ECE 320: Electronics I

ECE 111: Intro to ECE

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

Electrical and Computer Engineering

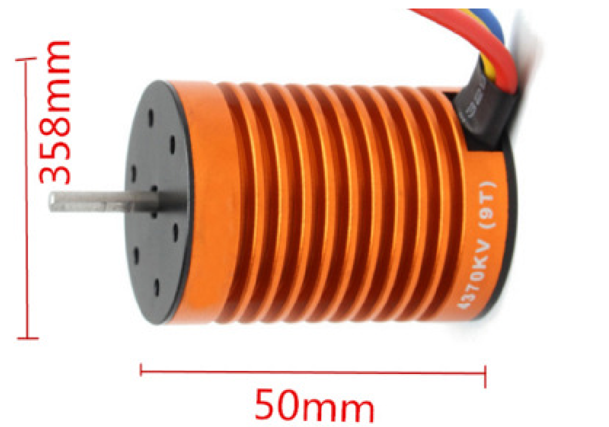
Why I like electrical and computer engineering:

- 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

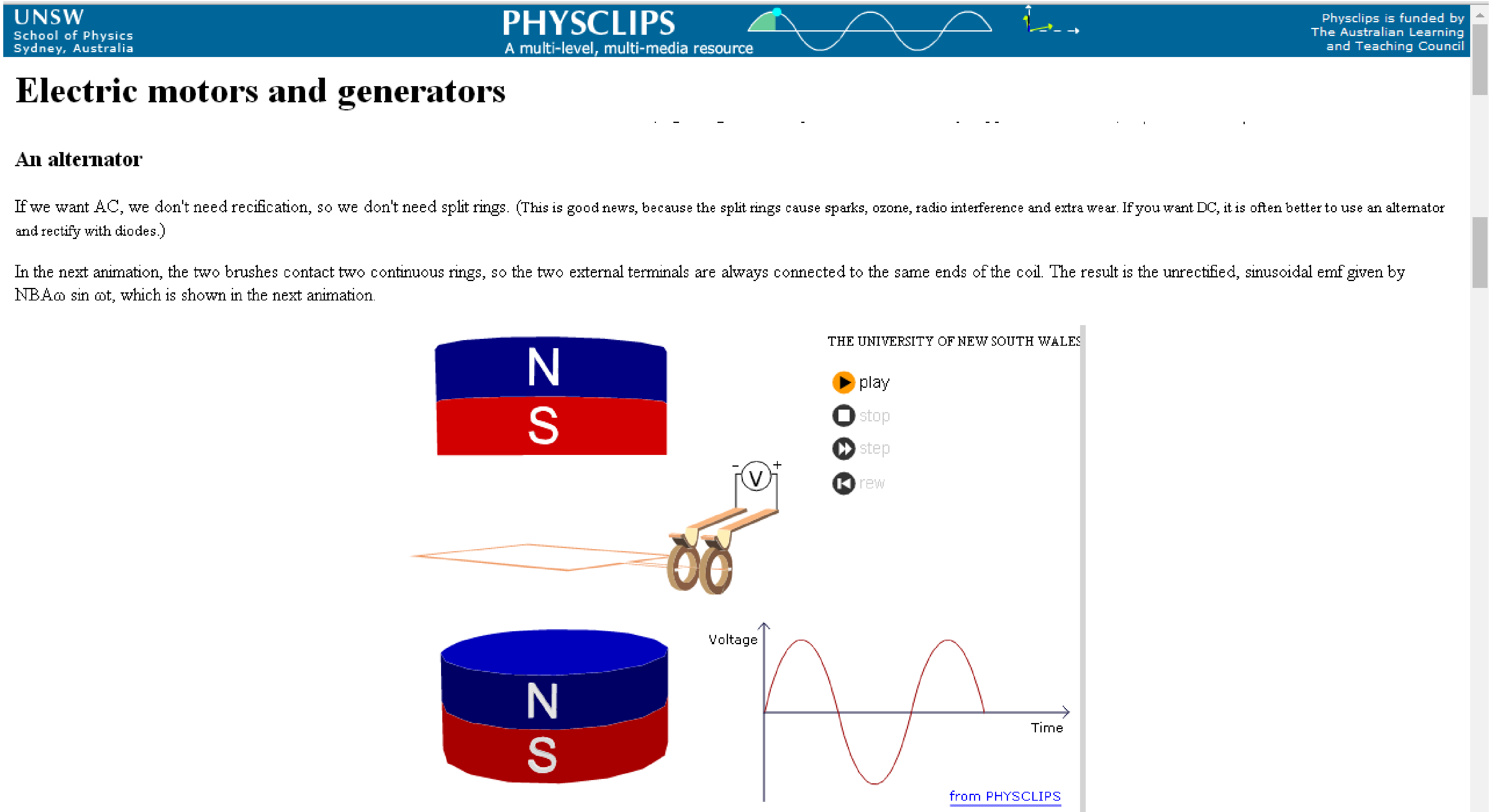
1990 Technology
1000W DC Servo Motor
40 lbs, $5000, 18" x 6" dia

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



3-Phase AC Synchronous Motors

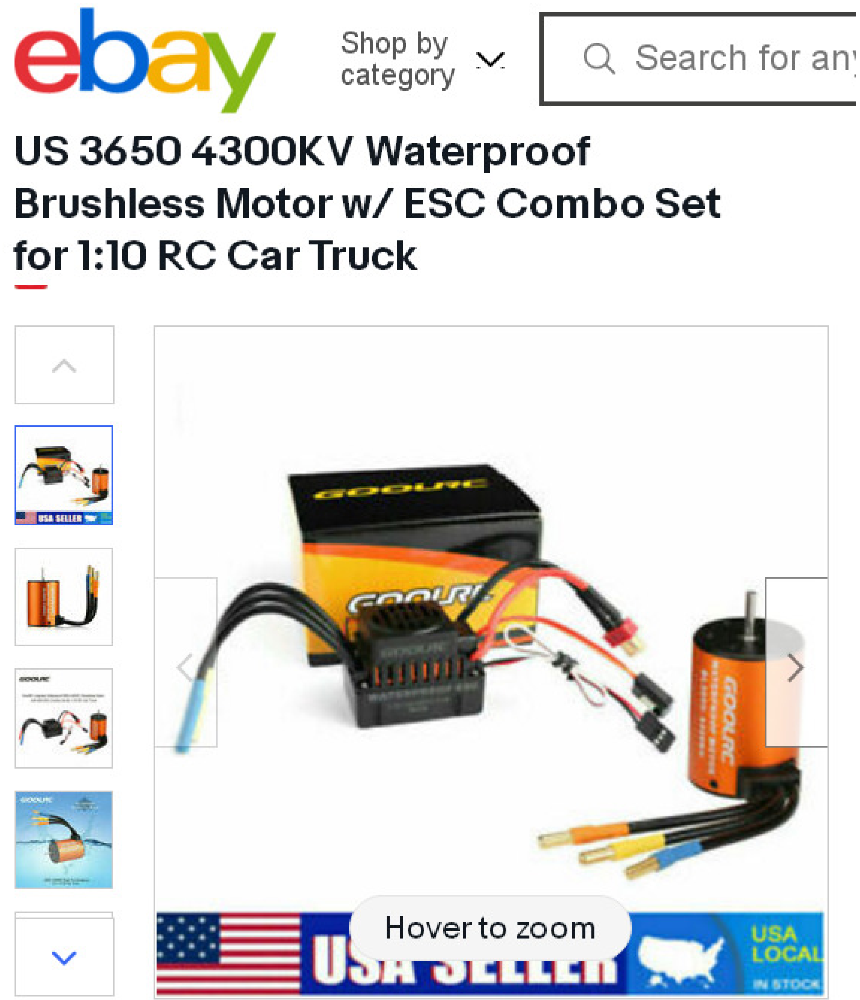
- Think Tesla motors or quadcopter motors

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

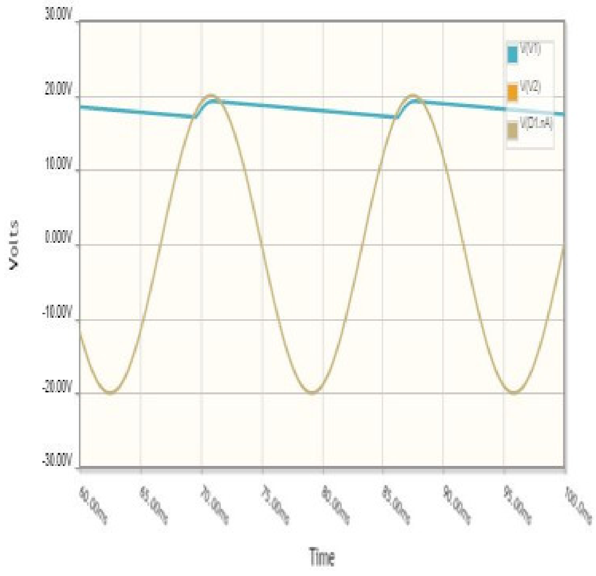
Problem

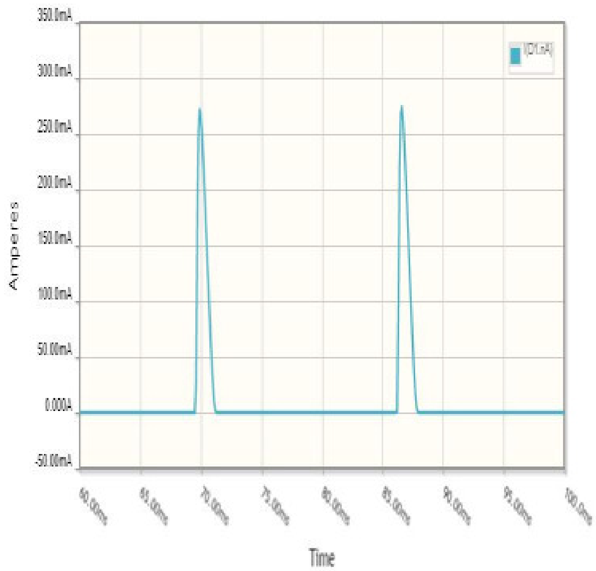
- This results in current spikes
- This creates losses in transformers
- It can also burn out neutral lines

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

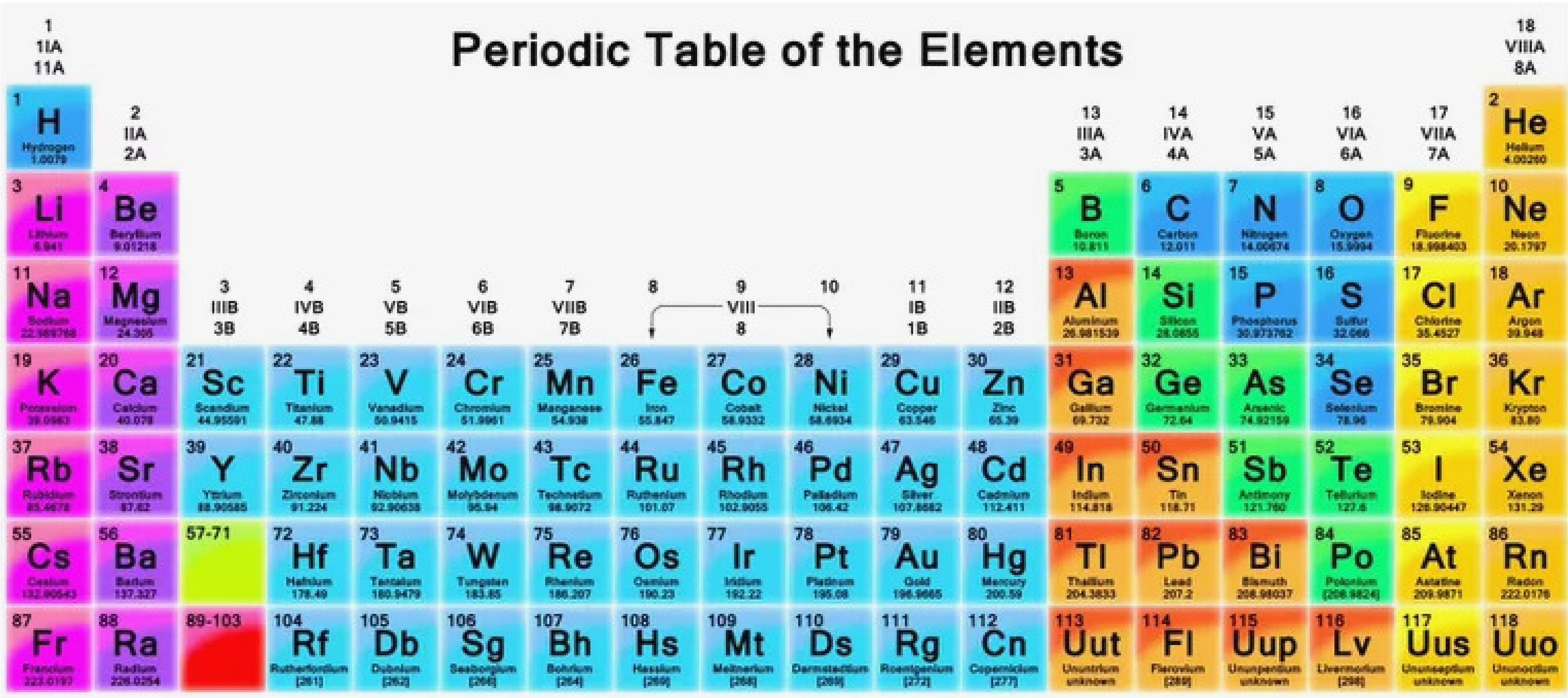
- Thermistors — temperature sensitive resistor
- Diodes — valve: allow current to flow in only one direction
- Transistors — diode + current amplifier
- SCR — voltage controlled valve
- Mosfet — voltage controlled resistor

Solution of circuits with nonlinear elements

- Solve N equations for N unknowns with nonlinear elements

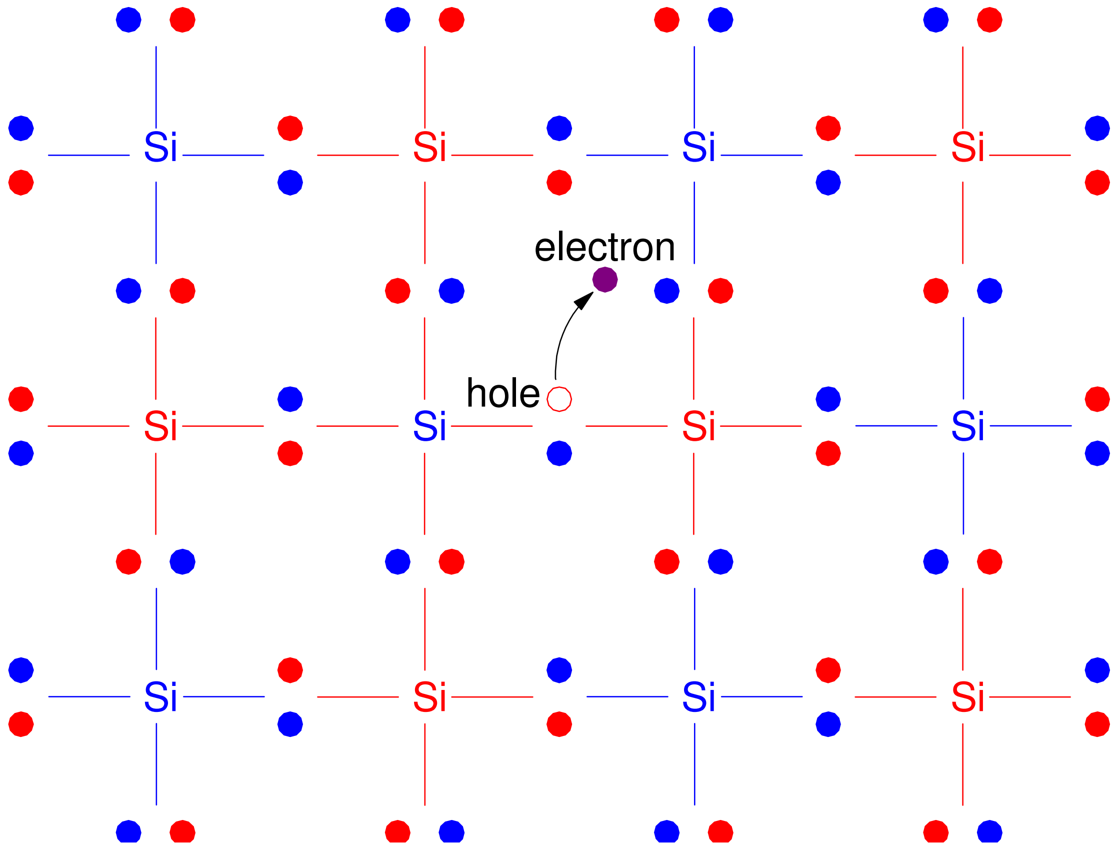
Semiconductors

Si, Ge: Column IVA of the periodic table



Holes and Electrons

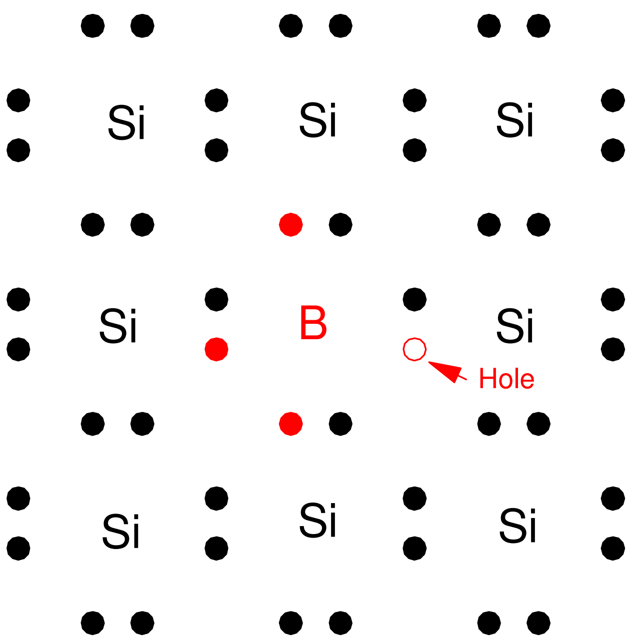
Semiconductors have two types of charge carriers: holes and electrons



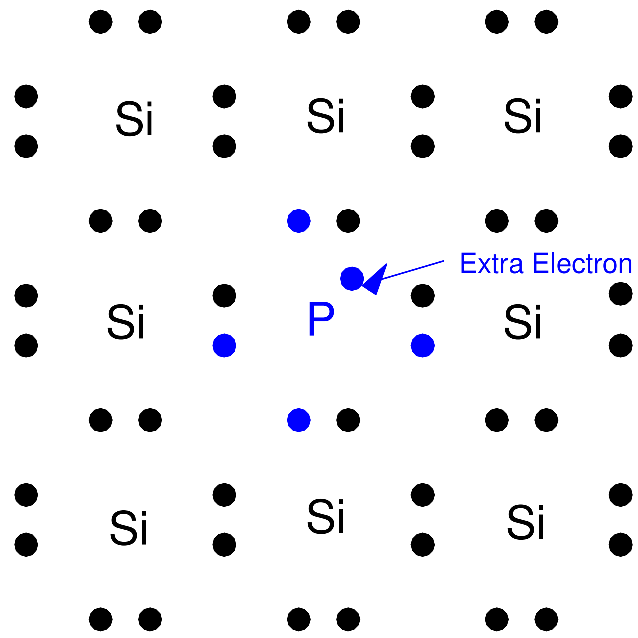
Doping

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)



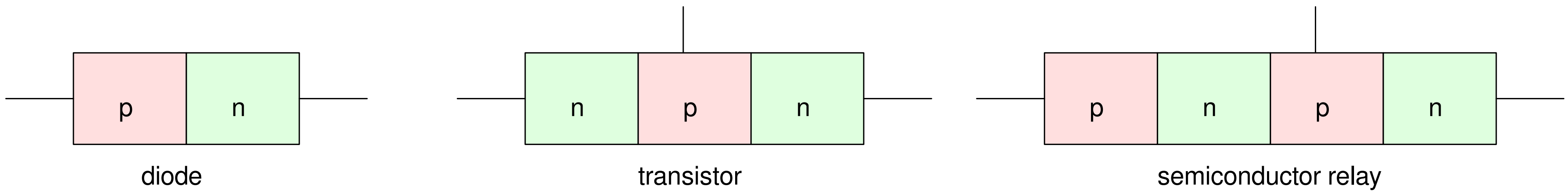
p-type silicon



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)

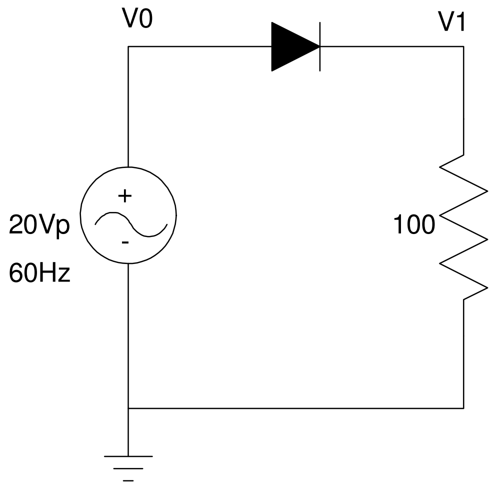


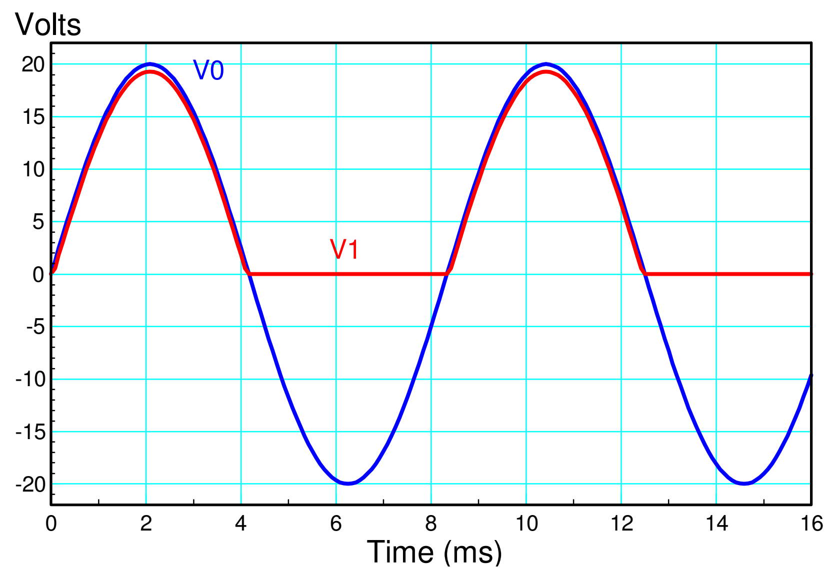
Diodes

- 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

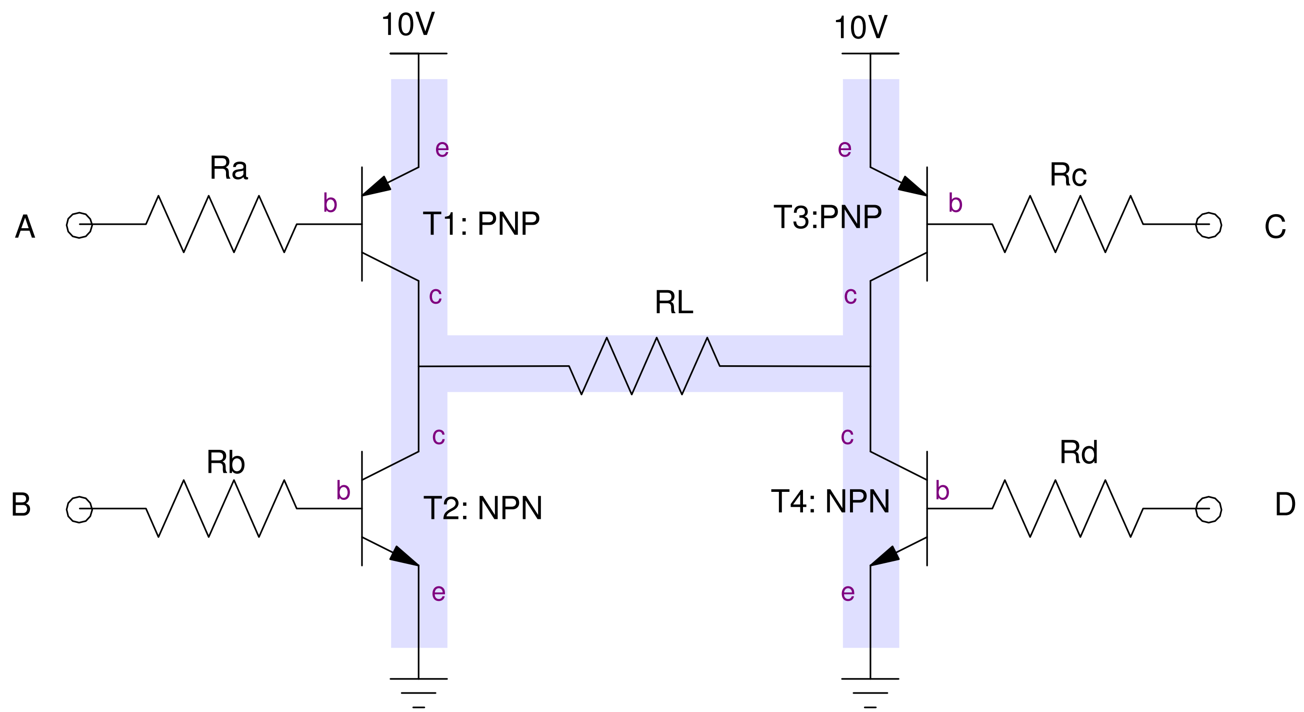
	W, Lumens	Price		Lm / W	eff
		new	@ 1000 hr		
Incandescent (c. 2000)	60W, 300 Lm	-	-	5.27	2.1%
Incancescent: GE 66247	43W, 620 Lm	$1.36	$1.38	14.4	5.7%
Halogen: Phillips 60W	43W, 750 Lm	$1.46	$1.48	17.4	6.9%
CFL: Philips 823031 CFL	13W, 860Lm	$3.50	$0.36	66.2	26.4%
LED: Sylvania 74765	8.5W, 800 Lm	$0.83	$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

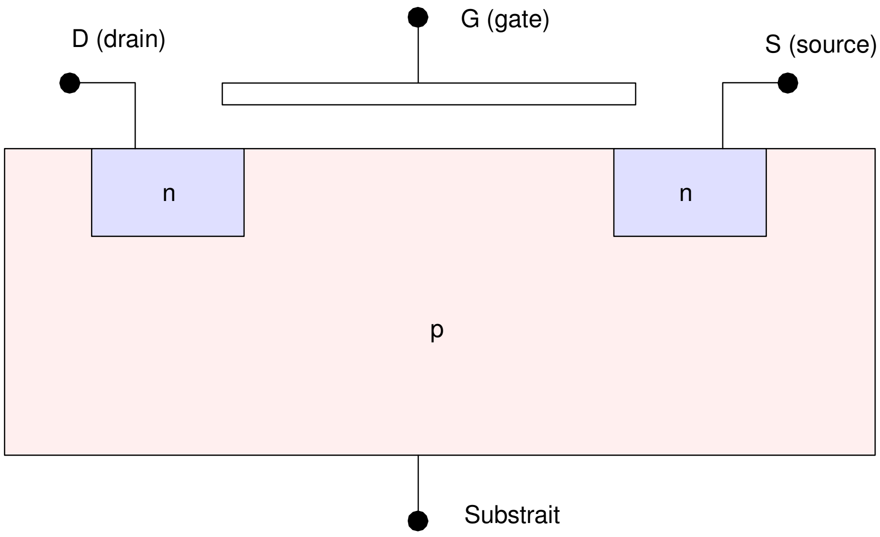
Note that transistors dump voltage (meaning they will get hot when used as an amplifier). The four transistors at the top are likewise connected to a heat-sink.

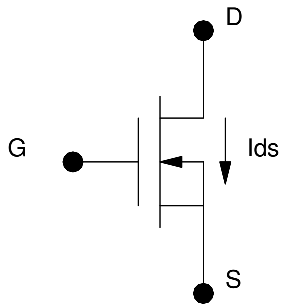
MOSFET

- Voltage controlled resistor

Heart of DC to AC converters

Heart of CMOS logic (building block of computers)





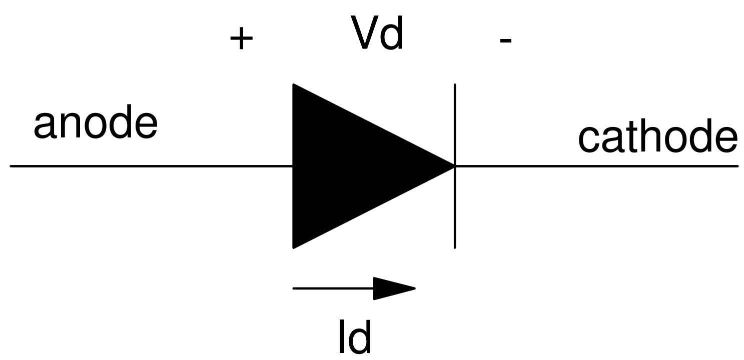
Symbol

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.

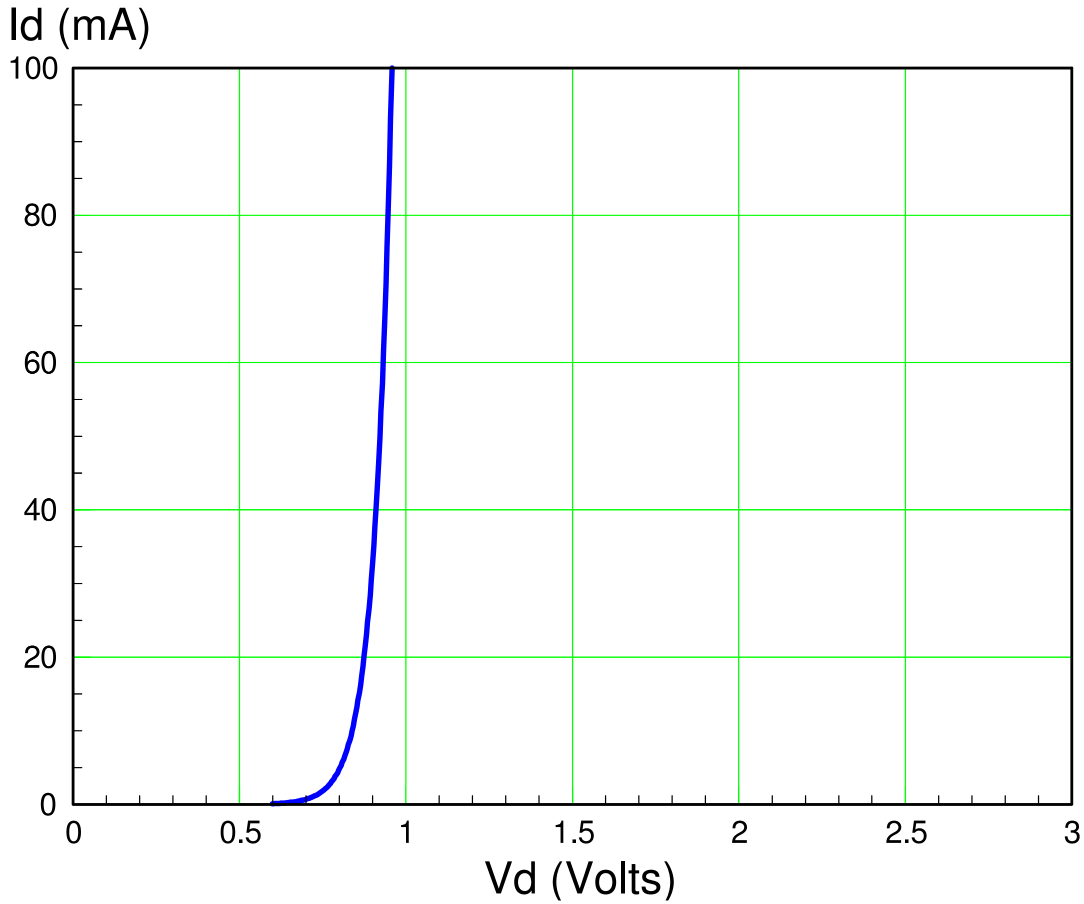
The symbol for a diode acts as a reminder of this: it looks like an arrow which points in the direction current can flow



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

The VI characteristics for a diode are nonlinear

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



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

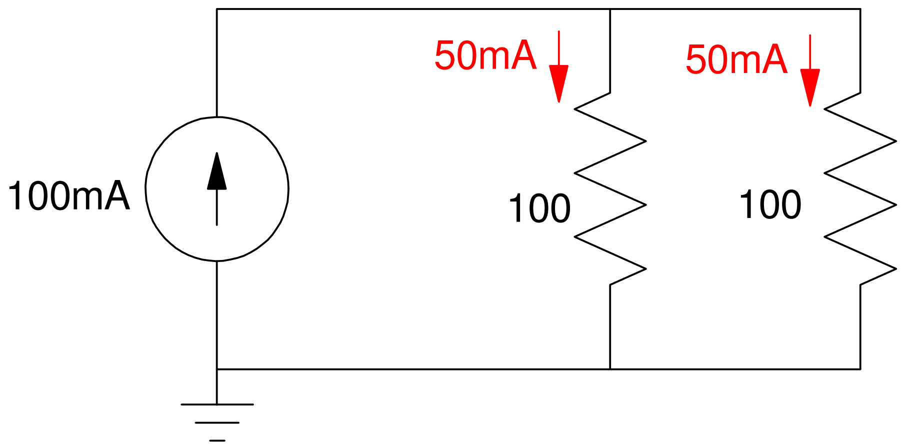
In electronics, you deal with *nonlinear* circuit elements

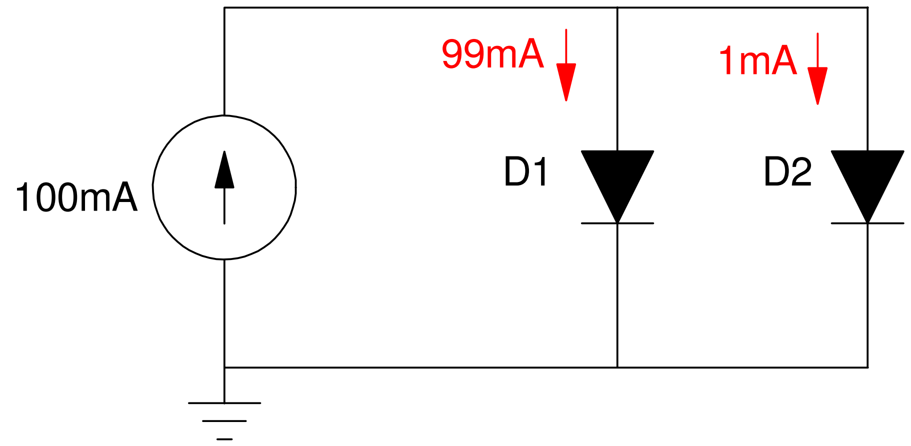
- Diodes, Transistors, MOSFETs
- You still have N equations for N unknowns
- But linear algebra no longer works (the equations are nonlinear)

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





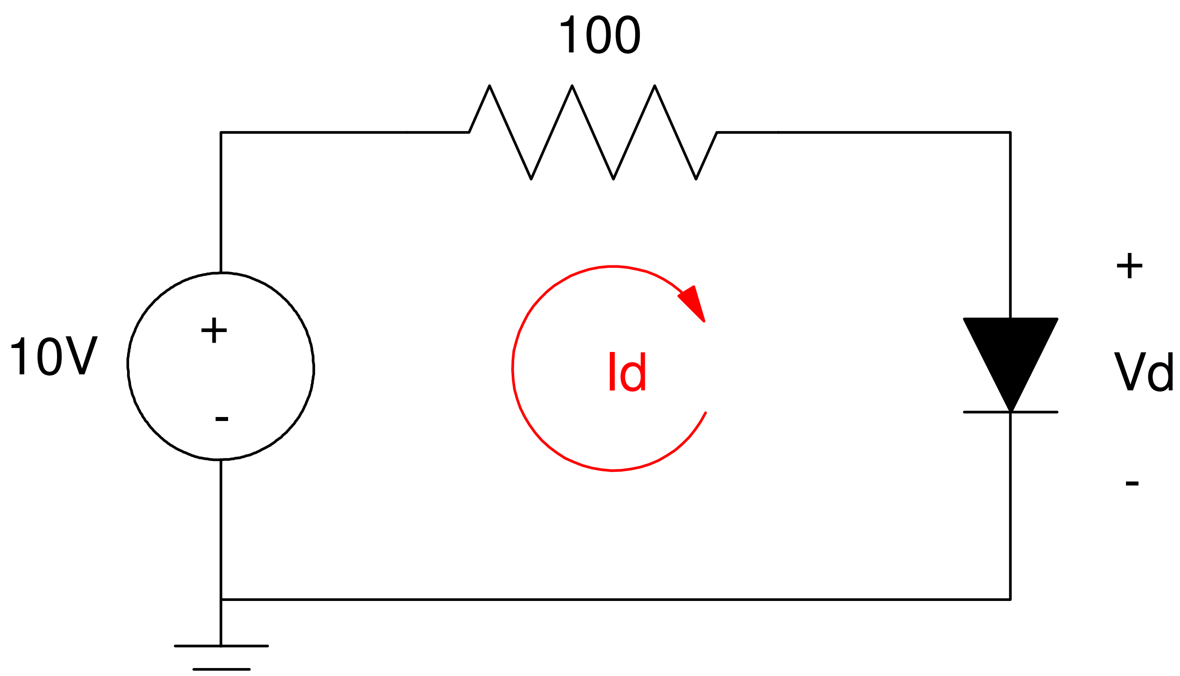
Nonlinear Equations are Hard to Solve

Example: Single diode circuit:

- 2 equations for 2 unknowns:

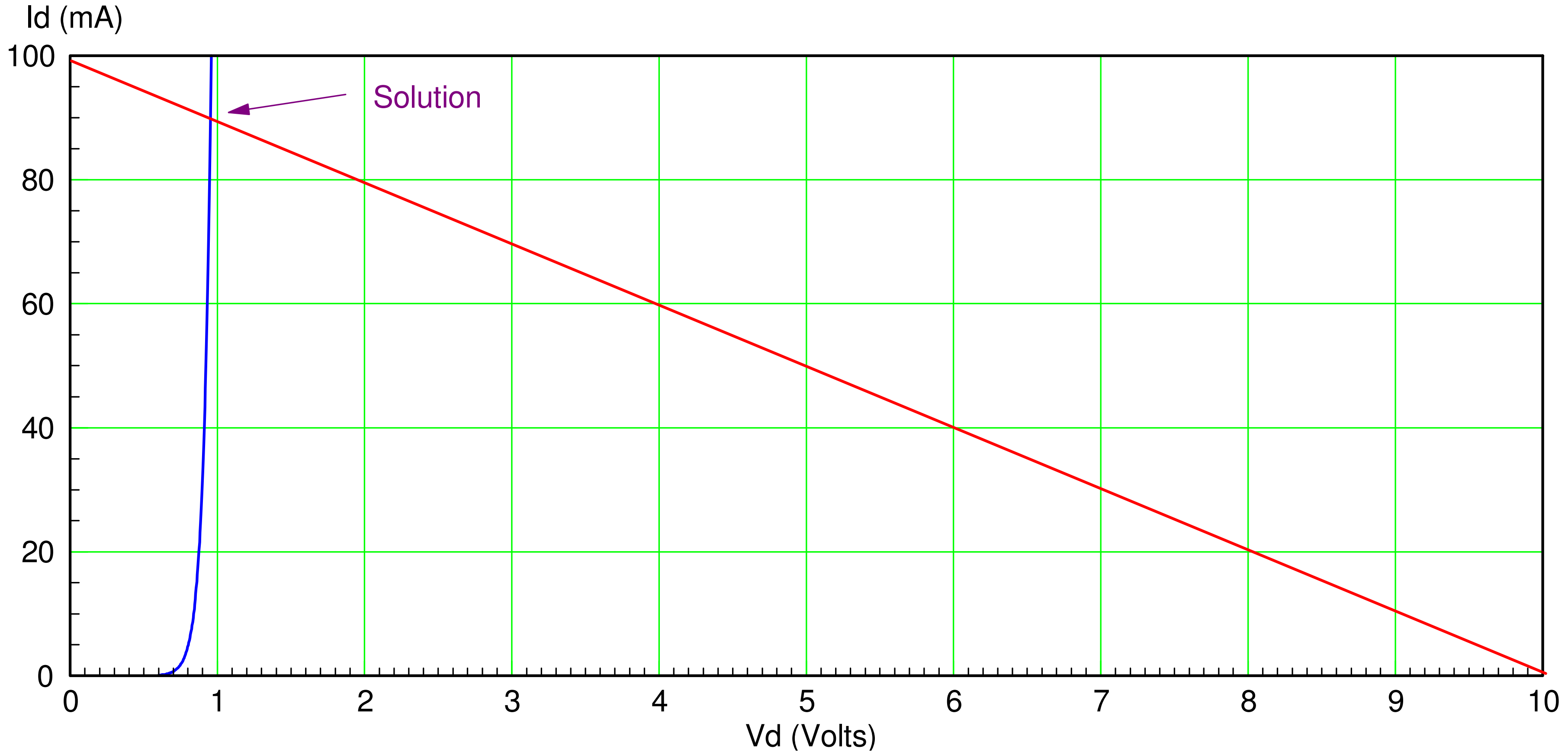
$$V_d = nV_T \ln\left(\frac{I_d}{I_{dss}} + 1\right) = 0.0377 \ln\left(\frac{I_d}{7.69 \cdot 10^{-11}} + 1\right)$$

$$V_d + 100 I_d = 10$$



Load Line Analysis:

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



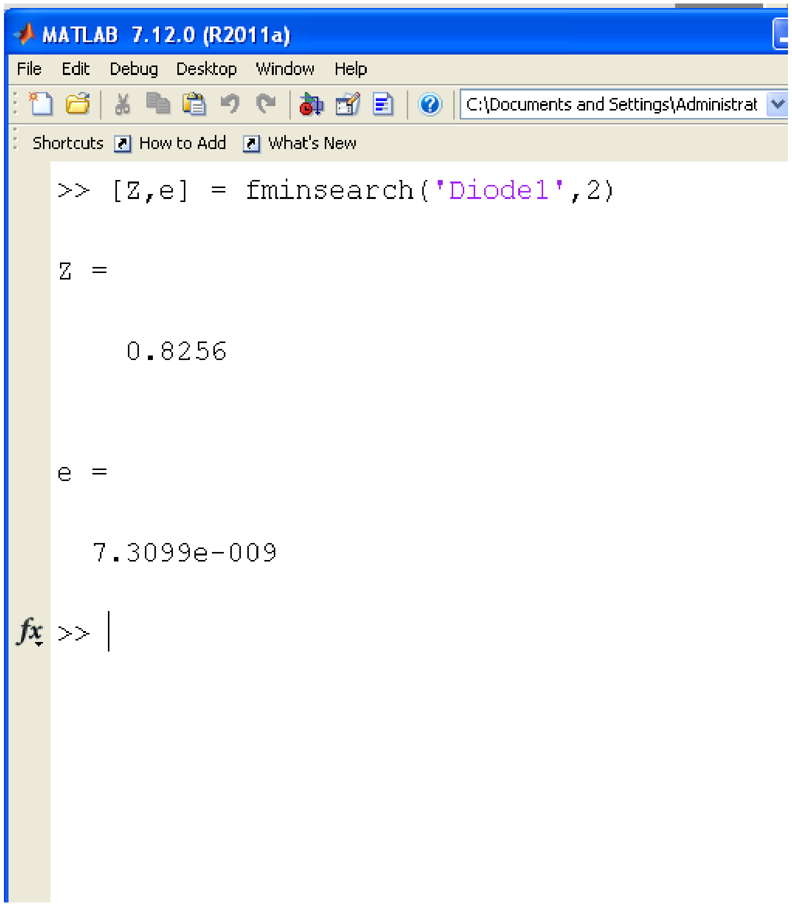
Numerical Solution

- Matlab to the rescue!

Guess Vd

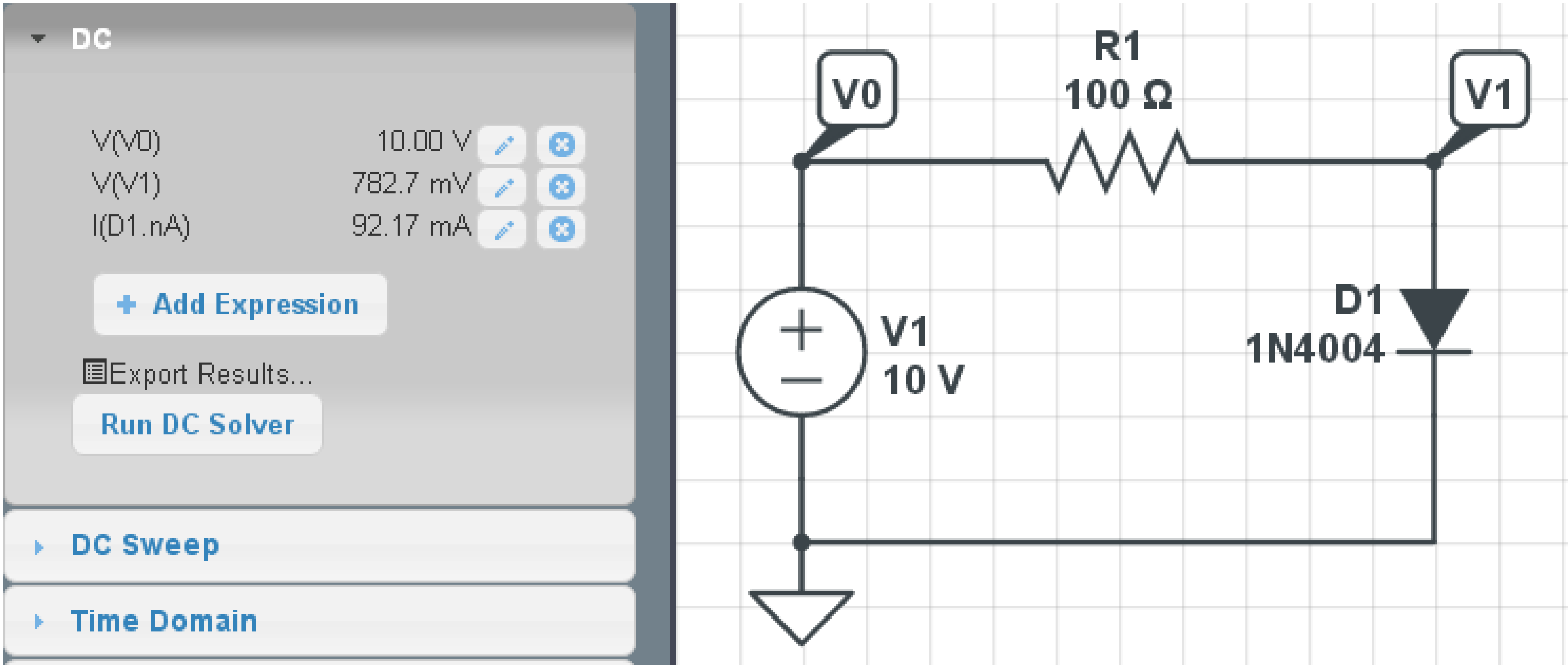
- Compute Id (diode equation)
- Compute the excess current (voltage nodes)
- Minimuze the error using *fminsearch()*

```
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
```

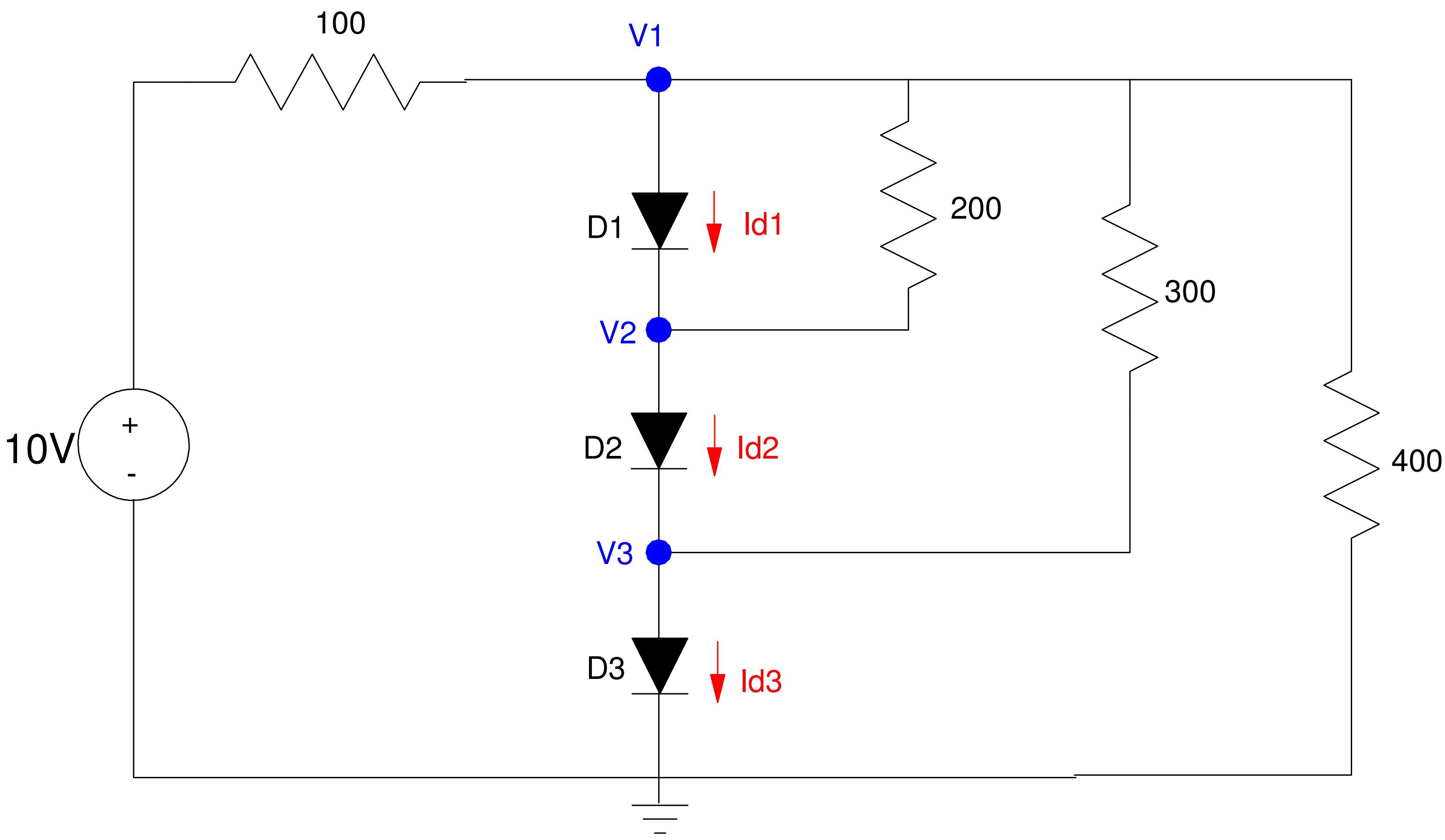


CircuitLab Solution

- Matlab: Vd = 0.8256V



Example 2: Multi-Diode Circuit



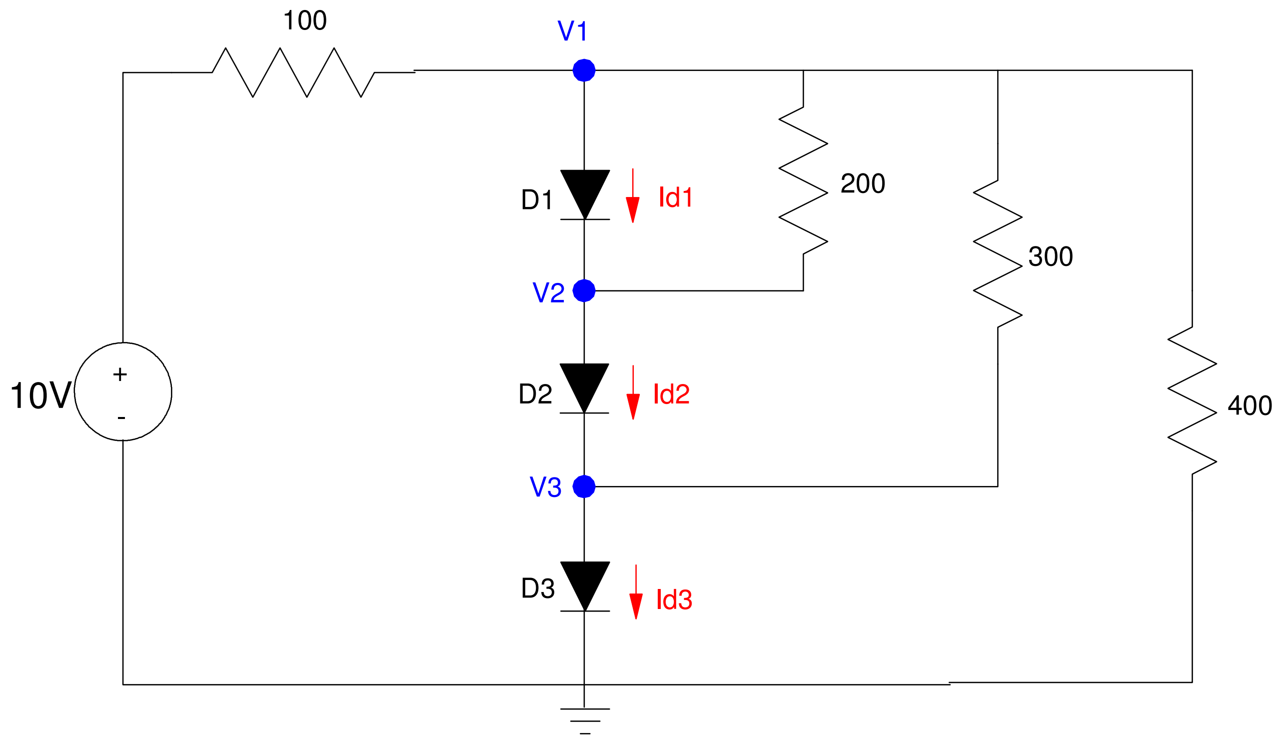
Numerical Solution

Load Lines won't work

- Need to plot in 6 dimensions

Numerical solution still works:

- Solve 6 equations for 6 unknowns
- fminsearch



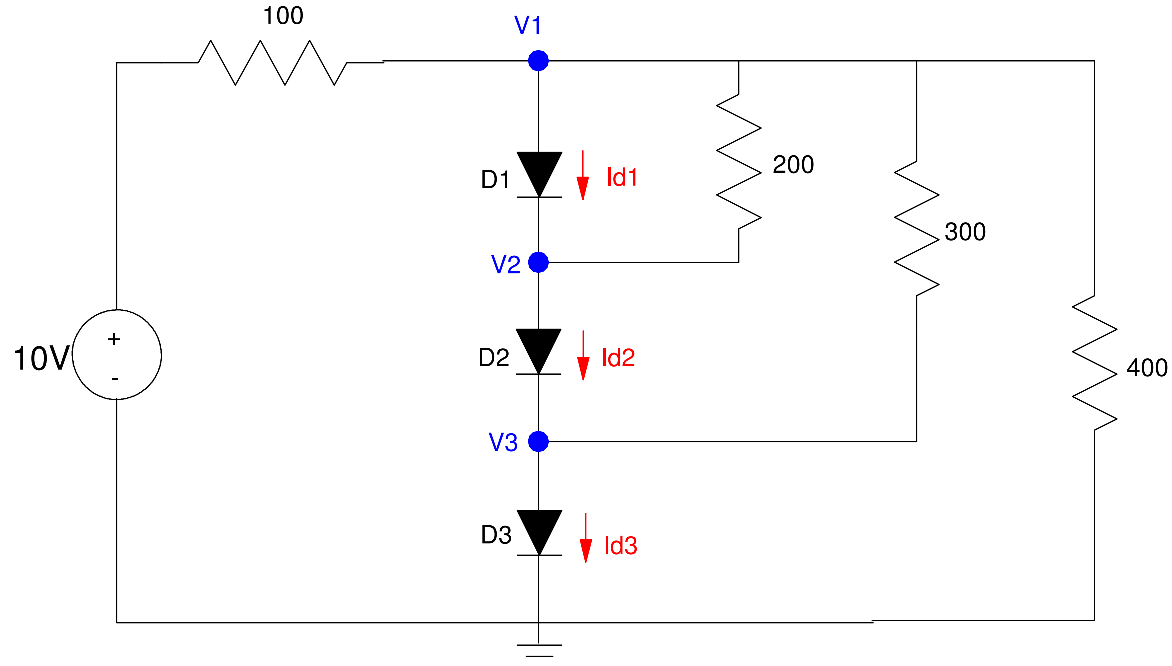
N-equations for N unknowns

Diode equations (1..3)

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

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

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

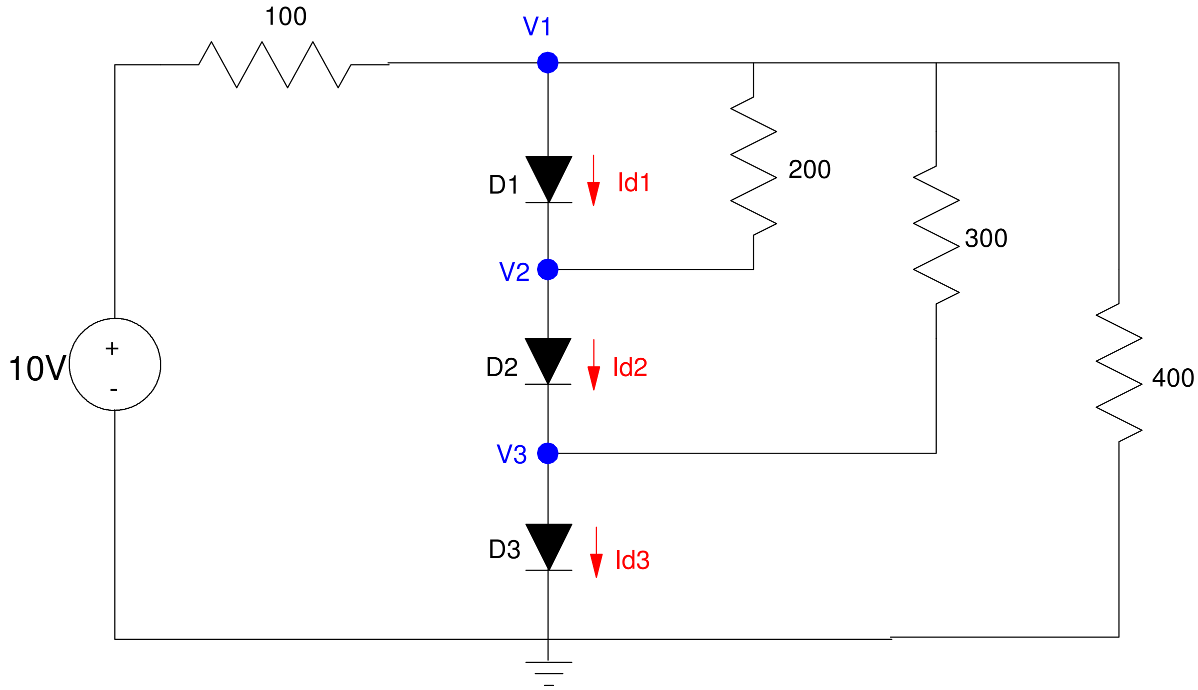


Voltage Node equations (4..6)

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

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

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



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

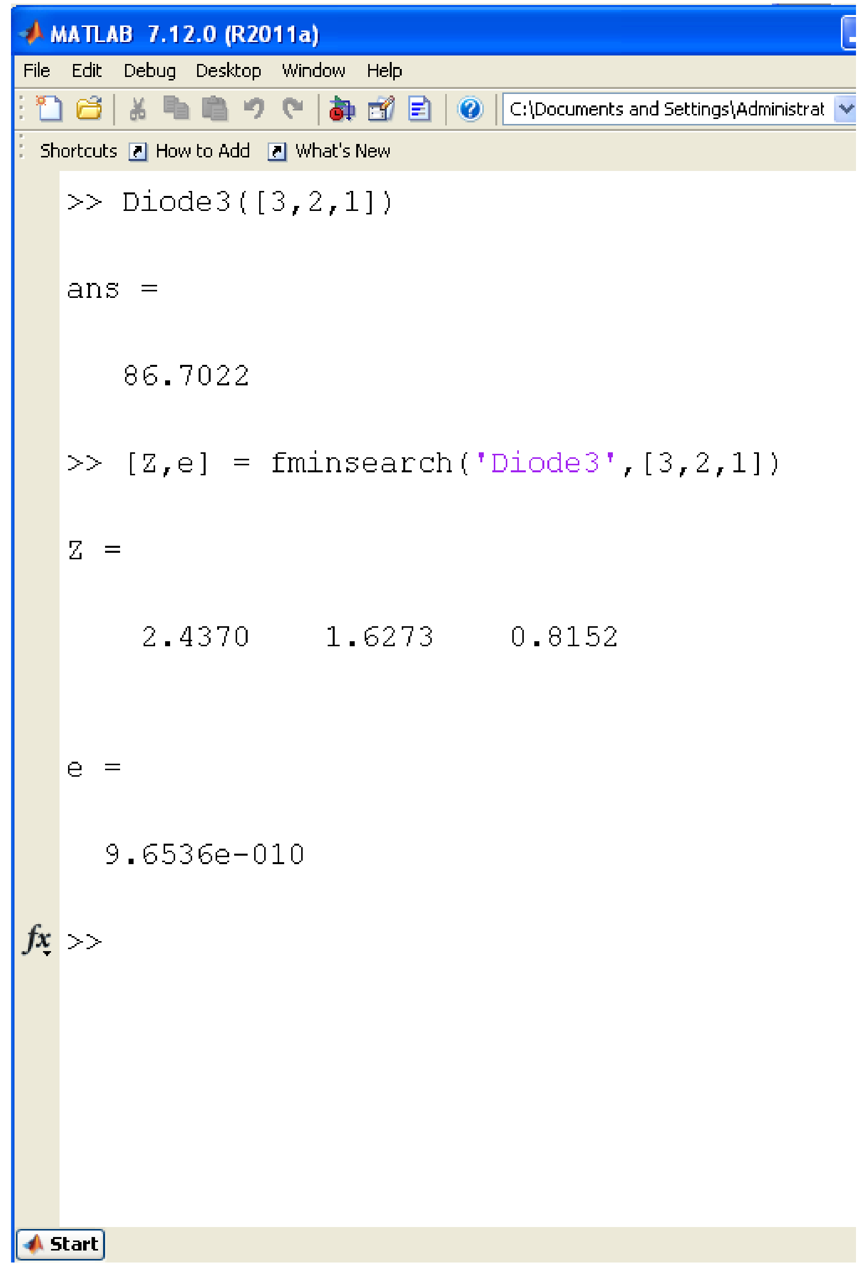
$$J = e_1^2 + e_2^2 + e_3^2$$

```
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*

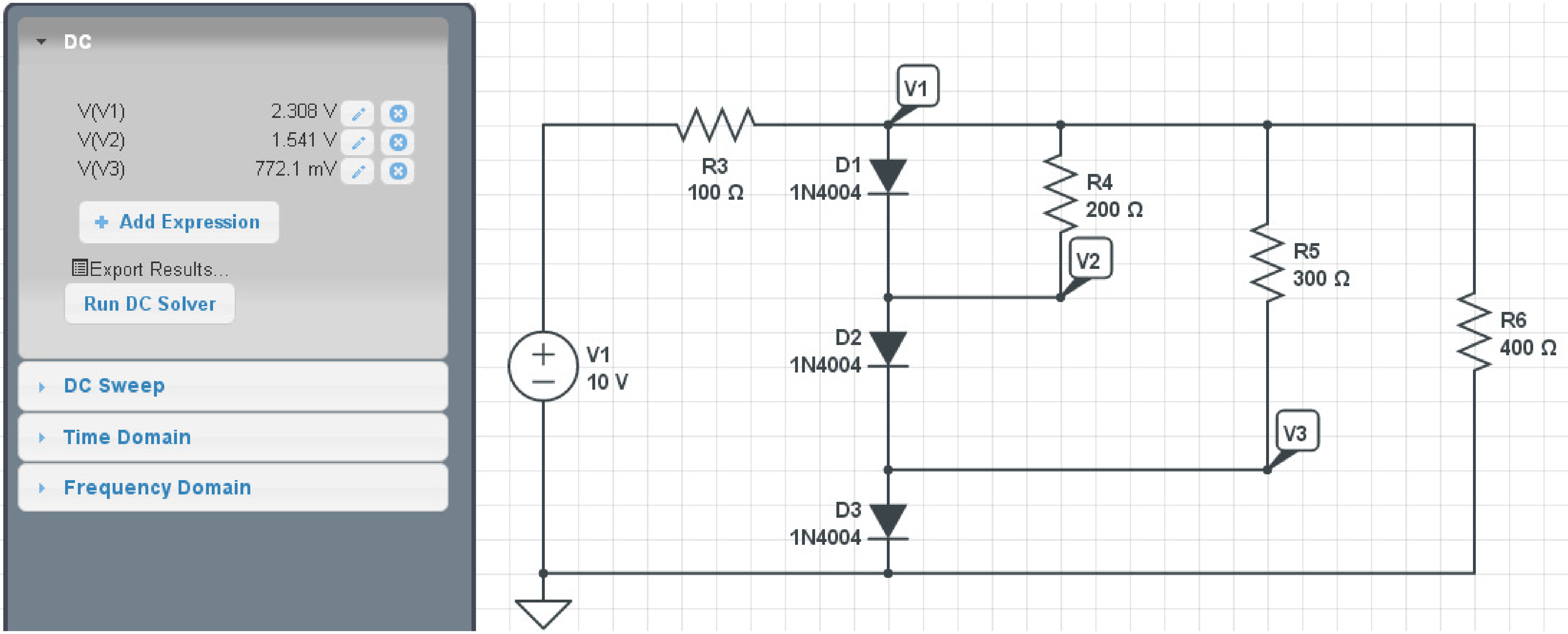
The solution found by MATLAB is

- 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