ECE 320: Electronics I

ECE 111: Week #18

Please visit Bison Academy for corresponding
lecture notes, homework sets, and solutions

Electrical and Computer Engineering

Why I like electrical and computer engineering:

- As long as technology advances, we've got jobs
- You're never going to be stuck doing the same job day after day, year after year
- As long as technology advances, anything I design today can be improved tomorrow.

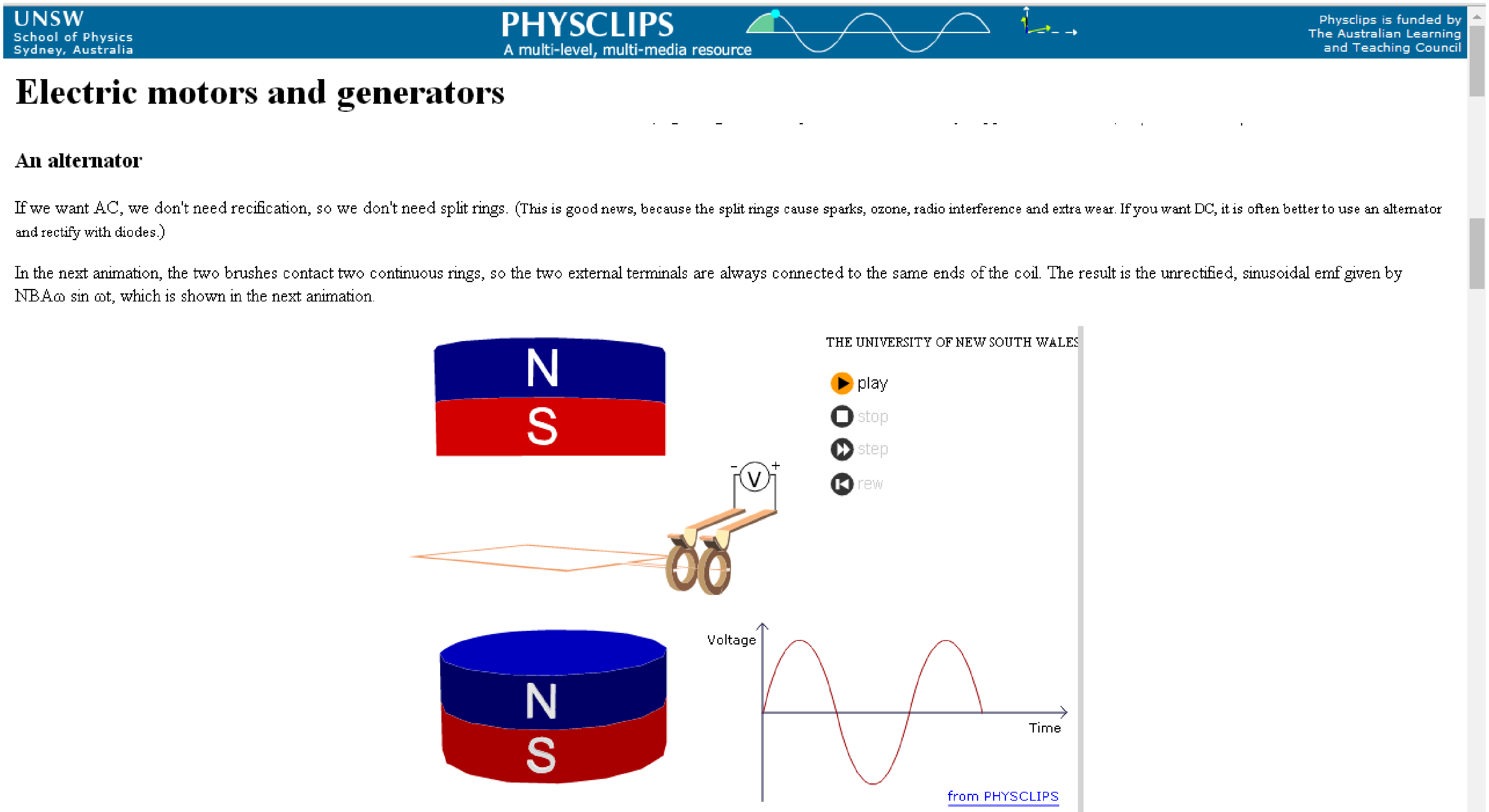
Example #1: Motors

1990 Technology
1000W DC Servo Motor
40 lbs, \$5000, 18" x 6" dia

2022 Technologyebay
900W Brushless7 Motor
9oz, \$35 (including controller)

1990 Motors (DC) vs. 2022 Motors (AC)

- How Motors Work
- https://www.animations.physics.unsw.edu.au/jw/electricmotors.html


UNSW
School of Physics
Sydney, Australia

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Electric motors and generators

An alternator

If we want AC, we don't need recification, so we don't need split rings. (This is good news, because the split rings cause sparks, ozone, radio interference and extra wear. If you want DC, it is often better to use an alternator and rectify with diodes.)

In the next animation, the two brushes contact two continuous rings, so the two external terminals are always connected to the same ends of the coil. The result is the unrectified, sinusoidal emf given by NBAω sin ωt, which is shown in the next animation.

3-Phase AC Synchronous Motors

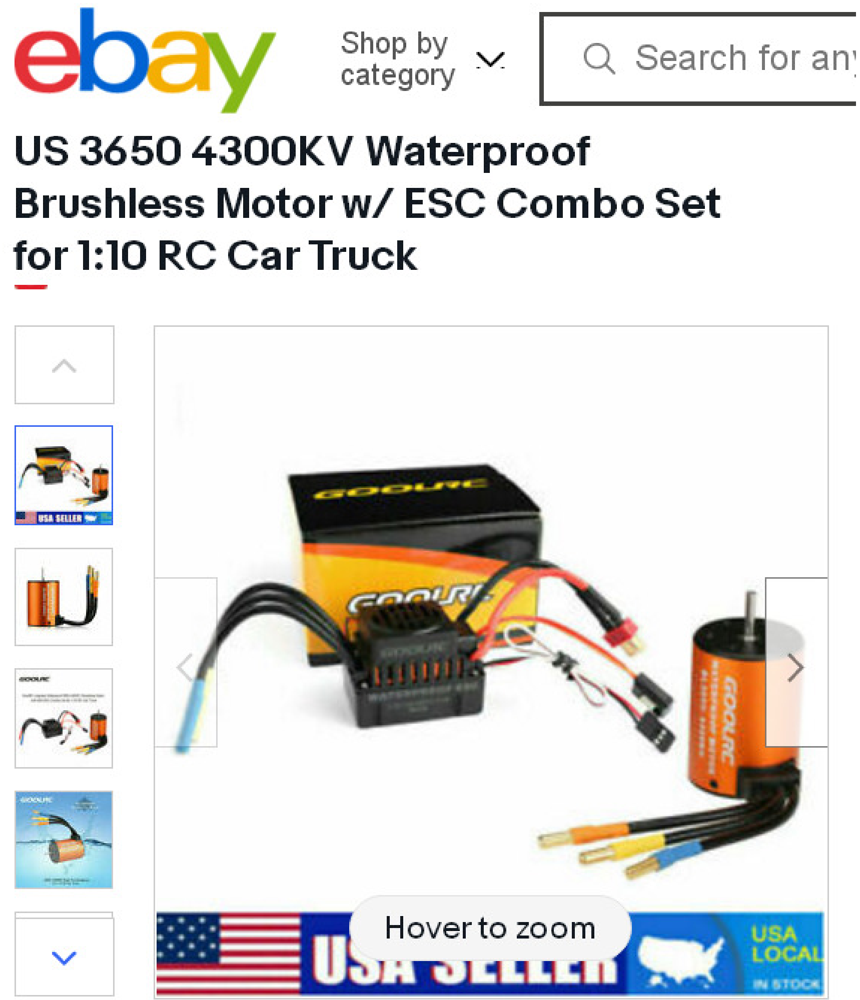
- Think Tesla motors or quadcopter motors

Much harder to drive

- Input is a 3-phase AC sine wave
- Frequency is speed
- Lead angle is torque

If you can figure it out

- Size & weight are reduced
- Efficiency is increased
- You open up a wide range of applications (1hp in a 9oz package)



To make an AC motor work...

DC to AC converter

- Acceleration
- Battery (DC) to Motor (AC)
- ECE 320 Electronics I
- ECE 437 Power Electronics
- ECE 438 Electric Drives

AC to DC

- Braking
- Motor (AC) to Battery (DC)
- ECE 320 Electronics I
- ECE 437 Power Electronics
- ECE 438 Electric Drives

The heart of all of this is electronics

Example #2: Lighting

As long as technology advances, we've got jobs

1970: Incandescent Light Bulb

- 2% efficient
- 30% of the nation's energy went to lighting

2022: LED Light Bulb

- Electronic device (diode)
- 36% efficient
- 80% efficient is possible in theory
- 5% of the nation's energy goes to lighting

Problem with LED Lighting

- Problem: Convert 60Hz AC to DC

Current Solution:

- Use electronics to pass current briefly

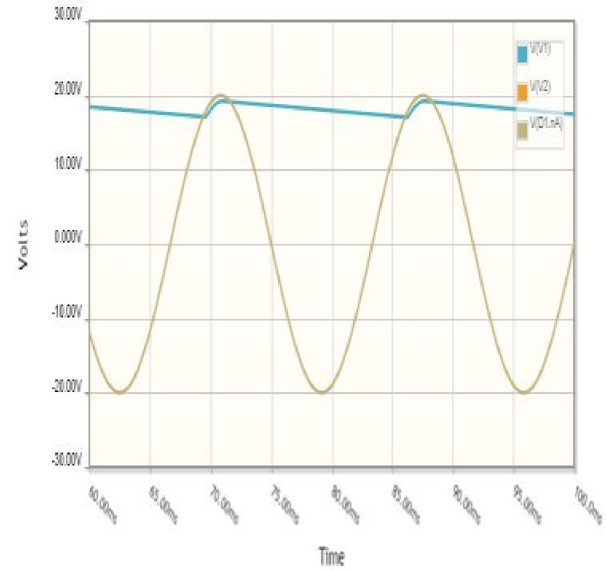
Problem

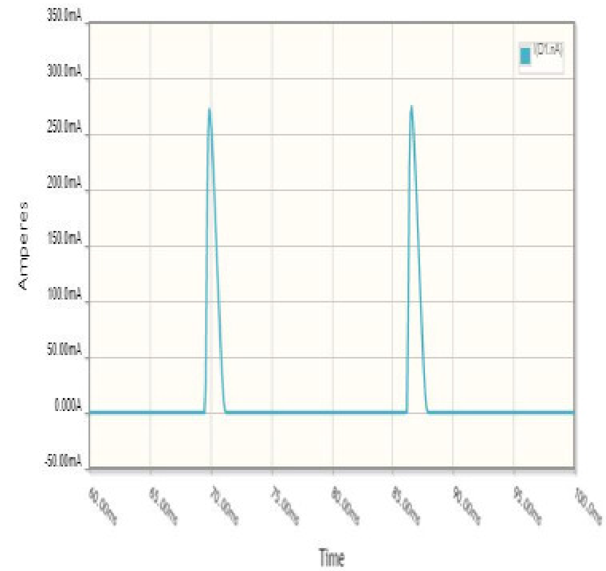
- This results in current spikes
- This creates losses in transformers
- It can also burn out neutral lines

How do you make

- The AC current a nice clean sine wave,
- The DC current a nice clean constant
- At 90-95% efficiency with electronics?

Whoever figures this out will make billions





Electronics I

Analysis of circuits with semiconductor elements

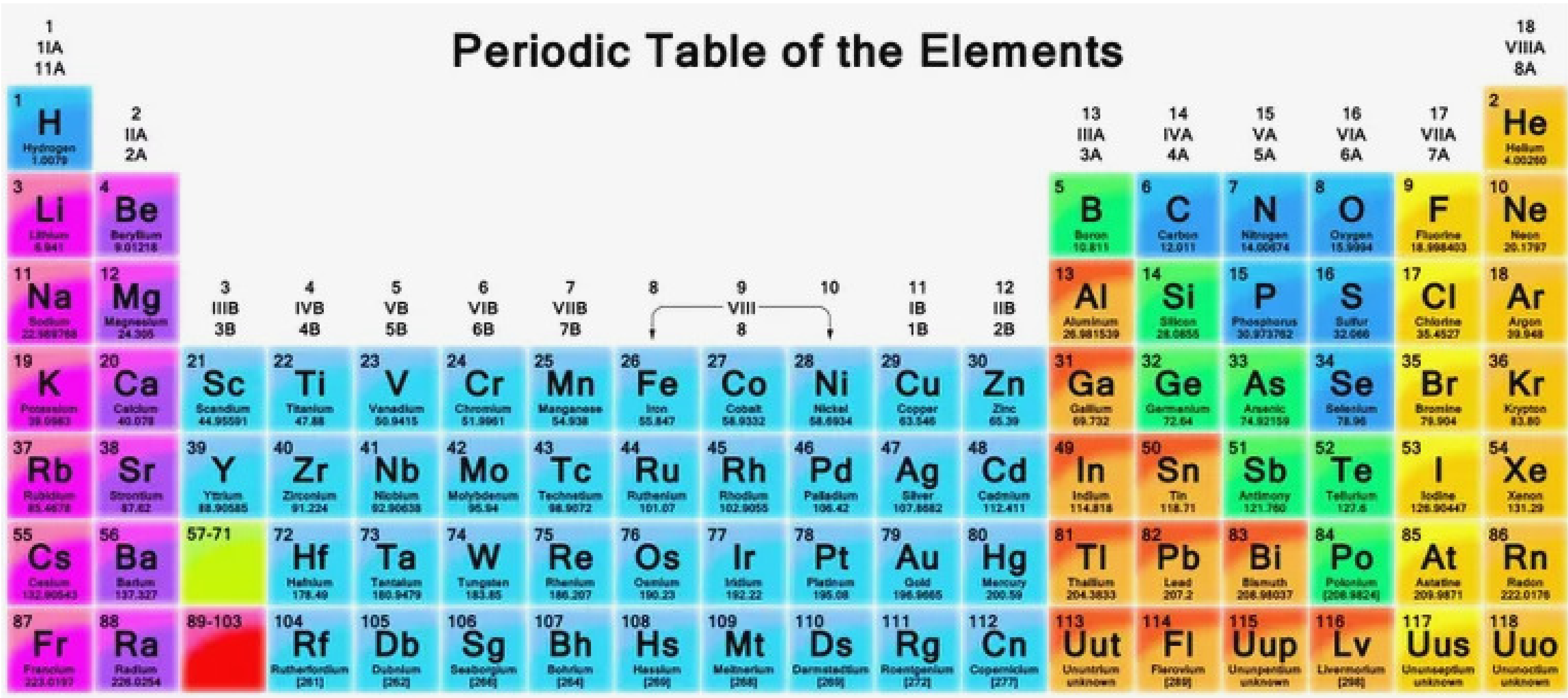
• Thermistors	temperature sensitive resistor
• Diodes	valve: allow current to flow in only one direction
• Transistors	diode + current amplifier
• SCR	voltage controlled valve
• Mosfet	voltage controlled resistor

Solution of circuits with nonlinear elements

- Solve N equations for N unknowns with nonlinear elements

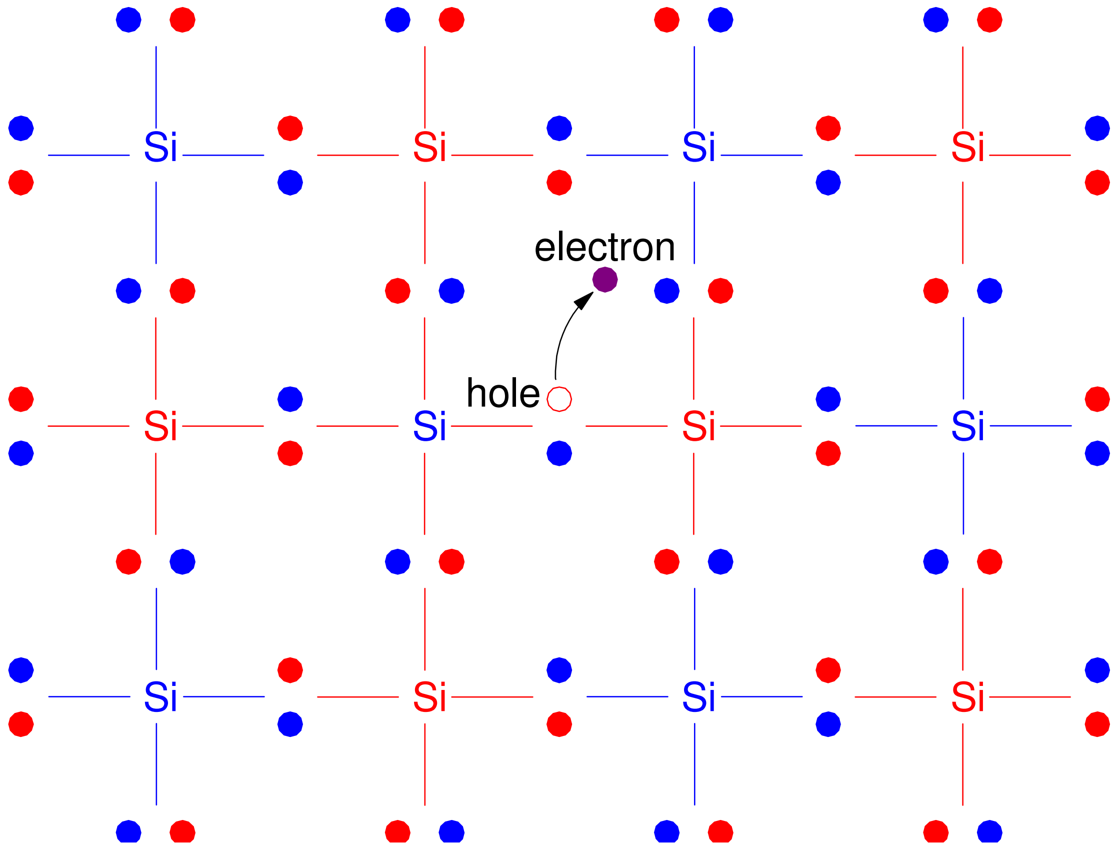
Semiconductors

Si, Ge: Column IVA of the periodic table



Holes and Electrons

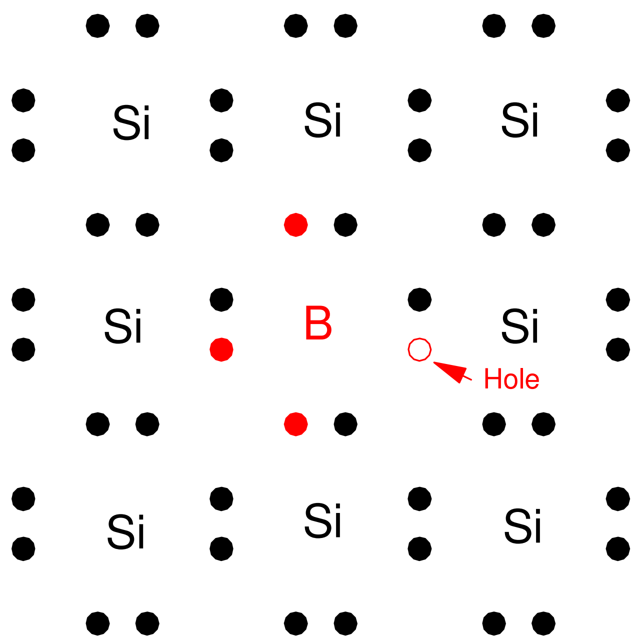
Semiconductors have two types of charge carriers: holes and electrons



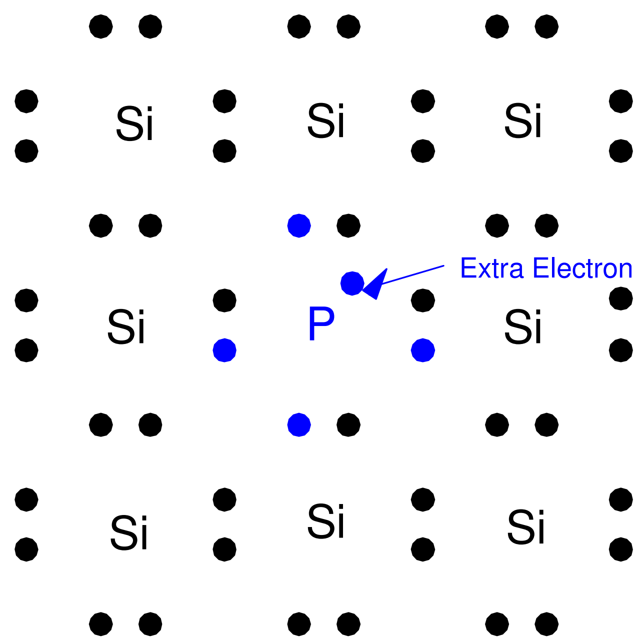
Doping

By doping, you can control what type of carriers exist in the semiconductor

- Dope with Boron: Almost all of the charge carriers are holes (p-type)
- Dope with Phosphorus: Almost all of the charge carriers are electrons (n-type)



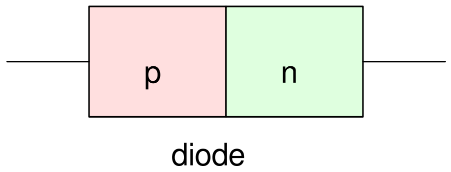
p-type silicon

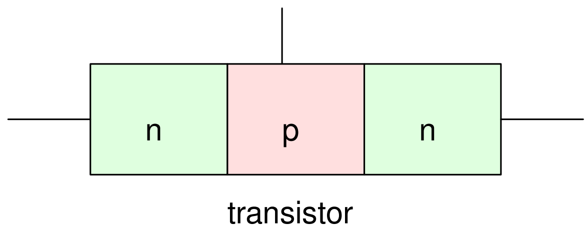


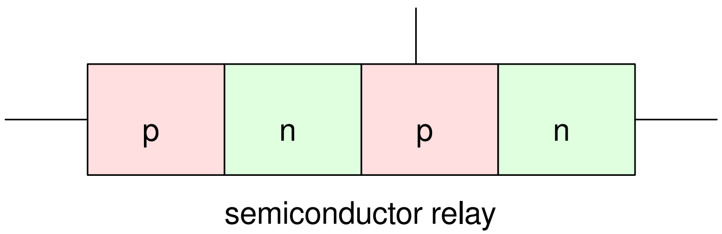
n-type silicon

Semiconductor Devices

- np: diode (valve)
- npn, pnp: transistor (current amplifier)
- pnpn: semiconductor relay (voltage controlled valve)
- npn + gate: MOSFET (voltage controlled resistor)





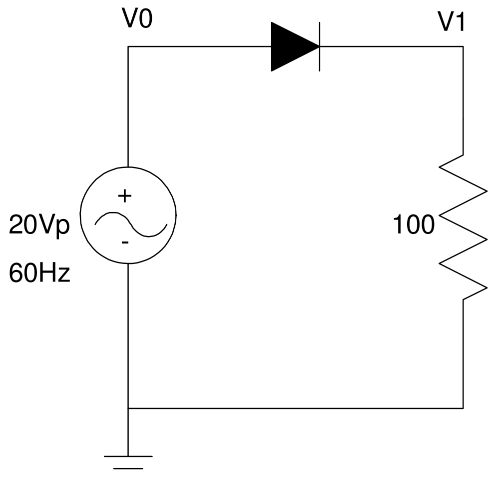


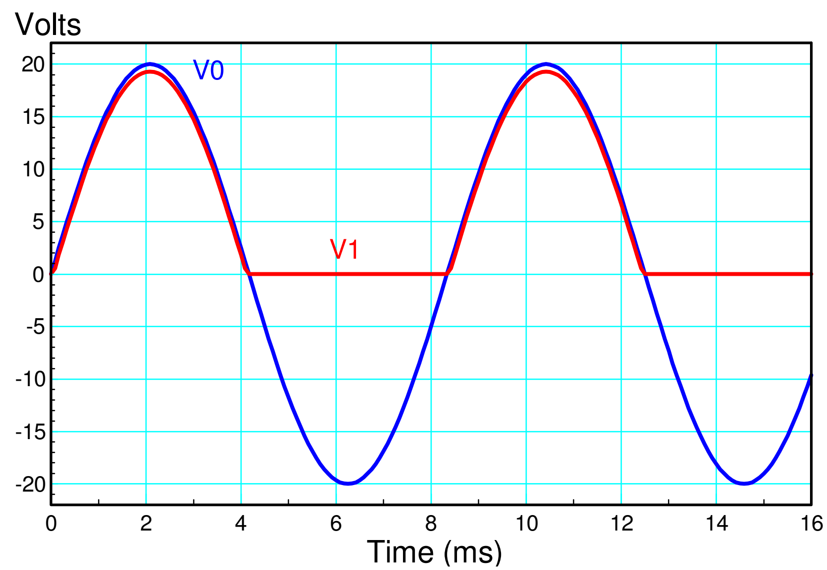
Diodes

- A pn junction makes a diode

Diodes are valves

- They only allow current to flow one way
- They allow you to find the maximum or minimum of a set of voltges
- With diodes, you can convert AC to DC





Diodes

With diodes, you can convert current to light

- Light Emitting Diodes
- *Much* more efficient than incandescent lights

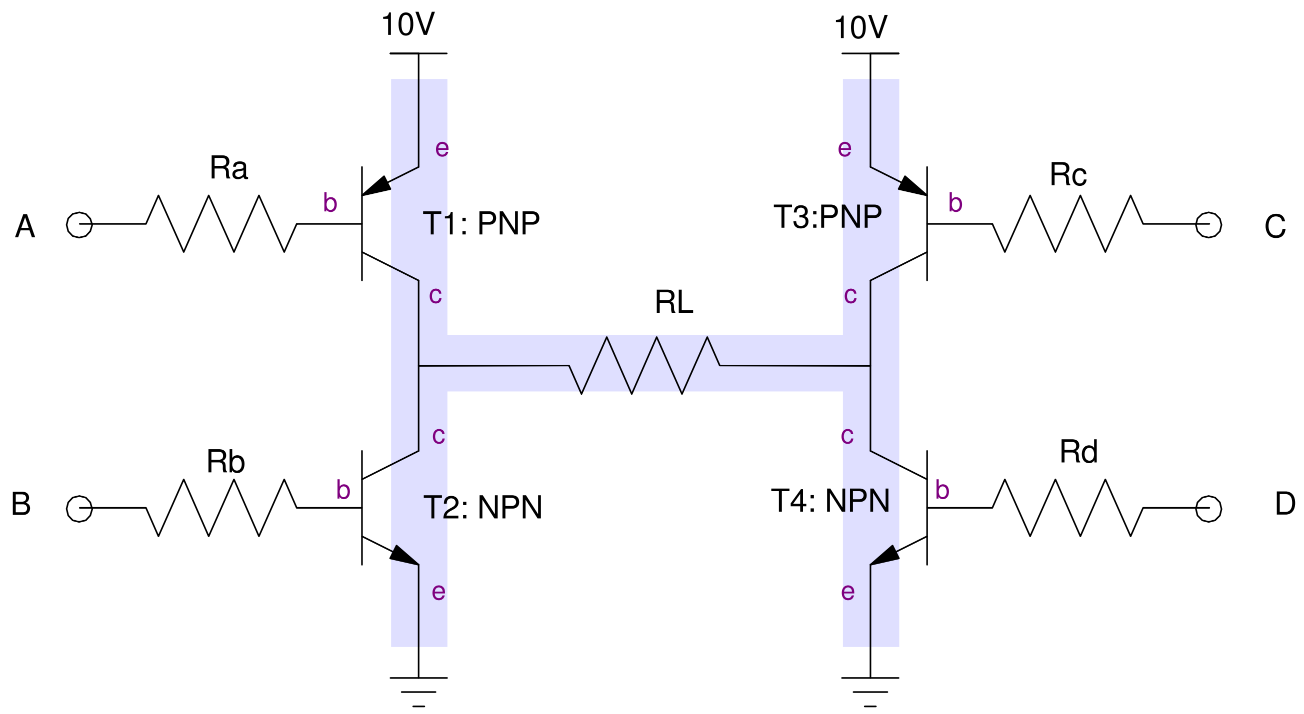
	W, Lumens	Price		Lm / W	eff
		new	@ 1000 hr		
Incandescent (c. 2000)	60W, 300 Lm	-	-	5.27	2.1%
Incancescent: GE 66247	43W, 620 Lm	$1.36	$1.38	14.4	5.7%
Halogen: Phillips 60W	43W, 750 Lm	$1.46	$1.48	17.4	6.9%
CFL: Philips 823031 CFL	13W, 860Lm	$3.50	$0.36	66.2	26.4%
LED: Sylvania 74765	8.5W, 800 Lm	$0.83	$0.075	94.1	37.5%
Street Lights:					
Mercury: GE 175W Street	175W / 7850 Lm	$11.29		36	14%
Sodium: BulBrite	70W / 6000 Lm	$8.95		86	34%
100W LED	100W / 9000 Lm	$8.29		90	36%
LED Light (theory)				201	80%
Ideal Black Body	-	-		251	100%

Transistors

- npn or pnp

Transistors act as electronic switches

- Allow a small device (microprocessor) turn on and off a motor, power LED, etc
- Allow a small device to drive a motor forwards and backwards (H-bridge)
- Heart of a DC to AC converter (used for driving AC synchronous motors)



Transistors (cont'd)

Transistors also act as current amplifiers

- Allow you to amplify an analog signal (push-pull amplifier)
- Heart of a stereo
- Covered in ECE 321 Electronics 2

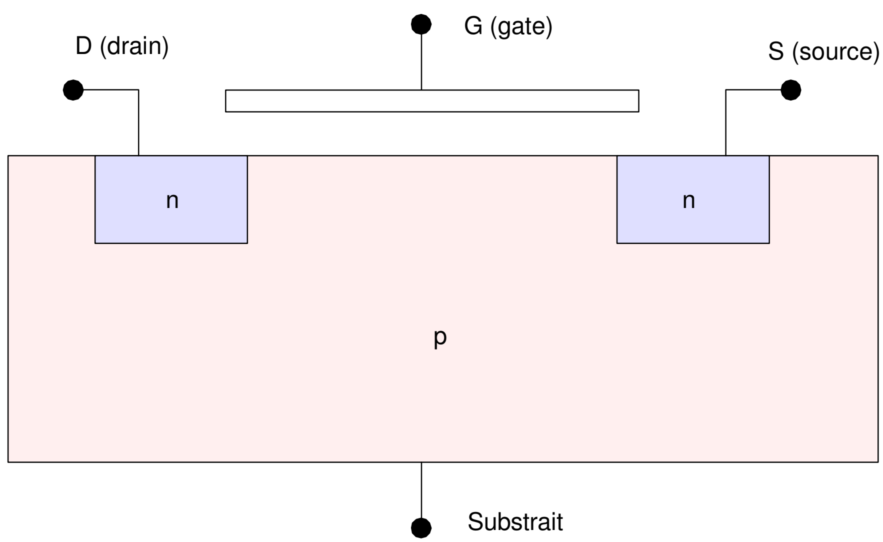
Note that transistors dump voltage (meaning they will get hot when used as an amplifier). The four transistors at the top are likewise connected to a heat-sink.

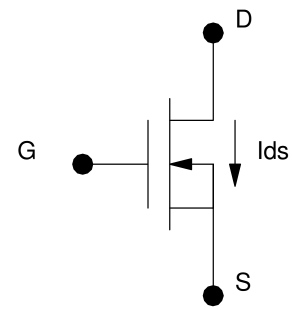
MOSFET

- Voltage controlled resistor

Heart of DC to AC converters

Heart of CMOS logic (building block of computers)





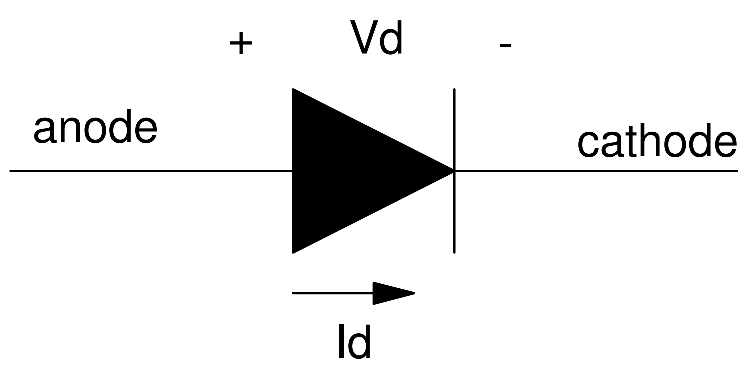
Symbol

Diode VI Characteristics

A diode is a nonlinear circuit element which acts like a valve:

- The resistance is low when you try to force current to flow from the anode to cathode
- The resistance is high when you try to force current to flow from the cathode to the anode.

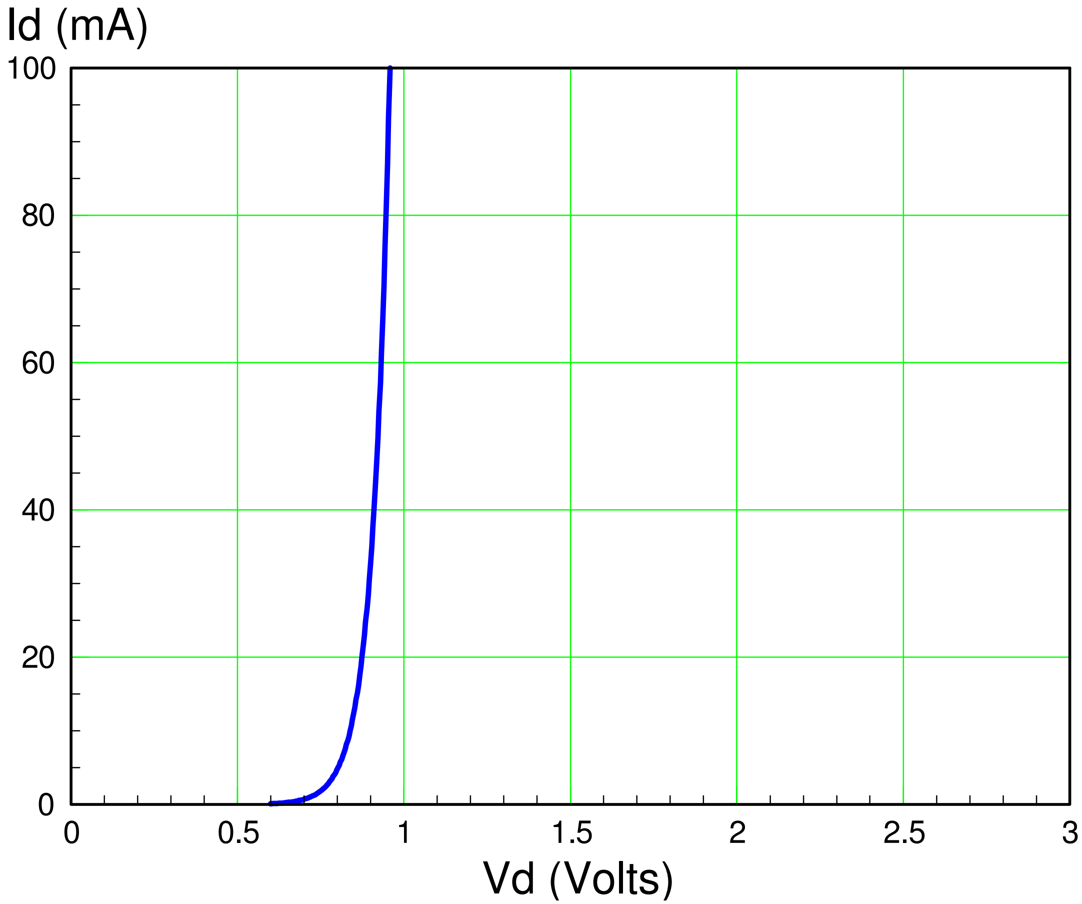
The symbol for a diode acts as a reminder of this: it looks like an arrow which points in the direction current can flow



Symbol for a diode: current only flows from anode to cathode

The VI characteristics for a diode are nonlinear

$$I_d = I_{dss}\left(\exp\left(\frac{V_d}{nV_T}\right) - 1\right) \qquad\qquad V_d = nV_T \ln\left(\frac{I_d}{I_{dss}} + 1\right)$$



What makes electronics so hard?

In circuits, you deal with linear circuit elements

- Resistors, Capacitors, Inductors
- Linear algebra can be used to solve these problems
- N equations for N unknowns

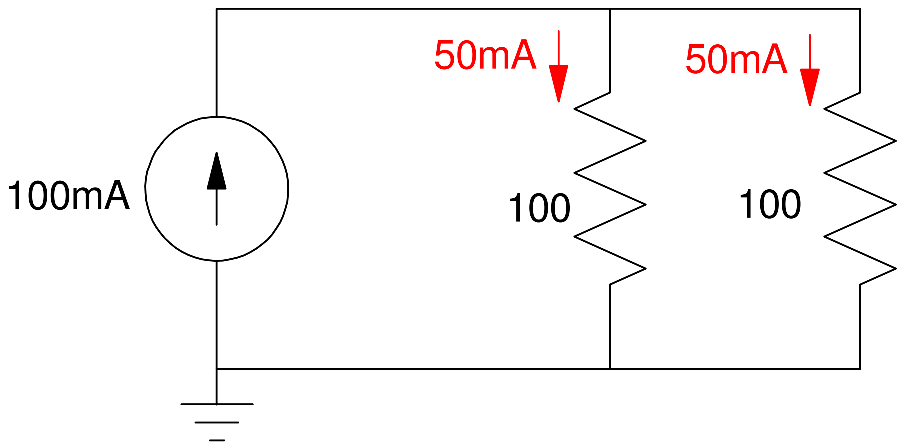
In electronics, you deal with *nonlinear* circuit elements

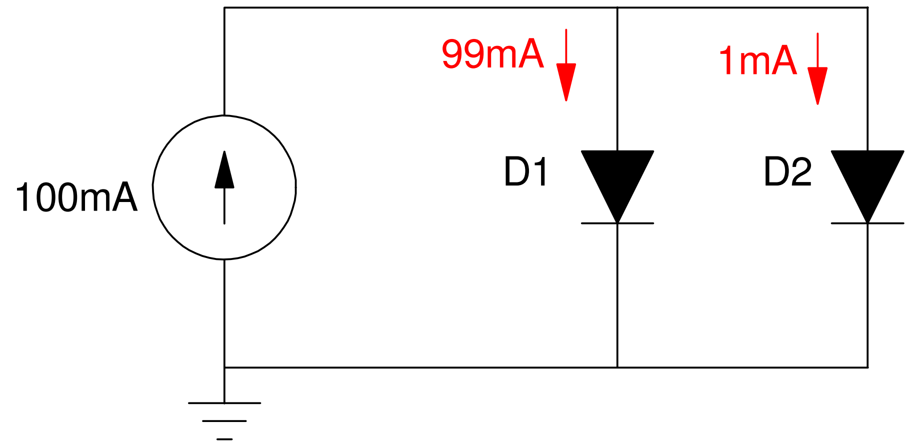
- Diodes, Transistors, MOSFETs
- You still have N equations for N unknowns
- But linear algebra no longer works (the equations are nonlinear)

Nonlinear Elements Behave Weird

Example: Resistors vs. Diodes in Parallel

- Two resistors in parallel share the load equally
- Two diodes in parallel do not: one takes the brunt of the current





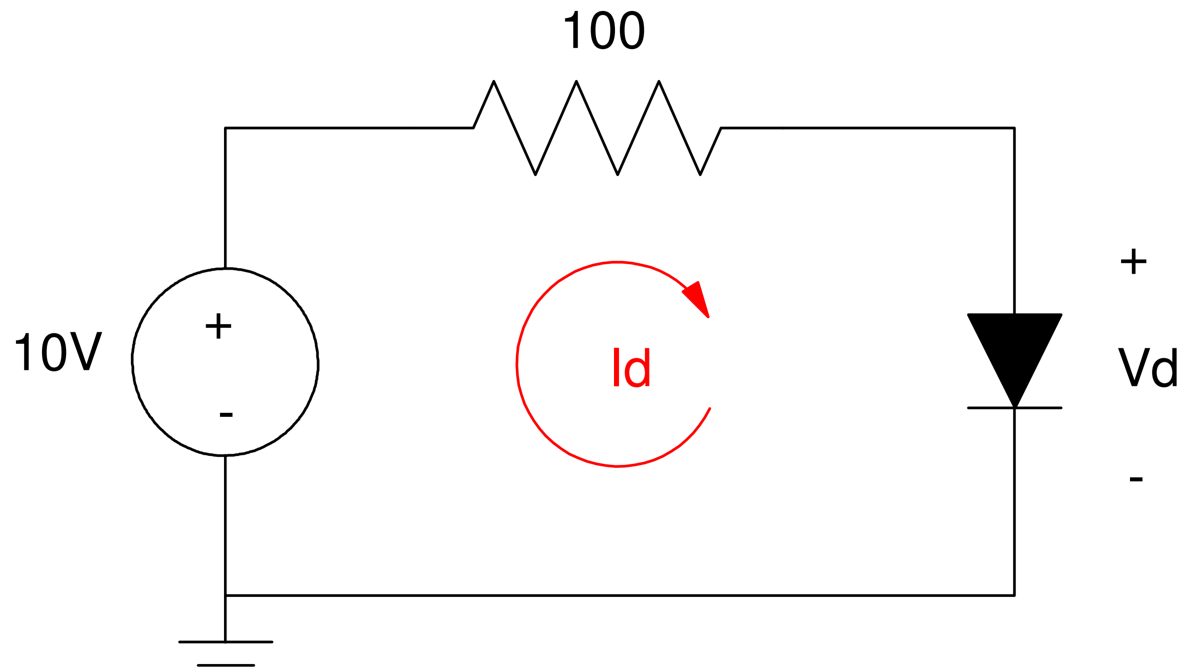
Nonlinear Equations are Hard to Solve

Example: Single diode circuit:

- 2 equations for 2 unknowns:

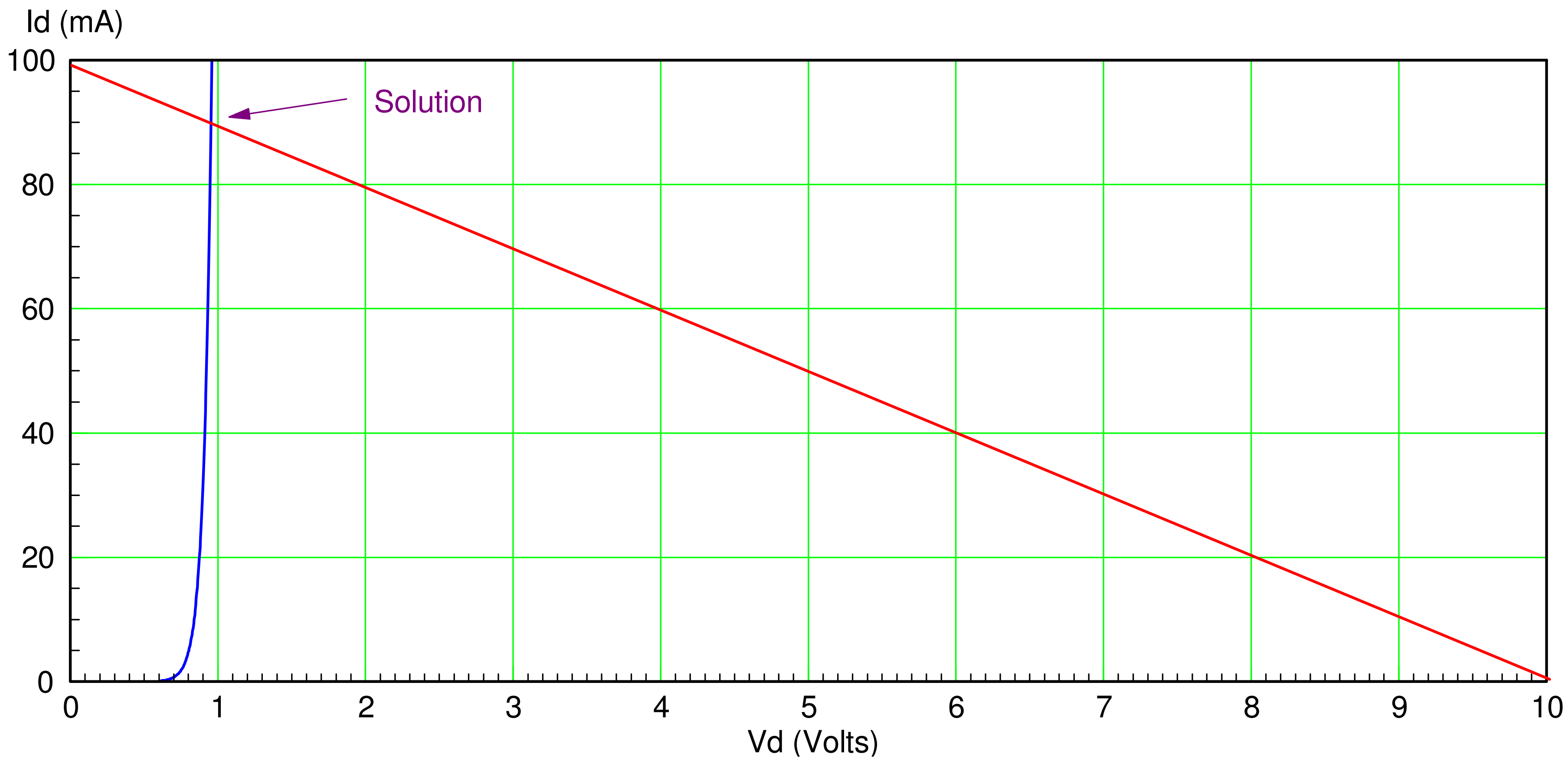
$$V_d = nV_T \ \ln\left(\frac{I_d}{I_{dss}} + 1\right) = 0.0377 \ln\left(\frac{I_d}{7.69 \cdot 10^{-11}} + 1\right)$$

$$V_d + 100 I_d = 10$$



Load Line Analysis:

- Plot Id vs. Vd for both equations
- The solution is where they intersect



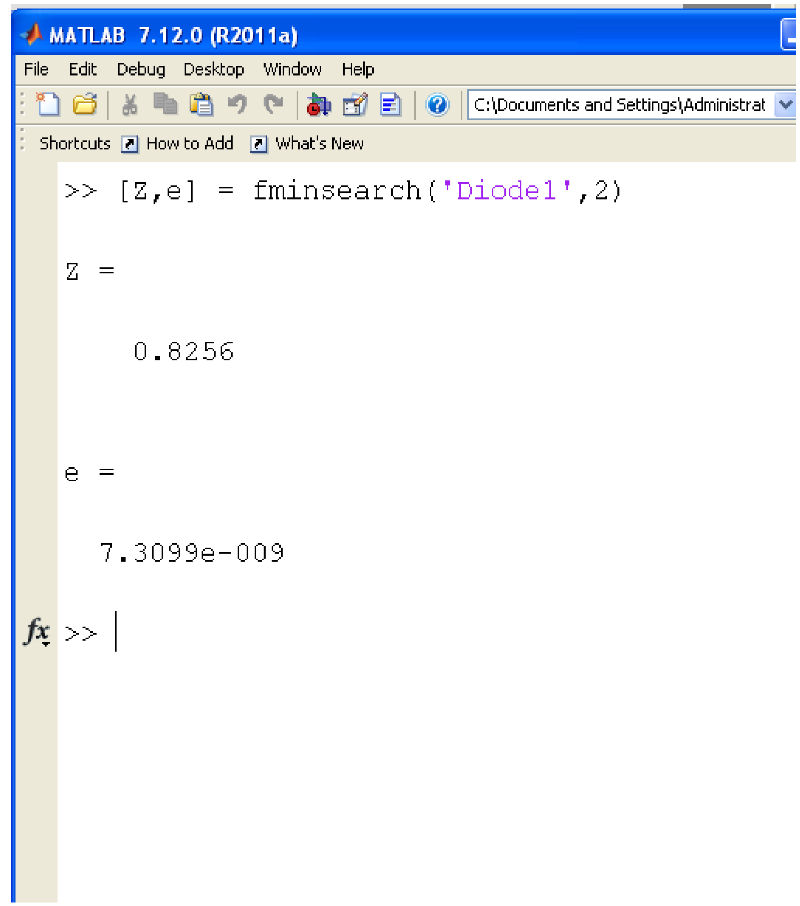
Numerical Solution

- Matlab to the rescue!

Guess Vd

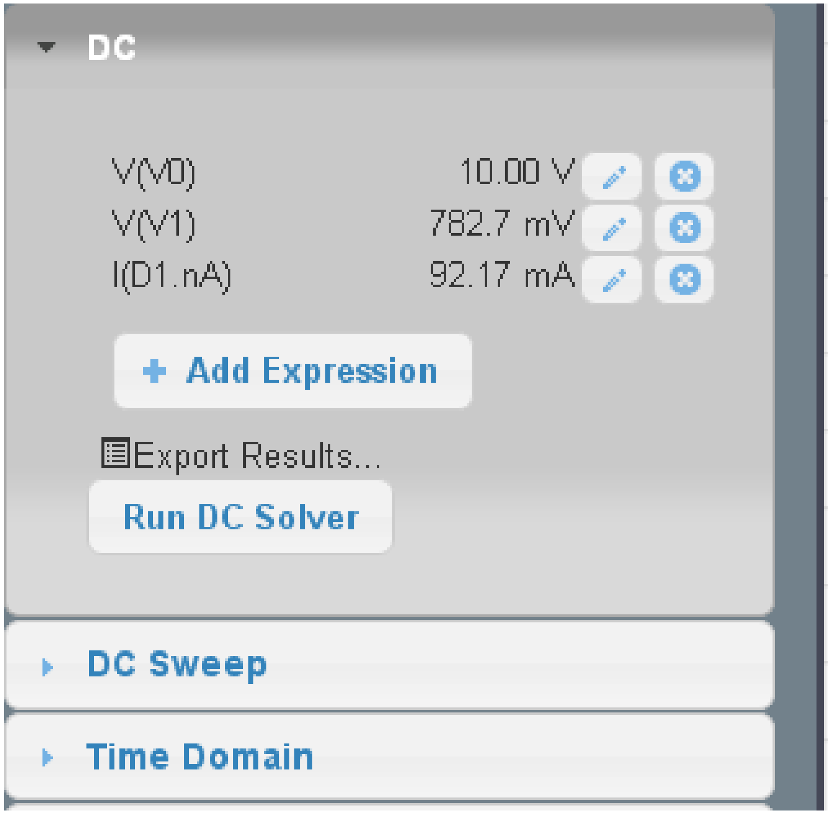
- Compute Id (diode equation)
- Compute the excess current (voltage nodes)
- Minimuze the error using *fminsearch()*

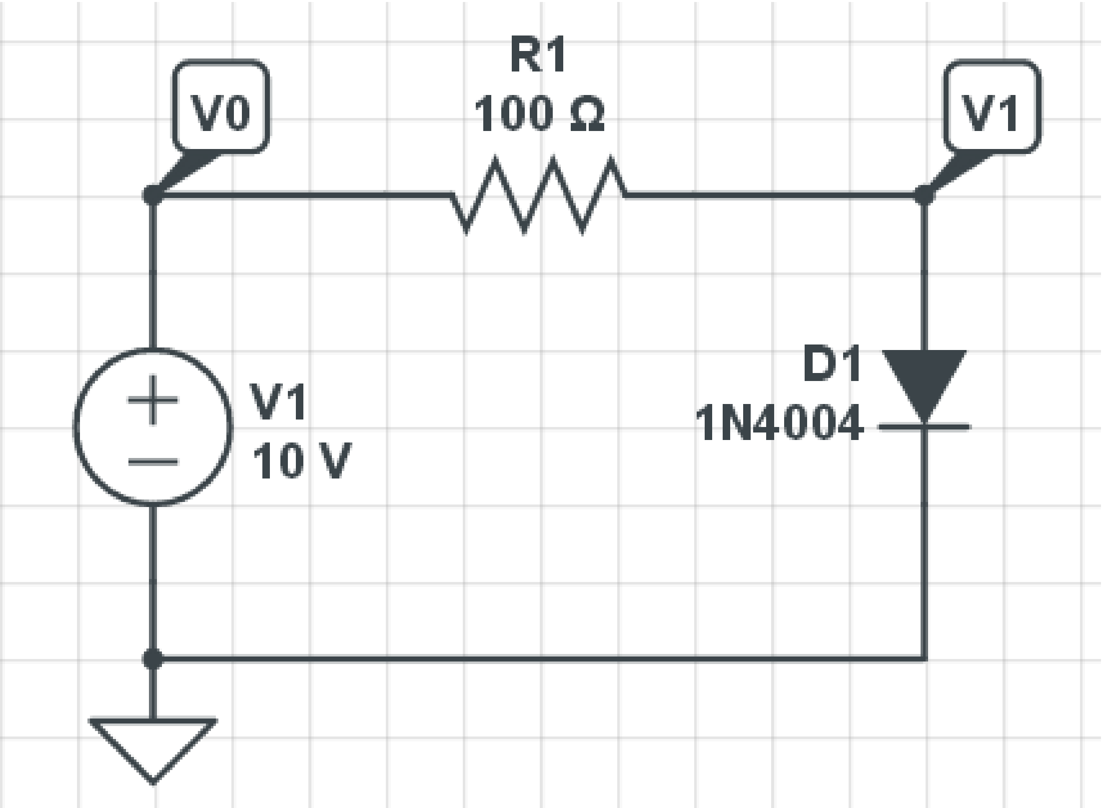
```
function [ J ] = Diode1( z )

  Vd = z(1);

  Idss = 7.69e-11;
  nVt = 0.0377;

  Id = Idss* exp( Vd/nVt - 1 );

  e1 = Id + (Vd - 10)/100;

  J = (e1)^2;

  end
```



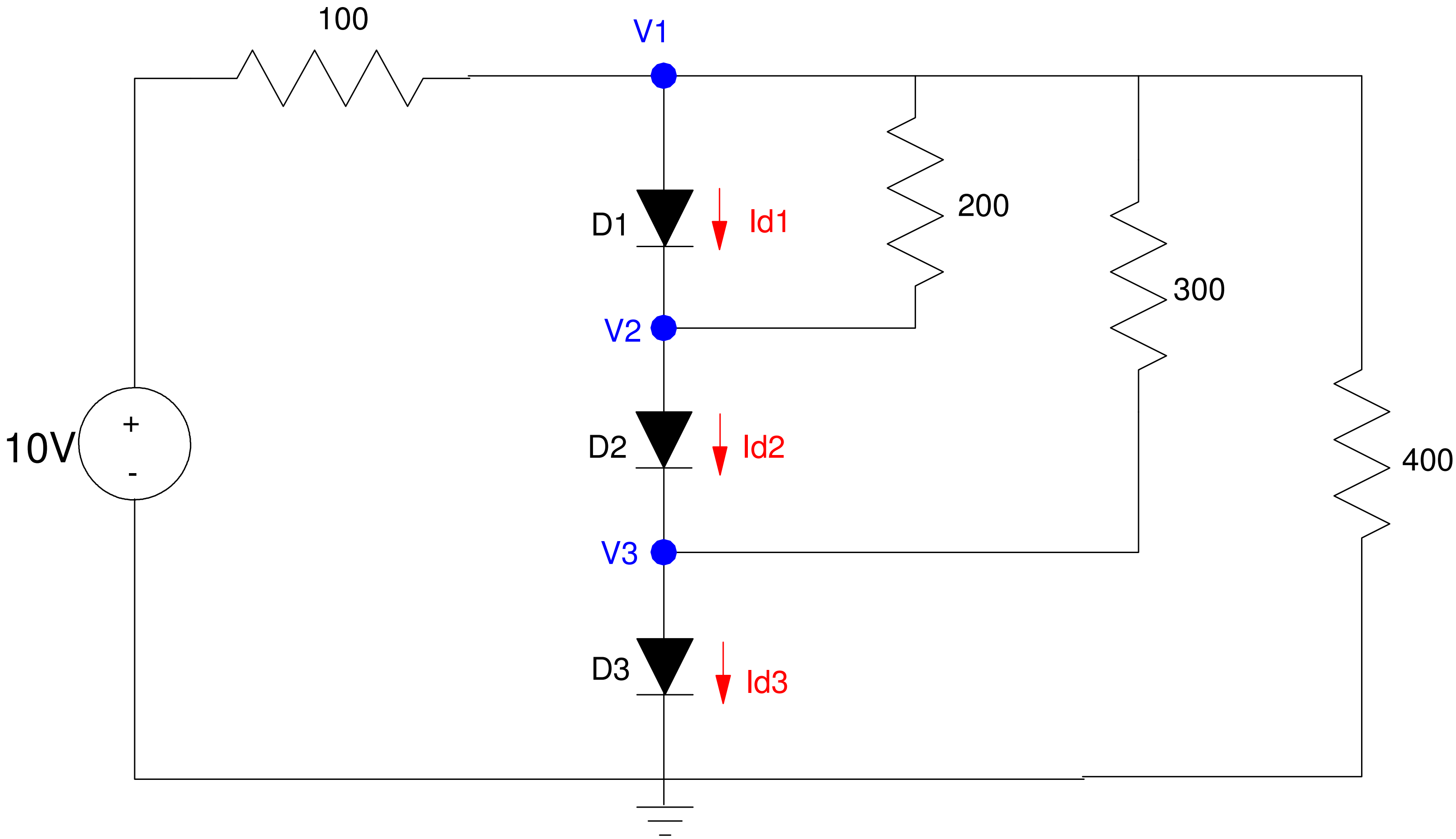
CircuitLab Solution

- Matlab: Vd = 0.8256V





Example 2: Multi-Diode Circuit



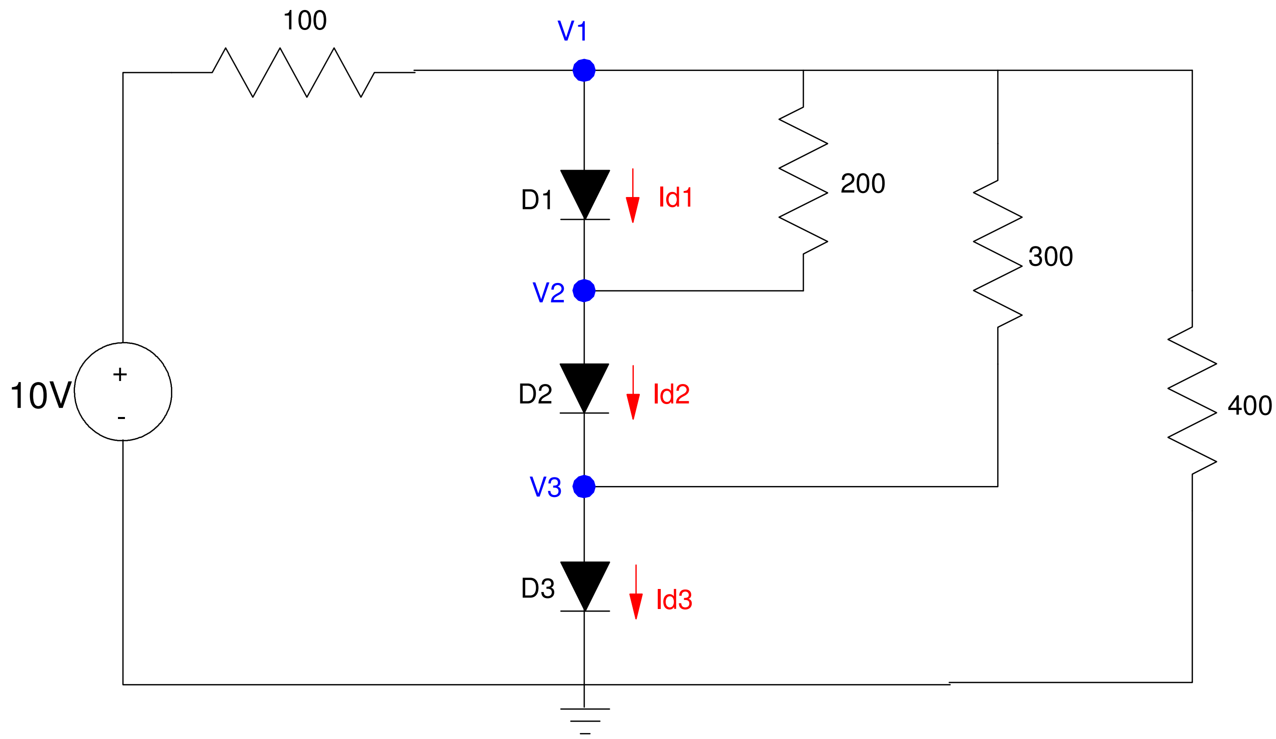
Numerical Solution

Load Lines won't work

- Need to plot in 6 dimensions

Numerical solution still works:

- Solve 6 equations for 6 unknowns
- fminsearch



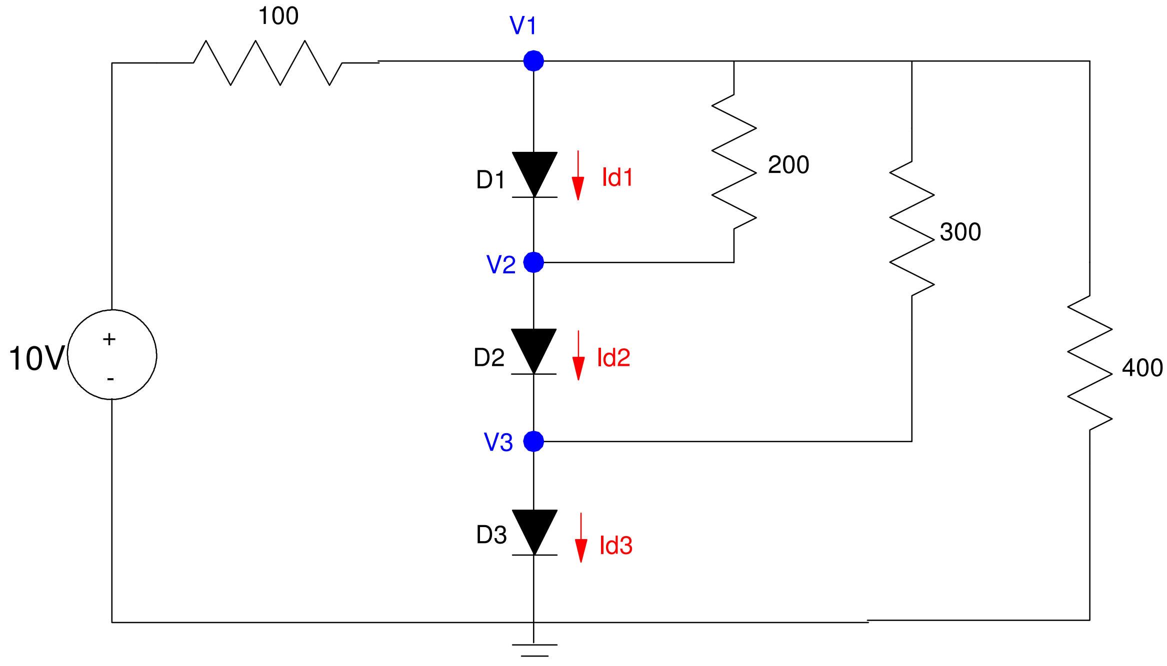
N-equations for N unknowns

Diode equations (1..3)

$$I_{d1} = I_{dss}\left(\exp\left(\frac{V_1 - V_2}{nV_T}\right) - 1\right)$$

$$I_{d2} = I_{dss}\left(\exp\left(\frac{V_2 - V_3}{nV_T}\right) - 1\right)$$

$$I_{d3} = I_{dss}\left(\exp\left(\frac{V_3 - 0}{nV_T}\right) - 1\right)$$

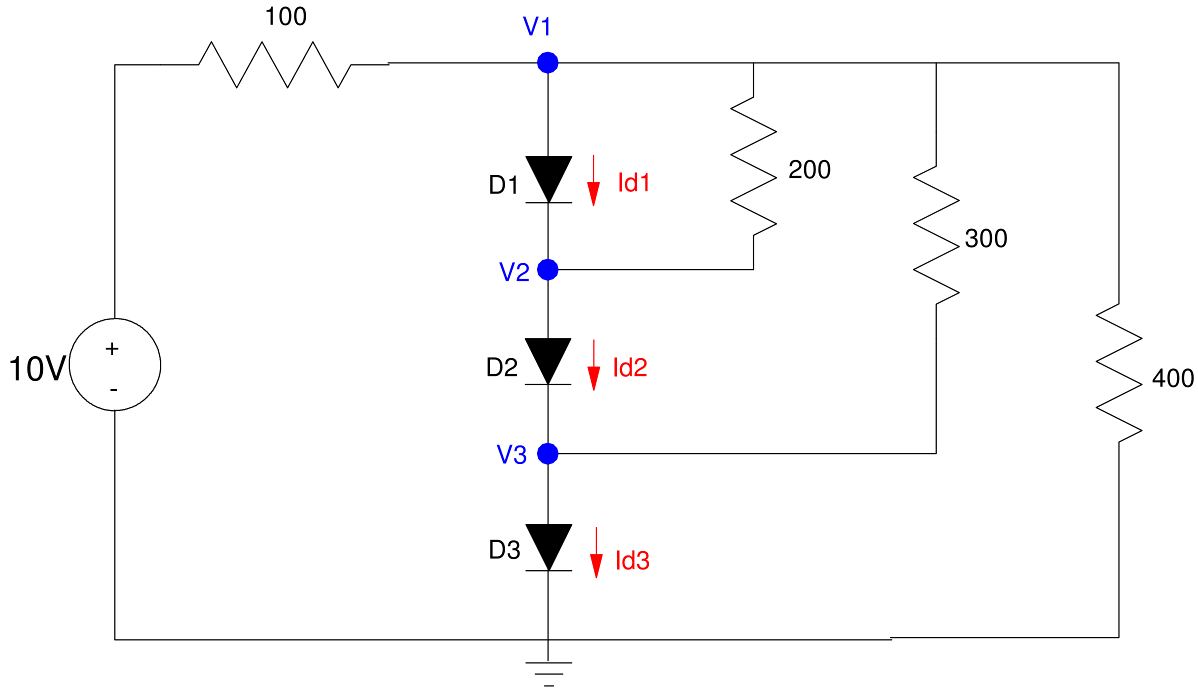


Voltage Node equations (4..6)

$$\left(\frac{V_1-10}{100}\right)+I_{D1}+\left(\frac{V_1-V_2}{200}\right)+\left(\frac{V_1-V_3}{300}\right)+\left(\frac{V_1-0}{400}\right)=0$$

$$\left(\frac{V_2-V_1}{200}\right)-I_{D1}+I_{D2}=0$$

$$\left(\frac{V_3-V_1}{300}\right)-I_{D2}+I_{D3}=0$$



Procedure:

i) Guess the voltages (V1, V2, V3)

ii) Compute the diode currents:

$$I_{d1} = I_{dss}\left(\exp\left(\frac{V_1 - V_2}{nV_T}\right) - 1\right)$$

$$I_{d2} = I_{dss}\left(\exp\left(\frac{V_2 - V_3}{nV_T}\right) - 1\right)$$

$$I_{d3} = I_{dss}\left(\exp\left(\frac{V_3 - 0}{nV_T}\right) - 1\right)$$

iii) Find the excess current (error) from each node:

$$e_1 = \left(\frac{V_1 - 10}{100}\right) + I_{d1} + \left(\frac{V_1 - V_2}{200}\right) + \left(\frac{V_1 - V_3}{300}\right) + \left(\frac{V_1}{400}\right)$$

$$e_2 = \left(\frac{V_2 - V_1}{200}\right) - I_{d1} + I_{d2}$$

$$e_3 = \left(\frac{V_3 - V_1}{300}\right) - I_{d2} + I_{d3}$$

iv) Compute the sum square error

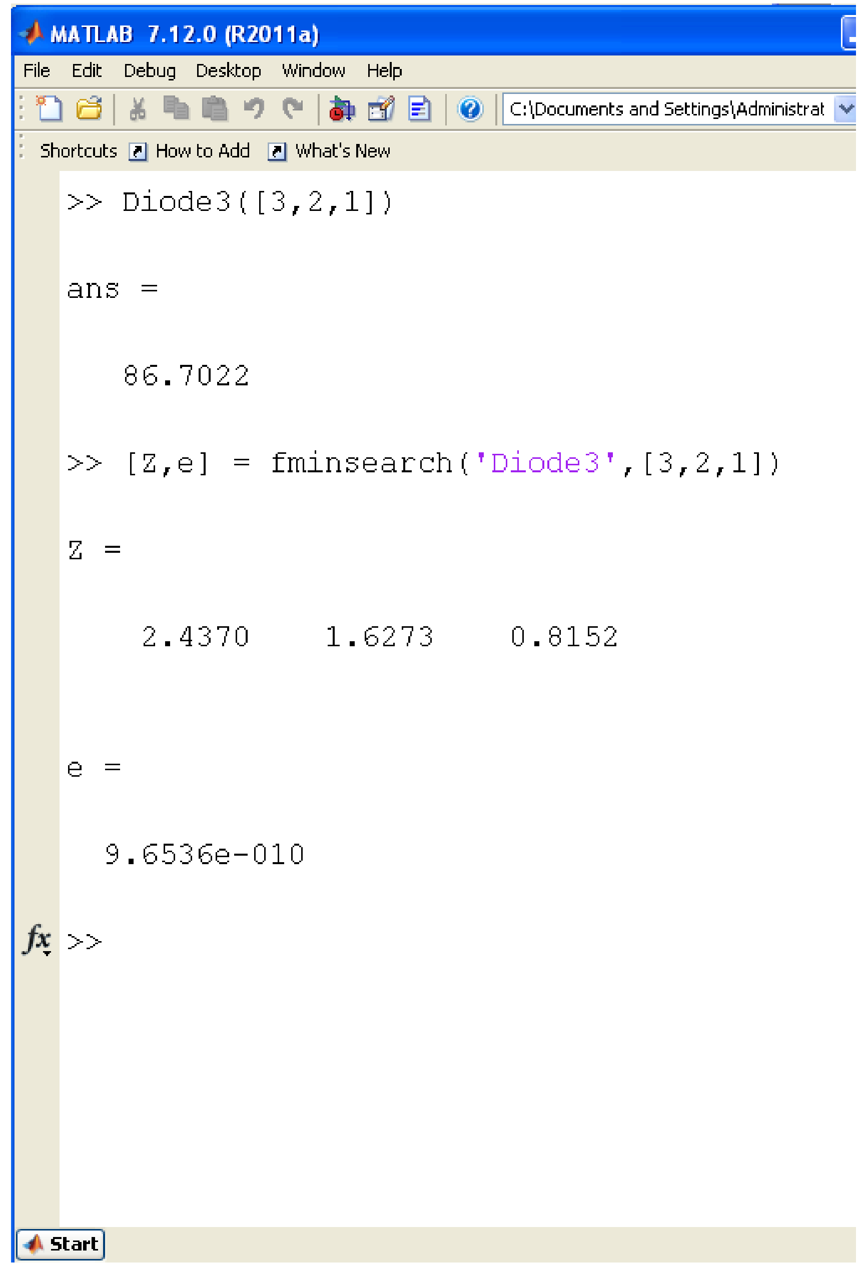
$$J = e_1^2 + e_2^2 + e_3^2$$

```
function [ J ] = Diode3( z )

   V1 = z(1);
   V2 = z(2);
   V3 = z(3);

   Idss = 7.69e-11;
   nVt = 0.0377;

   Id1 = Idss* exp( (V1 - V2)/nVt - 1 );
   Id2 = Idss* exp( (V2 - V3)/nVt - 1 );
   Id3 = Idss* exp( (V3 - 0)/nVt - 1 );

   e1 = (V1 - 10)/100 + Id1 + (V1-V2)/200 + (V1-V3)/300 + (V1/400);
   e2 = (V2-V1)/200 - Id1 + Id2;
   e3 = (V3-V1)/300 - Id2 + Id3;

   J = (e1)^2 + (e2)^2 + (e3)^2;
   end
```

Solving with *fminsearch*

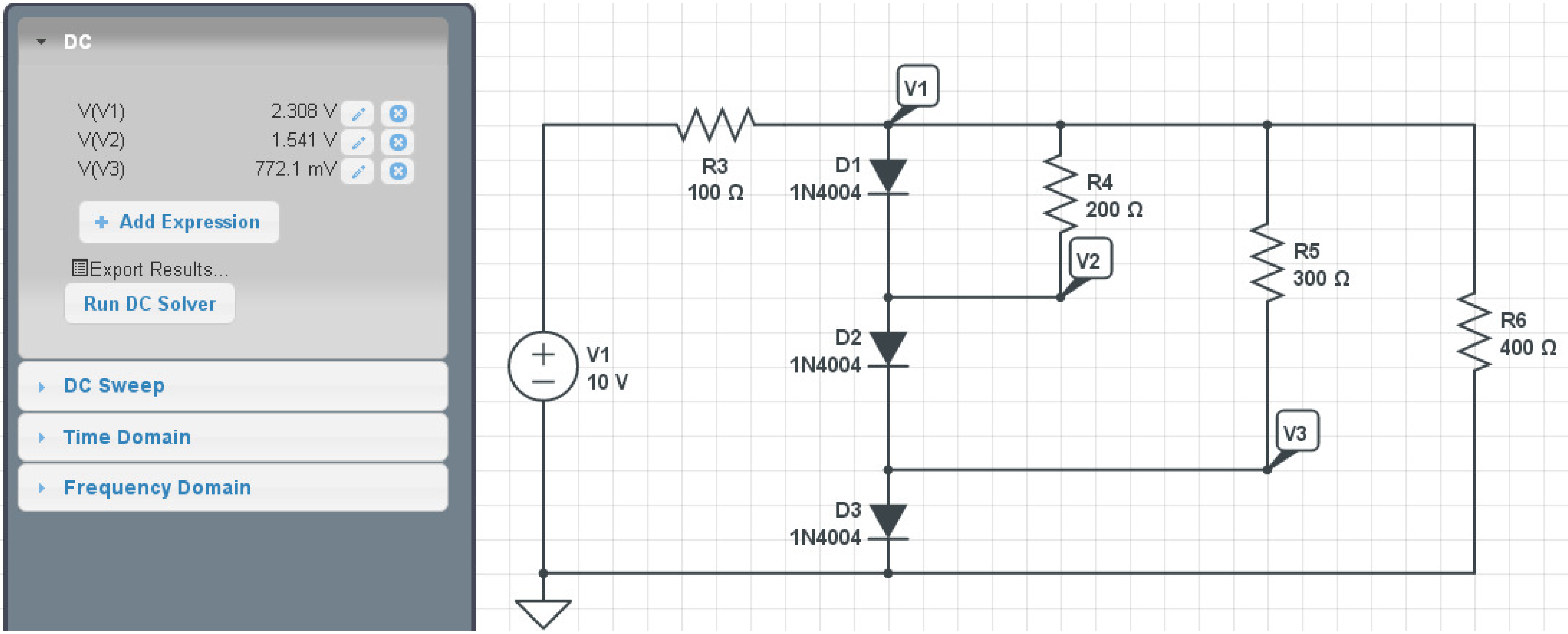
The solution found by MATLAB is

- V1 = 2.4370V
- V2 = 1.6273V
- V3 = 0.8152V



Check with CircuitLab

- Matlab Solution: V1 = 2.4370V, V2 = 1.6273V, V3 = 0.8152V
- Answers are slightly different (slightly different diode model used for a 1N4004)



Summary

In Electronics, you deal with nonlinear circuit elements

- Thermistors, Diodes, Transistors, MOSFETs, SCR's, etc.

Voltage Nodes, Current Loops still apply

- Solve N equations for N unknowns
- Only now, they are N nonlinear equations

fminsearch is a very useful tool. With it

- You can solve N equations for N unknowns
- Even when the equations are nonlinear