Power Converters For An Electric Vehicle

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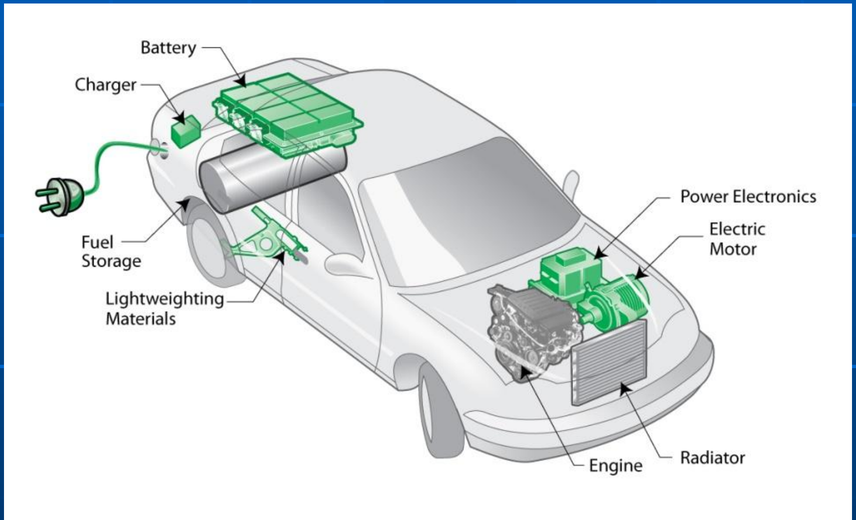
Why the electric car?

- Improves fuel economy
- Reduces carbon emissions
- HEV vs PHEV

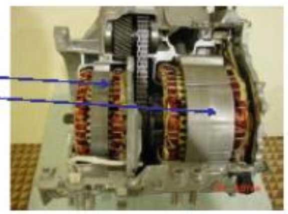


Electric Car Examples

Automotive Motor Drive Applications

30 kW, 8 pole
IPM S/A

50 kW, 8 pole
IPM M/G

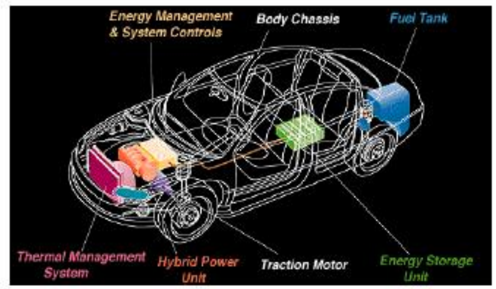


Toyota Prius Alternator and Traction Motor

Inverter 1

Inverter 2

Toyota Prius Power Conversion Box



Ford Escape Hybrid

MSRP Range: $26,780 - $28,405

2.3 L, DOHC Engine

33 mpg (City)

Honda Insight

MSRP Range: $19,180 - $21,380

1.0 L, SOHC Engine

57 mpg (City)

Honda Civic

MSRP Range: $19,650 - $20,950

1.3 L, VTEC Engine

47 mpg (City)

Toyota Prius

MSRP: $20,295

1.5 L, DOHC Engine

60 mpg (City)

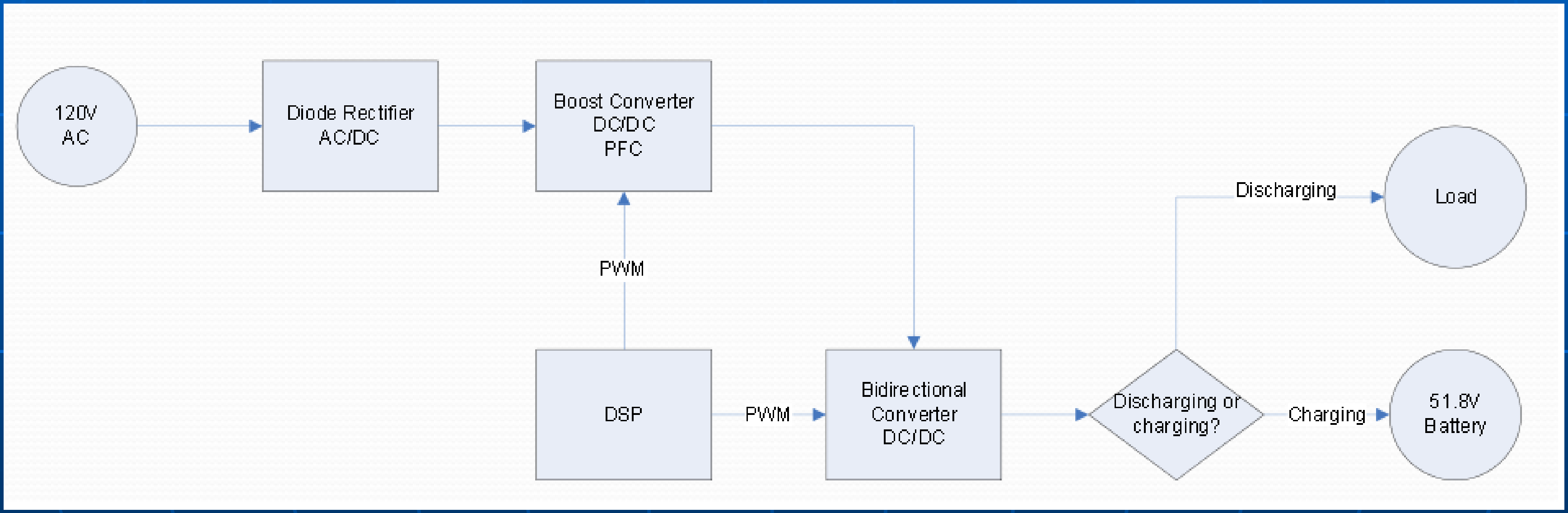
Outline

- Brief Summary of Project
- Functional Description
  - System Block Diagram
  - Performances Specifications
- Battery Testing and DSP
- Results

Project Summary

- PFC Circuit (Power Factor Correction)
- Bidirectional Converter
- Battery Testing Circuit
- DSP Programming

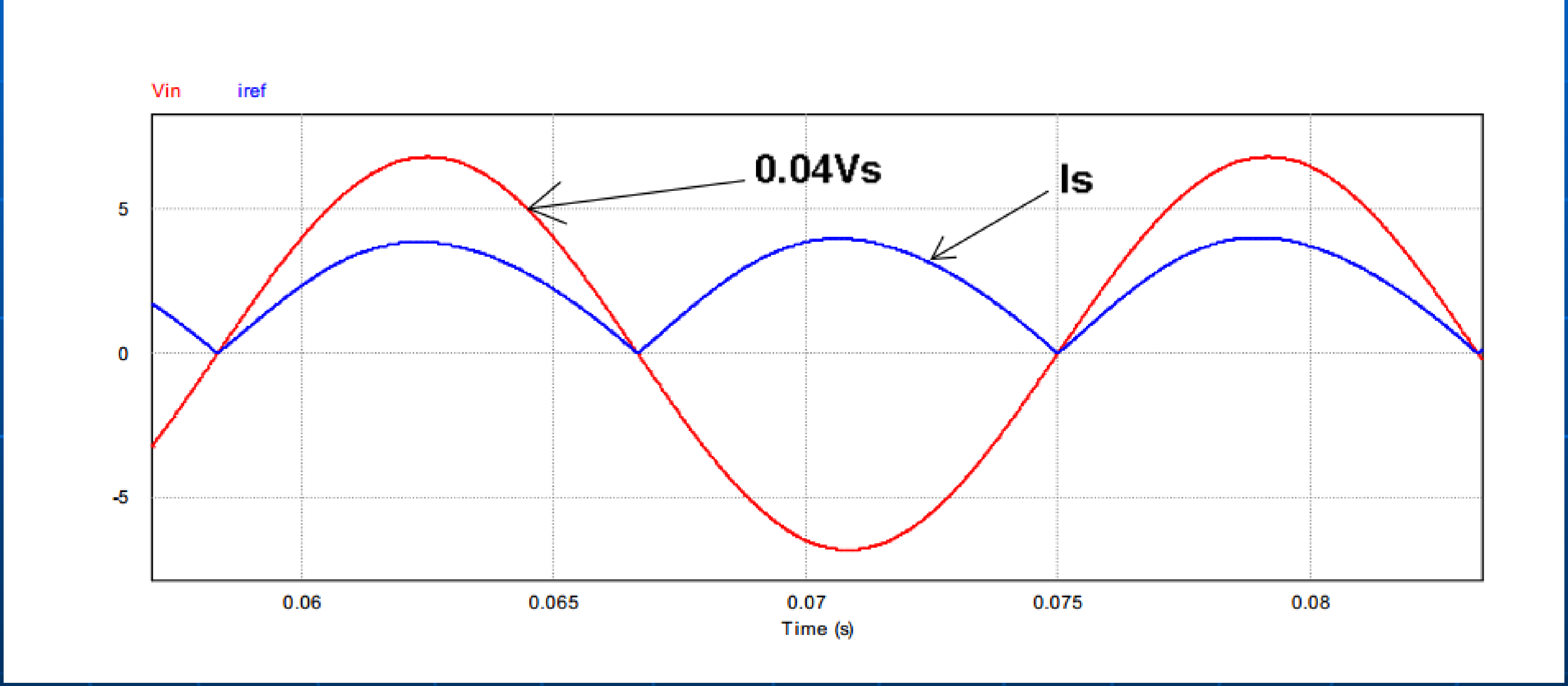
System Block Diagram



Why do we need PFC?

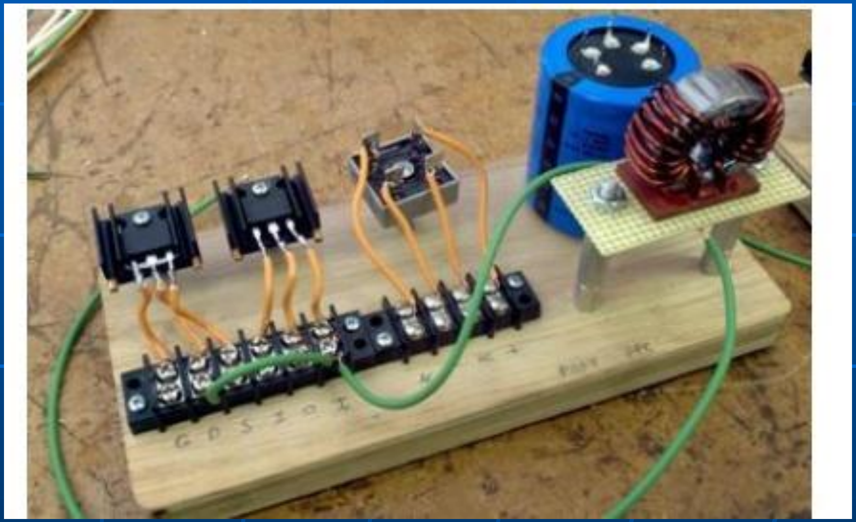
- Improves the efficiency of the system
- PHEV should control PFC
- Increase the amount of real power and reduce reactive power
- Use switch-mode boost converter

Power Factor Waveforms

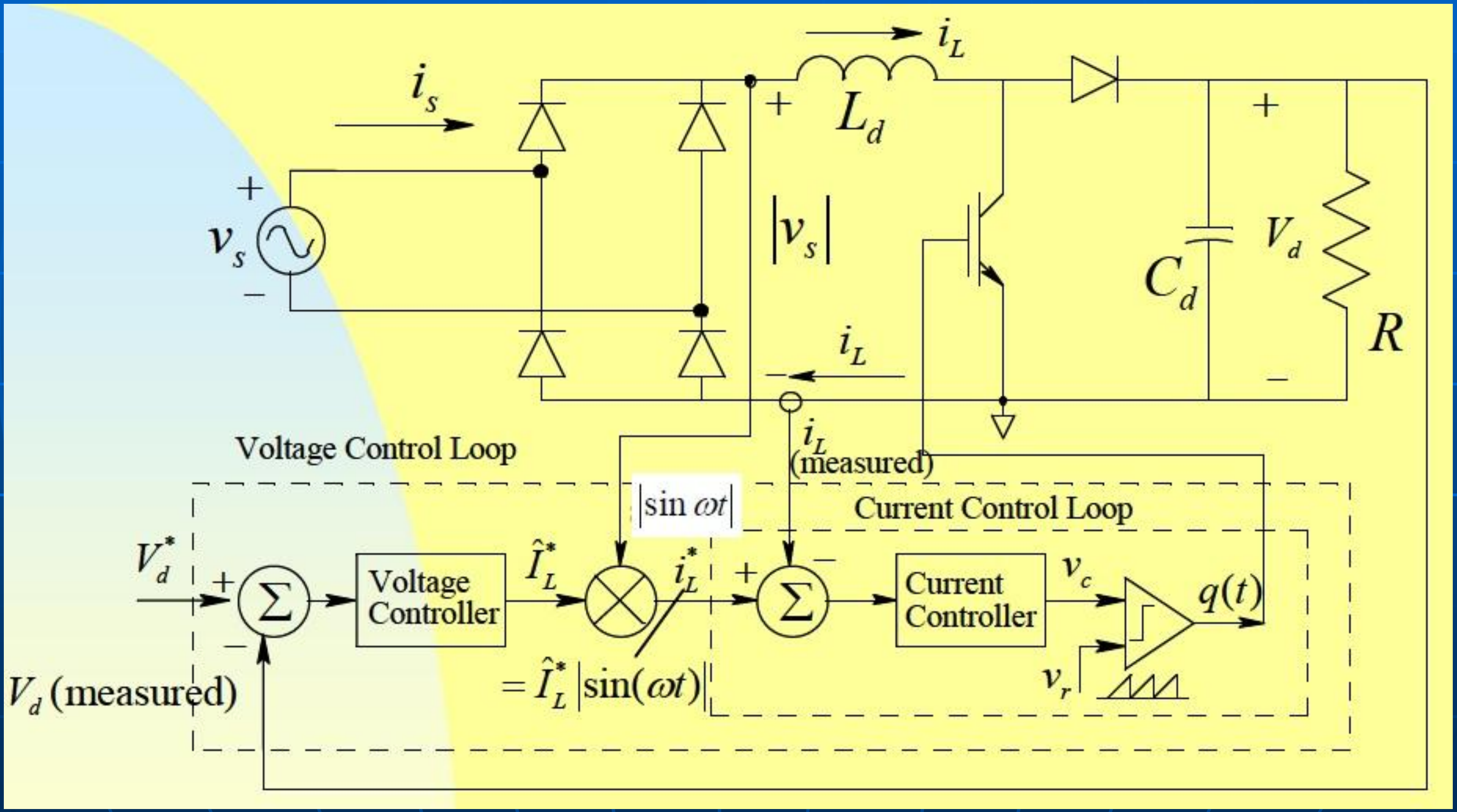


Designing The PFC Circuit

- Re-made PFC Circuit
- Modified power diode to MOSFET
- Replaced Bridge Rectifier
- Circuit was tested using a IR2110



Control PFC Circuit

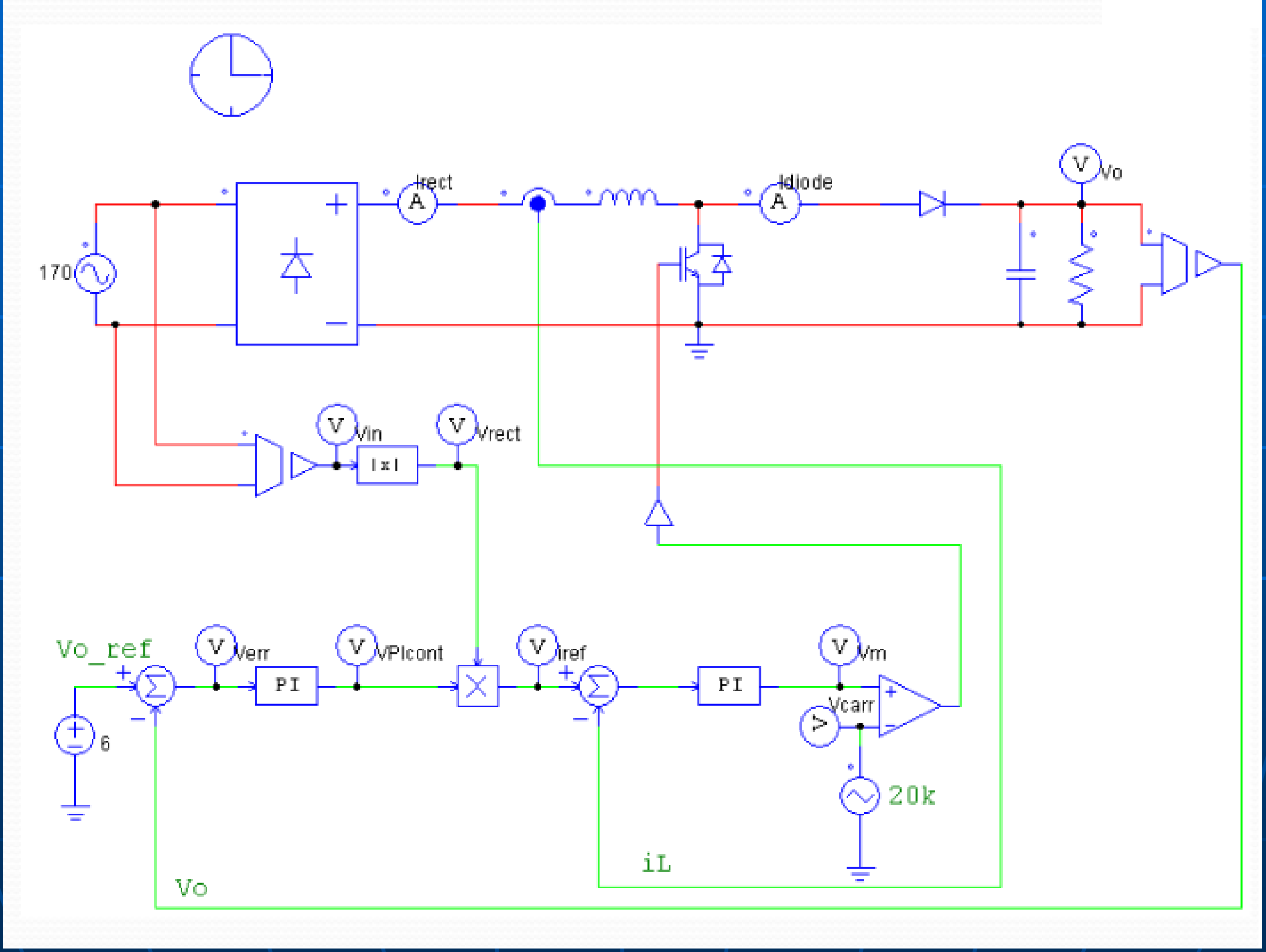


Transfer Function (PFC)

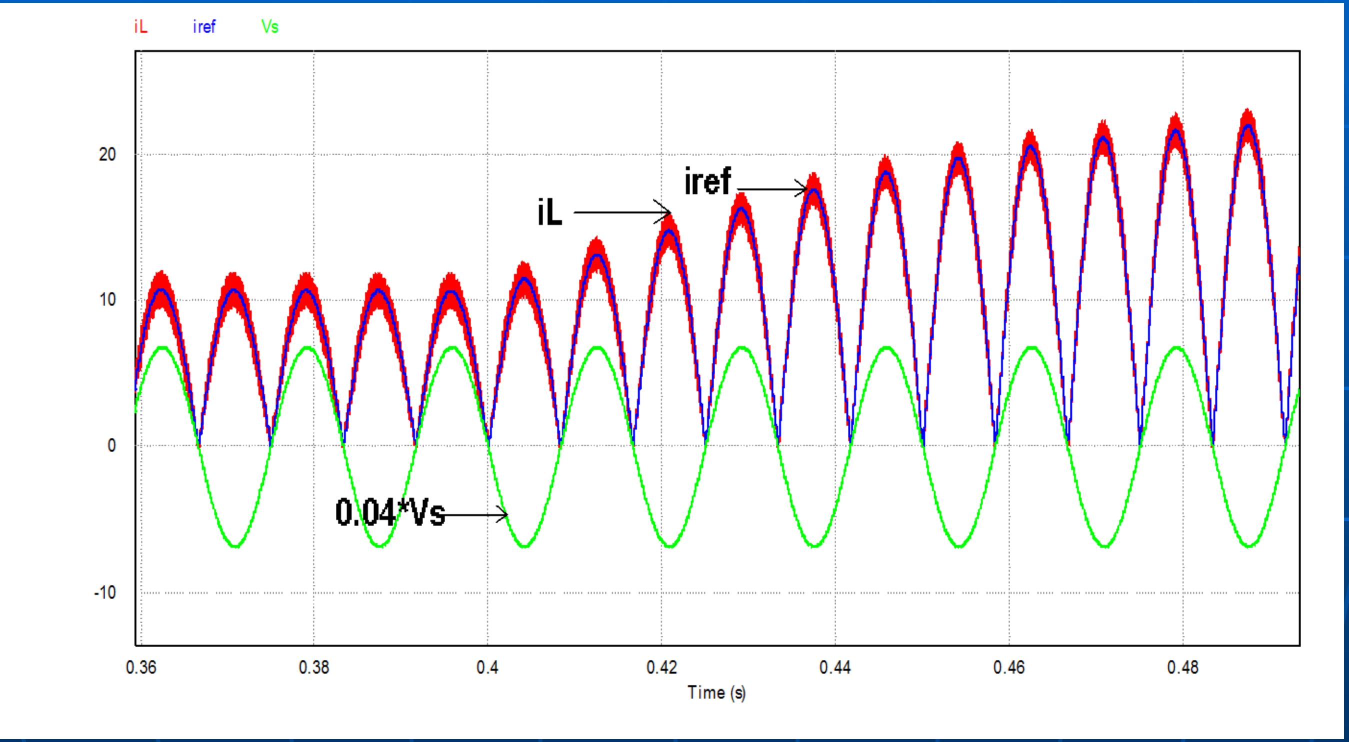
$$G_{ps_{pfc}} = \frac{\tilde{i}_L}{\tilde{d}} \frac{(s)}{(s)} \cong \frac{V_o}{sL_d}$$

$$\frac{\widetilde{V_d}}{\tilde{i}_L}(s) = \frac{1}{2} \frac{\widehat{V_s}}{V_d} \frac{\frac{R}{2}}{1 + s\left(\frac{R}{2}\right)C}$$

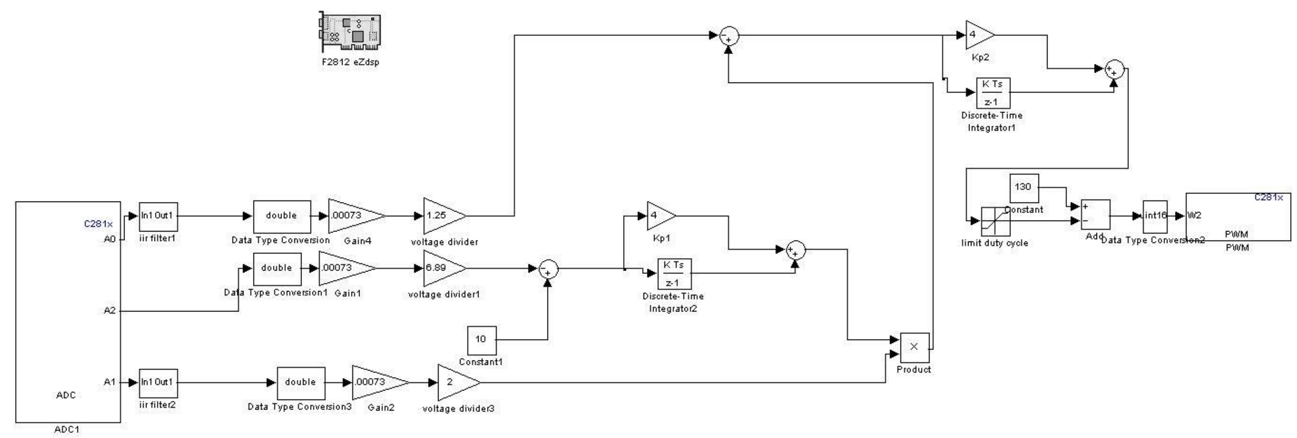
Power Factor Correction



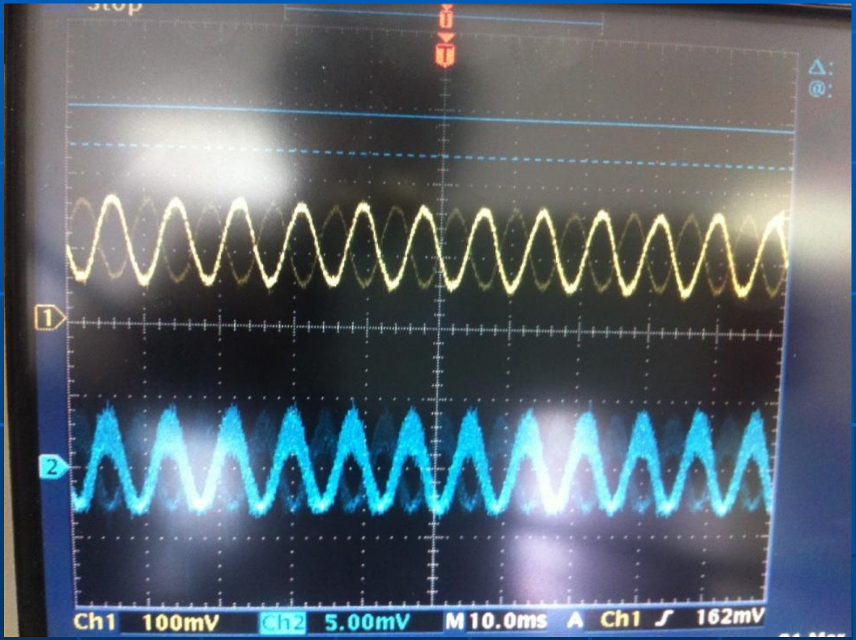
PFC PSIM Results

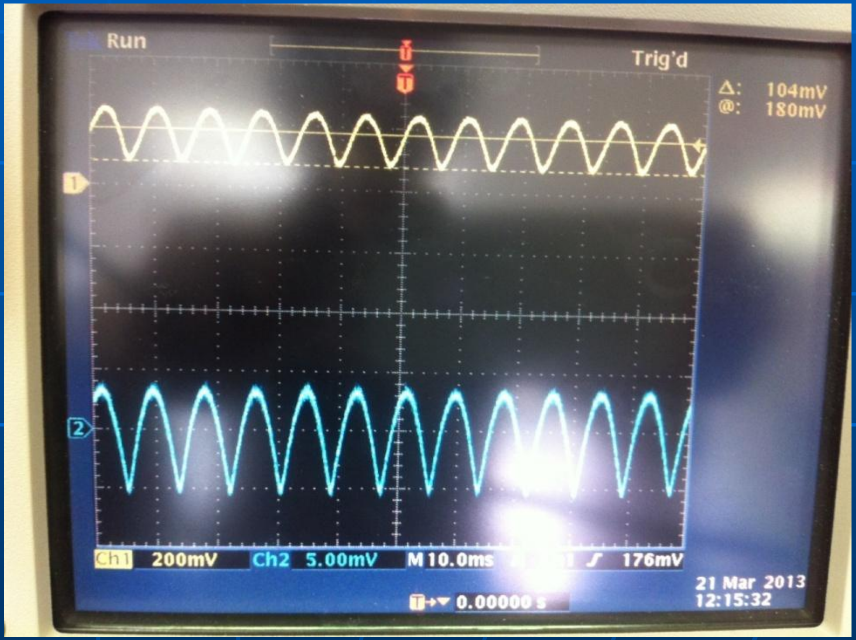


PFC Simulink Model



PFC Results


Ch1 100mV
Ch2 5.00mV
M 10.0ms A Ch1 162mV

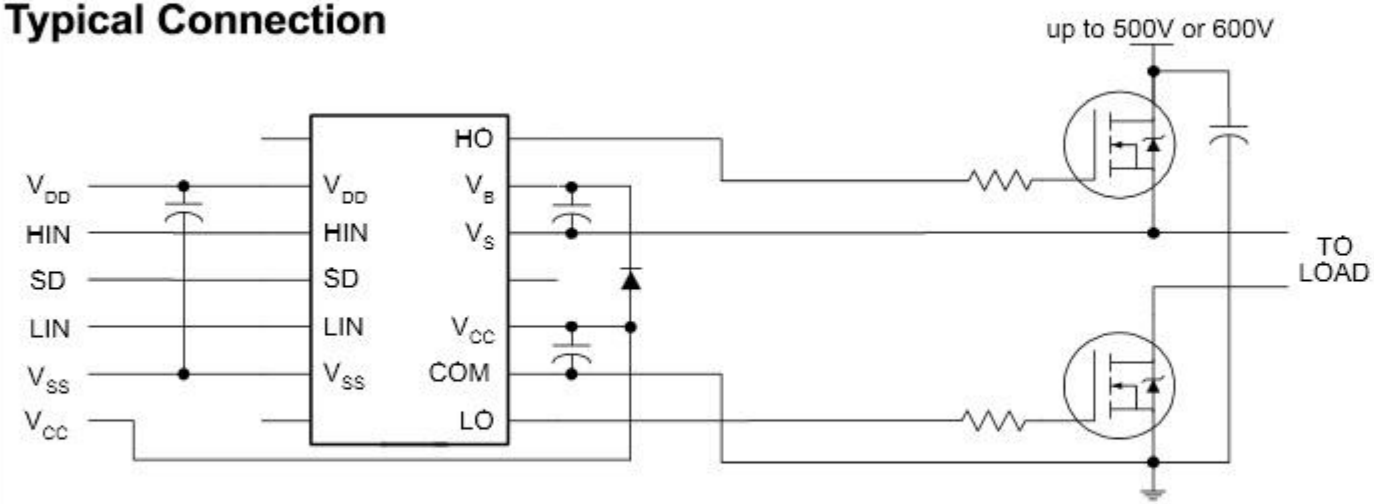

Run
Trig'd
Δ: 104mV
@: 180mV
Ch1 200mV
Ch2 5.00mV
M 10.0ms
176mV
21 Mar 2013
12:15:32
0.00000 s

Why use a gate driver?

- Used as a medium between PWM output from the DSP and input from the high power circuit
- DSP does not supply enough voltage
- Gate driver physically switches the transistor
- Has it’s own power supply to effectively output at a higher voltage

IR2110 Gate Driver Layout

Typical Connection



(Refer to Lead Assignments for correct pin configuration). This/These diagram(s) show electrical connections only. Please refer to our Application Notes and DesignTips for proper circuit board layout.

Testing With IR2110

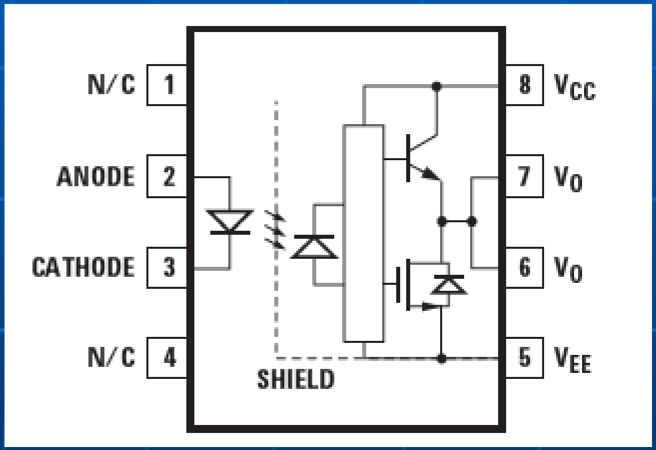
- Previous group recommended IR2110
- Used to test battery, bi-directional, and PFC
- No Isolation

Testing With IR2181

- Similar problems to the IR2110
- The high side would not properly output
- Was hard to isolate circuit

HCPL-3180 Gate Driver

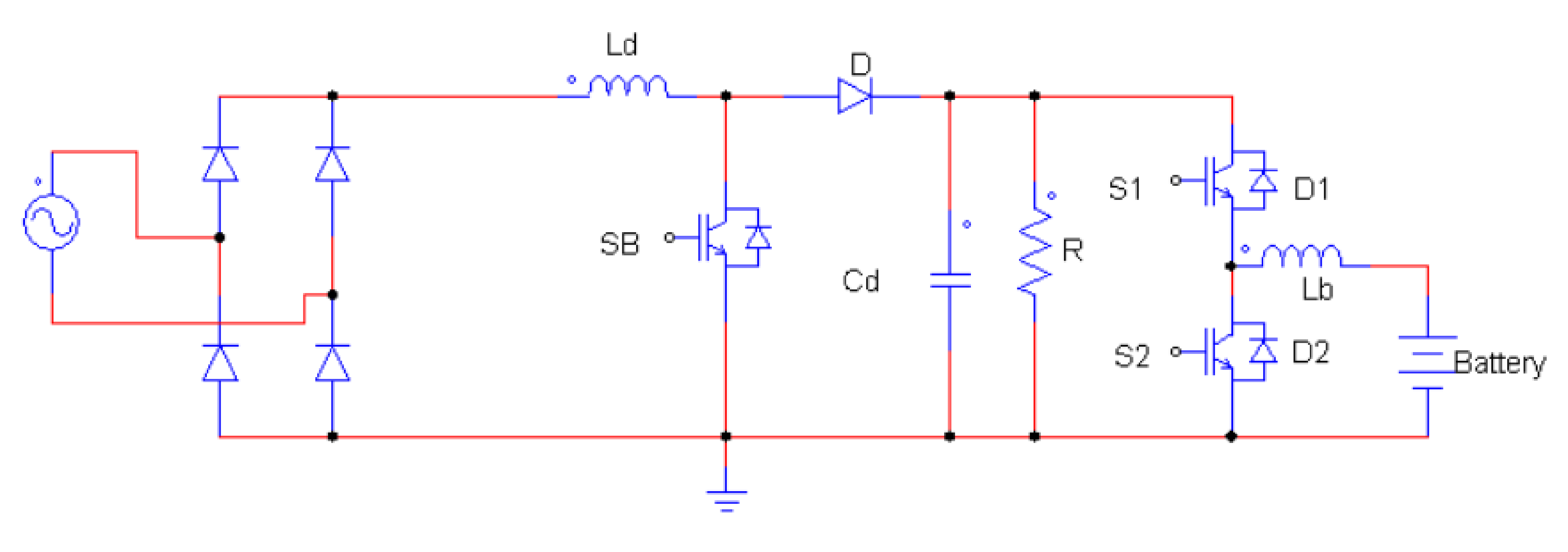
- Easier to use due to being optically isolated
- Ideally suited for high frequency driving of power MOSFETS (2.5Amp)
- One gate driver is used per MOSFET



MOSFET

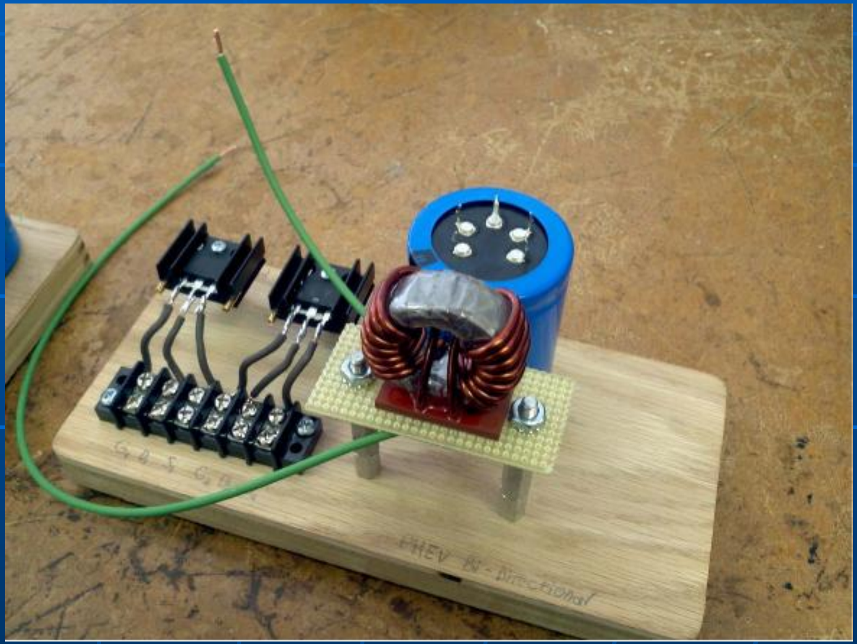
- IRFP460A N-Type
- $V_{DS} = 500V$
- $I_D = 20A$
- 55ns Rise Time
- High speed power switching

Bi-directional Converter



Designing The Bi-Directional Converter

- Redesigned from previous group's project
- Replaced the power diode with a MOSFET
- Circuit was tested using a HCPL-3180

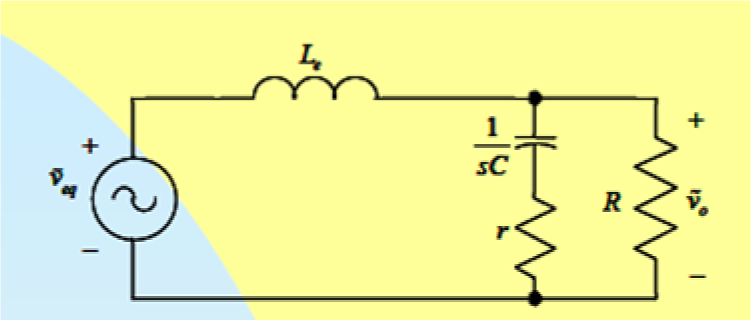


L equations and C equations

$$\Delta V_o = (V_o(1-D))/(8LCf^2)$$

$$\Delta i_L = V_o/L(1-D)T_s$$

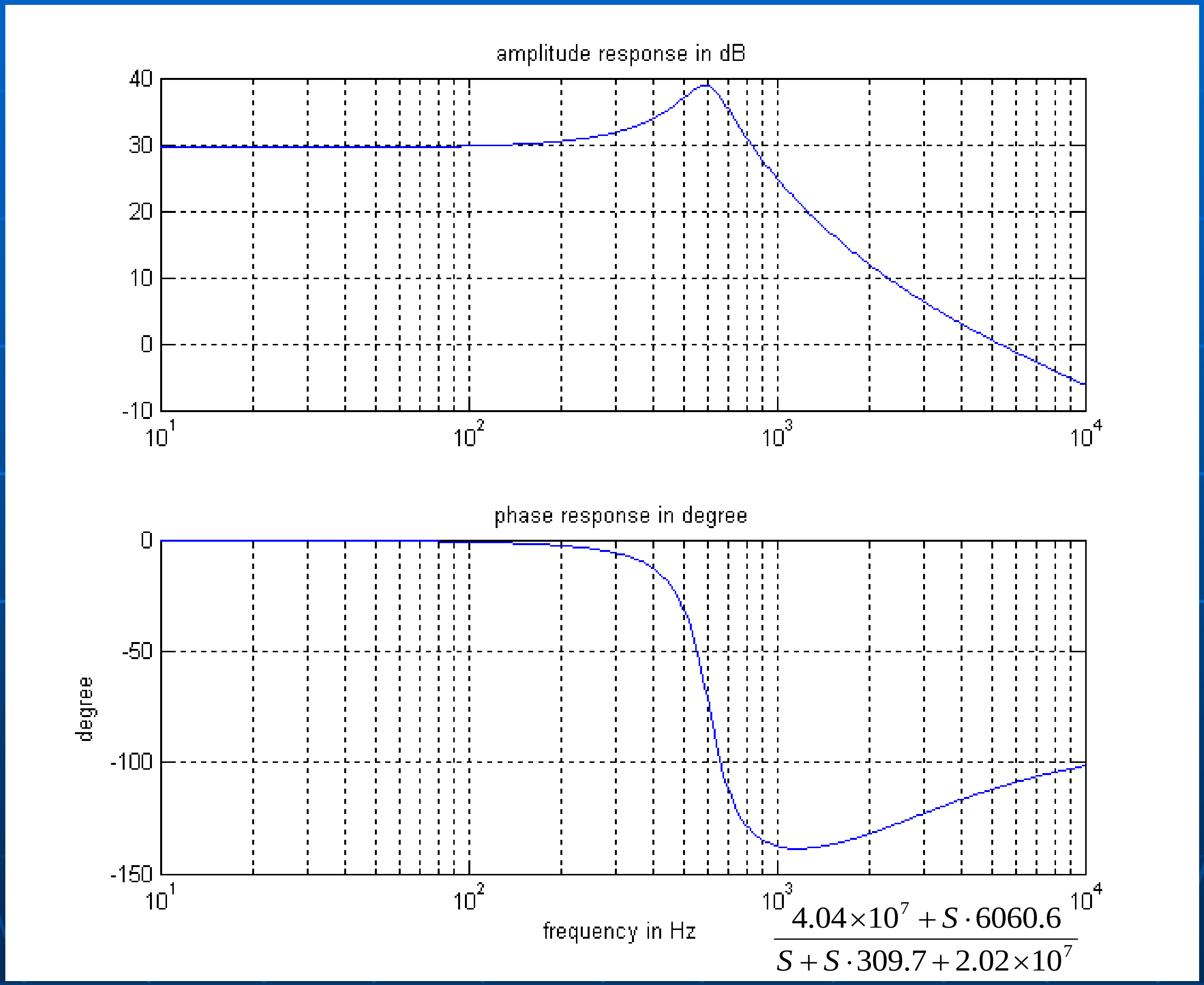
Buck Transfer Function



$$L_e = L\ (Buck)$$

$$\frac{\widetilde{v_o}}{\tilde{d}} = \frac{V_{in}}{LC}\frac{1 + srC}{s^2 + s\left(\frac{1}{RC} + \frac{r}{L}\right) + \frac{1}{LC}}$$

Buck Transfer Function Response



$$\frac{4.04\times10^{7}+S\cdot6060.6}{S+S\cdot309.7+2.02\times10^{7}}$$

Buck Voltage Controller Equations

$$G_c(s) = \frac{sk_p + k_i}{s}$$

$$f_c > \frac{1}{2\pi\sqrt{LC}}$$

$$|G_c(s)|_{fc} = \sqrt{k_p^2 + \left(\frac{k_i}{w}\right)^2}$$

$$\angle G_c(s)_{fc} = \tan^{-1}\left(\frac{-\frac{k_i}{w}}{k_p}\right)$$

Buck Voltage Controller Equations

$$1 = |G_c(s)|_{f_c} \cdot |G_{pwm}(s)|_{f_c} \cdot |G_{ps}(s)|_{f_c} \cdot k_{fb}$$

$$1 = |G_c(s)|_{f_c} \cdot .263 \cdot 5.7 \cdot 1$$

$$\phi_{boost} = -90^o + \phi_{pm} - \angle G_{ps}(s)_{fc}$$

$$k_p = .444 \qquad k_i = 806.1$$

Buck Current Controller Equations

$$\phi_{boost} = -90^o + \Phi_{pm} - \angle G_{ps}(s)_f$$

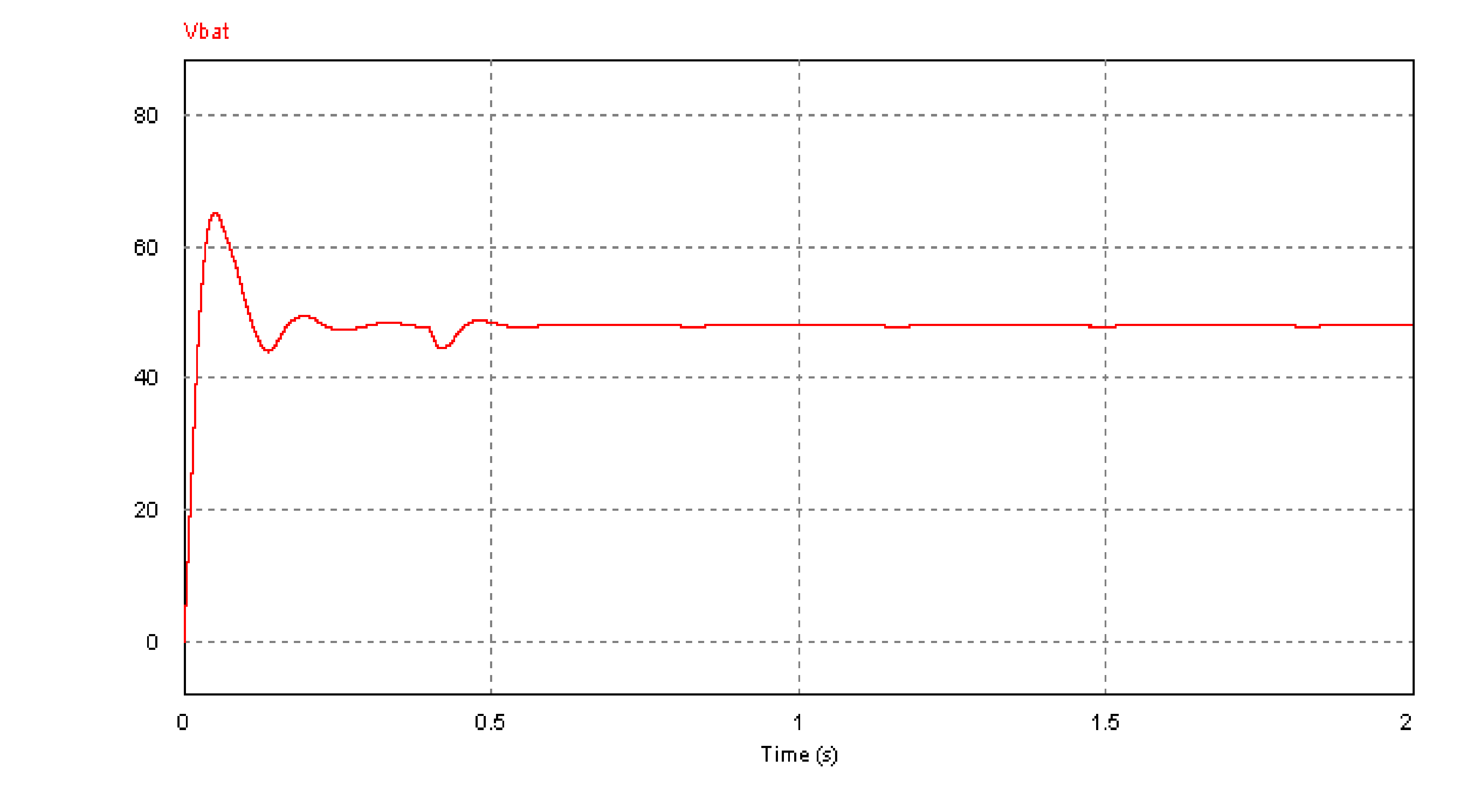
$$|G_C(s)|\ X\ |G_{ps}(s)|_{fc} = 1$$

$$\phi_{boost} + (-90^o) = \angle G_c$$

$$|G_c(s)|_f = \sqrt{k_p^2 + \left(\frac{k_i}{w}\right)^2}$$

$$\angle G_c(s)_f = \tan^{-1}\left(\frac{\frac{-k_i}{w}}{k_p}\right)$$

Buck Voltage Controller Equations

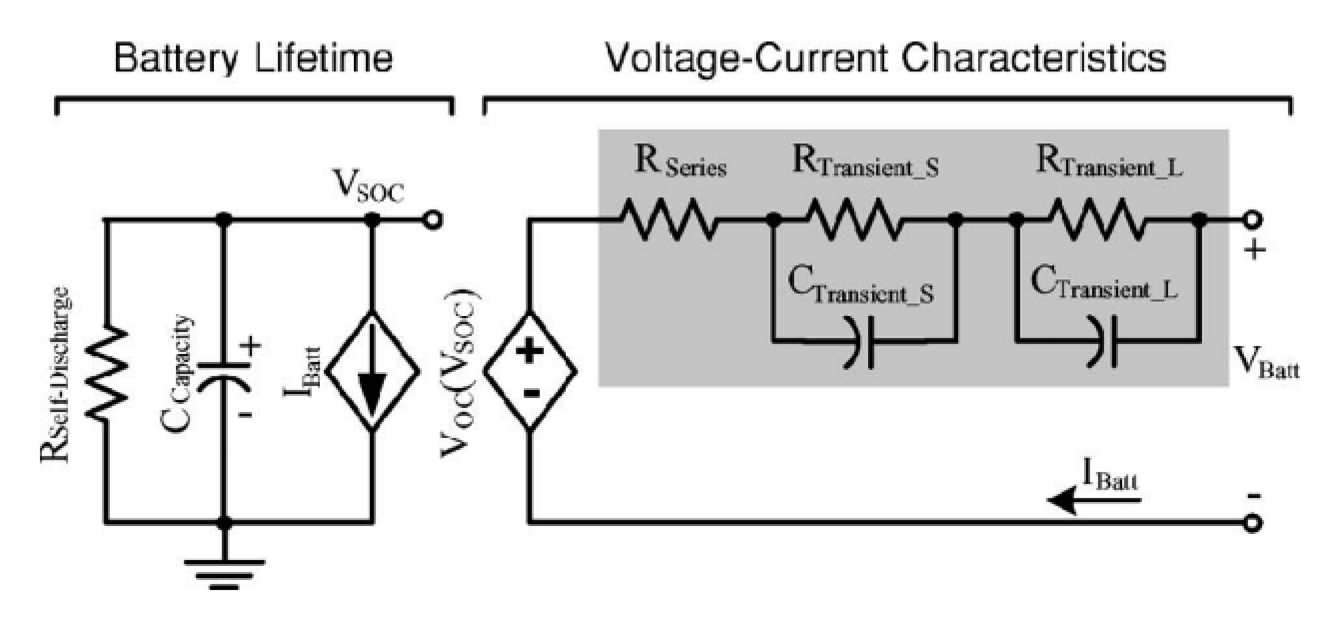


Battery Specs for Low and High Voltage

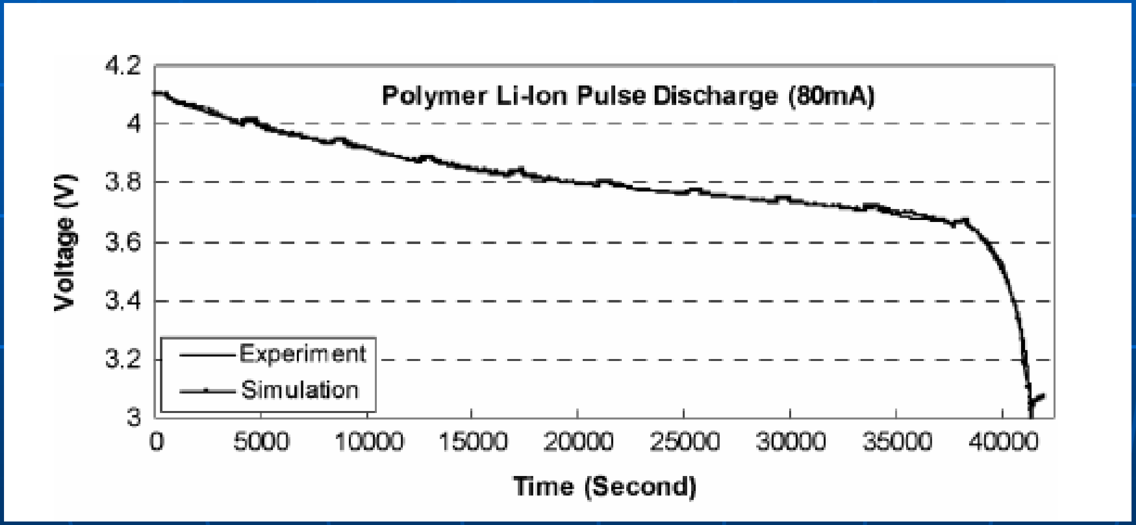
- 7.4V
- 3000 MilliWatt Hours

- 51.8V
- 10Amp-Hours
- Max Discharge Rate 40A

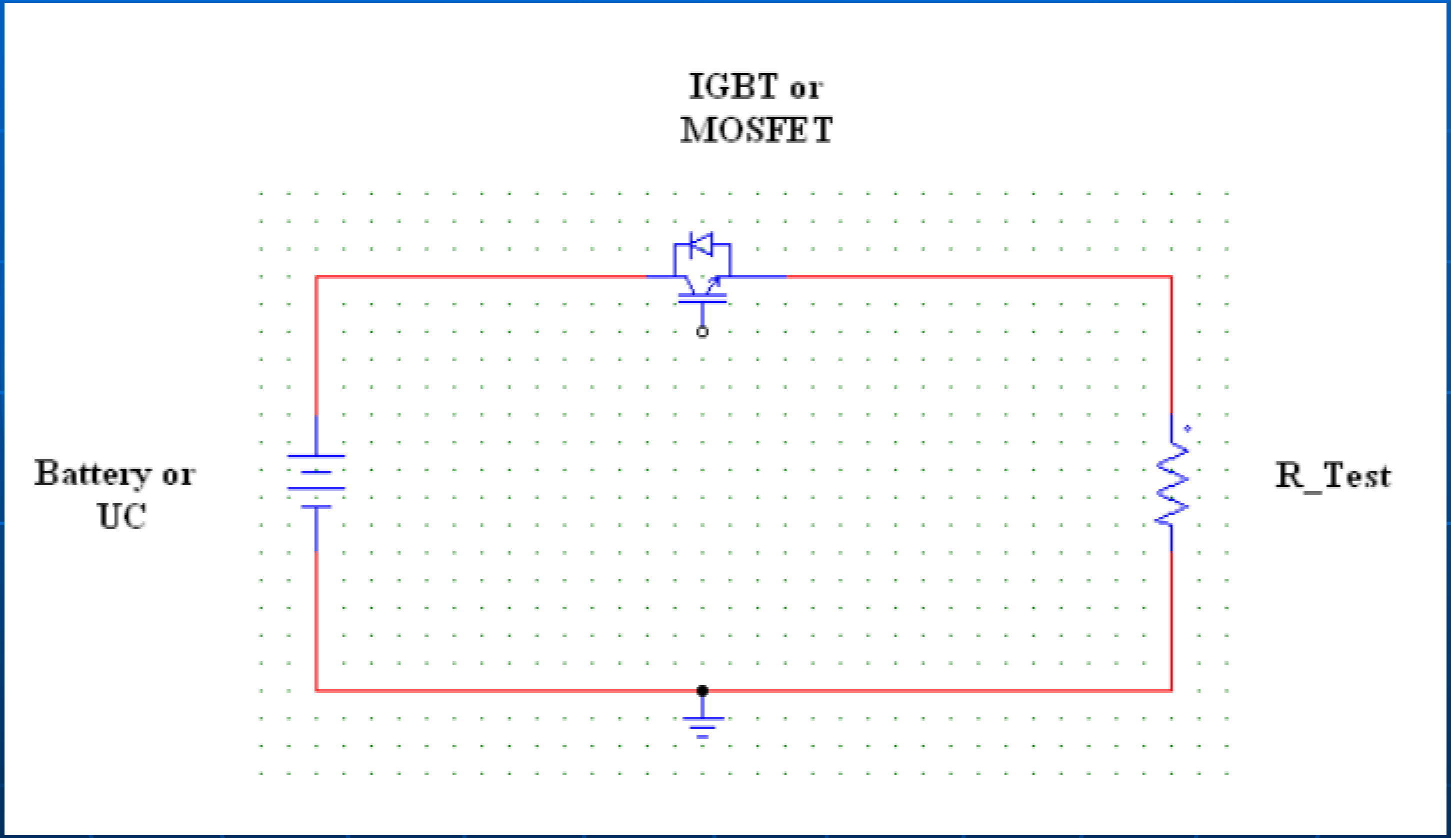
Battery Model



Battery Discharging Rate



Battery Testing Circuit



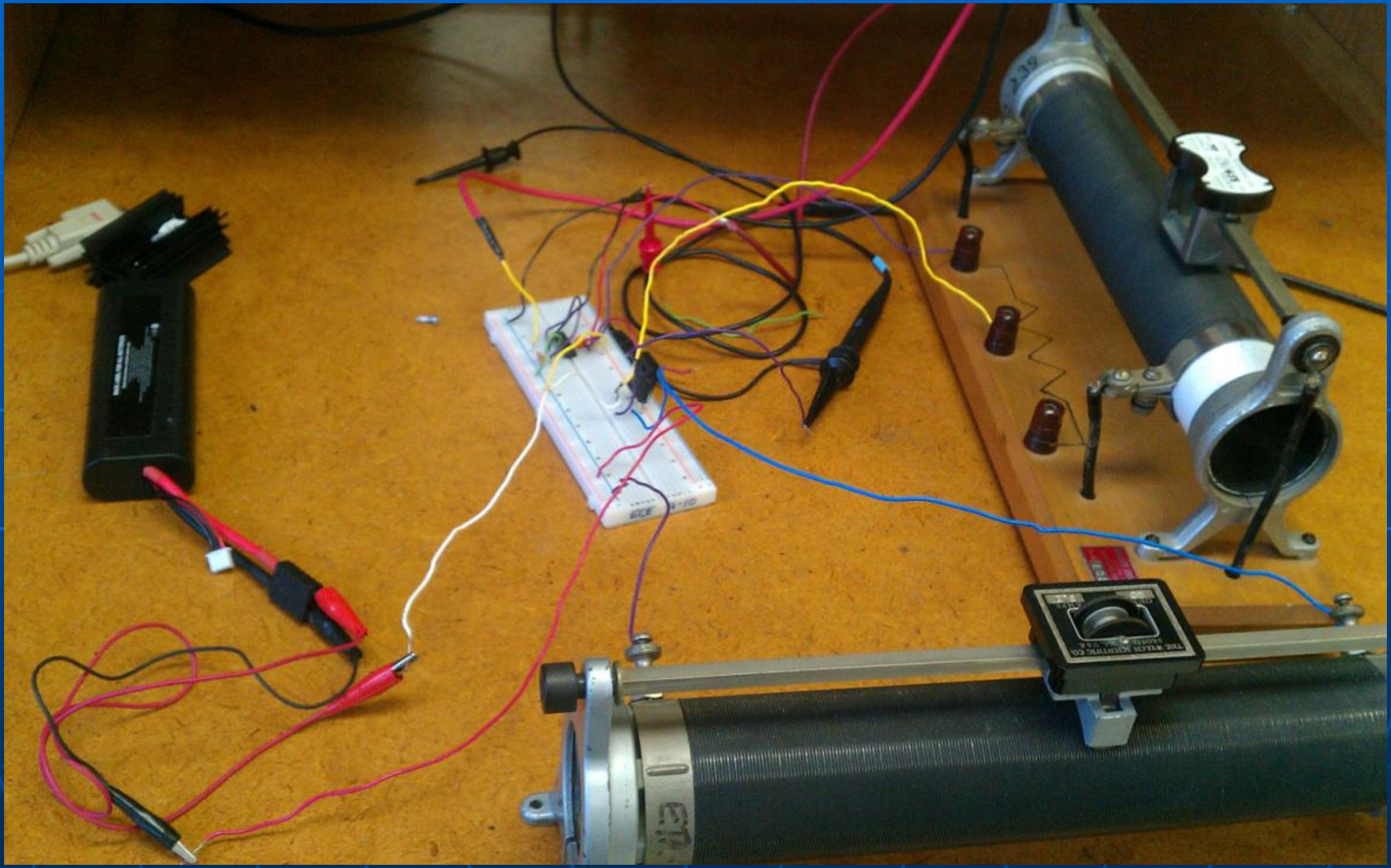
Battery Testing Circuit

- IR2110 used as gate driver
- G4PC30UD IGBT used
- 20ohm resistor used for small scale
- 100ohm resistor used for large scale

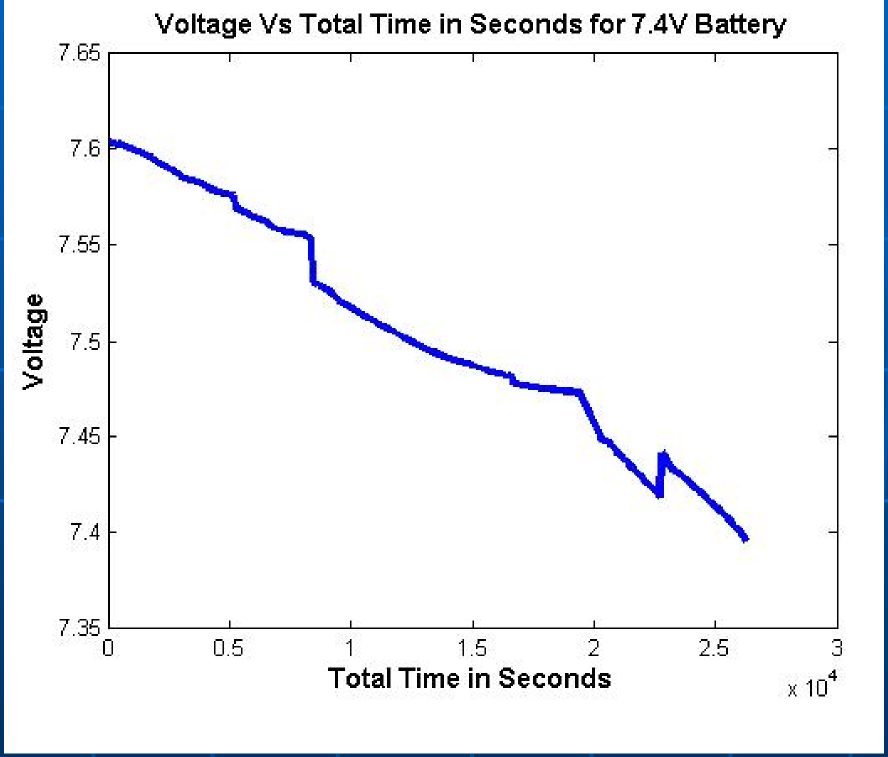
IGBT

- G4PC30UD IGBT used
- $V_{CES} = 600V$
- $V_{CE(on)} = 1.95V$
- @$V_{ge} = 15V$, $I_c = 12A$
- Optimized for high operating frequencies

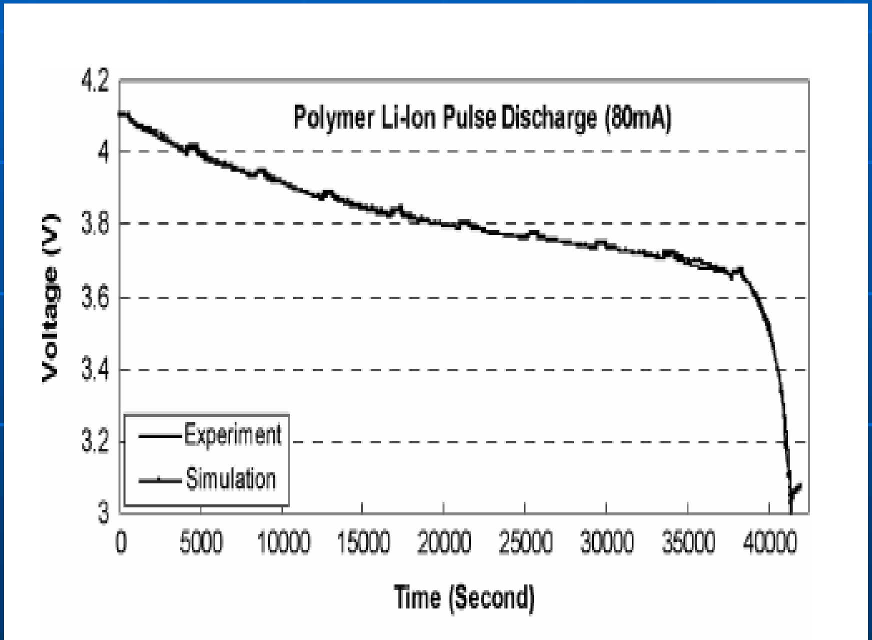
Battery Testing Small Scale

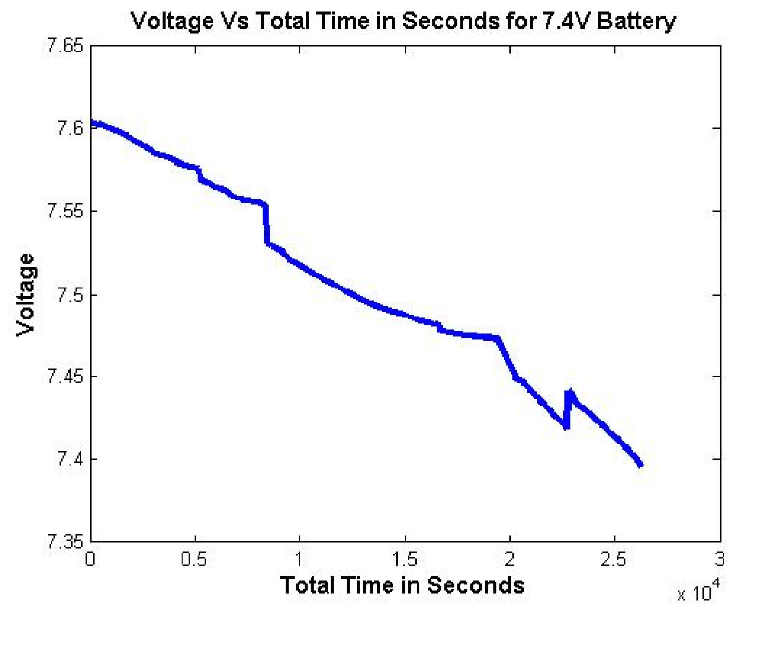


Small Scale Results

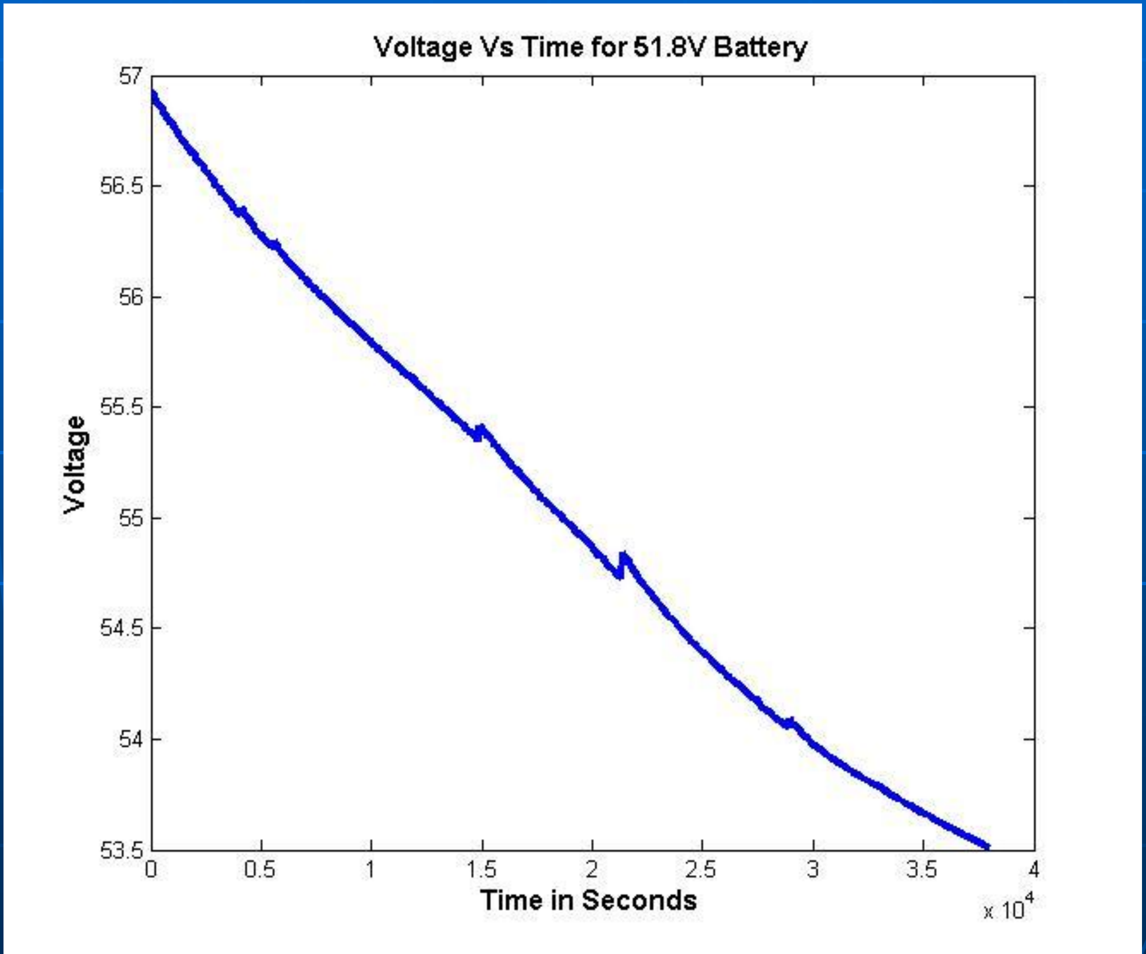


Comparison of Discharging Rate





Discharging Rate of 51.8V Battery



Equations

$$V_{oc}(SOC) = -1.031e^{-35*SOC} + 3.685 + 0.2156*SOC - 0.1178*SOC^2 + 0.3201*SOC^3$$

$$R_{Series}(SOC) = 0.1562*e^{-24.37*SOC} + 0.07446$$

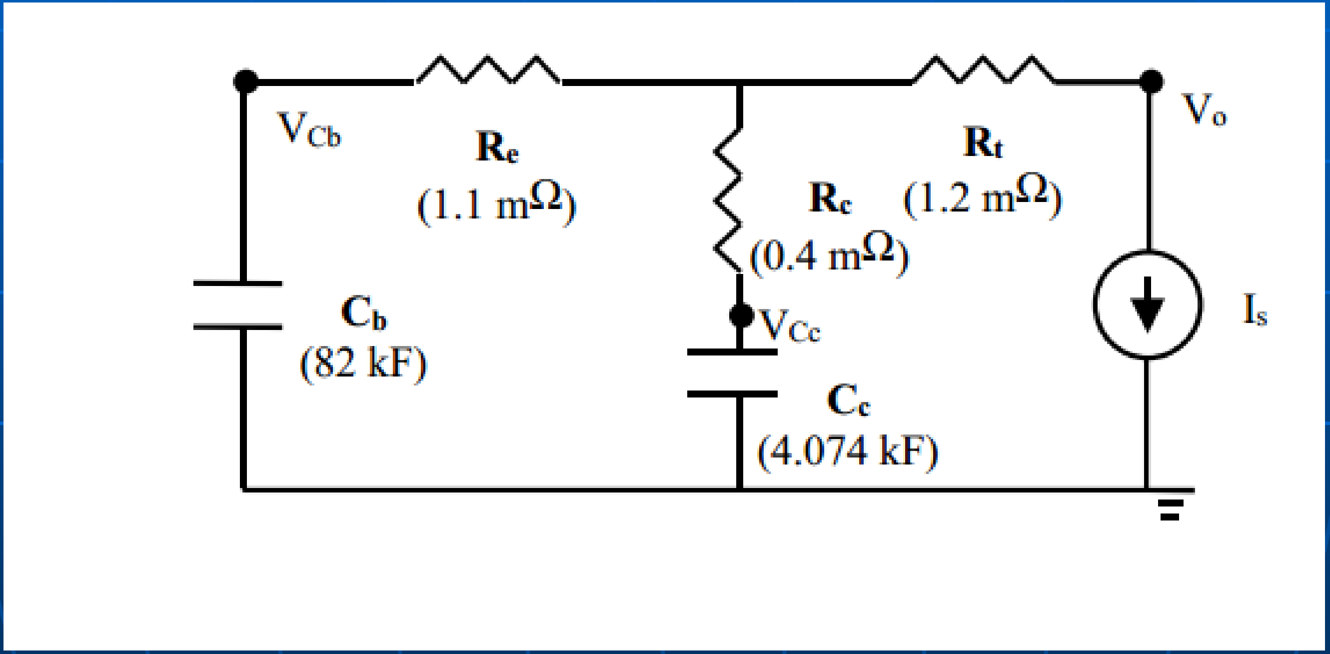
$$R_{Transient_S}(SOC) = 0.3208*e^{-29.14*SOC} + 0.04669$$

$$C_{Transient_S}(SOC) = -752.9*e^{-13.51*SOC} + 703.6$$

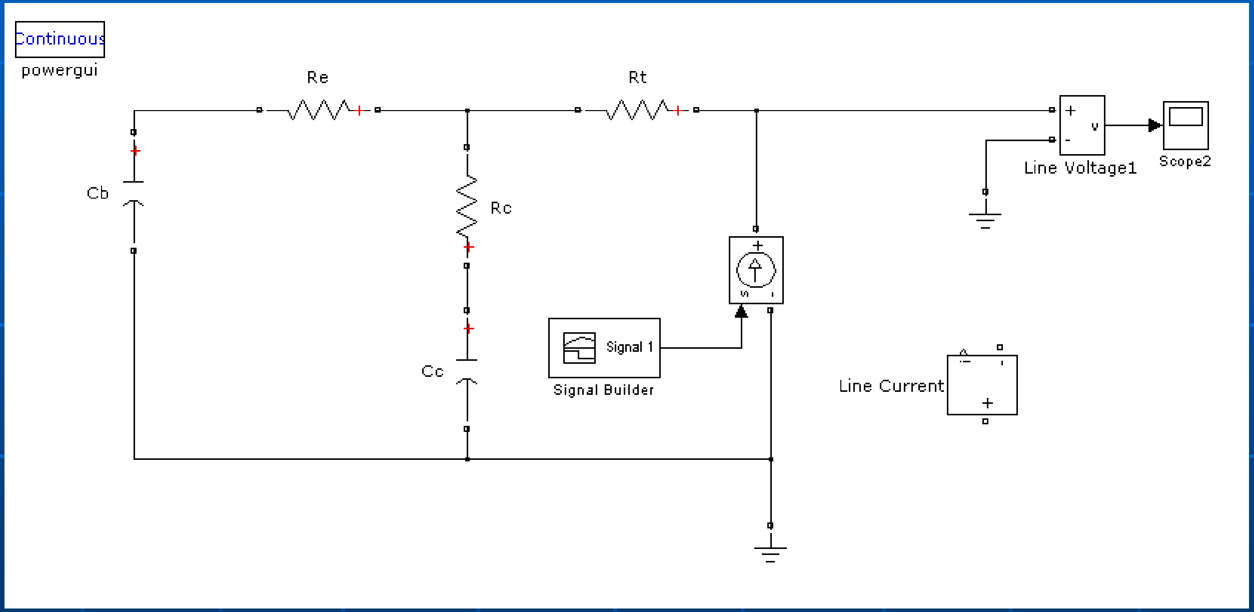
$$R_{Transient_L}(SOC) = 6.603*e^{-155.2*SOC} + 0.04984$$

$$C_{Transient_L}(SOC) = -6056*e^{-27.12*SOC} + 4475$$

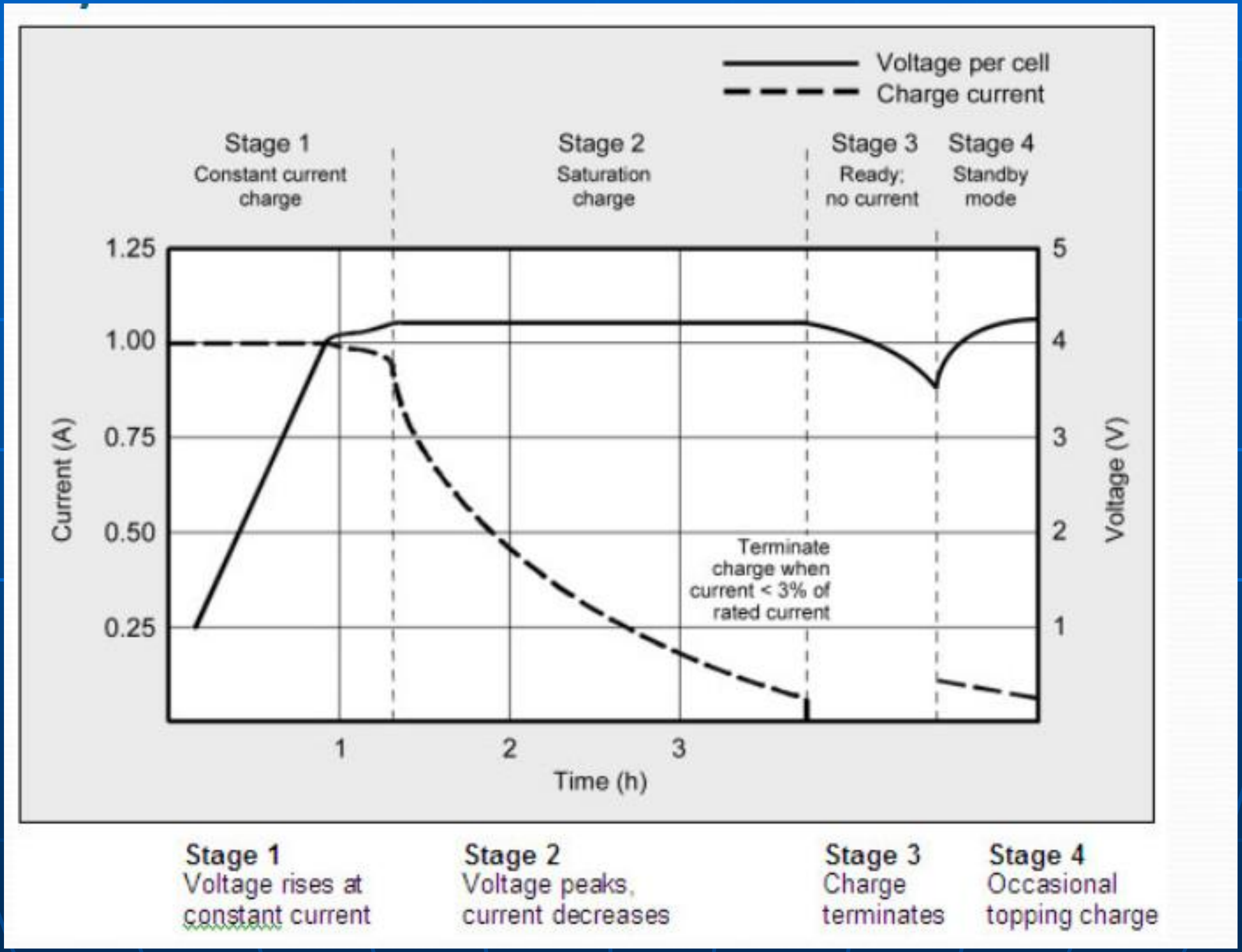
Saft Model



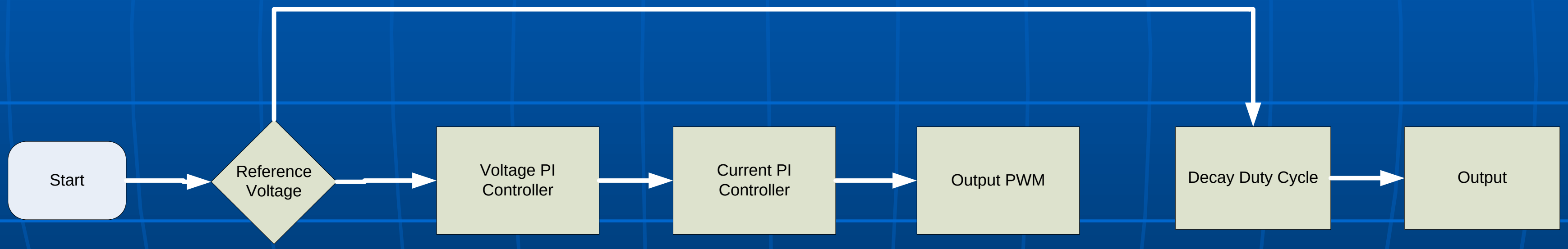
Saft Model


Continuous
powergui
Re
Rt
Cb
Rc
Cc
Signal 1
Signal Builder
Line Voltage1
Scope2
Line Current

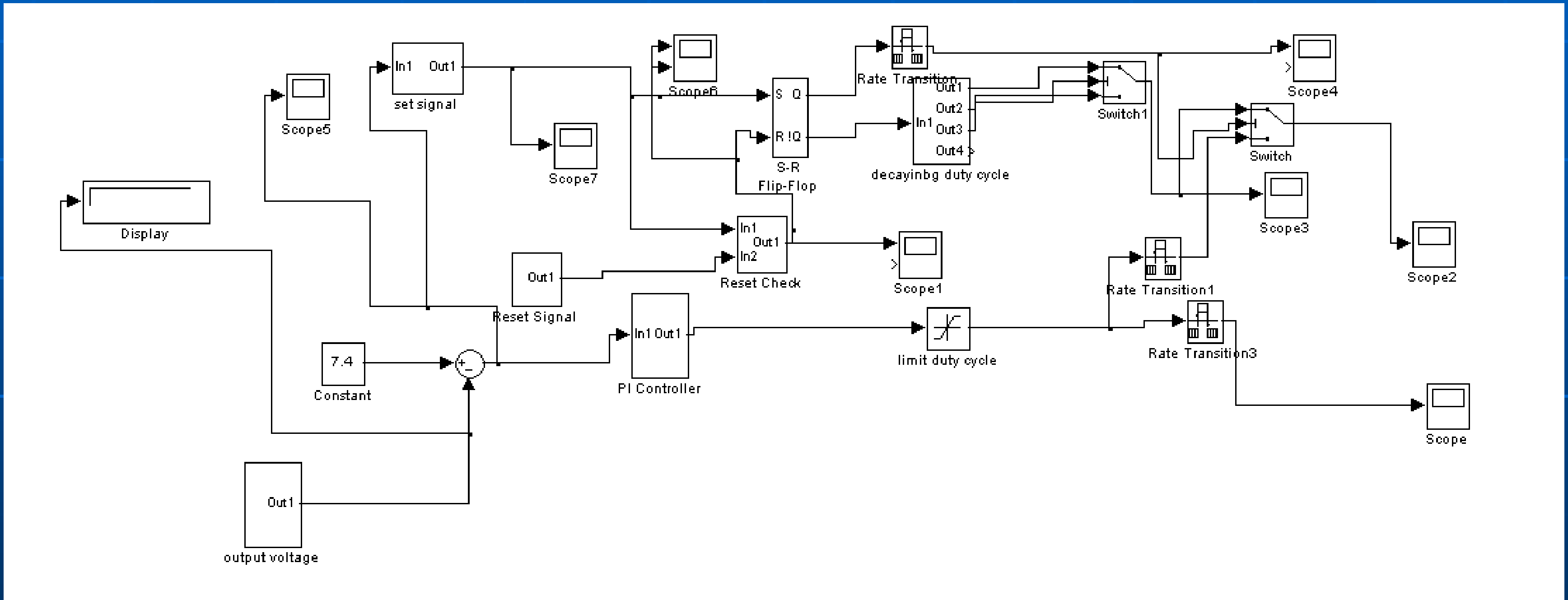
Charging


Voltage per cell
Charge current
Stage 1
Constant current
charge
Stage 2
Saturation
charge
Stage 3
Ready;
no current
Stage 4
Standby
mode
1.25
1.00
0.75
0.50
0.25
Current (A)
5
4
3
2
1
Voltage (V)
Terminate
charge when
current < 3% of
rated current
1
2
3
Time (h)
Stage 1
Voltage rises at
constant current
Stage 2
Voltage peaks,
current decreases
Stage 3
Charge
terminates
Stage 4
Occasional
topping charge

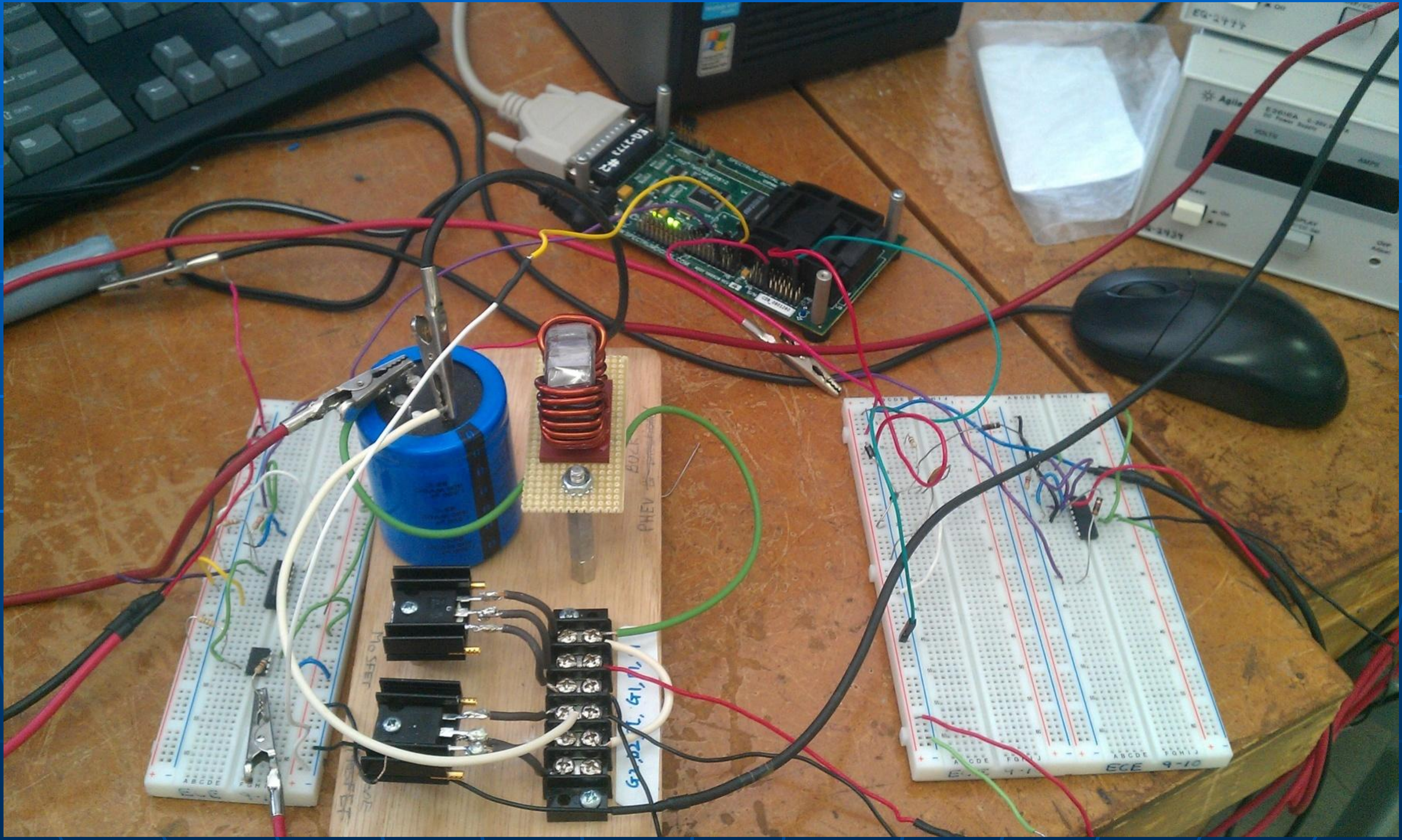
Flow Chart with buck



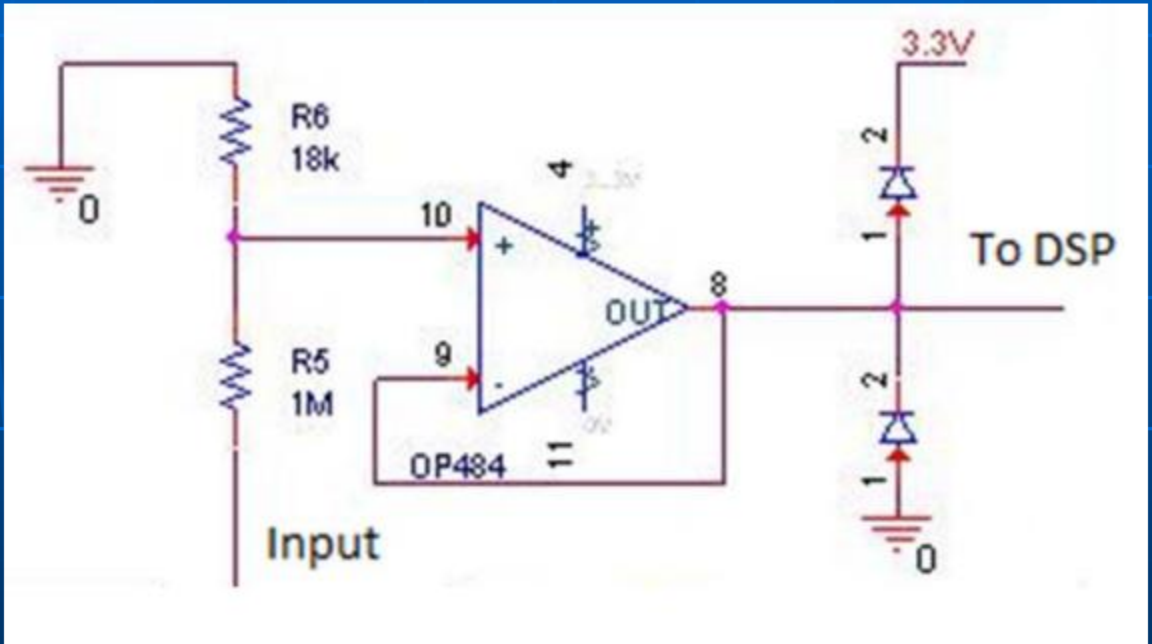
Simulink Model



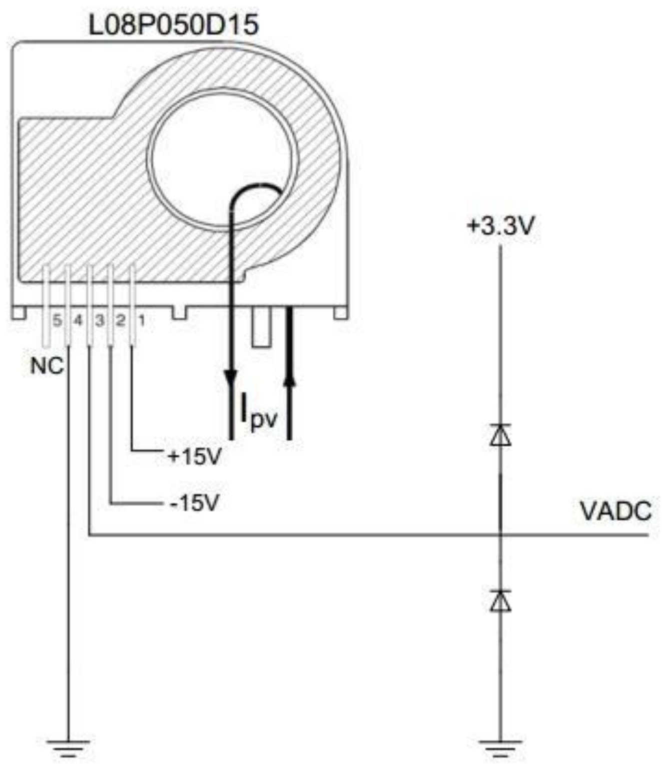
Full Buck System



Designing the Voltage Sensing Circuit



Current Sensor



DSP Board Specs

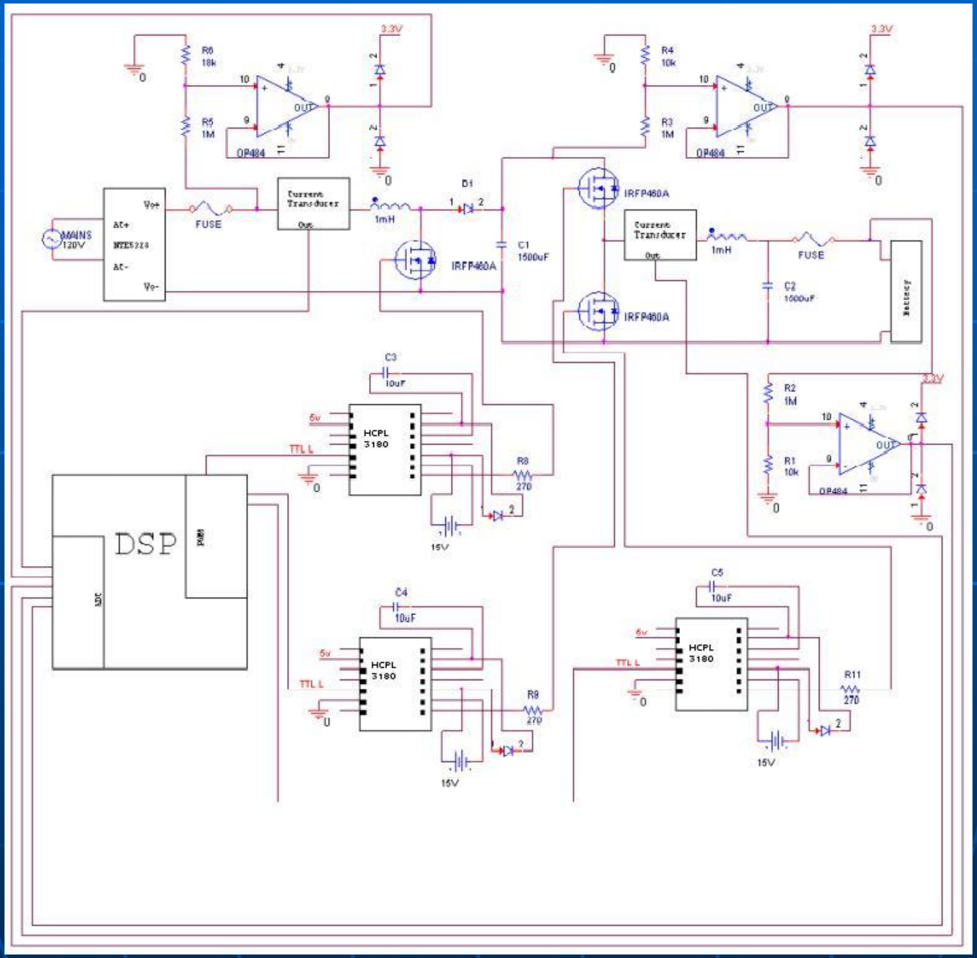
The control algorithm is implemented by a Texas Instruments TMS320F2812 32-bit fixed-point DSP. It has the following features:

- high-performance static CMOS technology, 150 MHz (6.67-ns cycle time);
- high-performance 32-bit CPU;
- Flash devices: up to 128 K × 16 Flash;
- 12-bit ADC, 16 channels.

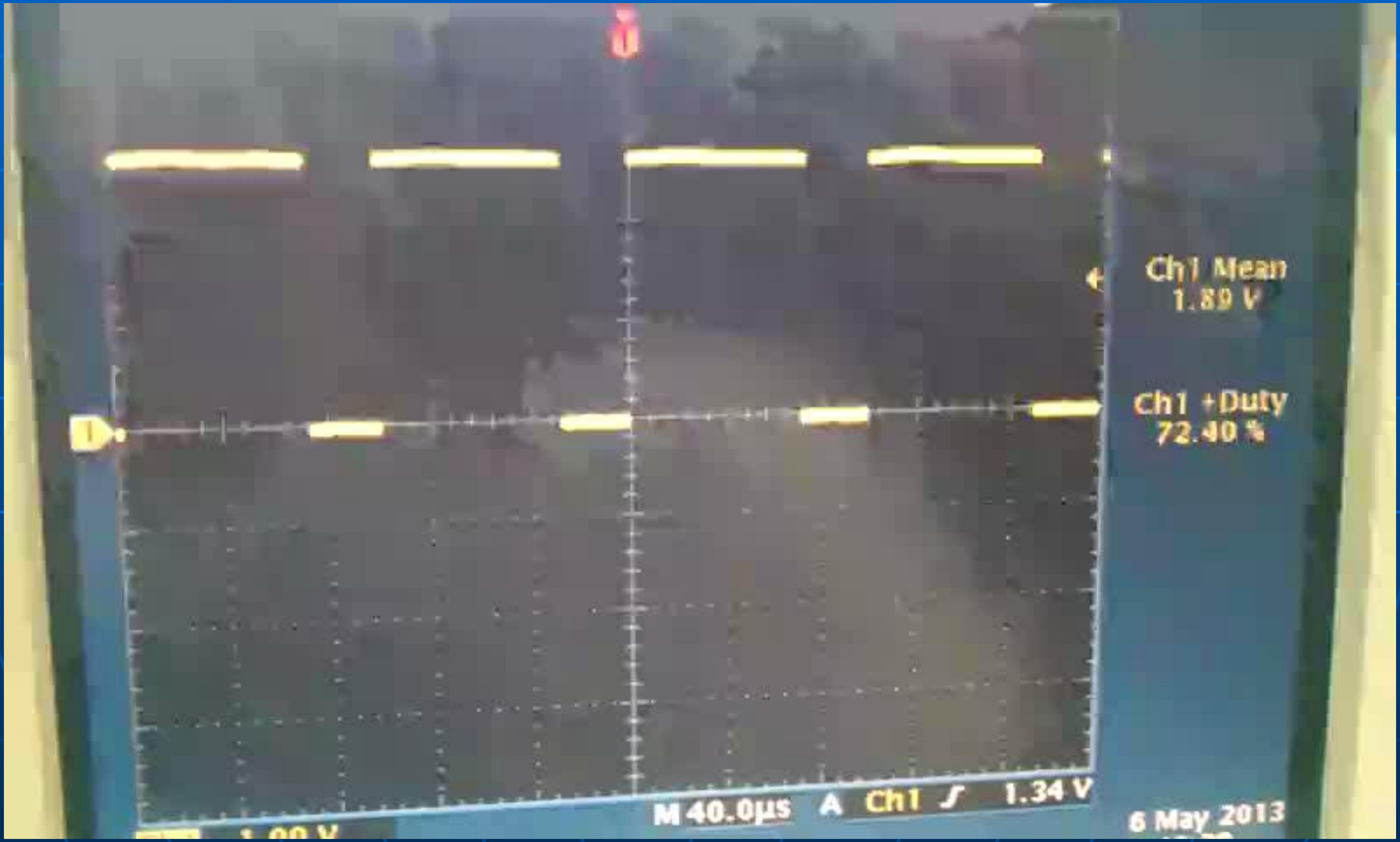
Why use DSP?

- Fast, reliable, and Ideal for controlling
- Generates a pulse width modulated signal
- Voltage values are calculated by DSP algorithms

Overall System Design



Results



Completed Work

- Battery Testing
- Bi-directional and PFC Redesigned
- Buck Charging model

Future Work

- PCB Designing
- Discharge the battery through an inverter to run a variable load
- Build a protective structure for the battery

References

- [1] N. Mohan. First Course on Power Electronics. Minneapolis: MNPERE, 2009.
- [2] Daly, et. Al. “Electric Vehicle Charger for Plug-In Hybrid Electric Vehicles.” PHEV: Plug-in Hybrid Electric Vehicle Charger. 26 Sept. 2011. Web, 24 Sept. 2012.
- [3] B. Bagci. “Programming and use of TMS320F2812 DSP to control and regulate power electronic converters.” Master Thesis, Fachochschule Koln University of Applied Sciences, Cologne, Germany, 2003.
- [4] G. Mathieu, “Design of an on-board charger for plug-in hybrid electrical vehicle (PHEV), “Master Thesis, Chalmers University of Technology, Goteborg, Sweden, 2009.
- [5] L. Zhou, “Evaluation and DSP based implementation of PWM approaches for single-phased DC-AC converters,” Master Thesis, Florida State University, Tallahassee, Florida, United States 2005.
- [6] M. Hedlund, “Design and construction of a bidirectional DCDC converter for an EV application,” Master Thesis, Uppsala University, Uppsala, Sweden, 2010.
- [7] Y. Tian, “Analysis, simulation and DSP based implementation of asymmetric three-level single phase inverter in solar power system,” Master Thesis, Florida State University, Tallahassee, Florida, United States, 2007.
- [8] Application Note AN-978, http://www.irf.com/technical-info/appnotes/an-978.pdf
- [9] http://www.nrel.gov/vehiclesandfuels/energystorage/pdfs/evs17paper2.pdf
- [10] M. Chen, “Accurate Electrical Battery Model Capable of Predicting Runtime and I-V Performance, “ IEEE Transaction, Vol. 21, No. 2, June 2006.

Questions?