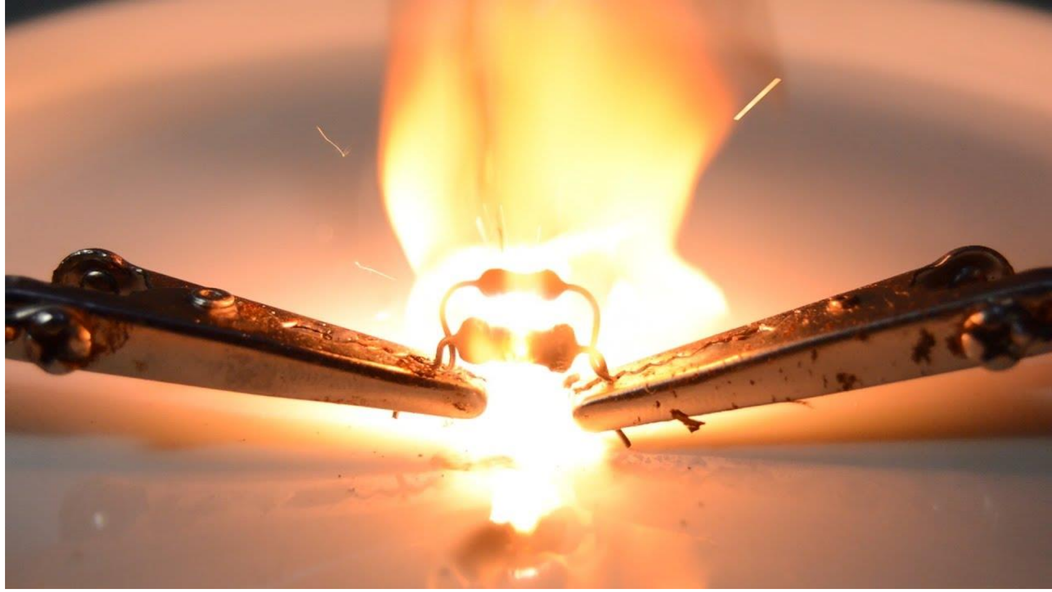


Ohm’s Law in the Real World

MARTIN BUEHRING – KB4MG

MATT PESCH – KK4NLK

SEPTEMBER, 2019

What actually is Ohm's Law?

- Based on work that started with Lord Cavendish in 1781 and his Leyden jar experiments.
- Georg Ohm did his work in 1825-1826 and published it in 1827
- Using Voltaic piles (like a battery) and he discovered that there was a linear relationship between voltage and current with a constant resistance.
- All this work was considered to be physics. His work was ridiculed by the German Minister of Education and banned from teaching.
- In the 1850's the design of the telegraph system was made possible by Ohm's work which described this relationship of V=IR

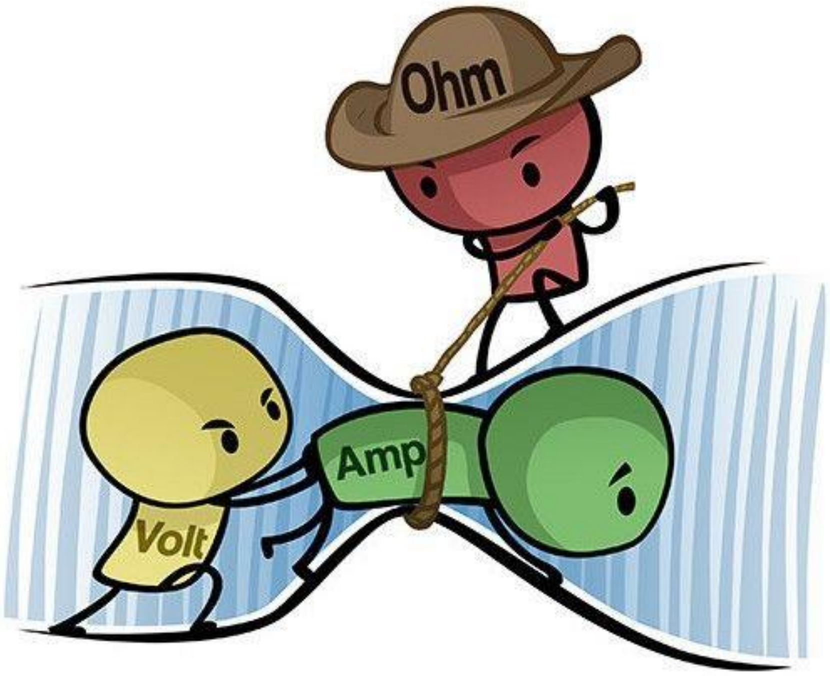
Georg Ohm

Units

V Voltage – electric potential or electric tension
- Measured in Volts, named for Alessandro Volta (*it*)
- 1 volt = 1 joule of work per 1 coulomb of charge
- Sometimes called **E** for the electromotive force

I Current – Rate of flow past a point
- Measured in Amperes , named for Andre Ampere (*fr*)
- One Ampere is one coulomb of charge past a point in one second.

R Resistance – opposition to the flow of electricity (electrons)
- Measured in Ohms (*ge*)
- Really related to G conductance measured in Siemens
- G = I/V or 1/R -> so the inverse of G is R resistance.



1 coulomb = 6.24 x 10^{18} electrons

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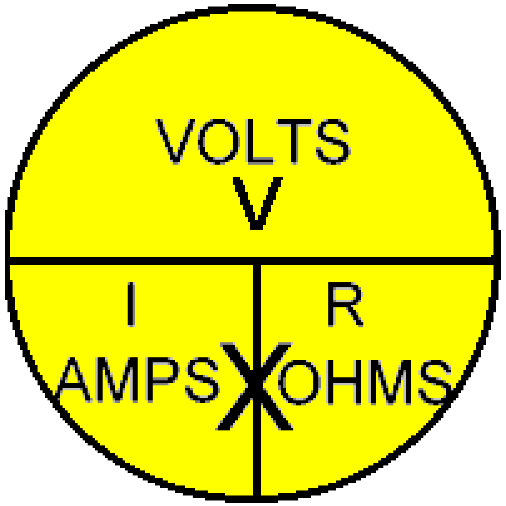
The basics

Ohms Law states that the current through a conductor between two points is directly proportional to the voltage across the two points.

His original equation is V=IR for constant values of R

Ohm Circle helps us remember the various versions of the law based on what values we know.

- We cover the one we don’t know and calculate it with what we do know.



V=IR   I=V/R   R=V/I

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Resistors

Basic electronics component used to limit current is circuit, adjust signal levels, divide voltages, bias active elements like transistors, terminate transmission lines, and much more.

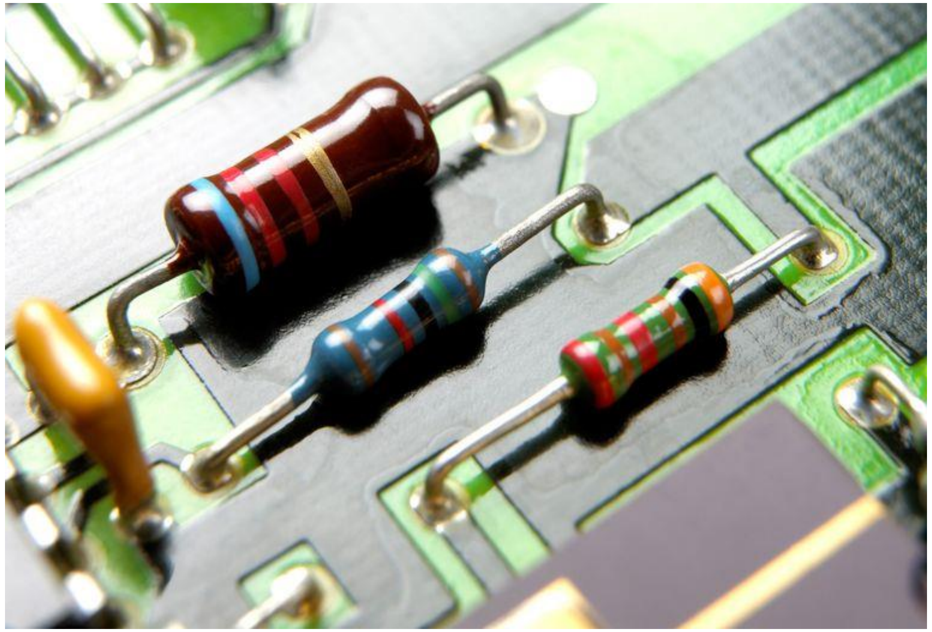
Made of differing materials for different purposes.

Various power ratings based on uses

Have varying manufacturing tolerances

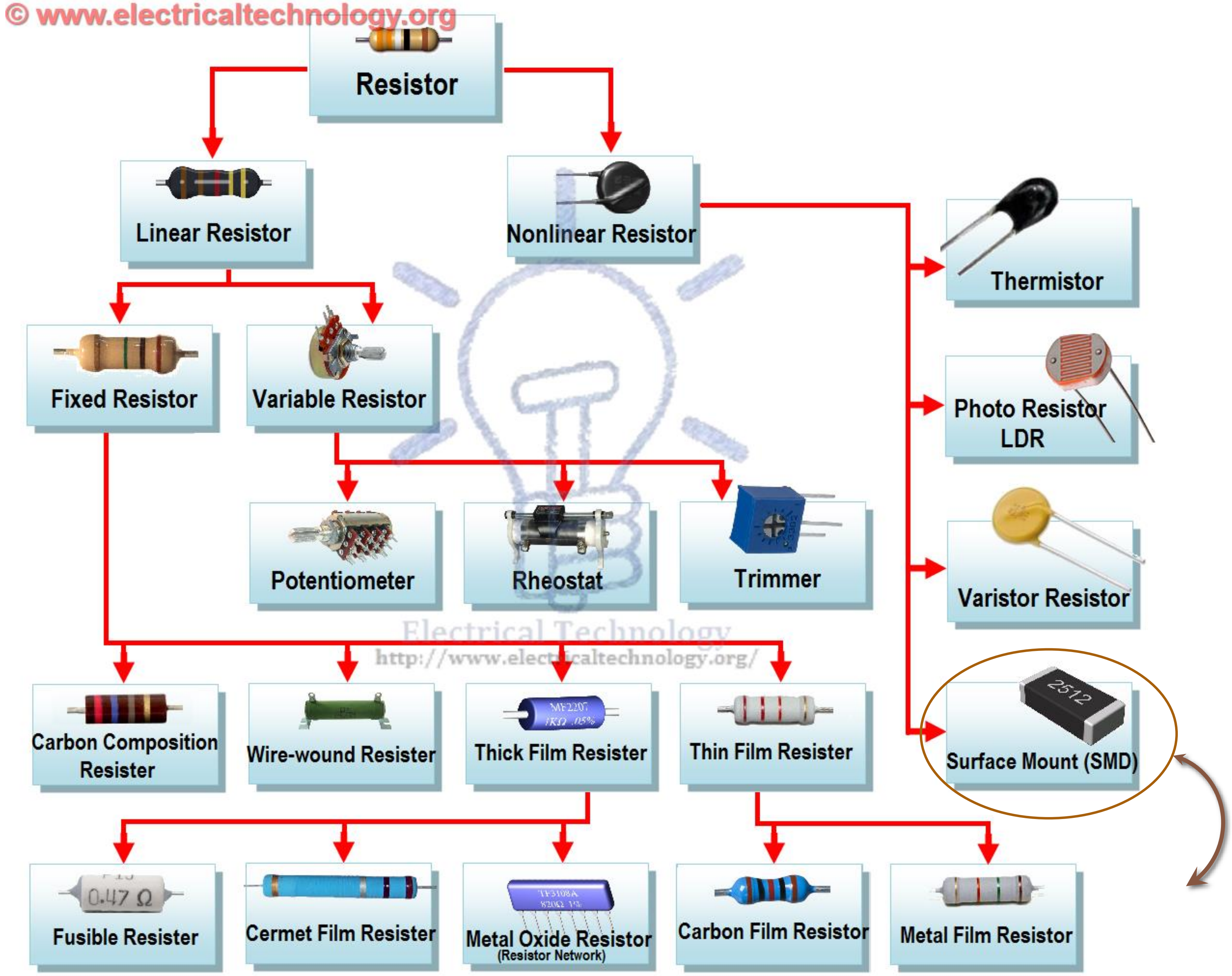
- Very small (.001%) and up to ±20% variance in value

Fixed or variable ohmic values



Types

Fuse is a type of resistor made to fail



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What about wires?

- Wires are actually resistors in the real world, but in most cases can be ignored if they are of proper size for the circuit current.
- The resistance of a wire is based on three factors:
  - Length L
  - Cross sectional area A
  - Resistivity of the material is made of $R = \frac{\sigma L}{A}$
  - Example: 20 gauge wire 1000ft long
    - Will be about 10.36 Ω

Material	Resitivity, ρ(Ω-m)	Temperature Coefficient, $\alpha(c^{o})^{-1}$
Conductors		
Silver	1.59×10^{-8}	0.0061
Copper	1.68×10^{-8}	0.0068
Gold	2.44×10^{-8}	0.0034
Aluminium	2.65×10^{-8}	0.00429
Tungsten	5.6×10^{-8}	0.0045
Iron	9.71×10^{-8}	0.00651
Platinum	10.6×10^{-8}	0.003927
Mercuy	98×10^{-8}	0.0009
Nichrome(Ni,Fe,Cr alloy)	100×10^{-8}	0.0004
Semiconductors		
Carbon(Graphite)	$(3\text{-}60)\times10^{-5}$	-0.0005
Germanium	$(1\text{-}500)\times10^{-3}$	-0.05
Silicon	0.1 - 60	-0.07
Insulators		
Glass	$10^{9}\text{-}10^{12}$	
Hard rubber	$10^{13}\text{-}10^{15}$	

Q: If silver is better than gold, why do we use Gold on high reliability contacts?

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Standard and Metric Wire Comparison Table

Available Wire Size AWG	Available Wire Size Metric
16	1.5
14	2.5
12	4
10	6
8	10
6	16
4	25
2	35
1	50
0	
2/0	70
3/0	95
4/0	120

KEY: AWG WIRE SIZE — CLOSEST EQUIVALENT IN METRIC

CIRCUIT TYPE		CURRENT FLOW IN AMPS															
Non-Critical 10% VOLTAGE DROP	Critical 3% VOLTAGE DROP	5A	10A	15A	20A	25A	30A	40A	50A	60A	70A	80A	90A	100A	120A	150A	200A
0 to 20 ft	0 to 6 ft	16 AWG	16 AWG	14 AWG	14 AWG	12 AWG	10 AWG	8 AWG	6 AWG	6 AWG	6 AWG	4 AWG	4 AWG	4 AWG	2 AWG	1 AWG	2/0 AWG
30 ft	10 ft	16 AWG	14 AWG	12 AWG	12 AWG	10 AWG	10 AWG	8 AWG	6 AWG	6 AWG	6 AWG	4 AWG	4 AWG	4 AWG	2 AWG	1 AWG	2/0 AWG
50 ft	15 ft	16 AWG	12 AWG	10 AWG	10 AWG	8 AWG	8 AWG	6 AWG	6 AWG	4 AWG	4 AWG	4 AWG	2 AWG	2 AWG	2 AWG	1 AWG	2/0 AWG
65 ft	20 ft	14 AWG	10 AWG	10 AWG	8 AWG	6 AWG	6 AWG	6 AWG	4 AWG	4 AWG	2 AWG	2 AWG	2 AWG	2 AWG	1 AWG	0 AWG	2/0 AWG
80 ft	25 ft	12 AWG	10 AWG	8 AWG	6 AWG	6 AWG	6 AWG	4 AWG	4 AWG	2 AWG	2 AWG	2 AWG	1 AWG	1 AWG	0 AWG	2/0 AWG	3/0 AWG
100 ft	30 ft	12 AWG	10 AWG	8 AWG	6 AWG	6 AWG	4 AWG	4 AWG	2 AWG	2 AWG	1 AWG	1 AWG	0 AWG	0 AWG	2/0 AWG	3/0 AWG	4/0 AWG
130 ft	40 ft	10 AWG	8 AWG	6 AWG	6 AWG	4 AWG	4 AWG	2 AWG	2 AWG	1 AWG	0 AWG	0 AWG	2/0 AWG	2/0 AWG	3/0 AWG	4/0 AWG	4/0 AWG
165 ft	50 ft	10 AWG	6 AWG	6 AWG	4 AWG	4 AWG	2 AWG	2 AWG	1 AWG	0 AWG	2/0 AWG	3/0 AWG	3/0 AWG	3/0 AWG	4/0 AWG	4/0 AWG	
200 ft	60 ft	10 AWG	6 AWG	6 AWG	4 AWG	2 AWG	2 AWG	1 AWG	0 AWG	2/0 AWG	3/0 AWG	3/0 AWG	4/0 AWG	4/0 AWG	4/0 AWG		
	70 ft	8 AWG	6 AWG	4 AWG	2 AWG	2 AWG	1 AWG	0 AWG	2/0 AWG	3/0 AWG	3/0 AWG	4/0 AWG	4/0 AWG				
	80 ft	8 AWG	6 AWG	4 AWG	2 AWG	2 AWG	1 AWG	0 AWG	2/0 AWG	3/0 AWG	4/0 AWG	4/0 AWG					
	90 ft	8 AWG	4 AWG	2 AWG	2 AWG	1 AWG	0 AWG	2/0 AWG	3/0 AWG	4/0 AWG	4/0 AWG						
	100 ft	6 AWG	4 AWG	2 AWG	2 AWG	1 AWG	0 AWG	2/0 AWG	3/0 AWG	4/0 AWG							
	110 ft	6 AWG	4 AWG	2 AWG	1 AWG	0 AWG	0 AWG	3/0 AWG	4/0 AWG	4/0 AWG							
	120 ft	6 AWG	4 AWG	2 AWG	1 AWG	0 AWG	2/0 AWG	3/0 AWG	4/0 AWG								
	130 ft	6 AWG	2 AWG	2 AWG	1 AWG	0 AWG	2/0 AWG	3/0 AWG	4/0 AWG								

Rows labelled CIRCUIT LENGTH.

AWG WIRE SIZE CHART

Wire scale not to actual size

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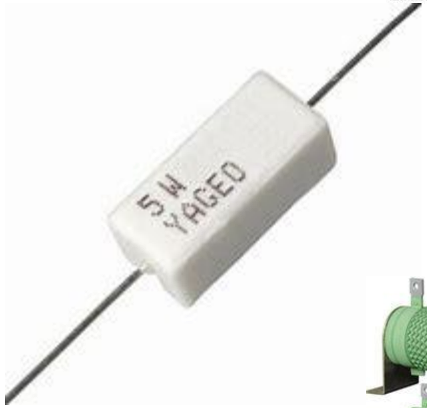
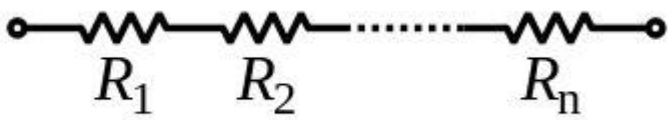
Interactive Session

- Show the basic Ohm’s Law calculations
- Show series resistor problems
- Show parallel resistor problems
- Duplicate the problem in the real world with real components
  - Take actual measurements and discuss methods
- Why do the answers differ from theory?
- Practical application
  - Maximum power transfer theorem and ham radio
  - What may be different with RF ? What about antenna tuners?
- Wrap –up and Questions



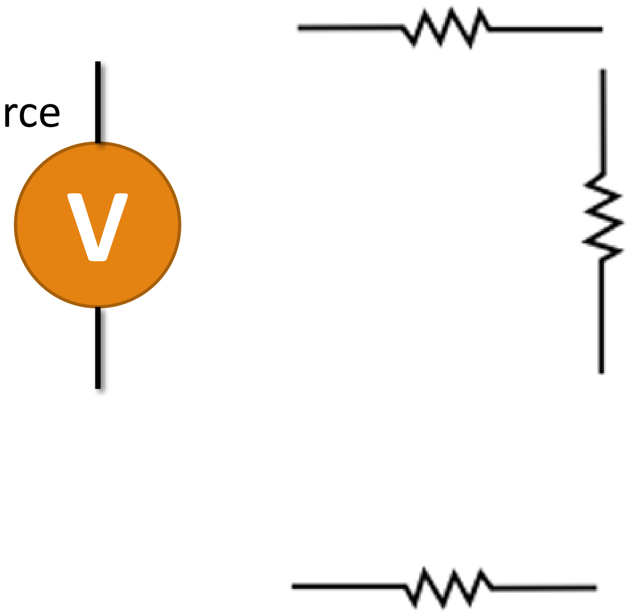
Thanks Matt -KK4NLK for assisting me today!

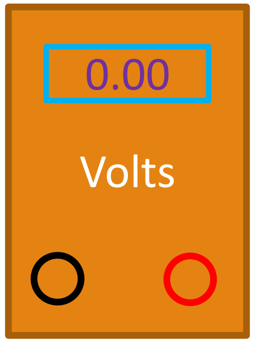
Series circuits



$$R_{eq} = R_1 + R_2 + \cdots + R_n.$$

Ideal voltage source





Voltage = anything we want
Current = infinite
Internal Resistance = 0Ω

$$\Sigma_{Rise} = \Sigma_{falls}$$

Voltage divider

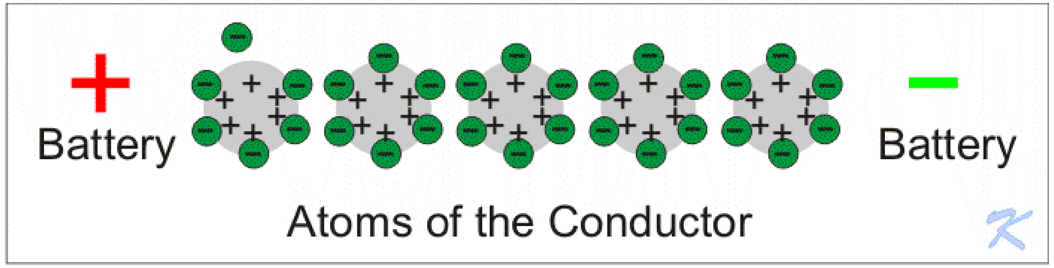
Conventional vs Actual Current Flow

Conventional current flow is from positive to negative (often shown as ground).

- Benjamin Franklin responsible for this belief.
- This is the frame of reference for measurements we take with instruments
- It is very important to know what circuit ground to use for your measurements
- Some designs use separate analog and digital grounds.

In the physical world (physics, chemistry, etc) current flow is – to +

- Movement of electrons is from the negative to more positively charged location
- Free electrons are ones torn away from the outer shell of atoms that make up the conductor.
- Credited to physicist JJ Thompson in 1897



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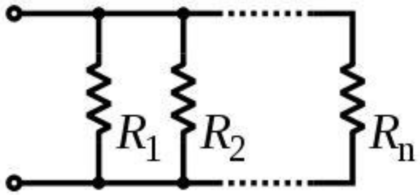
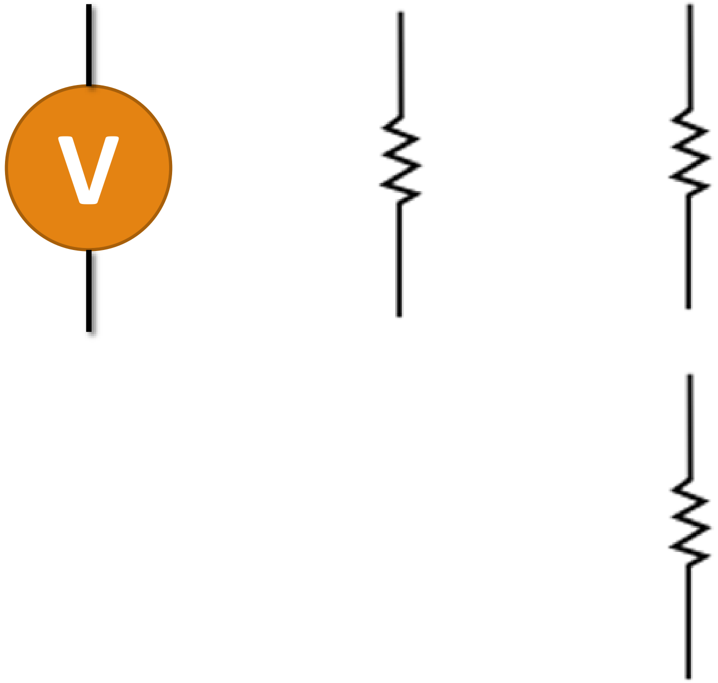
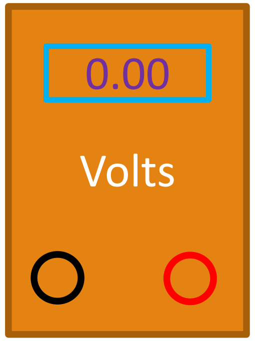
Parallel circuits



$$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}.$$





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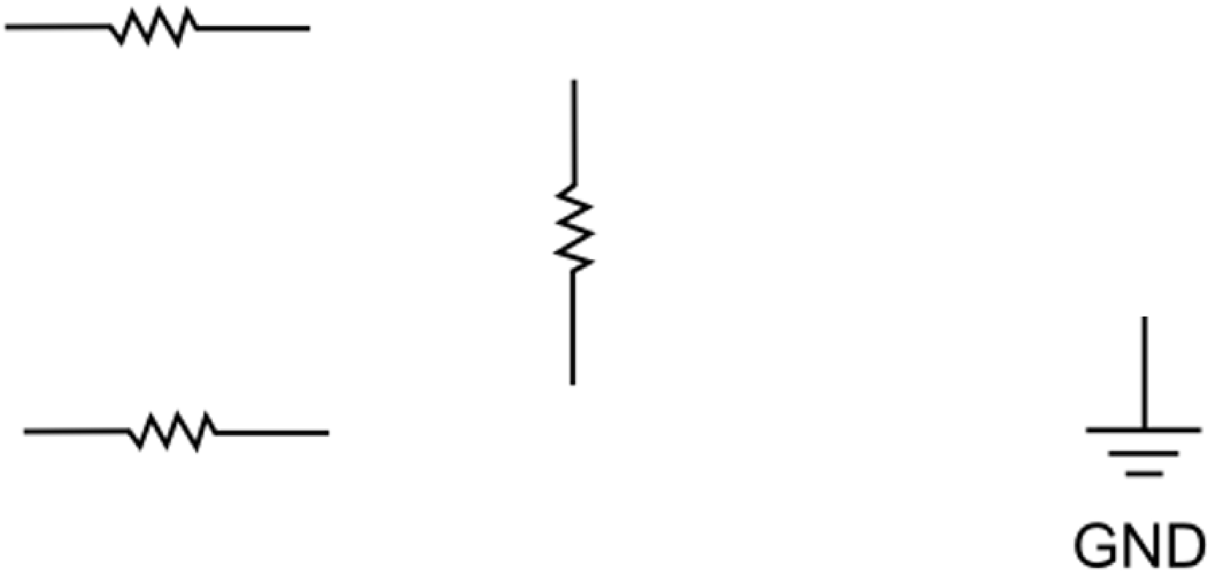
Real world with power supply

Fluke 115



Consider the variables in the circuit

What is the power source?

- How much voltage and current can it actually source?

How are things connected and with what wires or materials?

What are the tolerances of the components?

- All things in the real world have a specified tolerance (which means we design to “tolerate” the differences.)
- Know what you need for accuracy and use the right components
- Tighter tolerance = more cost ($$$).

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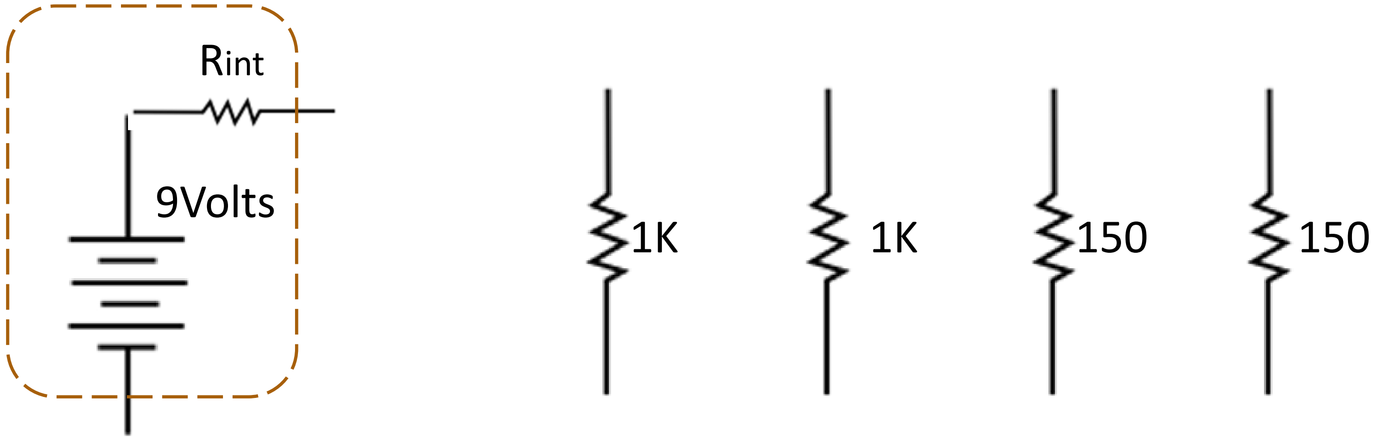
In the real world with a battery



Power considerations

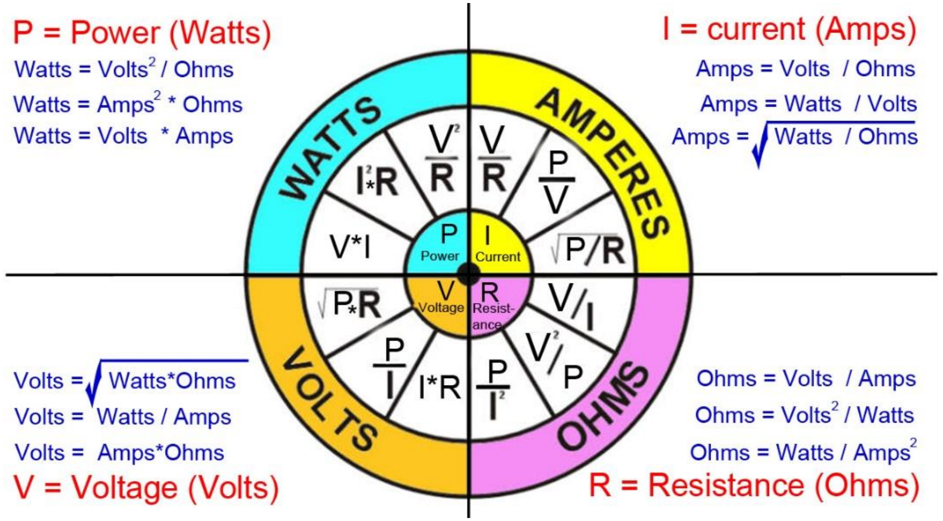
Power dissipation is a key requirement and must have a margin of safety.

Power dissipation = heat (wasted power)

Power rating for components is usually 2X the calculated power for safe operating ranges.

$$P = I^2R$$

(Increases as the square of the current – ie exponentially)



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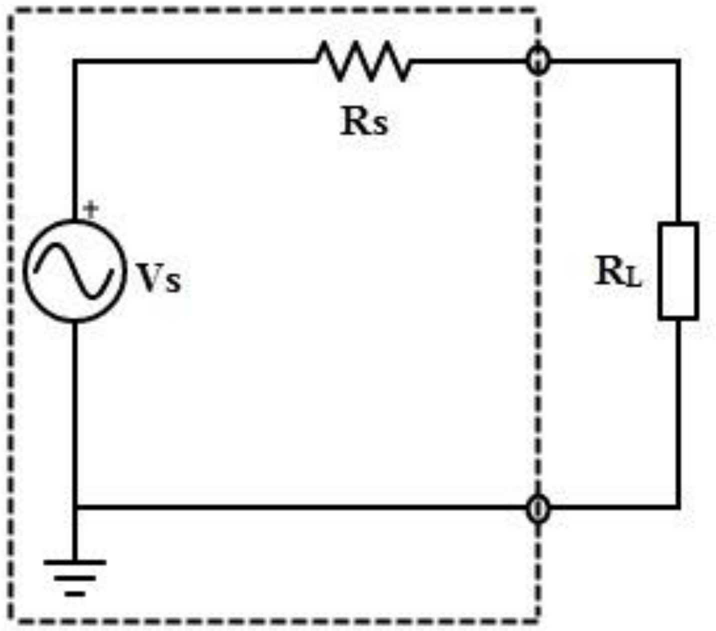
Application of Ohms Law
Maximum Power Transfer Theorem

Maximum Power Transfer Theorem

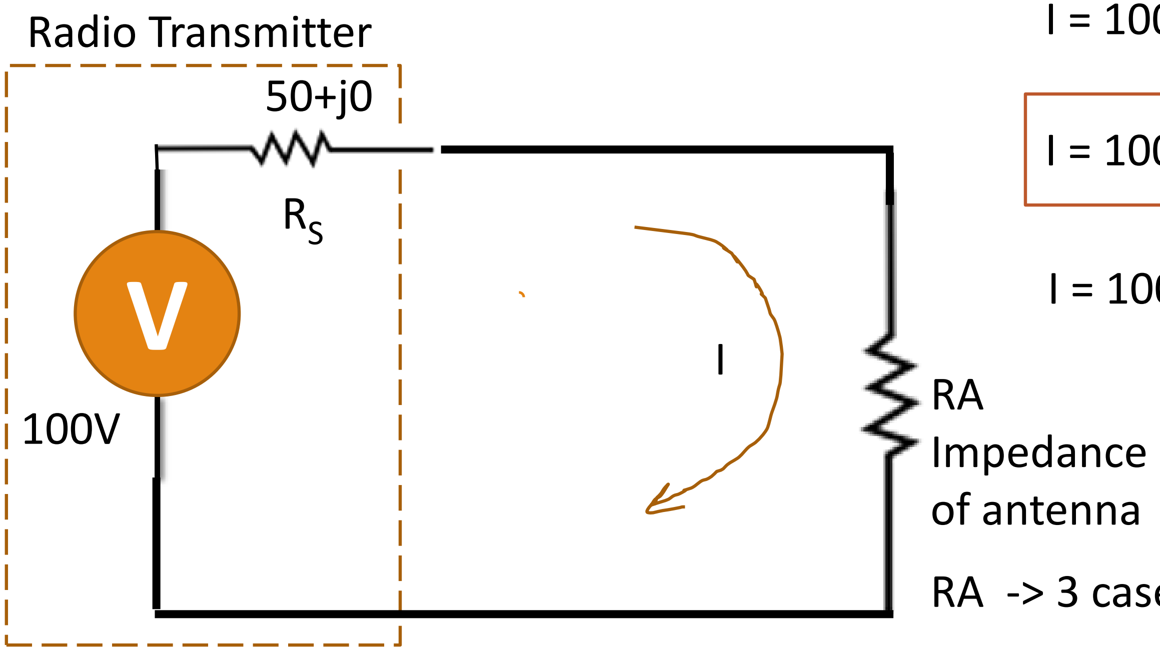
- In a linear DC network, maximum power is delivered to the load when the load resistance is equal to the internal resistance of the source.
- Also called Jacobi's Law

Application

- This applies to DC but has a similar corollary for AC, thus for RF circuits as well.
- A transmitter match to an antenna (the load) will radiate the most power if the two are matched impedance.
- At a perfect 1:1 match, the antenna will appear as 50+j0 ohms of impedance.



Proof using Ohms Law



I = 100V/(50+**25**) Ω = 1.33 A Power = I^2R = $(1.33)^2$ (25 Ω) = 44.4 Watts

I = 100V/(50+**50**) Ω = 1 A Power = I^2R = $(1.0)^2$ (50 Ω) = 50 Watts

I = 100V/(50+**100**) Ω = .66 A Power = I^2R = $(.66)^2$ (100 Ω) = 44.4 Watts

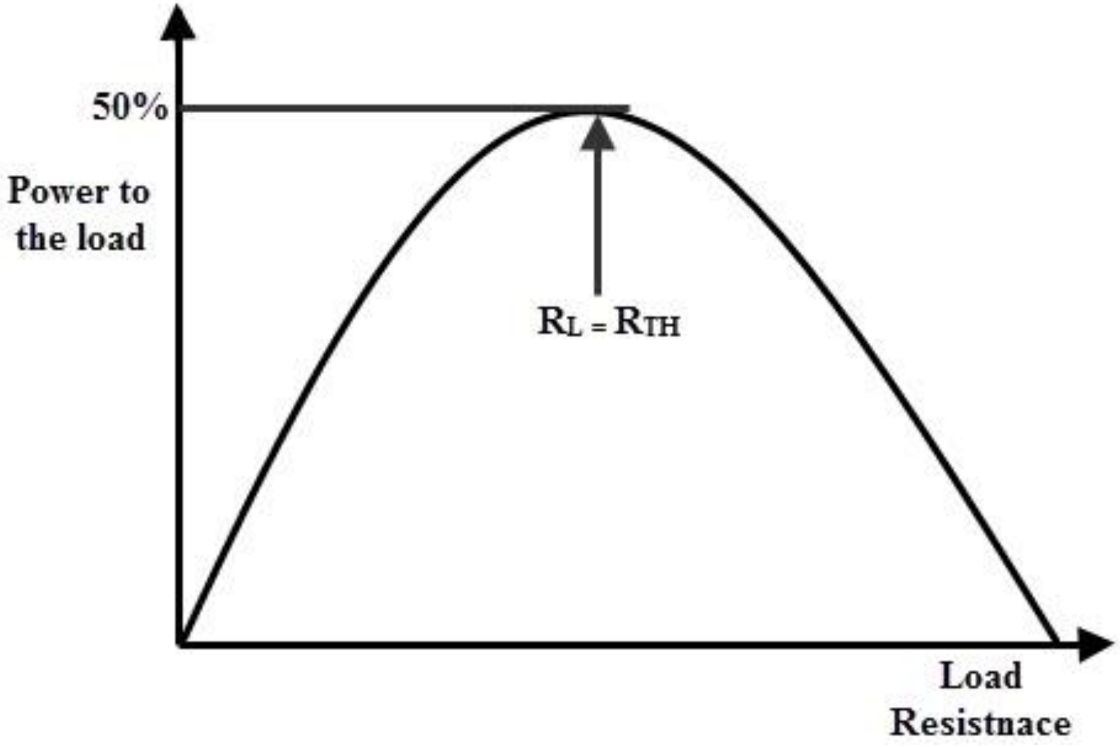
RA -> 3 cases : 25+j0 Ω 50 +j0 Ω 100 +j0 Ω

Getting Maximum Power

Anything that does not match the source impedance will not transfer maximum power.

The best solution is an antenna that is perfectly tuned for the band you want to operate on

Antenna Tuners only makes the radio "happy" and does not make the antenna any better.



Antenna matching

Radio wants to see 50 ohms

-Tuner “transforms” these (Z)Impedances to get a match with the antenna
-Max power is delivered by the radio to the tuner
-Some power is lost in heat in the tuner, but the radio is “happy” with the 50 ohm load it sees.

Antenna impedance is Not 50 but 35+j16 ohms
Tuner adds 15-j16 ohms to get the match

Only at **resonance** is any antenna a 50ohm resistive load

Go forth and calculate Ohms Law

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Thank you - Questions & Comments