Lecture 1

Introduction and basic circuit theory

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6.117 Pedagogy

- **Objective:** Introduce students to the fundamentals of practical electrical engineering (EE) in a relaxed, project-oriented environment

- Emphasis on practicality rather than theory
- Hands-on exposure to a variety of topics
- No tests/quizzes, no homework, no lab/lecture on Fridays

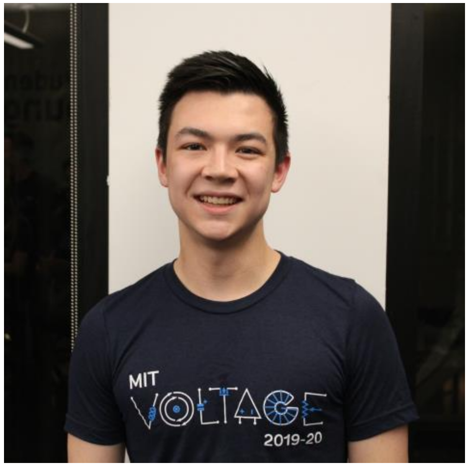
Course mechanics

Lectures (4-231): MW 2:30 – 4:00pm

Labs (38-601):

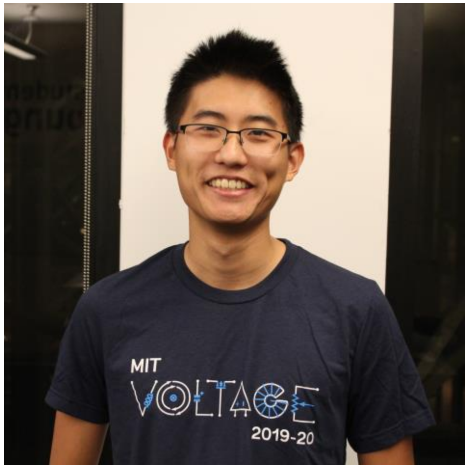
- Section 1: MW 4:00 – 7:00pm
- Section 2: TR 1:00 – 4:00pm
- Section 3: TR 4:00 – 7:00pm

Course staff



Sam Chinnery, lecturer

Savannah Inglin, TA



Tim Magoun, TA

Reed Foster, TA

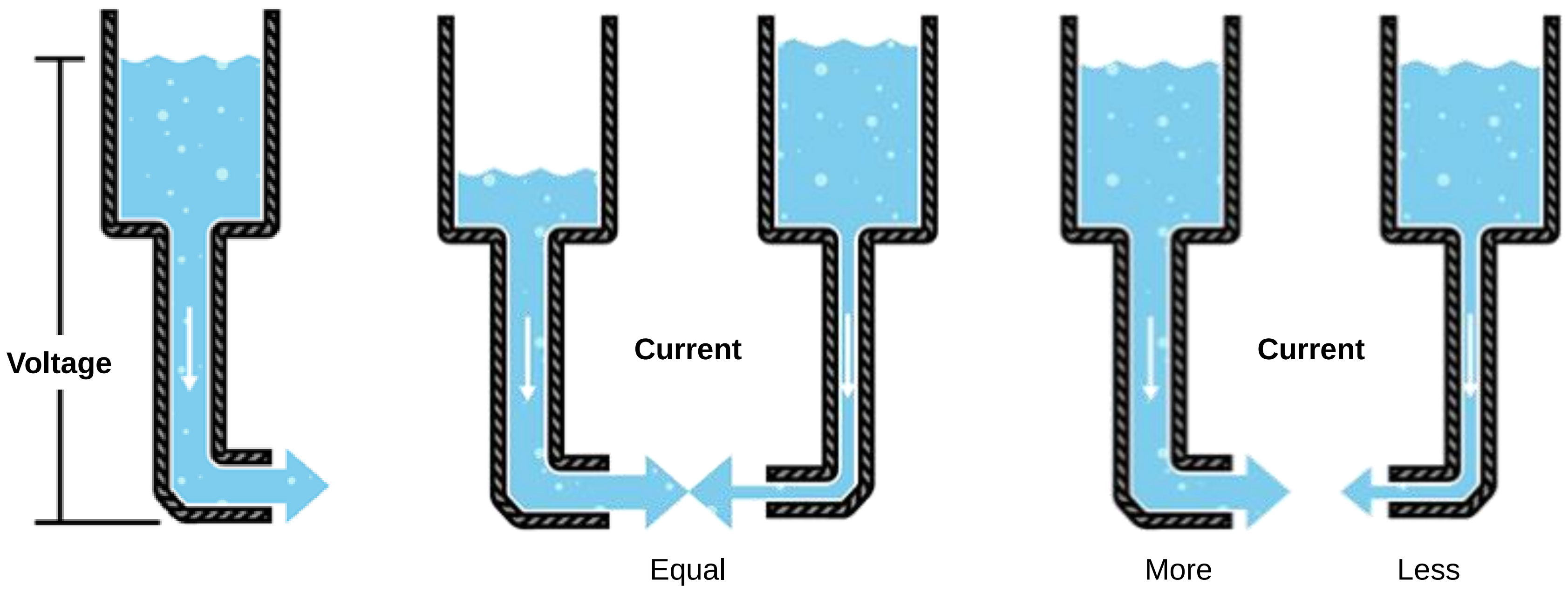
Agenda

1. Course overview and logistics
2. EE conventions, units and acronyms
3. DC circuits: Ohm’s law and resistors
4. AC circuits: capacitors and inductors
5. Lab overview and safety

EE conventions, units and acronyms

Voltage and current

- **Analogy**: Water in pipes is “charge”
- Think of voltage as “pressure,” current as “flow rate”



Common units

Quantity	Unit	Symbol
Voltage	**Volt**	V
Current	**Ampere (amp)**	A
Resistance	**Ohm**	Ω
Capacitance	**Farad**	F
Inductance	**Henry**	H
Frequency	**Hertz**	Hz

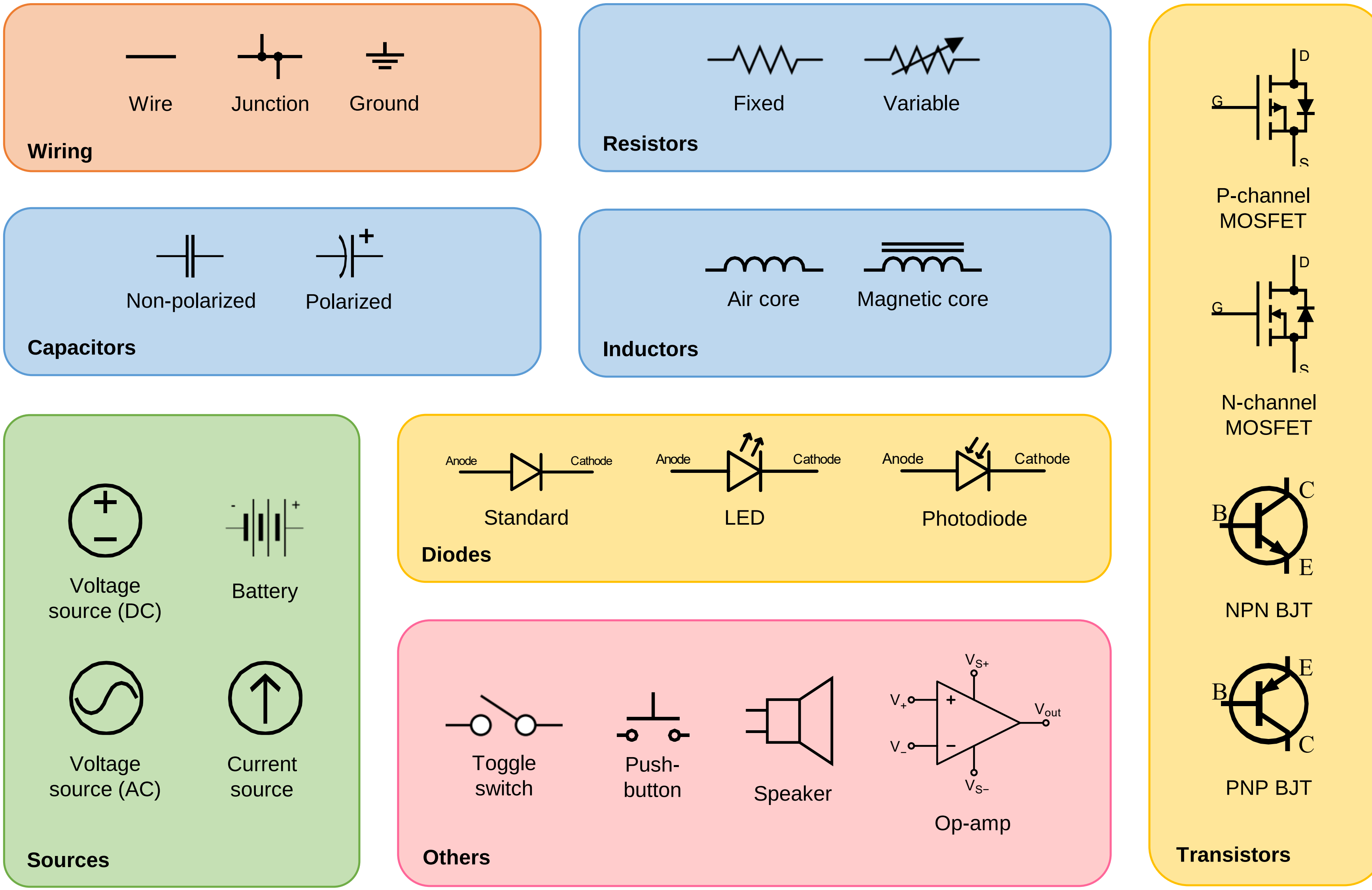
Unit multipliers

Prefix	Symbol	Multiplier
tera-	**T**	10^{12}
giga-	**G**	10^{9}
mega-	**M**	10^{6}
kilo-	**K**	10^{3}
(none)	**(none)**	10^{0}
milli-	**m**	10^{-3}
micro-	**μ**	10^{-6}
nano-	**n**	10^{-9}
pico-	**p**	10^{-12}

Common acronyms and abbreviations

Short	Long
AC	Alternating current
DC	Direct current
BJT	Bipolar junction transistor
MOSFET	Metal-oxide-semiconductor field-effect transistor
SMD, SMT	Surface-mount device, surface-mount technology
PTH	Plated through-hole
DIP	Dual inline package
PCB	Printed circuit board
RF	Radio frequency
RMS	Root mean square
cap	Capacitor
pot	Potentiometer
op-amp	Operational amplifier

Schematic symbols



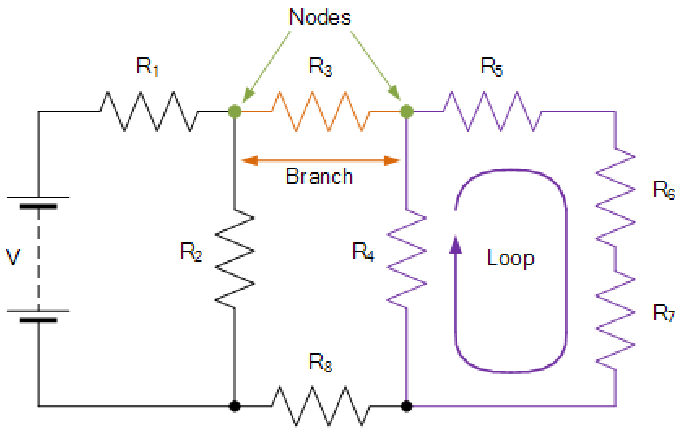
DC circuits

Ohm's law and resistors

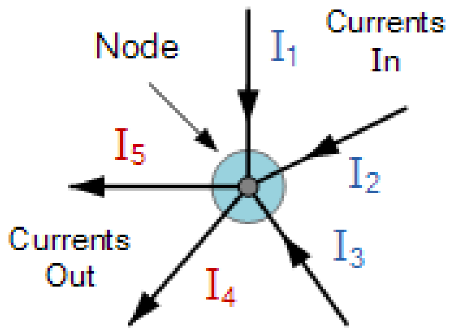
Circuits

- A **circuit** is any closed loop through which current flows.
- Circuits obey two basic laws:
  - Kirchoff's **current law** (KCL): Currents into a node sum to 0
  - Kirchoff's **voltage law** (KVL): Voltages around a loop sum to 0

An example circuit

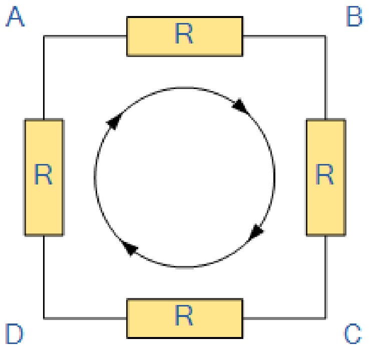


Kirchoff's current law



$$I_1 + I_2 + I_3 + (-I_4 + -I_5) = 0$$

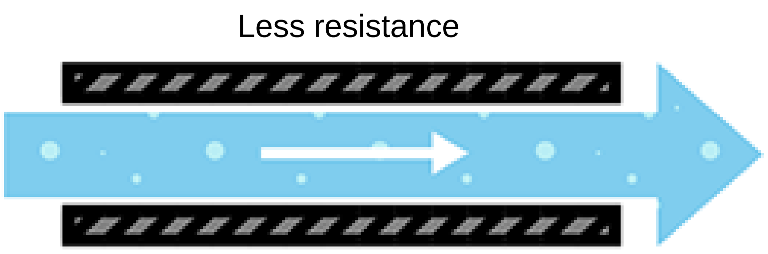
Kirchoff's voltage law

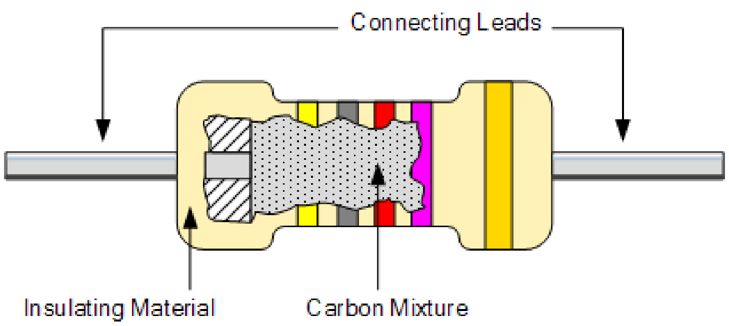


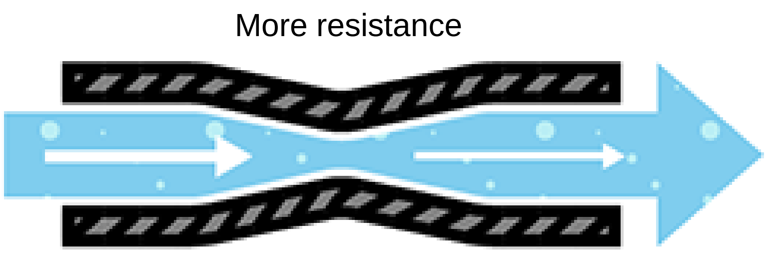
$$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$$

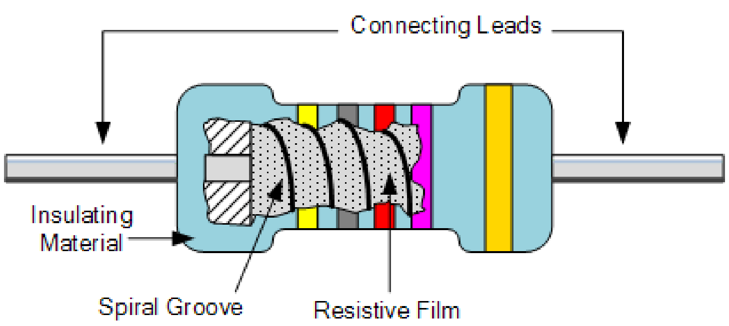
Resistors

- **Water analogy:** A resistor is a “narrower pipe”
- Resists the flow of current, as the name suggests

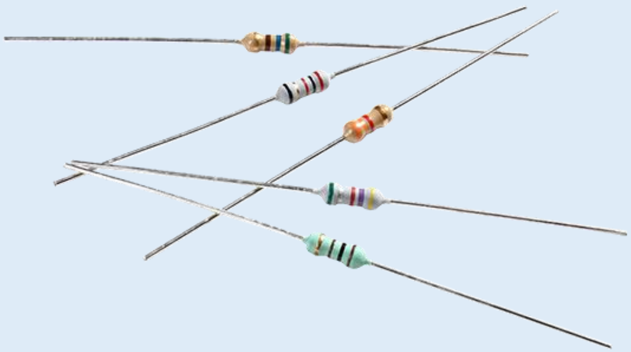


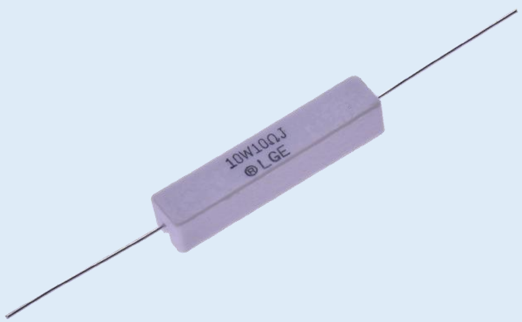




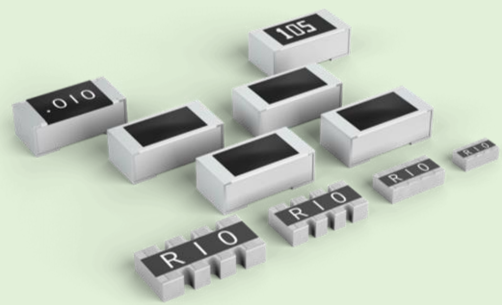


Resistors





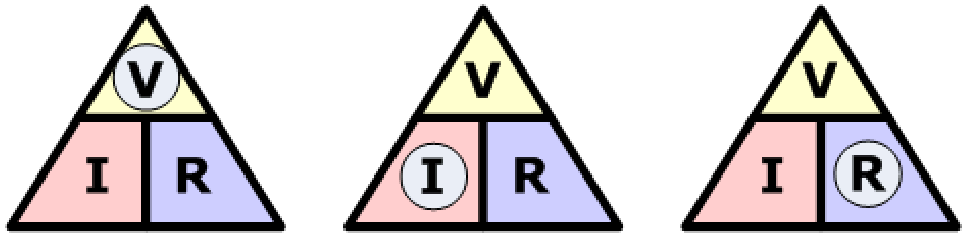
Through-hole (PTH)



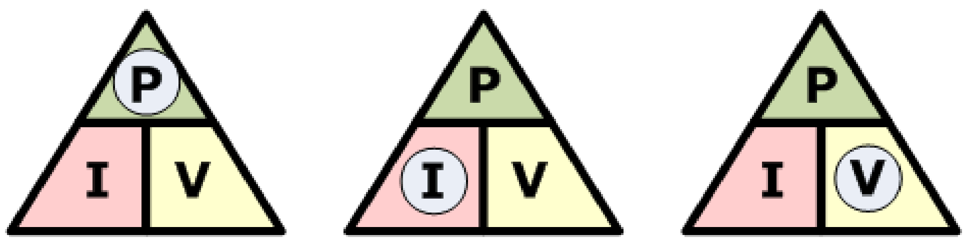
Surface-mount (SMD)

Ohm's Law

$$Current, (I) = \frac{Voltage, (V)}{Resistance, (R)} \text{ in } Amperes, (A)$$



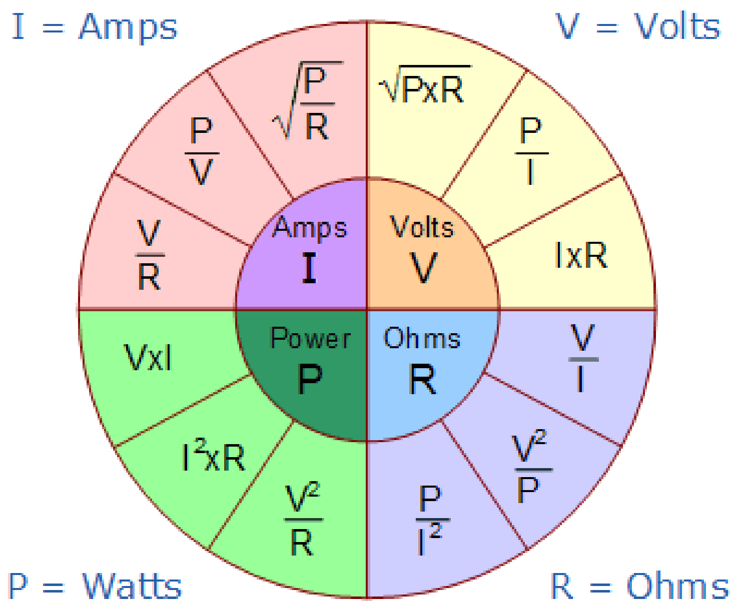
$V = I \times R$ $\qquad I = \frac{V}{R}$ $\qquad R = \frac{V}{I}$



$P = I \times V$ $\qquad I = \frac{P}{V}$ $\qquad V = \frac{P}{I}$

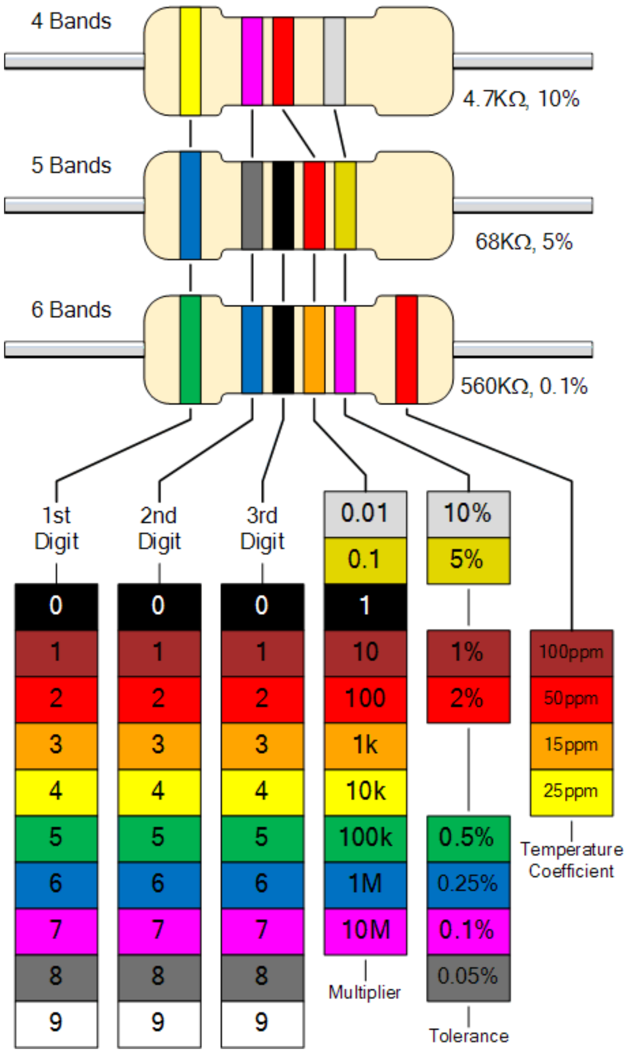
Ohm’s Law

- **Ohm’s Law:** Relationship between voltage, current, resistance and power
- All four can be determined from any two known values



Ohms Law Formulas				
Known Values	Resistance (R)	Current (I)	Voltage (V)	Power (P)
Current & Resistance	---	---	$V = IxR$	$P = I^2xR$
Voltage & Current	$R = \frac{V}{I}$	---	---	$P = VxI$
Power & Current	$R = \frac{P}{I^2}$	---	$V = \frac{P}{I}$	---
Voltage & Resistance	---	$I = \frac{V}{R}$	---	$P = \frac{V^2}{R}$
Power & Resistance	---	$I = \sqrt{\frac{P}{R}}$	$V = \sqrt{PxR}$	---
Voltage & Power	$R = \frac{V^2}{P}$	$I = \frac{P}{V}$	---	---

Resistor color code

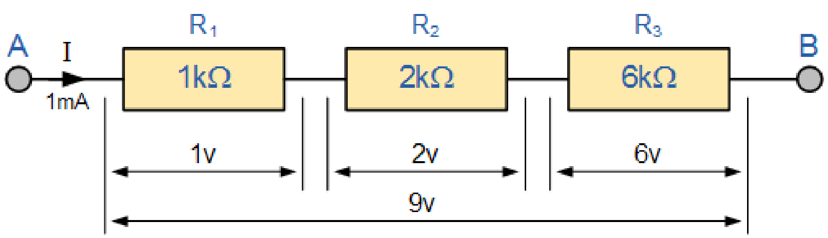


Color	Digit	Multiplier	Tolerance
Black	0	1	
Brown	1	10	± 1%
Red	2	100	± 2%
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	± 0.5%
Blue	6	1,000,000	± 0.25%
Violet	7	10,000,000	± 0.1%
Grey	8		± 0.05%
White	9		
Gold		0.1	± 5%
Silver		0.01	± 10%
None			± 20%

Series and parallel combinations

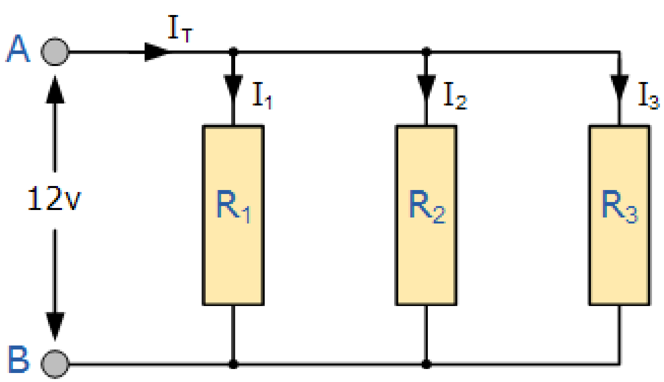
- Resistances in **series** add
- Resistances in **parallel** add "inversely"

Series resistances



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

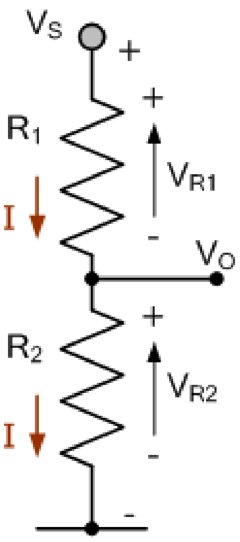
Parallel resistances



$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \;\ldots\ldots + \frac{1}{R_n} \text{ etc}$$

Voltage divider circuit

- **Voltage divider:** Two resistors in series
- Predictable voltage between the two resistors (V_o)



$$V_S = V_{R1} + V_{R2} \quad \text{(KVL)}$$

$$V_{R1} = I \times R_1 \quad \text{and} \quad V_{R2} = I \times R_2$$

$$\text{Then}: \; V_S = I \times R_1 + I \times R_2$$

$$\therefore \; V_S = I\left(R_1 + R_2\right)$$

$$\text{So}: \; I = \frac{V_S}{(R_1 + R_2)}$$

$$I_{R1} = \frac{V_{R1}}{R_1} = \frac{V_S}{\left(R_1 + R_2\right)}$$

$$\therefore \; \boxed{V_{R1} = V_S\left(\frac{R_1}{R_1 + R_2}\right)}$$

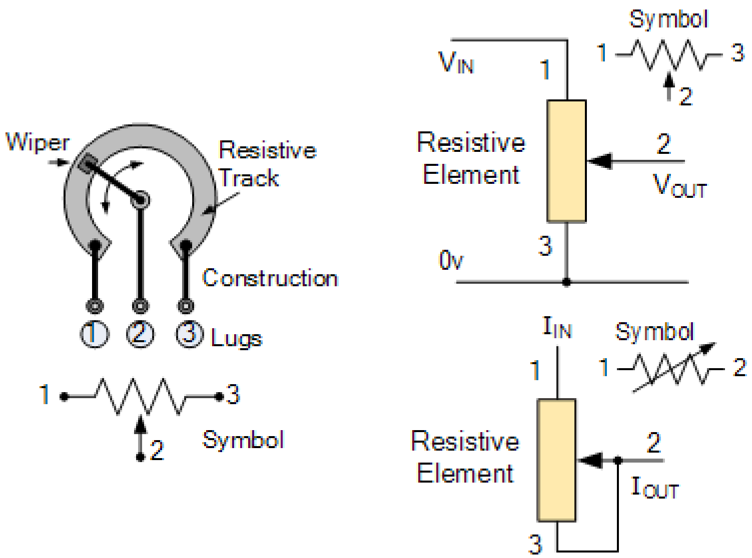
$$I_{R2} = \frac{V_{R2}}{R_2} = \frac{V_S}{\left(R_1 + R_2\right)}$$

$$\therefore \; \boxed{V_{R2} = V_S\left(\frac{R_2}{R_1 + R_2}\right)}$$

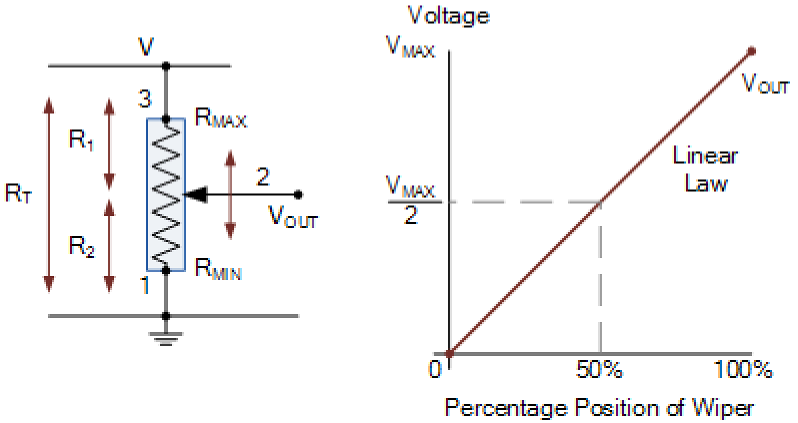
Potentiometers

- A **potentiometer** is a variable resistor.
- Can be used as a voltage divider or a simple resistor (by connecting the wiper to the resistive element)

Construction (left) and use (right)



Potentiometer as a voltage divider

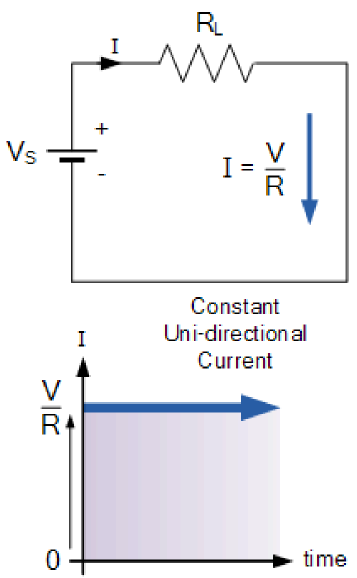


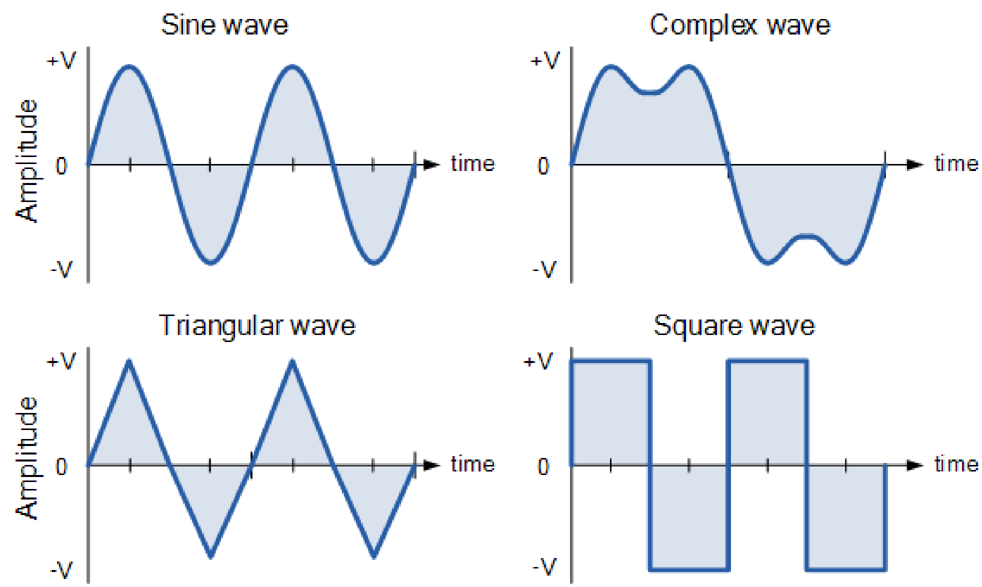
AC circuits

Capacitors and inductors

Alternating current

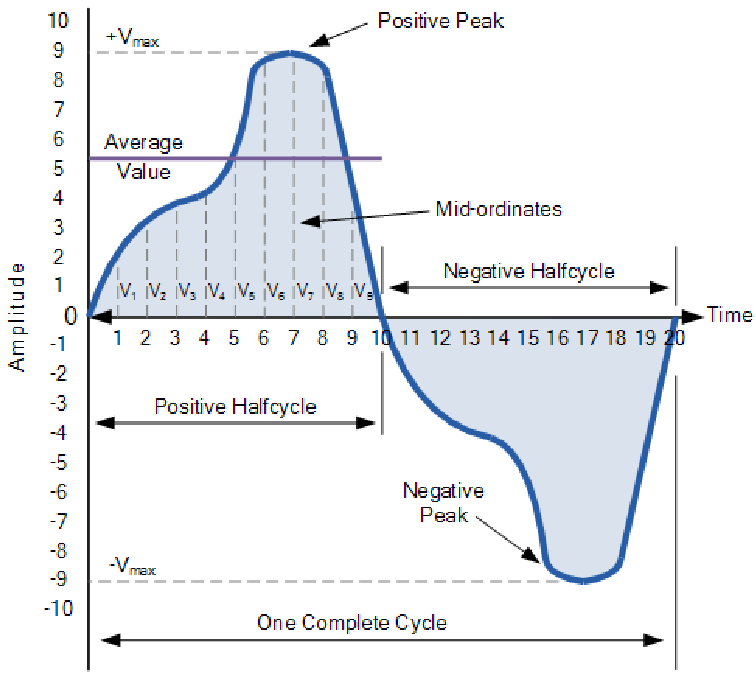
- **Alternating current (AC):** an electrical current that periodically reverses direction
- **Frequency:** the length of one **period** of the signal





RMS voltage

- **Root-mean-square (RMS):** “Effective value” of an AC waveform
- Calculated as the *root* of the average (*mean*) of the *square* of the voltage or current

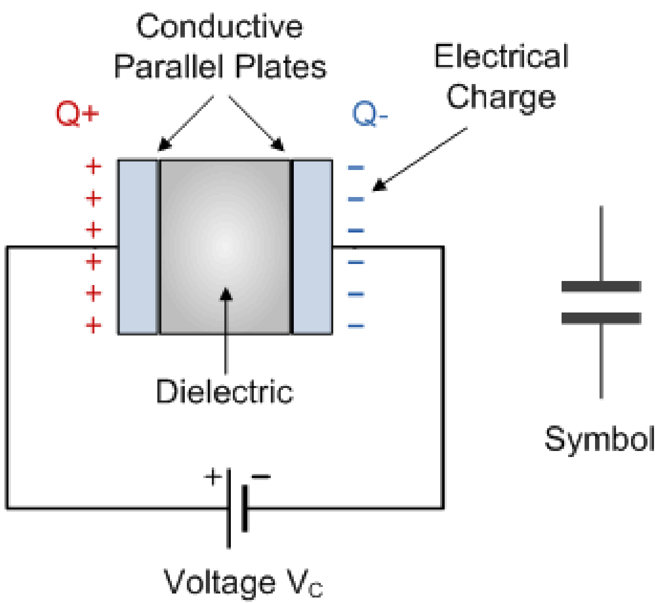


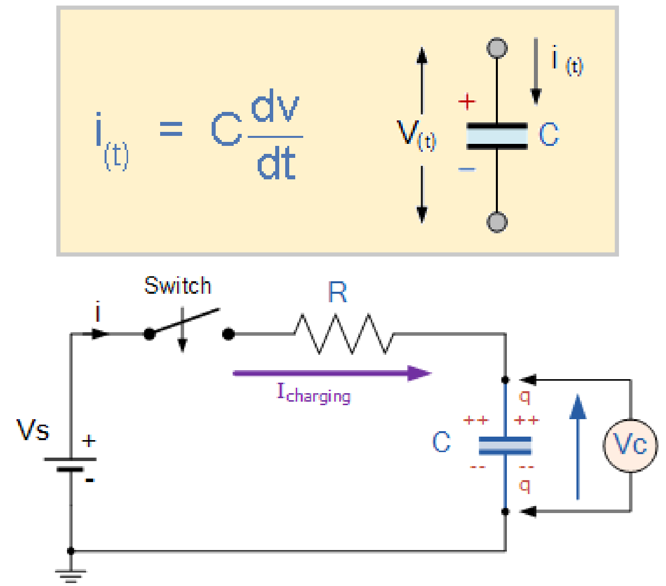
$$V_{RMS} = \sqrt{\frac{V_1^2 + V_2^2 + V_3^2 + V_4^2 + \ldots + V_n^2}{n}}$$

Convert From	Multiply By	Or By	To Get Value
Peak	2	$(\sqrt{2})^2$	Peak-to-Peak
Peak-to-Peak	0.5	1/2	Peak
Peak	0.707	$1/(\sqrt{2})$	RMS
Peak	0.637	$2/\pi$	Average
Average	1.570	$\pi/2$	Peak
Average	1.111	$\pi/(2\sqrt{2})$	RMS
RMS	1.414	$\sqrt{2}$	Peak
RMS	0.901	$(2\sqrt{2})/\pi$	Average

Capacitors

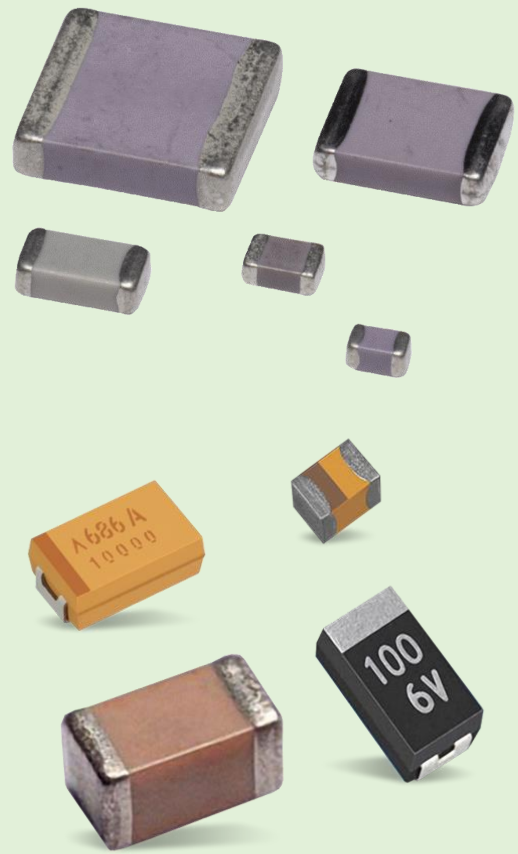
- **Capacitor:** stores energy in the form of electrical charge
- Value measured in **Farads** (F)
- Typically drawn as two parallel plates
- Opposes changes in voltage across the capacitor





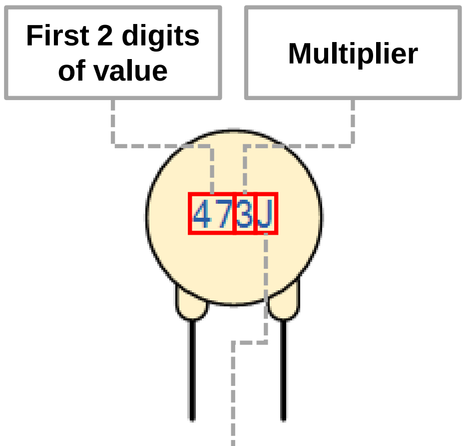
Capacitors

Through-hole (PTH)



Surface-mount (SMD)

Capacitor markings



Tolerance:

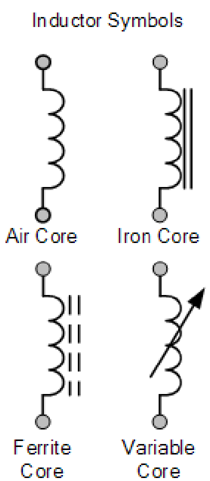
Letter	Tolerance
D	± 0.5%
F	± 1%
G	± 2%
J	± 5%
K	± 10%
M	± 20%
Z	+80% / -20%

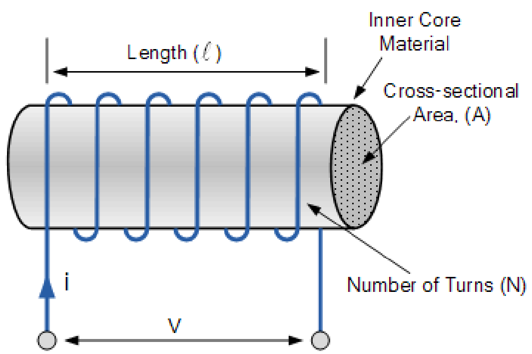
Picofarad (pF)	Nanofarad (nF)	Microfarad (μF)	Code
10	0.01	0.00001	100
15	0.015	0.000015	150
22	0.022	0.000022	220
33	0.033	0.000033	330
47	0.047	0.000047	470
100	0.1	0.0001	101
120	0.12	0.00012	121
130	0.13	0.00013	131
150	0.15	0.00015	151
180	0.18	0.00018	181
220	0.22	0.00022	221
330	0.33	0.00033	331
470	0.47	0.00047	471
560	0.56	0.00056	561
680	0.68	0.00068	681
750	0.75	0.00075	751
820	0.82	0.00082	821
1,000	1	0.001	102
1,500	1.5	0.0015	152
2,000	2	0.002	202
2,200	2.2	0.0022	222
3,300	3.3	0.0033	332

Picofarad (pF)	Nanofarad (nF)	Microfarad (μF)	Code
4,700	4.7	0.0047	472
5,000	5	0.005	502
5,600	5.6	0.0056	562
6,800	6.8	0.0068	682
10,000	10	0.01	103
15,000	15	0.015	153
22,000	22	0.022	223
33,000	33	0.033	333
47,000	47	0.047	473
68,000	68	0.068	683
100,000	100	0.1	104
150,000	150	0.15	154
200,000	200	0.2	254
220,000	220	0.22	224
330,000	330	0.33	334
470,000	470	0.47	474
680,000	680	0.68	684
1,000,000	1000	1	105
1,500,000	1500	1.5	155
2,000,000	2000	2	205
2,200,000	2200	2.2	225
3,300,000	3300	3.3	335

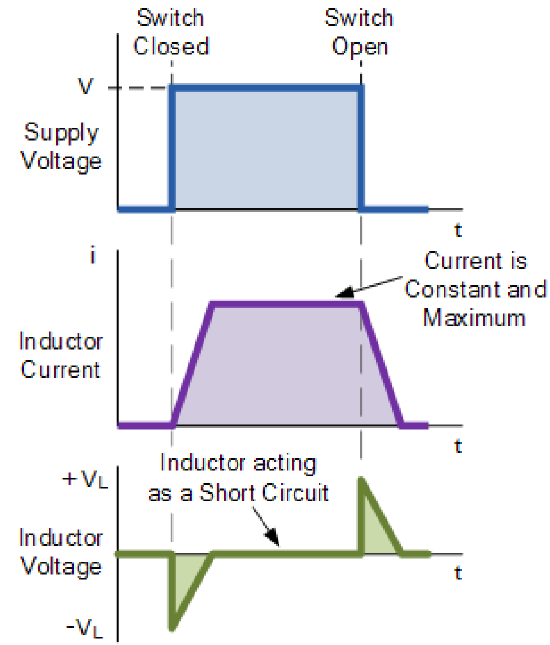
Inductors

- **Inductor:** Stores energy in the form of a magnetic field
- Value measured in **Henries** (H)
- Typically drawn as a coil of wire
- Opposes changes in current

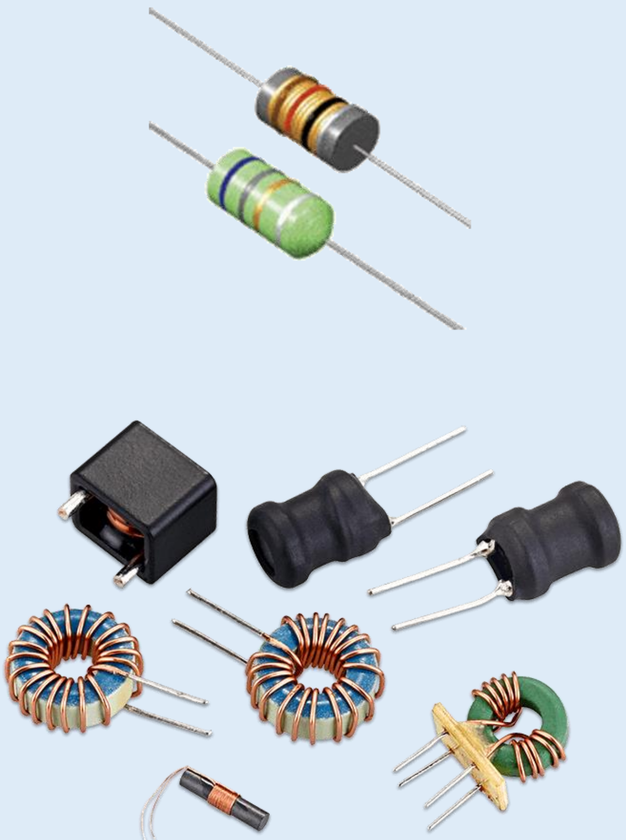




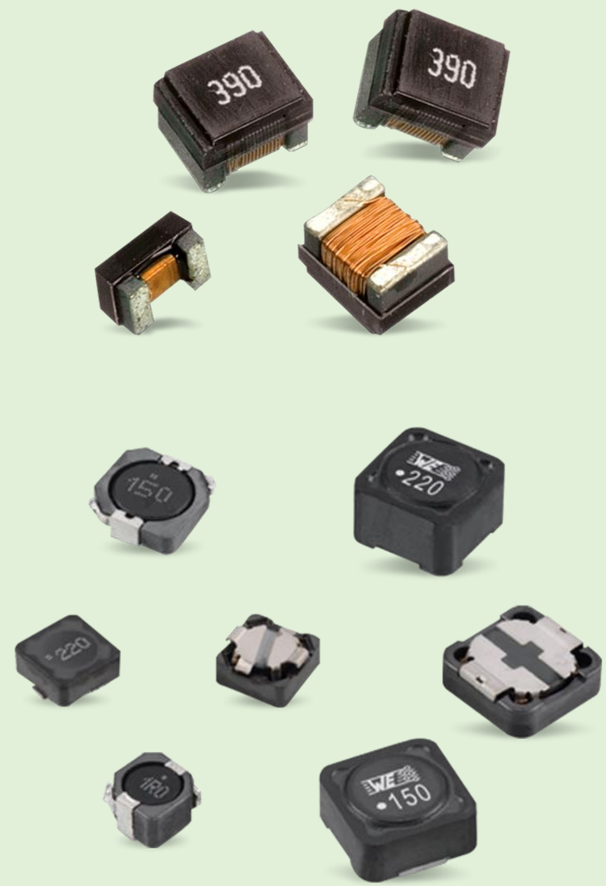
$$V_L = -L\frac{di}{dt}$$



Inductors



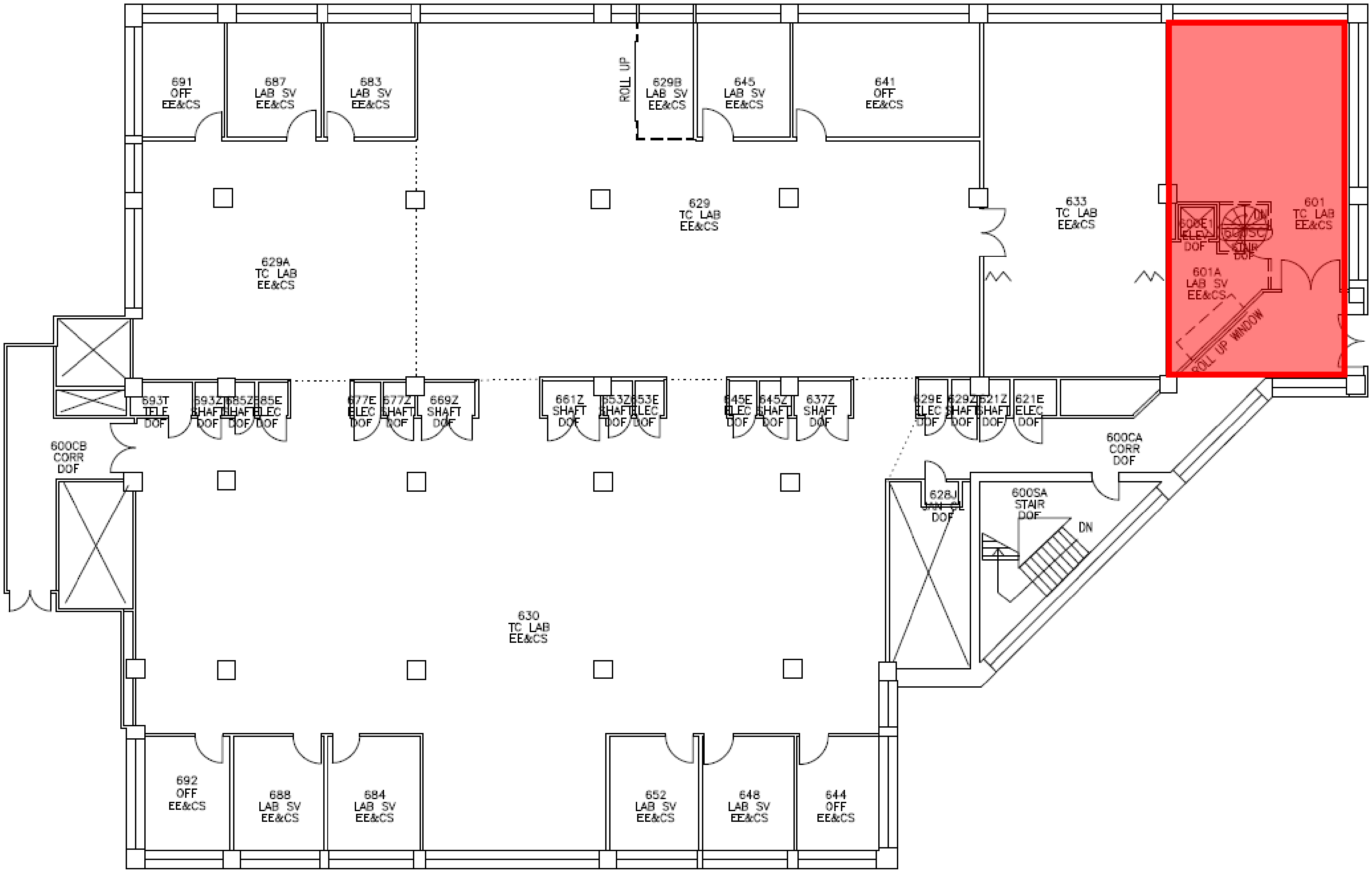
Through-hole (PTH)



Surface-mount (SMD)

Lab overview and safety

Lab space

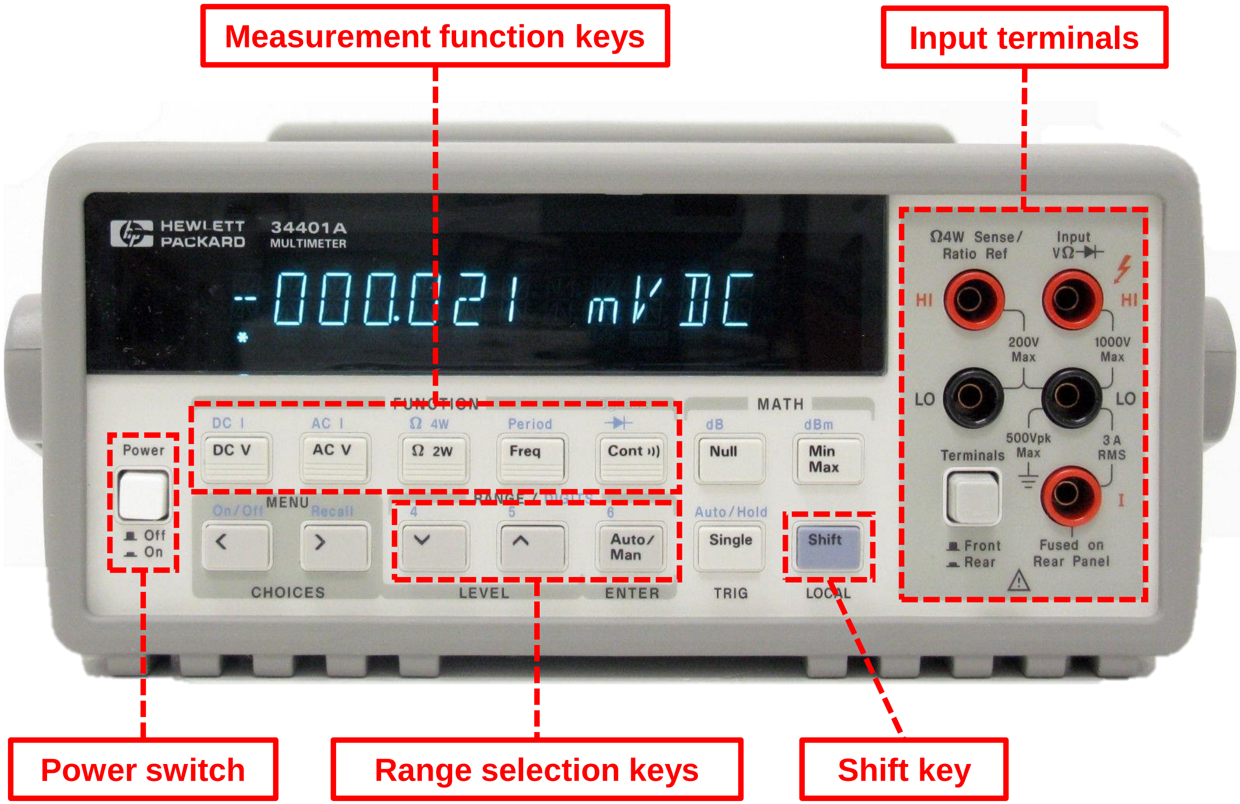


691 OFF EE&CS
687 LAB SV EE&CS
683 LAB SV EE&CS
ROLL UP
629B LAB SV EE&CS
645 LAB SV EE&CS
641 OFF EE&CS
629 TC LAB EE&CS
633 TC LAB EE&CS
601 TC LAB EE&CS
601A LAB SV EE&CS
ROLL UP WINDOW
629A TC LAB EE&CS
600CB CORR DOF
600CA CORR DOF
600SA STAIR DOF
DN
628J DOF
630 TC LAB EE&CS
692 OFF EE&CS
688 LAB SV EE&CS
684 LAB SV EE&CS
652 LAB SV EE&CS
648 LAB SV EE&CS
644 OFF EE&CS

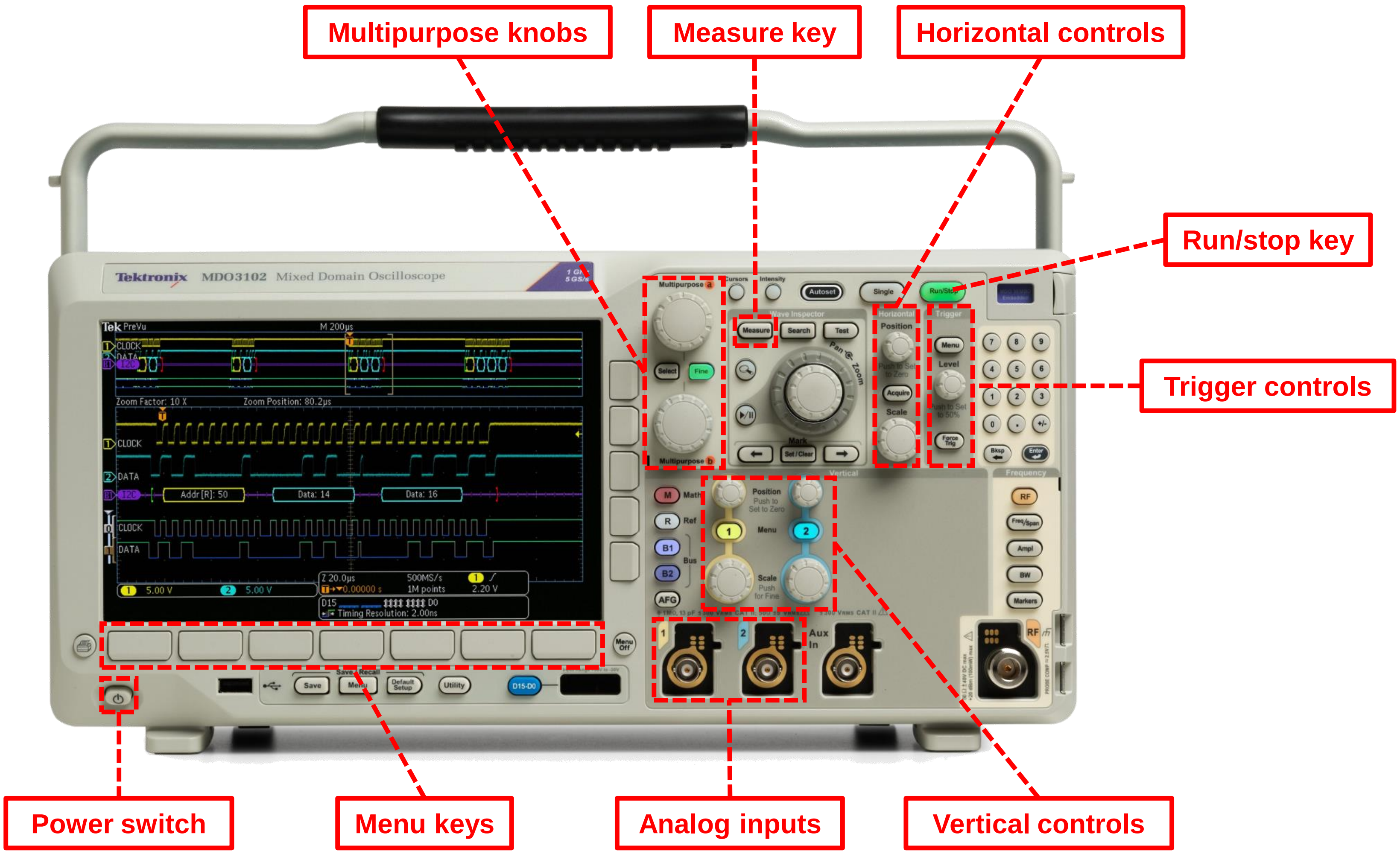
Instrumentation

- Digital multimeter (DMM)
- Oscilloscope
- Function generator

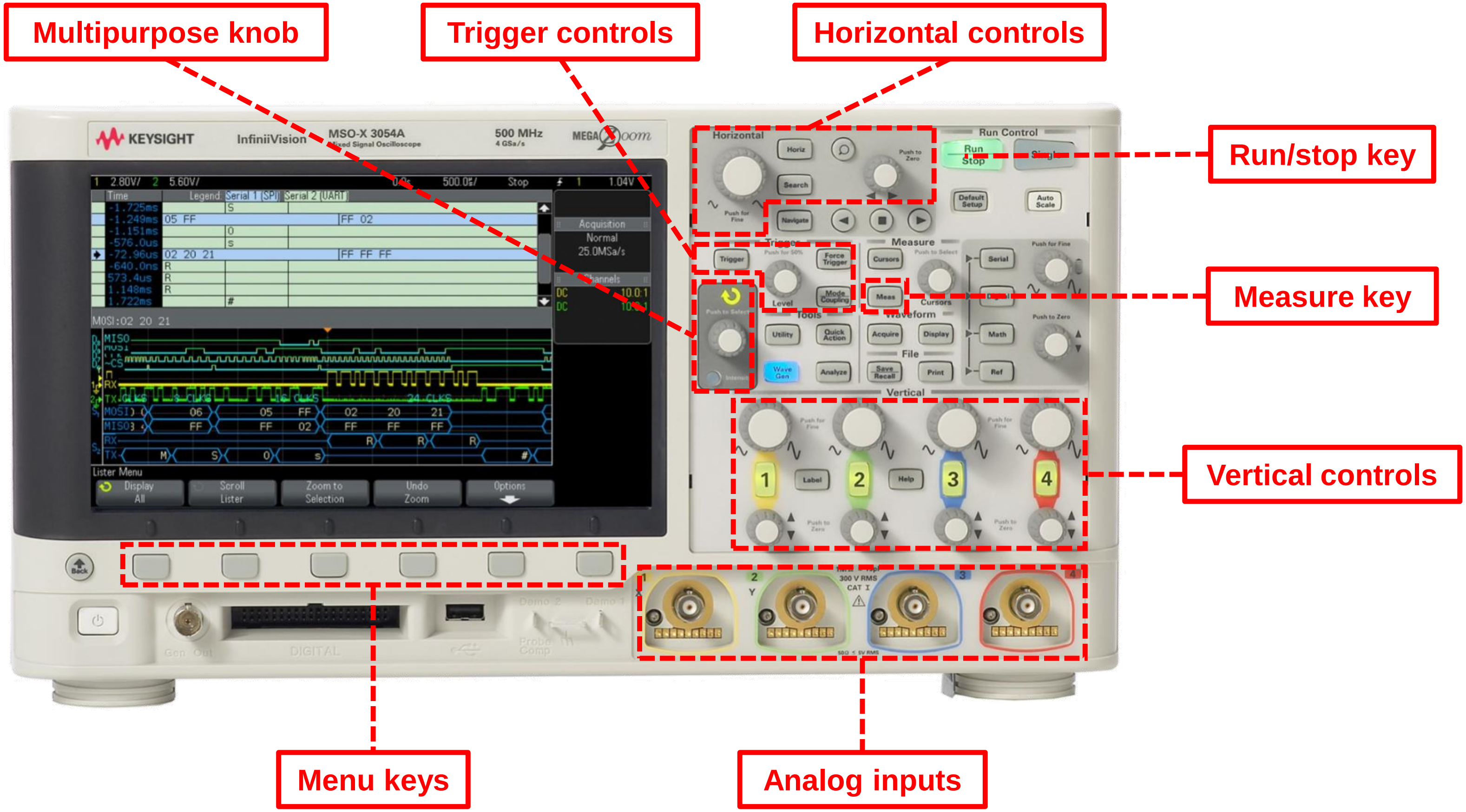
Digital multimeter (DMM)



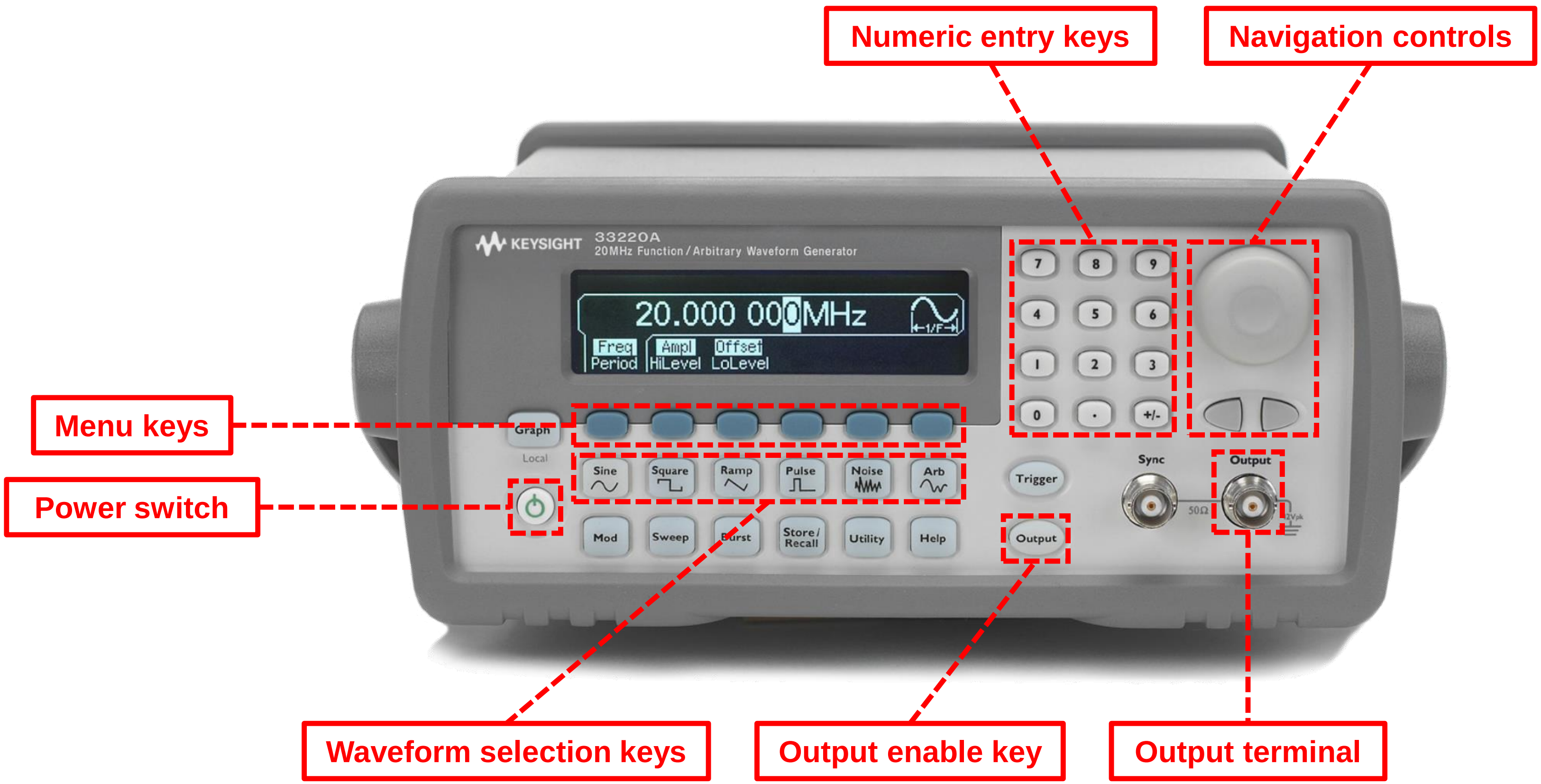
Oscilloscope (type 1)



Oscilloscope (type 2)



Function generator



Tools

- Needle-nose pliers
- Wire cutters (diagonal pliers)
- Wire strippers
- Solderless breadboard
- Soldering iron

Needle-nose pliers; wire cutters

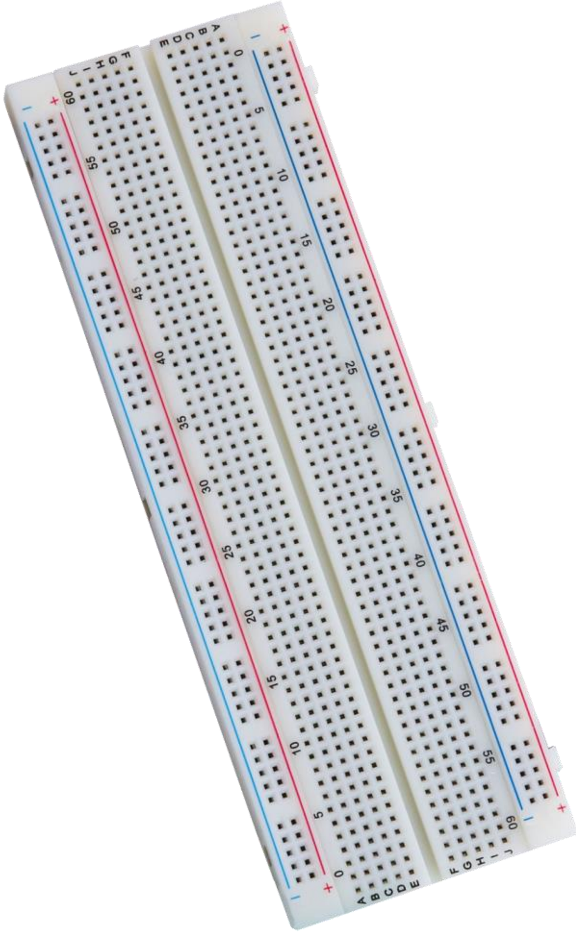
Needle-nose pliers

Wire cutters ("diagonal pliers")

Wire strippers

Solderless breadboard

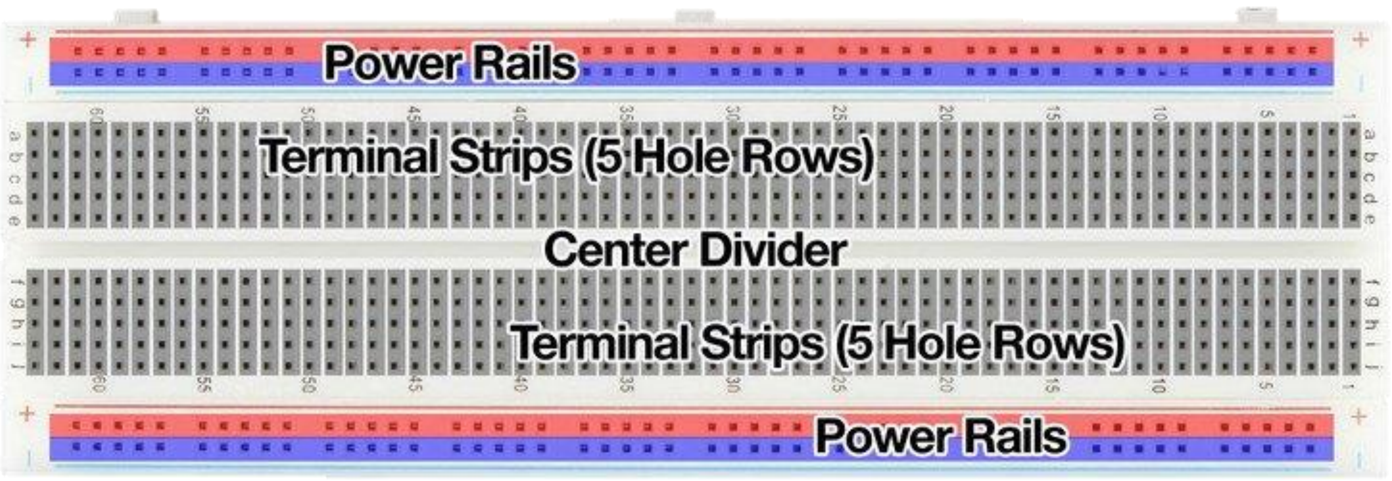
Large breadboard with power supply



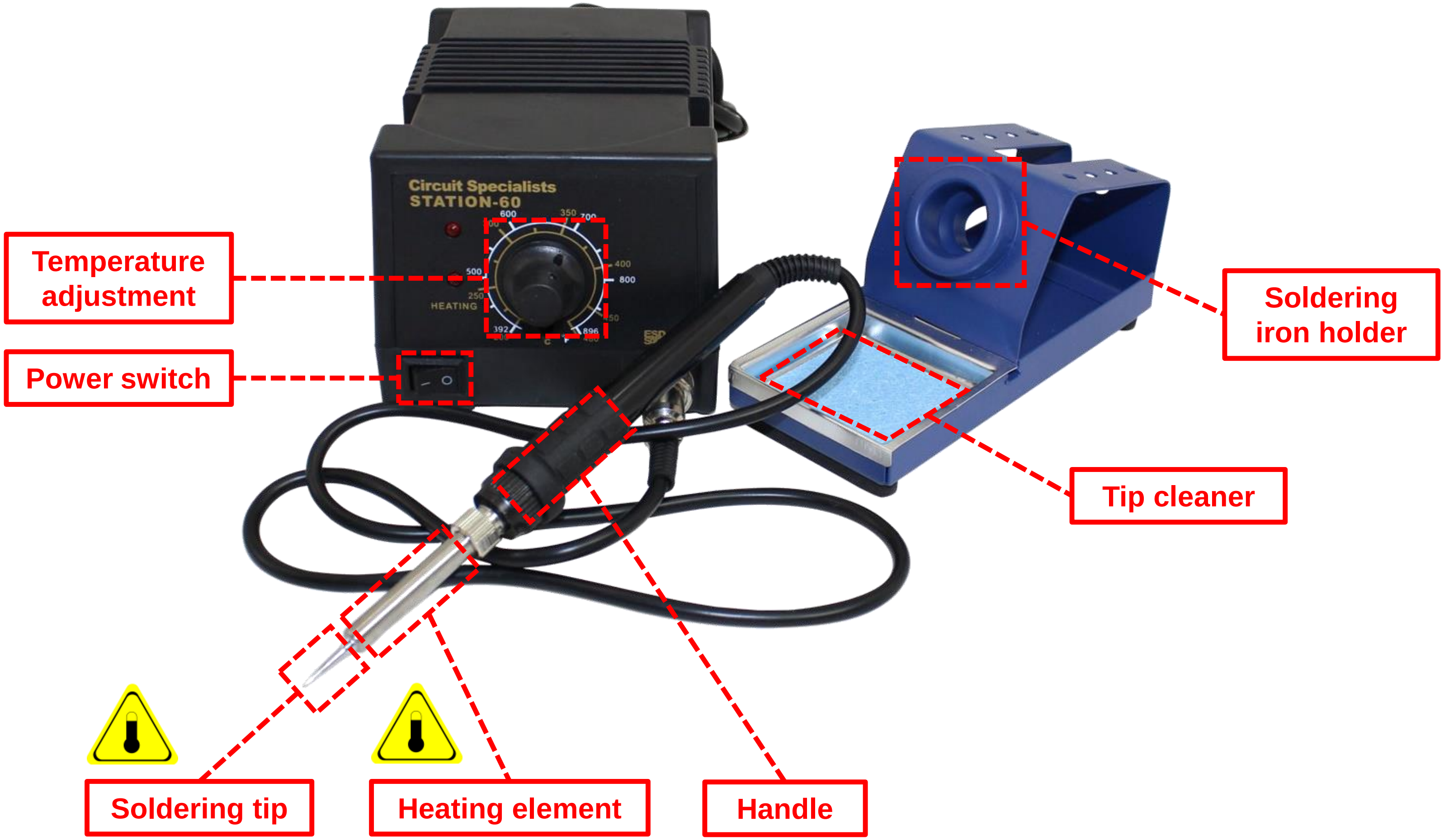
Small breadboard

Solderless breadboard

- **Breadboard:** Convenient way to prototype circuits
- Terminal strips go top-to-bottom for signals, side-to-side for power rails

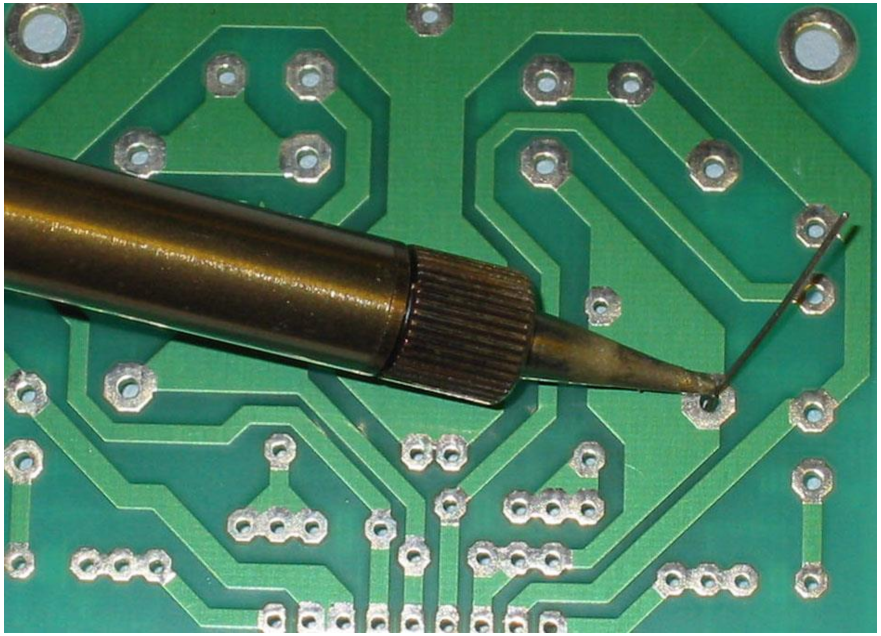


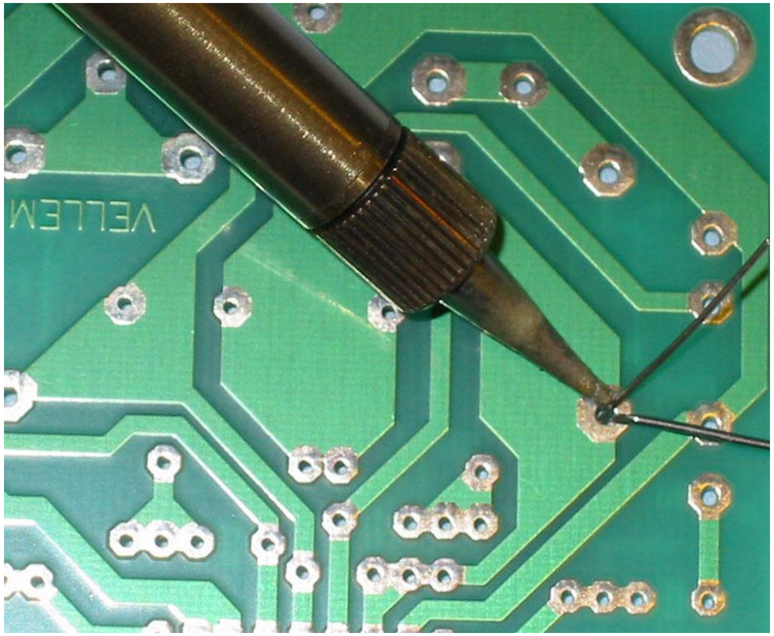
Soldering station



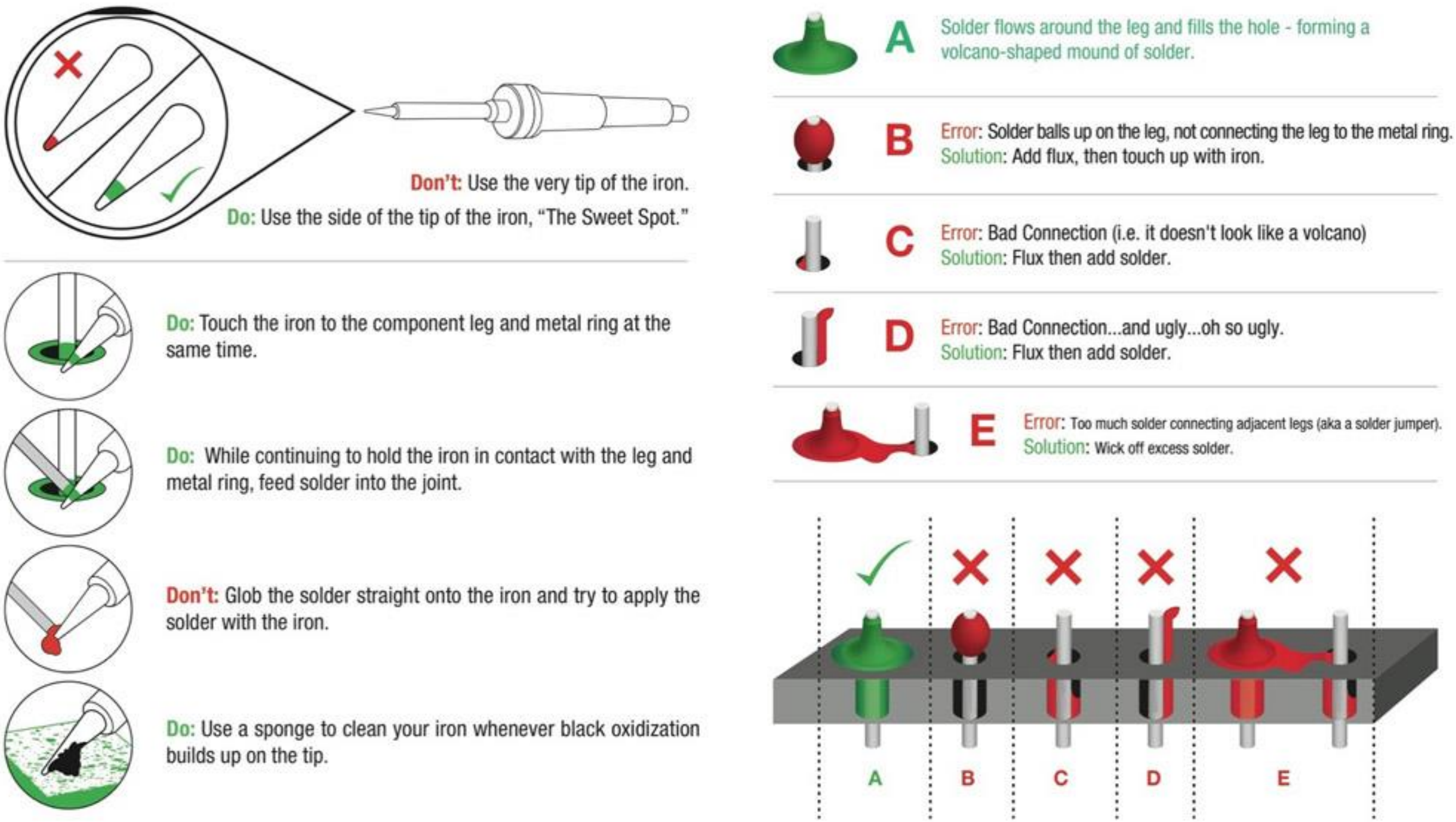
Soldering technique

- Apply the soldering iron to the **component** first, then feed the solder into the joint
- Some components take longer to heat than others



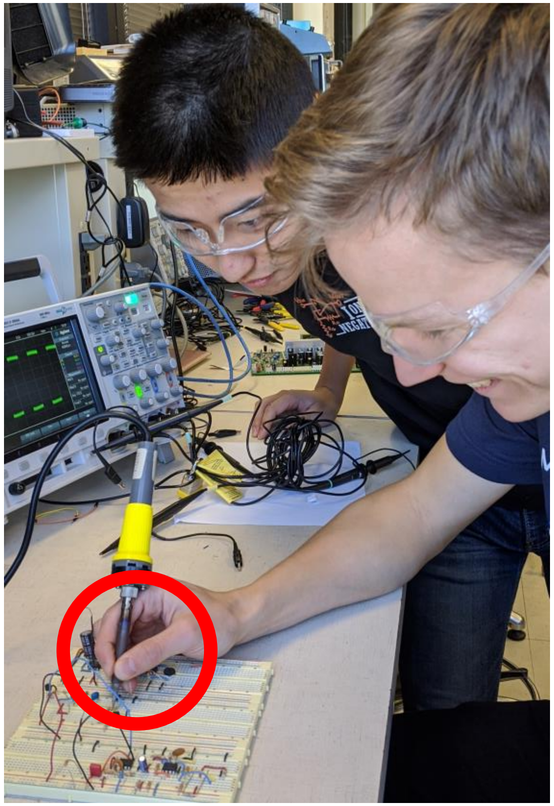


Soldering technique



Safety

Don’t do this!



…or this

…or this

Electrical safety

- Currents as low as **5-10 mA** can cause death
- **Skin resistance** ranges from 1k (wet) to 500k (dry)
- Death can result from **as low as 50 volts**
- Body can sense **9 volts** under the right conditions

Chemical safety

- Solder contains **lead**, a known neurotoxin
- **Never bring food** into the lab to avoid contamination
- Always **wash hands with soap and water** immediately after leaving the lab