Transducers and sensors

- All instruments based on measuring signals

  therefore need to understand

  the types of signals
  properties and characteristics of transducers
  applications which are appropriate
  impact on the instrument systems

- Transducer

  devices which produce an electrical signal proportional to a variable of interest

  why? *automation for speed, convenience (eg alarm) or objectivity*
  ease further manipulation of measurements
  extend range of processing beyond simple calculations

  digital processing now very cheap

- Big area - so which transducers should interest us most? Try to find:

  examples of components used for control or monitoring purposes

  sensors which exhibit properties of ***general interest***,
  even if employed for special purposes (like physics research...)

Major transducer types

- Control or measurement

  temperature, pressure, humidity, B-field, sound, strain, acceleration,...

  growing area of bio-chemical sensors

  beyond scope of these lectures but many common principles
  electrical output often desirable for reasons already cited

- ionisation sensors

  general purpose light detection (especially optical communication),

  radiation detection (α, β, γ, x-ray, charged particle,...)

  many examples of sensors developed for physics which now form components for general use

  and vice-versa

  specialised state of art instruments often exploit new technologies

Equivalent circuits

- To use any device, we need an effective model of it

  should characterise important properties

- Most common & simple picture

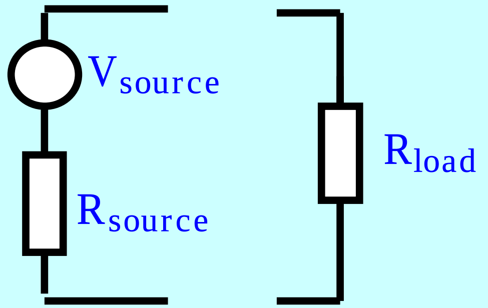
  Voltage source } with associated impedance
  Current source

  this defines how to connect it to a useful circuit

Voltage source

$i = V_{source}/(R_{source}+R_{load})$

$V_{load} = iR_{load} = V_{source}R_{load}/(R_{source}+R_{load})$



if $R_{source} \gg R_{load}$ $\quad V_{load} \ll V_{source}$

if $R_{source} \ll R_{load}$ $\quad V_{load} \approx V_{source}$

we can only sometimes choose R_{source}

usually defined by transducer - may influence transducer selection

but often transducer chosen first

we do not always have complete freedom over R_{load}

eg if long cables are required

- To measure voltages, will often require a high load impedance

or low source impedance, if intervening circuit

- Matching

if $R_{load} = R_{source}$ obtain maximum power transfer from source to load

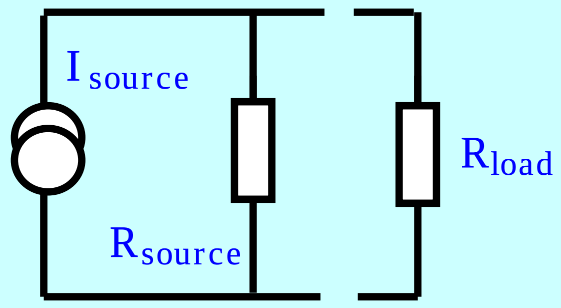
then $V_{load} = V_{source}/2$

Current source

$V_{load} = I_{source}(R_{source} \,||\, R_{load}) = I_{source}R_{source}\, R_{load} \,/(R_{source}+R_{load})$

$I_{load} = I_{source}R_{source} \,/(R_{source}+R_{load})$

$if\ R_{load} << R_{source} \quad I_{load} \approx I_{source}$



same comments as previous about ability to choose R_{source} and R_{load}

•To measure currents, will usually require a low load impedance

or high (parallel) source impedance, if intervening circuit

•Matching

$R_{load} = R_{source}$ to obtain maximum power transfer from source to load

but this is not always done for practical reasons - discuss later

•Should note that neither source nor load impedance is always simple resistance

Temperature measurement

- Traditional - mercury thermometer
  - need long, accurately dimensioned tube
  - calibrated scale
    - *eg ice, steam*
- What limits precision? (problem sheet)
  - accuracy of tube bore
  - practical length of accurate tube
  - operating temperature (melting point of glass?)
  - change in metal dimensions & ability to observe them
  - change in dimensions of tube with temperature
- Although well developed technology, not very practical for many applications
  - especially those requiring automation & control
    - *cheap, accurate digital thermometers now seem to be widely used in hospitals & for home use - not all electronic*
- Similar discussion for bi-metallic thermostat
  - several electronic alternatives are available

Temperature sensor - characteristics required

- Specifications include

  Accuracy

  probably will depend on T, precision will depend on application, but should be known

  Linearity

  output (voltage or whatever..) should be α *T (K,°C,* $T-T_0$*,..)*

  Interchangeability

  would like to be able to replace the sensor and get similar results

  Signal size

  ease of measurement

  Remote sensing

  typically sensor can't be right at source, especially if hot or cold

  Temperature range

  specs are unlikely to be met from 0K to ∞

  Cost

- even if we think of a medical thermometer, these requirements do not change much

Thermocouple

•junction between two different metals can produce a small voltage

value typically very small (10-100μV/°C)

depends approximately on difference between two junction temperatures

- one should be reference

well known properties -

so can choose type appropriate to requirement and interchangeable

very convenient for quick, simple measurements

eg control applications

Caveats

relative measurements excellent but absolute measurements need care

define reference point (& maintain constant!)

physics of thermocouple

hot wire end produces a temperature gradient

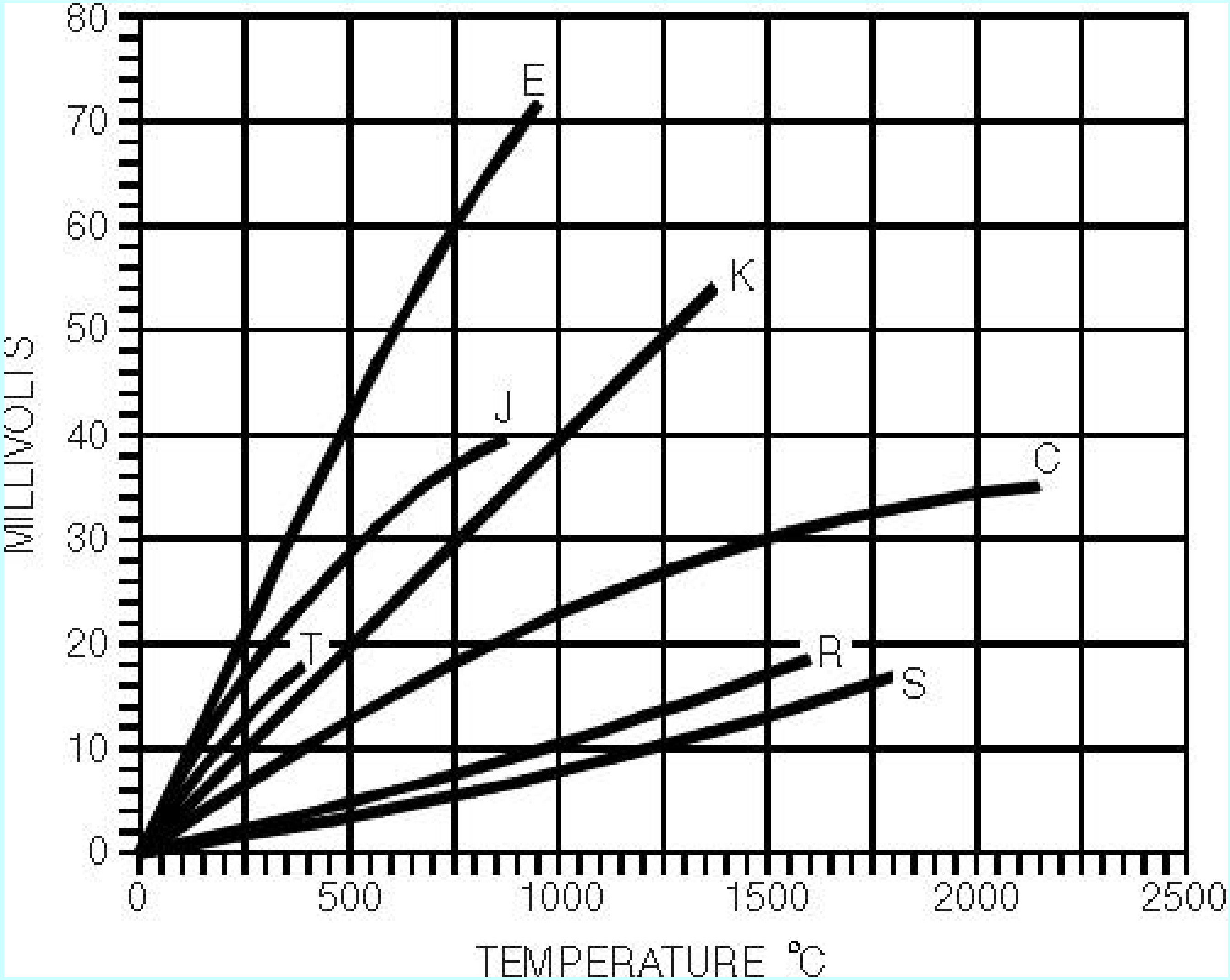
so a carrier density gradient

equilibrium is established when an electric field in the wire balances the carrier diffusion

not practical to put voltmeter across ends of wire - could be hot!

Types of thermocouple (ii)

•www.isi-seal.com/Technical_Info/ Tech_Thermocouple.htm



Types of thermocouple

Type	Metal-1	Metal-2	Tmax	Sensitivity	Vout (mV)	Vout (mV)	Vout (mV)	Rlead
			degC	µV/degC	mV	mV	mV	Ω/m
				at 20degC	reference junction at 0degC			typical
					(100 degC)	(400 degC)	(1000 degC)	
J	Iron	Constantan	760	51.5	5.27	21.85		12
K	Chromel	Alumel	1370	40.3	4.10	16.40	41.27	20
T	Copper	Constantan	400	40.3	4.28	20.87		10
E	Chromel	Constantan	1000	60.5	6.32	28.94	76.36	24
S	Platinum	90%Pt-10%Rh	1750	5.9	0.65	3.26	9.59	6
R	Platinum	87%Pt-13%Rh	1750	5.8	0.65	3.41	10.50	6
B	94%Pt-6%Rh	70%Pt-30%Rh	1800	0.0	0.03	0.79	4.83	6
C	95%W-6%Rh	74%W-26%Rh	2320	25.7	2.5	10.0	25.7	
	Constantan	**55%Cu-45%Ni**						
	Chromel	**90%Ni-10%Cr**						

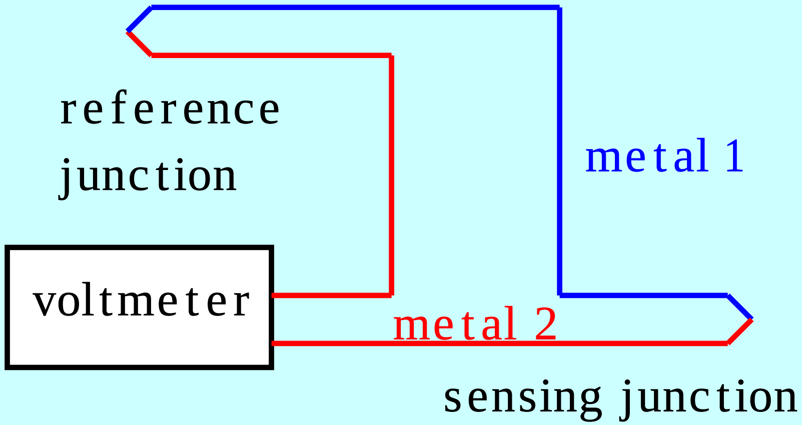
- Junctions are welded by manufacturer

  Often equipped to plug into digital volt meter

  reference to room temperature with internal circuitry

  "home-made" systems need care in adding wires -can add another junction

Thermocouple readout



- place reference junction at defined temperature

  not practical for most situations

- use compensation circuit to correct for ambient conditions

  principle of most temperature meters

  = another temperature measuring device needed!

  however, not practical to place integrated circuit at hot node!

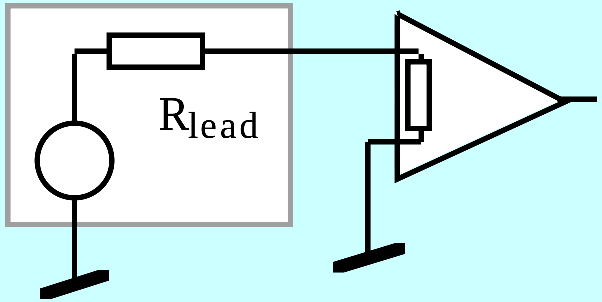
- practical issues

  low output voltage to be measured eg 20K x 50µV/K = 1mV

  measuring amplifier needs careful design to avoid noise

  amplifier input resistance should be reasonably high

  lead resistance not negligible if long



Thermistor

- Semiconductor device with well defined R-T characteristic

  coefficient of R vs T ~ -4%/°C ie. $\Delta R/R = \alpha\Delta T$

  $R_{typical} \sim k\Omega$

  precise conformity to standard from manufacturers

  range ~ -50°C to +300°C

  easy to use, with large change in value with temperature

Practical issues

provide current source to operate

accuracy depends on application

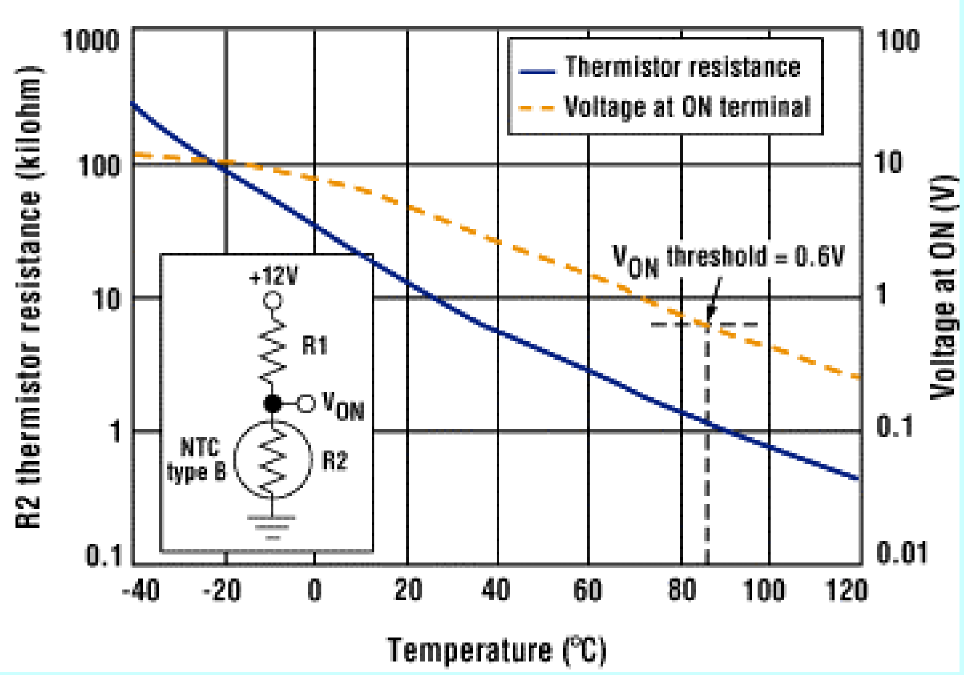
non-linear R-T behaviour

accurate applications => careful circuit choice (eg balancing bridge)

circuit self-heating can influence

small ΔT - thermal noise could be concern

need calibration



Temperature ICs

•Band-gap circuits

Based on semiconductor junction diode   I ~ exp(qV/kT)

•eg AD590 - discuss more later

Manufacturer's specs   (read them!!)

Two terminal sensor (V_{supply}: +4V to +30V)

Linear output current 1µA/K , ±0.3°C over range

T range -55°C to +150°C

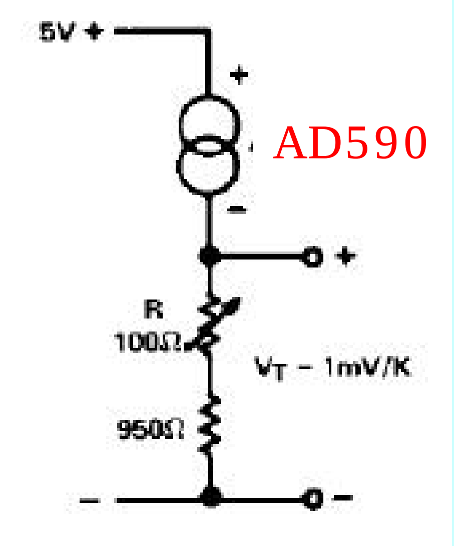
Calibrated, with accuracy ±0.5°C

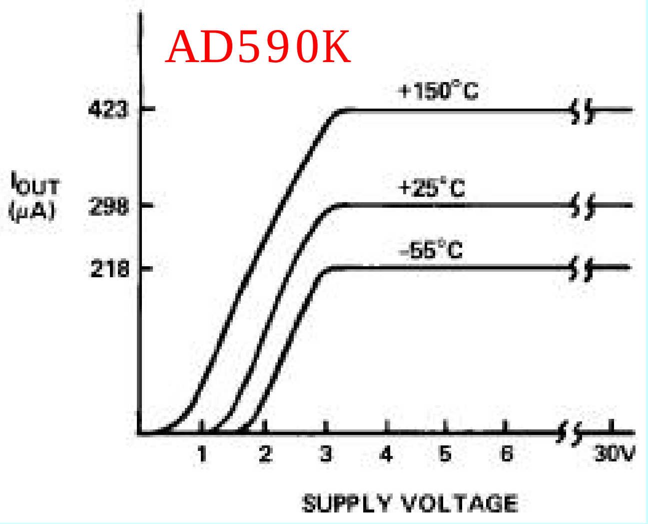
Can be used remotely (x100 feet!), with long wires

Low cost (≈£10 for <25)

NB several versions

	Absolute error	Non-linearity
J	±5.0	±1.5
K	±2.5	±0.8
L	±1.0	±0.4
M	±0.5	±0.3





•Custom ICs -

can design reference circuits,

eg to save space or remote locations