Low Carbon Footprint Electric Lawn Mower

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Problem

The amount of pollution produced by a lawn mower in one hour is the same as eight new cars driving 55 MPH for one hour

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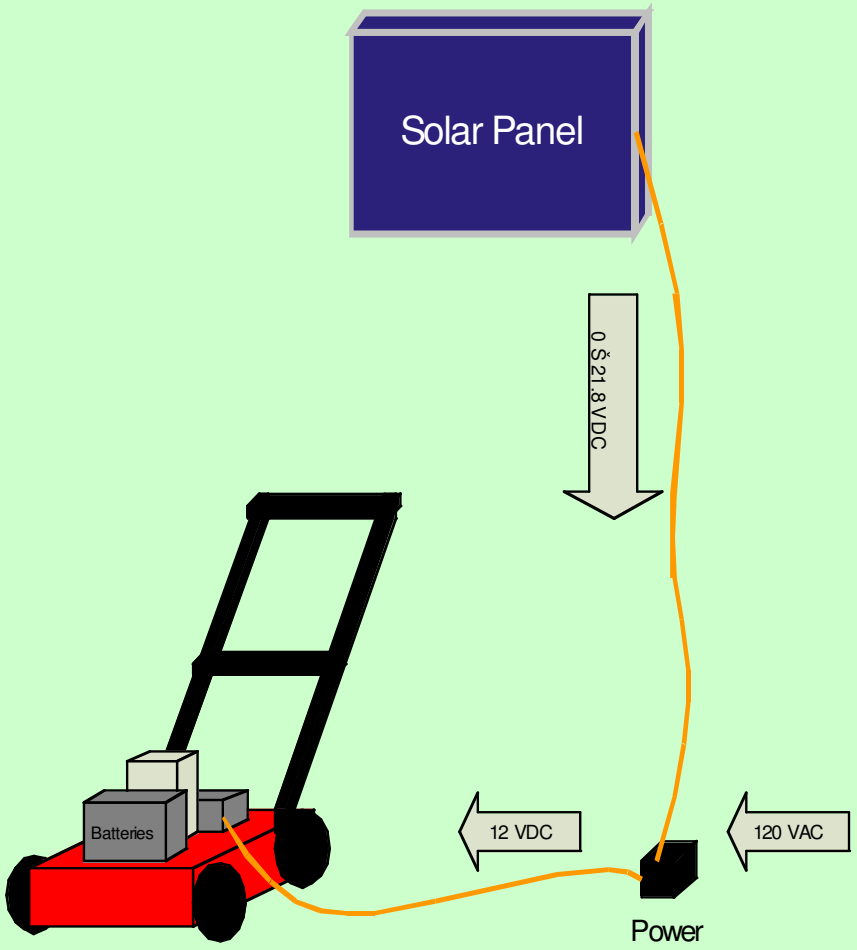
- Project Specifications
- Overall System
- Motor
- Battery
- Solar Energy
- Charging the Battery
- Controls
- Results
- Conclusions

Project Specifications

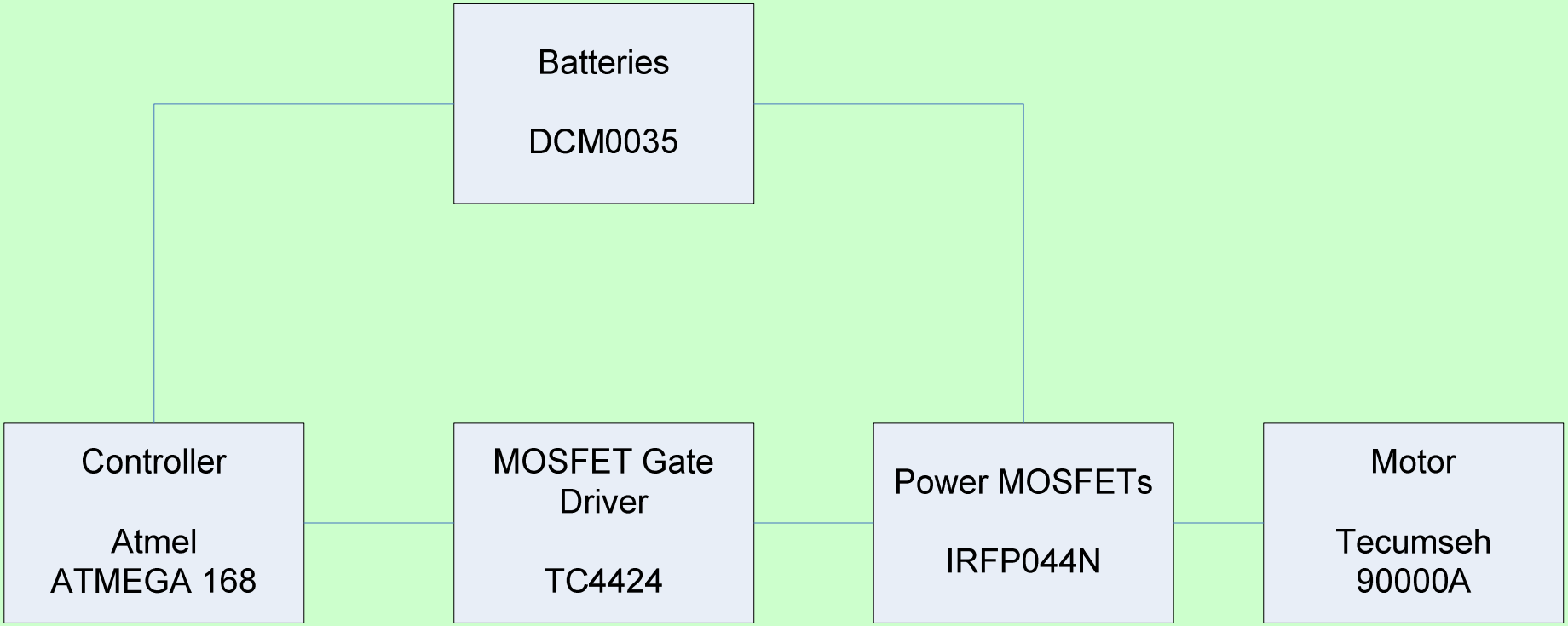
- Performance similar to a gasoline powered mower
- Mow a 10,000 sq. ft. lawn in 1 hour
- Keep mower weight under 90 lbs.
- Use solar energy to recharge the battery in 1 week
- Utilize intelligent controls for mowing and charging

Overall System

- Mower System
- Charging System



Mower System



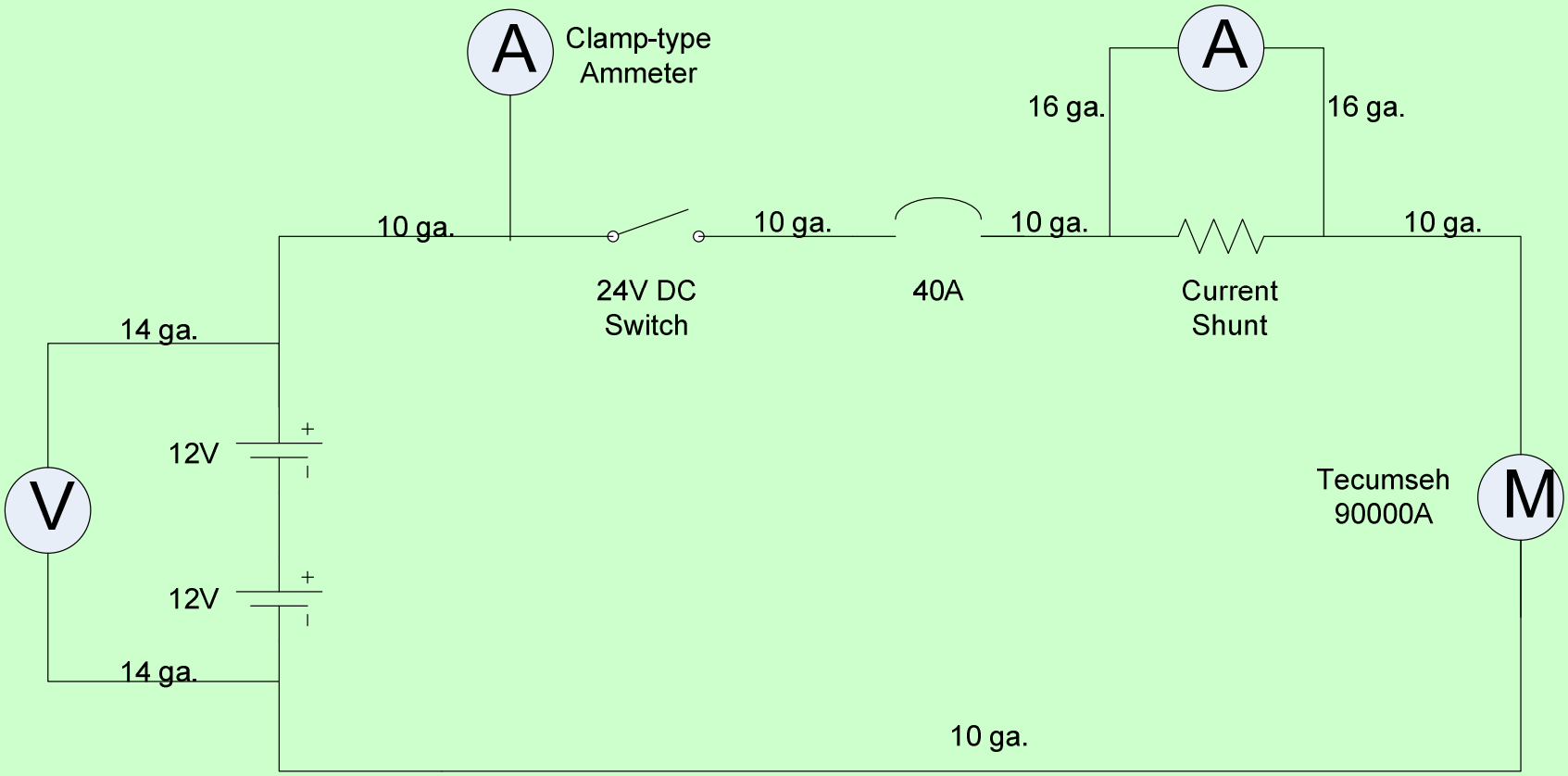
Motor

Tecumseh 90000A

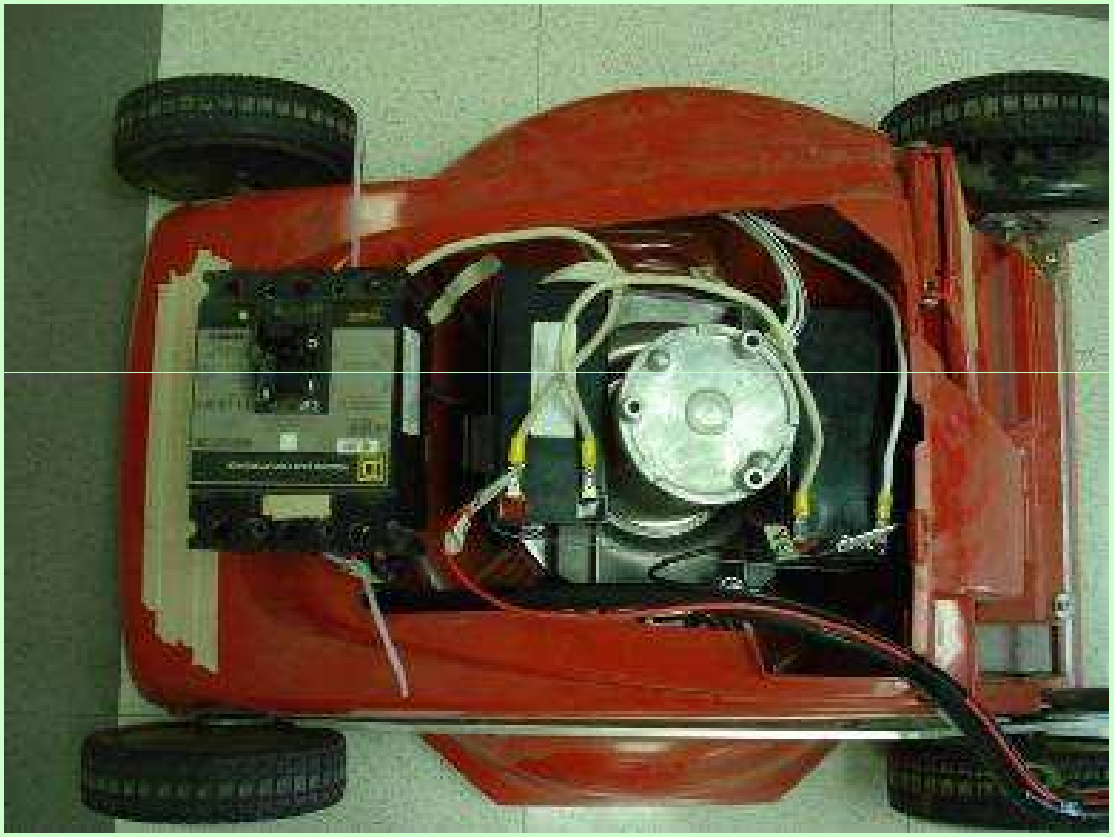
Motor Specs

- Input Voltage = 24 VDC
  - Can be achieved with two 12V batteries in series
- 3200 RPM
- 1.54 HP
- Weight = 15 pounds

Initial Motor Tests



Initial Motor Tests



Initial Motor Test Results

- Average Running Current ≈ 18 Amps
- Maximum Running Current ≈ 40 Amps
- Cut Grass as well as gas mower

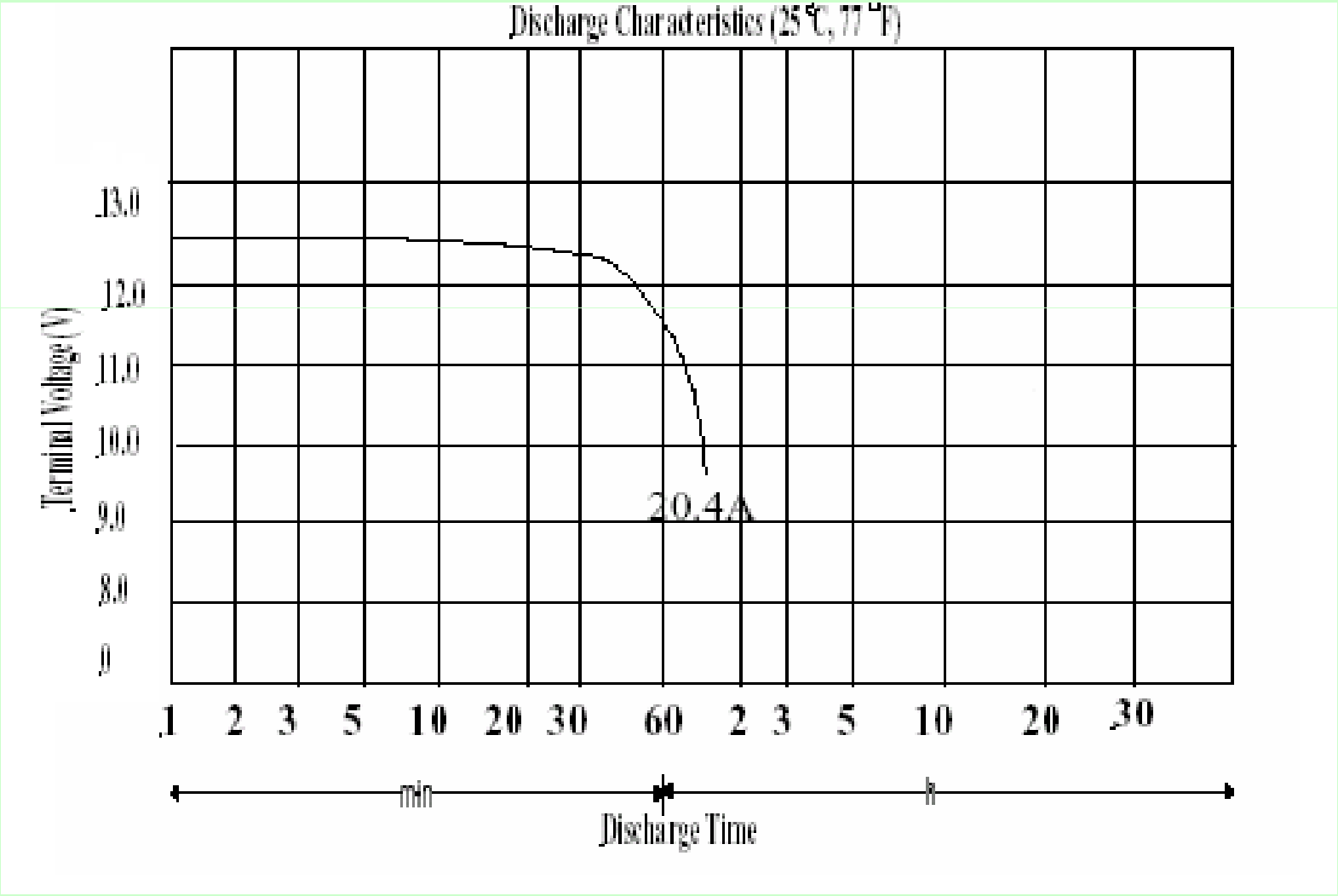
Choosing Batteries

- Different chemistry make-ups
  - Nickel Cadmium
  - Nickel metal hydride
- Price vs. capacity and weight

- Deep Discharge Lead Acid
  - Rated in amp*hours

Choosing Batteries

35 A*h battery

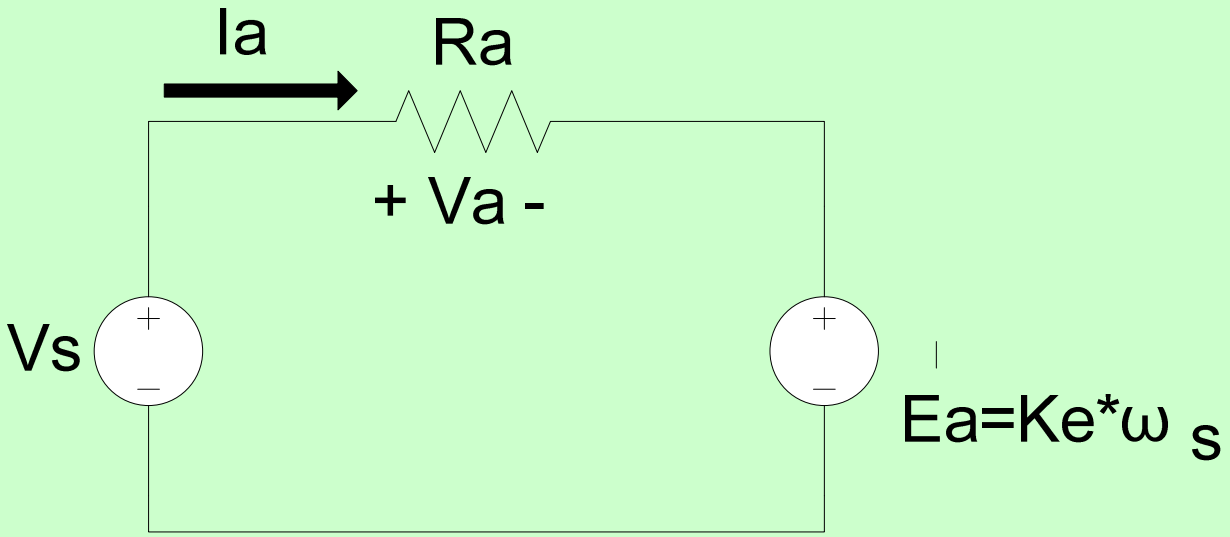


Motor Modeling

- Purpose
- Simulation in PSPICE

Motor Characteristics

In order to not introduce back EMF, motor shaft cannot spin during test



$$R_a = \frac{V_s}{I_a}$$

Motor Characterisitcs

At Vs=12 Volts and no load measure Vs, Ia and ωs

$$-V_s + I_a R_a + E_a = -V_s + I_a R_a + K_E \omega_S = 0$$

$$K_E = K_T = \frac{V_s - I_a R_a}{\omega_S}$$

Motor Characteristics

Compute the static friction coefficient ($T_{S.F.}$) and the viscous friction coefficient (b).

Find Ia at 8V and 12 V

2 equations, 2 unknowns

<u>Sum of the torques</u>

$$T_{developed} - T_{S.F.} - b\omega_s = K_T I_a - T_{S.F.} - b\omega_s = 0$$

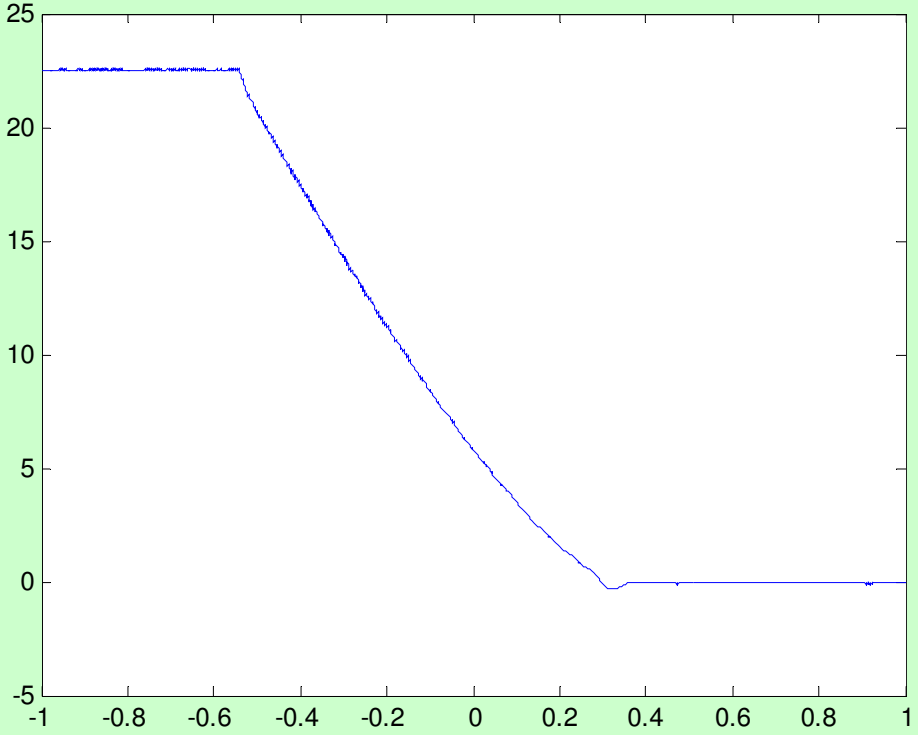
Motor Characteristics

Perform a coast down test to find $E_a(\omega_s) = V_{O.C.}(\omega)$

to compute moment mass of inertia (J)

$$J = b * \tau$$

$$\omega(t) = \left[\frac{V}{K_t} + \frac{T_{S.F.}}{b} \right] e^{\frac{-t}{\tau}}$$



Motor Characteristics

$$R_a = .0825\ \Omega$$

$$K_E = K_T = 0.68723\left[\frac{N*m}{A}\right]$$

$$T_{S.F.} = .272504[N*m]$$

$$b = .000535\left[\frac{N*m}{rad/s}\right]$$

$$J = .000912\left[kg*m^2\right]$$

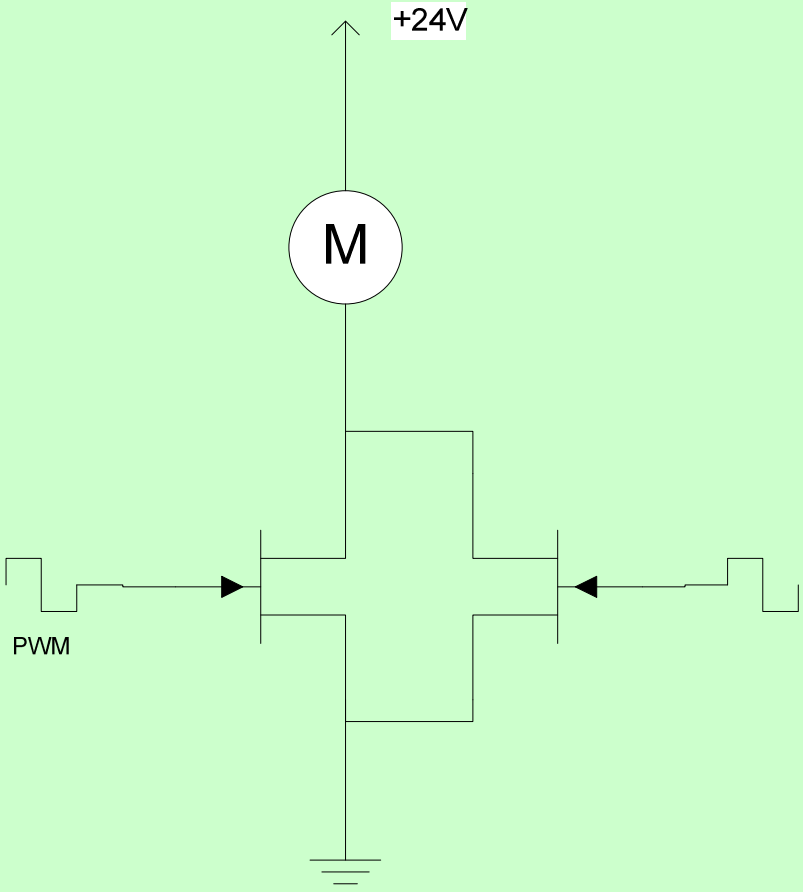
Motor Driver

IRFP044N

- Vds Max = 55V
- Rds (on) = 0.02Ω
- Id max = 53 A

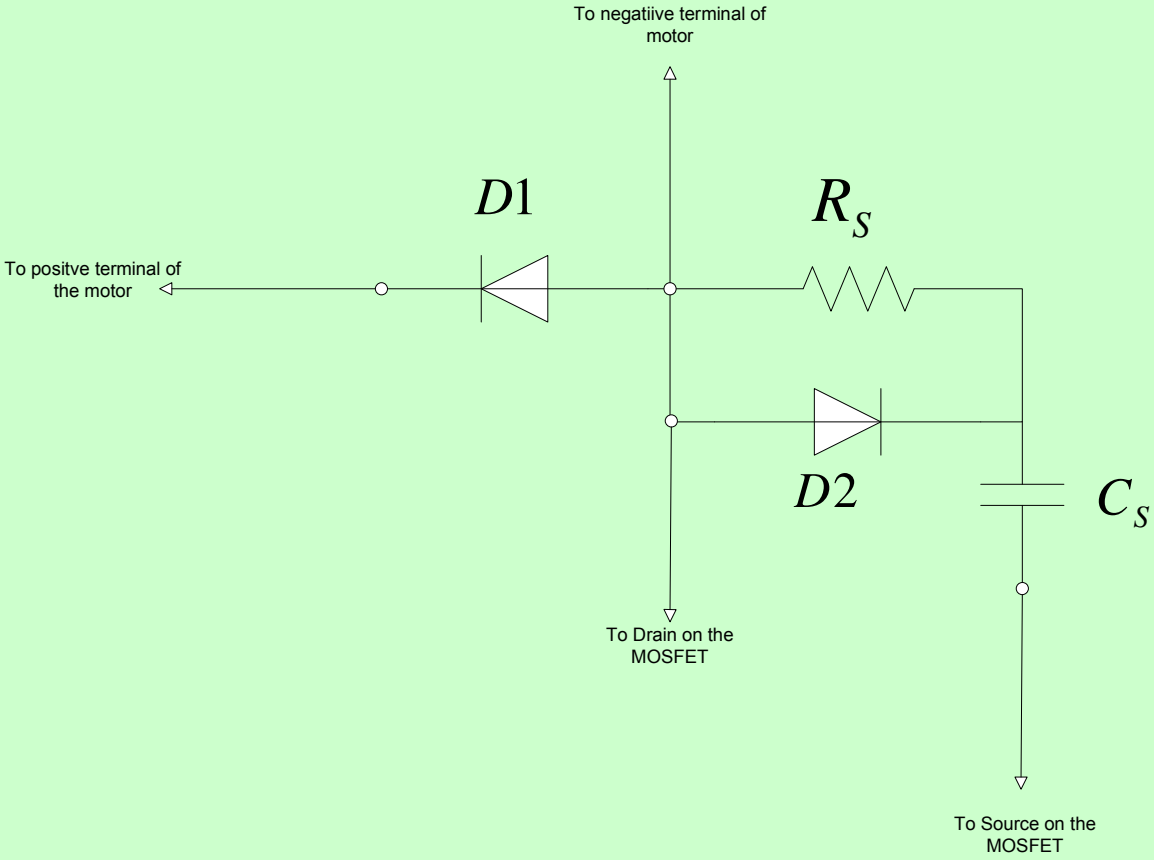
TC4424

- Gate Driver Chip
- Takes 0-5V input from Microcontroller
- Outputs 0-15V PWM to the Gate of the MOSFET



Snubber Circuit

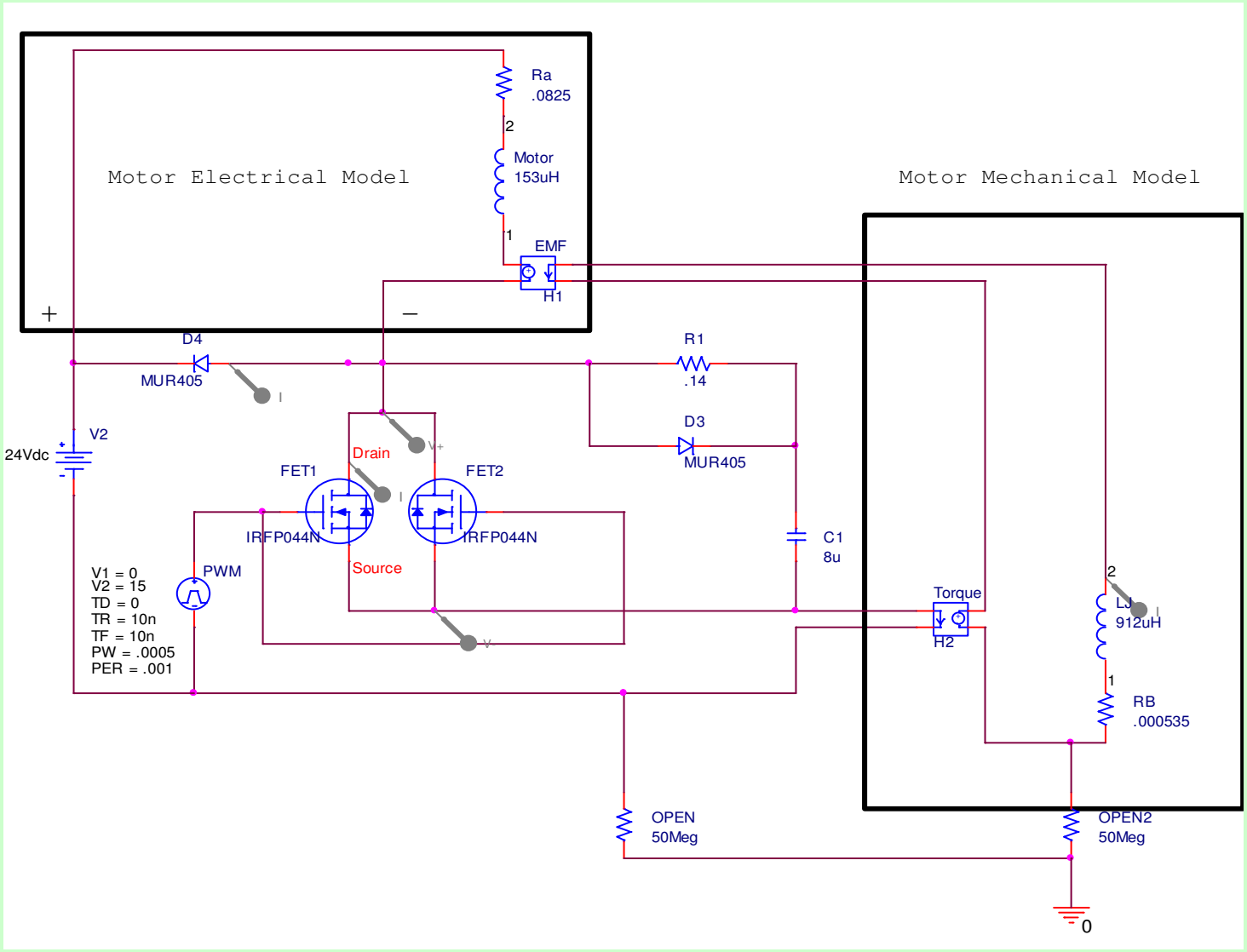
- Purpose: To keep voltage across Vds on the MOSFET below 55 volts



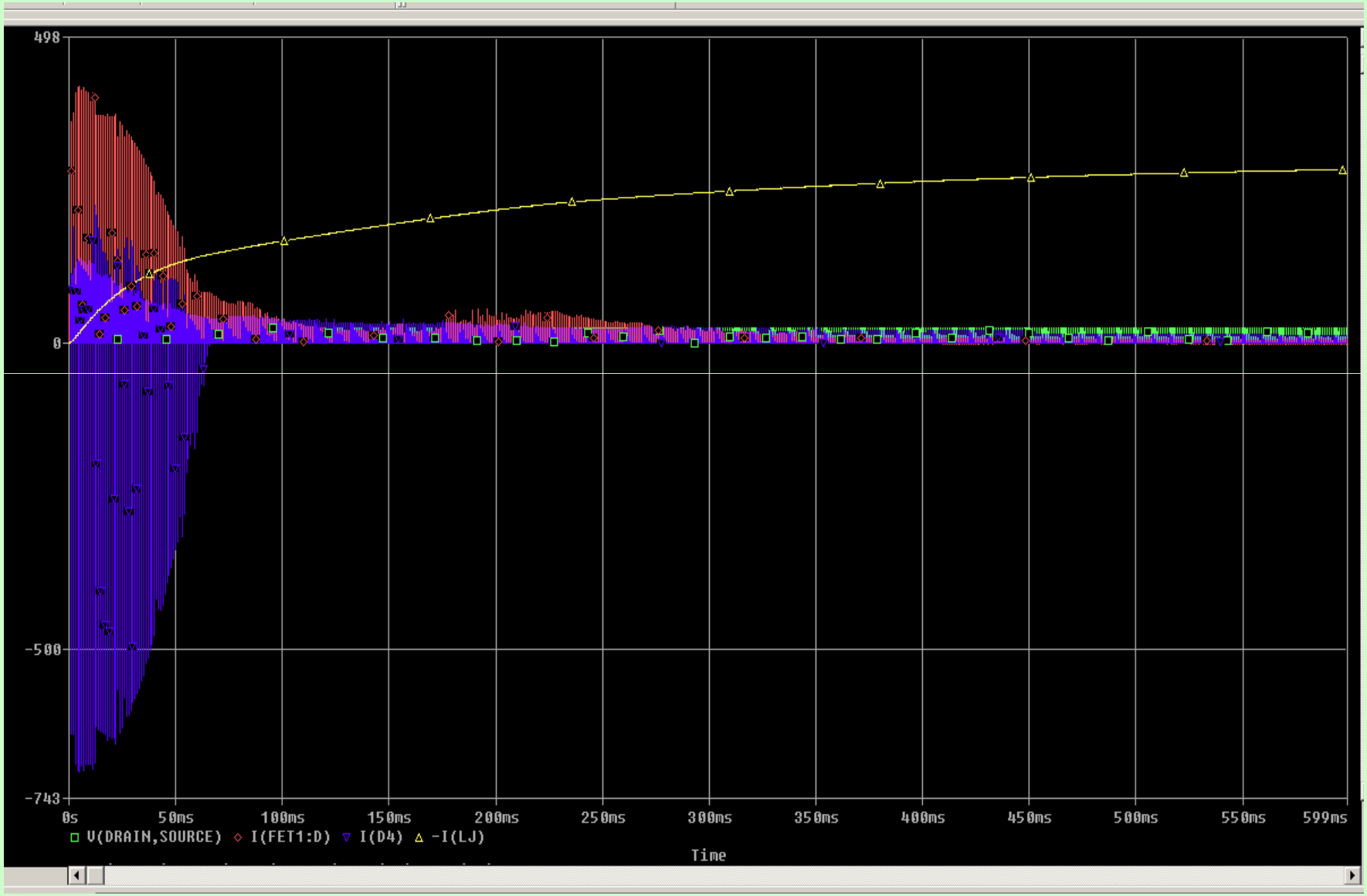
Issues with Motor Driver

- FETs overheating
- Snubber capacitor failure

PSPICE circuit schematic

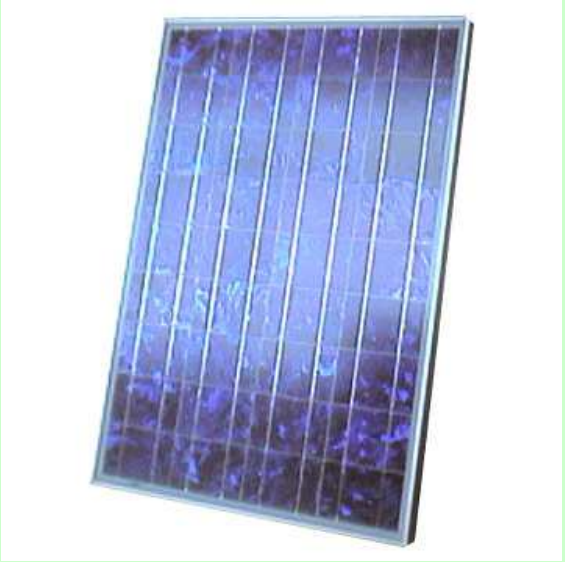


PSPICE Simulation



Solar Charger System

- Solar Panel
  - BP 350
- Charger Controller
  - UC3909 Switchmode Lead-Acid Battery Charger
- Charger Circuit
  - Buck Converter
  - Protective Circuitry



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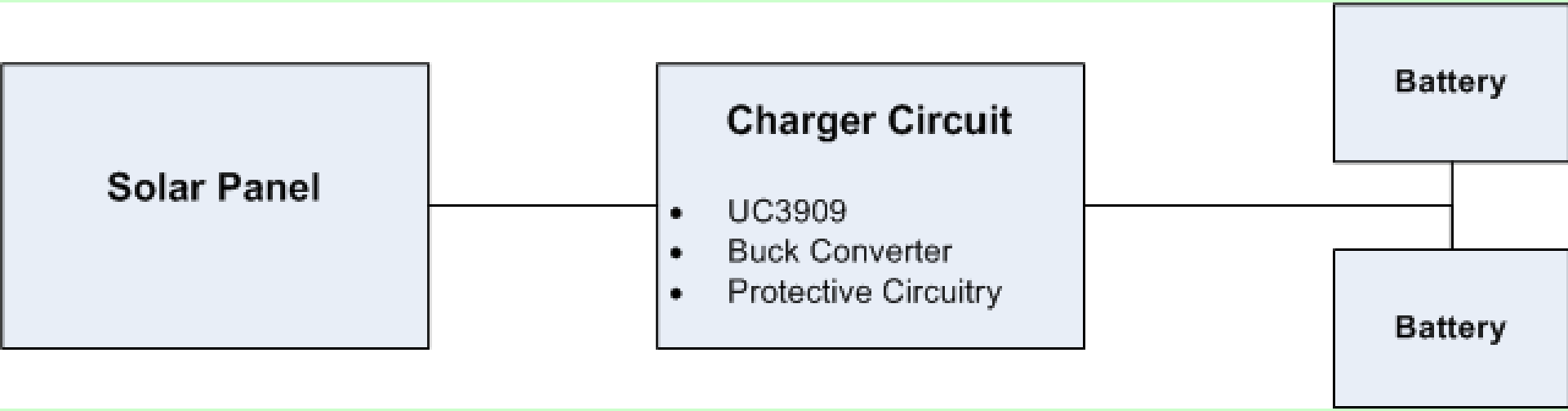


Solar Panel Sizing

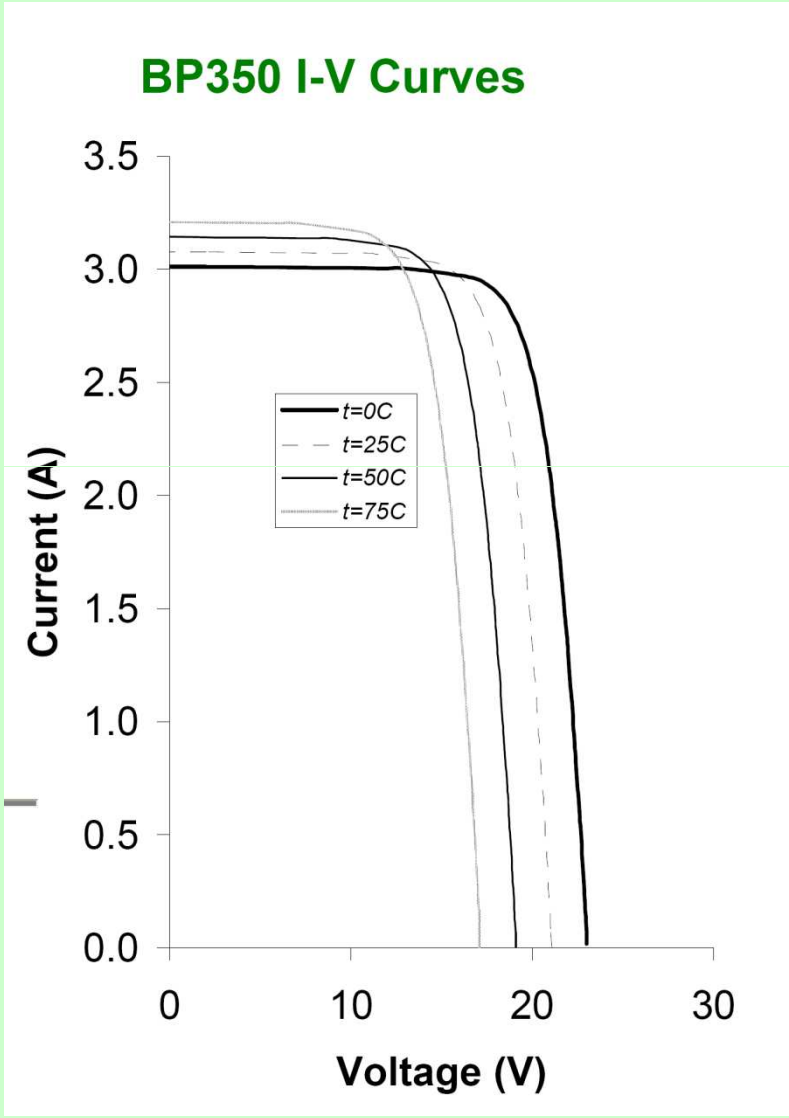
Things to consider:

- Voltage and Current Output
  - Need to be Higher than 12V
  - Current needs to break down sulfation
- Power Rating
  - Need enough energy to charge the batteries
- Efficiency
  - Used to calculate energy collected from available solar radiation

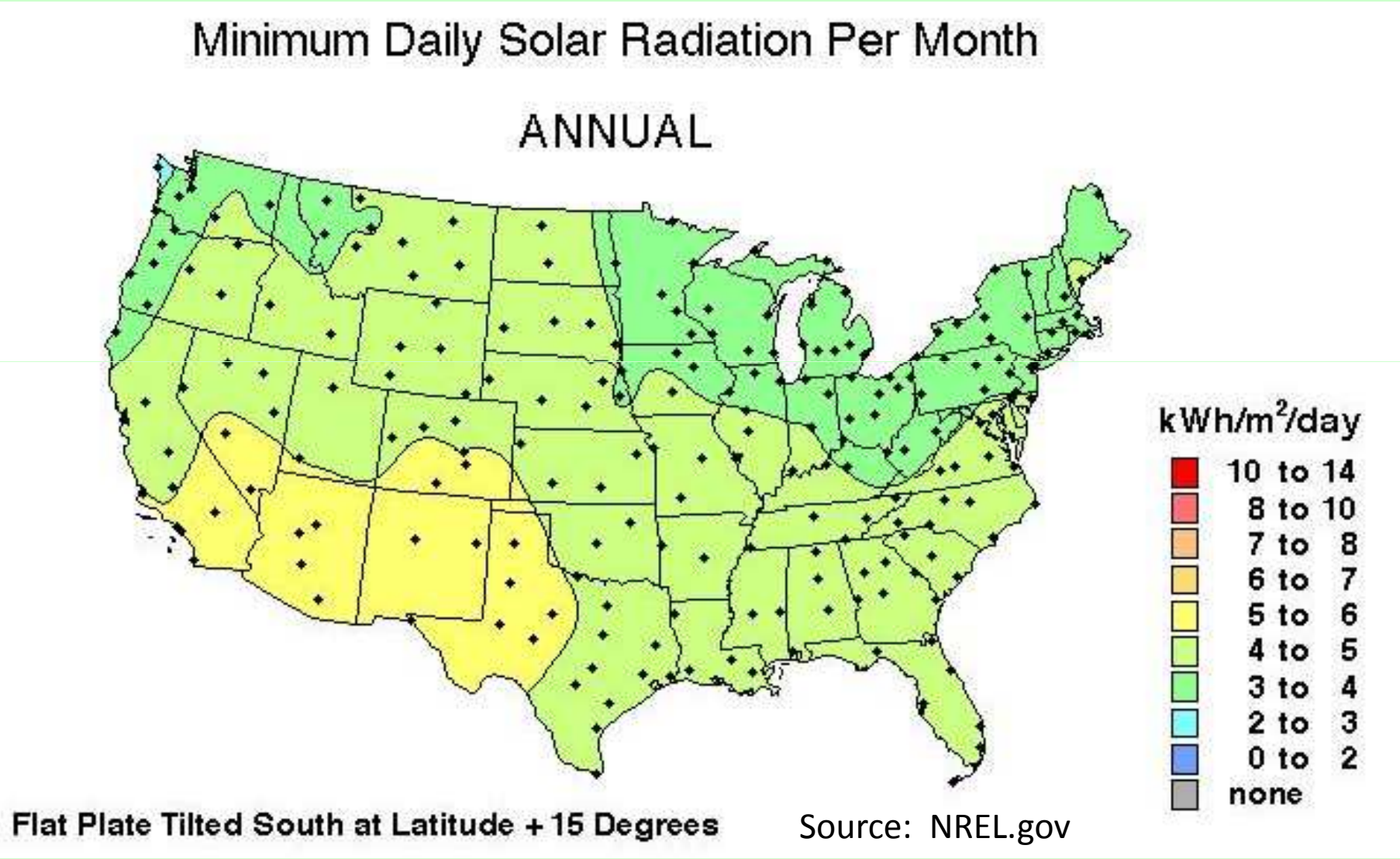
Solar Panel Sizing

BP 350 Specifications at Peak Power:

- 50 W
- 17.5V
- 2.9A
- 10% efficiency



Solar Panel Sizing



Source: NREL.gov

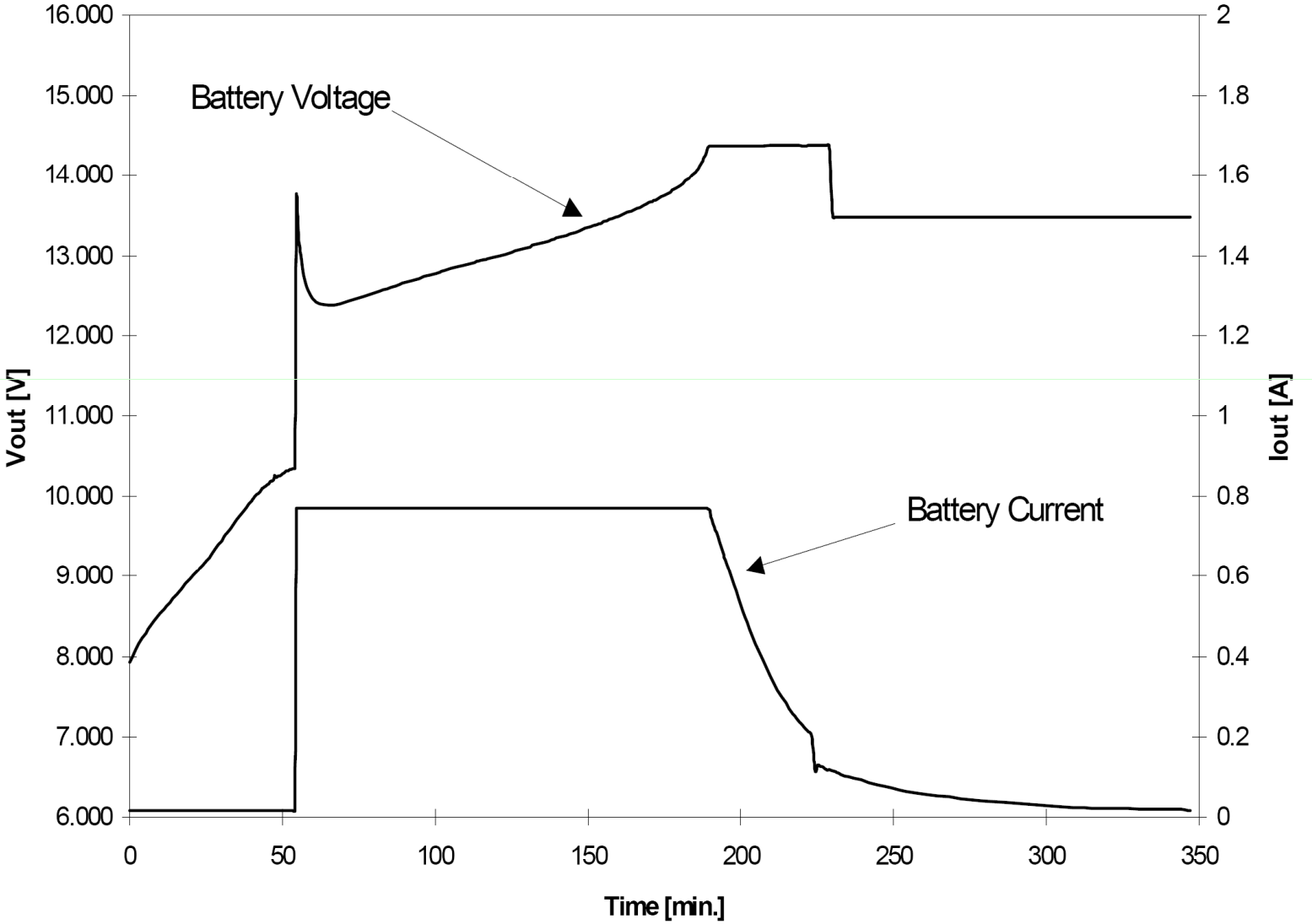
Solar Panel Sizing

Month	KW-Hrs/day Solar Energy Emmitted(NREL)	KJ / day of Solar Energy Collected	actual days to charge 2 - 35AH batts
January	2.0	353	8.6
February	3.0	530	5.7
March	4.0	706	4.3
April	4.0	706	4.3
May	5.0	883	3.4
June	5.0	883	3.4
July	5.0	883	3.4
August	5.0	883	3.4
September	4.0	706	4.3
October	3.0	530	5.7
November	2.0	353	8.6
December	1.0	177	17.1

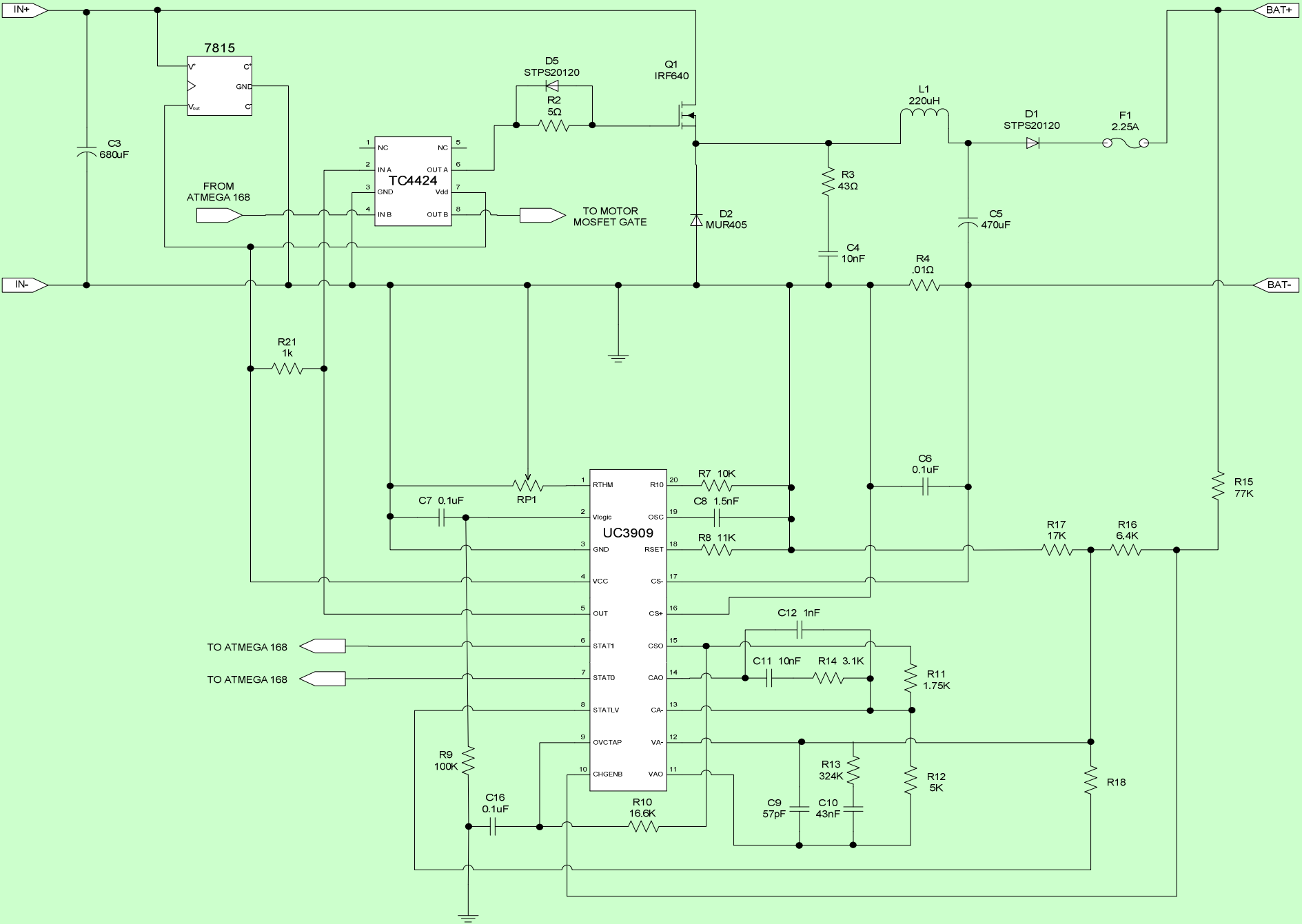
UC3909 Features

- Controls Charge States
  - Trickle
  - Bulk
  - Overcharge
  - Float
- Charge state output to microcontroller
- Battery Temperature Input for optimal charging

Charging Lead Acid Batteries



Charger Circuit

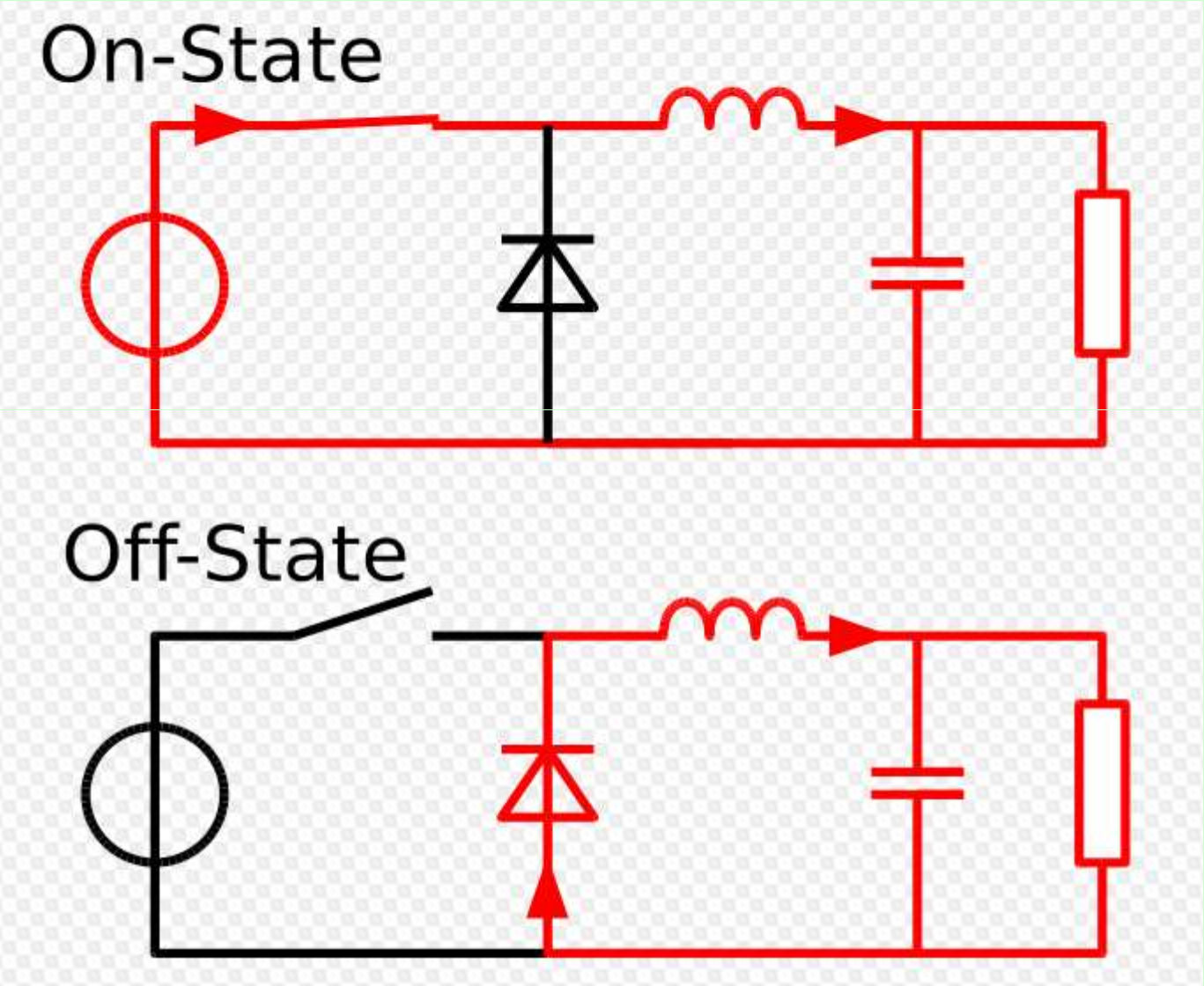


Buck Converter

Purpose:

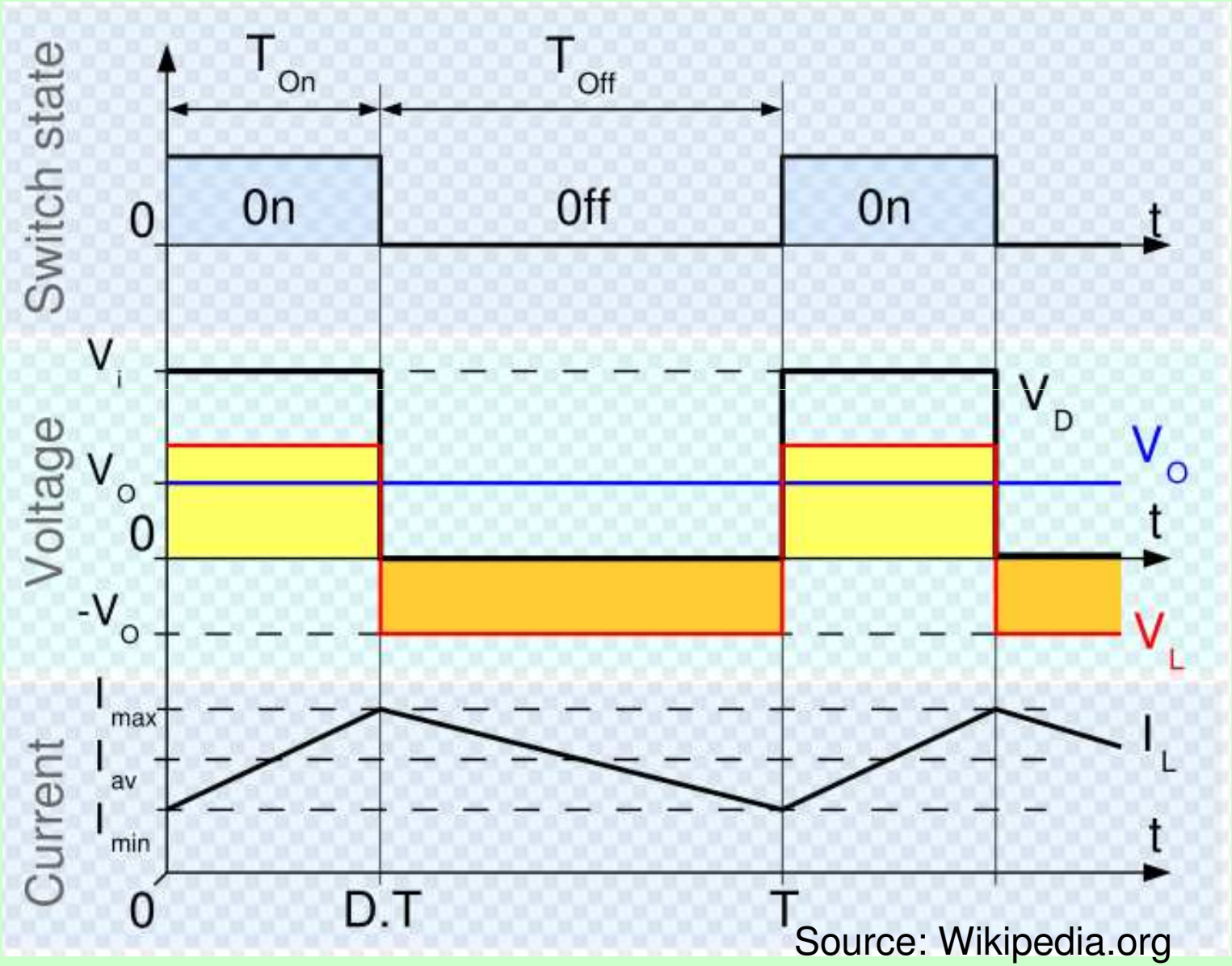
- To Provide Constant Current/voltage to a load (batteries)
- To adjust the constant current/voltage based on a PWM input.
  - High duty cycle means higher V/I
  - Low duty cycle means lower V/I

Buck Converter



Source: Wikipedia.org

Buck Converter



Source: Wikipedia.org

Issues with Charger Subsystem

- Voltage is not up to the proper level for charging
- Need to further debug buck converter
- Need to charge batteries using the solar panel

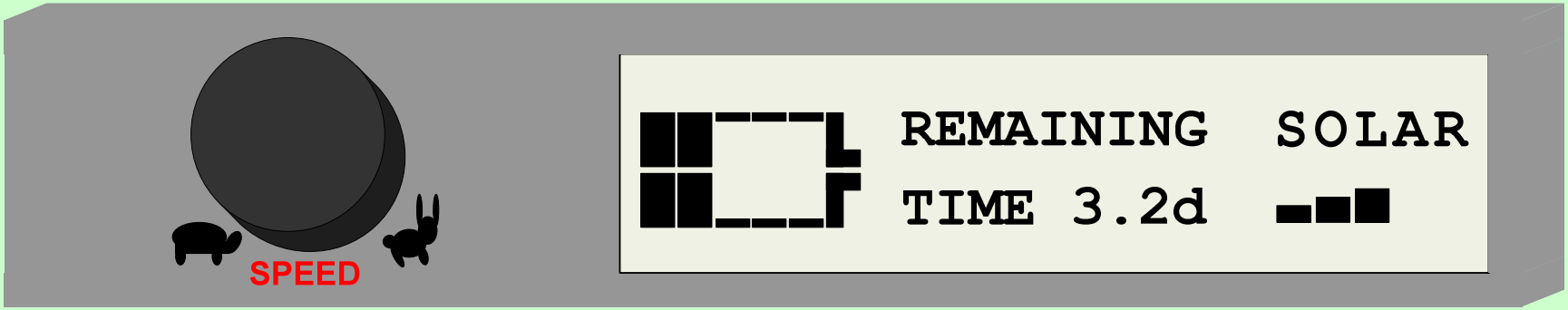
Controlling the Mower

- User Interface
- Speed Control
- Safety
- Display
- State of Charge measurement

Microcontroller

ATMEGA168

User Interface



Speed Control

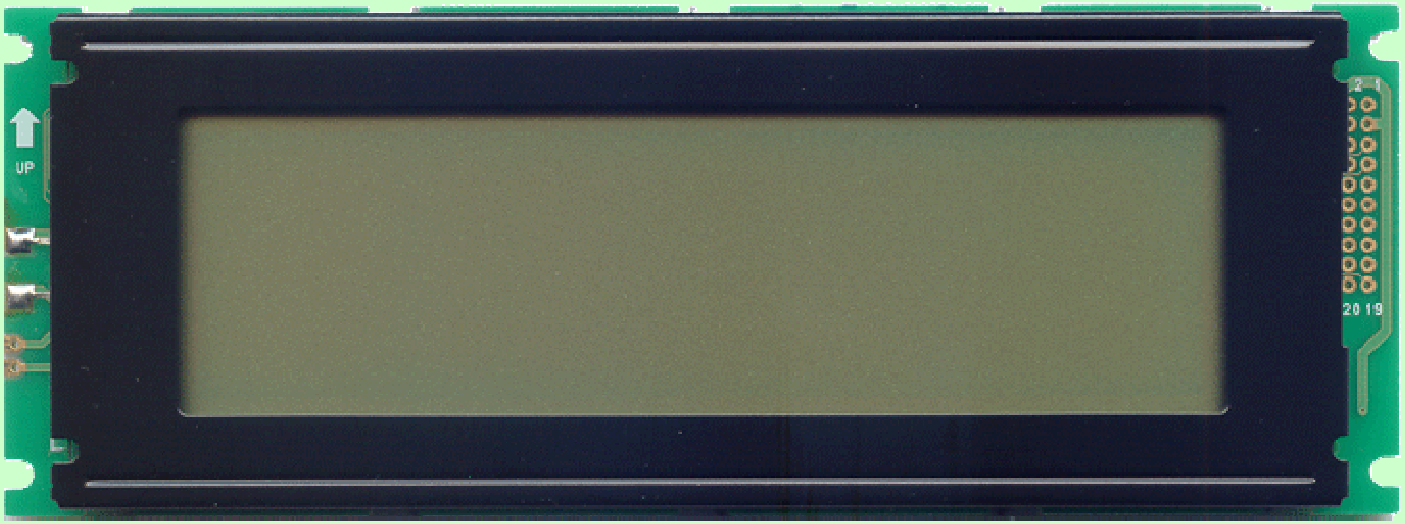
- Voltage Divider using 10k potentiometer
- A/D Conversion
- PWM output
  - Lowest setting outputs 50% duty cycle
  - Highest setting outputs 100% duty cycle

Safety

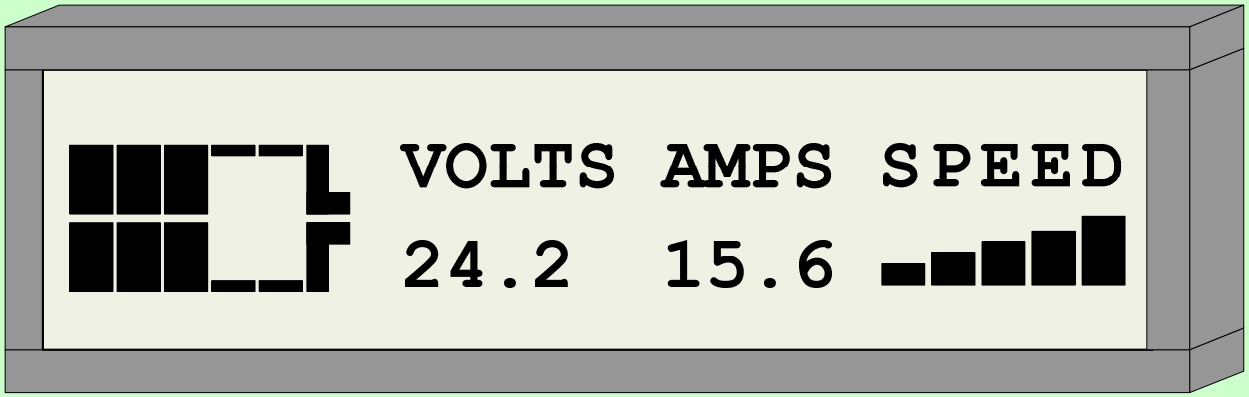
- Safety Switch
- PWM output is set to zero when disengaged
- Over-current protection
- Fuses
- Battery Protection

Display

Optrex 2x20 character LCD with HD44780 Controller

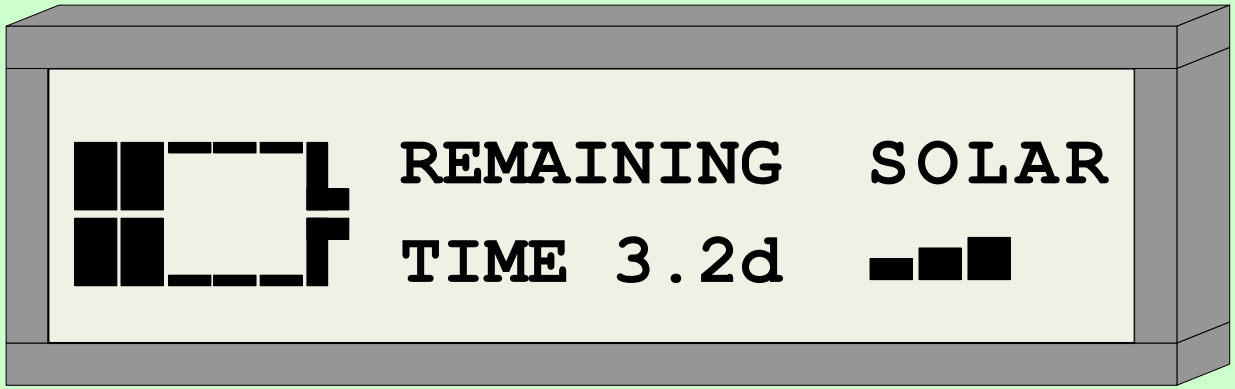


Display



Mowing

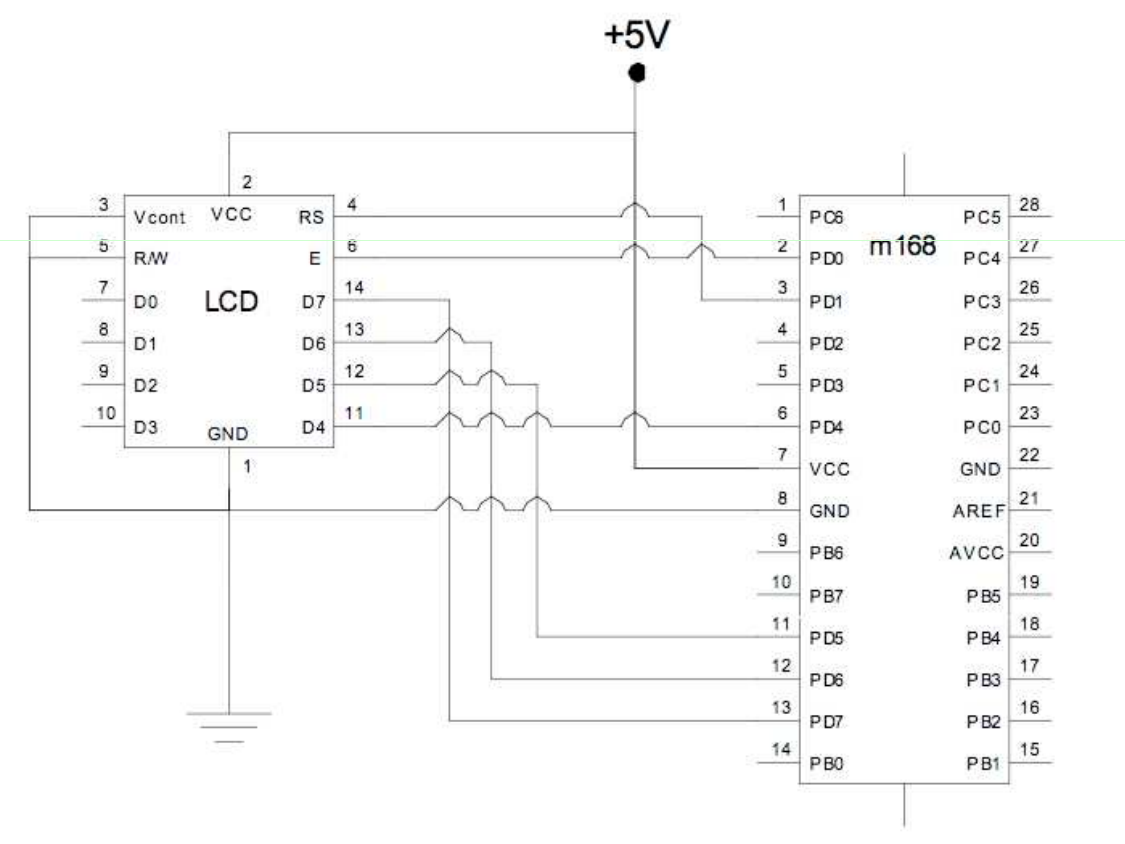
Display



Charging

Display

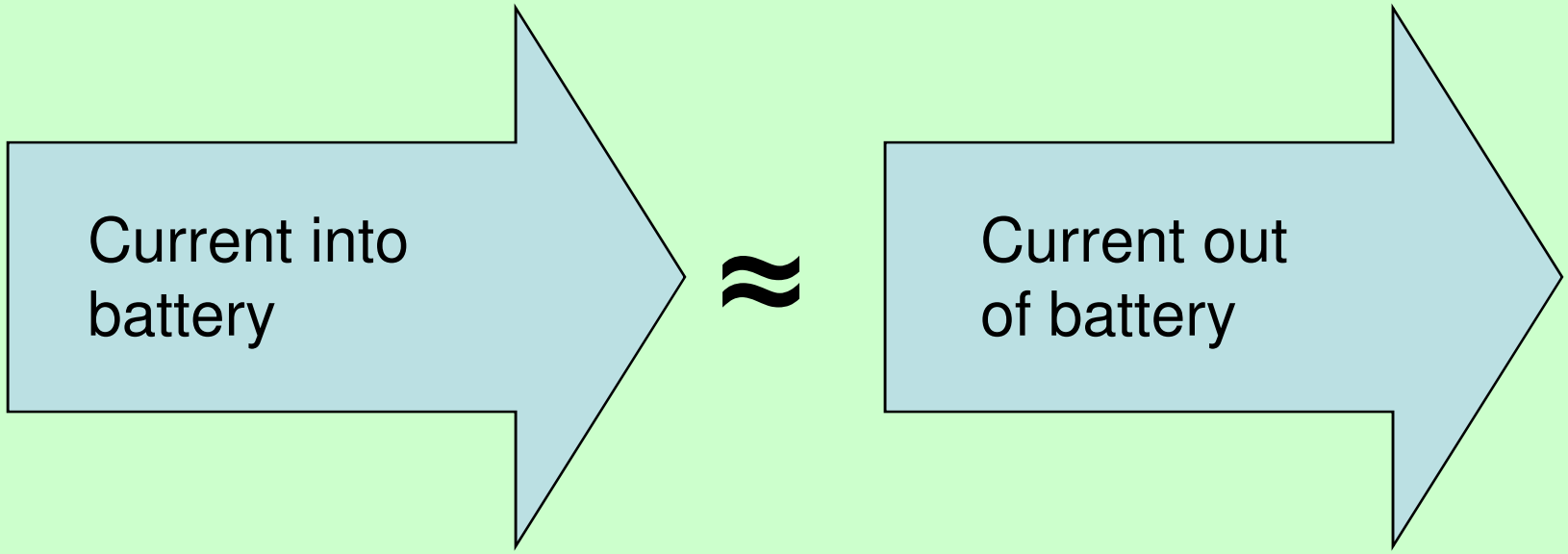
4-bit control vs. 8-bit control



State of Charge

- Importance
- Methods
  - Terminal Voltage
  - Specific Gravity of Electrolyte
  - Current Counting

Current Counting



Current Counting

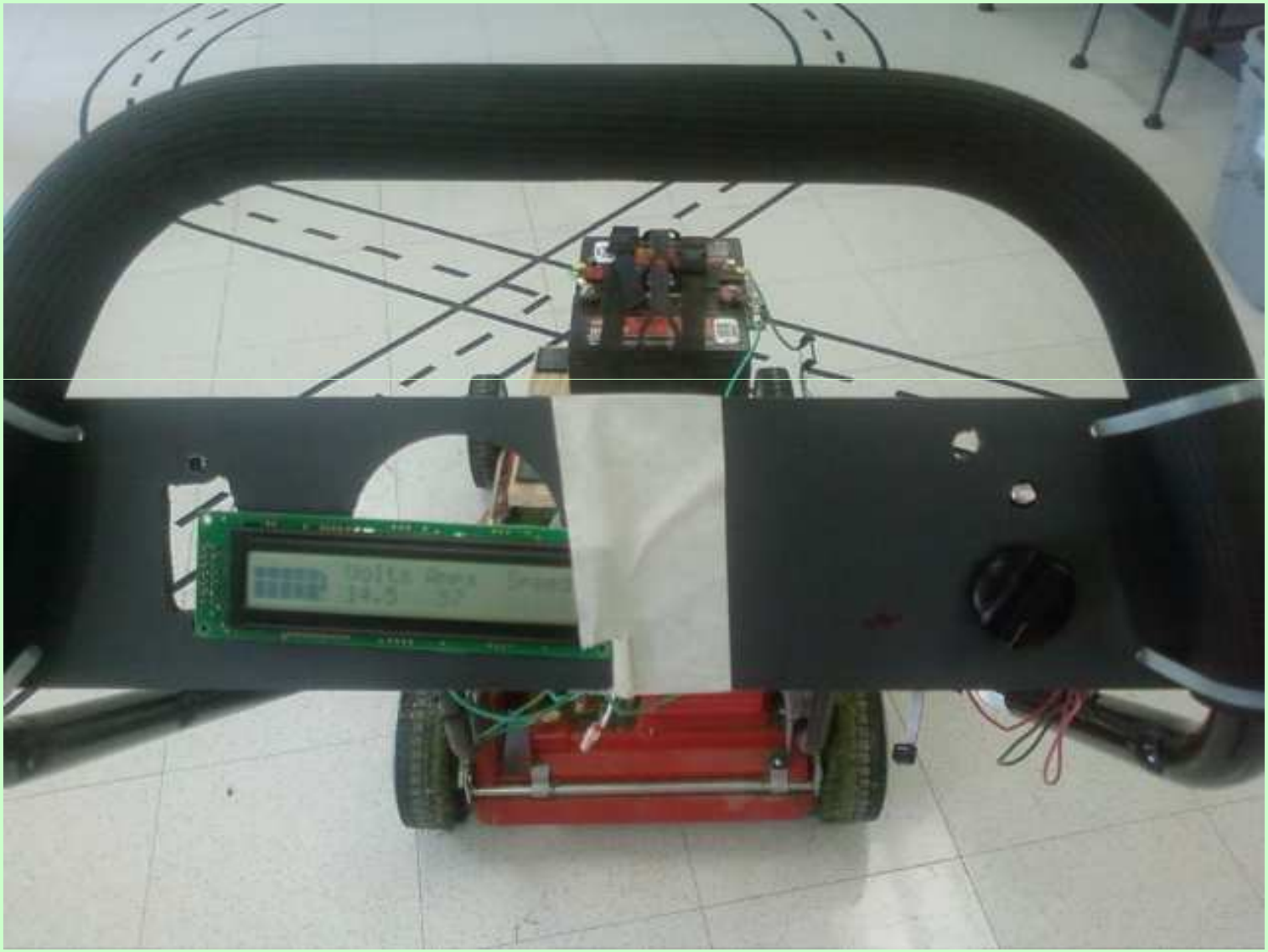
- $SOC = SOC_0 \pm 1/capacity * \int I dt$
- Measure current every 10ms
- Integrate for 1 second
- Recalibrate SOC_0 after a rest of four hours using terminal voltage method

Issues with Controls

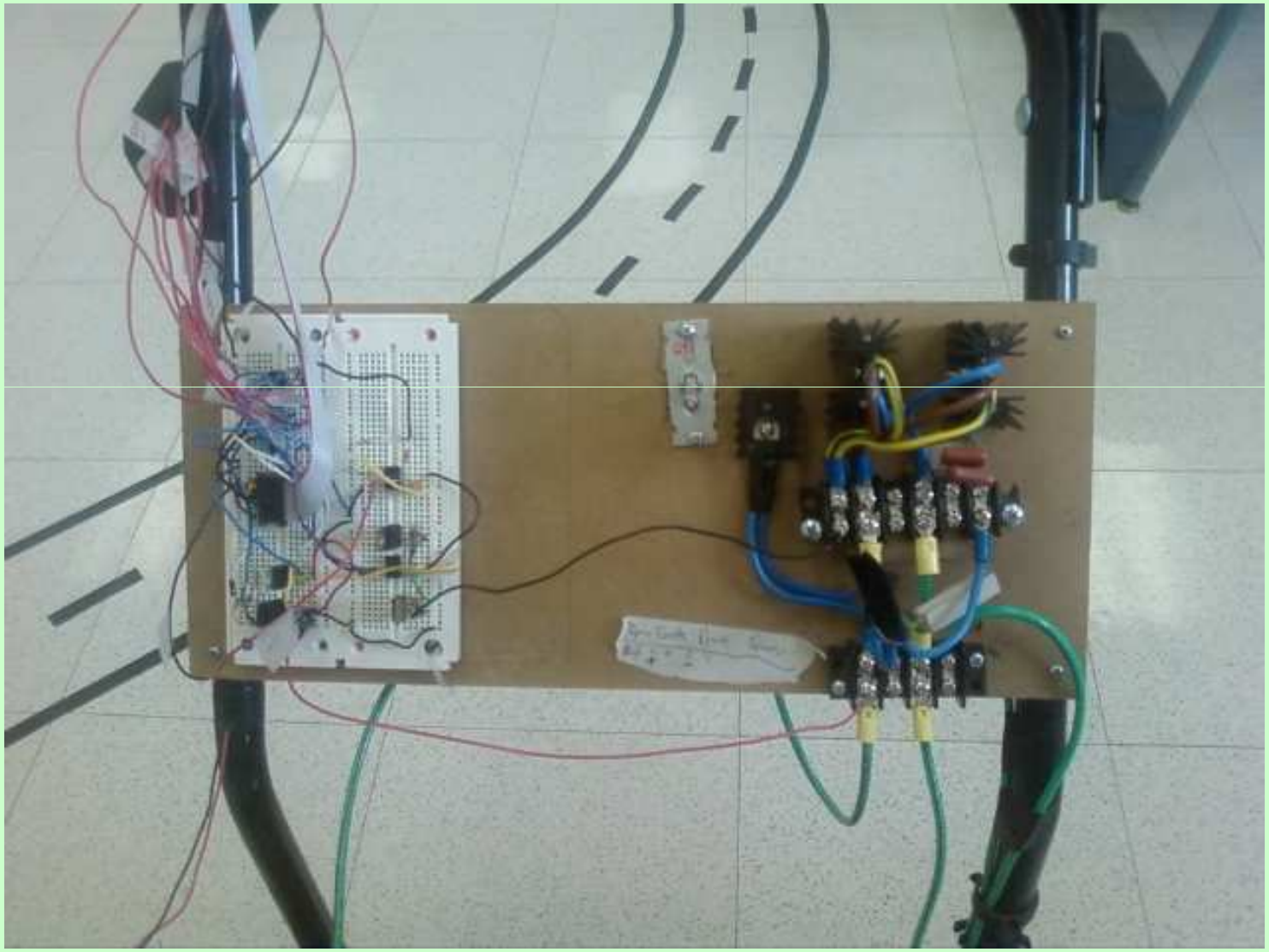
- Inaccurate Current Measurement
- Battery Voltage Measurement Circuitry
- Too much current drawn

Final System Test

Final System Test



Final System Test



Final System Test

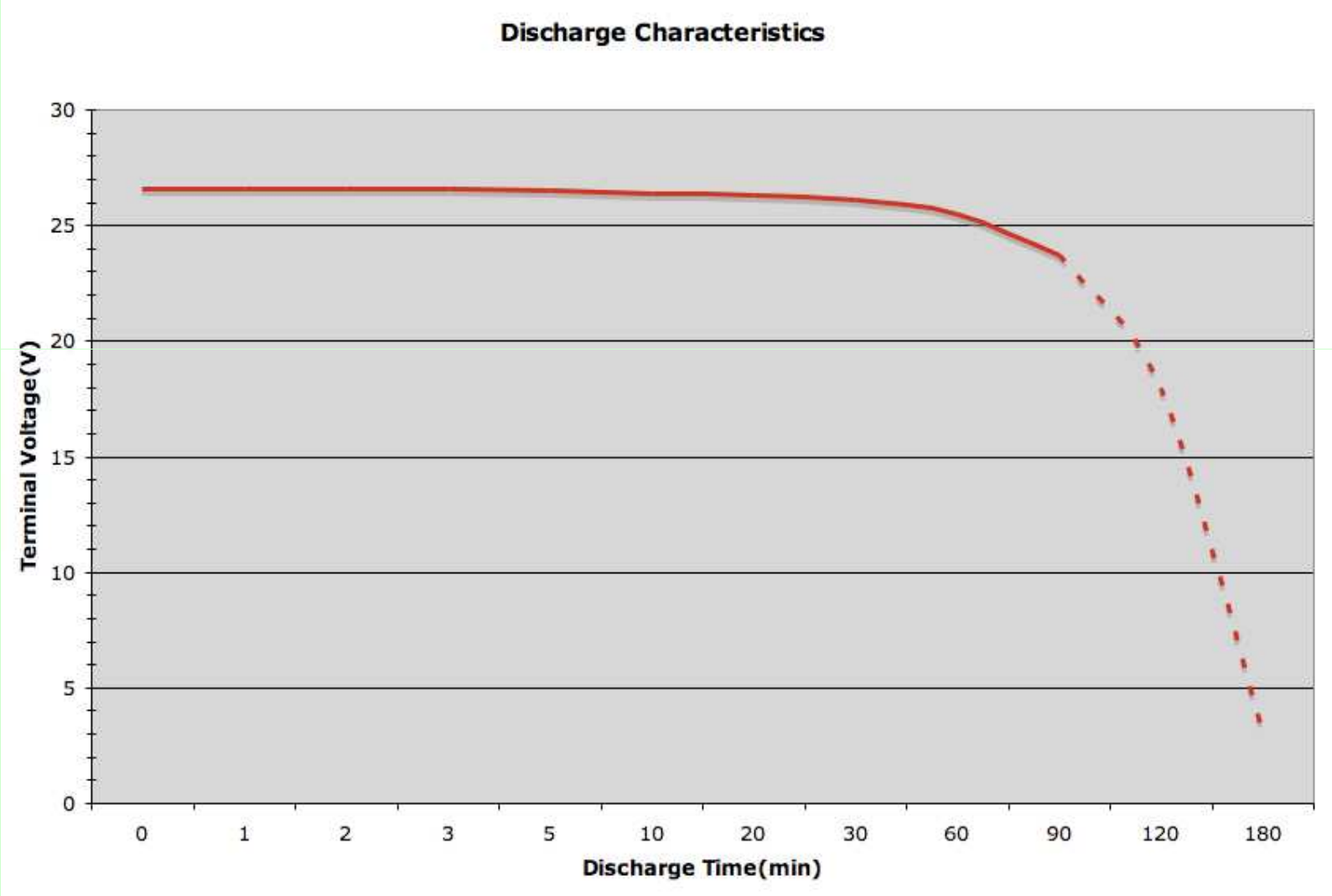
- Grass Conditions
  - Extremely dense in spots
  - Wet
  - 3” tall
- Mower settings
  - Blade spinning at full speed
  - 1.5” cut off the top of grass

Final System Test

Results

- Mowed 13,000 sq. ft.
- Elapsed Time = 1.5 hrs
- Initial Voltage = 26.6V
- Final Voltage=23.77V

Results


Discharge Characteristics
Terminal Voltage(V)
30
25
20
15
10
5
0
0
1
2
3
5
10
20
30
60
90
120
180
Discharge Time(min)

Improvements

- Brushless DC Motor
- Charging from AC power
- Self Propelled
- Better Mower Deck

Questions