University of Illinois ECE445: Senior Design Laboratory

DC-DC Converter for EWB Wind Turbine Project

Group 3
Jeong-Ah Lee
Chris Livesay
Qing Janet Wang

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Introduction

- DC-DC converter that connects a wind turbine output ranging from 40 – 70 V to charge 12 V lead-acid batteries.
- Will be used to improve a village's access to electricity from wind sources in India.

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Benefits

- Impact on Education
- Impact on Health
- Other Electronic Equipments

Product Features

- Reliable and Low Cost
- Simple operation
- Provides power from previously unused energy
- High impact and large availability

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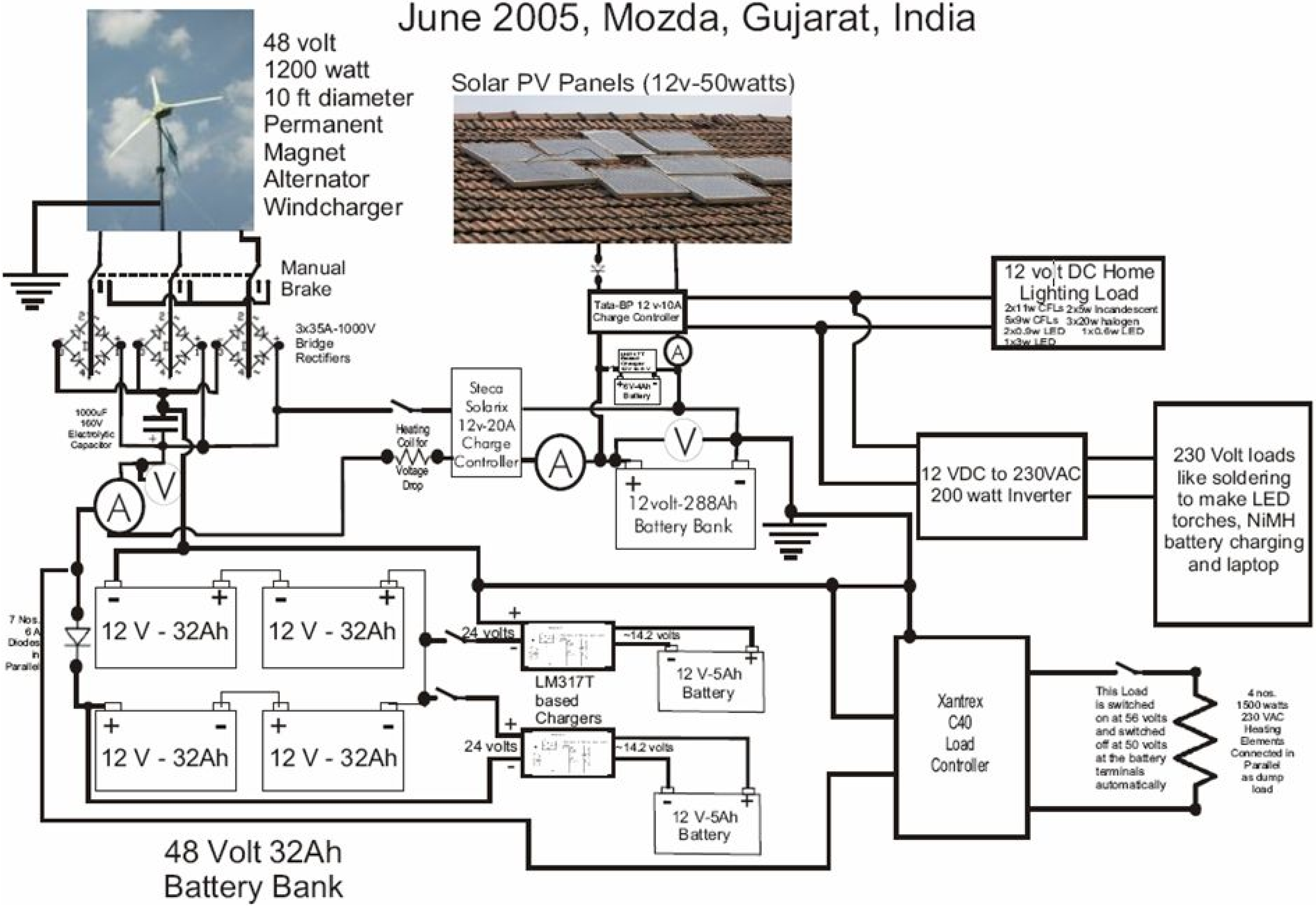
Performance Requirements

- Output is user-adjustable between 12V and 15V at 10A, regulated
- Does not create radio frequency interference
- Does not drain battery when wind generator is not producing power
- Input and output protection:
  - Input over-voltage protection
  - Input and output overload protection
  - Input and output short circuit protection
  - Input and output reverse polarity protection

Wiring Schematic for Mozda Collective Windmill and Photovoltaic System
June 2005, Mozda, Gujarat, India



Mozda H.A.W.T. Wind Turbine

- 48 V, 1200 VA, star connected three phase ac generator [12 pole rotor, 9 coil stator]
- Maximum output voltage is around 65 V
- May exceed 125 V in case of failure (wire breakage, generator disconnection, etc.)
- Windmill Clip

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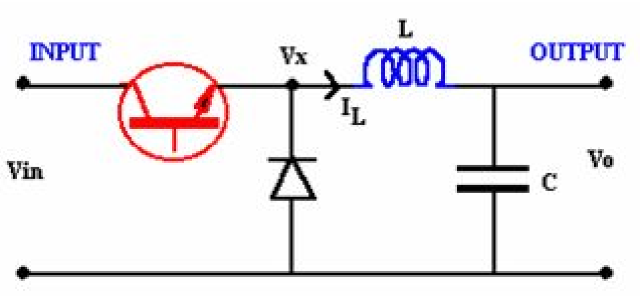
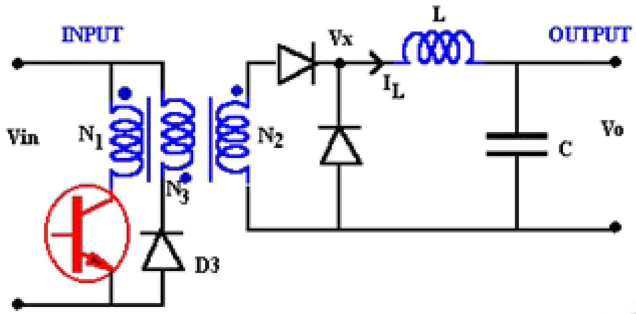
Design Overview

- PWM Controller
  - To drive the converter MOSFET
- DC-DC Buck Converter
  - Input: 35 V – 85 V dc
  - Output: 12 V – 15 V dc
- Input and Output Protection
- Efficiency
  - Desire 85% efficiency

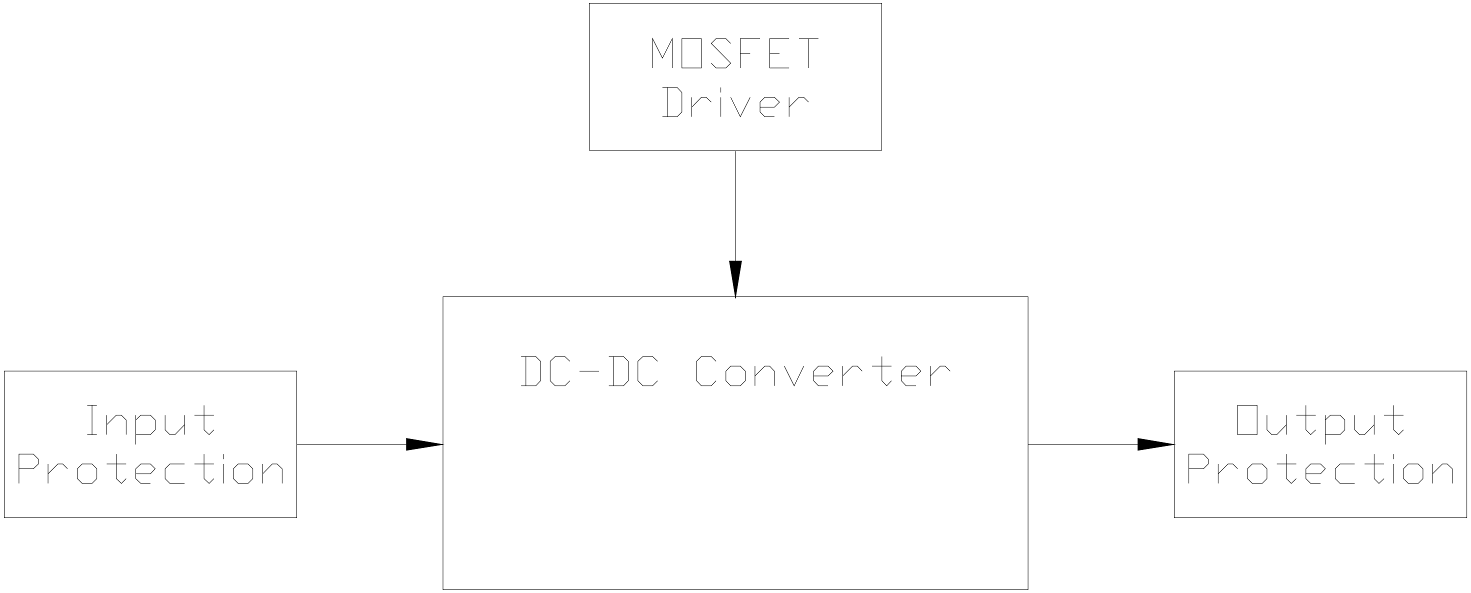
Buck vs. Flyback Converter

- Buck Converter:
  - Low cost
  - Least number of components
  - Poor load regulation
- Flyback Converter:
  - Low output ripple and noise
  - More reliable compared to buck converter, but more components





Block Diagram



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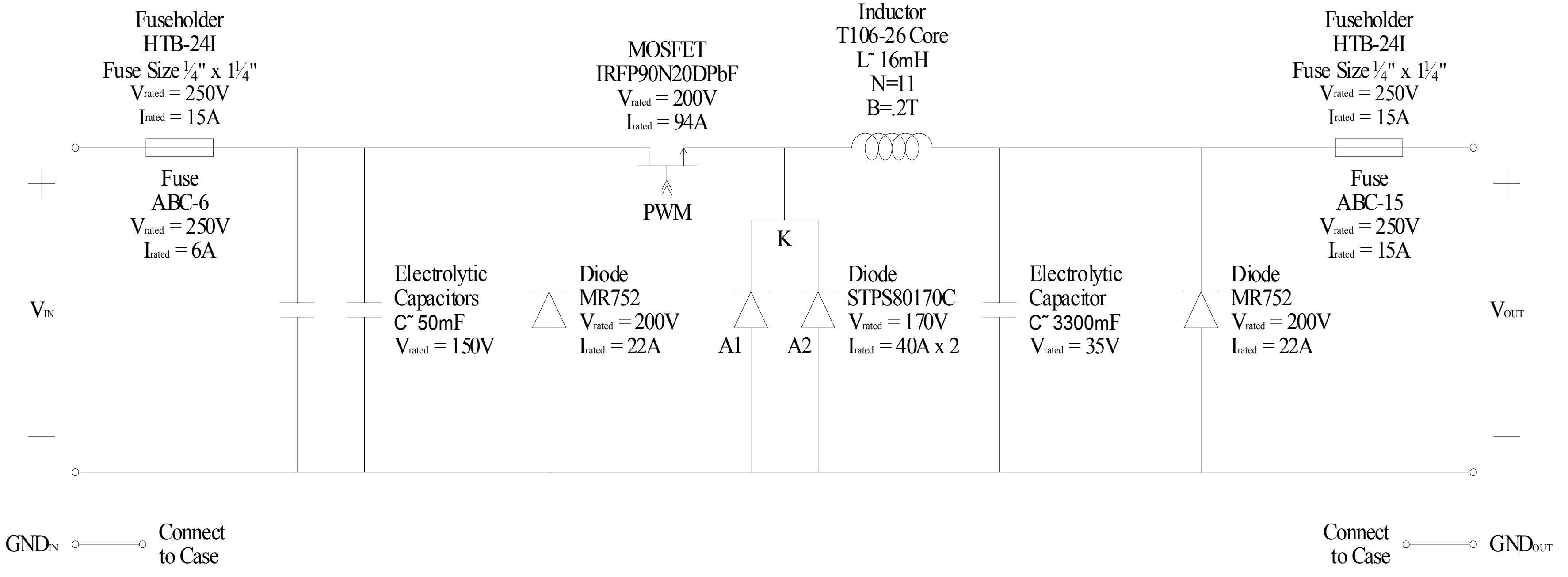
Buck Converter



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Buck Converter Components

MOSFET

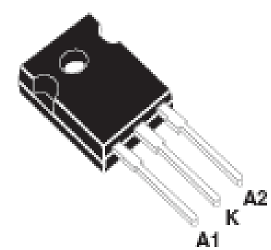
- On-resistance must be low to reduce I^2R loss
- Logic-level gate drive

IRFP90N20D
TO-247AC

V_{DSS}	$R_{DS(on)}$ max	I_D
200V	0.023Ω	94A⑥

Diode

- Must be a Schottky diode (quick on/off time)
- Low forward voltage drop



TO-247
STPS80170CW

$I_{F(AV)}$	2 x 40 A
V_{RRM}	170 V
T_j	175 °C
V_F(max)	0.74 V

Inductor Design

When selecting an inductor for a Buck converter, as with all switching regulators, you will need to define or calculate the following parameters:

- Maximum input voltage = 85V
- Output voltage = 15V
- Designed switching frequency = 100 kHz
- Maximum ripple current

$$L_{CRIT} = \frac{R_{OUT} * T}{2}(1 - D)$$

$$L_{CRIT} = \frac{R_{OUT}}{2 * f}(1 - D)$$

$$L_{CRIT} = \frac{1.5}{2 * 100000}(1 - .141)$$

$$L_{CRIT} = 6.443\mu F$$

$$\boxed{L = 10\mu F}$$

$$D = \frac{V_{OUT}}{V_{IN}}$$

$$\frac{12}{85} < D < \frac{15}{35}$$

$$\boxed{.141 < D < .429}$$

$$B_{max} = \frac{\mu * N * I_{OUT}}{l}$$

$$B_{max} = \frac{75 * \mu_o * 11 * 10}{.0649}$$

$$\boxed{B_{max} = .160T}$$

$$N = \sqrt{\frac{L * l}{\mu * A}}$$

$$N = \sqrt{\frac{10 * 10^{-6} * .0649}{75 * \mu_o * .000066}}$$

$$\boxed{N = 11}$$

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Output Filter Capacitor

- Limits the output voltage ripple
- Equivalent Series Resistance (ESR) should be kept low to reduce I^2R loss
- Aluminum Electrolytic: Low cost and high capacitance in a small package
- Design target: $\Delta v = \pm 0.5\%$
- Calculation:

$$C = I_{OUT} * \frac{D}{\Delta V * f_{SW}}$$

$$C = \frac{.429}{.01 * 1.5 * 100000}$$

$$\boxed{C > 286 \mu F}$$

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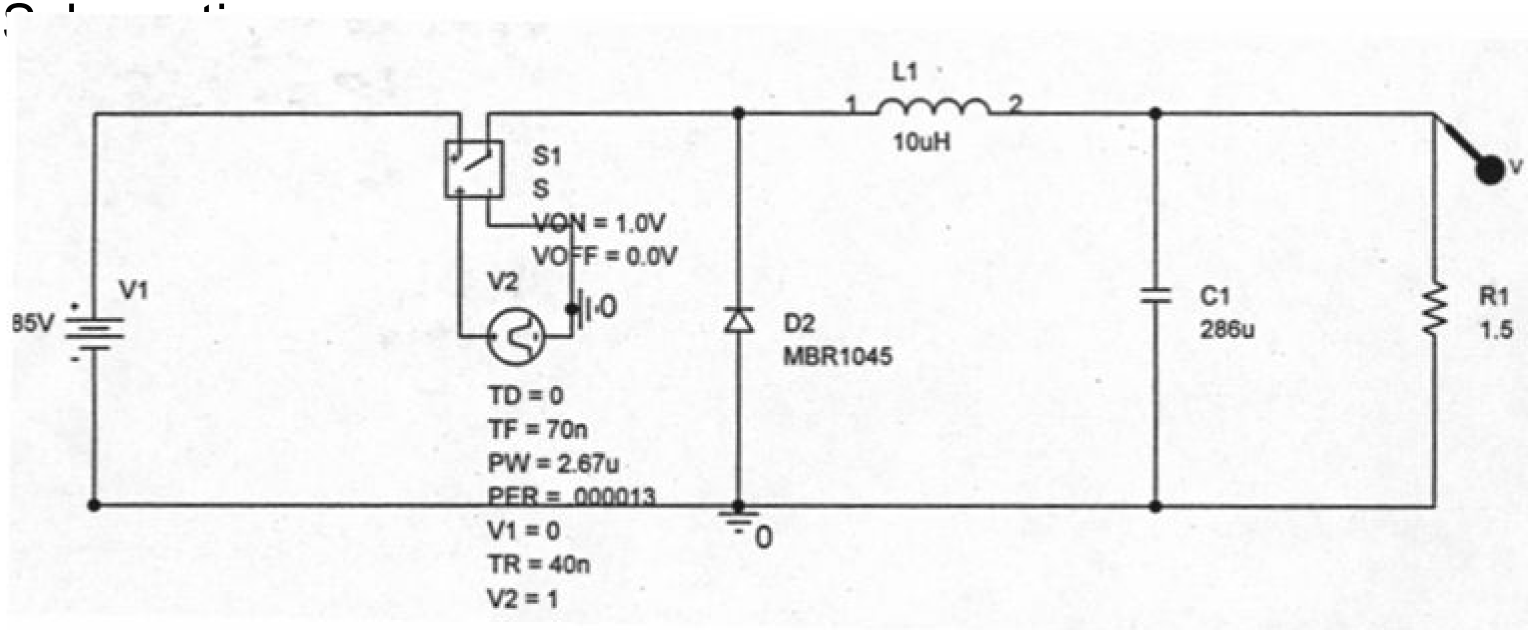
Simulation & Waveforms

- In order to verify the overall design PSPICE was used to simulate the Buck Converter with a switch acting as the MOSFET driver
- Schematic



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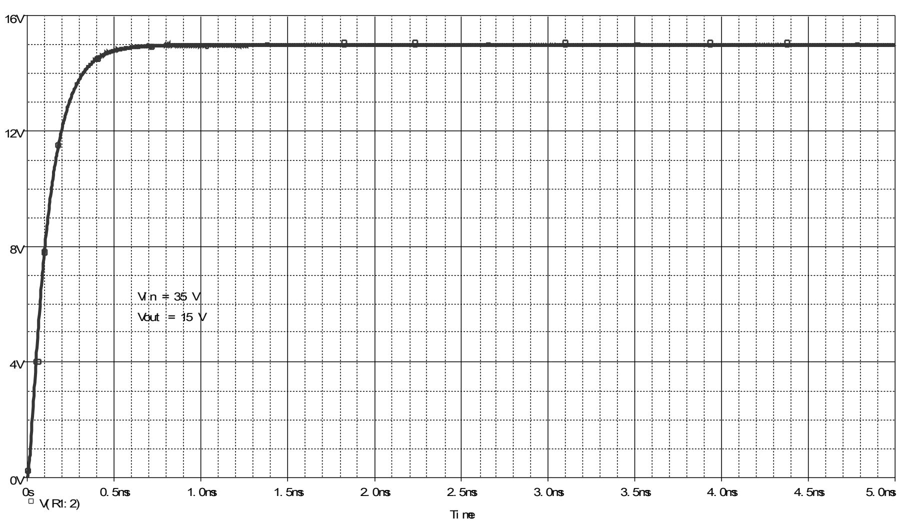
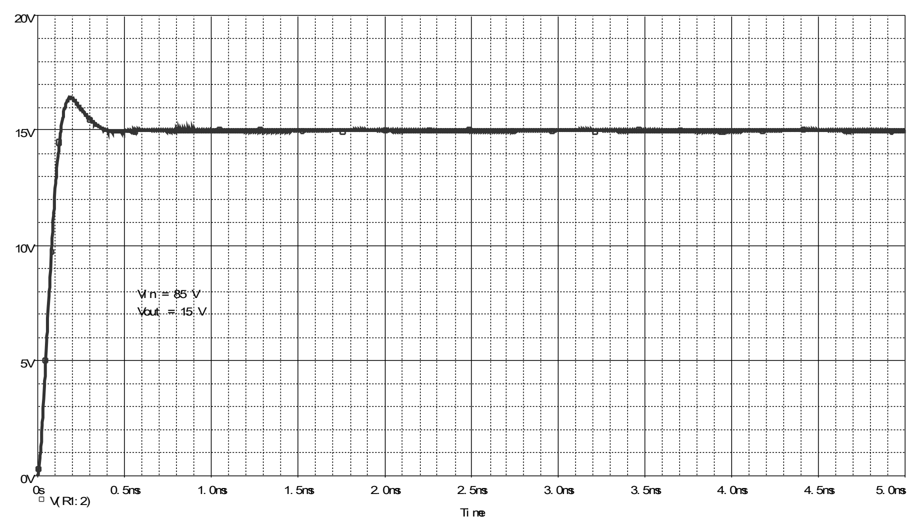
Simulation & Waveforms

- The duty ratio was adjusted accordingly to achieve the desired output voltage.

Vin = 35 V; Vout = 15 V; D=0.612



Vin = 85 V; Vout = 15 V; D=0.205



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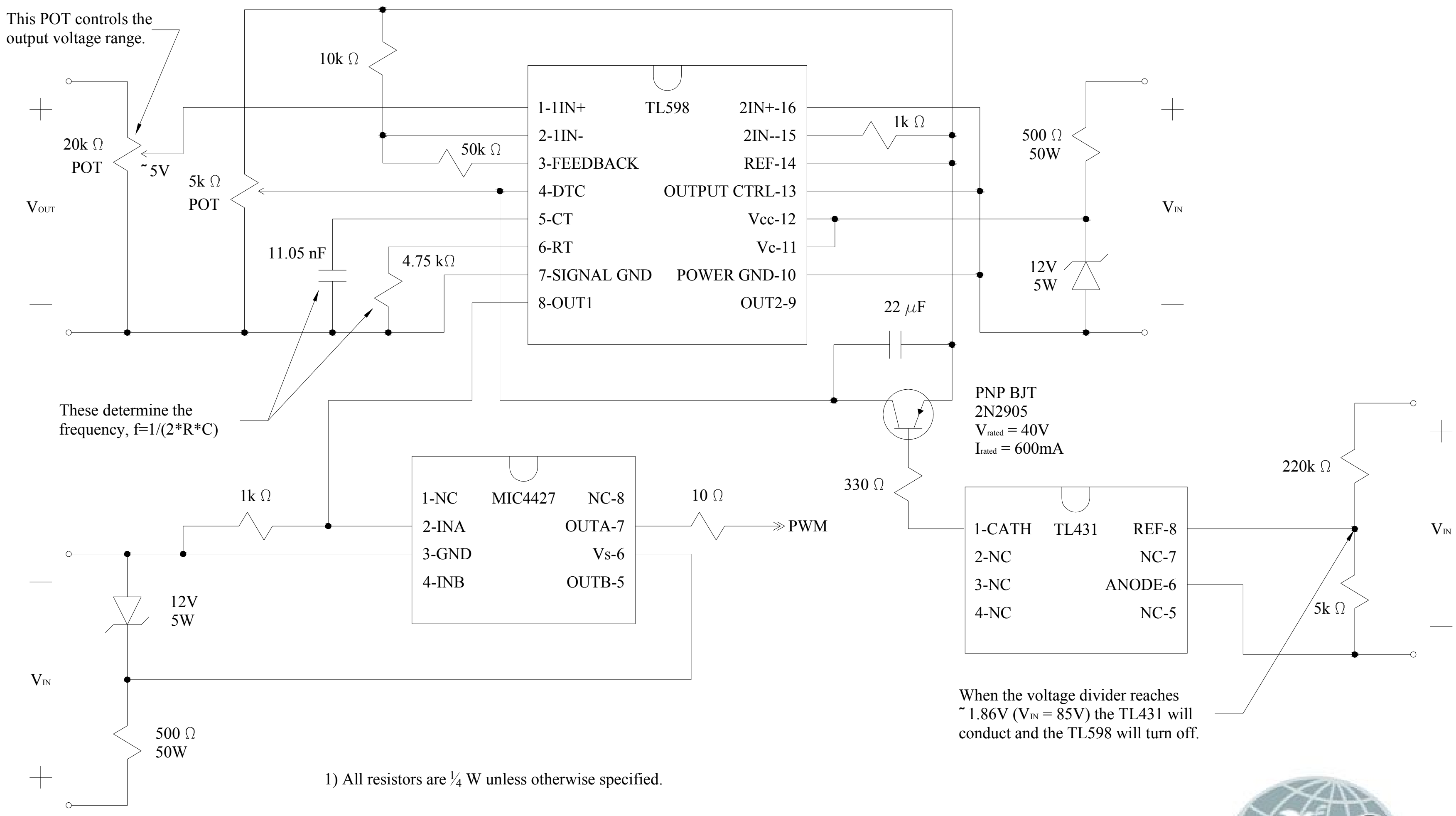
PWM Control Circuit



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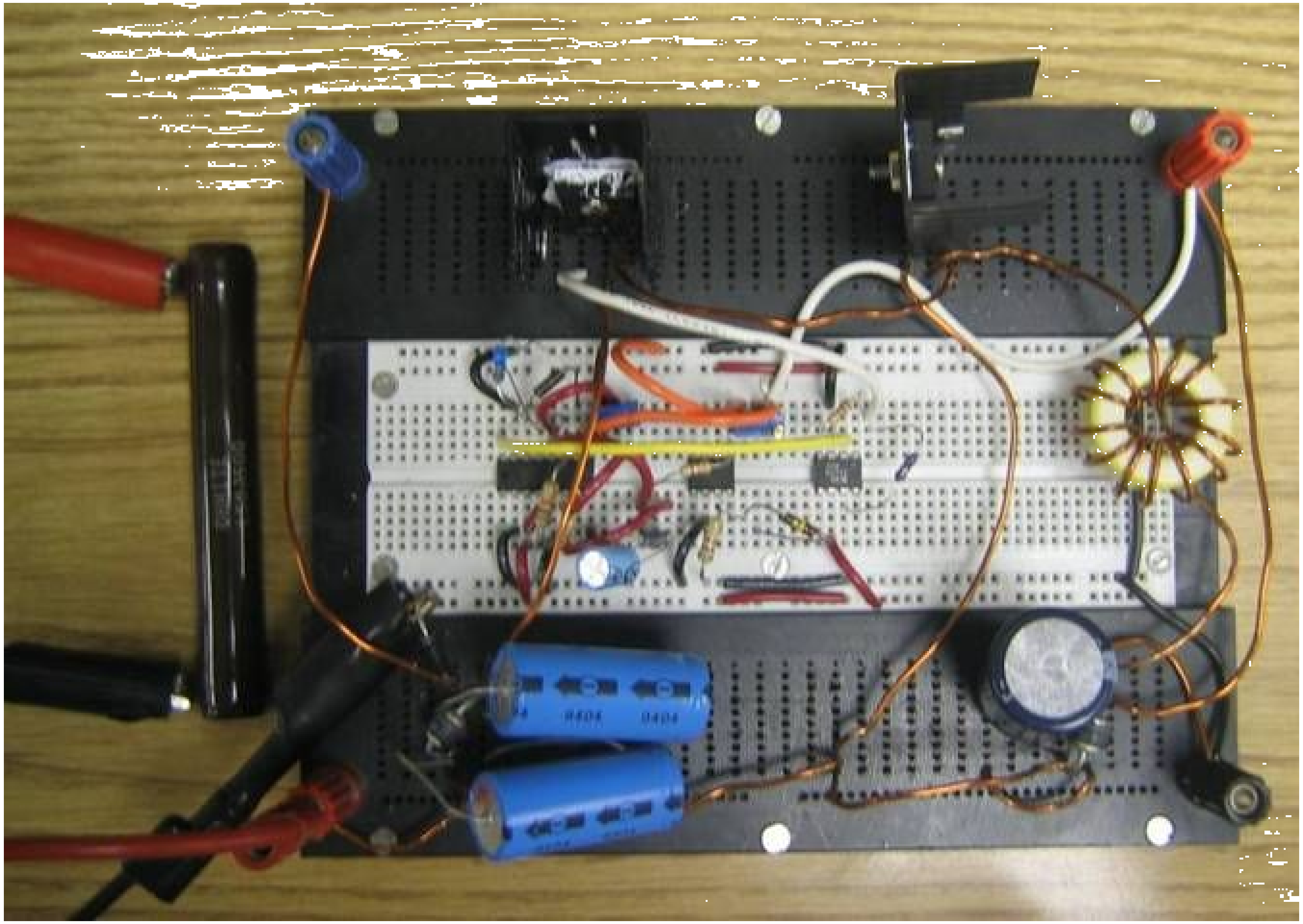
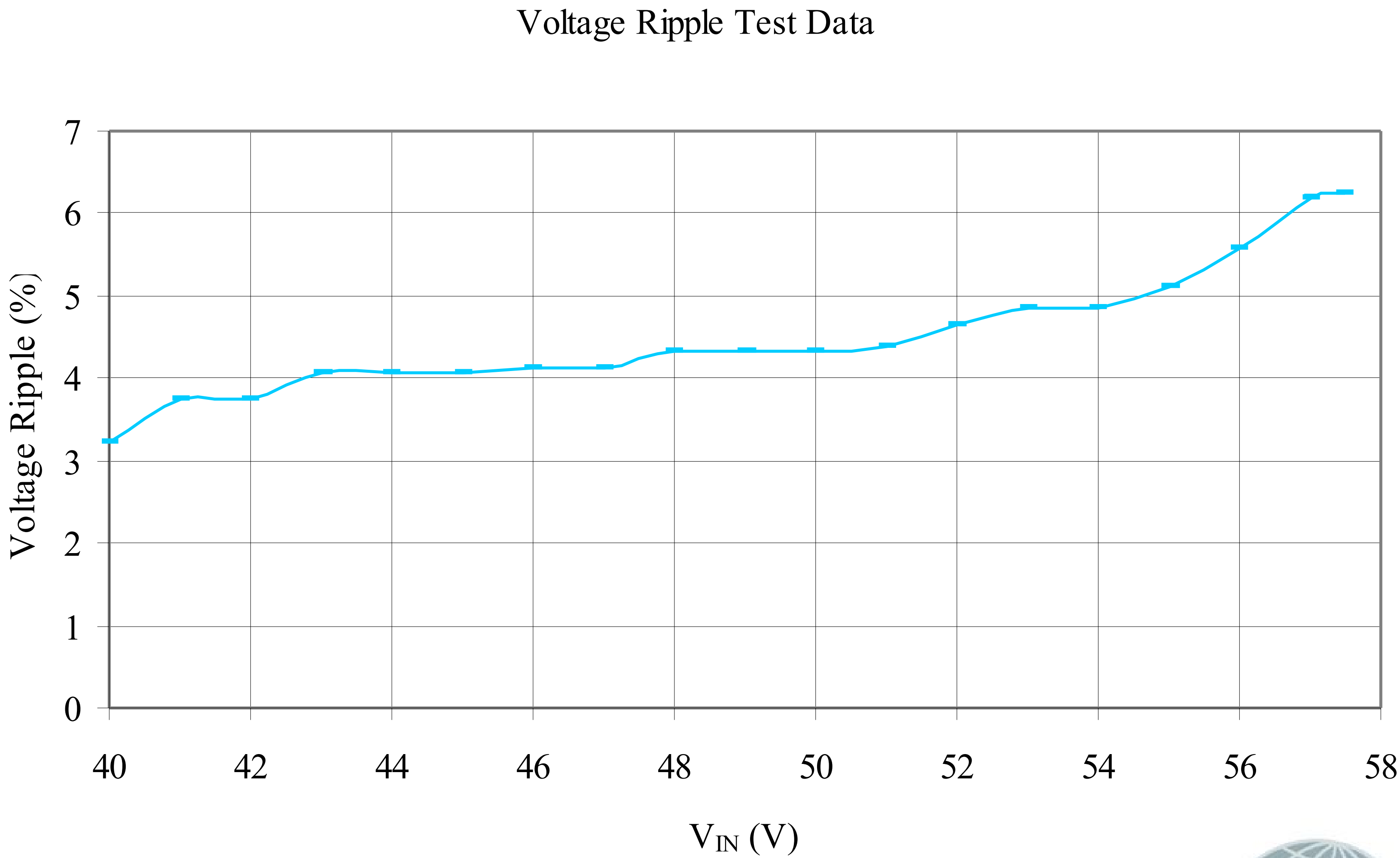
The DC-DC Converter

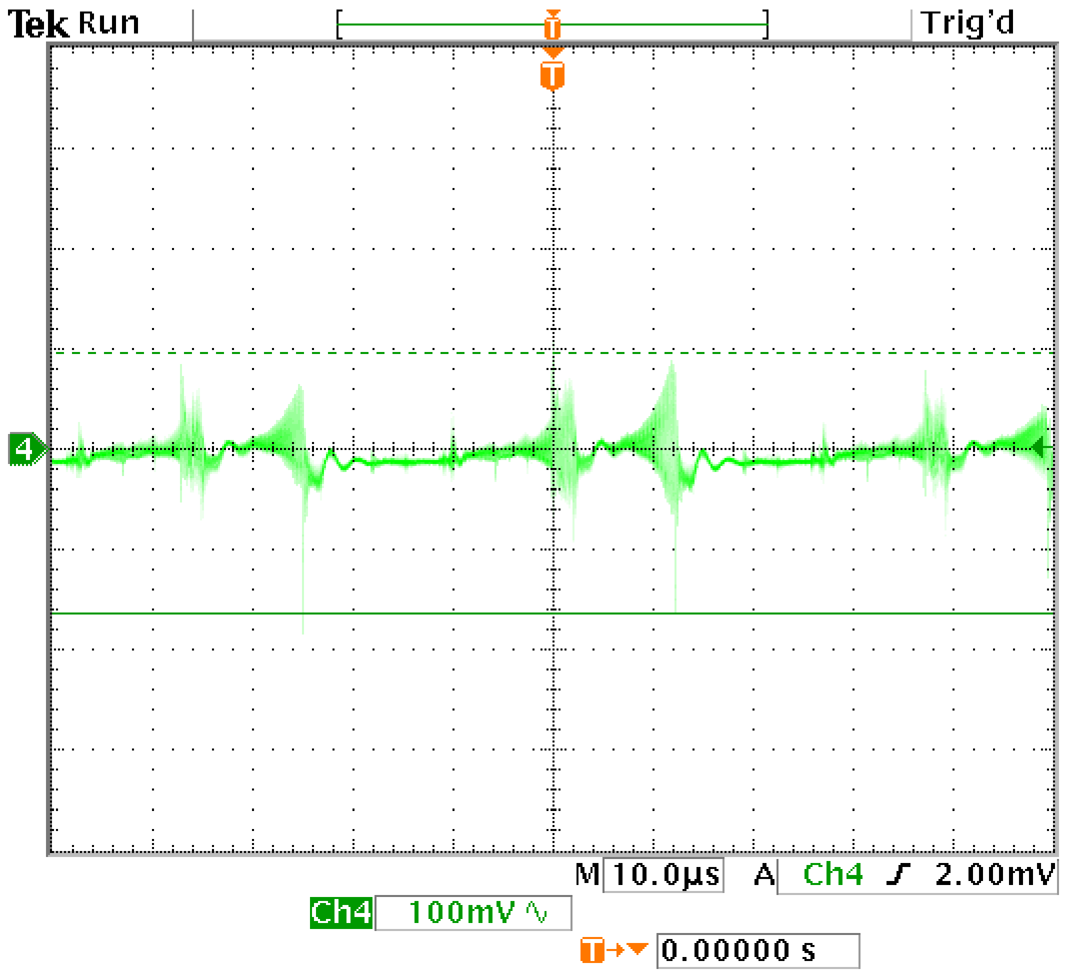


Testing – Output Voltage Ripple



Testing – Output Voltage Ripple

- Vin = 48 V



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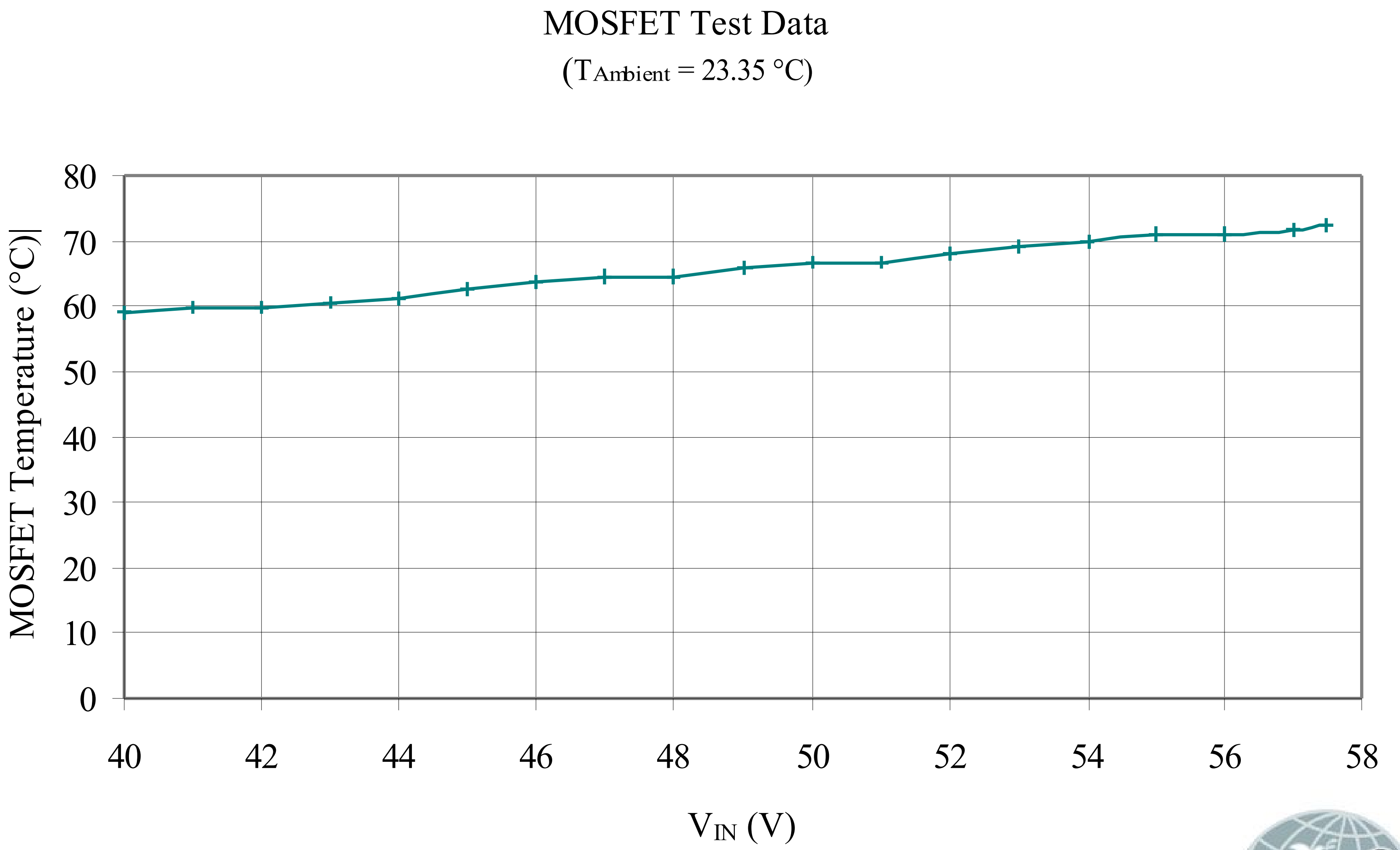
Testing - Temperature



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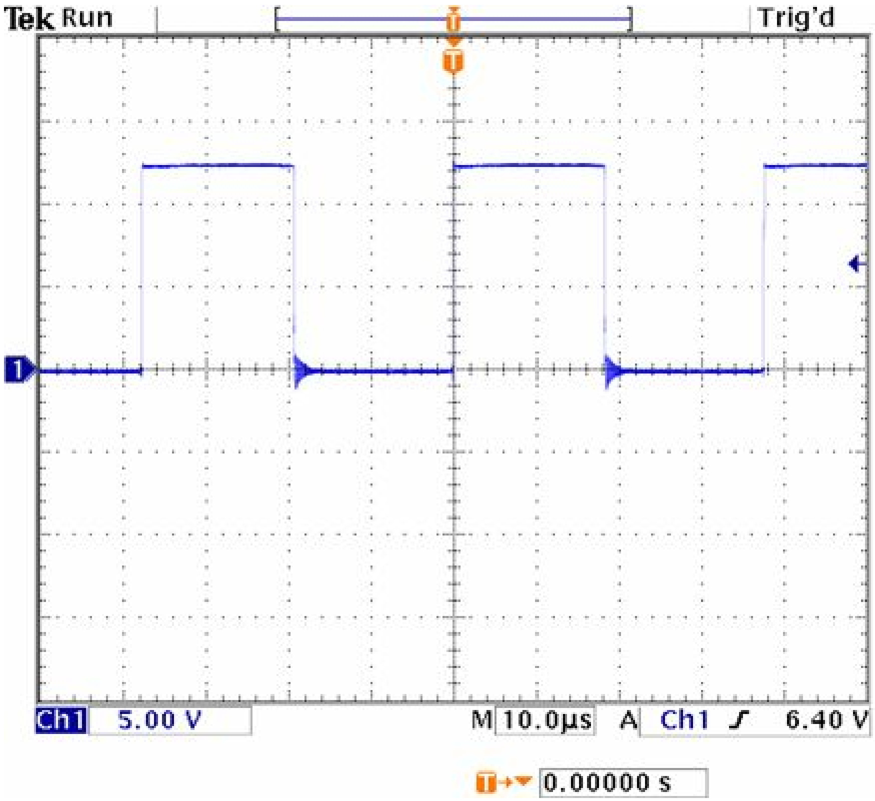
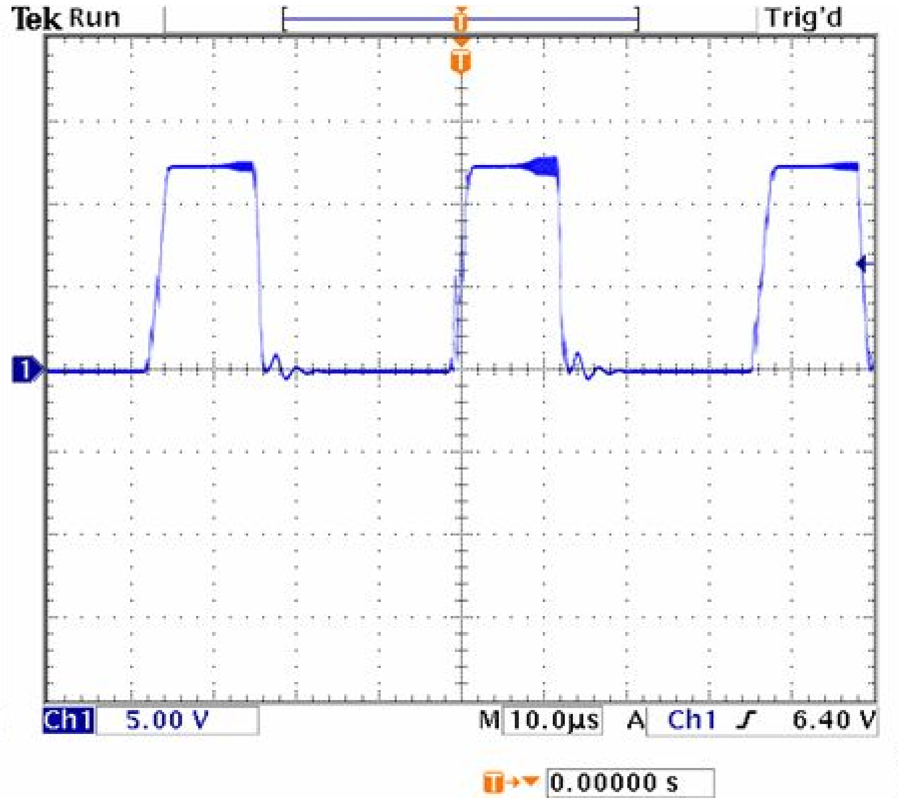
MOSFET Gate Signal





When not connected to MOSFET
Vin = 48 V

When connected to MOSFET
Vin = 48 V

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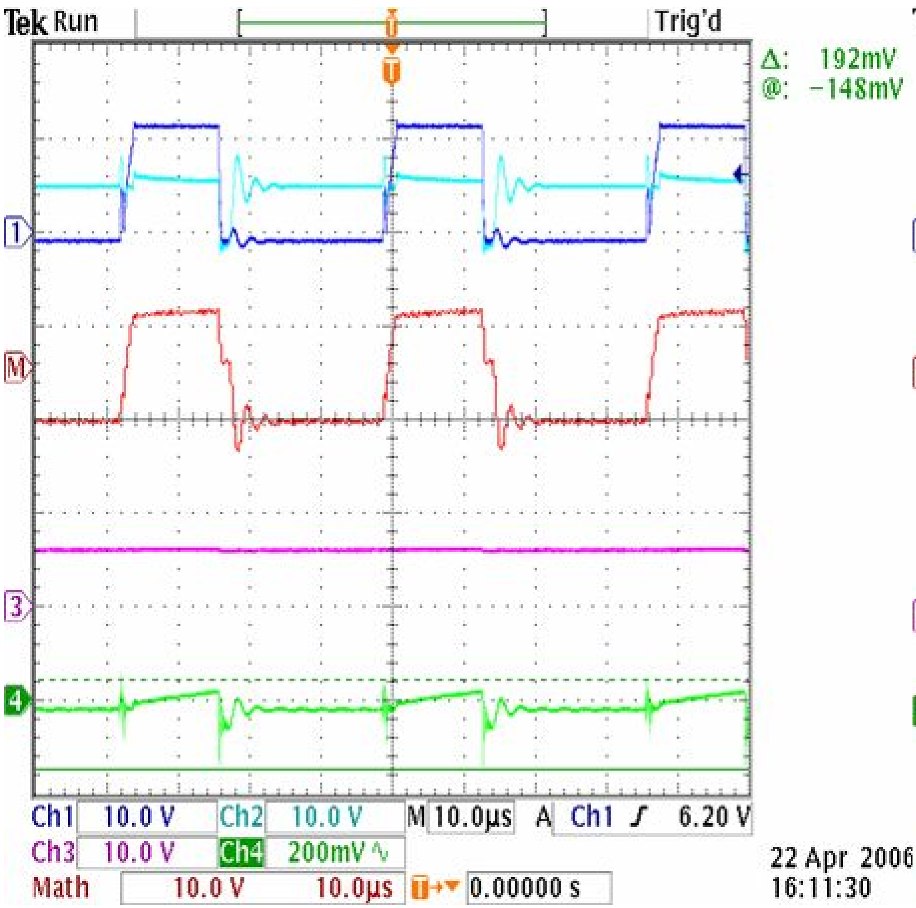
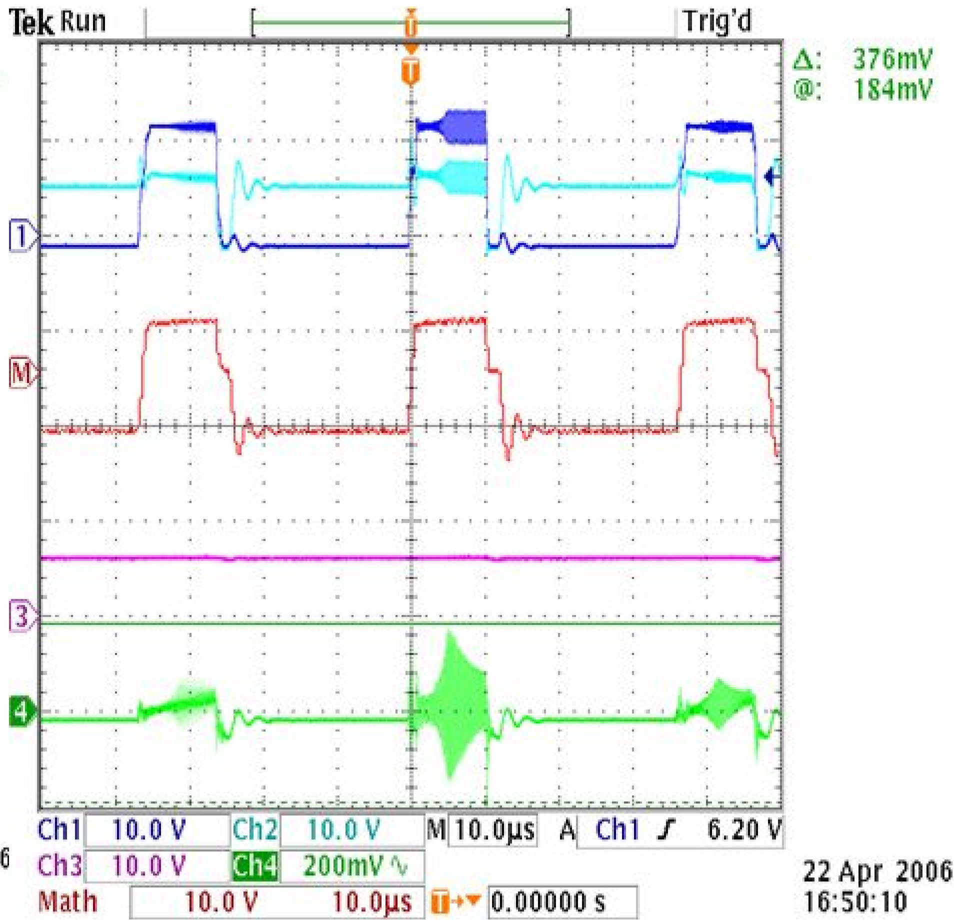
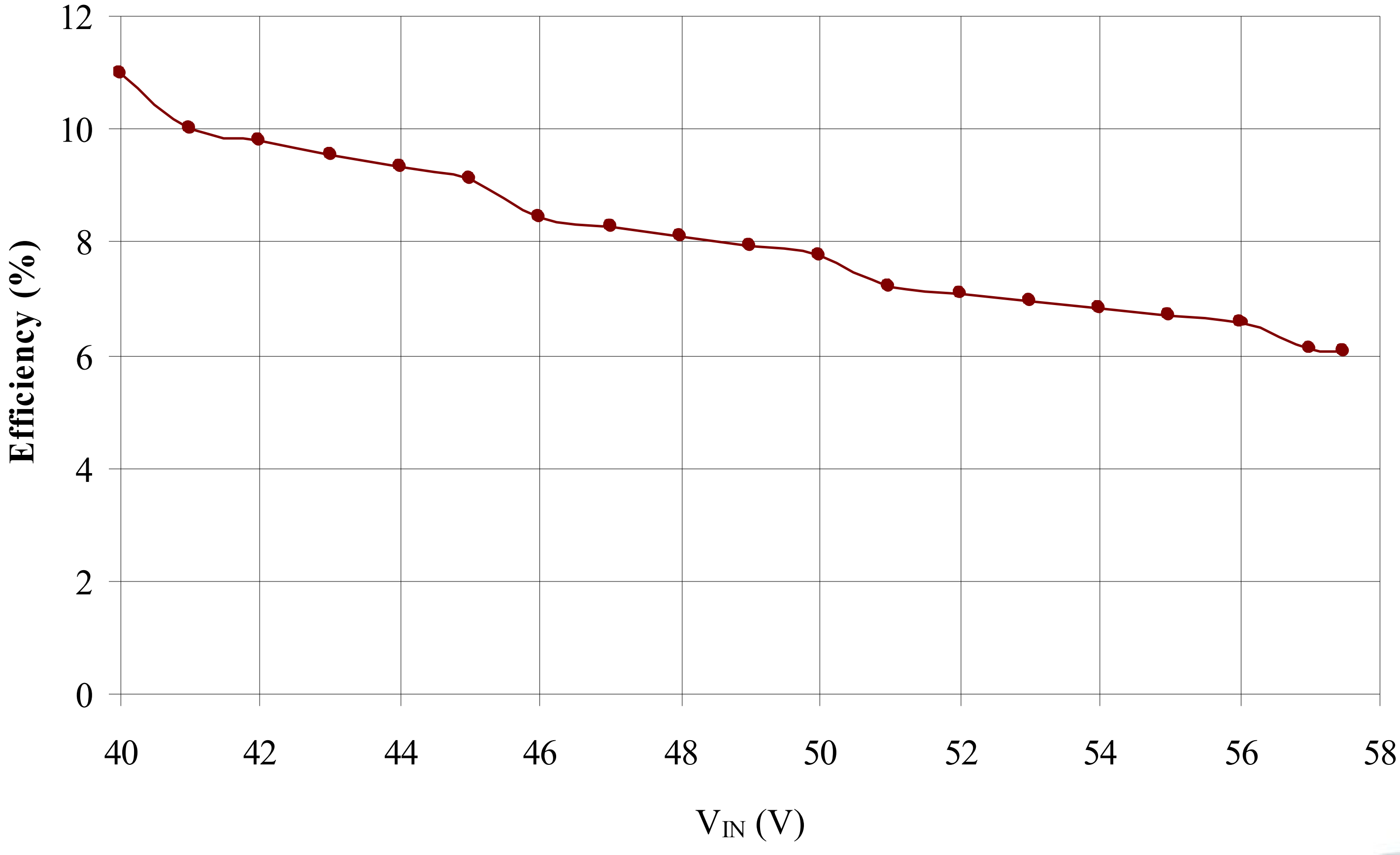
Results





Ch1: Gate Voltage
Ch2: Source Voltage
Math: Gate-Source Voltage
Ch3: Output Voltage
Ch4: Output Ripple Voltage

Efficiency vs. V_{IN}



Challenges

- MOSFET heating
- Low efficiency
  - Conduction Losses
    - MOSFET on-resistance
    - Voltage drop across diode
  - Control Circuit Power Consumption
  - Switching Losses

Successes & Summary

- Our converter works.
- But only at low power.
- We met input and output protection specifications.
- Obtained a maximum of 11% efficiency on bread board.
- Recommendations:
  - Research MOSFETs more.
  - Different control chips.

Credits

- Professor Jonathan W. Kimball
- Professor Patrick Chapman
- Professor P. Scott Carney
- Michael Mazgaonkar - EWB India, Gujarat
- Austin Kirchhoff

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Thank You