Transducers (physical quantity → electrical quantity)

Light -

① photomultiplier (PM) - single photon counting, 1 channel

② CCD (Charge Coupled Device) - measure dozen photons with 10^6 channels. An array (say 1000×1000) of "buckets" individually convert photons to electrons & store the results. (Note: like real buckets these electron buckets have a maximum capacity & may leak a bit - FYI typically they leak in (electrons from outside join those produced by photons) rather than leak out). During an exposure the electrons accumulate in these buckets and the end result is 10^6 buckets each with maybe 10^4 electrons. In order to count the electrons in a bucket, the electrons are dumped on a (small) capacitor and the resulting voltage measured with a ADC. The actual transfer of electrons to the capacitor is done as a "bucket brigade" ie an analog shift register - the final result (an image) is a 1000×1000 matrix of integers

③ photodiode, phototransistor, photodarlington

a "back biased" diode does not conduct essentially because inside the diode the path for conduction has been blocked by a (voltage dependent) insulator — this is the PN junction to be discussed in Analog Electronics. Photons absorbed in this insulating region (depletion zone) produce e^- hole$^+$ (ionized atom) pair which as they exit the region are an electric current

Net result: photon → current

transistors & darlingtons are ways to multiply this current by β & β^2 — larger currents are easier to measure.

Temperature

① Platinum Resistance Thermometer (an example of a resistance temperature device – RTD)

The resistance of metals depends approx linearly on absolute temperature. Particular alloys of Pt have become international standards for temperature. [ie the "exact" relation between T & R is tabulated] Excellent precision over a wide range of temps (70 K → 1000 K) is possible. Disadvantage for small ΔT: the percentage change in R between 273 K & 274 K will be about $\frac{1}{3}\%$ ie a small <u>relative</u> change from a small <u>relative</u> change in T.

Advantage: standardized

② Thermocouple – junctions between dissimilar metals held at different temps – the voltage difference is approx proportional to the temperature difference.

$$\Delta V \underset{\overset{\uparrow}{43\,\frac{\mu V}{K}}}{\propto} (T_1 - T_2)$$

For standard metals ("Types") the relationship between T & ΔV is tabulated. Common Types:

T → Cu/constantan

K → chromel-alumel ← good at higher temps

Advantage – cheap
standardized ; Disadvantage – small $\underset{\mu V \sim mV}{\underset{\nearrow}{\Delta V}}$
small
easy to make

Remark: Unintended thermocouples can be a problem when attempting accurate DC voltage measurements

③ Thermistor: $R \propto e^{Q/T}$

cheap, usually uncalibrated, large fractional changes in R for "normal" temps, R sized to match typical ohm meters (kΩ — note most common Pt resistors is 100Ω)

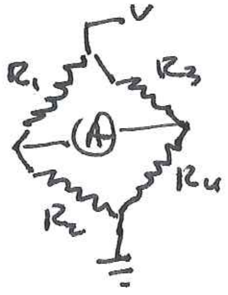
④ IC sensors — specs will include error range covers "normal" temps, cheap & easy to use with typical DMM

Remark: physical effects — like vapor pressure, melt/freeze, superconducting transitions may be used to calibrate temp transducers — particularly required for work < 4K.

Motion —

① Linear (or rotary) variable differential transformer (LVDT) — the location of a Fe slug between a pair of primary/secondary transformer coils affects the voltage in the secondary

② Strain gauge — the geometry of a wire determines its resistance $R = \rho \frac{l}{A}$ — small stretches of wire result in small changes in R which can be detected via wheatstone bridge



if $\frac{R_1}{R_2} = \frac{R_3}{R_4}$ then Ⓐ $= 0$

small changes in shape of R_3 result in small currents thru Ⓐ. Main reason for circuit:

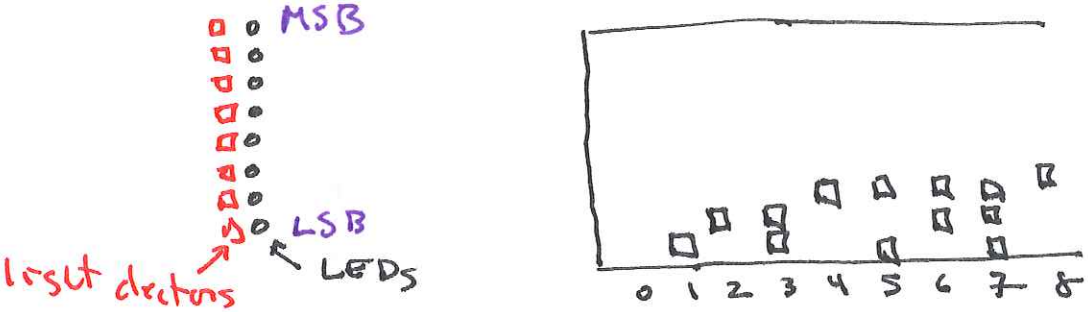
Ⓐ measures changes in R_3 which would be a very small fraction of R_3

③ Interferometry – measure motion ~λ light

④ Piezoelectric – voltage changes size of object (& reverse) – Note: these size changes are generally "small" ie ~λ light

⑤ Optical encoders –

Absolute: write binary count as a sequence of holes that let light thru (=1) or not (=0)

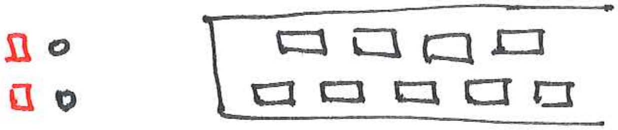


binary # location can be read off by which LEDs shine thru

Note: holes often Gray Code so only one change at a time to eliminate "in between" state

Note: Gives absolute location (rather than Δx) but expensive & not super accurate.

Incremental optical encoders – give Δx (with sign)



if strip moves ← bottom LED leads; if strip moves → top LED leads

Note: you can actually take this output immediately to a up/down counter to get total displacement from some starting location.

Relatively cheap & accurate – but start must be known to get actual location rather than displacement

Vacuum — pressure often measured in mm Hg = torr
where 760 torr = 1 atm $\approx 10^5 \frac{N}{m^2}$ = 1 bar

Mechanical pumps (rotary or piston) might get to 10^{-6} torr. Atom based pumps (eg diffusion pumps) might get you to 10^{-10} torr.

→ thermocouple gauges → a "vacuum" is an insulator, so a constant heat source will reach higher temps in "vacuum". Measure that temperature use a calibration to convert to pressure

→ ionization gauge → At "high vacuum" the mean free path of particles can be macroscopic (eg cm). A stream of high speed electrons may mostly hit nothing. At slightly higher pressures electrons occasionally hit residual atoms ionizing them (ie $Ar \rightarrow Ar^+ + e^-$) collect the positive ions by putting a ⊖ charge wire near the electron stream. The larger the ion current, the more gas is present.