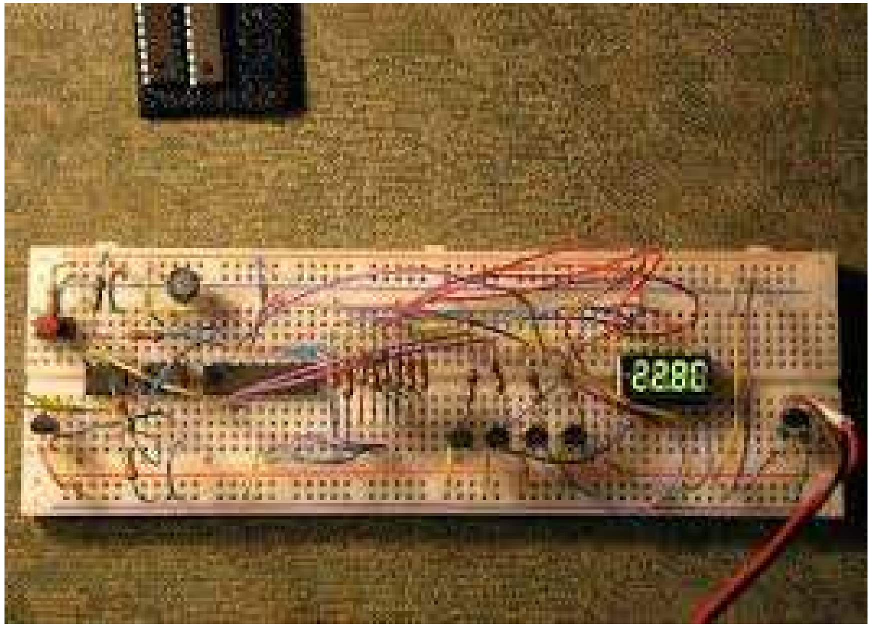
ENGG1000

Electrical Stream 2018

Lecture Week 4 – Simple Sensor Circuits

UNSW AUSTRALIA

Never Stand Still | Faculty of Engineering | School of Electrical Engineering and Telecommunications



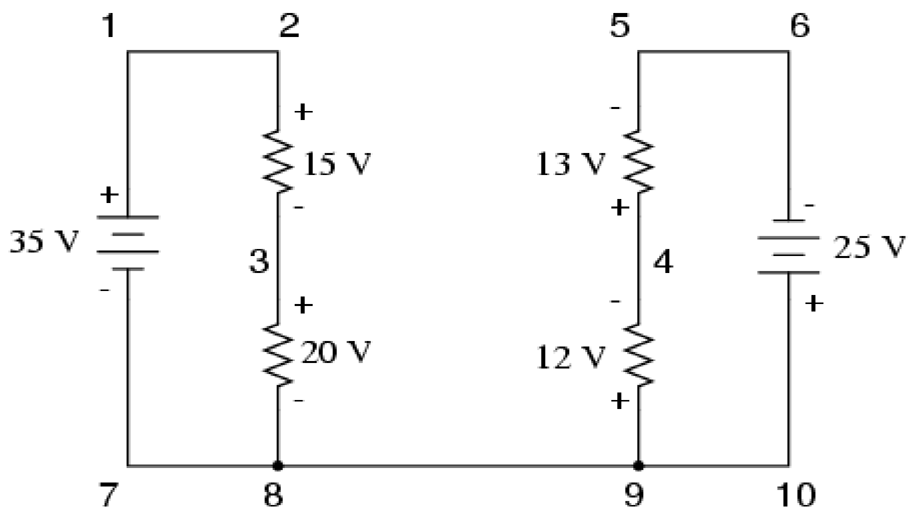
Advice from Students from Previous Years

- Start early and test as much as possible. When you find a flaw, fix it to the maximum extent possible. None of this "It probably won't be a problem.." stuff.
- The internet is a great source of info
- Learnt that organisation is very necessary in all activities
- It is always better to begin early rather than regret later
- Learnt to rely on and trust my team members
- Do not expect your design to work every time
- Use components that will actually work properly with each other
- Building this was fun :P
- Working as a team is vital
- COMMUNICATION..........something there wasn't enough of
- an initial plan would have been helpful
- Testing is paramount to success.....test that ***** as many times as you can!
- construction should start asap to allow sufficient testing
- be prepared to modify ur design during the construction stage, you are bound to run into small complications that you didn't foresee
- everyone needs to get involved, many hands make light work
- keep everything as simple as possible
- if things can go wrong, they usually happen at the worst time

Fundamental Laws - KVL

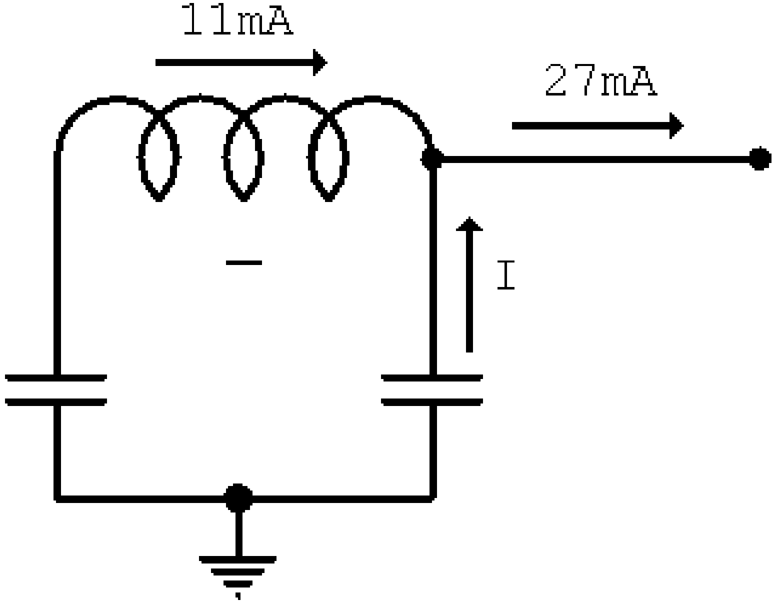
- Conservation of energy
- The sum of voltages around any closed loop in a circuit must be zero

$$V_1 + V_2 + V_3 + \ldots = 0$$



Fundamental Laws - KCL

- Conservation of Electrical charge
- The net current flowing into any junction is always equal to the net current flowing out

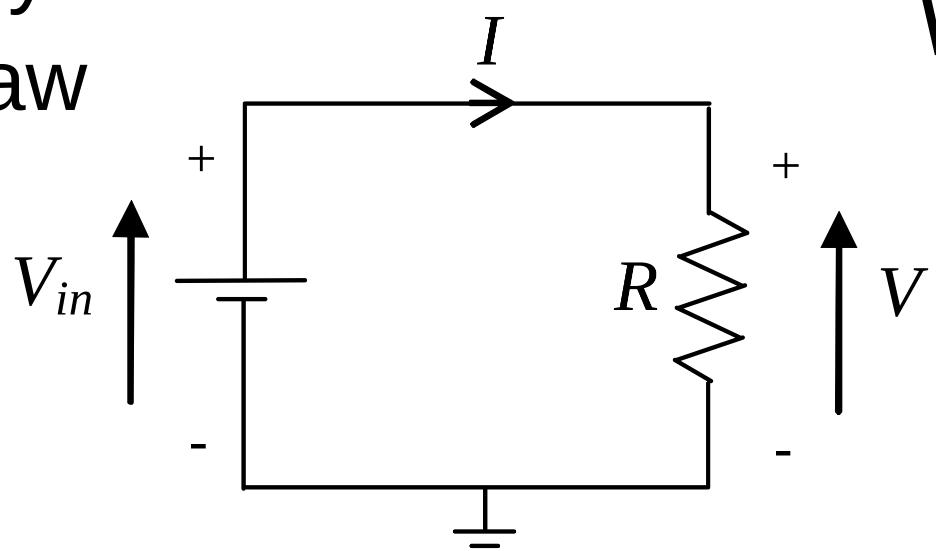


$$I_1 + I_2 + I_3 + \ldots = 0$$

Voltage, Current and Resistance

- The simplest is for current and voltage to be linearly related
- Ohm's Law

$$V = IR$$



  - Current *I* is the flow of positive charge through the circuit in Amps (A)

Practical Resistors

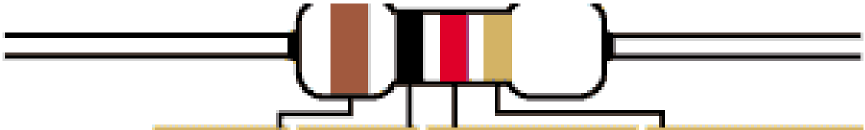
- Standard 0.25W wire-wound

- Surface mount

- Variable resistors

source: http://australia.rs-online.com

Practical Resistors



Gold	-	-	÷10	5% tolerance
Black	0			
Brown	1	1	0	1% tolerance
Red	2	2	00	
Orange	3	3	000	
Yellow	4	4	0000	
Green	5	5	00000	
Blue	6	6	000000	
Violet	7	7	0000000	
Grey	8	8		
White	9	9		

- Measured in Ohms (Ω)
- Huge range of values
- Actual values vary

sources: http://australia.rs-online.com, extra.shu.ac.uk/dac

Power Dissipation

- Power dissipated in a resistor is

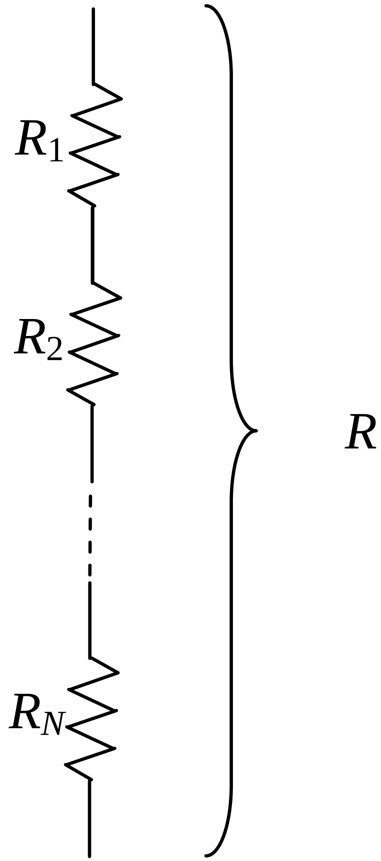
$$P = VI = I^2 R = \frac{V^2}{R}$$

- Resistors have ratings
  – Regular lab resistors: 0.25W
  – Exceed this and they will burn !

Resistive Circuits

- Resistors connected in series **increase** the total equivalent resistance

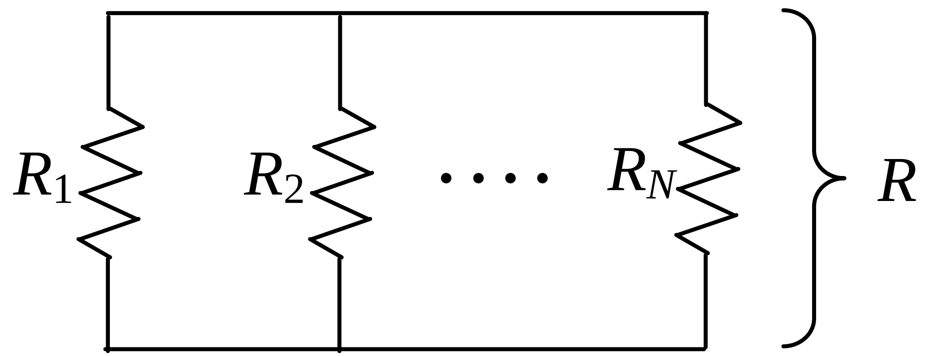
$$R = R_1 + R_2 + \ldots + R_N$$



Resistive Circuits

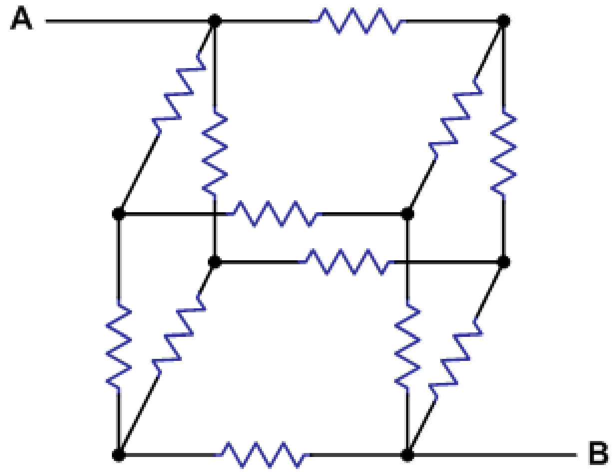
- Resistors connected in parallel **decrease** the total equivalent resistance

$$R = R_1 // R_2 // \ldots // R_N = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_N}}$$



A Problem

All resistors are 1 Ω



What is the resistance between A and B?

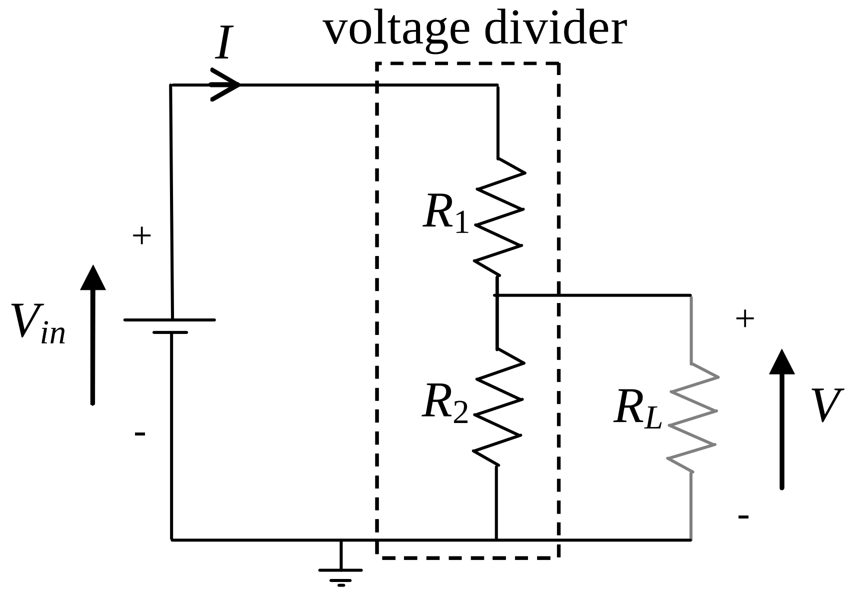
The Voltage Divider

- Assume there is no R_L ($R_L = \infty$)

$$V = IR_2 \quad \text{and} \quad I = \frac{V_{in}}{R_1 + R_2}$$

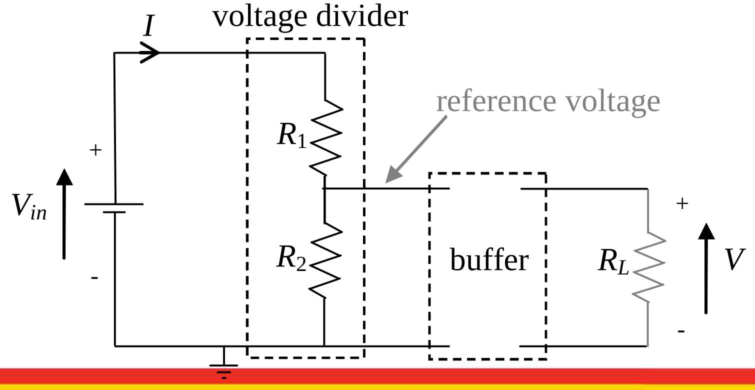
so

$$V = \frac{R_2}{R_1 + R_2} V_{in}$$



The Voltage Divider

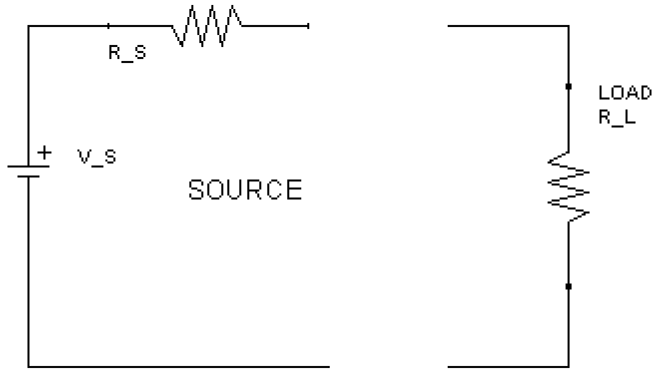
- Can use this circuit to step down voltages by a constant factor $\dfrac{R_2}{R_1 + R_2}$
- Take care: in practice $R_L \neq \infty$ $\quad V = \dfrac{R_2 // R_L}{R_1 + R_2 // R_L} V_{in}$
  – Small $R_L \Rightarrow$ affects the voltage division
  – Large $R_L \Rightarrow$ most power dissipated in divider
- Voltage divider good as reference voltage



Voltage Sources

- Real voltage sources have internal resistance
- When a load is connected, the supplied voltage is really

$$V_O = \frac{R_L}{R_S + R_L} V_S$$



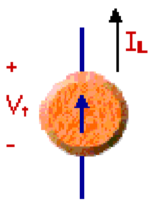
- The ideal is $R_L >> R_S$
- Important to realise this when you drive one circuit by another – may not always be possible!

Voltage Sources

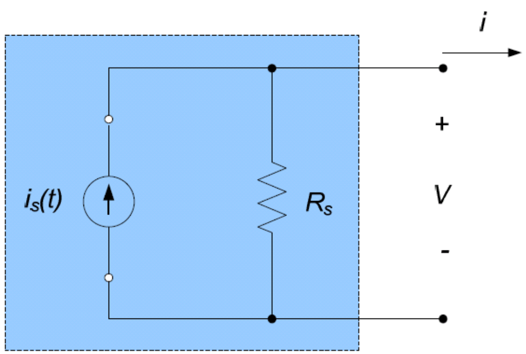
- Practical Solutions for Buffers:
  - Zener Diodes
  - Transistors
  - Operational Amplifiers
- Aim of a ‘Buffer’:
  - From the view of the Load, make the source impedance $\rightarrow 0$
  - Source provides same voltage, regardless of how much current is drawn
  - From the view of the Source, make the load impedance very large

Current Sources

- By analogy, can also construct current sources
  - Will use transistors and op-amps (later)
- An ideal current source can supply the same current, regardless of the load that is attached

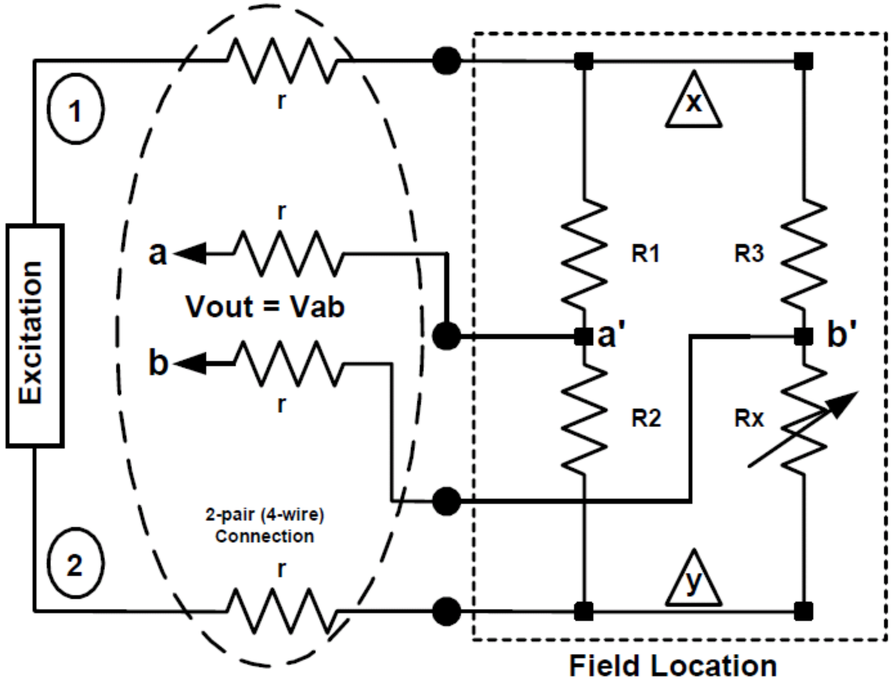


- Non-ideal current source offers some level of shunt(parallel) resistance



Bridge Circuits

- Useful for sensing applications:



$$\text{Vout} = \frac{\text{V12}}{2} * \left(\frac{\text{R-Rx}}{\text{R+Rx}} \right)$$

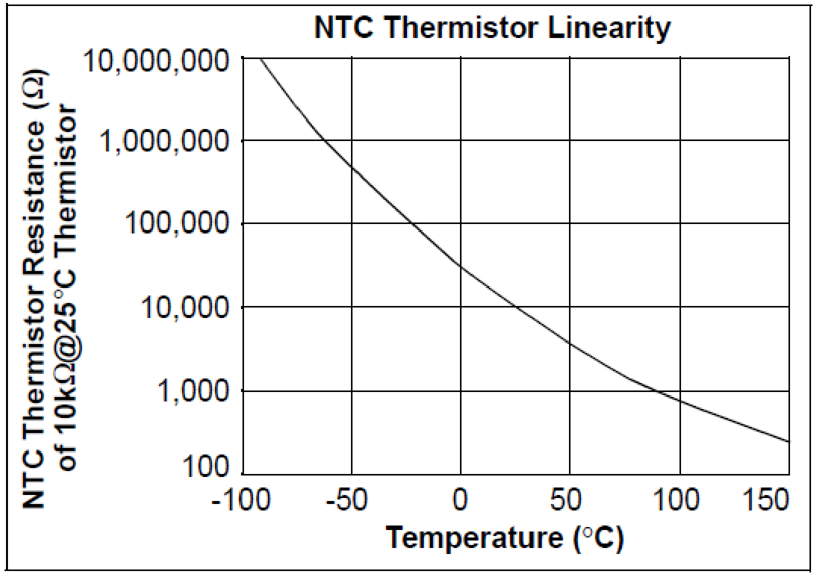
$$\frac{\text{Change in Vout}}{\text{Change in Rx}} = \text{V12}*\left[\frac{-\text{R}}{(\text{R+Rx})^2} \right]$$

$$\text{Rx} = (\text{R} + \Delta\text{R}) \qquad \text{R} >> \Delta\text{R}.$$

$$\text{Vout} \sim -\frac{\text{V12}}{4} * \left(\frac{\Delta\text{R}}{\text{R}} \right)$$

Example: Thermistor

- Effectively a temperature dependent resistor
- Most common are Negative Temperature Gradient (NTC) thermistors



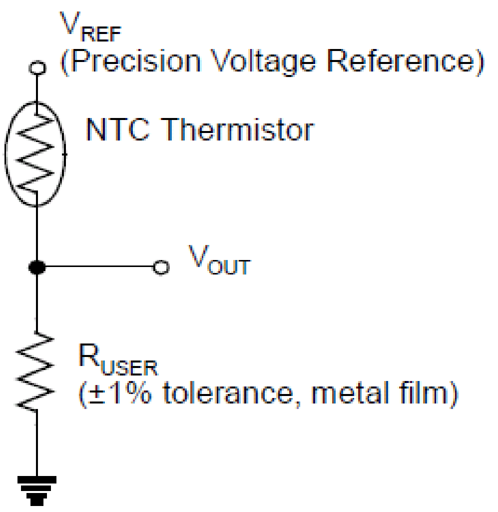
$$T = 1/(A_0 + A_1(\ln R_T) + A_3(\ln R_T^{\;3}))$$

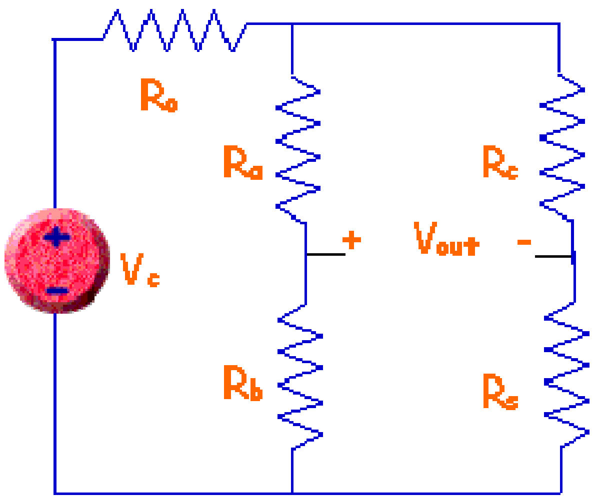
$$\ln R_T = B_0 + B_1/T + B_3/T_3$$

Constants available from Datasheets

Thermistor Circuits

- Some examples: aim to use either a fixed voltage reference or current reference:
  - To produce a voltage or current that can be sampled by ADC or a comparator

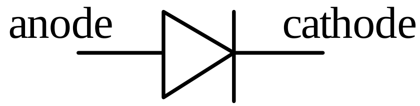


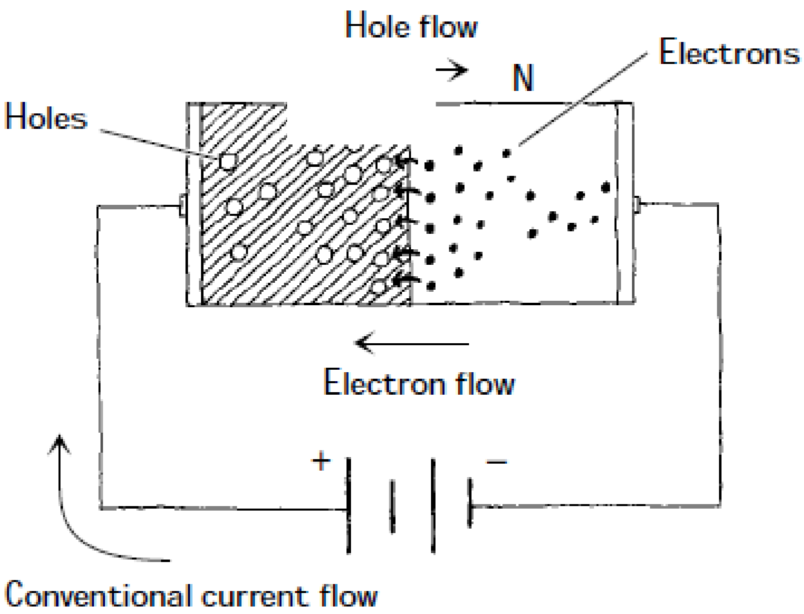


Diodes

- $V_D < V_{on}$
  - Diode is reverse-biased
    - i.e. "off" or acts as an open circuit
- $V_D > V_{on}$
  - Diode is forward-biased
    - i.e. "on" or acts as a short circuit
- Summary: a diode conducts current in one direction
  - Good for protecting sensitive components
- Caveat: $V_{on} \approx 0.6$ to 0.7V

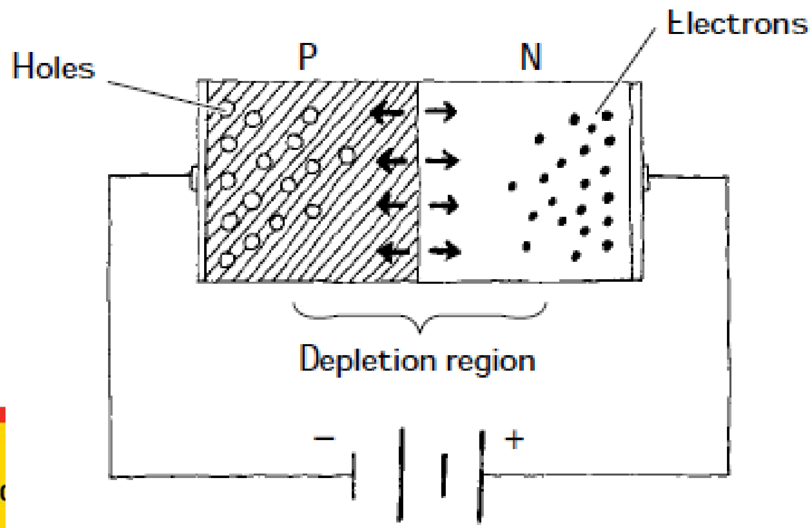
How?





- Forward biased
  - – conductor

N: has ‘spare’ electrons
P: has ‘missing’ electrons



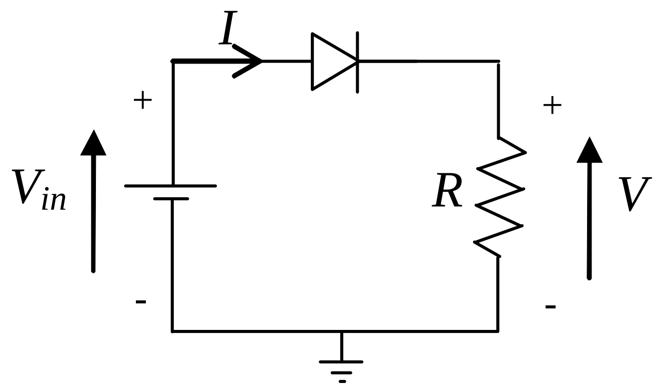
- Reverse biased
  - – insulator

Diode properties can be *electrically* controlled

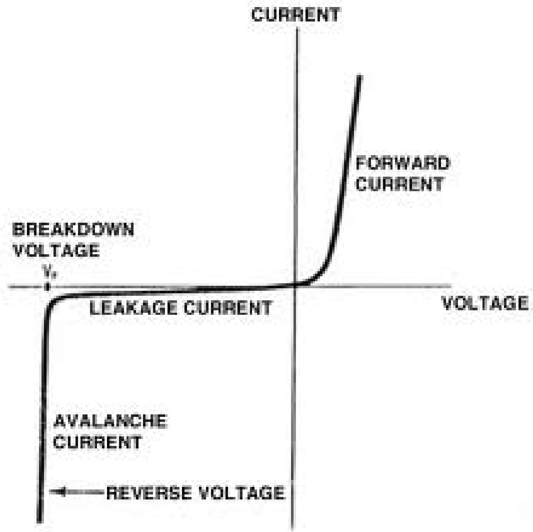
source: Scherz, 2000

Analysis of Diode Circuits

- Split into two cases:
- $V_{in} < V_{on}$
  – No current flows through diode $\Rightarrow V = 0$
- $V_{in} > V_{on}$
  – Diode has voltage $V_D = V_{on}$, so $V = V_{in} – V_{on}$
  and $I = \frac{V}{R} = \frac{V_{in} - V_{on}}{R}$



Real Diodes



- True I-V relationship:
- The forward current does

Increase slightly as the

voltage increases

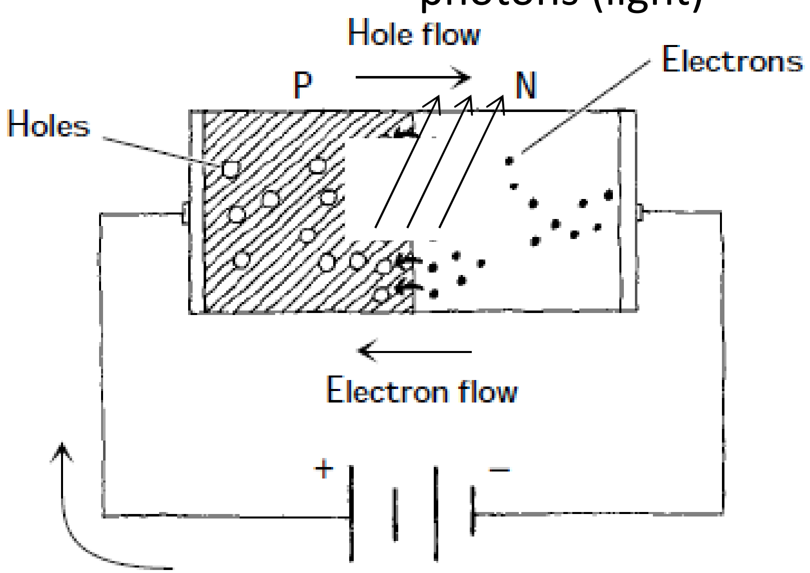
- There is a reverse leakage current
  - Due to the thermal creation of electron-hole pairs
- As previously stated, it can break down if the reverse voltage is very large
  - A normal diode will not recover

Source: http://openwetware.org/wiki/20.309:DiodePrimer

Light Emitting Diodes (LEDs)

– Forward bias

– Light emitted when electrons combine with holes, and fall into a lower energy level



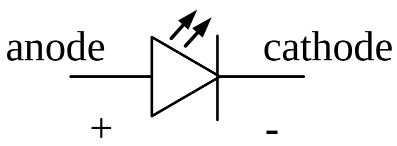
source: Scherz, 2000

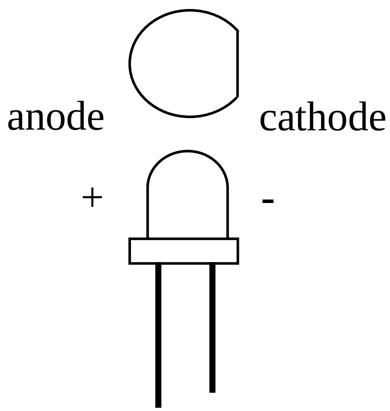
Light Emitting Diodes (LEDs)

Same operation as a diode

V_{on} may be 1.5V to 3.6V

Needs current to be supplied within a given range





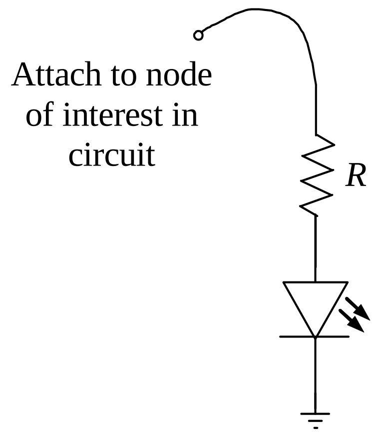
source: http://australia.rs-online.com

LEDs as Test Equipment

You may not always have access to the electronics labs test equipment

You may want a visual check of several points in your circuit

LEDs can be handy for checking if a voltage is roughly what you expect

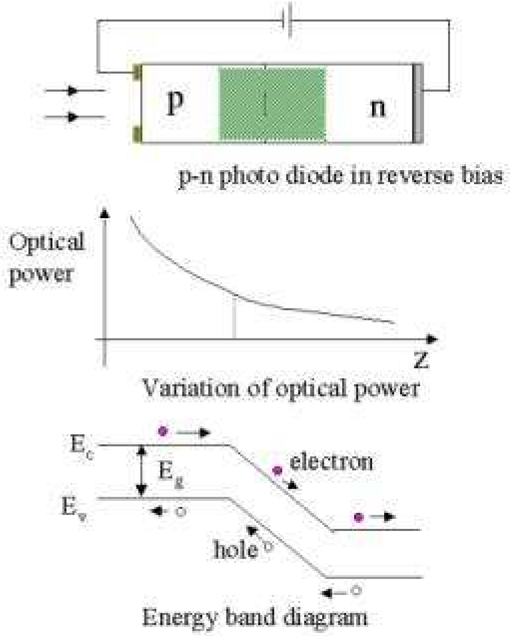


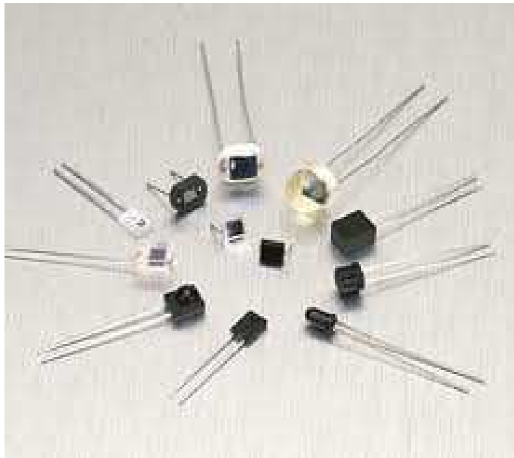
Photodiodes

Convert light into current

An absorbed photon can create an electron-hole pair

- Reverse-bias a p-n junction
- Expose this to light via a transparent enclosure - lens





Source: http://www.phys.ksu.edu/personal/mnakarmi/detector/detector.html

Photodiodes

- The increase in reverse current is proportional to the incident light intensity
- However the current is very small for small light intensities
  - pin diode – intrinsic region between the p and n regions
  - Phototransistors – with internal gain
- Very rapid response (order of nanoseconds)
  - Used in high speed apps. (optical fibres)

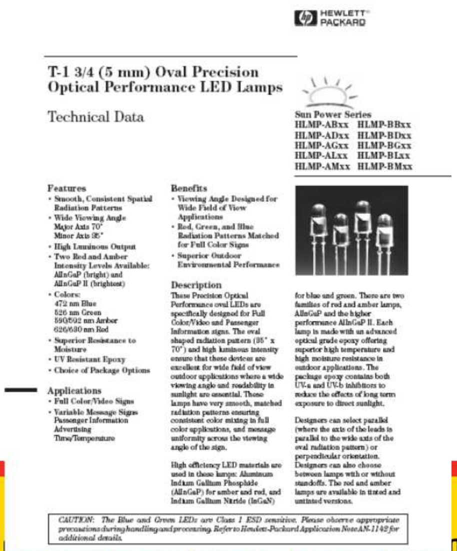
Photodiodes

The performance and sensitivity depends on the material

- Silicon – peak 850nm, sensitive 400-1000nm
- Ge – peak 1500nm, sensitive 300-2000nm
- Metal-semiconductors diode (variable): eg Gold-Silicon range 300-700nm
- pin – diodes – often hetro-structures like InGaAs/InGaAsP
- Research and read the datasheets!

What are my Component's Specifications?

- Everything has a data sheet
  - Link on Moodle – Electrical Stream -> Electrical Component Datasheets
  - Search Internet for other components' data sheets
- e.g. to find V_{on} and max operating current for an LED:



Electrical/Optical Characteristics at $T_A = 25°C$

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Conditions
Typical Viewing Angle Major Minor	$2\theta_{1/2}$		 70 35		°C	
Forward Voltage Amber (λ_d = 590 nm) Amber (λ_d = 592 nm) Red (λ_d = 626 nm) Red (λ_d = 630 nm) Blue (λ_d = 472 nm) Green (λ_d = 526 nm)	 V_F		 2.02 2.15 1.90 2.00 3.5 3.5	 2.4 2.4 2.4 2.4 4.0 4.0	 V	 I_F = 20 mA

Absolute Maximum Ratings at 25°C

	Amber and Red	Blue and Green
DC Forward Current	50 mA	30 mA

source: http://engg1000.ee.unsw.edu.au/datasheets/Optical/LED-5mm-datasheet.pdf

Diode – Clipper Circuit

- Limits the maximum/minimum values of a signal

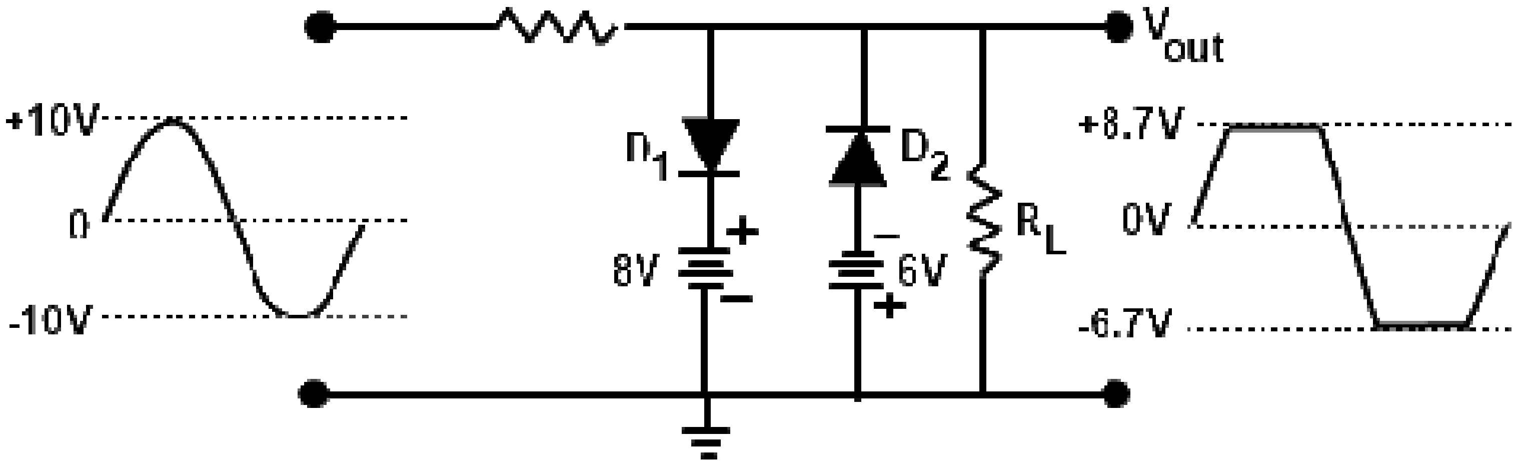
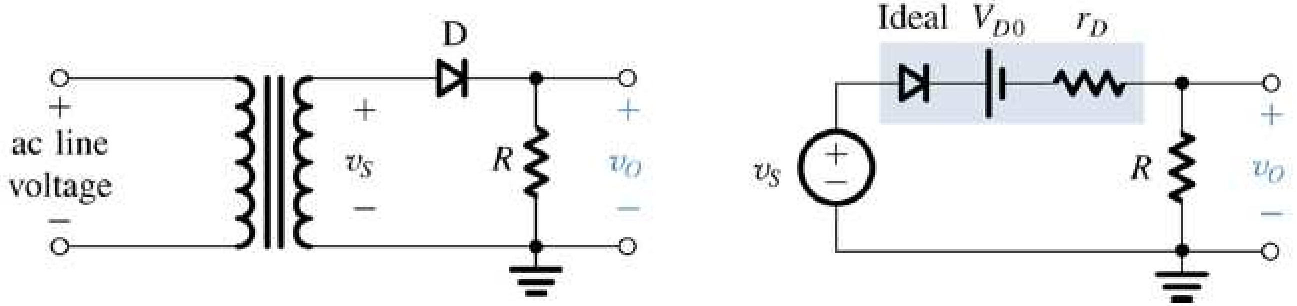


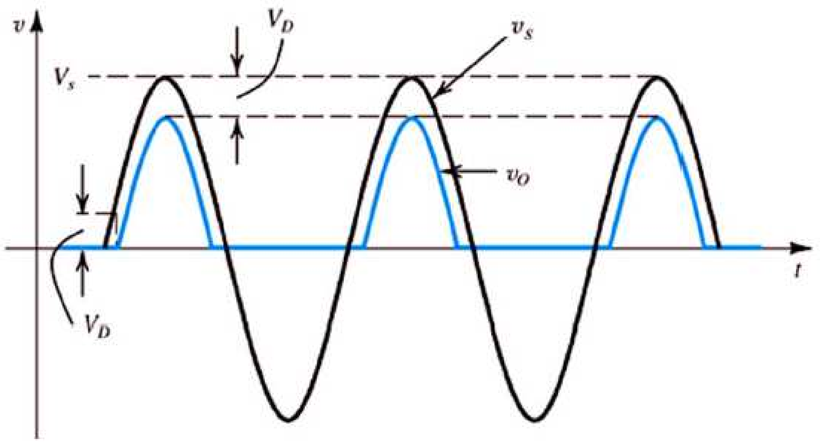
Figure (d): Double diode clipper

Source: http://www.daenotes.com/electronics/devices-circuits/clipper-clamper

Half-Wave Rectifier

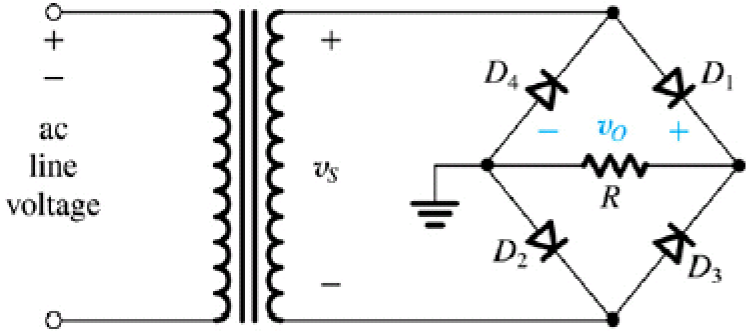
- Circuit has sensing & AC-DC conversion applications…

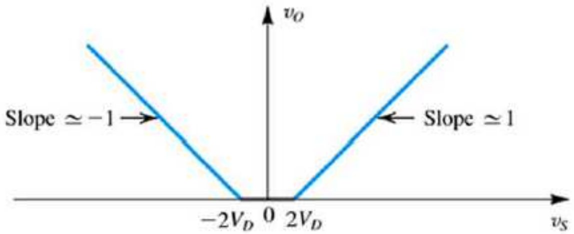


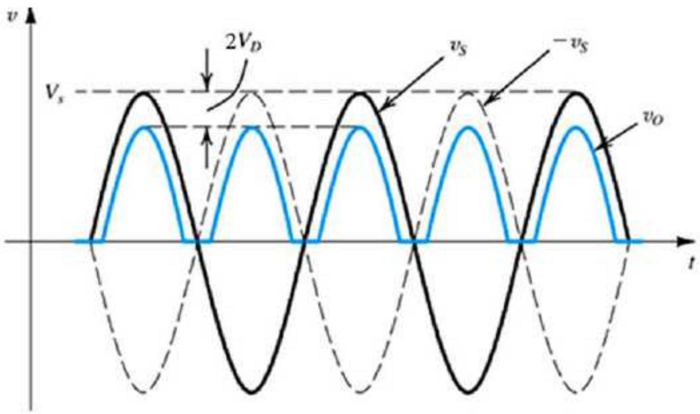


Full-Wave Rectifier

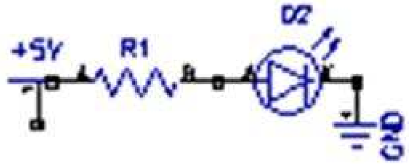
- Another application of the Bridge circuit:







Recap - Diodes



- Talked about LEDs and Photo-diodes
- Good application is in detecting a black-line on a surface
- Simple LED circuit emits light signal
  - Perhaps IR – less prone to external interference
  - Light areas reflect more light, black line reflects less
- Simple photodiode/phototransistor to detect reflected light intensity
  - Matched to LED
  - Comparator & logic to interpret
  - Perhaps multiple sensors in different areas – differential?

Announcements

- Labs Open
  - Every Monday 2-6pm and Thursday 2-6pm
  - EE labs EEG14 and EE214
- Lab Exercises
  - Lab 1 this week – introduction
  - Labs 2, 3 & 4 available next week
  - Any one of them for 10%
  - Attend as convenient
- Lab Equipment
  - Breadboard would be ideal