502 | 4.512 | 4.522 | 4.532 | 520 |
| 530 | 4.532 | 4.542 | 4.552 | 4.562 | 4.572 | 4.582 | 4.592 | 4.602 | 4.612 | 4.622 | 4.632 | 530 |
| 540 | 4.632 | 4.642 | 4.652 | 4.662 | 4.672 | 4.682 | 4.692 | 4.702 | 4.712 | 4.722 | 4.732 | 540 |

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Revised to ITS-90

$$t^* = 504 + t_x$$

$$t_x \text{ °C} \rightarrow (4{,}275 - 4{,}273) \text{ mV}$$

$$(505 - 504) \text{ °C} \rightarrow (4{,}283 - 4{,}273) \text{ mV}$$

$$t^* = 504 + \frac{4{,}275 - 4{,}273}{4{,}283 - 4{,}273} \cdot (505 - 504) = 504{,}2 \text{ °C}$$

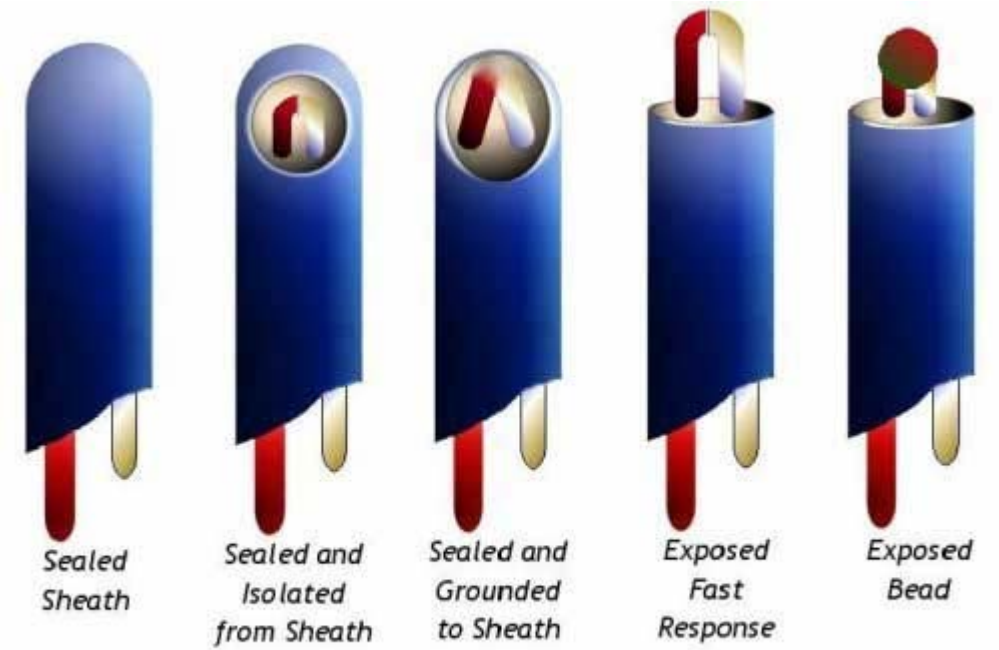
$$t^* = t_1 + \frac{E^* - E_1}{E_2 - E_1} \cdot (t_2 - t_1)$$

# Automatic compensation of reference junction

# Thermopile and differential thermocouple

# Handheld thermocouples


# Thermocouple sheath

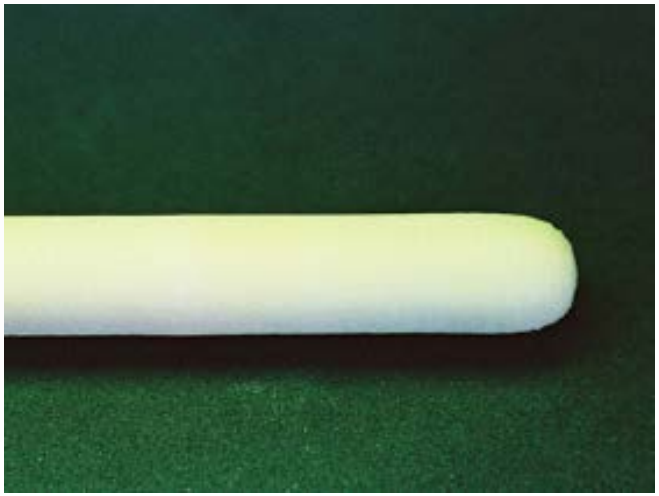


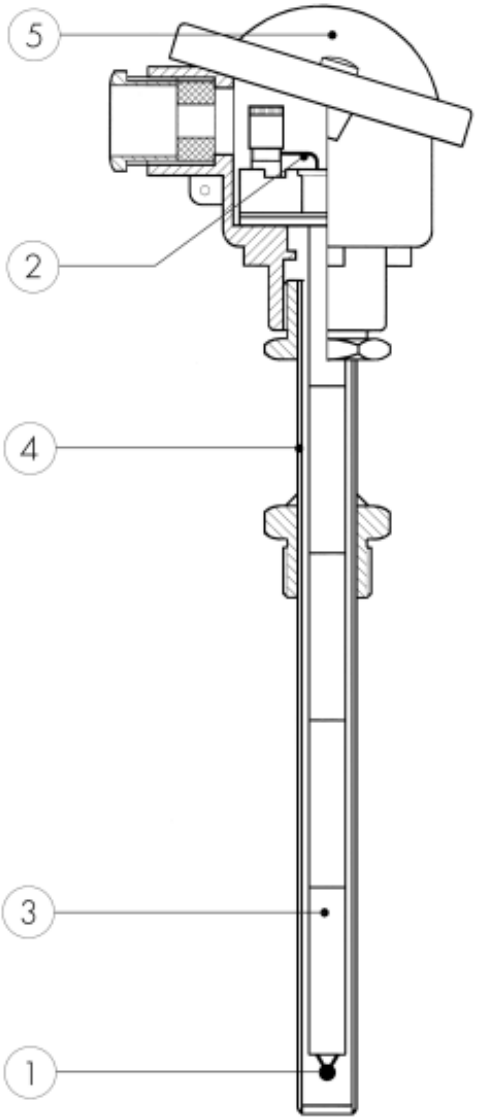

Thermocouple Sheath Options

# Construction

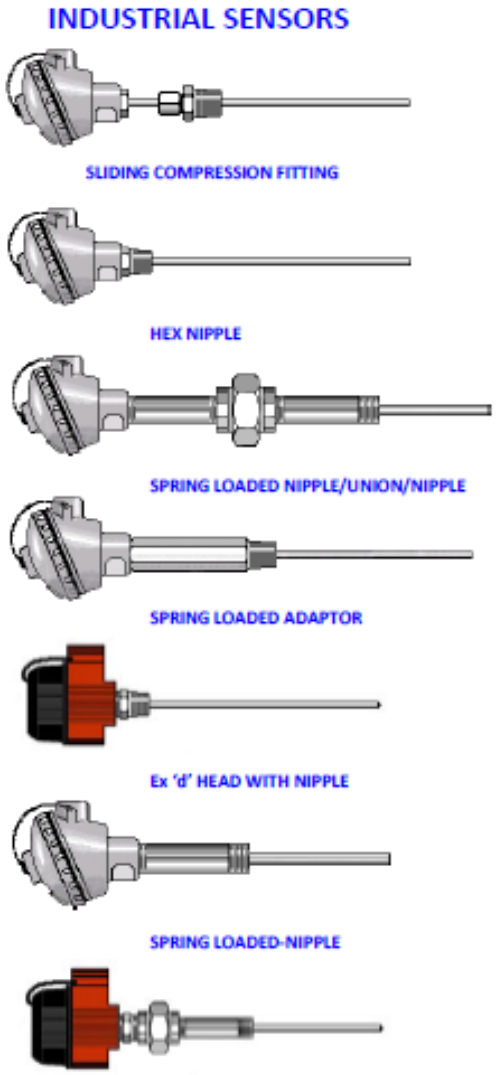
In order to protect the thermocouple from damage under influence of aggressive environment the measuring junction needs to be placed into the sheath.

1 – junction
2 – wire
3 – insulation
4 – sheath
5 – head





# Industrial thermocouples

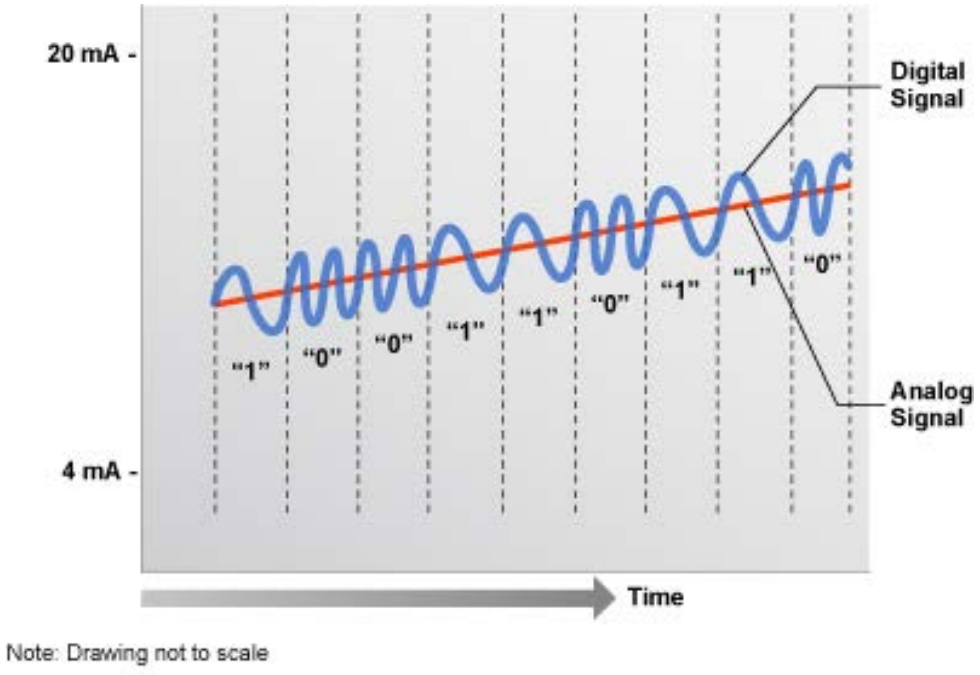



# Transmitters


# Universaalsed mõõteriistad


# HART normeerivad muundurid

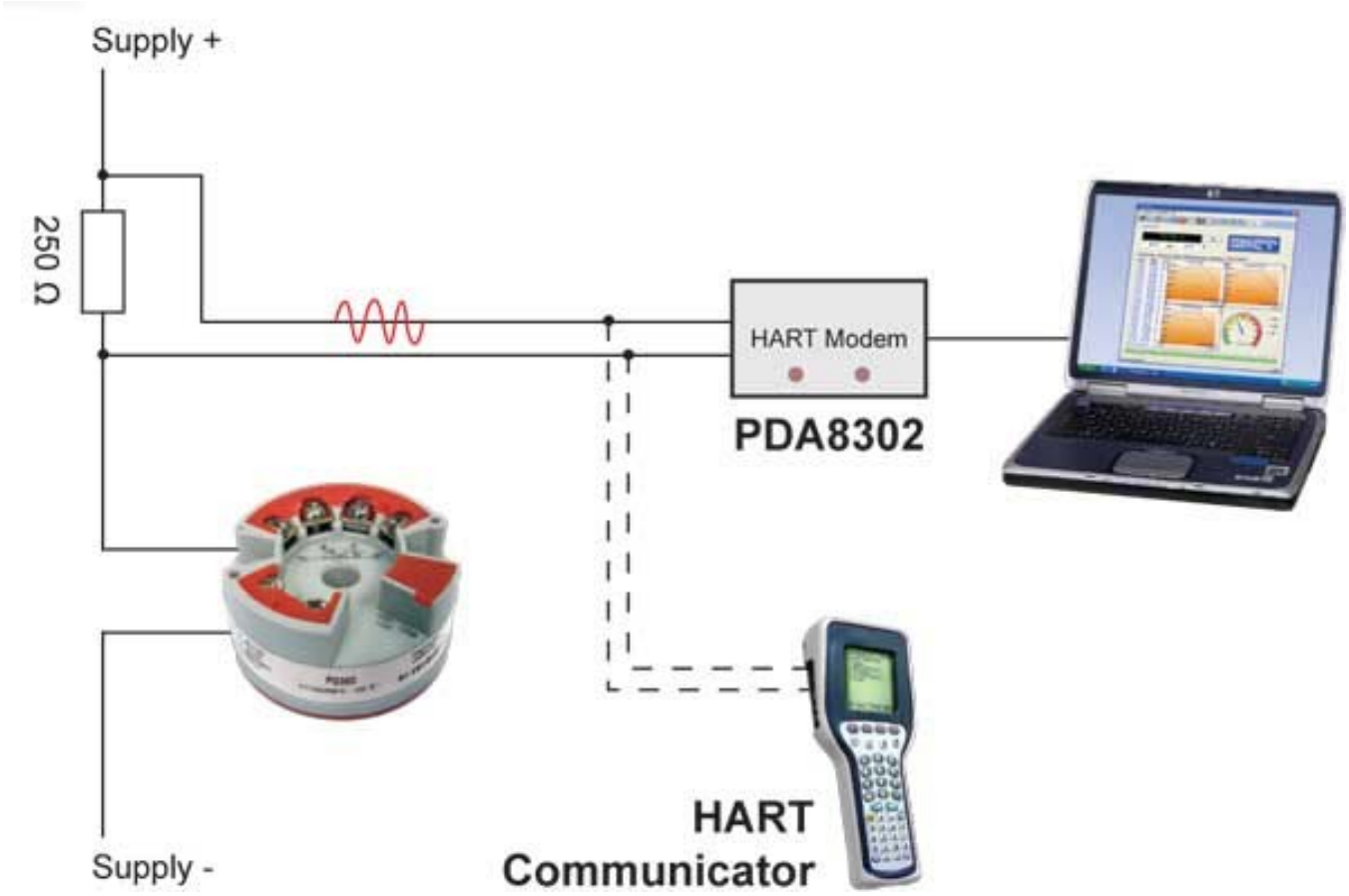
HART-reeglistikule vastavad normeerivad muundurid võimaldavad lisaks analoogsignaalile samal ajal üle kanda ka digitaalset signaali samade juhtmete kaudu.



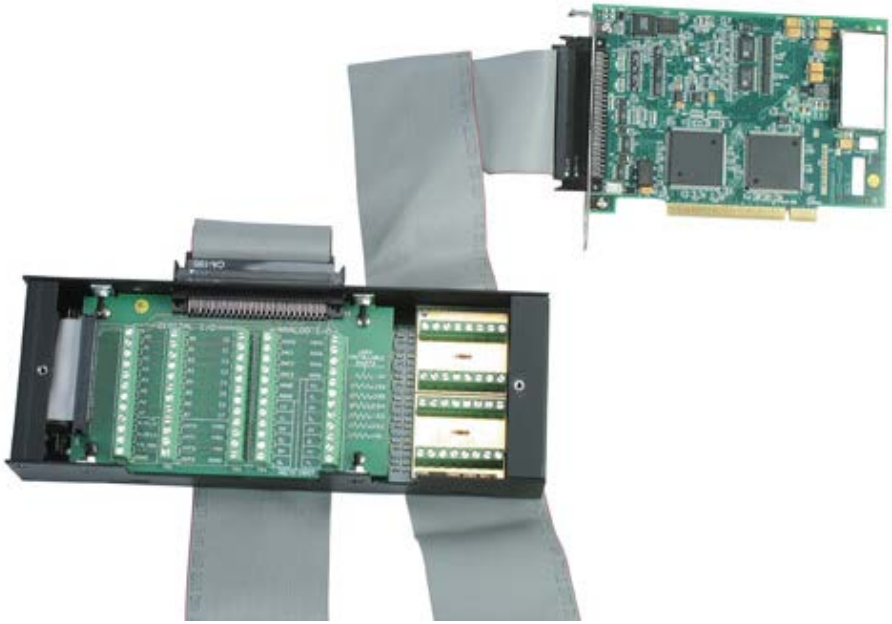

Digital over Analog

Sellisel viisil ülekantav info võib sisaldada andmeid mõõtekoha numbri kohta, mõõteseadme kalibreerimisandmeid, andmeid mõõtseadme häire kohta jne.

# HART protocol transmitter



# Connecting to PC



Plug-in card


Data acquisition module

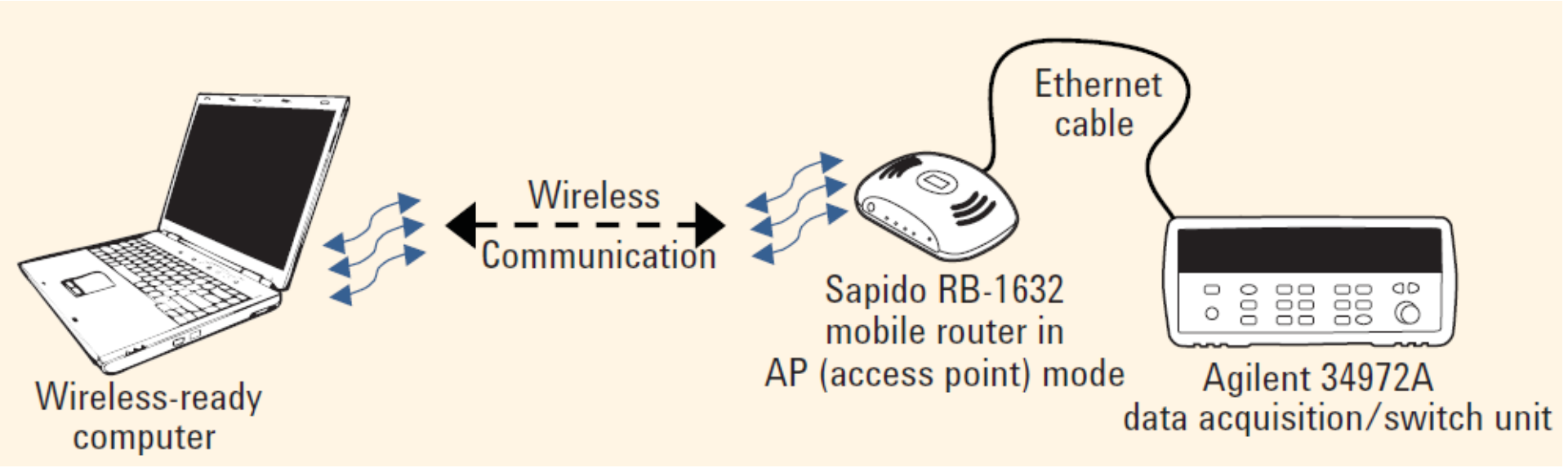
# Data transmission (*wireless*)



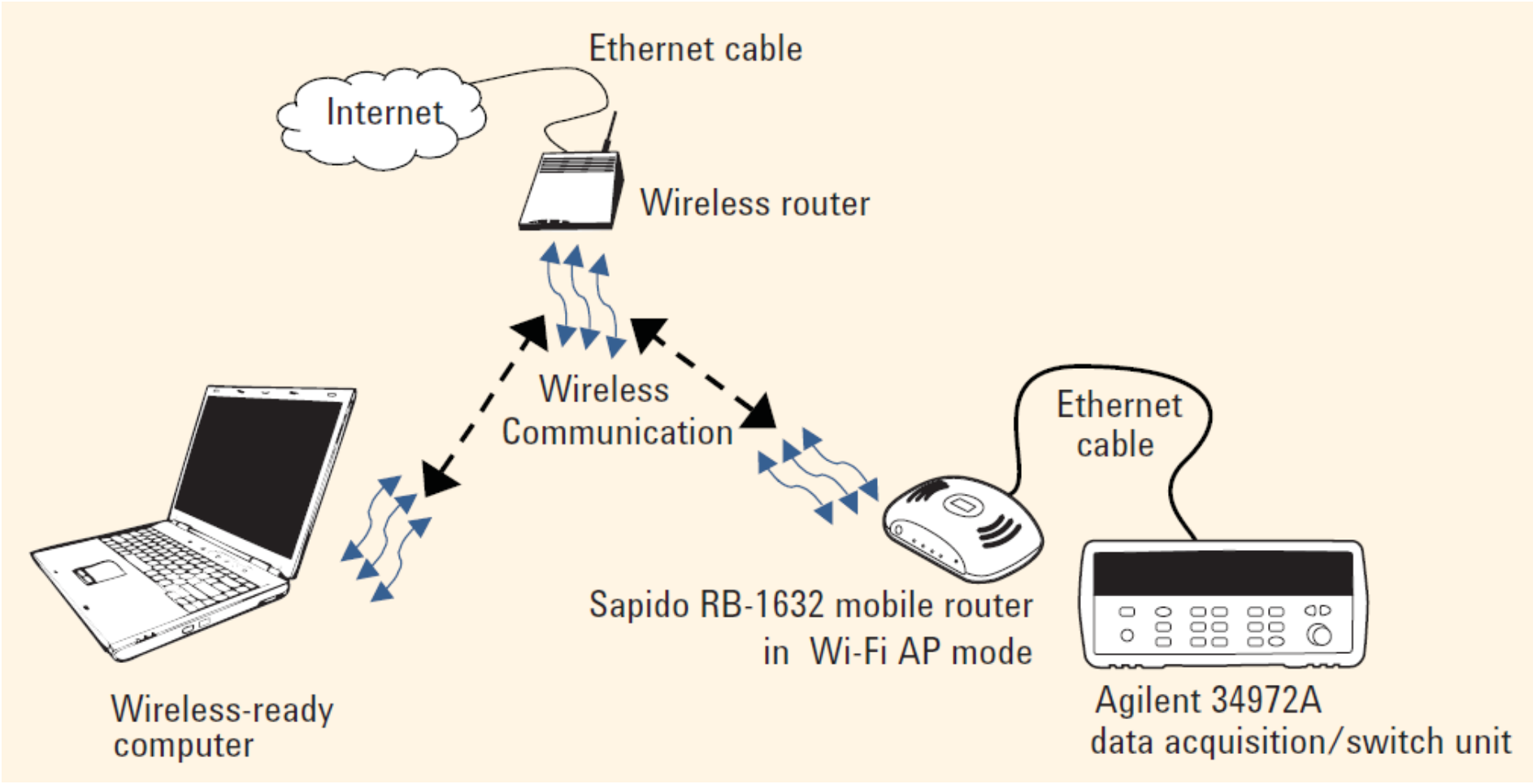
Transmitters


Reciever

# Data transmission (*wireless*)



# Data transmission (*wireless*)



# Data loggers