

Physics 120B: Lecture 6

Sensors

(bit incomplete, still)

Sensing Categories

- Voltage
 - starting easy: analog in
- Distance
 - acoustic or light
- Speed
 - hard; usu. via distance
- Acceleration
 - accelerometers
- Light Level
 - phototransistors, photodiodes
- Object Passage
 - photogate (light source/sense)
- Sound Level
 - microphone to rectifier?
- Temperature
 - RTD, thermistor, AD-590
- Magnetic Flux
 - coil and EMF
- Pressure
 - pads?
- Mass
 - spring stretch?
- Strain
 - strain gauge

http://en.wikipedia.org/wiki/List_of_sensors for overwhelming list

Voltage

- Crudest version is digital: HIGH or LOW: **1-bit** resolution
 - lots of digital inputs to handle this
 - option for internal pull-up resistor to V_{CC}
- Analog in provides **10-bit** (0–1023) on Arduino
 - considered on crude-to-modest side: 50 mV in 5 V
 - high-end is **16-bit** (65536 values)
 - seldom meaningful to carry more precision than this
 - **12-bit** is also common, and 4× improvement over 10-bit
 - **8-bit** is painful: 0.2 V in 5 V
 - but fine for some applications
- Voltage is seldom what you fundamentally want to know, but is often the electronic analog of a physical quantity of greater interest
 - generally, “converter” can be termed *transducer*

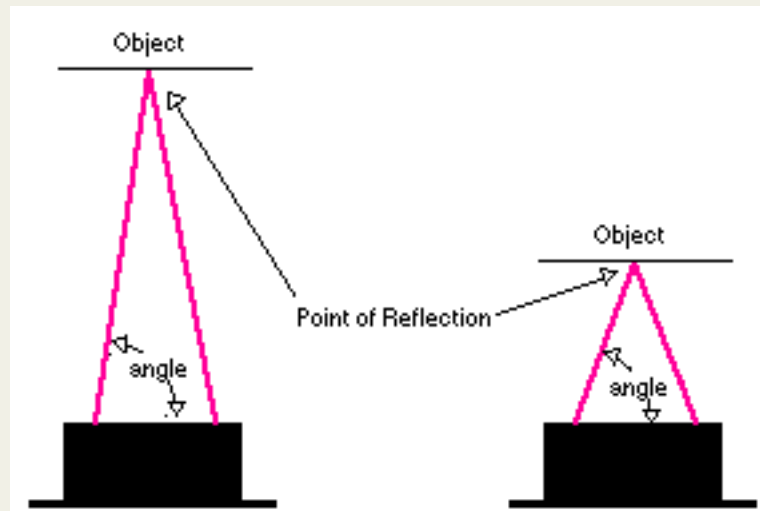
Distance

- Popular 120B metric
 - collision avoidance; parallel park; target approach
- Acoustic variety
 - ultrasound burst and time-of-flight measurement
 - Parallax Ping unit is integrated unit, \$30
 - 2 cm to 3 m (dep. on surface type)
 - must send 2 μ s pulse on SIG pin
 - then listen for return pulse
 - duration of pulse is round-trip time
 - must switch same pin between input/output
 - use `pulseIn()` to measure input duration
- Other modules in lab to roll your own acoustic sensor



Distance via Light?

- Not time-of-flight; forget about it! Leave that to pros
- Clever sensing of angle between emitter and receiver



from <http://roborugby.ucd.ie/distsensor.html>

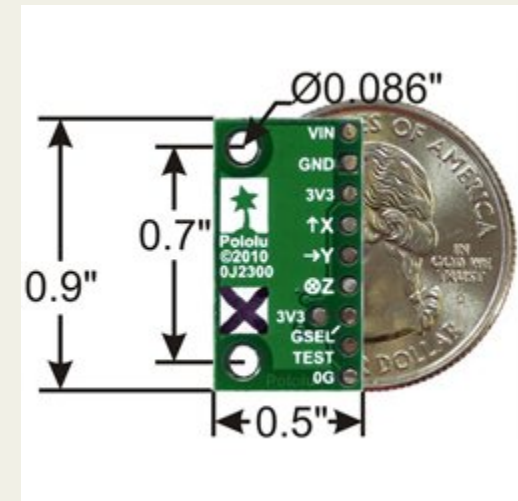
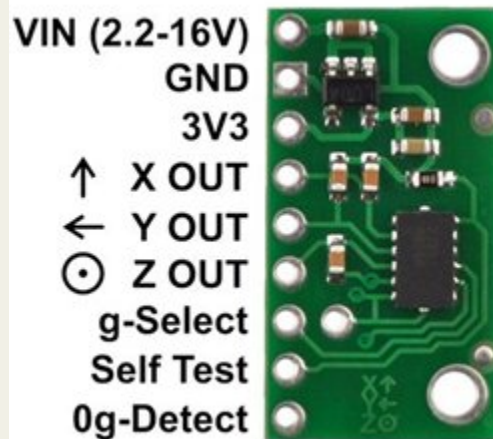
- Detector is linear array behind lens
 - angle maps to position, indicating distance
- Smarts on board, so GND, +5 V in; analog voltage out proportional to distance, though not linearly so

Measure Speed?

- Galileo and Einstein would both agree that this is hard to directly sense
- Options
 - measure distance and rate of change
 - noise in distance measurement can make for ratty/spiky velocity
 - Doppler?
 - measure rotation rate of wheel or axle engaged in motion
 - what speedometers do
 - can use photogate for once/revolution knowledge

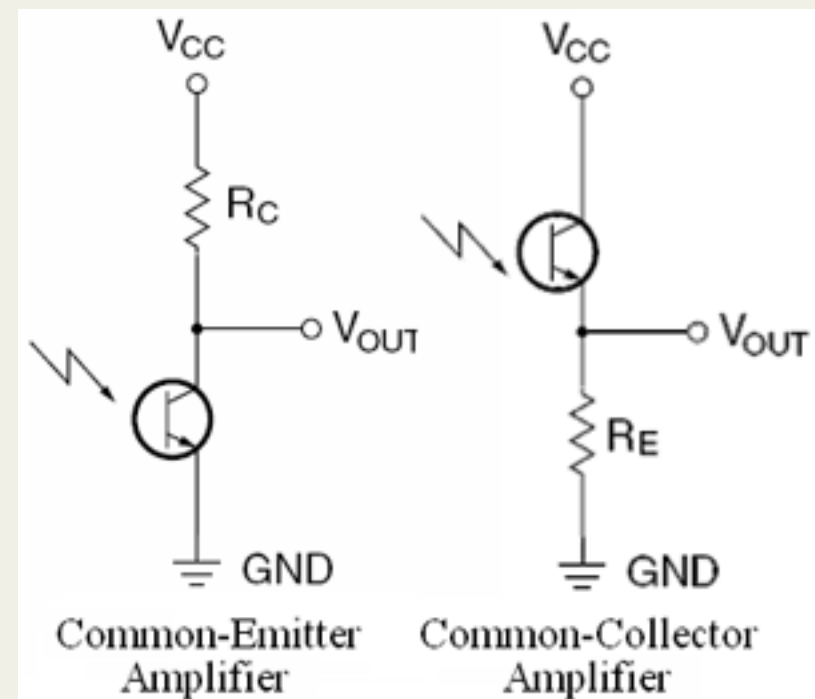
Acceleration

- This is something we *can* directly sense
- Recent rapid advances; driven by MEMs and smartphones
 - 3-axis accelerometer based on micro-cantilevers capacitively sensed
 - bitty MMA7361L unit, \$15
 - centers output on $\frac{1}{2}$ of 3.3 V
 - default roughly $\pm 1.5g$, but can config. for $\pm 6g$
 - zero-g detection and digital flag



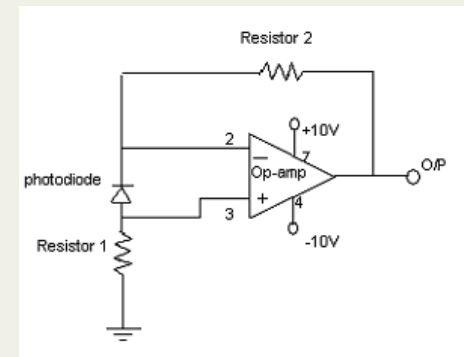
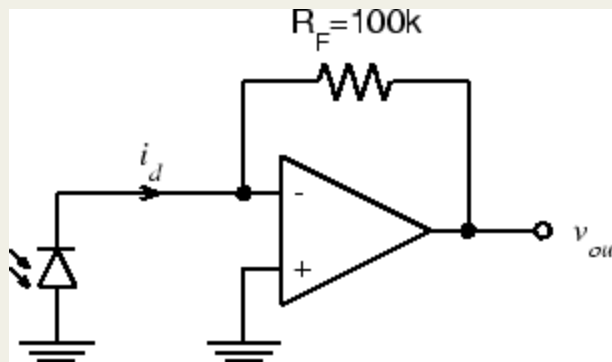
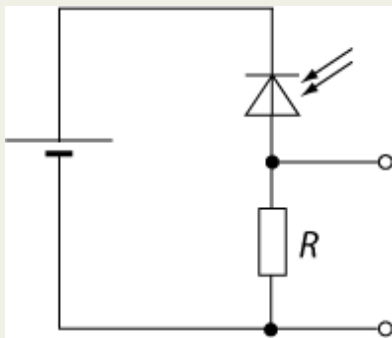
Light Level

- Lots of options:
phototransistor,
photodiode most
common
 - photons knock electrons
loose, which either
constitute a base current
(phototransistor) or direct
into current (photodiode)
- Phototransistor (right)
effectively has some gain
already
 - 10 k Ω usually about right



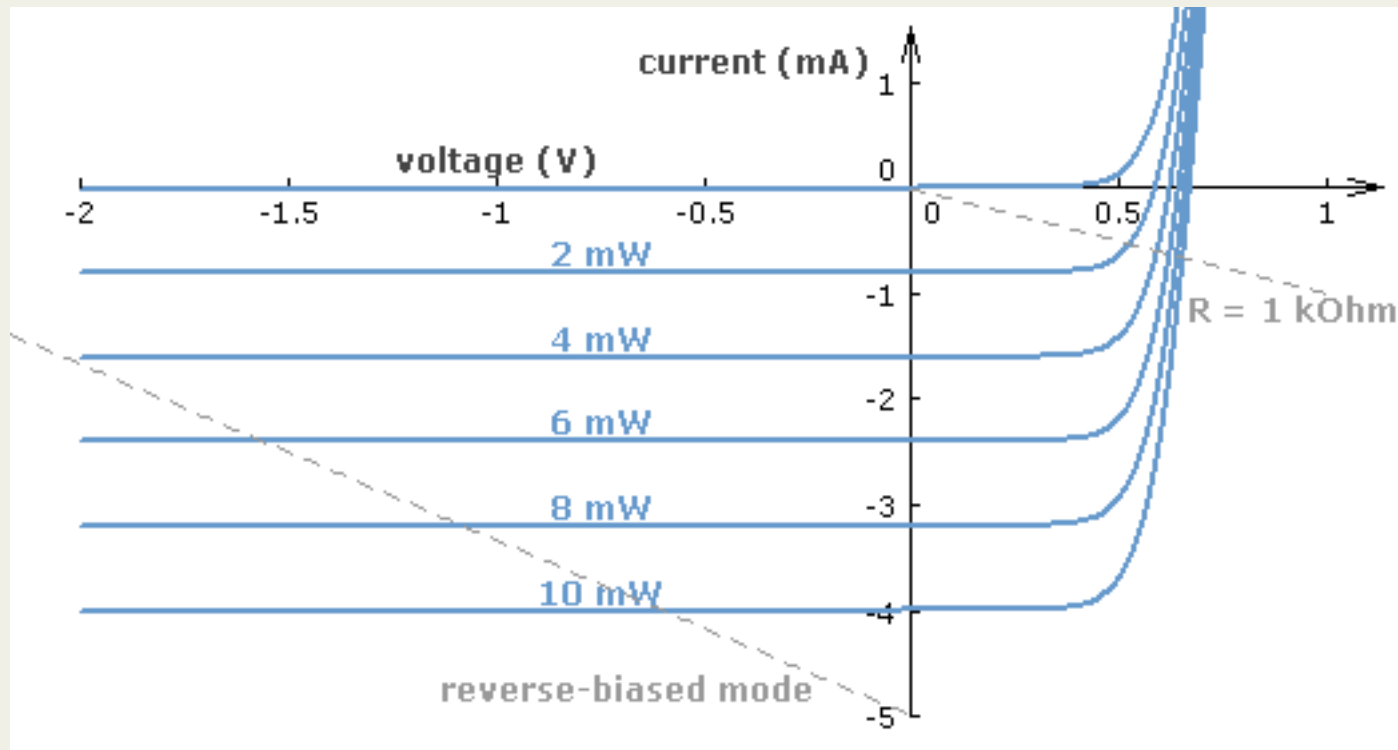
Photodiode Read Out

- Many options for photodiode
 - reverse bias, developing voltage across resistor
 - zero bias, in op-amp feedback mode



- Typically < 0.4 A per Watt incident
 - stream of photons at 550 nm \rightarrow 0.447 A at 100% Q.E.
 - so 1 mm² detector in full sun (1000 W/m²) is 1 mW
 - thus at best 0.5 mA current (puny)
 - tend to want pretty large resistor to build up voltage

Photodiode IV Curve



- At zero or reverse bias, current is proportional to incident light power
 - note approximate relation: $I \approx 0.4P$
 - matches quantum expectations

Object Passage

- We often need to know if something is physically present, has passed through, count rotations, etc.
- Can have simple scheme of light source and light detector, where the something of interest passes between
 - termed a *photogate*
 - interruption of light level pretty unmistakably sensed
 - pulse duration, via `pulseIn()`, may even speak to velocity
- Magnetic

Temperature

- Exploit temperature dependence of materials
 - RTD: resistive temperature device
 - usually laser-etched platinum spiral, often $1000\ \Omega + 3.85 \times (T\ ^\circ\text{C})\ \Omega$
 - linear, good absolute calibration
 - but a resistor: need to fashion accurate current source and read off voltage (make ohmmeter)
 - thermistor: exploits conduction electron density as e^T
 - nonlinear, due to exponential dependence on T
 - AD-590: Analog Devices
 - supply 5 V and a route for current (resistor), and output current is proportional to temperature
 - measure current as voltage across provided resistor
- Caution: resistors often 200 ppm per $^\circ\text{C}$
 - for accuracy, may want low “tempco” resistors

Sound Level

- Microphone is transducer for acoustic vibrations into voltage
 - usually membrane that vibrates is part of capacitor
 - can rectify resulting waveform, low-pass, and measure level

Magnetic Flux

- A loop of wire (or many loops) will develop EMF according to changing magnetic field
 - can amplify, rectify, etc.
- A Hall sensor can measure DC magnetic field

Pressure

- Pressure pads: 2 conductors separated by carbon film, squeezes out; so more conductivity: bite pads
- Capacitive pressure deflects membrane (lab pressure meter)
- Party-roller paper tube

Mass/Weight

- “Spring” stretch plus flexometer (strain gauge)

Strain

- Strain gauge can tell you about minute flexing of a structural beam/material

Other Sensors

- Direction
 - HM55B Compass Module from Parallax (\$30)
- Motion
 - infrared motion sensor

Coherent Detection

- Sometimes fighting to discern signal against background noise
 - photogate in bright setting, for instance
- One approach is *coherent detection*
 - modulate signal at known phase, in ON/OFF pattern at 50% duty cycle
 - accumulate (add) in-phase parts, while subtracting out-of-phase parts
 - have integrator perform accumulation, or try in software
 - but if background is noisy in addition to high, integration better
 - basically background subtraction