



Basic Circuits Review

ME240



Two basic classes of circuits

- Direct current

- Current always flows in the same direction

- Alternating current

- Current reverses direction at some predetermined frequency

Three “passive” component types

- Resistors



- Capacitors



- Inductors



Resistors



- A resistor is a device that “resists” the flow of current.
- Typically made of carbon or alloy wire
- Resistors are rated in Ohms (Ω)
- All resistors have a tolerance
 - Typically 10%, but others are available
- Color coded or labeled with value
 - Code is available on class web site

DC Resistor Circuits

- Ohms law

- E – Voltage (Volts)

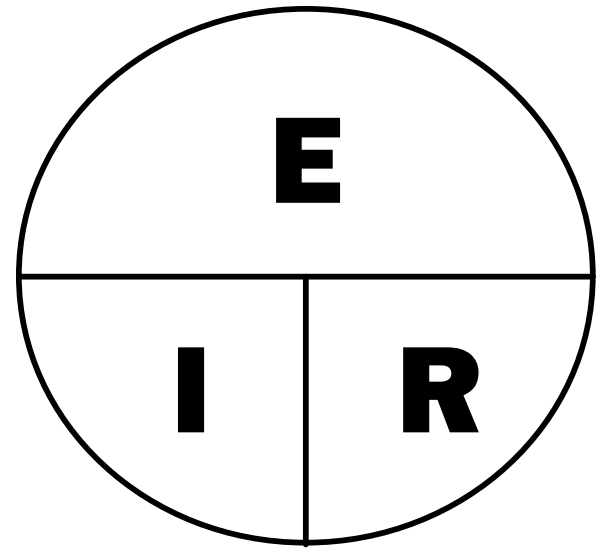
- I – Current (Amps)

- R – Resistance (Ohms)

- Voltage = Current x Resistance

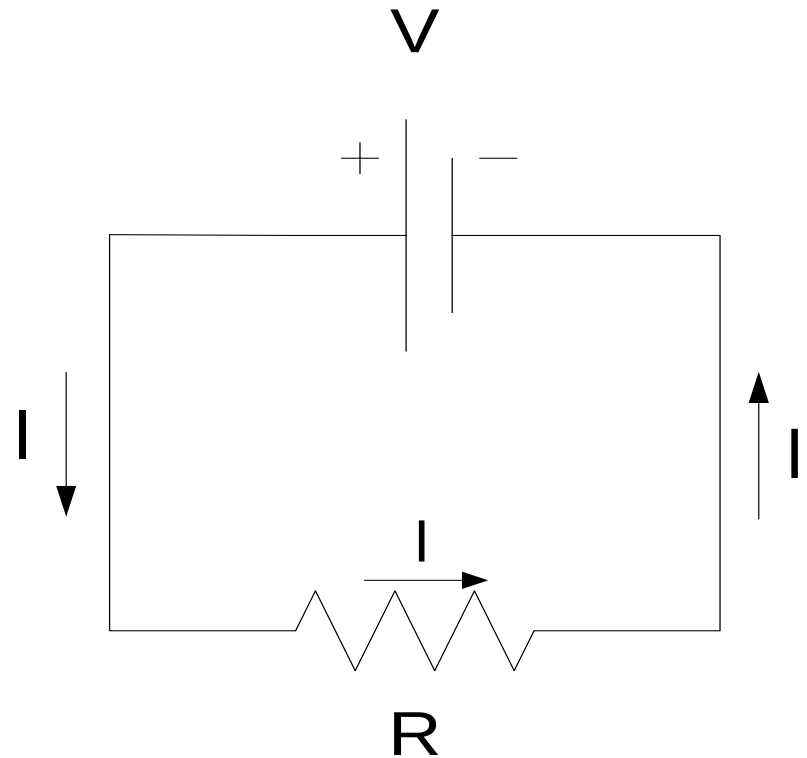
- Current = Voltage / Resistance

- Resistance = Voltage / Current

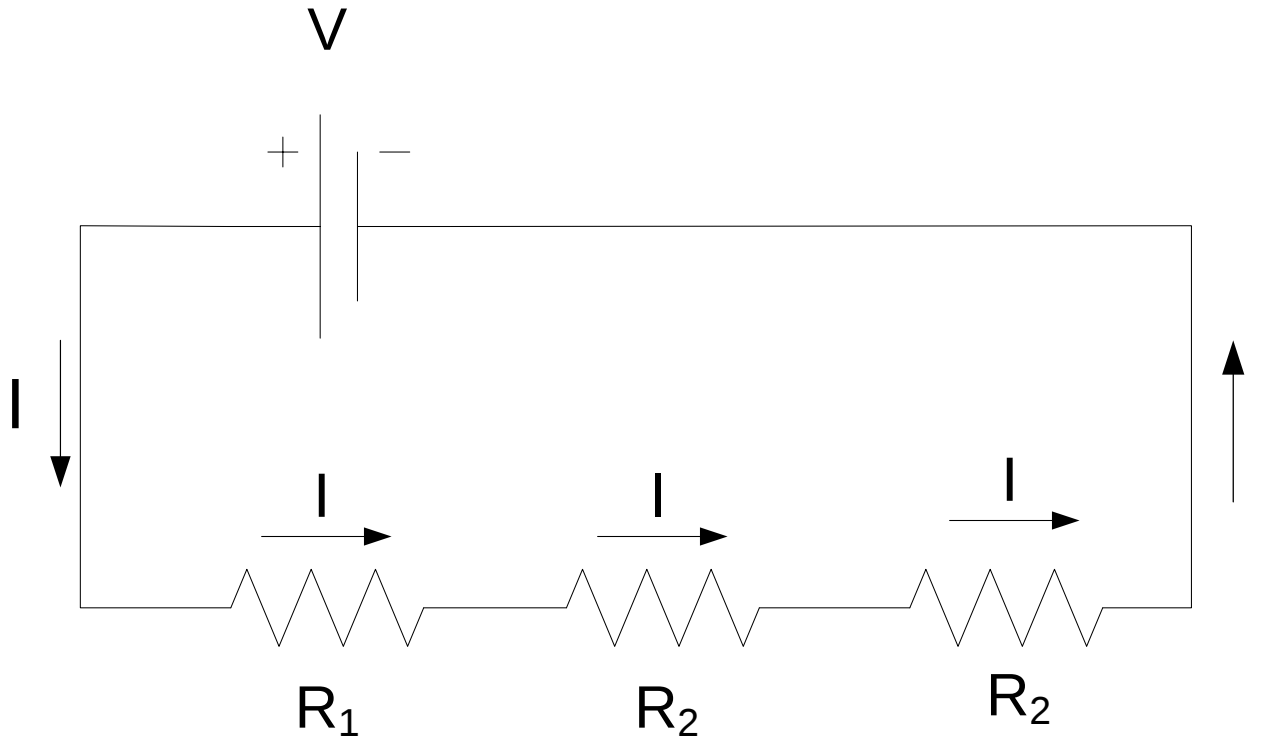


A note about current

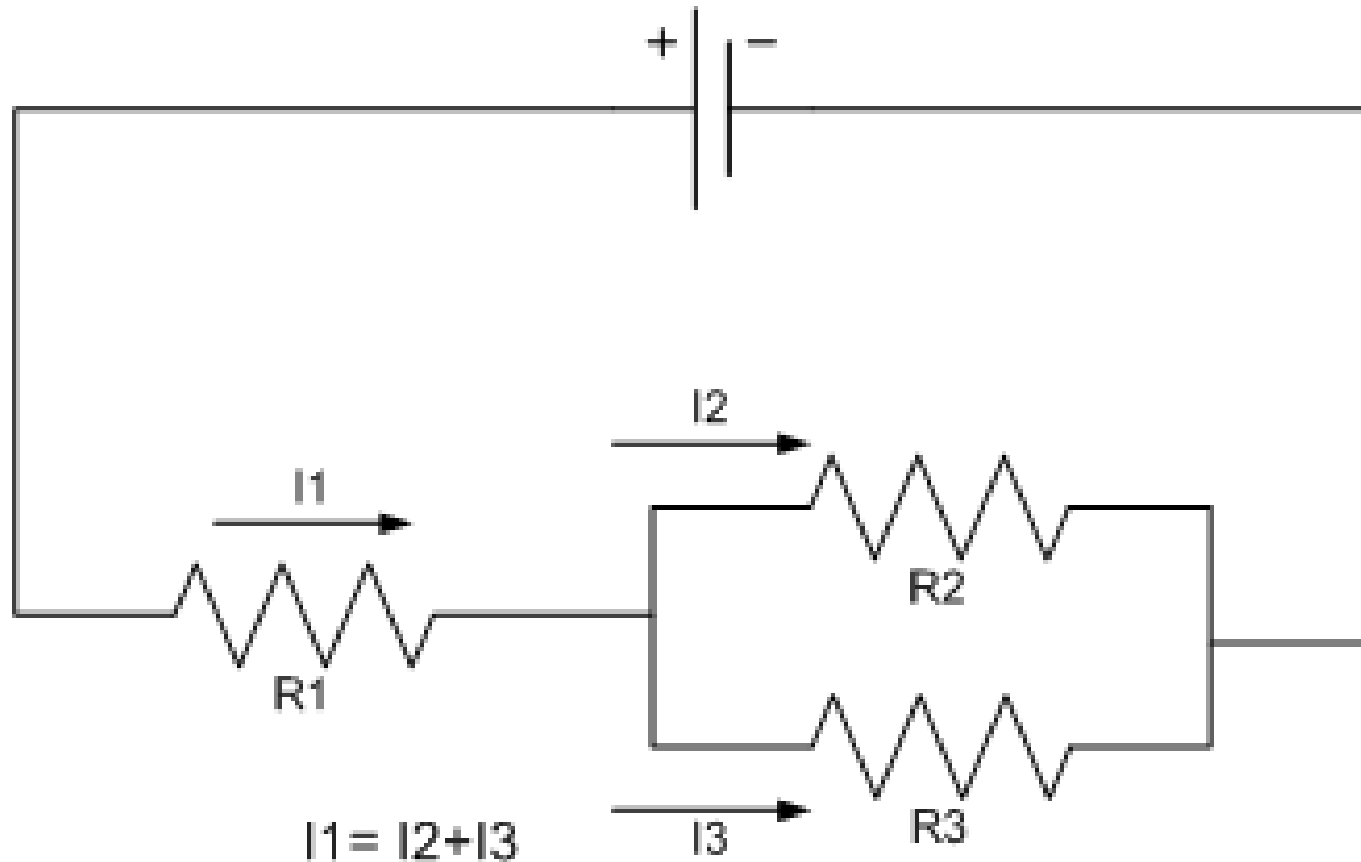
- Current in a closed loop is the same at all points in the loop!



Even in a series circuit



Current splits in parallel circuits

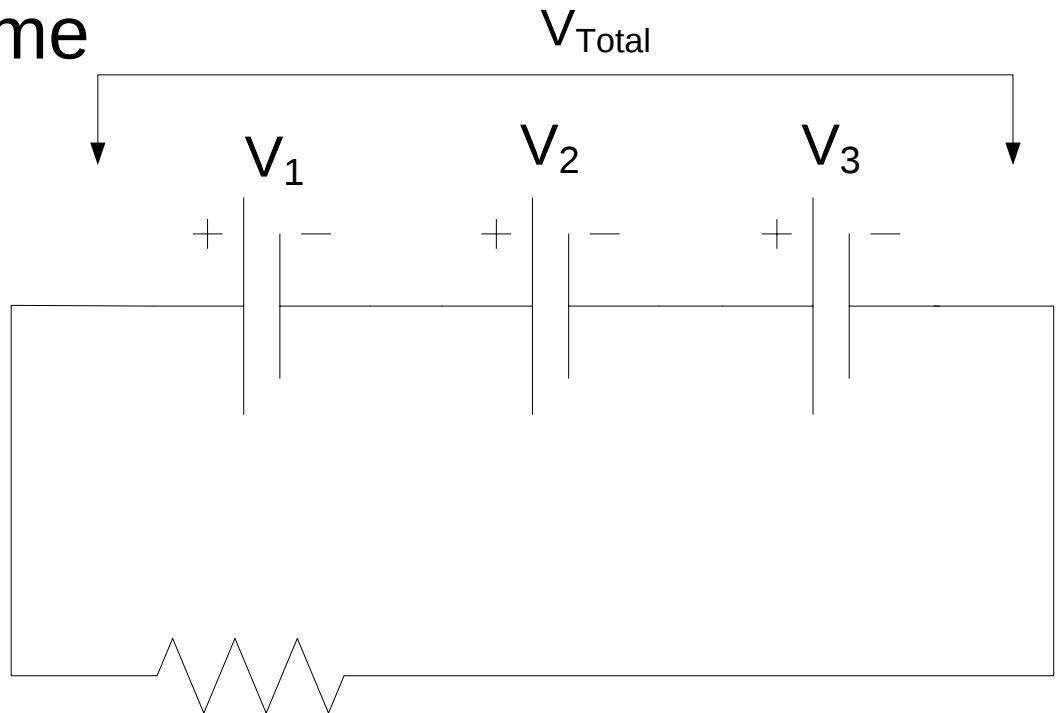


current into any node must equal the current out of the node

Power supplies

- Typical series battery circuit
- Voltages with same polarity add

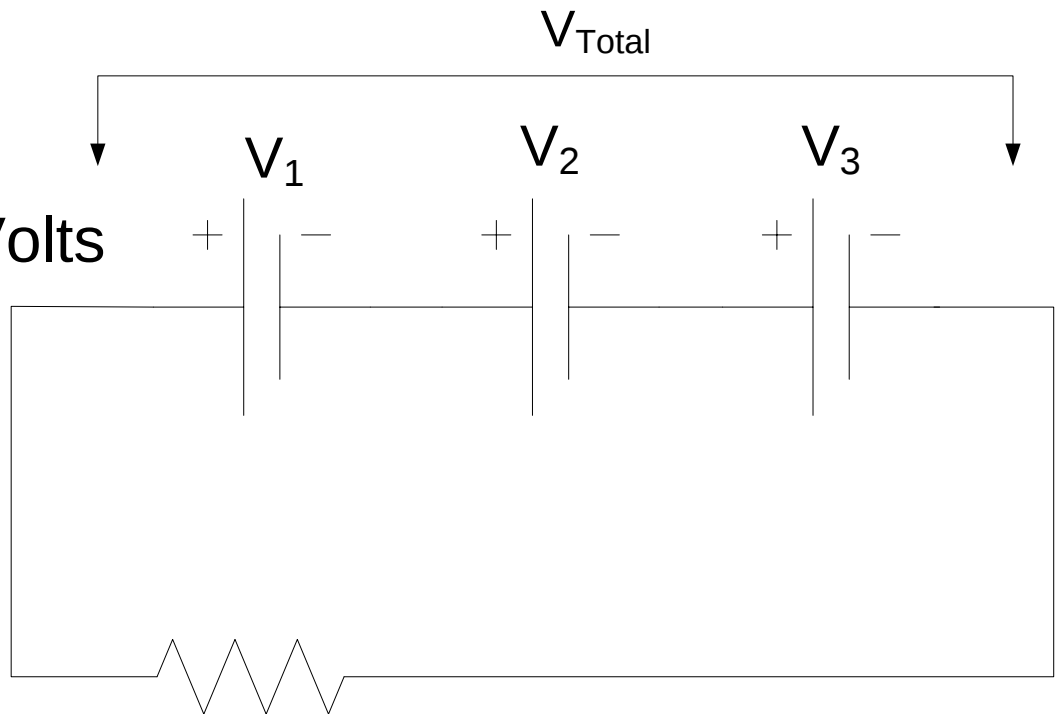
- $V_1 + V_2 + V_3 = V_{\text{total}}$



1.5 Volt Batteries

- Each battery in series
- Each battery = 1.5 Volts

- $1.5 + 1.5 + 1.5 = 4.5$ Volts

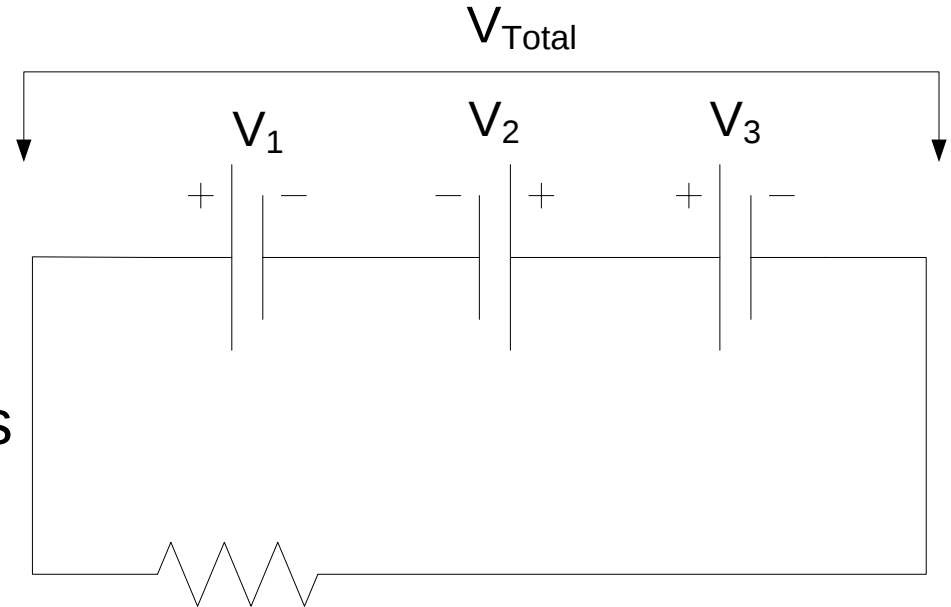


OOPS! One battery in backwards!

- Reversed voltages subtract
- Each battery = 1.5 Volts
- Note V_2 reversed

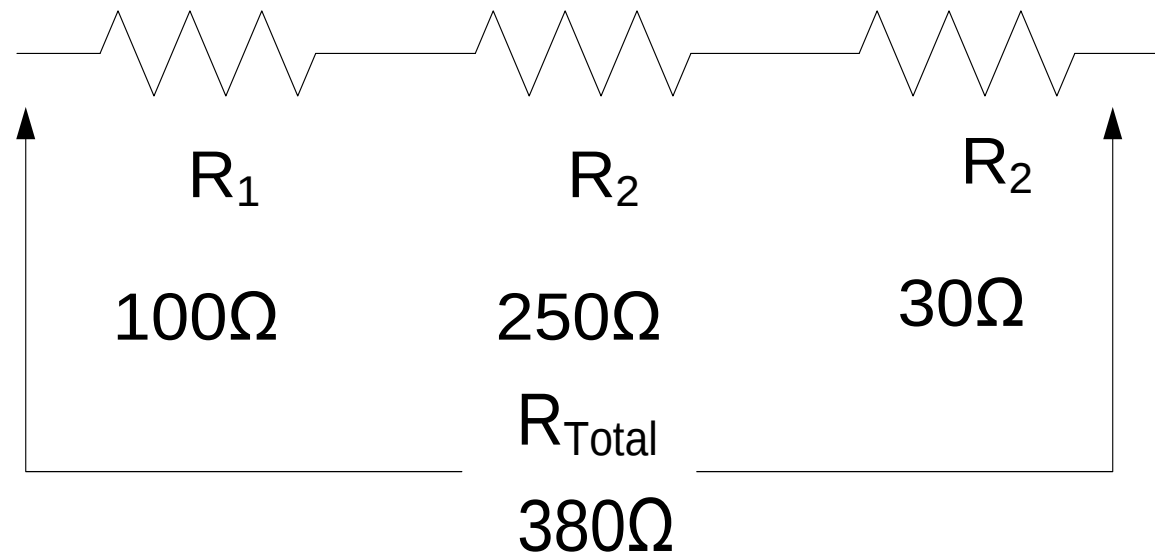
$$1.5 + (-1.5) + 1.5 = 1.5 \text{ Volts}$$

↑ ↑



Resistors in Series

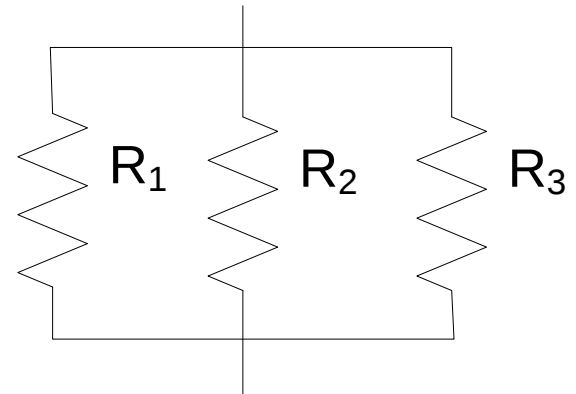
- Series resistors add in value



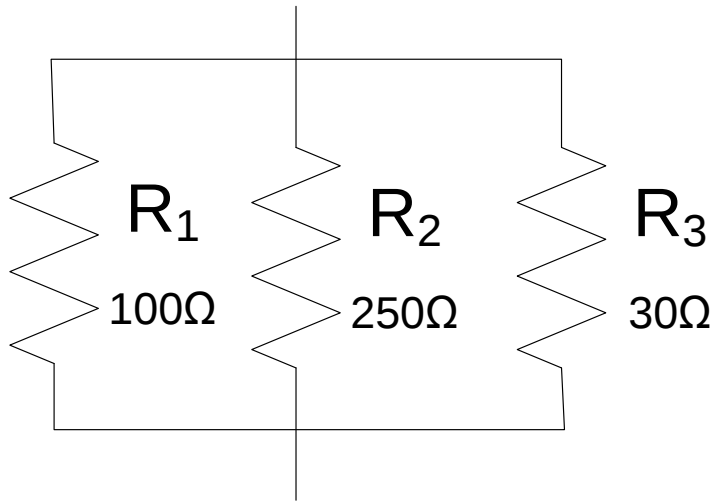
Resistors in Parallel

- Value determined by following formula:

$$R_{Total} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_N}}$$



Example

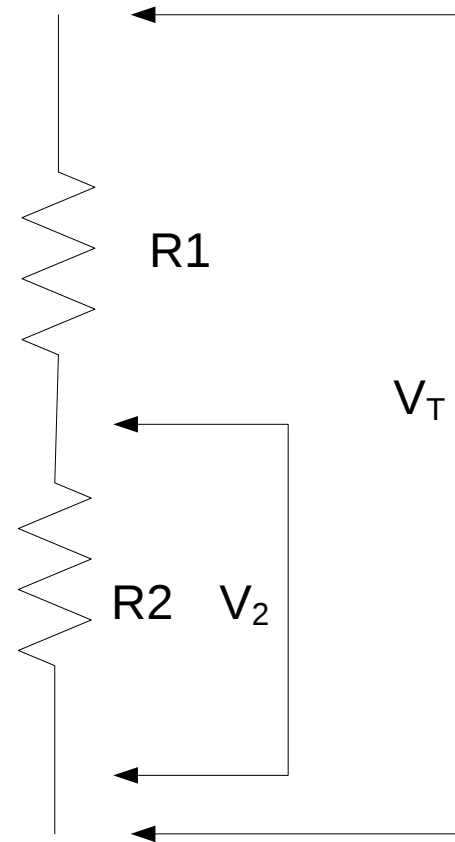


$$R_{Total} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_N}}$$

$$21.13\Omega = \frac{1}{\frac{1}{100} + \frac{1}{250} + \frac{1}{30}}$$

Voltage divider Network

- Current in a series circuit is same through both resistors
- Apply ohms law to each resistor and we will see if the current is constant, the resulting voltage will be different.

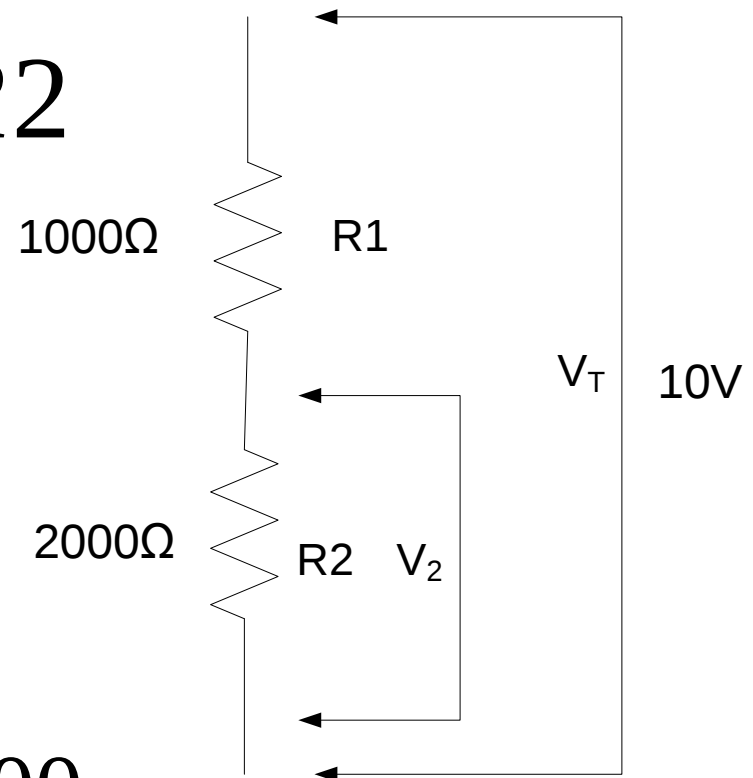


Voltage divider Network

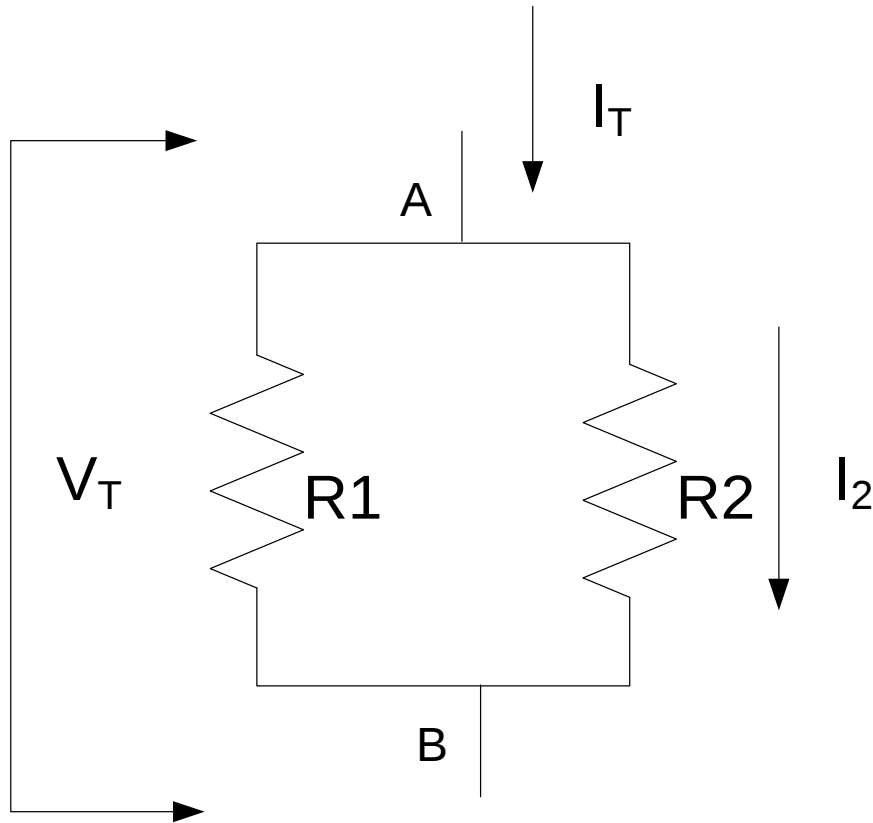
$$V_2 = \left(\frac{V_T}{R1 + R2} \right) \times R2$$

$$I = \frac{E}{R} = \frac{E}{R1 + R2} \quad V_2 = I_2 \times R_2$$

$$6.66 = \left(\frac{10}{1000 + 2000} \right) \times 2000$$



Current Divider Network



- Sum of current into a node equals the sum of the current out of a node (both node A and B)
- Voltage across each resistor is equal
- Apply ohms law to determine current in each leg.

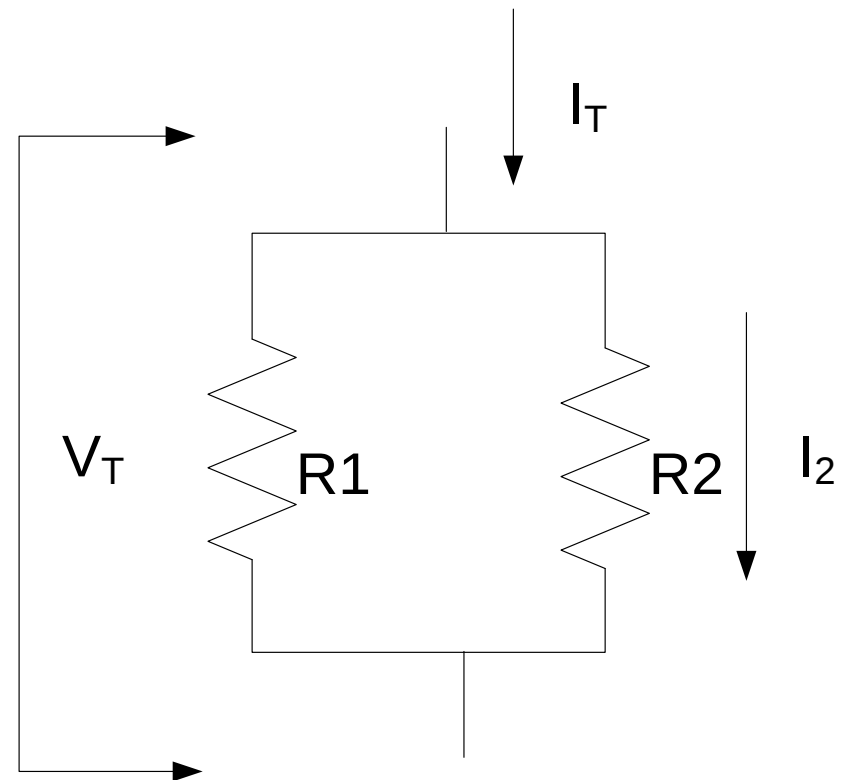
Current Divider Network

What is the current through R2? (I_2)

$$I_2 = \frac{V_T}{R_2} \quad V_T = I_T \times \left(\frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} \right)$$

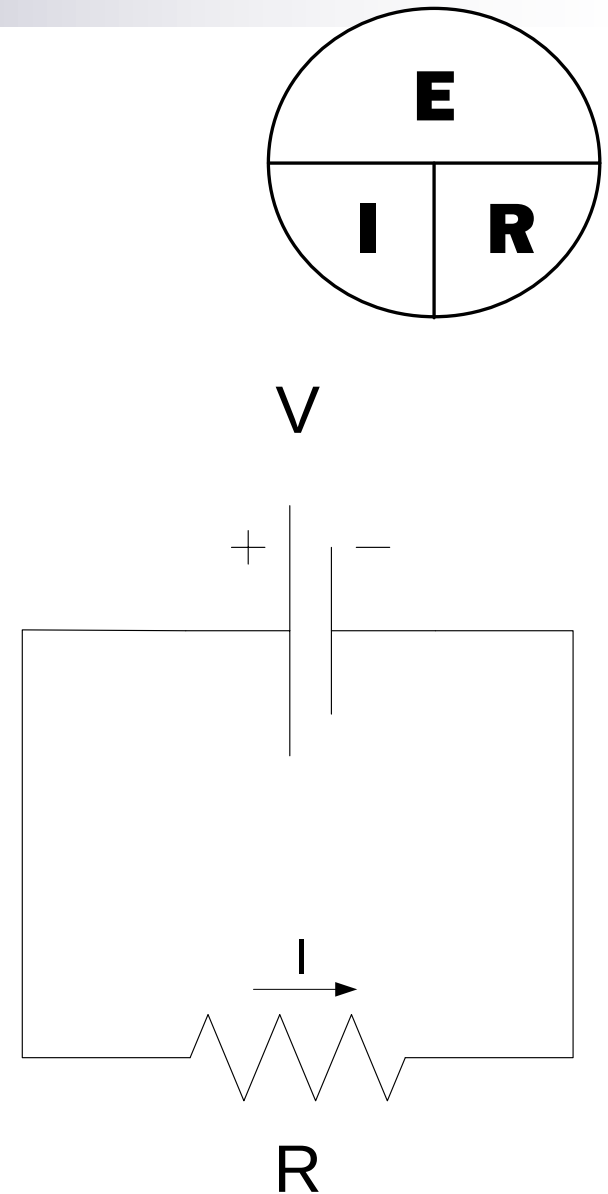
Re-write V_T

$$I_2 = \frac{I_T \left(\frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} \right)}{R_2}$$



Constant Voltage

- Voltage stays constant regardless of load resistance
- Current varies with load
- $V = 10$ Volts
- If $R = 100\Omega \rightarrow I = 100$ mA
- If $R = 500\Omega \rightarrow I = 20$ mA



Constant Current

- Current stays constant
- Voltage across the load changes with resistance

$$I = 20 \text{ mA}$$

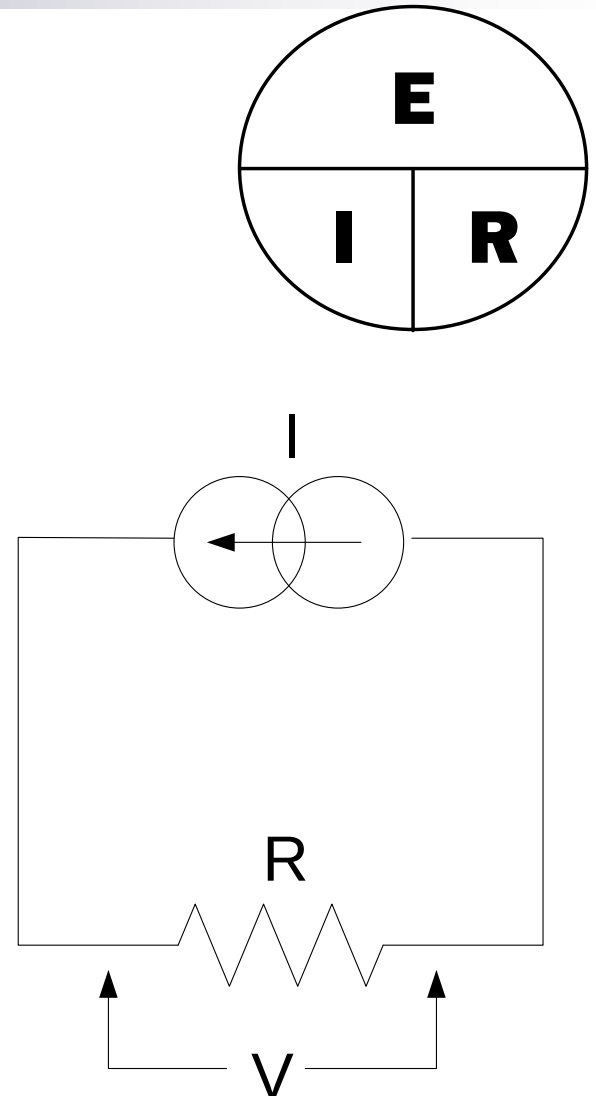
$$R = 200\Omega \rightarrow V = I \times R$$

$$V = .020 \times 200$$

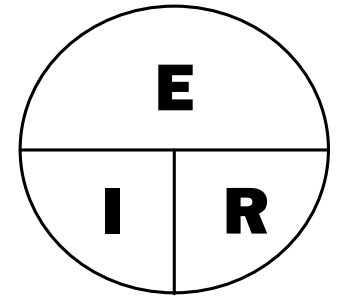
$$V = 4 \text{ Volts}$$

$$R = 600 \Omega \rightarrow V = .020 \times 600$$

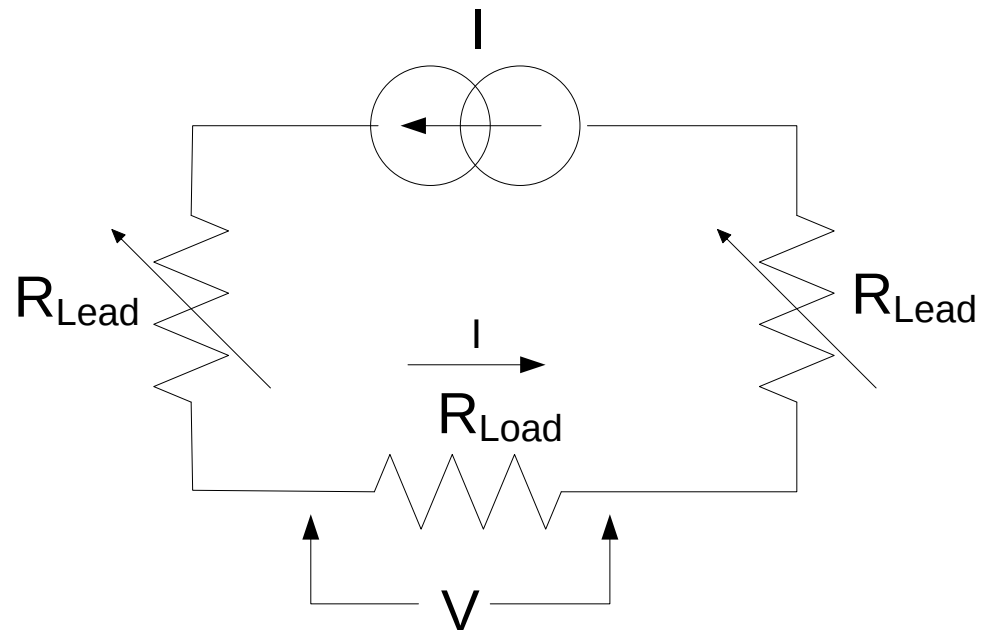
$$V = 12 \text{ Volts}$$



Lead resistance in a Current Loop



- As long as Source current and R_{load} stay constant, V will stay constant Regardless of what R_{lead} does.



Capacitors

- A capacitor is a device to store charge (energy)
- Rated in Farads
 - More common unit is microfarad (1×10^{-6})



Capacitors

- When contains **no charge**, effectively a **short** circuit (no resistance)
- When **fully charged**, effectively an **open** circuit (Infinite resistance)
- >>>Current flow varies with charge.

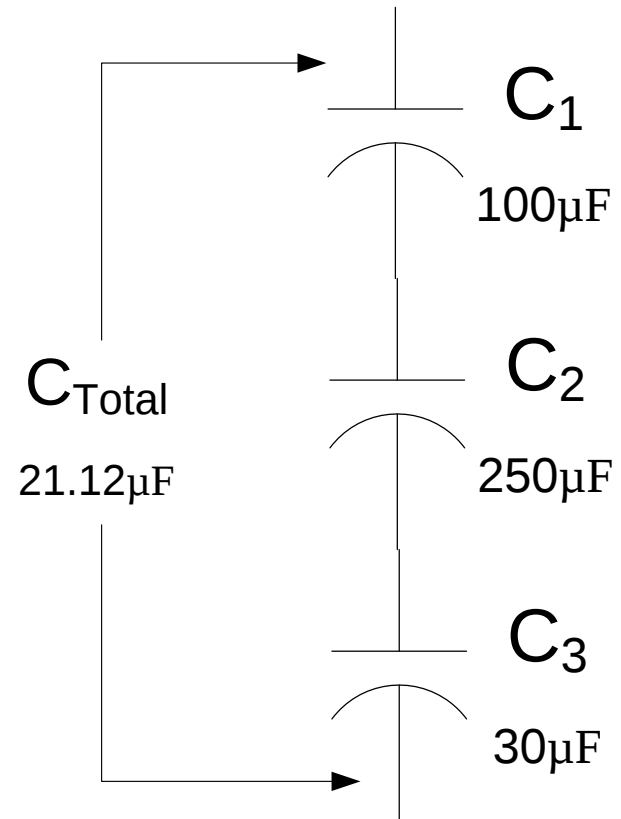
Series Capacitors

- Series capacitor value based on formula like paralleled resistors

$$C_{Total} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots + \frac{1}{C_N}}$$

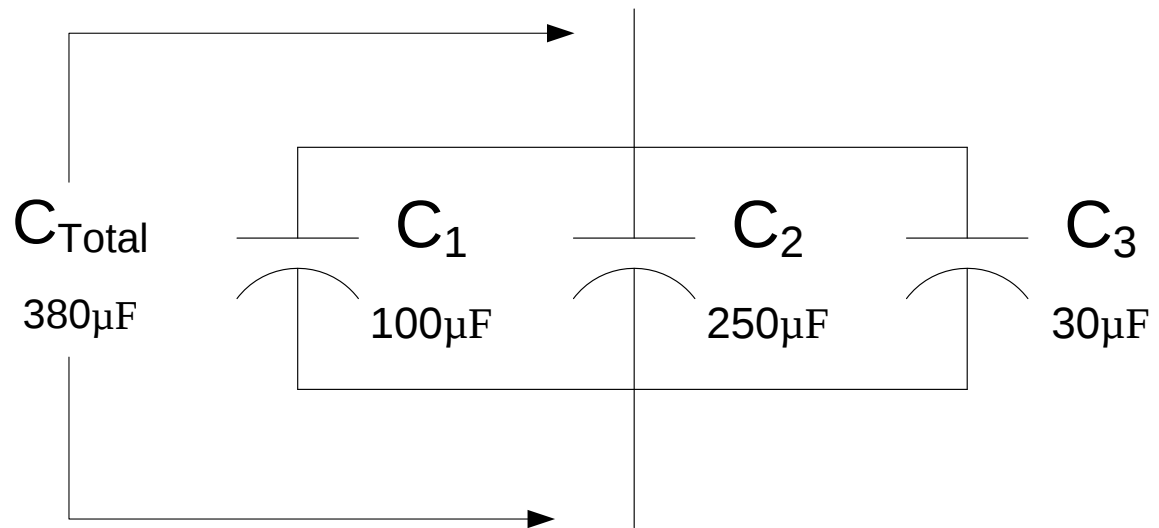
Series Capacitors

$$21.13\mu F = \frac{1}{\frac{1}{100} + \frac{1}{250} + \frac{1}{30}}$$



Parallel Capacitors

Parallel capacitors add
(like series resistors)





Rules of Current and magnetic fields

1. Moving a wire in a magnetic field creates a current
2. Moving a magnetic field past a wire creates a current
3. Flowing a current through a wire creates a magnetic field

Inductors



- An inductor is a coil of wire that resists the flow of current through the generation (change) of a magnetic field.
- Rated in “Henrys”
- Magnetic field only changes as current through coil changes.
- Once the current stops changing, the magnetic field stops changing!

Multiple coils

- No overlapping magnetic fields

- ☐ Series: Values add
- ☐ Parallel: Like resistors

$$L = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \dots + \frac{1}{L_n}}$$

- Two coils with the magnetic field overlapping

- ☐ Exhibit Mutual Inductance (Magnetic coupling)
- ☐ Can't be calculated easily



Mutual Inductance

- Air core
 - 60-70% maximum coupling
- Iron core
 - Approach 100%

We'll come back to this later....

AC effects on capacitors

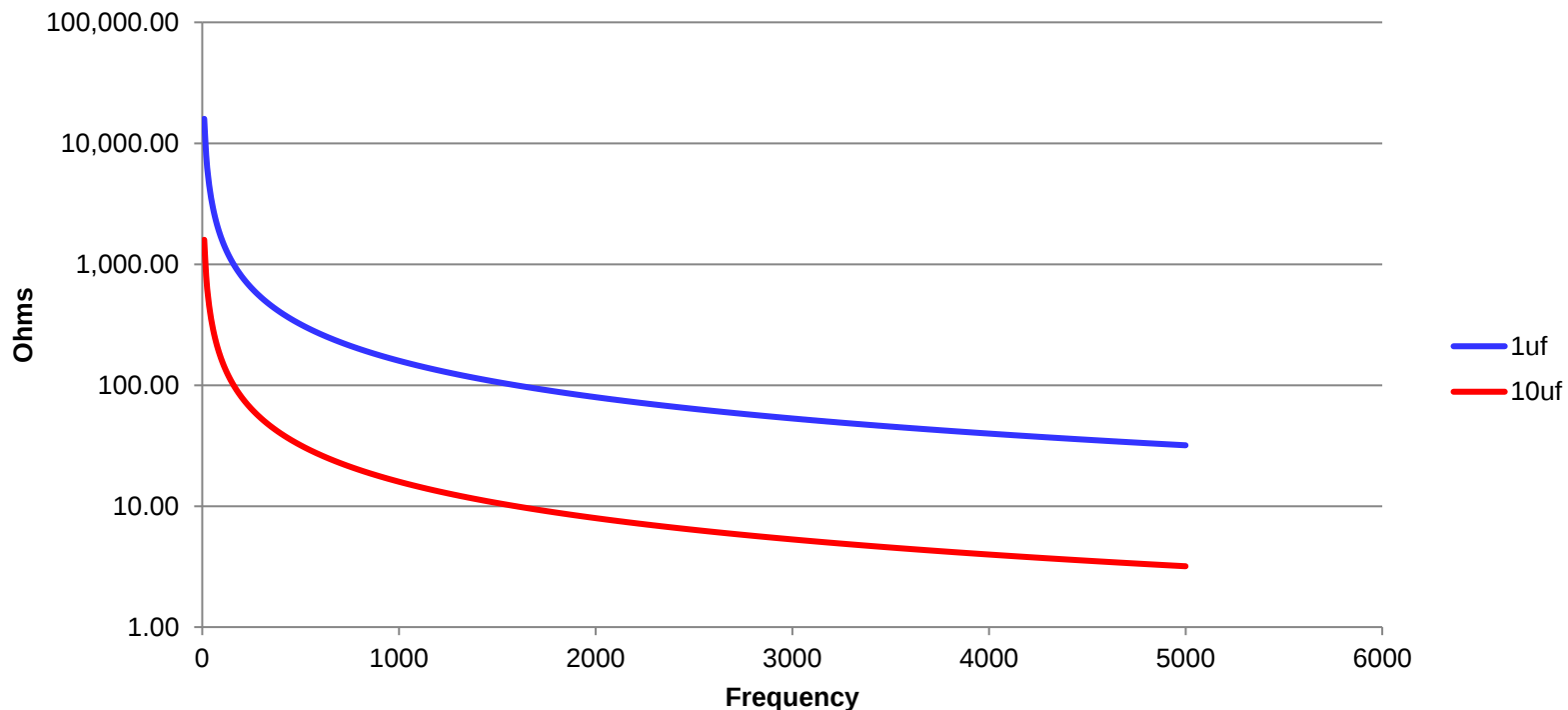
- Remember that the effective resistance of a capacitor changes with charge
- Since the current changes continuously the charge changes continuously!
- This resistance is called **Capacitive Reactance (X_C)**

$$X_C = \frac{1}{2\pi fC}$$

Effect of frequency

$$X_C = \frac{1}{2\pi fC}$$

- As frequency **increases**, reactance **decreases**
- Very non-linear response!



AC effects on inductors

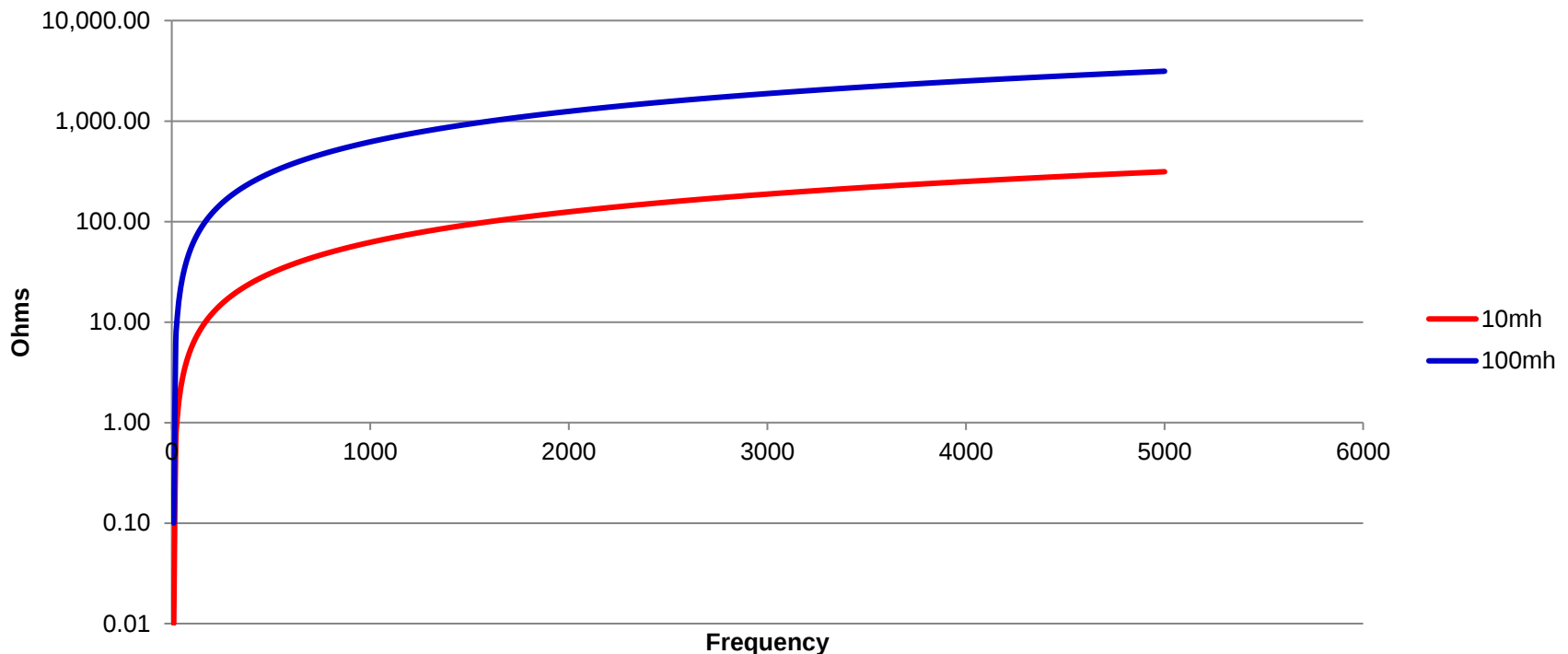
- Remember that the effective resistance of an inductor changes with the change in magnetic field
- This resistance is also called ***Inductive Reactance (X_L)***

$$X_L = 2\pi fL$$

Effect of Frequency

$$X_L = 2\pi fL$$

- As frequency *increases* reactance *increases*
- Non-linear response curve





Where is all this going???

IMPEDANCE

Impedance

- Sum of the DC resistance and the AC resistance (reactance)
- Given in ohms

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

- 
- Inserting an instrument into a circuit *will* affect the circuit !!!!

Why? The impedance of the meter changes the impedance of the circuit



Signal flow in circuits “Coupling”

- Resistive coupled circuits
 - Pass both AC and DC
- Capacitive coupled circuits
 - Pass AC and resist DC
- Inductively coupled
 - Single series coil (no mag coupling)
 - Pass DC and Resist AC
 - Multiple coils magnetically coupled
 - Pass AC ONLY
 - Commonly known as a Transformer

Special case inductors

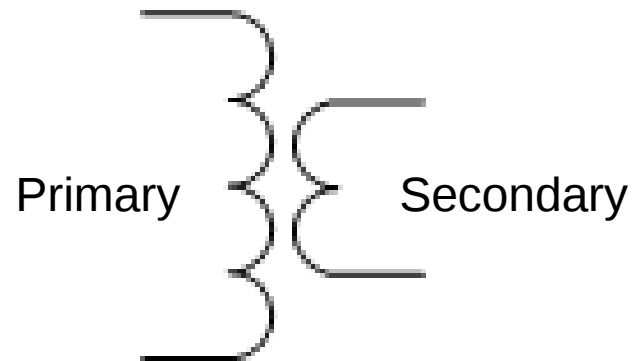
- Special case for Magnetically coupled coils!
 - Called a Transformer
 - Usually iron core so coupling is near 100%
 - Traditionally E shaped
 - Newer Toroid designs reduce EMI Generation

$$E_s = \frac{n_s}{n_p} E_p$$

Transformer facts!

- Voltage out dependent on turns ratio

$$E_s = \frac{n_s}{n_p} E_p$$



S: Secondary P: Primary Assumes 100% coupling

E: Voltage n: number of turns

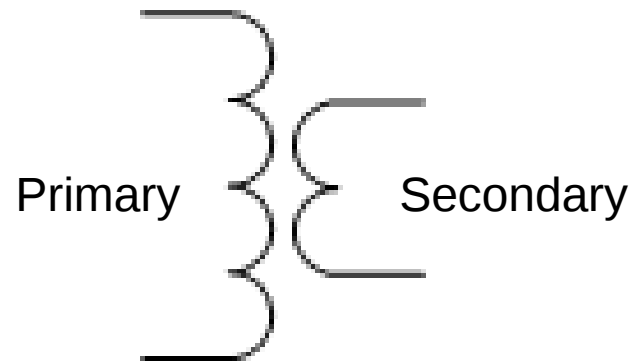
$$E_s = \frac{n_s}{n_p} E_p$$

Transformer facts!

- Power out = power in (almost)

- $(I \times E)_{\text{in}} = (I \times E)_{\text{out}}$

- If voltage drops then
then current goes up





Back to frequency effects

- Remember that capacitors and inductors change resistance with frequency
- This fact allows us to create circuits that exhibit high resistance to particular frequencies, and low resistance to others!

Who cares?

- In a
clear



This is NOT a perfect world !



Real world

- There are three major problems with real world signals:
 - Signals are noisy
 - Signals are noisy
 - Signals are noisy



Not to fear **Filter** is here

- Yes you too can filter noise!
- This is possible because of time constants of capacitor charging and inductor field expansion.

Simple Filters

- Use combinations of coupling to pass or block AC and DC components
- 3 types of passive filters:
 - RC (Resistor – Capacitor)
 - RL (Resistor – Inductor)
 - LC (Capacitor – Inductor)

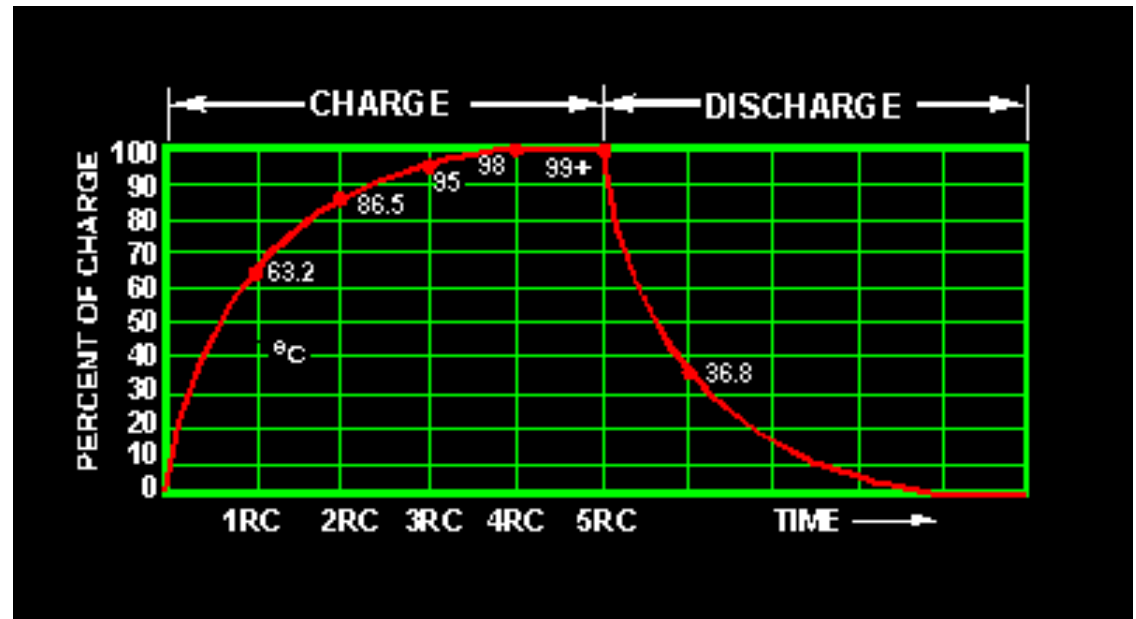
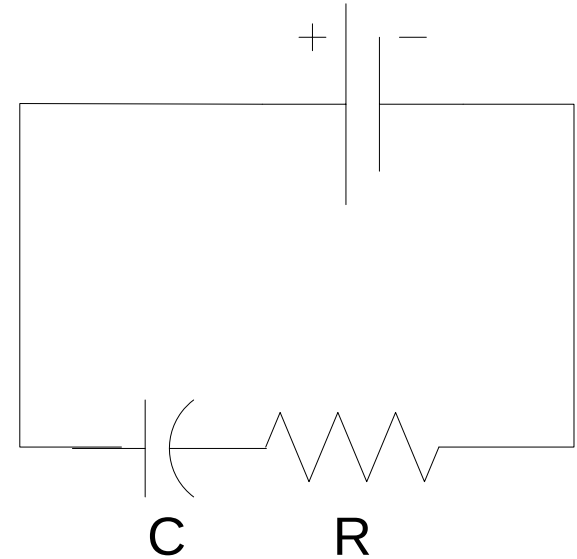


Simple RC filters

- Simple RC filters are most common.
 - Low pass
 - Pass low frequencies through
 - Block (or shunt to ground) high frequencies
 - High pass
 - Pass high frequencies through
 - Block low frequencies

Time constant

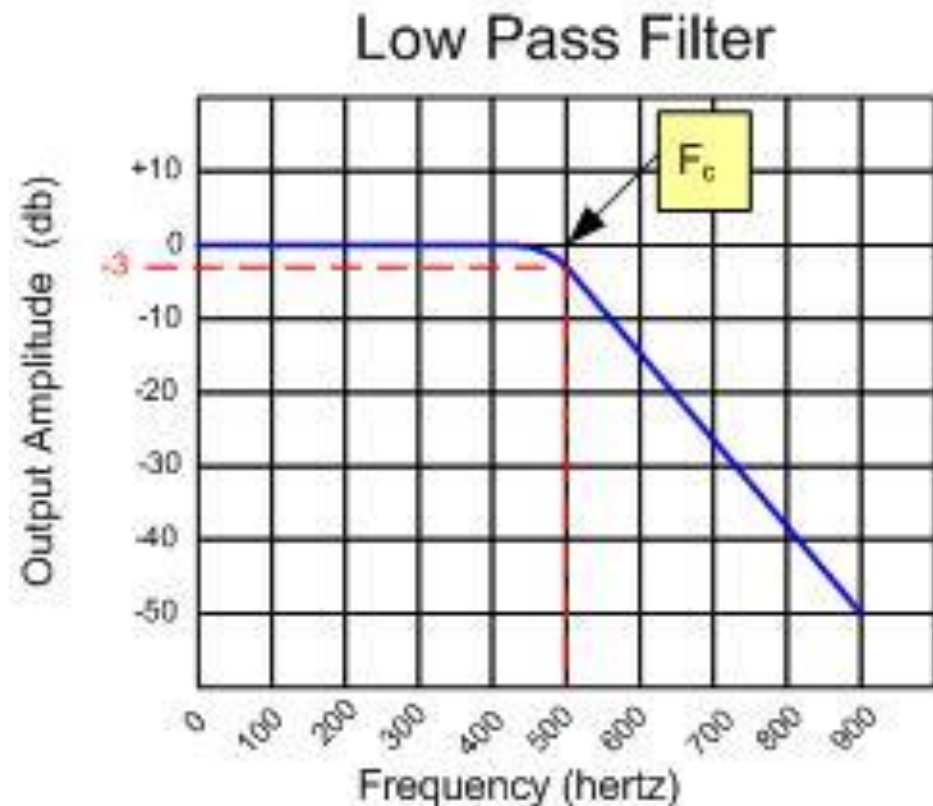
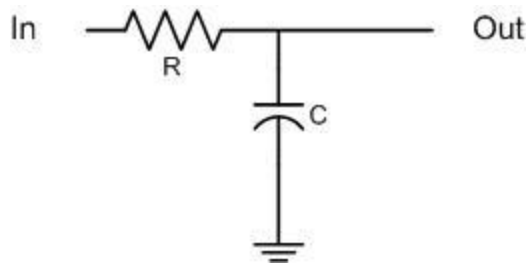
- Capacitor time constant
- $T=RC$
- $T=63\%$ full charge



Frequency for simple filters

- Frequency for filter roll off of RC filter

$$F_c = \frac{1}{2\pi RC}$$



Great... A new term dB?

- dB is a way to talk about amplitude in relative terms.

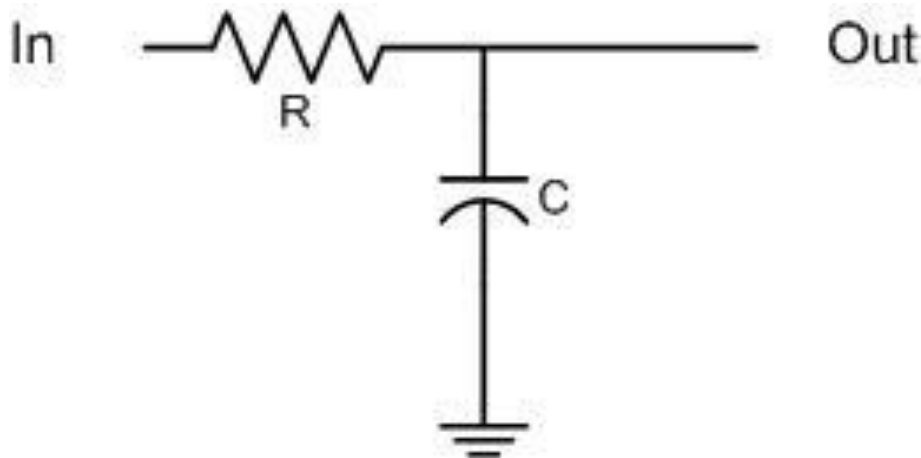
$$dB = 20 \log \frac{V_{out}}{V_{in}}$$

- -6dB represents
1/2 the amplitude

Vin	Vout	-db
10	10	0.0
10	9	-0.9
10	8	-1.9
10	7	-3.1
10	6	-4.4
10	5	-6.0
10	4	-8.0
10	3	-10.5
10	2	-14.0
10	1	-20.0

Low pass circuit

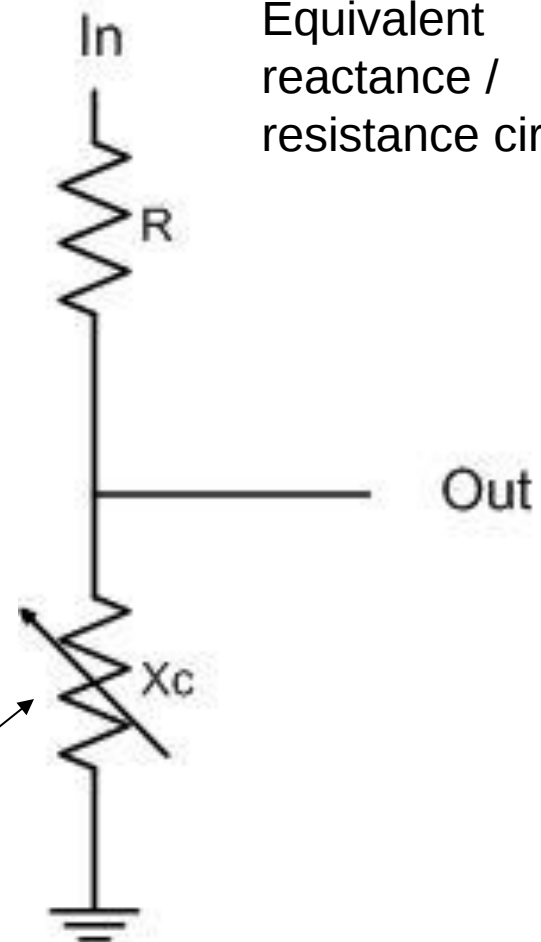
Low pass RC circuit



Frequency dependent resistance

Higher freq = lower resistance

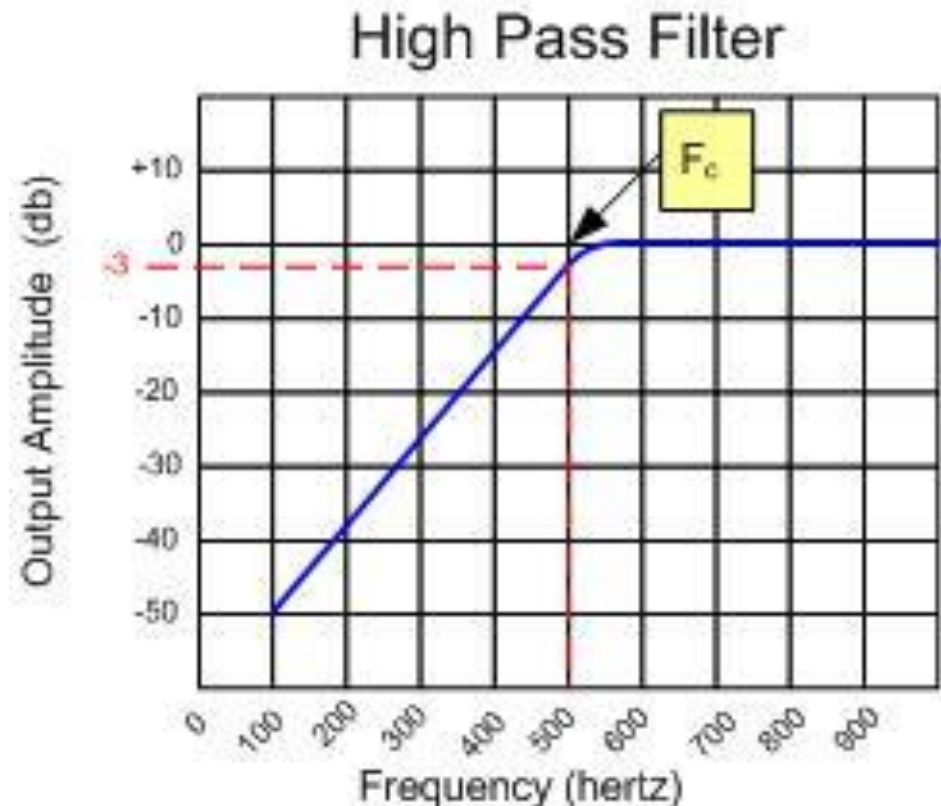
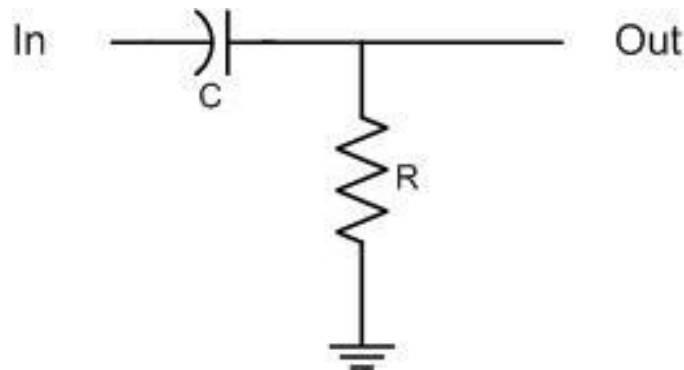
Equivalent
reactance /
resistance circuit



Frequency for simple filters

- Frequency for High Pass RC filter

$$F_c = \frac{1}{2\pi RC}$$





Active filters

- So far these have all been passive
 - Limited to gains of less than one (attenuation)
- Gains of more than one require an “active” circuit.
- Most common active components are operational amplifiers (op-amps) and transistors (Bipolar, FET).



Operational Amplifier (op-amp)

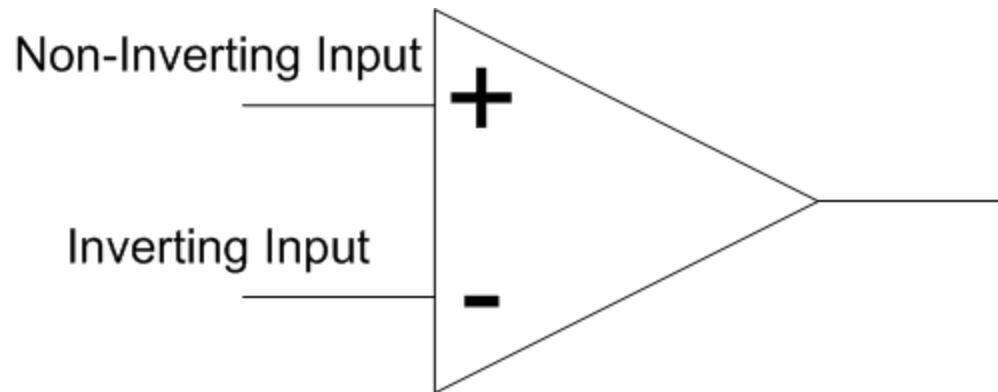
- Semiconductor device used in many types of circuits.
 - Gain Circuits
 - Active filters
 - Integrators / differentiators
- For our purposes we are interested in the gain circuits.



Amplifier gains

- Can be greater than one or less than one
- Can be inverting or non-inverting

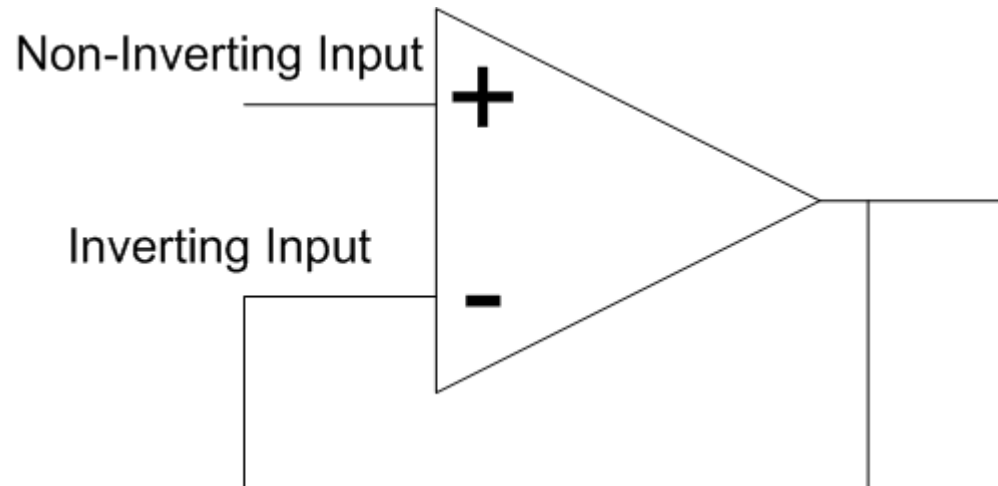
Simplified Op-Amp



- $V_{\text{out}} = (V_+ - V_-) G_{\text{open loop}}$

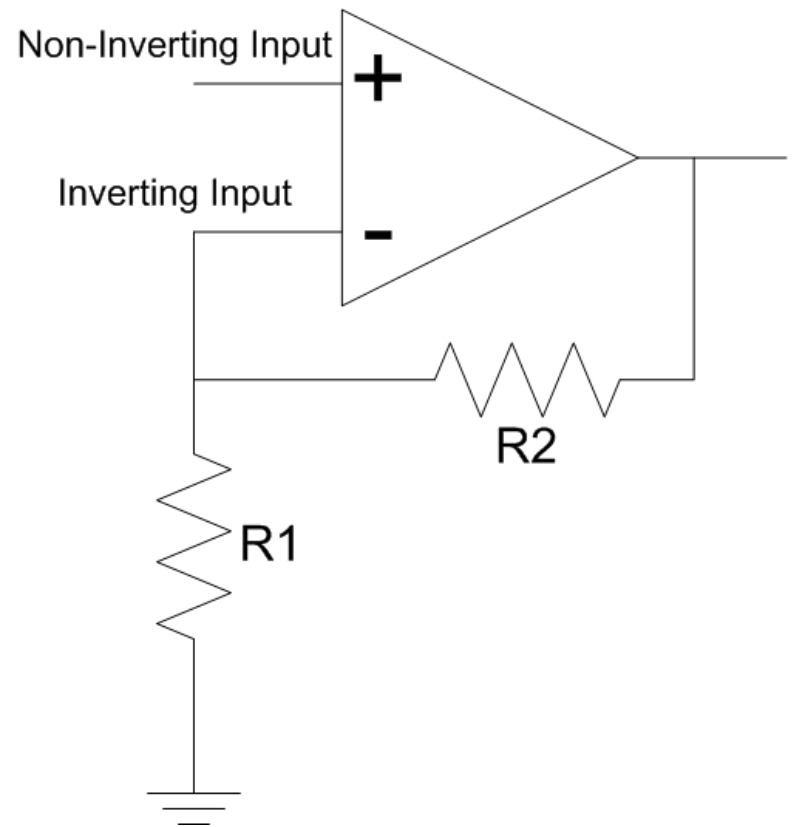
Voltage Follower

Gain = 1



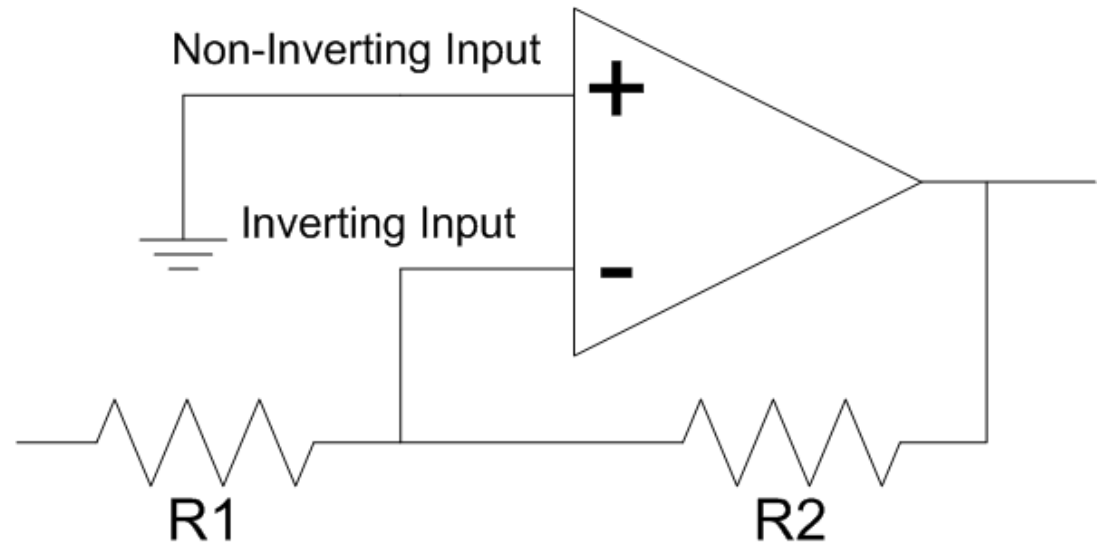
Non-inverting Amplifier

- Output voltage is same sign as input voltage
- $\text{Gain} = V_{\text{out}}/V_{\text{in}}$
- $V_{\text{out}} = V_{\text{in}} [1 + (R2/R1)]$



Inverting Amplifier

- Output voltage inverse sign of input voltage



- $V_{\text{out}} = V_{\text{in}} [-R2 / R1]$

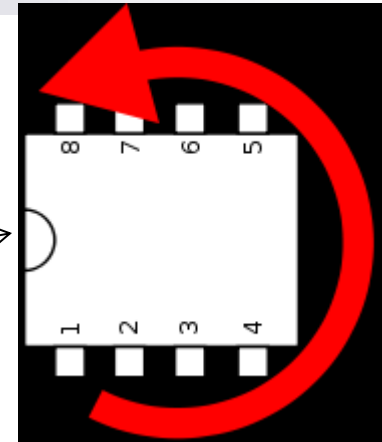


Op amp power supplies

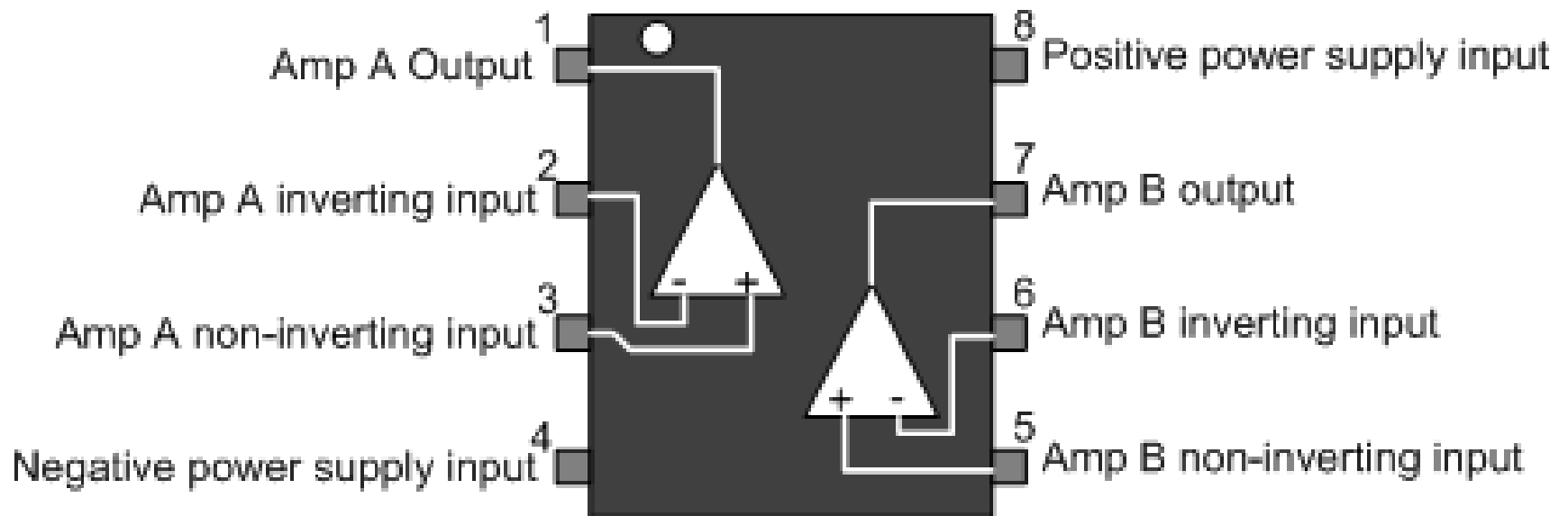
- Output can not exceed power supply limits, and typically only come with a few tenths of a volt of the supply
- Op-amps require two supplies
 - $+V$ and $-V$
 - $-V$ may or may not be ground (0V)

LM358N

Notch



LM358N



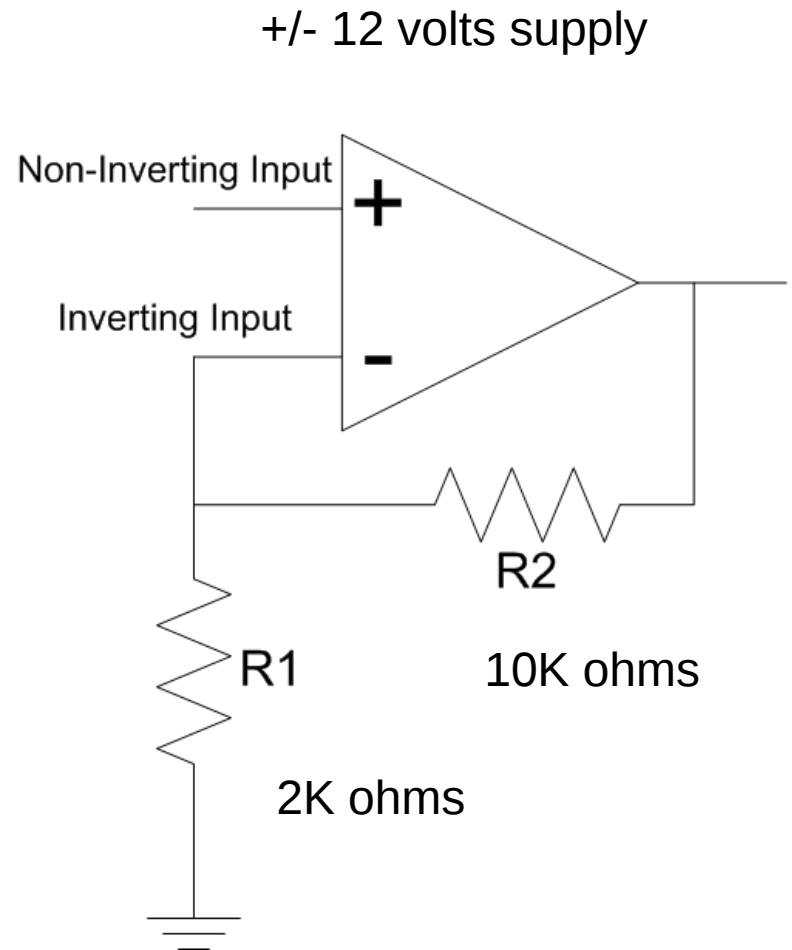
Example

$$V_{\text{out}} = V_{\text{in}} [1 + (R2/R1)]$$

$$V_{\text{out}} = V_{\text{in}} [1 + (10\text{K}/2\text{K})]$$

$$\text{For } .1 \text{ volt in } V_{\text{out}} = .6$$

$$\text{For } 1 \text{ volt in } V_{\text{out}} = 6$$





Putting all this to use!

- Several kinds of sensor outputs
 - ☐ Voltage
 - ☐ Current
 - ☐ Resistance
 - ☐ Frequency
 - ☐ Digital



Voltage output transducers

- High voltage output

- ☐ Typically ± 5 volts or ± 10 volts
- ☐ Only a few milliamps capacity

- Low Voltage output

- ☐ Typically less than ± 100 millivolts

- Both types read with standard voltmeter circuit

- Not good for long distances!

- ☐ Lead wire resistance can be a significant factor in the reading
- ☐ Lead wire resistance changes with temperature
 - Outside effects
 - Current load heating

Current output

- 0 – 20 milliamps
 - Good for long distance analog signals
 - Lead wire resistance does not affect readings
- 4 – 20 milliamps
 - The 4ma offset allows for “broken wire” sensing.
- Read with a load resistor and voltmeter circuit
- Typically limited to 24 Volts maximum output
 - The load resistance must be low enough to prevent voltage clipping. $R < V_{\max} / .020$

Resistance Output

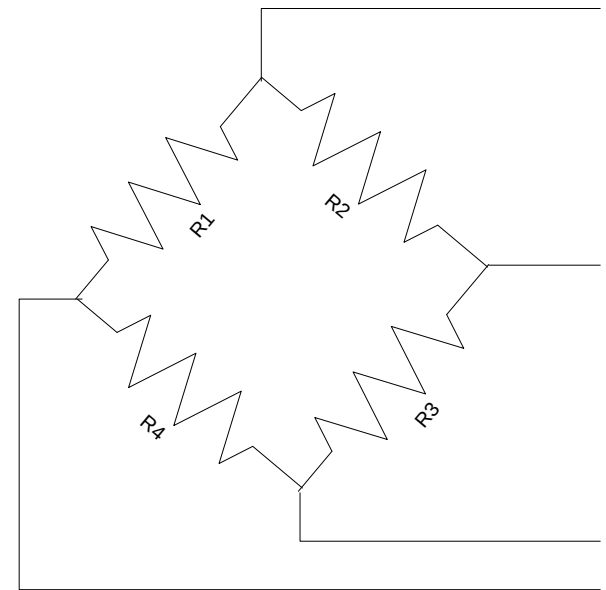
■ Two types

□ Single resistor

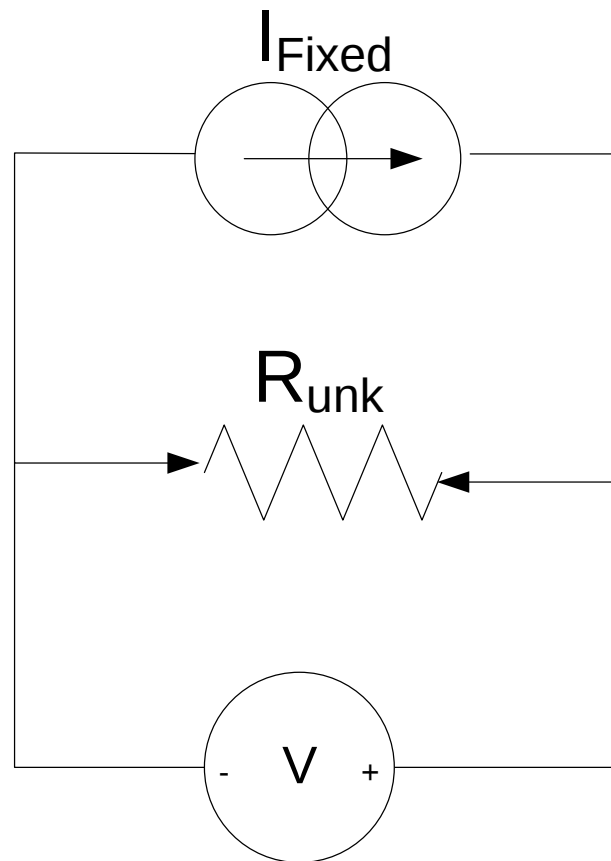
- This is a single variable resistance value

□ Balanced Bridge

- All values can change
- Typical in strain gage bridges
 - Temperature compensating
 - Provide “insensitivity” in particular directions

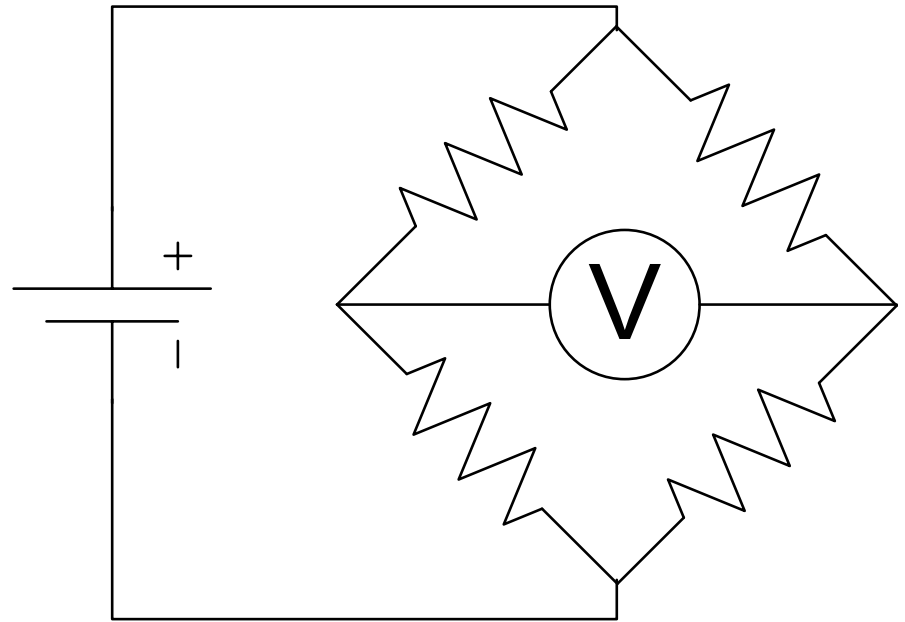


Reading a single resistance



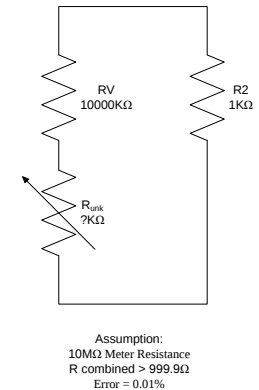
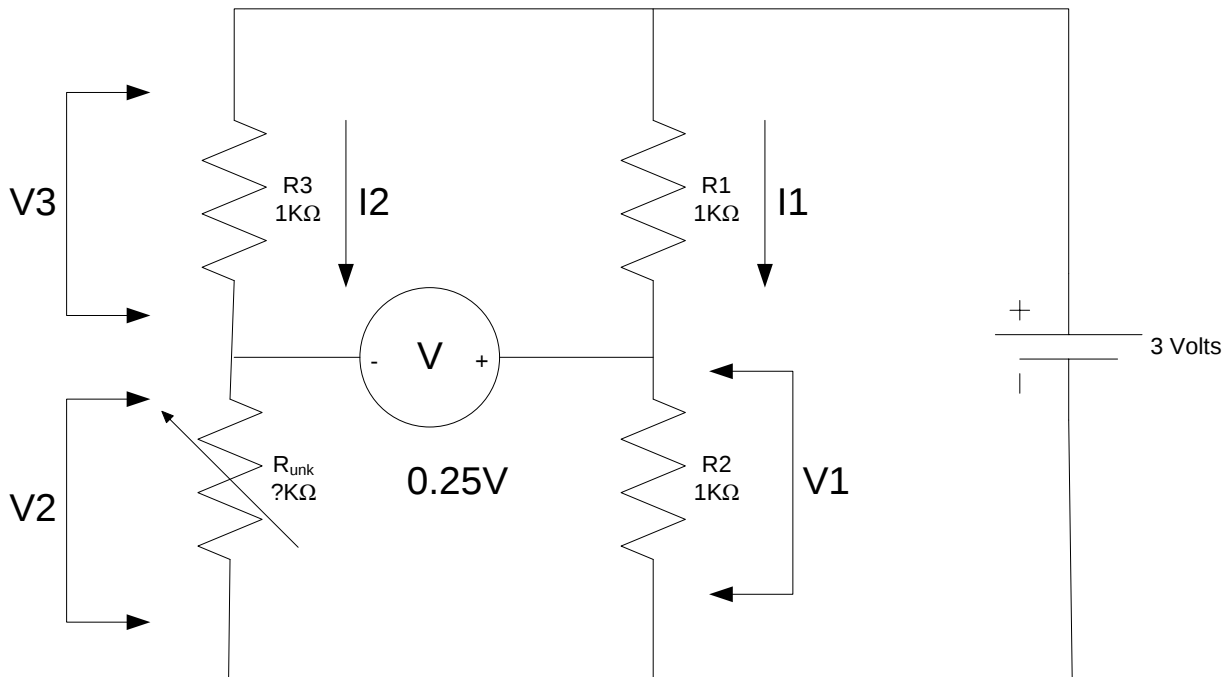
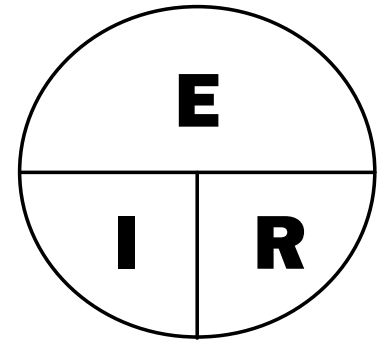
Reading resistances

- Galvanometer circuit
- Must know the relationship between the resistor values to make this work
- Diagonal resistors must be paired



Unbalanced bridge

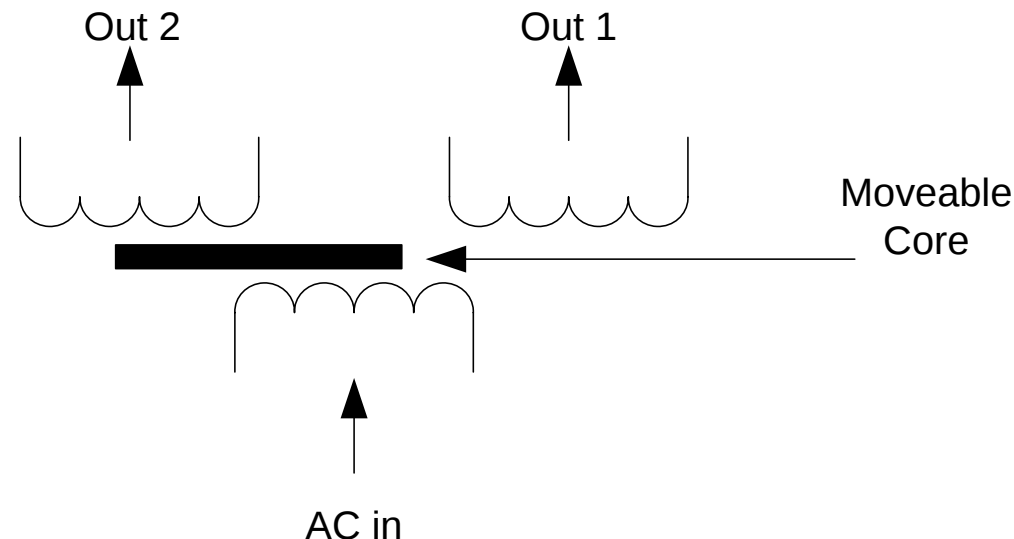
- Used to measure precision resistance



$$\begin{aligned}V1 &= 1.5 \text{ V} \\I1 &= 1.5 \text{ ma} \\V2 &= 1.5 - 0.25 = 1.25 \text{ V} \\V3 &= 3 - 1.25 = 1.75 \text{ V} \\I2 &= 1.75 \text{ ma} \\R_{\text{unk}} &= 1.25 / 1.75 \text{ ma} = 714.3\Omega\end{aligned}$$

Linear Variable Transformer

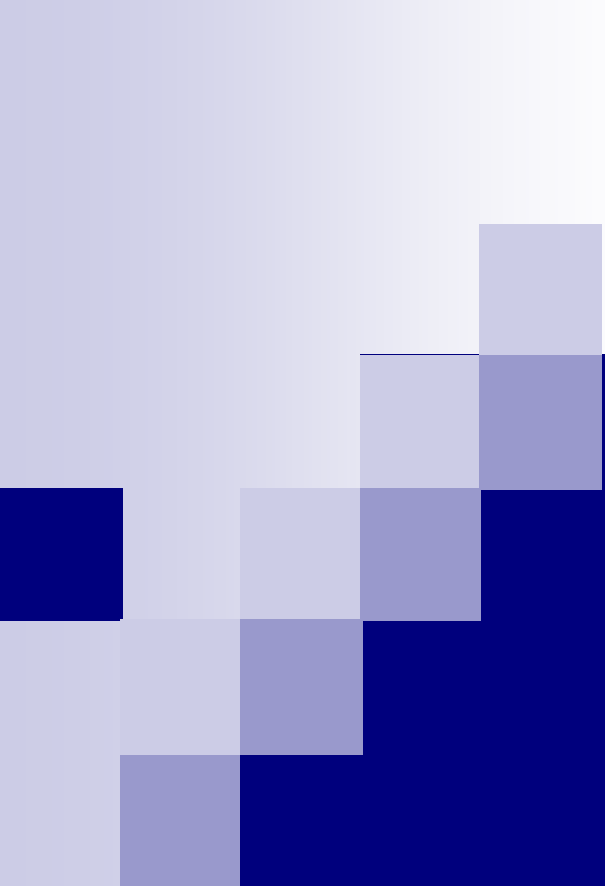
- As the core moves the percent of coupling between the coils changes
- Provides two AC output signals that must be compared to obtain the value.





Frequency output

- Typical on transformer devices and transducers using moving mechanical members (flow transducers)
- Work ok for long distance except
 - Induce noise in other lines
 - Susceptible to noise induced into its lines
 - Increases the cost for better filtering of inputs.
 - Low frequency systems $\approx 60\text{Hz}$ can be hard to tell the signal from the power line interference



Whew!!!

Questions?