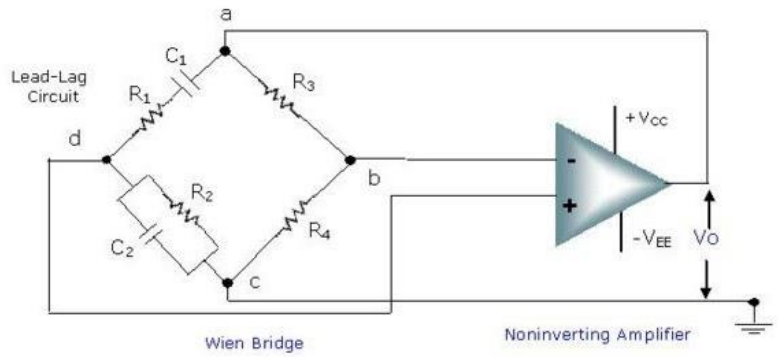
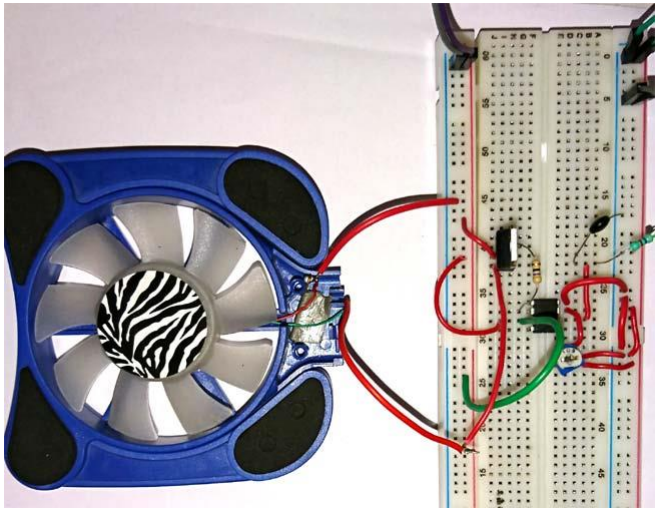
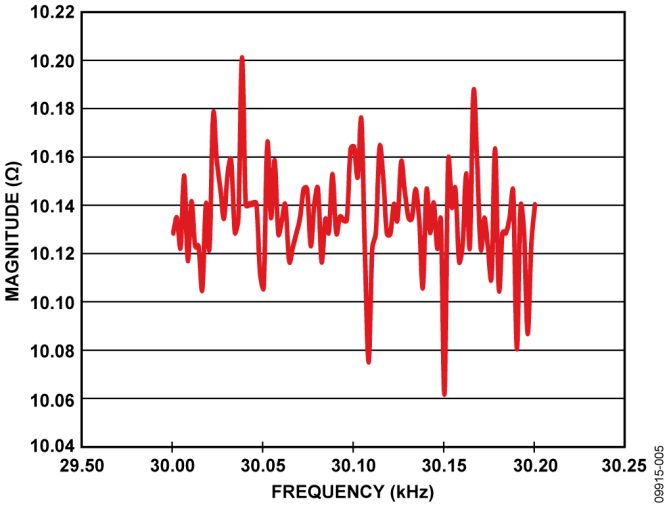
Analog Circuits 101

Dec 2018

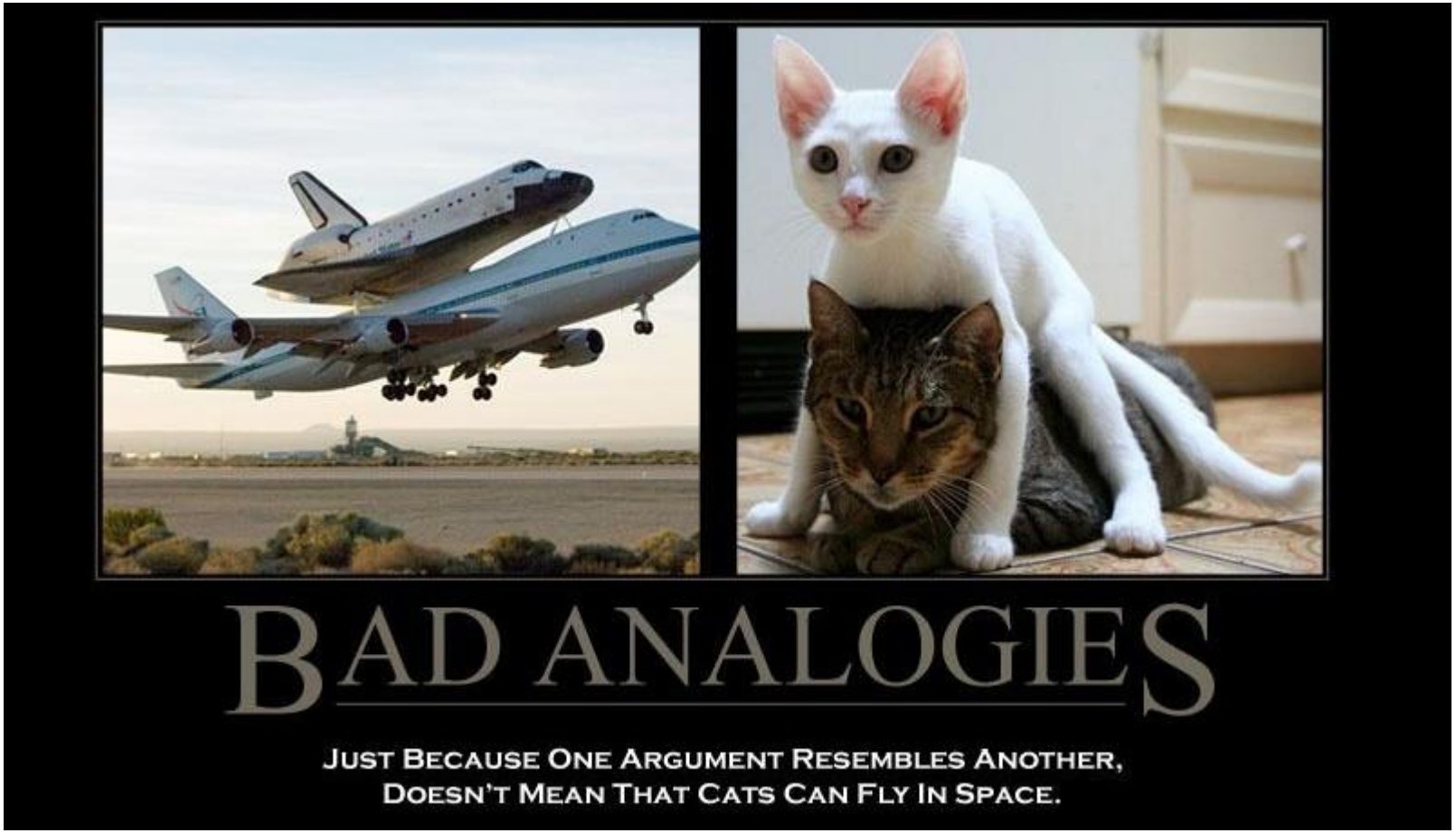






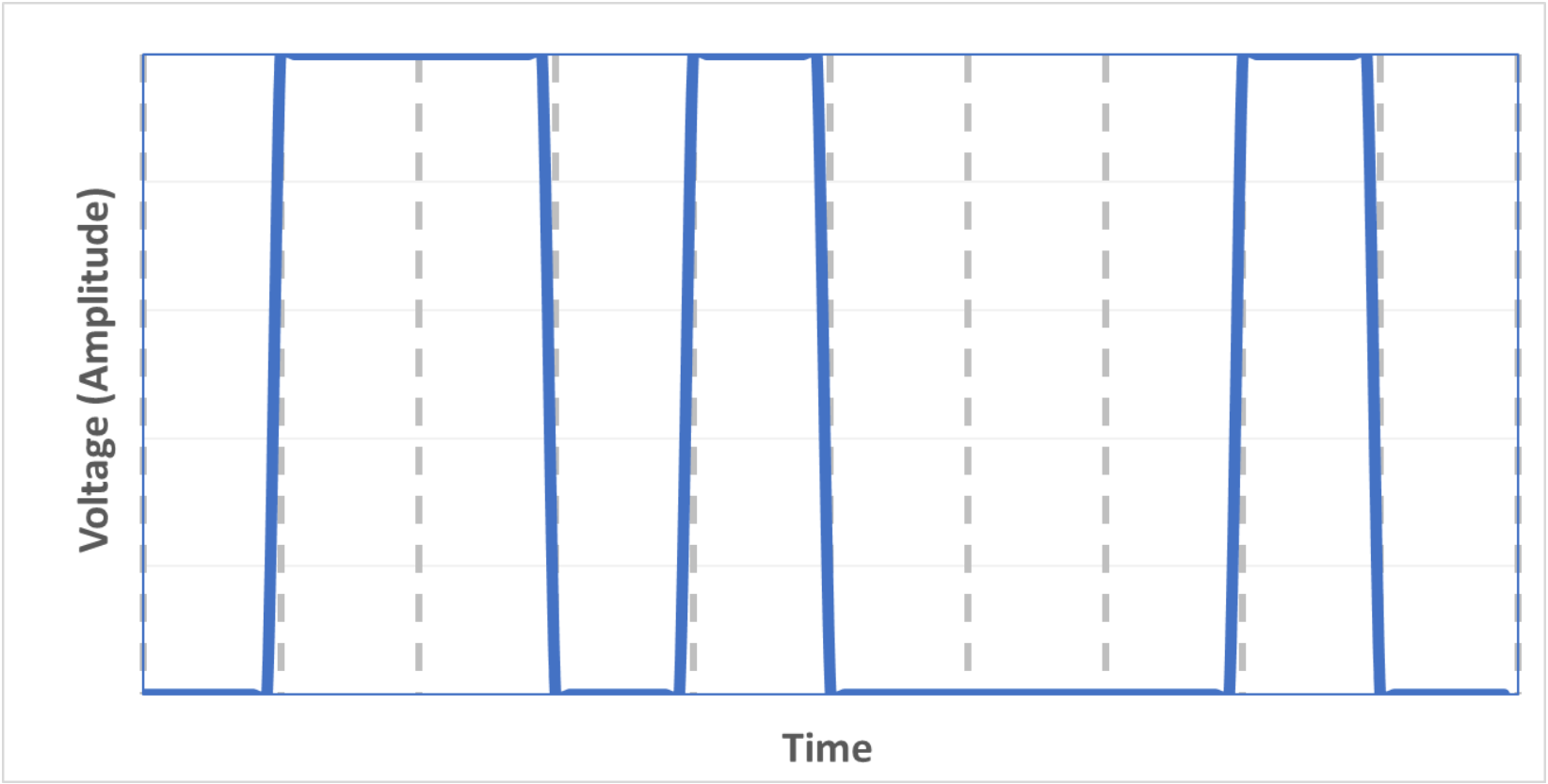
WARNING WARNING WARNING WARNING WARNING

Rules of thumb, assumptions and mixed-quality analogies to come!



Digital Signals

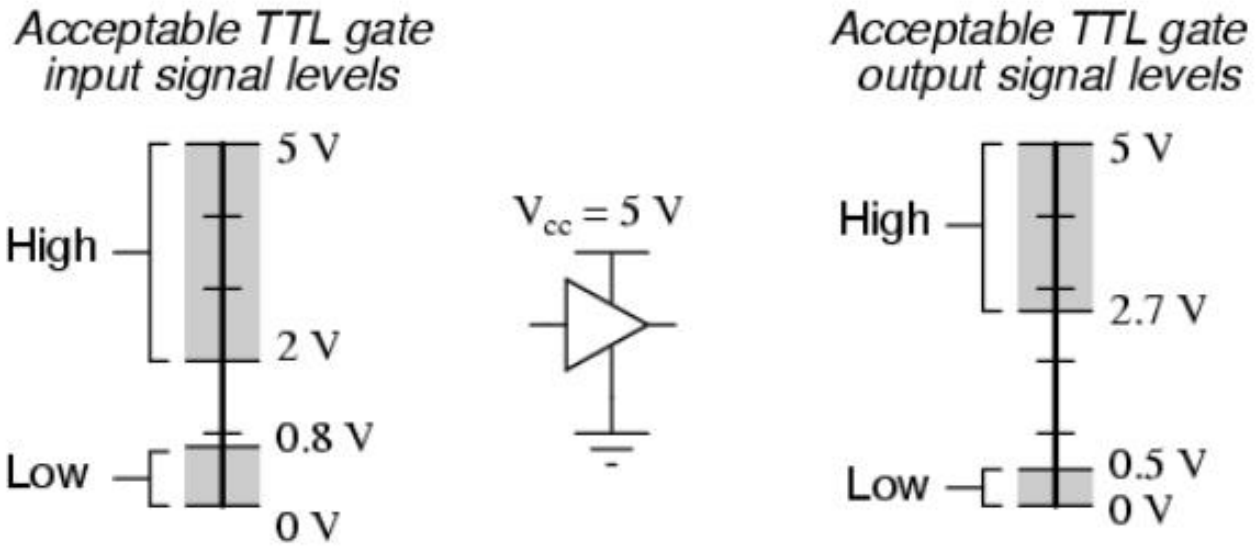
Discrete in *time* and *amplitude* (voltage)
Convey a series of symbols (e.g. 0, 1, 1, 0, 1, 0, 0, 0, 1, 0)
Low information density but relatively immune to noise



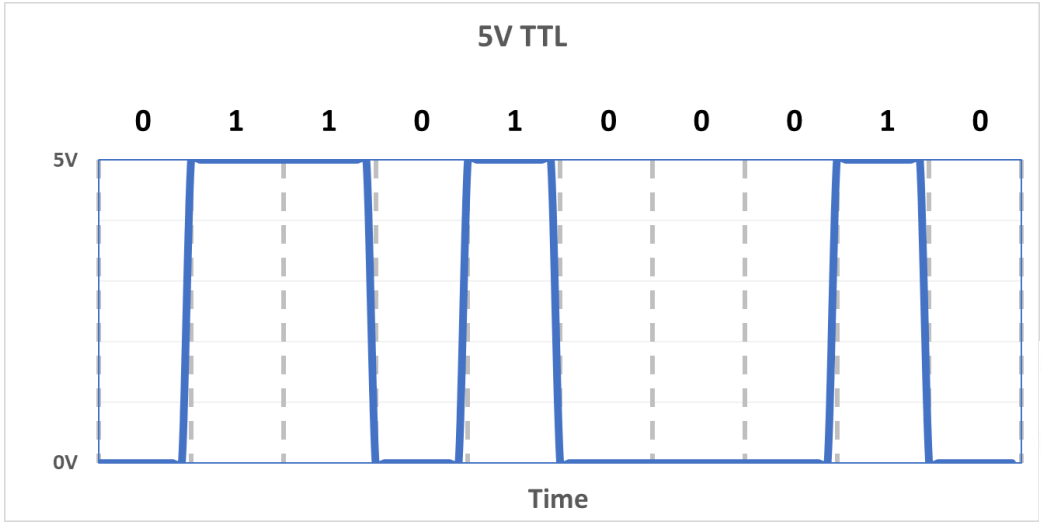
Digital Signals

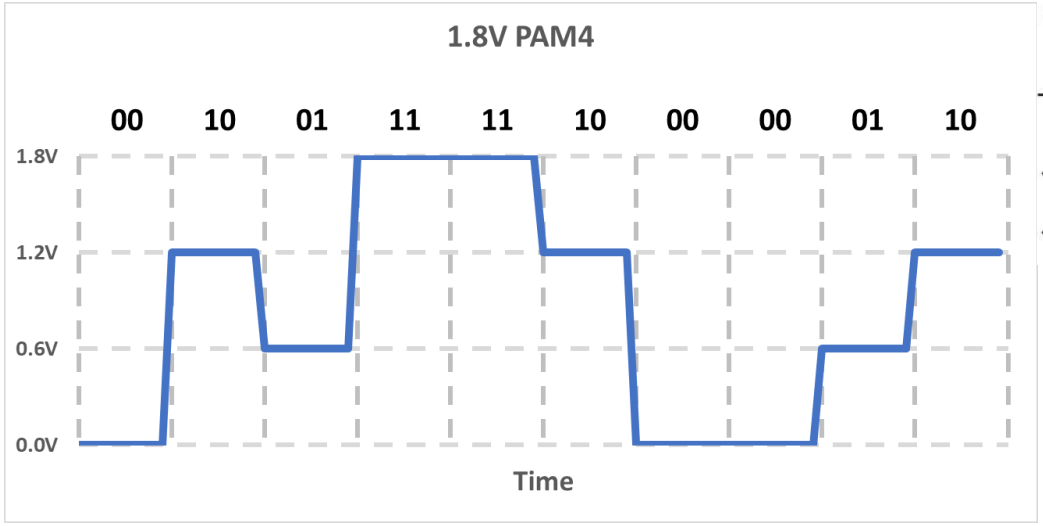
Voltage levels don't need to be precise

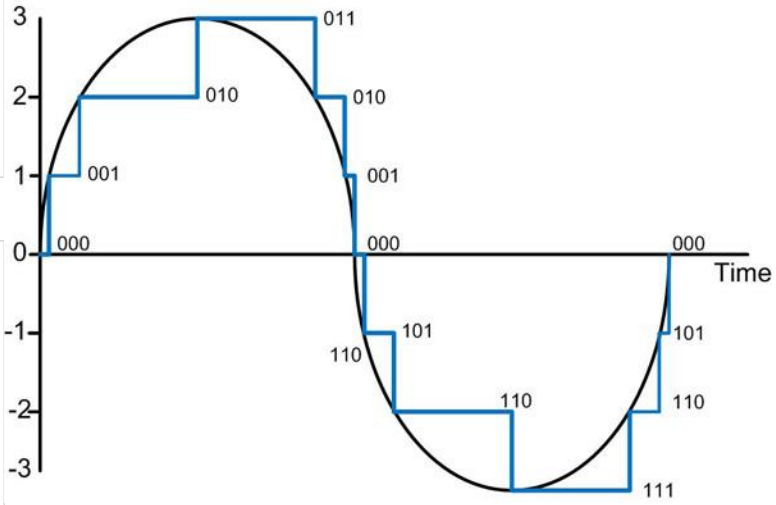
Wide ranges of circuits can just plug together



Digital Signal Examples



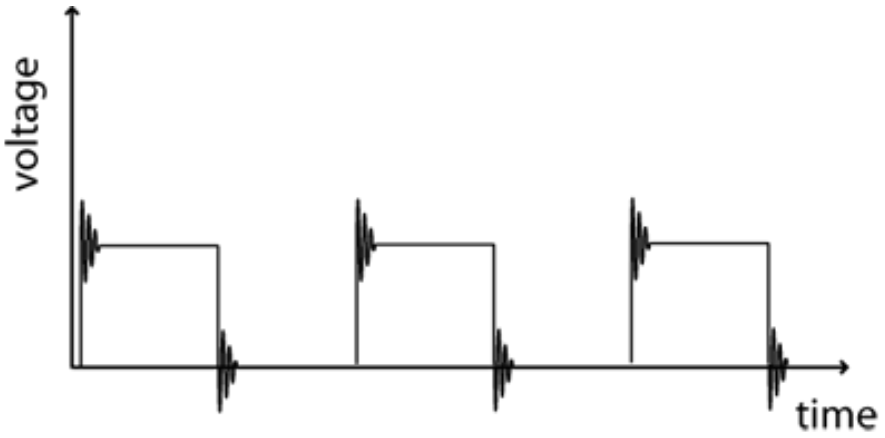


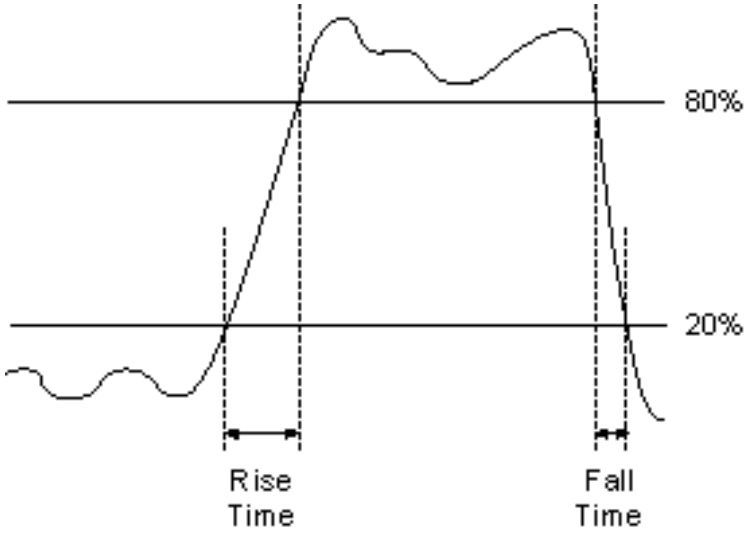


Digital Signal Integrity Issues

Preserve adequate rise/fall times

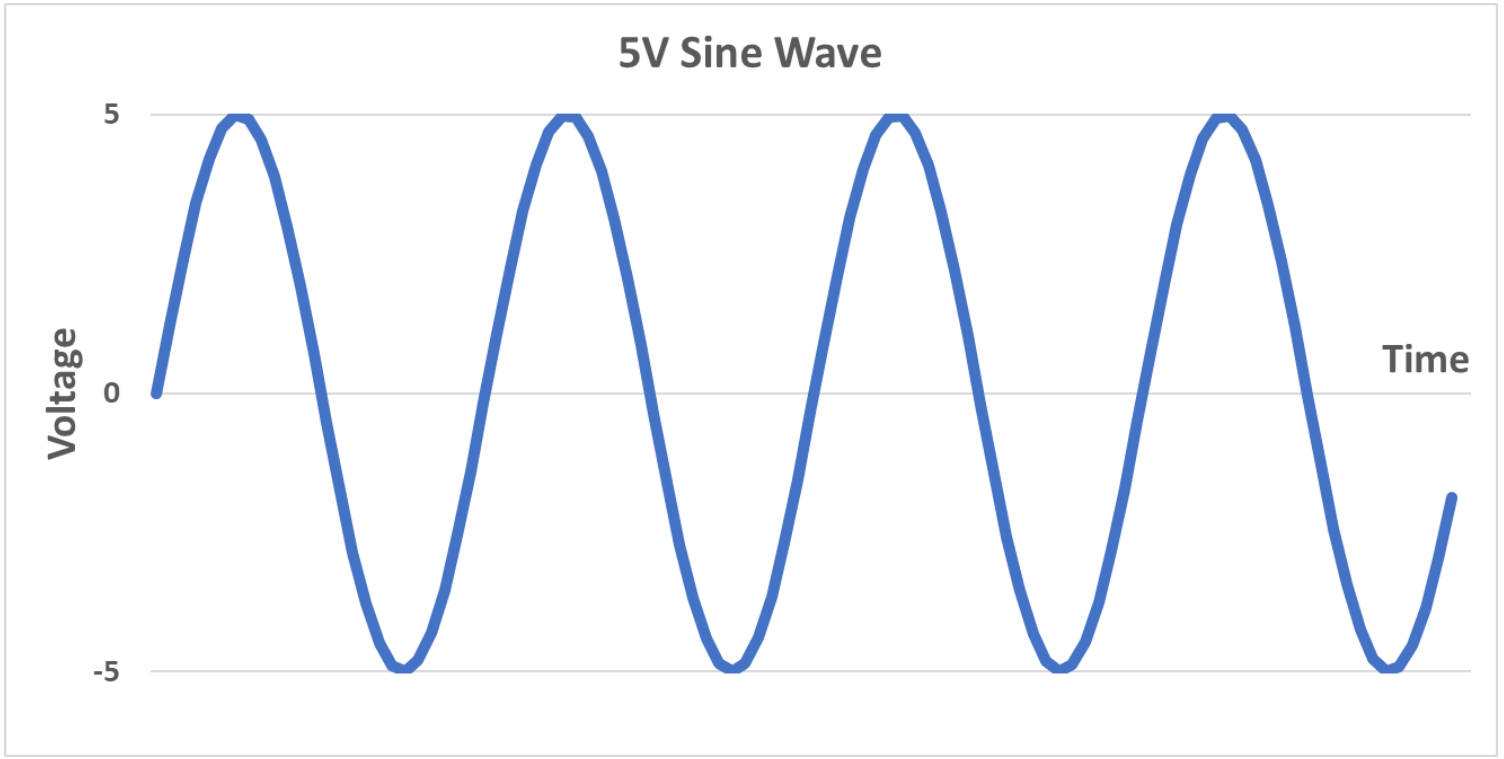
Keep ringing under control





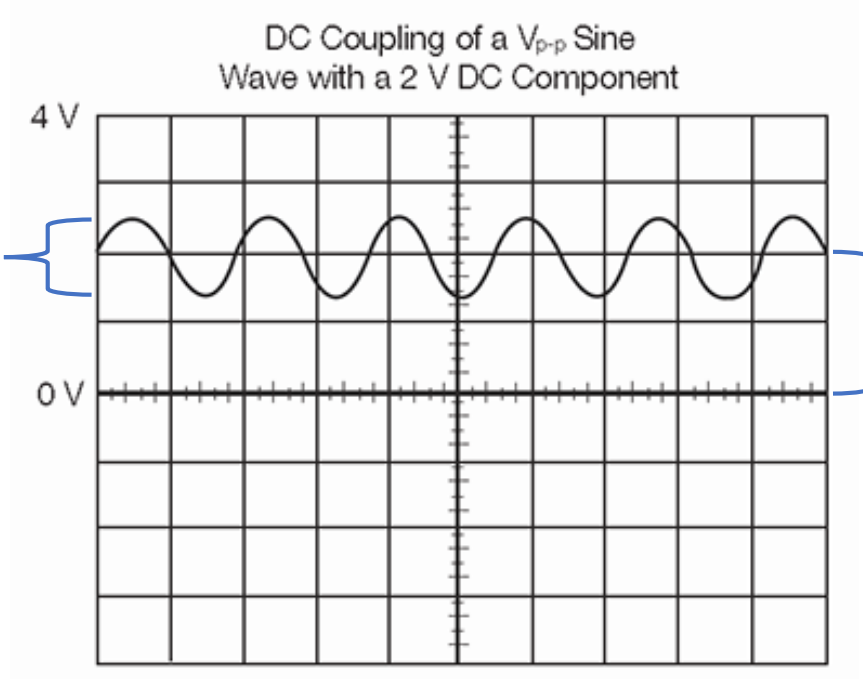
Analog Signals

Continuous in time and voltage (amplitude)
Represent some time varying quantity (e.g. sound pressure)
Potentially infinite information density (theoretically)



AC vs DC Components

AC

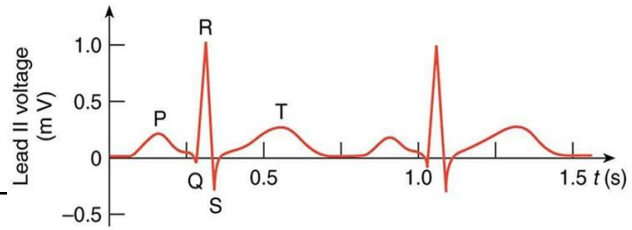


DC

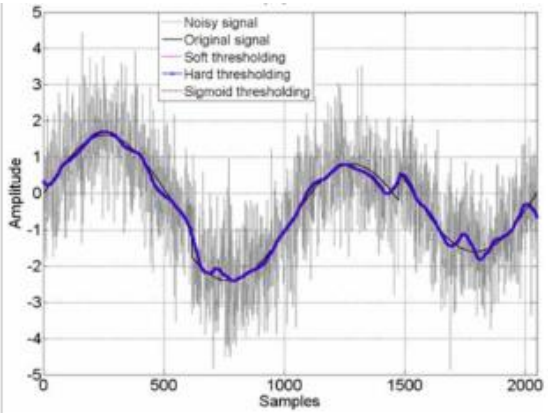
Analog Signal Characteristics

Welcome to the real world!

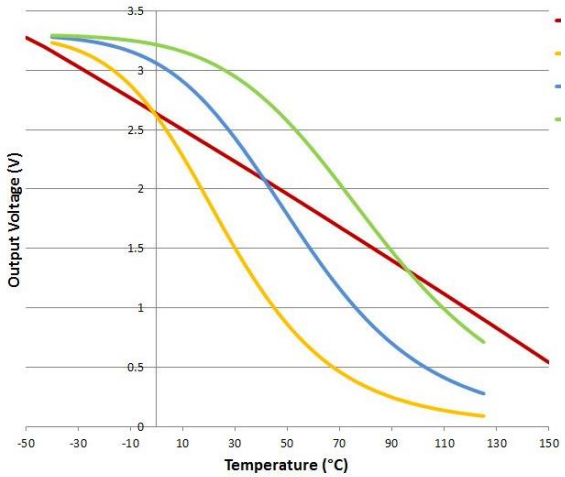
Maybe small voltage levels



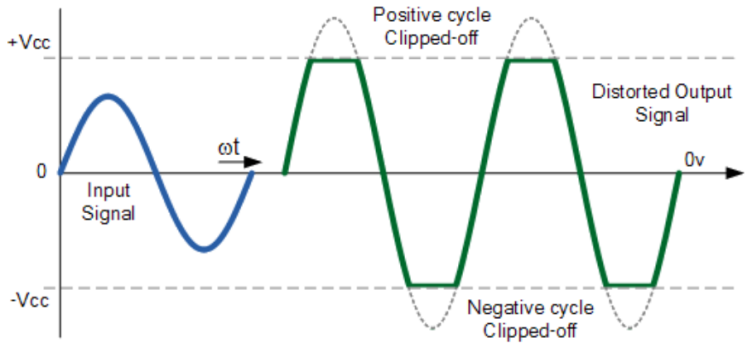
Can be noisy



Linear or nonlinear



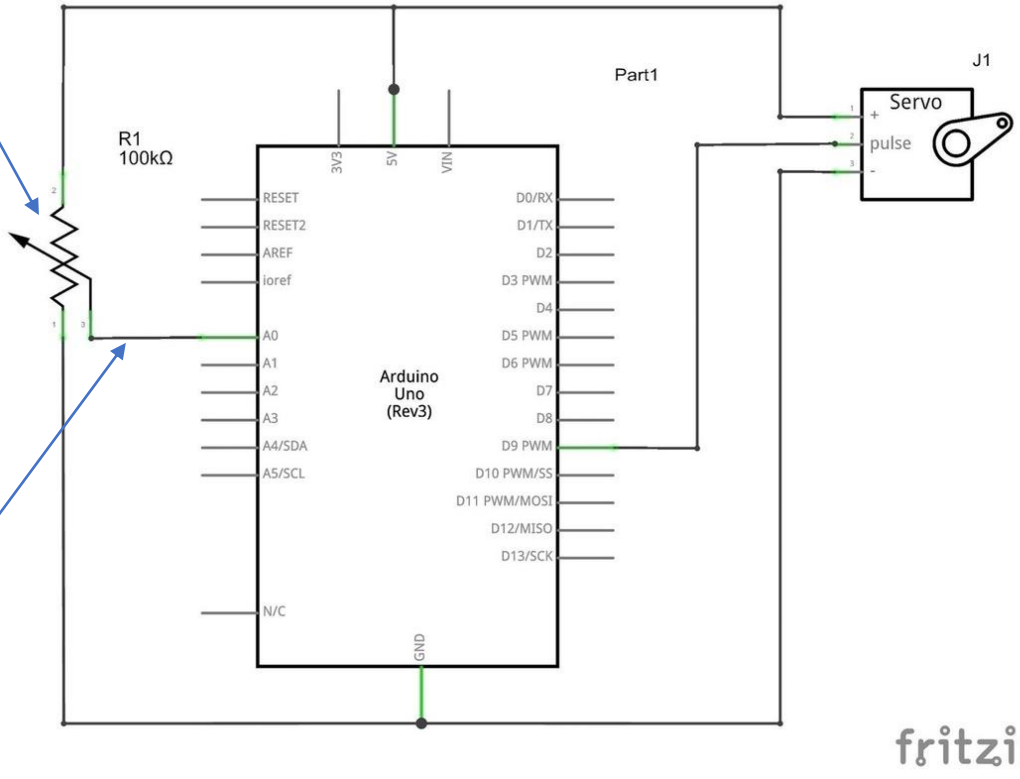
Can be distorted



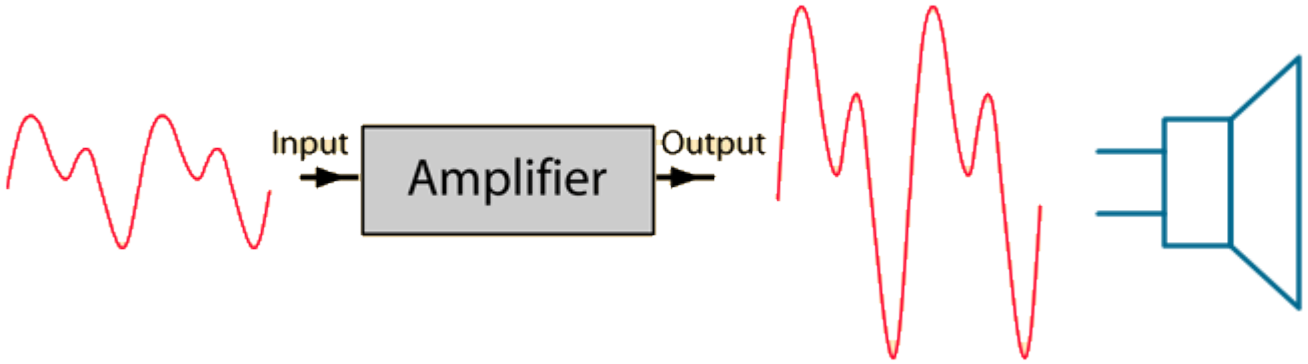
Example: Simple Motor Control

Knob

Analog voltage to be converted to digital by Arduino



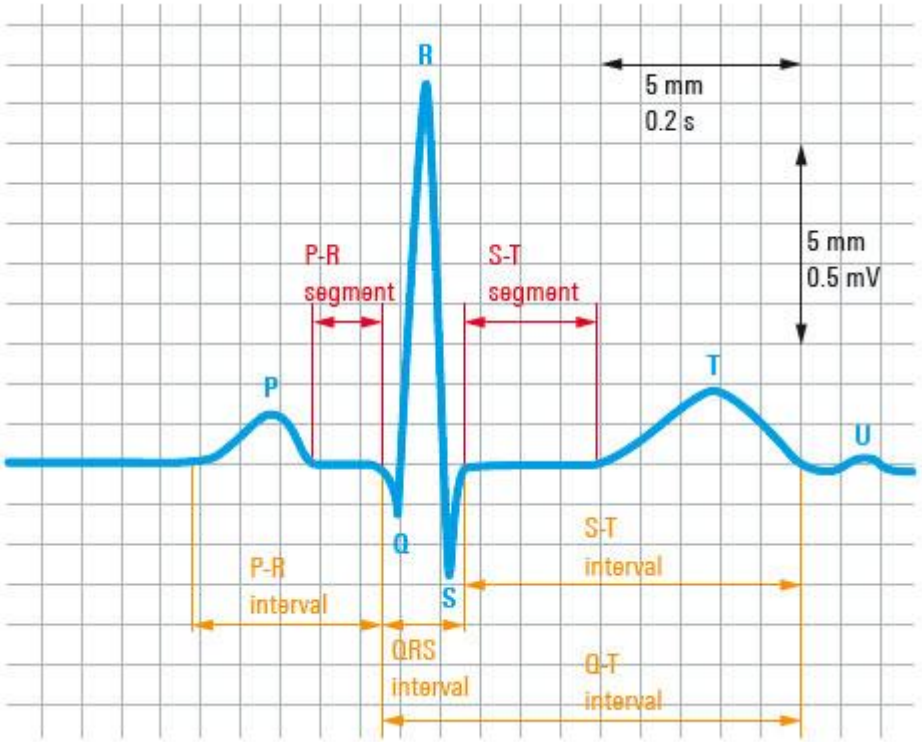
Example: Audio Amplifier



Increase signal amplitude

Input signal has +/- voltage, no DC
Output has +/- voltage, no DC
Not too much distortion

Example Signal - ECG



- Non-invasive
- 12 leads on body
- Measures electrical changes on the skin due to heart activity
- <1mV signal
  - Fetal ECG ~1µV
- 10kHz bandwidth

What makes analog hard?

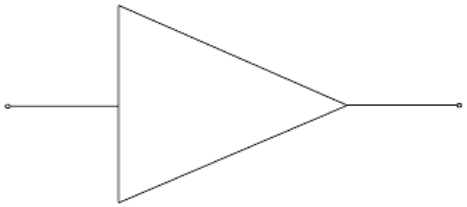
Digital – thinking process is more like a ***logic puzzle***; circuit elements are often fairly ***ideal building blocks***

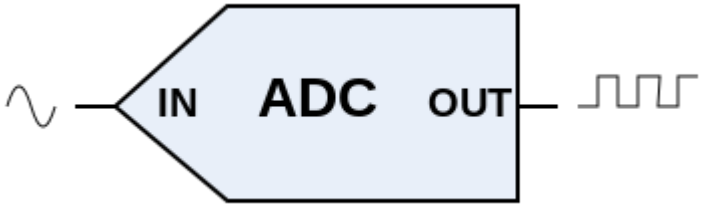
Analog –uses non-ideal components and “true” circuit design principles

- Signal min/max voltages
- DC offsets
- Distortion
- Bandwidth

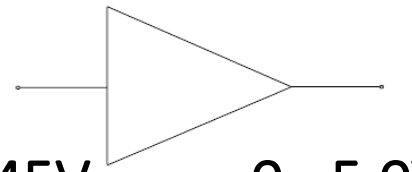
Project Time!

Let’s amplify a signal so it can optimally feed a microcontroller ADC

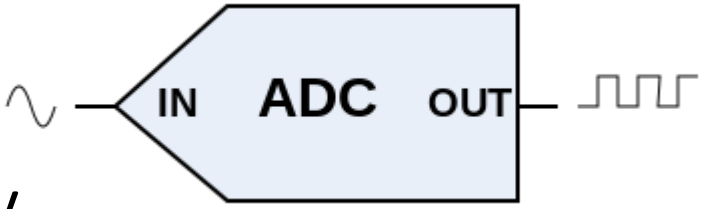




Signal Observations



5V Supply



+/- 0.45V
($0.9V_{P-P}$)

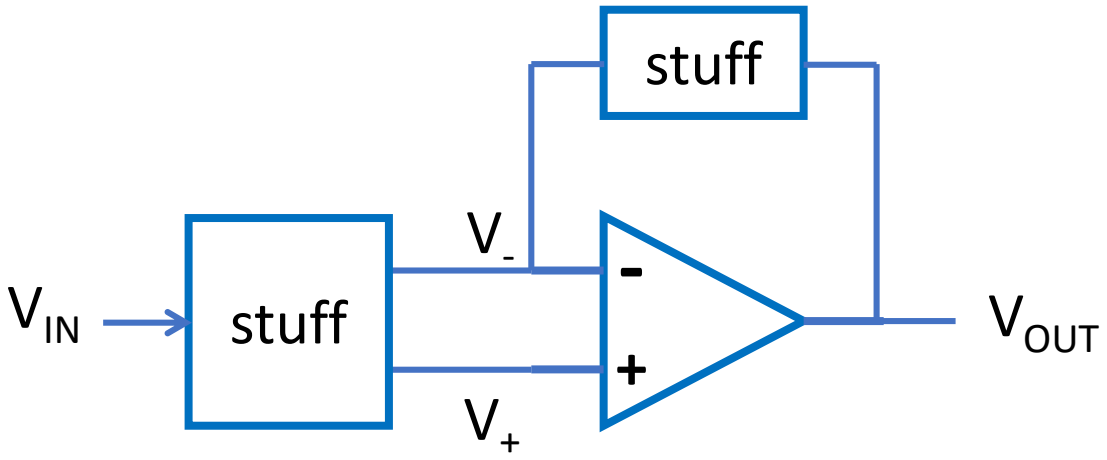
0 - 5.0V
($5V_{P-P}$)

Both +/- voltages
DC = 0V
<20KHz

Only + voltage
DC = 2.5V
<20KHz

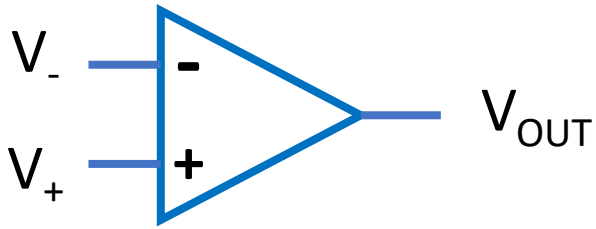
Amplify x5.5
Add 2.5V DC

Let's introduce the op-amp!



Will set V_{OUT} to force $V_- = V_+$

Ideal op-amp



Paraphrase: It's really good at trying to set V_{OUT} to force $V_- = V_+$

<u>Ideal Op-Amp:</u>

Current into V_+, V_- is zero

$V_+ = V_-$ (in "closed loop" operation)

Infinite "open-loop" gain: $V_{OUT} = (V_+ - V_-) \times \infty$

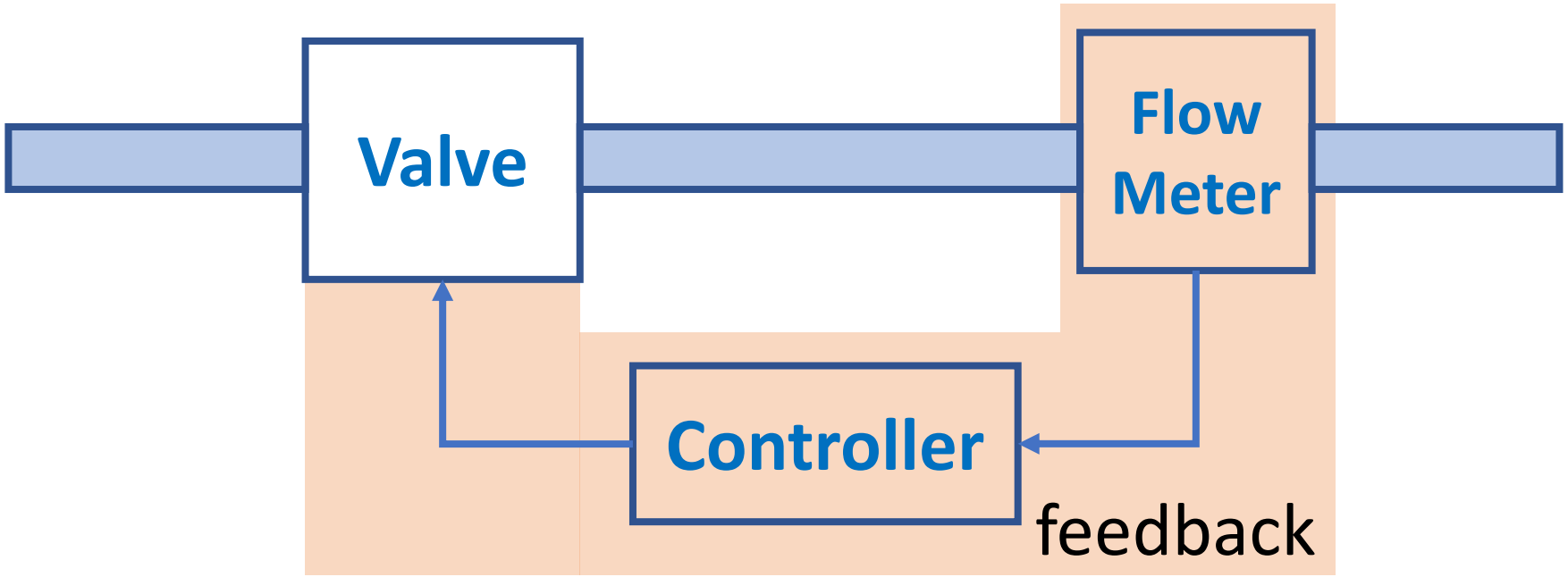
Open Loop Systems

A system that does its thing without measuring what's happening

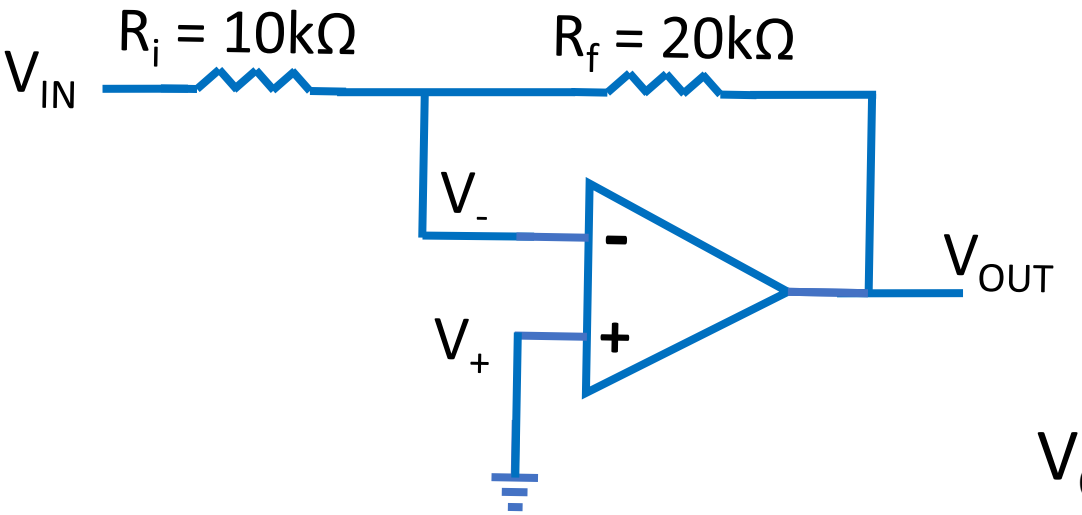
Closed Loop Systems

A system that adapts what it's doing based on what's happening

Closed Loop Systems



Standard Inverting Amplifier



$$V_{OUT} = -V_{IN} \times (R_f/R_i)$$

Ideal Op-Amp:

Current into V_+, V_- is zero

$V_+ = V_-$ (in closed loop circuit)

Infinite open-loop gain

Real op-amps: V_{IN} Limits

MCP6002

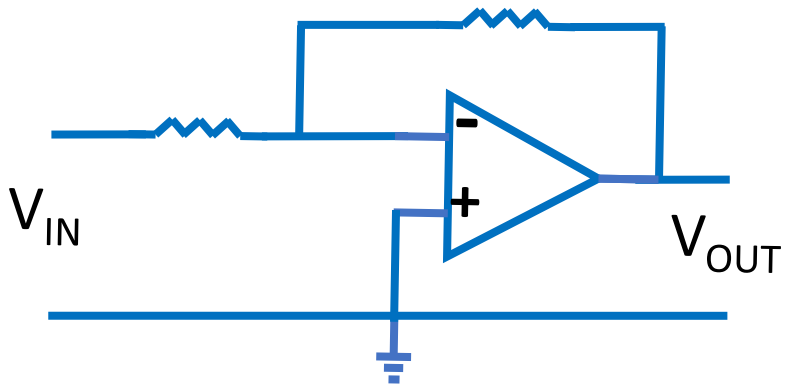
Common Mode Input Range	V_{CMR}	$V_{SS} - 0.3$	—	$V_{DD} + 0.3$	V	

"rail-to-rail" input

LM741 $V_S = \pm 15$ V, ·

Input voltage range	$T_{AMIN} \le T_A \le T_{AMAX}$		±12	±13	V

not "rail-to-rail"



Real op-amps: V_{OUT} Limits

MCP6002

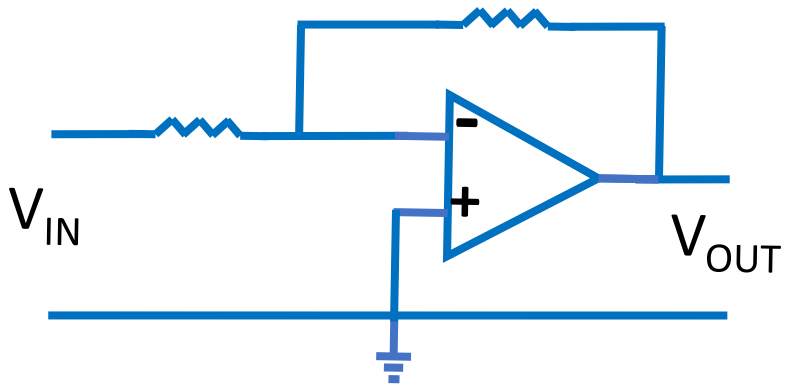
						$V_{CM} - V_{SS}$
Output						
Maximum Output Voltage Swing	V_{OL}, V_{OH}	V_{SS} + 25	—	V_{DD} – 25	mV	V_{DD} = 5.5V, 0.5V Input Overdrive
Output Short Circuit Current	I_{SC}	—	±6	—	mA	V_{DD} = 1.8V
		—	±23	—	mA	V_{DD} = 5.5V

"rail-to-rail" output

LM741

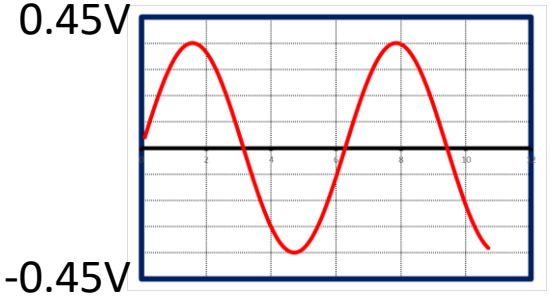
not "rail-to-rail"

Output voltage swing	V_S = ±15 V	$R_L \geq 10\ k\Omega$	±12	±14	V
		$R_L \geq 2\ k\Omega$	±10	±13	
Output short circuit current	T_A = 25°C			25	mA

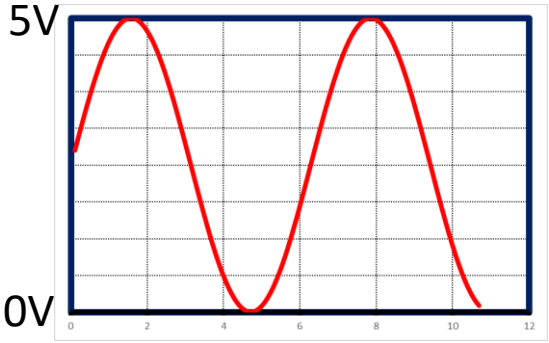


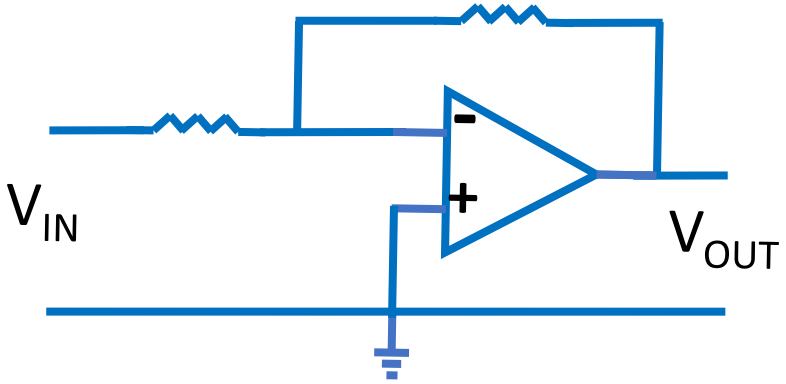
Input/Output DC Voltage Problem

V_{IN} has no DC component (it's an AC signal centered around 0V DC)

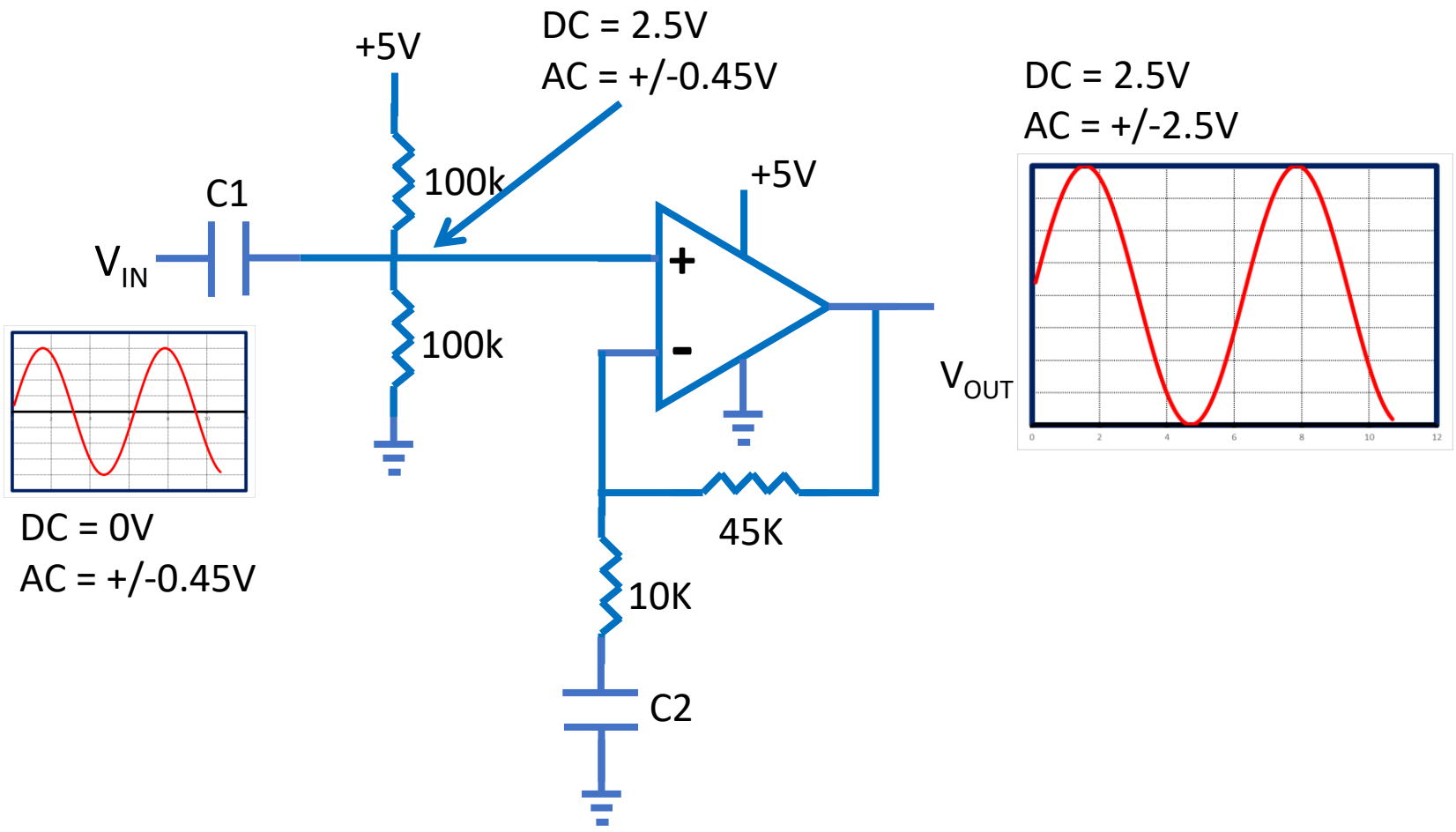


V_{OUT} should vary from 0V to 5V (centered around 2.5V DC)

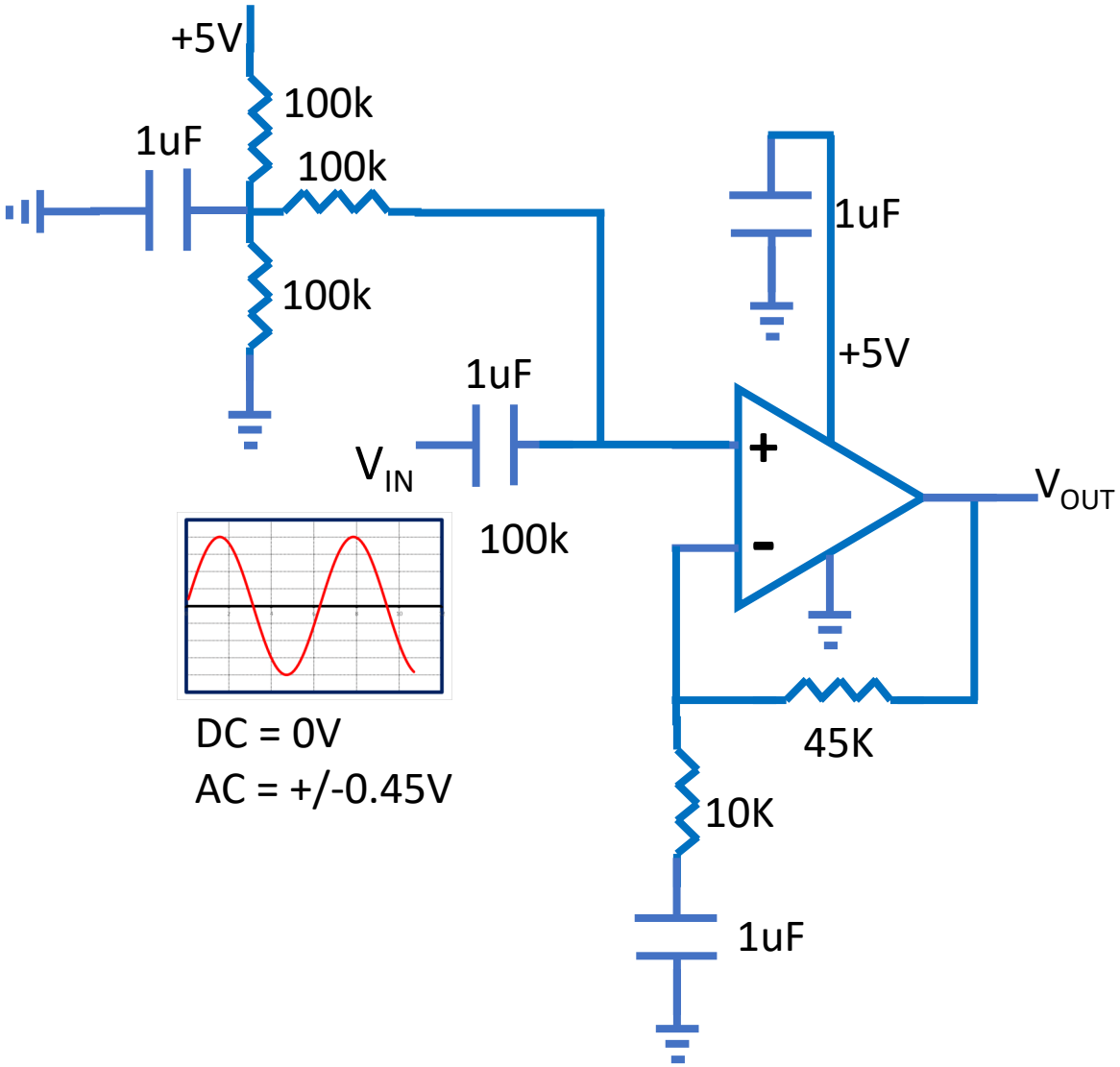




Real op-amps: I/O DC Offsets

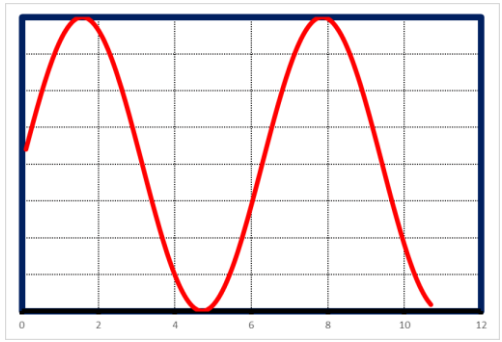


Final Circuit



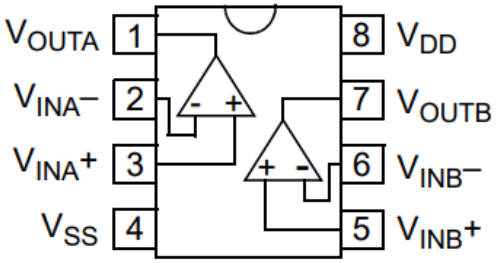
DC = 0V
AC = +/-0.45V

DC = 2.5V
AC = +/-2.5V



MCP6002

PDIP, SOIC, MSOP



Making op-amp circuits easier

Become familiar with a few basic op-amp circuits

- Inverting amp
- Non-inverting amp
- Summing amp

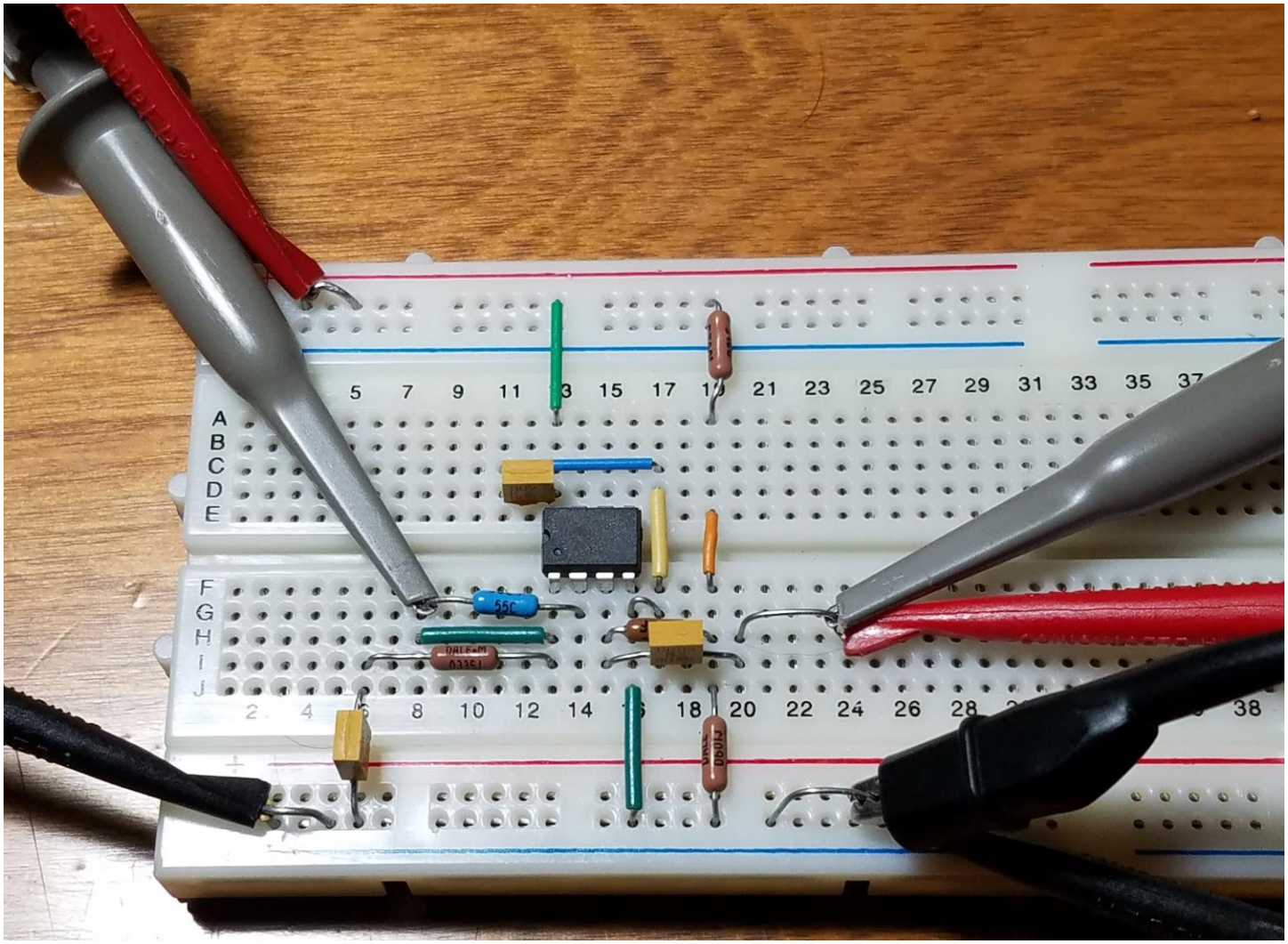
Take advantage of proven designs:

- application notes
- examples in data sheets, websites
- op-amp cookbooks

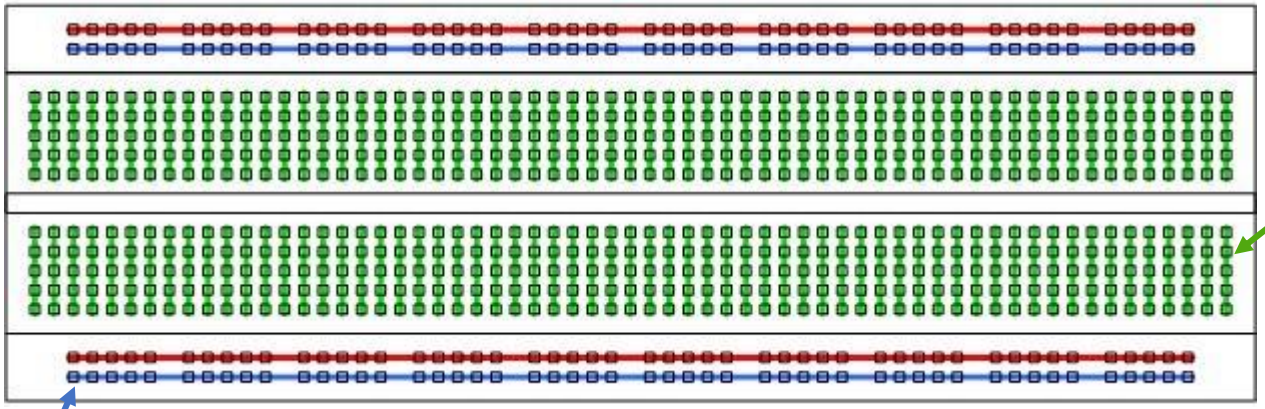
Go-to parts:

- Have a go-to rail/rail I/O 5V op-amp (KM MCP6002)
- Have a go-to split-supply 30V op-amp (KM NE5534)
- Unity gain stable, GBW ~MHz

Finished Circuit



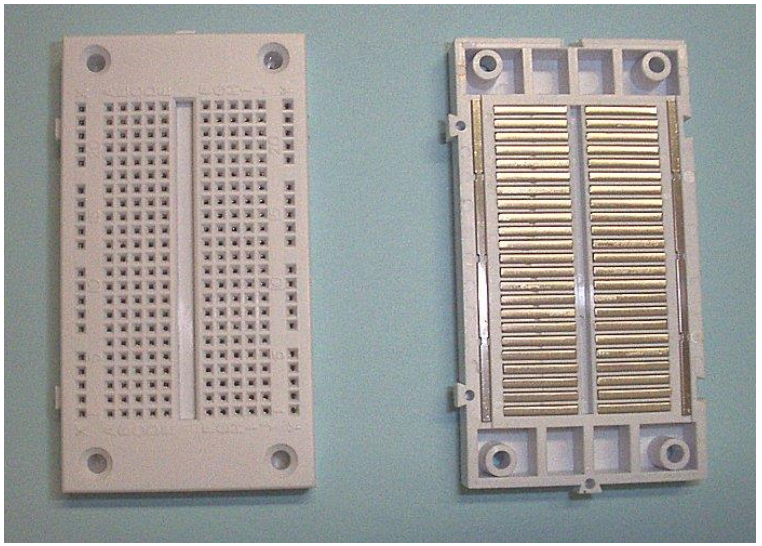
Using a breadboard



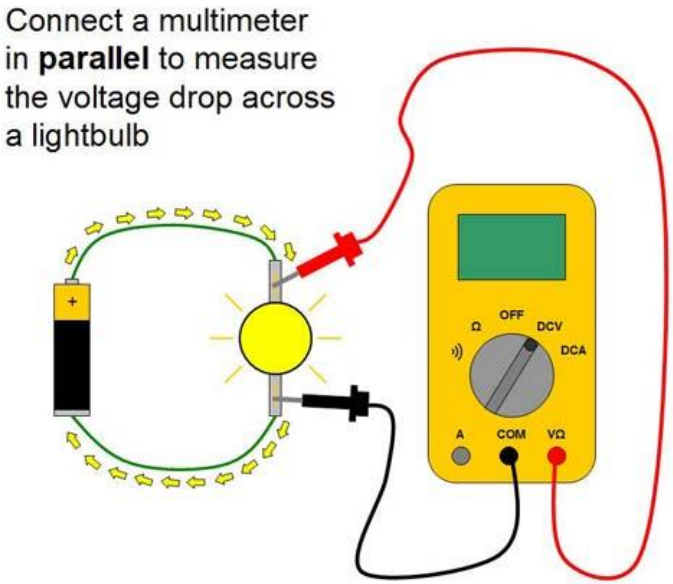
Circuit connections

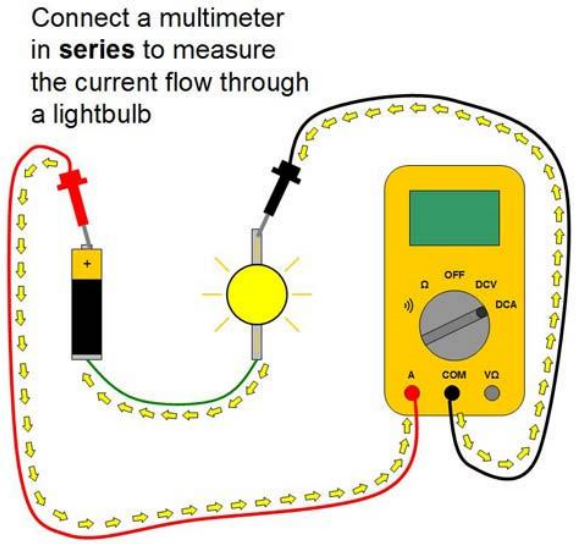
Power supply buses

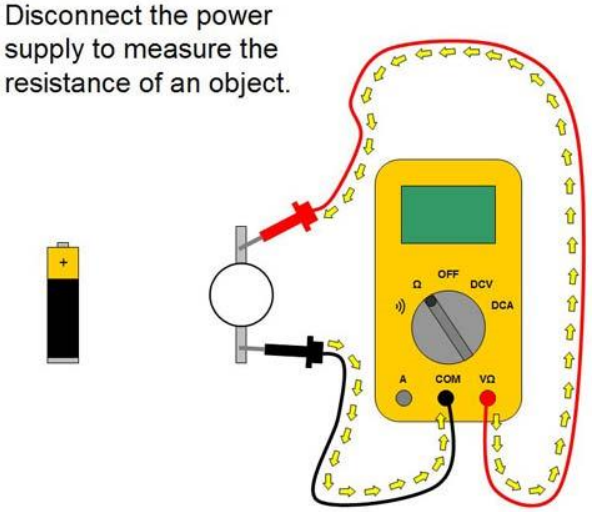
Internals of board



Using a Multimeter







- Voltage across
- Current through
- Resistance between
- Continuity between