MAS 836 Sensor Systems for Interactive Environments

Recitation #1 Feb 15th 2011

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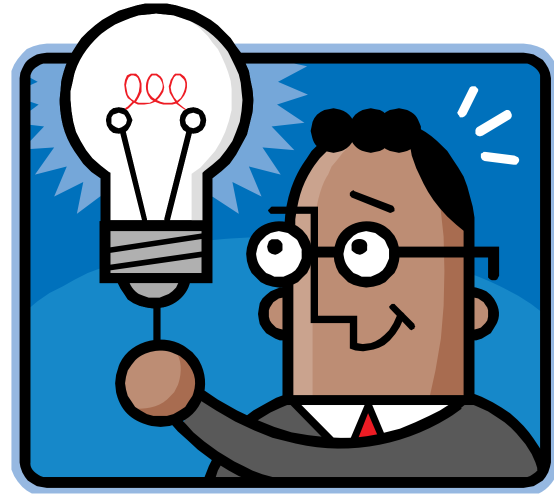
So… exactly what are we going to learn from the sensors class?

Input

Output



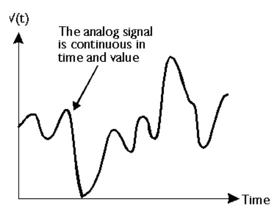
Sensors

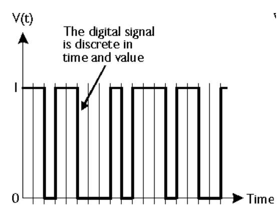
Active: sonar, FSR…
Passive: photodiodes, piezo microphone

A sensor is a device that receives a stimulus and responds with an electrical signal. -- J. Fraden

Electronics

Analog / Digital electronics





Output devices

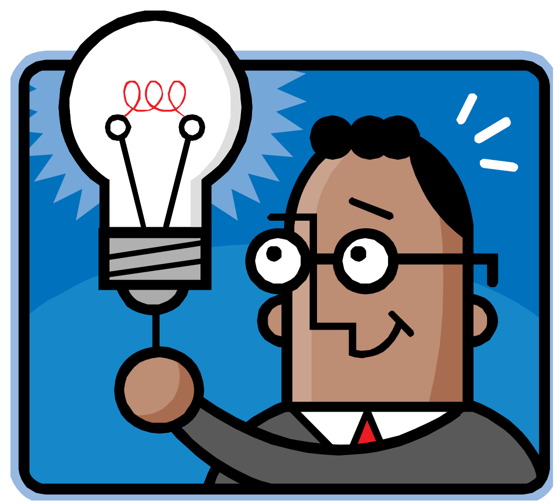
Leds / speakers / displays /computer ….

http://www-scm.tees.ac.uk/users/a.clements/DSP/ADintro.htm

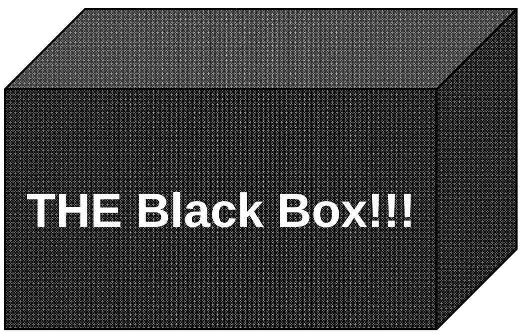
we’ll start with what’s inside the black box….

then introduce different sensors..

and you’ll have to figure out your final projects..



Okay.. tell me what's in the black box then…



- **Resistors**
  - Ohm's Law
  - Resistor in parallel / series
  - Voltage divider
  - Wheatstone bridge
- **Capacitors**
  - Gauss's Law
  - Capacitor in parallel / series
- **Inductors**
- **Diodes**
  - Zener diodes
- **Transistors**
- **Op Amps**
  - Ideal model
  - Comparator / Schmidt trigger
  - Voltage follower
  - Non-inverting Amp / Inverting Amp
  - Summing / Differential Amplifier
- and more!

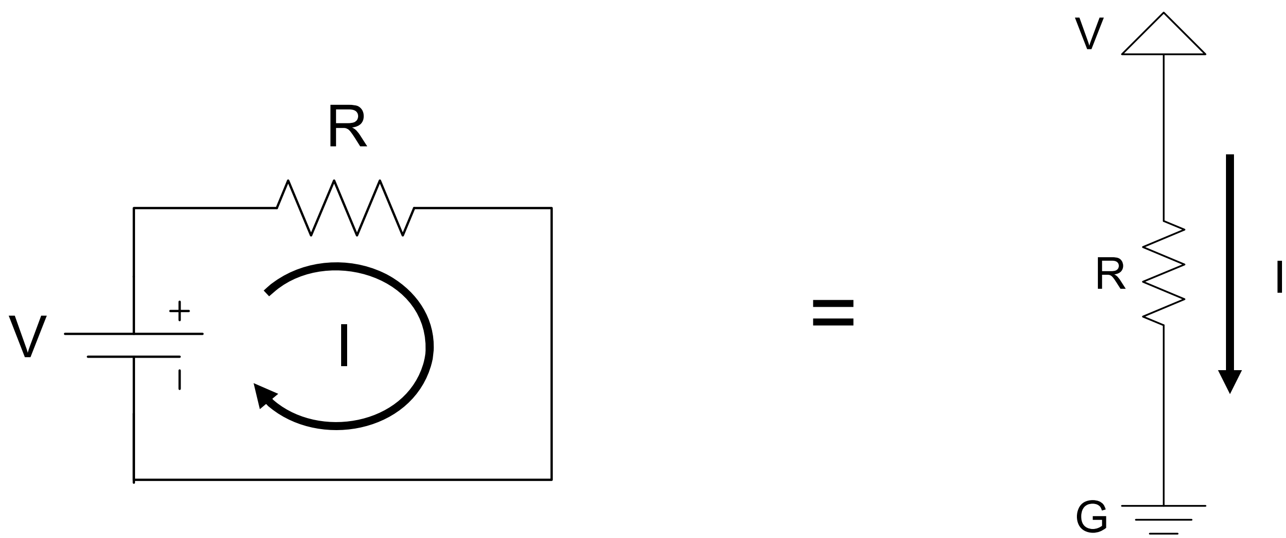
Resistors

- **Ohm's Law :** The voltage drop across a resistor is proportional to the current owing through it and is modeled by “Ohm's Law.”

V : “Voltage” is the potential the electrons drop across the circuit

I : “Electric Current” is the flux of electrons per unit time (Amperes)

R : “Resistance” relates voltage to current

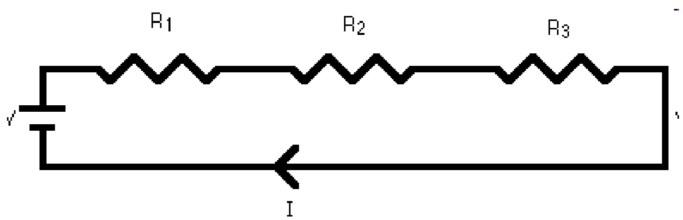


$$V = I \times R$$

Resistors

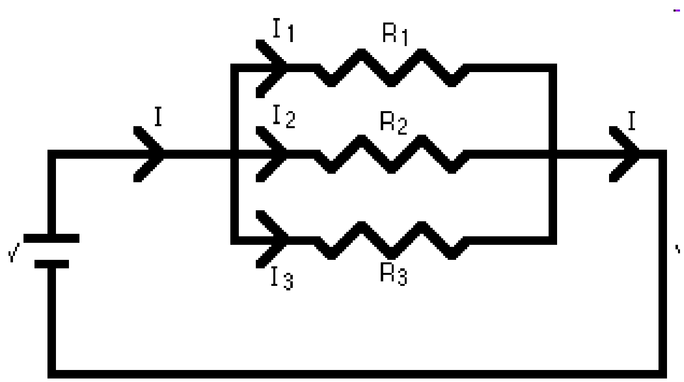
- **Resistors in Series :**

$$R_{total} = R_1 + R_2 + R_3 + \ldots.$$

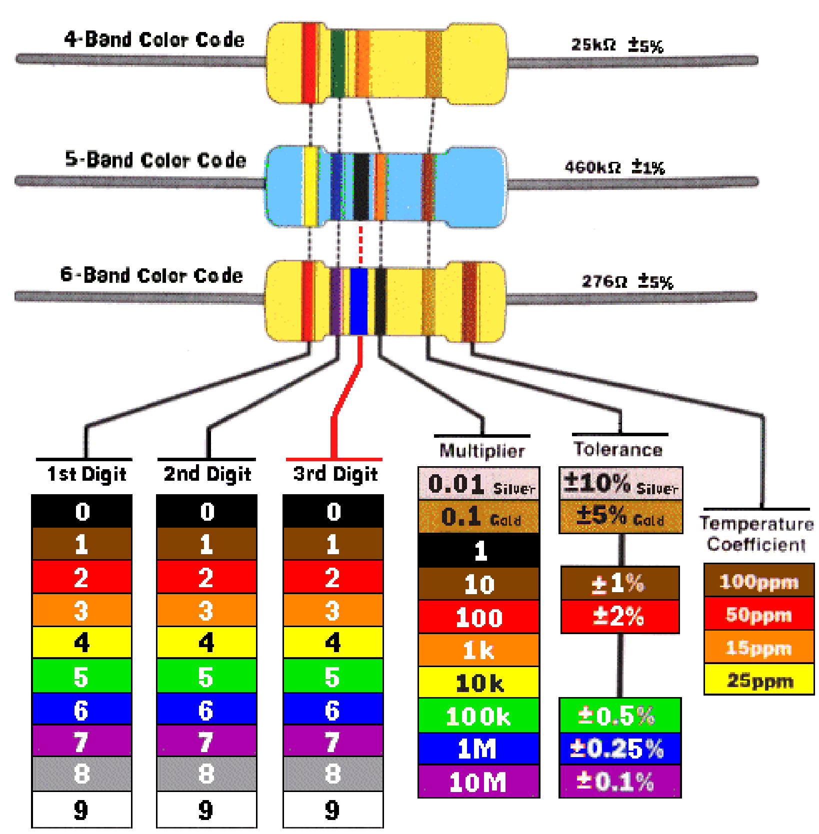


- **Resistors in Parallel :**

$$1/R_{total} = 1/R_1 + 1/R_2 + 1/R_3 + \ldots.$$



- **Resistor chart**



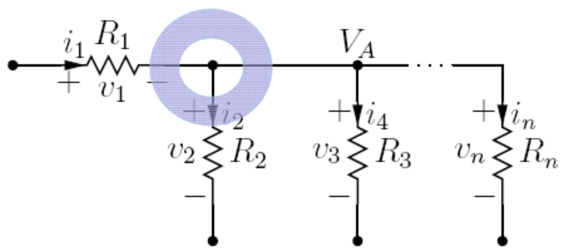
http://www.pyrouniverse.com/gallery2/data/500/resistors.gif

See more examples on http://physics.bu.edu/py106/notes/Circuits.html

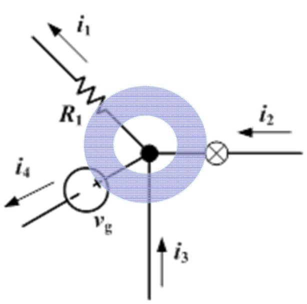
Resistors

- **Kirchhoff's Current Law :**
  To satisfy the conservation of charge (think flow of electrons), all currents owing into a node must sum to zero,

$$i_1 = \sum_{m=2}^{n} i_m$$



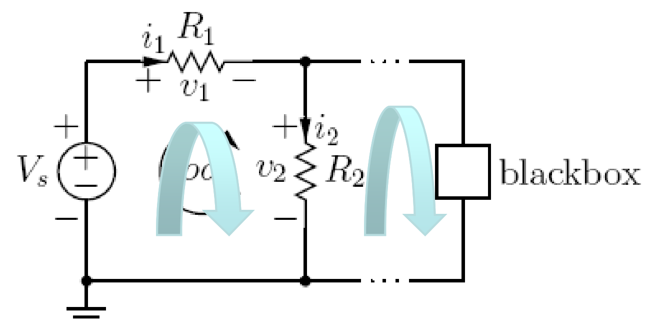
$$i_1 = i_2 + i_4 + \ldots\ i_n$$

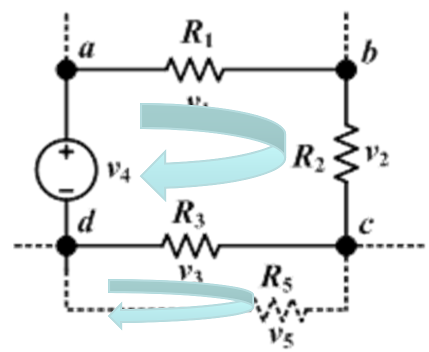


$$i_1 + i_4 = i_2 + i_3$$

- **Kirchhoff's Voltage Law :**
  The sum of all voltages around a loop of circuit elements is zero.

$$V_s = v_1 + v_2$$





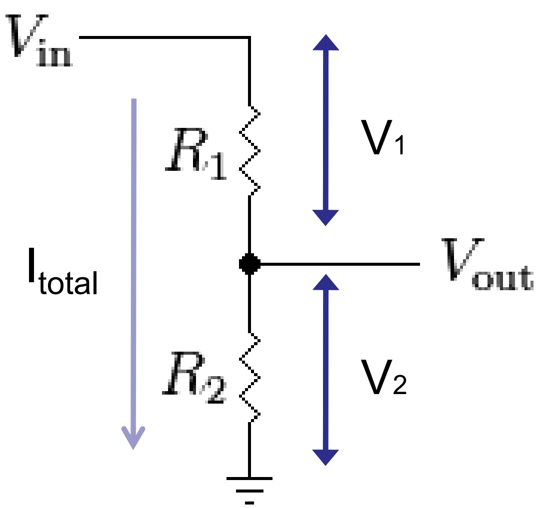
$$v_1 + v_2 + v_3 + v_4 = 0$$

There can be many many loops in the same circuit

Resistors

- **Voltage divider :**

  a simple linear circuit that produces an output voltage (V_{out}) *that is a fraction of its input voltage* (V_{in}).



Resistive Divider

$R_{total} = R_1 + R_2$

$i_{total} = i_1 = i_2$

$V_{in} = i_1 \times R_1 + i_2 \times R_2 = i_{total} (R_1 + R_2)$

$V_{out} = V_2 = i \times R_2$

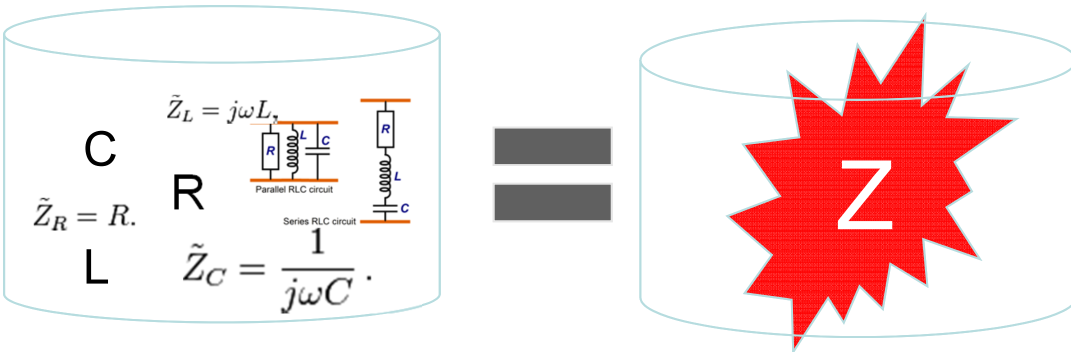
$$V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$$

Applications : reference voltage, voltage source…

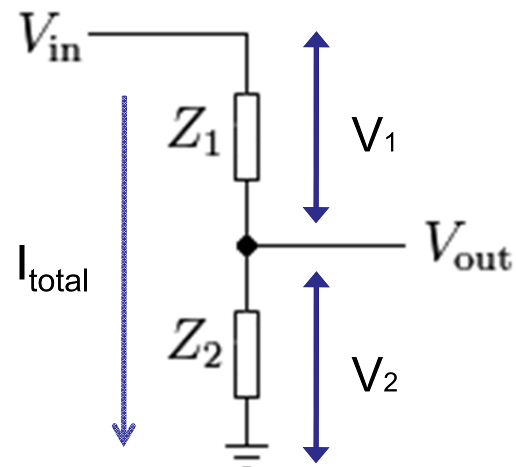
Impedance (Z)

Electrical impedance, or simply impedance, describes a measure of opposition to alternating current (AC). Electrical impedance extends the concept of resistance to AC circuits, describing not only the relative amplitudes of the voltage and current, but also the relative phases. I am impressed that you are still reading this. Impedance is defined as **the frequency domain ratio of the voltage to the current**

In short, things get complicated when capacitors and inductors are involved. Stuff might change with time. It's easier if we can do the math in the frequency domain…



For example – voltage divider



To sum up, some guy decided to put all the crazy math into a bucket and call it "Z"…

$$V_{out} = \frac{Z_2}{Z_1 + Z_2} \times V_{in}$$

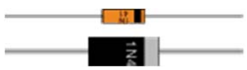
The input voltage is applied across the series impedances Z_1 and Z_2 and the output is the voltage across Z_2. Z_1 and Z_2 may be composed of any combination of elements such as resistors, inductors and capacitors.

http://en.wikipedia.org/wiki/Impedence http://www.calctool.org/CALC/eng/electronics/RLC_circuit

Diodes

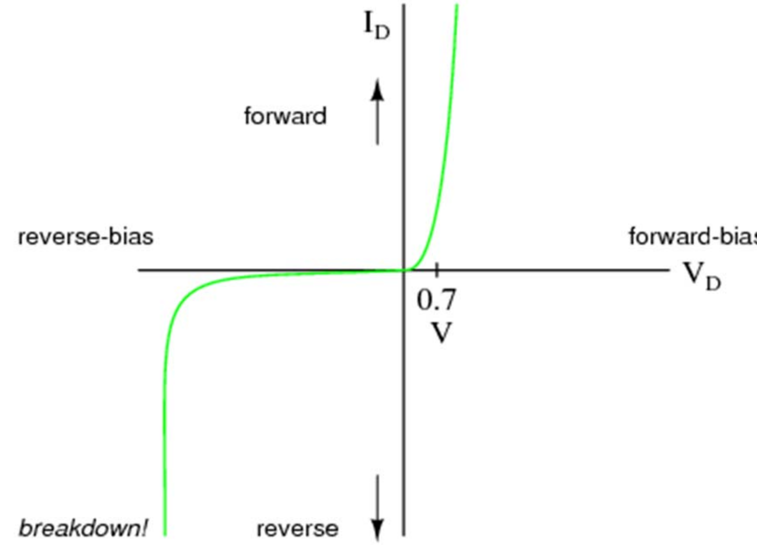
Diodes allow electricity to flow in only one direction.

Diode



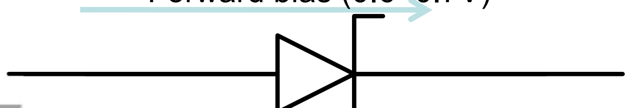
Forward bias (0.6~0.7V)

Reverse bias
(very large voltage,
normally destroy the diode)



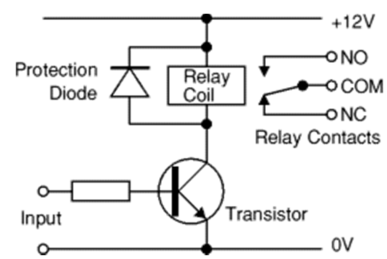
Zener Diode

Forward bias (0.6~0.7V)



Reverse bias
4.7V for example (4V7)

Applications : relay protection, rectifier,
Zener regulator… we'll see a lot of examples in the lab



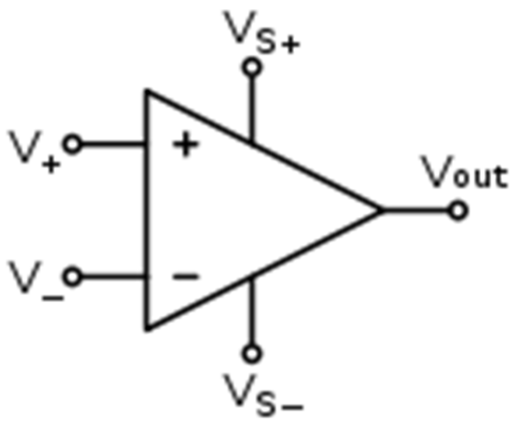
http://www.kpsec.freeuk.com/components/diode.htm

http://www.allaboutcircuits.com/vol_3/chpt_3/1.html

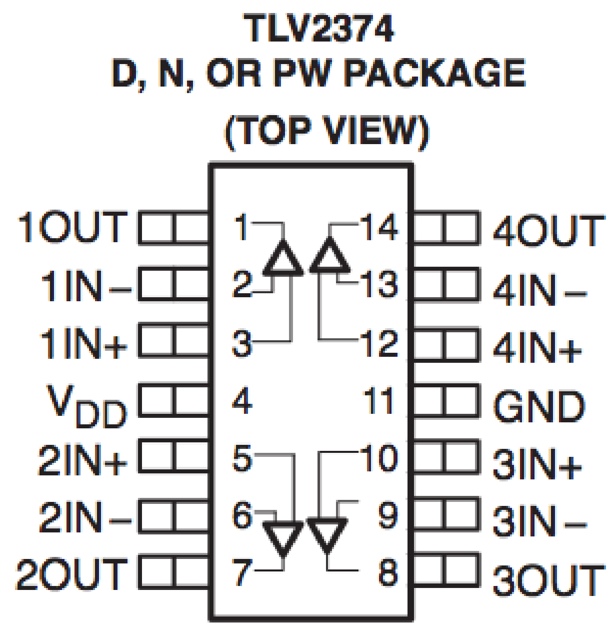
http://hyperphysics.phy-astr.gsu.edu/hbase/electronic/diodecon.html#c2

Op Amps

Circuit diagram symbol for an op-amp



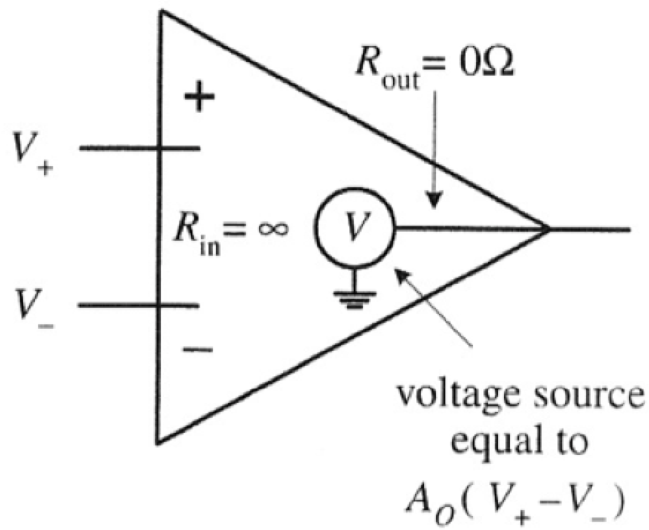
V_+: non-inverting input
V_-: inverting input
V_{out}: output
V_{s+}: positive power supply
V_{s-}: negative power supply

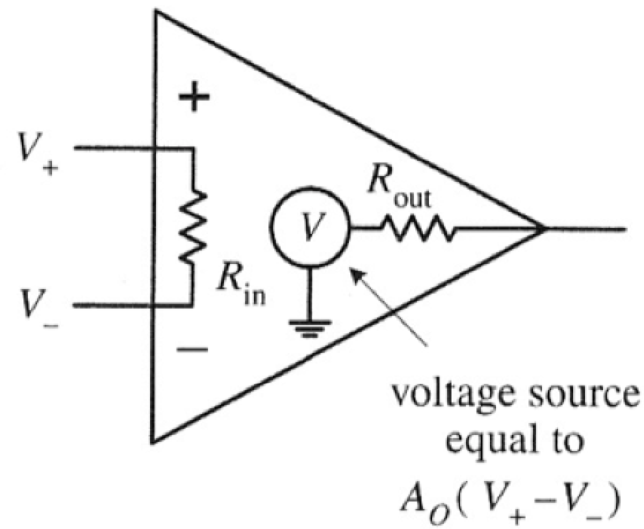


The 4 channel Op Amp we use in this class

Op Amps

Ideal model **Real model**



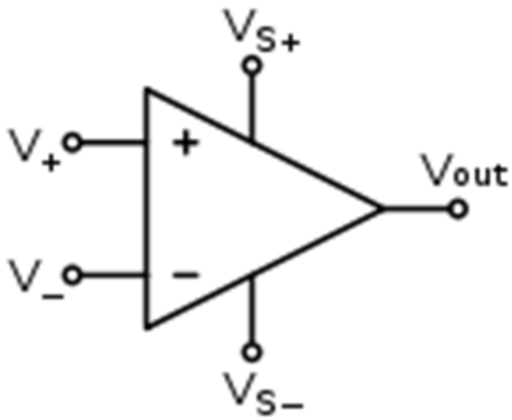


Rule 1: for ideal Op Amp $A_o = \infty$, in real life, $A_o = 10^4$-10^6

Rule 2: for ideal Op Amp $R_{in} = \infty$, in real life, $R_{in} = 10^6$-$10^{12}\Omega$
$R_{out} = 0$ $R_{out} = 10$ - 1000Ω

Rule 3: input terminals draw no current, in real life it's almost true.. (within picoamps)

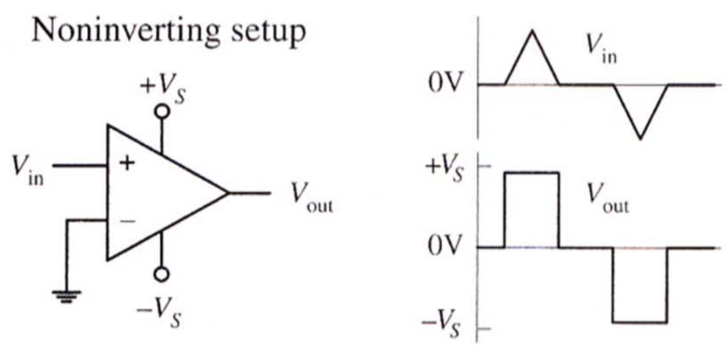
Rule 4: When negative feedback, current flows through feedback resistor to make V+ equal to V-

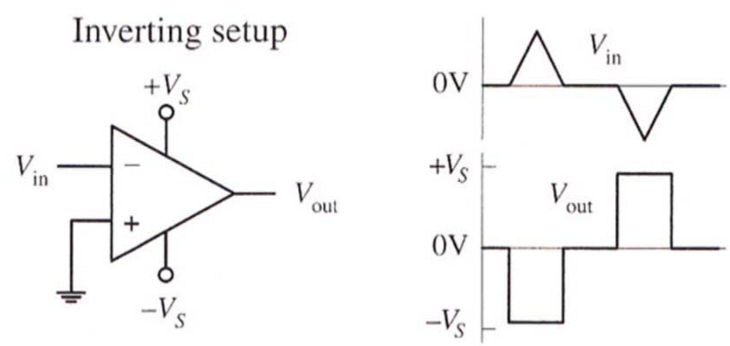


Without feeback loops, $V_o = A_o (V_+ - V_-)$

Ao can be very big! But even though Op Amps can do magic, the output can't be bigger than Vs+ or smaller than Vs-.
Therefore, Vout will saturate if it's out of range

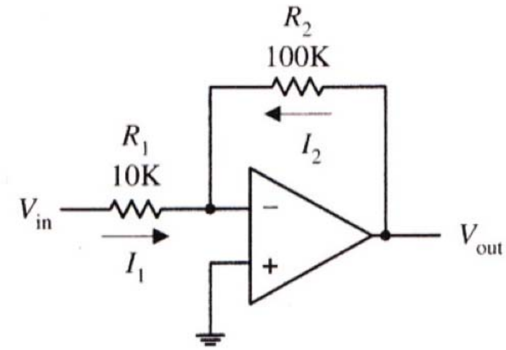
Using Op Amps as comparator

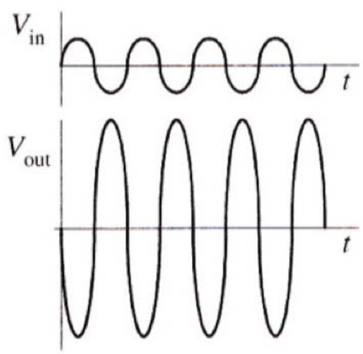




Op Amps

Inverting Amplifiers



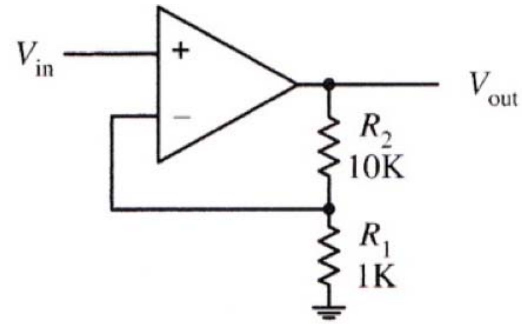


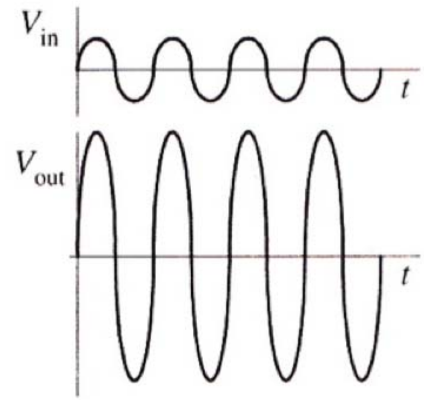
$$I_1 = \frac{V_{in} - V_-}{R_1} = \frac{V_{in} - 0\,\mathrm{V}}{R_1} = \frac{V_{in}}{R_1}$$

$$I_2 = \frac{V_{out} - V_-}{R_2} = \frac{V_{out} - 0\,\mathrm{V}}{R_2} = \frac{V_{out}}{R_2}$$

$$\text{Gain} = \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$$

Non-Inverting Amplifiers





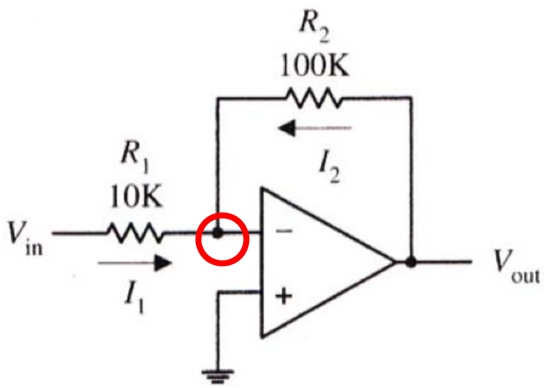
$$V_- = \frac{R_1}{R_1 + R_2} V_{out} = V_{in}$$

Rearranging this equation, you find the gain:

$$\text{Gain} = \frac{V_{out}}{V_{in}} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

Op Amps

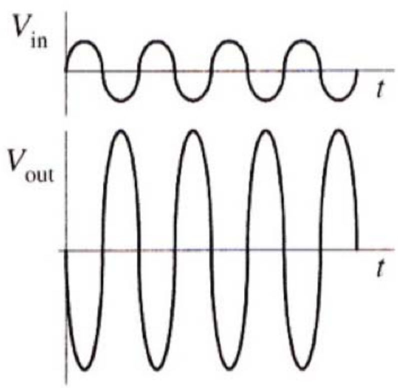
Inverting Amplifiers



Op Amp Rule 4
Current from negative feedback will try to keep V+ = V-

V+ = 0V, therefore, V- = 0V

Kirchhoff Current's Law:
all currents flowing into a node must sum to zero



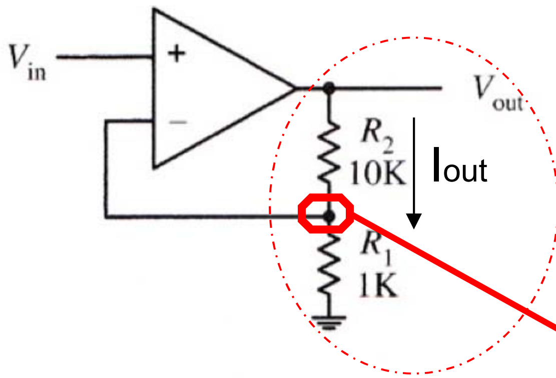
$$I_1 = \frac{V_{in} - V_-}{R_1} = \frac{V_{in} - 0\,V}{R_1} = \frac{V_{in}}{R_1}$$

$$I_2 = \frac{V_{out} - V_-}{R_2} = \frac{V_{out} - 0\,V}{R_2} = \frac{V_{out}}{R_2}$$

$$\text{Gain} = \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$$

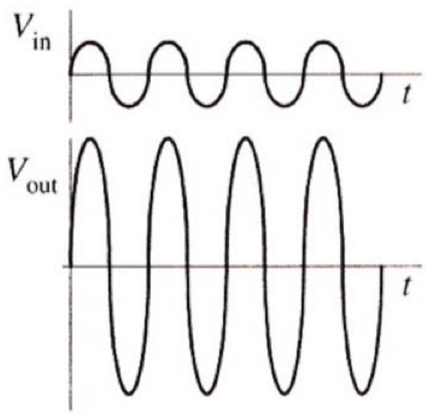
Op Amps

Non-Inverting Amplifiers



Voltage divider

Op Amp Rule 4
Current from negative feedback will try to keep V+ = V-



$$V_- = \frac{R_1}{R_1 + R_2} V_{out} = V_{in}$$

Rearranging this equation, you find the gain:

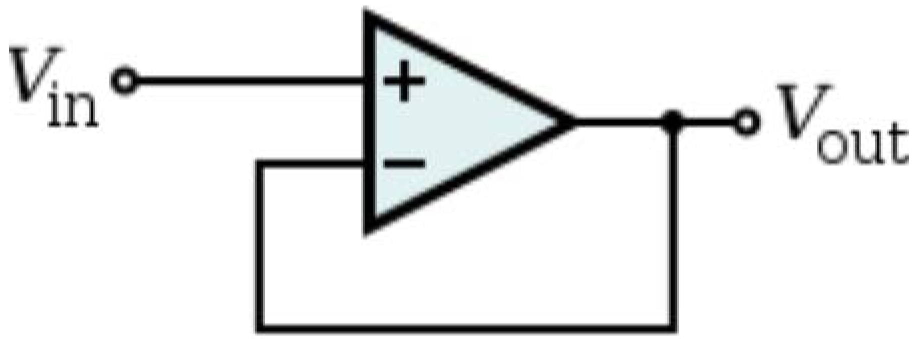
$$\text{Gain} = \frac{V_{out}}{V_{in}} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

Application: Voltage-to-Current Converter

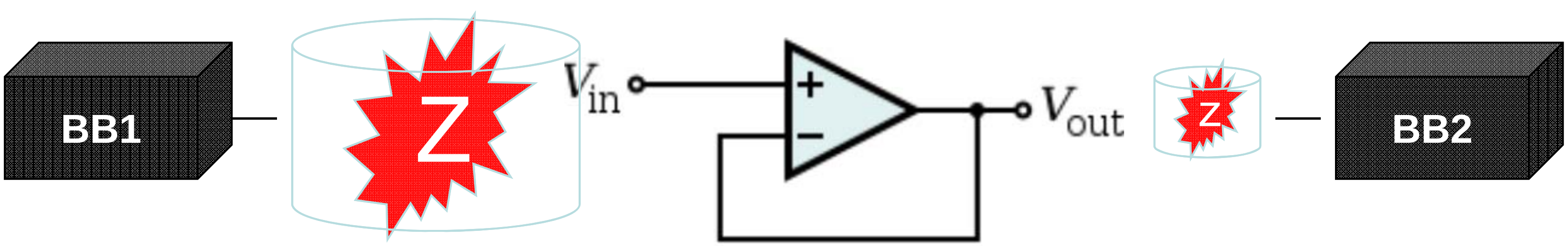
$I_{out} = V_{out} / R_1 + R_2 = V_{in} / R_2$

Op Amps

Unit Gain Amplifiers (buffer)

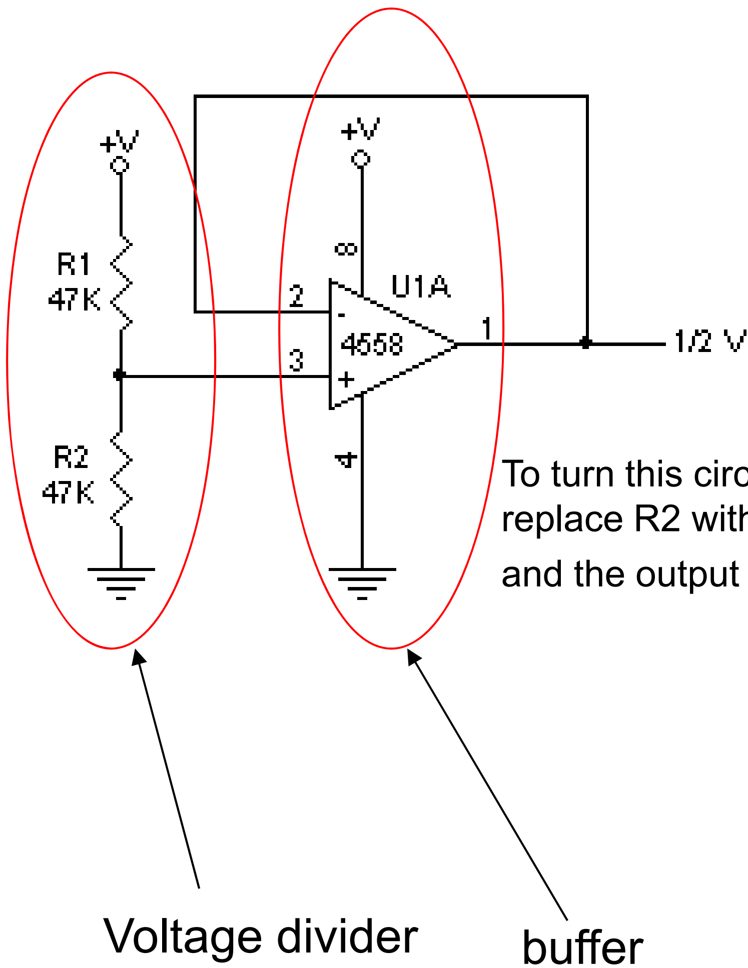


Rule 2: for ideal Op Amp $R_{in} = \infty$ → very high impedance
$R_{out} = 0$ → very low impedance
Remember "Z"?



Op Amps

Example application
An opamp can also be used as a bias generator (or reference) for providing 1/2 the power supply voltage for other opamps on the same board using a single ended (uni-polar) power supply.



To turn this circuit into a power regulator,
replace R2 with a zener and R1 with an appropriate value,
and the output of the opamp will provide a buffered regulated voltage source.

http://www.pic101.com/op_amp.htm

Decibel (dB) and why do we care about it

Decibel (dB) is defined as the power (P) ratio between two signals.

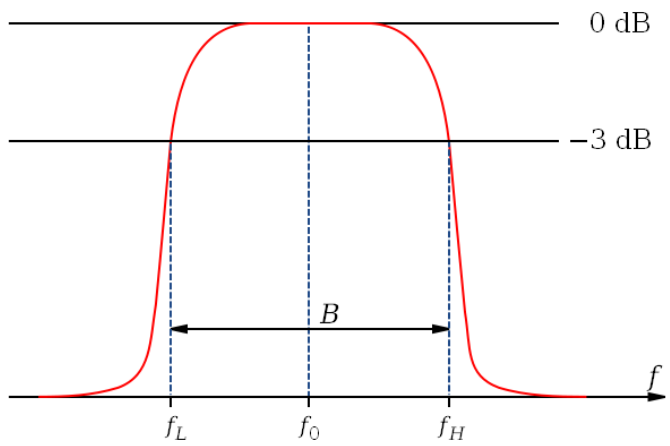
$$dB = 10 \cdot \log_{10}\left(\frac{P1}{P2}\right), \text{ where the log is base 10.}$$

It is used to express the magnitude of a physical quantity
(usually power or intensity) relative to a specified or implied reference level

In the world of electronics, dB is used to define

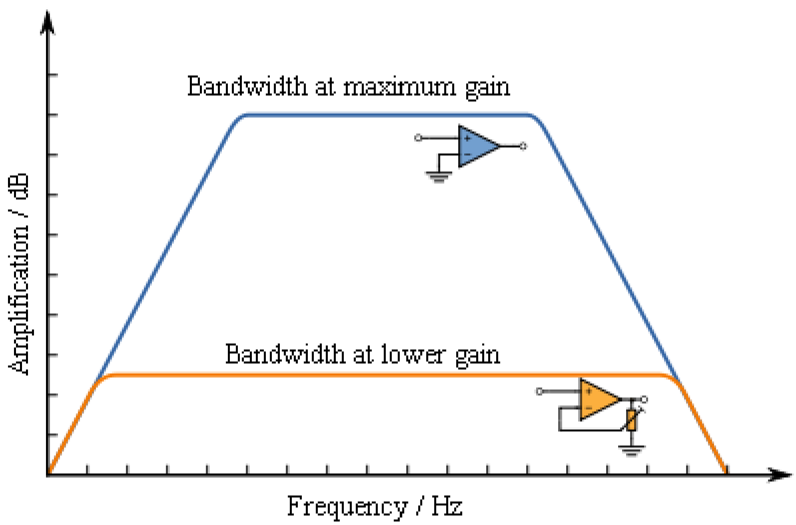
- Cut off frequency
- f_{3dB} point
- half power point
- …

When the power of a signal is cut in half
dB = 10 log(0.5) = -3dB



Bandwidth

Bandwidth is the difference between the upper and lower frequencies in a contiguous set of frequencies.



Gain-bandwidth

The gain-bandwidth product (GBWP, GBW, GBP or GB) for an amplifier is the product of the closed-loop gain (constant for a given amplifier) and its −3 dB bandwidth.