ECE ILLINOIS

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ECE 445 – Senior Design

Multi-Source, High-Power Converter

Spring, 2012

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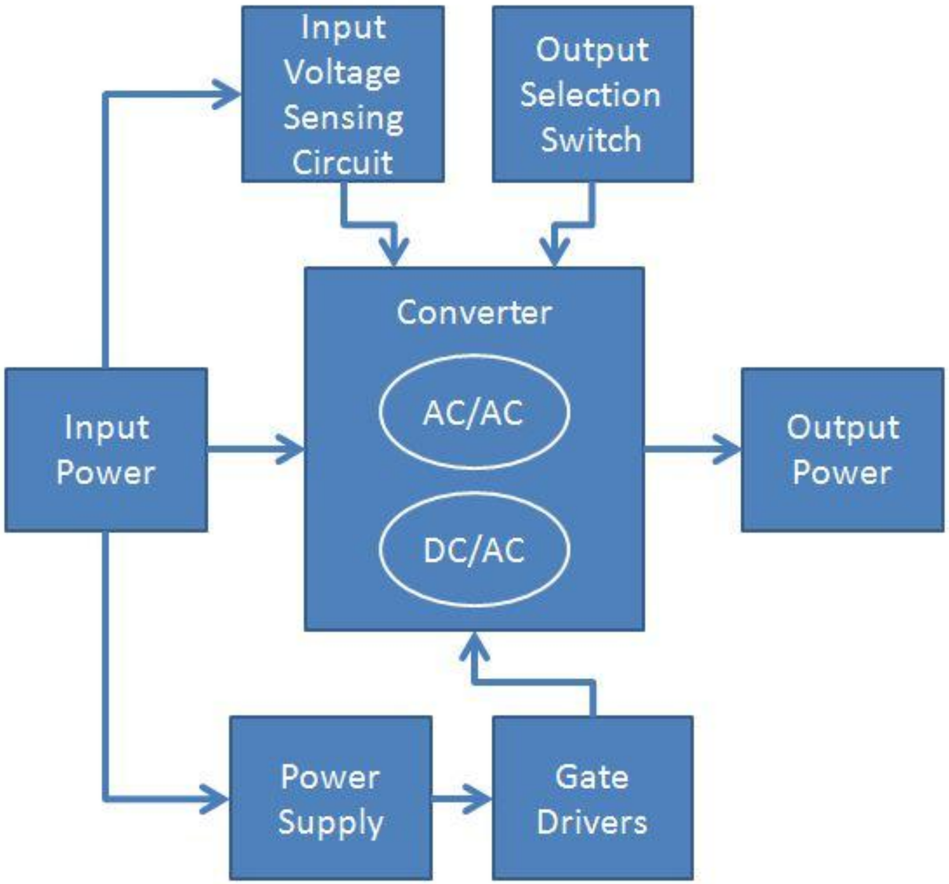
Introduction

- Idea:
  - Convert standard AC voltages (Europe and U.S.) back and forth
  - Convert running car battery DC voltage to either AC standard

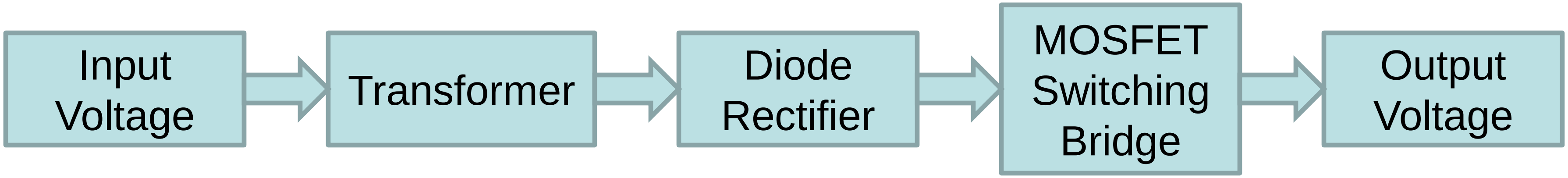
- Motivation:
  - Bridge gap between international AC voltages
  - Power critical items from running car battery during power outage
  - Supply high power to power tools or communication devices if car breaks down on the road

Overview

- Inputs:
  - 115Vac/60Hz
  - 230Vac/50Hz
  - 14Vdc
- Outputs:
  - 115Vac/60Hz
  - 230Vac/50Hz
- Maximum Power:
  - 1,000 W for DC-AC
  - 650 W for AC-AC

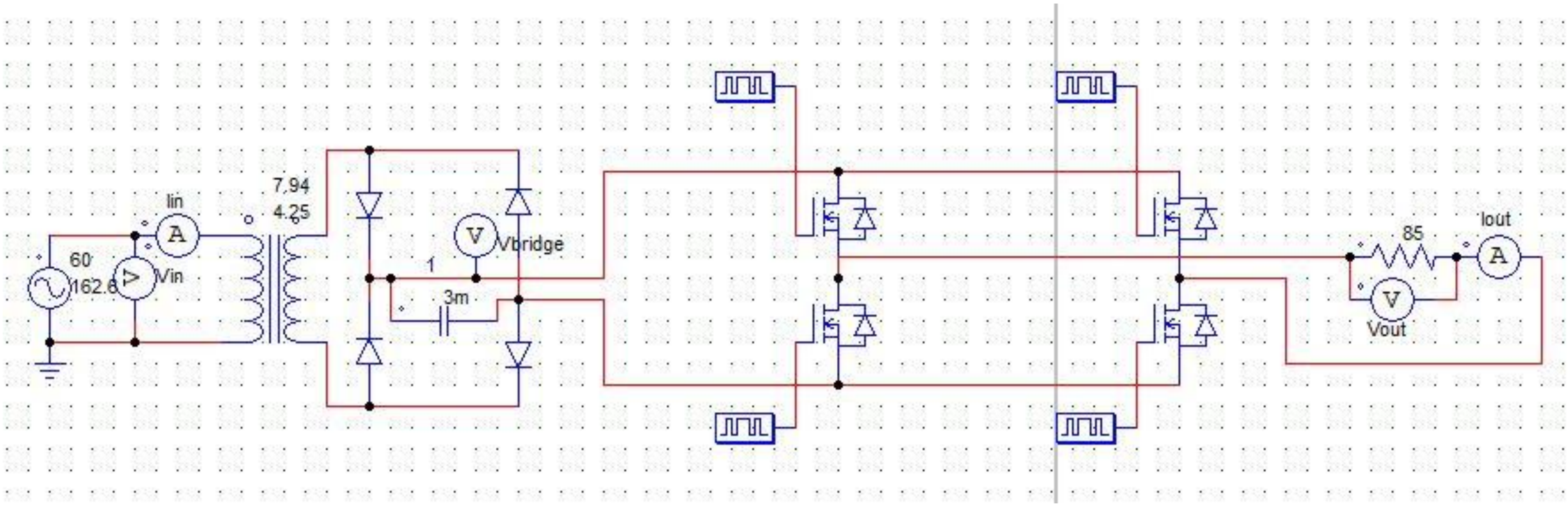


AC/AC Circuit: General Topology

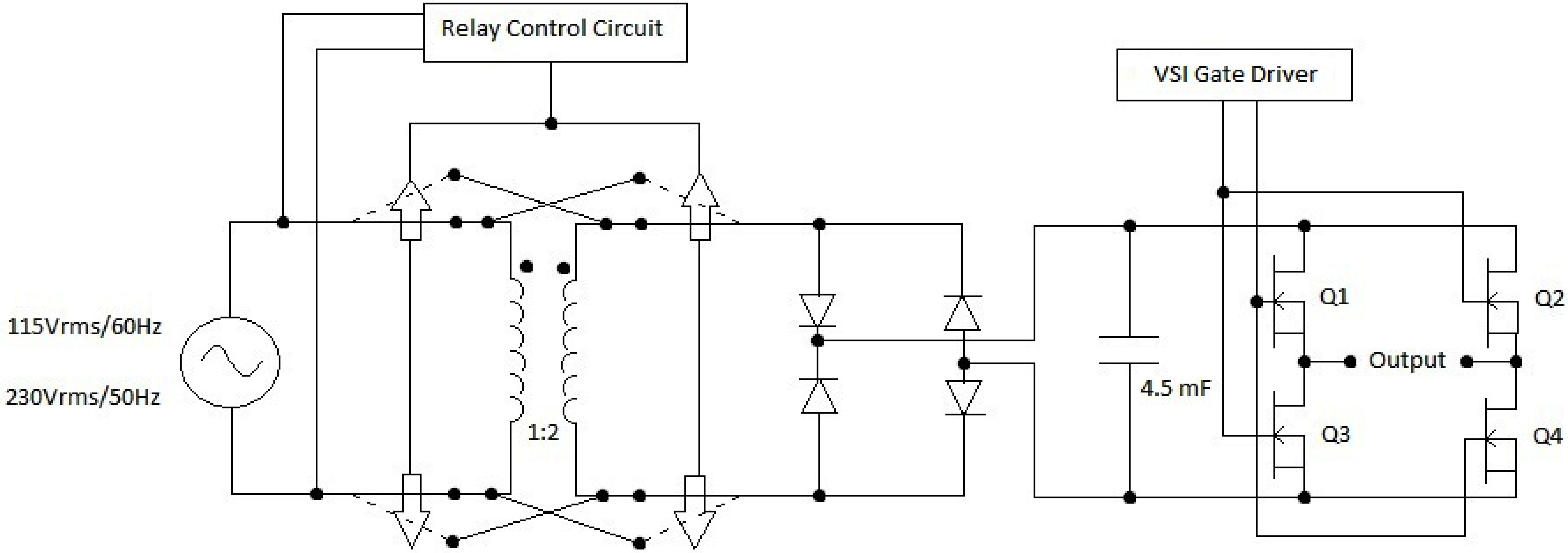


- AC input voltage is fed into 1:2 or 2:1 transformer
- AC signal is then rectified using a full wave diode bridge and a filtering capacitor
- Rectified DC voltage is then switched at the appropriate frequency (60Hz or 50Hz) using a MOSFET bridge
- A VSI wave is received at the output

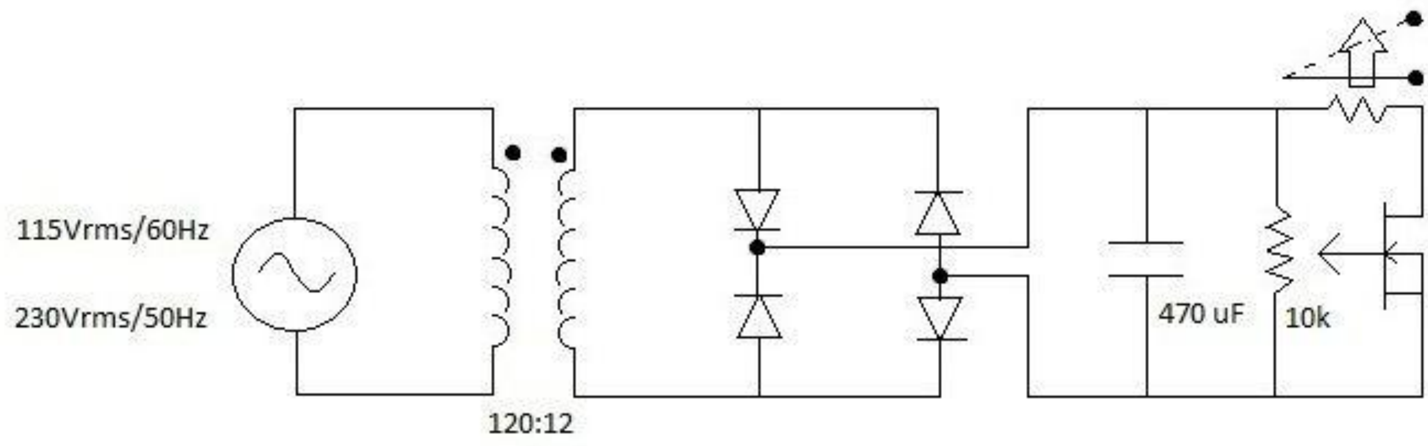
AC/AC Converter: Initial Design



AC/AC Converter: Actual Implementation

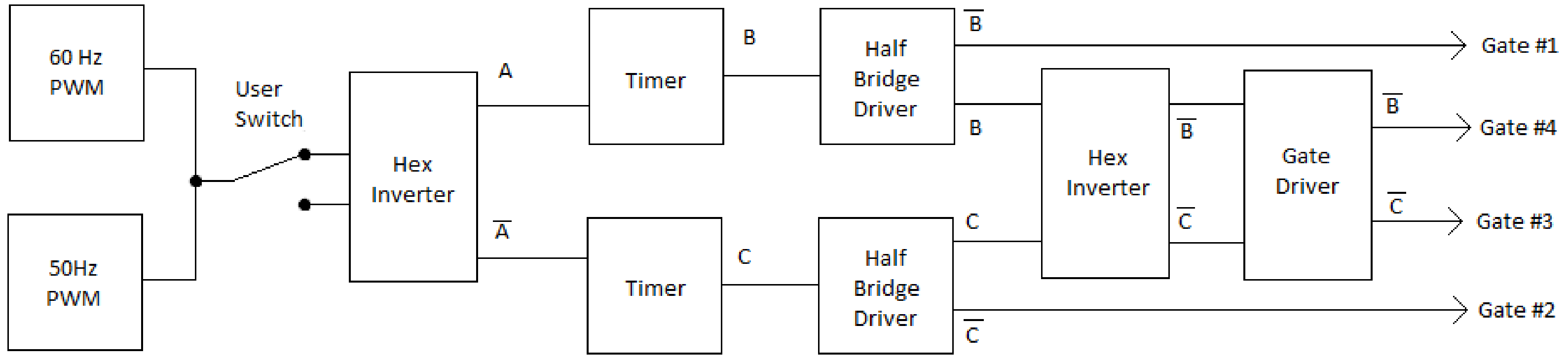


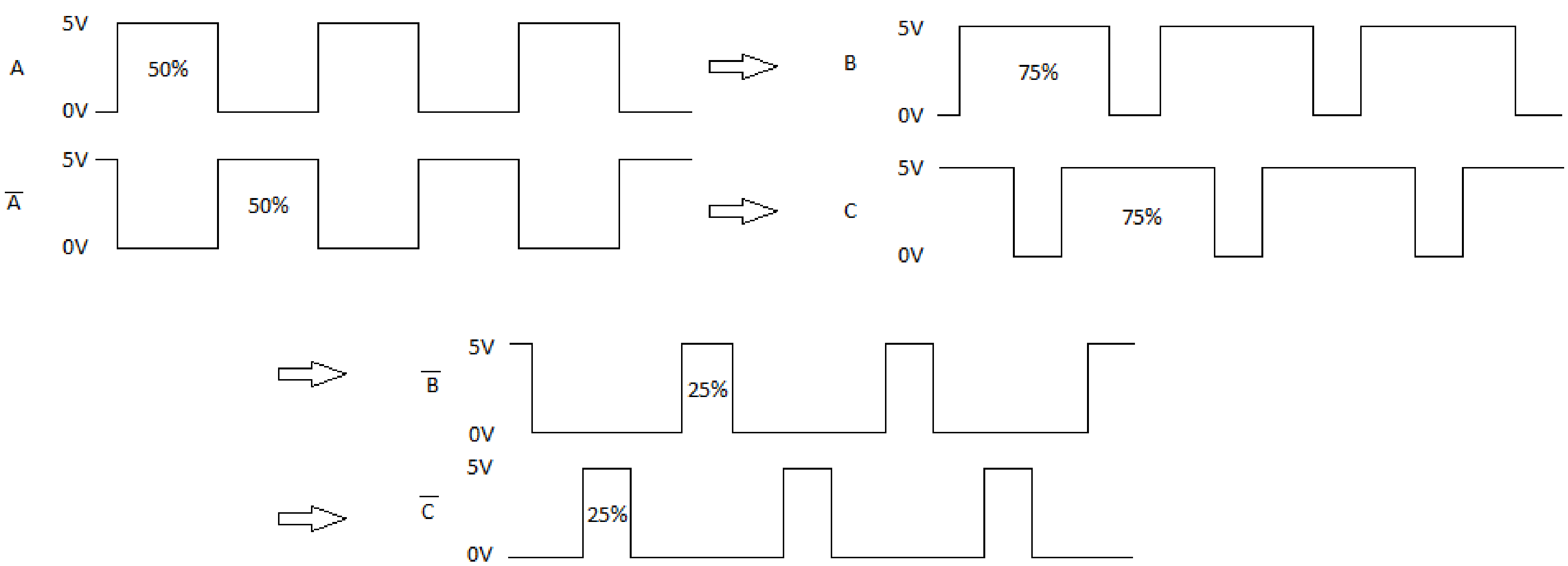
Automatic Step-up/Step-down Selection



- Uses small transformer to step down the input voltage
- Diode bridge and filter capacitor rectify input voltage to 12Vdc/24Vdc
- Potentiometer creates a voltage divider
- 115V input ➔ Vgate < Vthreshold ➔ Relay stays in initial position
- 230V input ➔ Vgate > Vthreshold ➔ Relay switches to second position

VSI Circuit and Waveforms





The Importance of a VSI Waveform

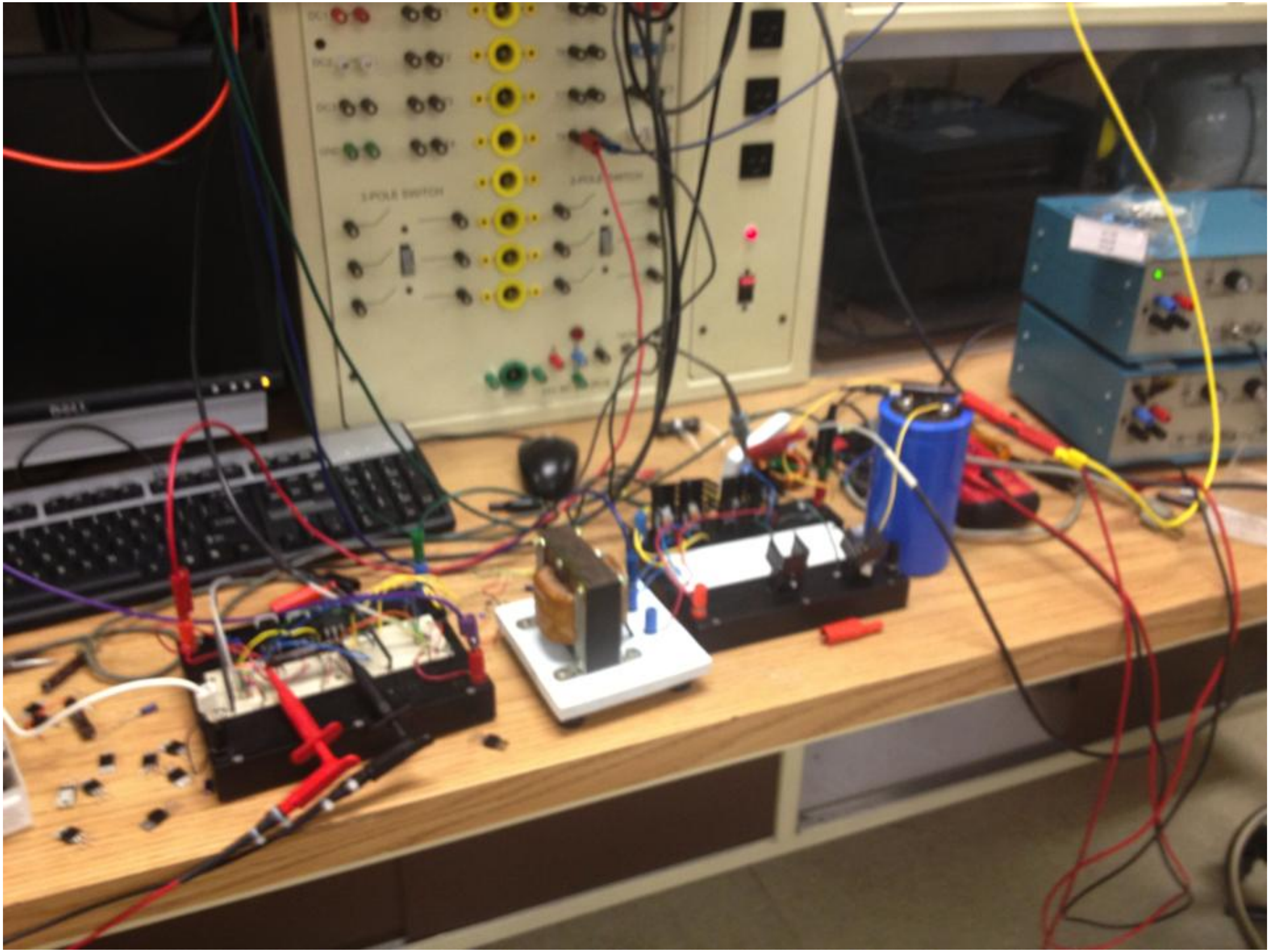
- Rectifier and filter capacitor create a DC voltage based on peak value of AC waveform

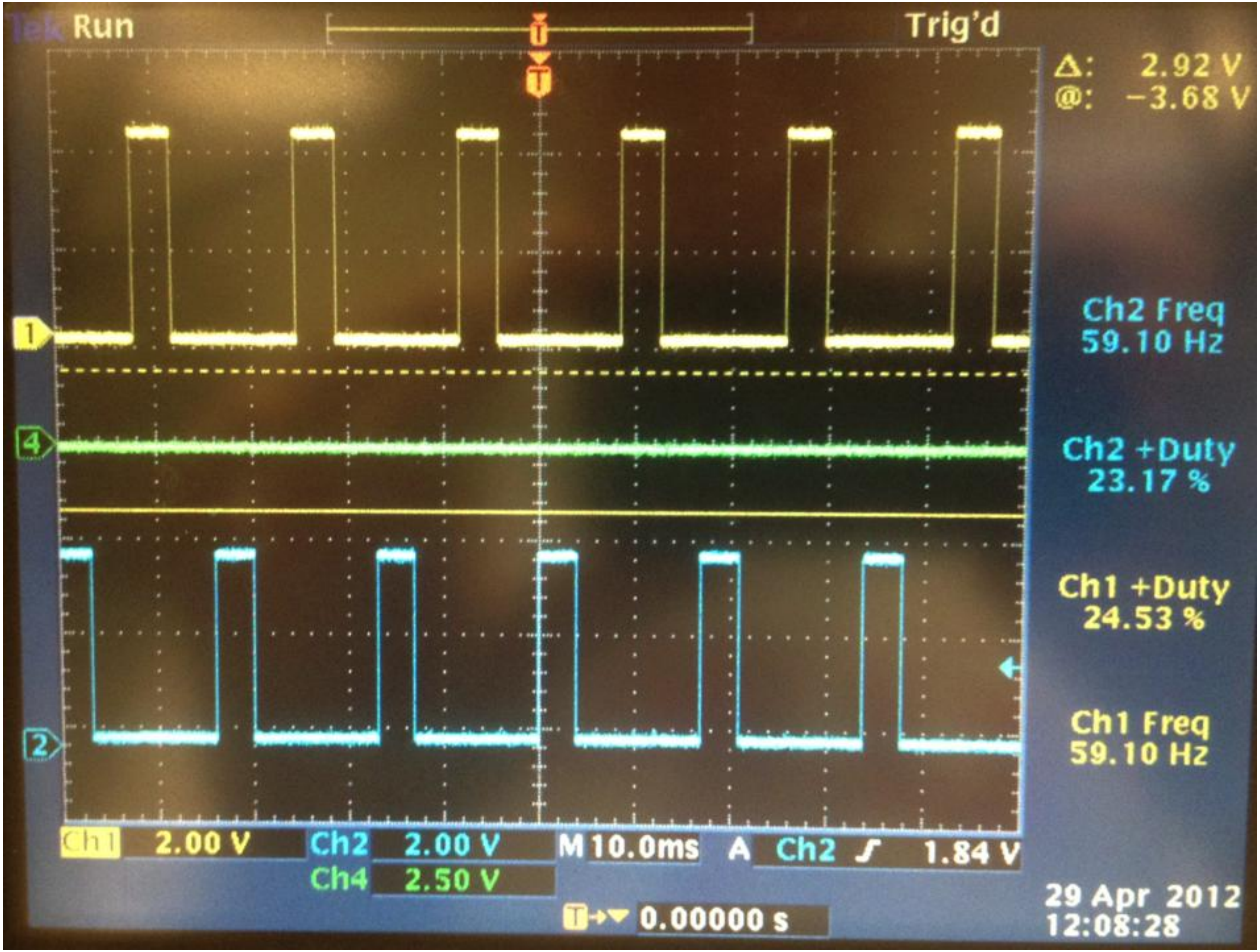
- 115Vrms = 163Vpeak → 163Vdc
- 230Vrms = 325Vpeak → 325Vdc

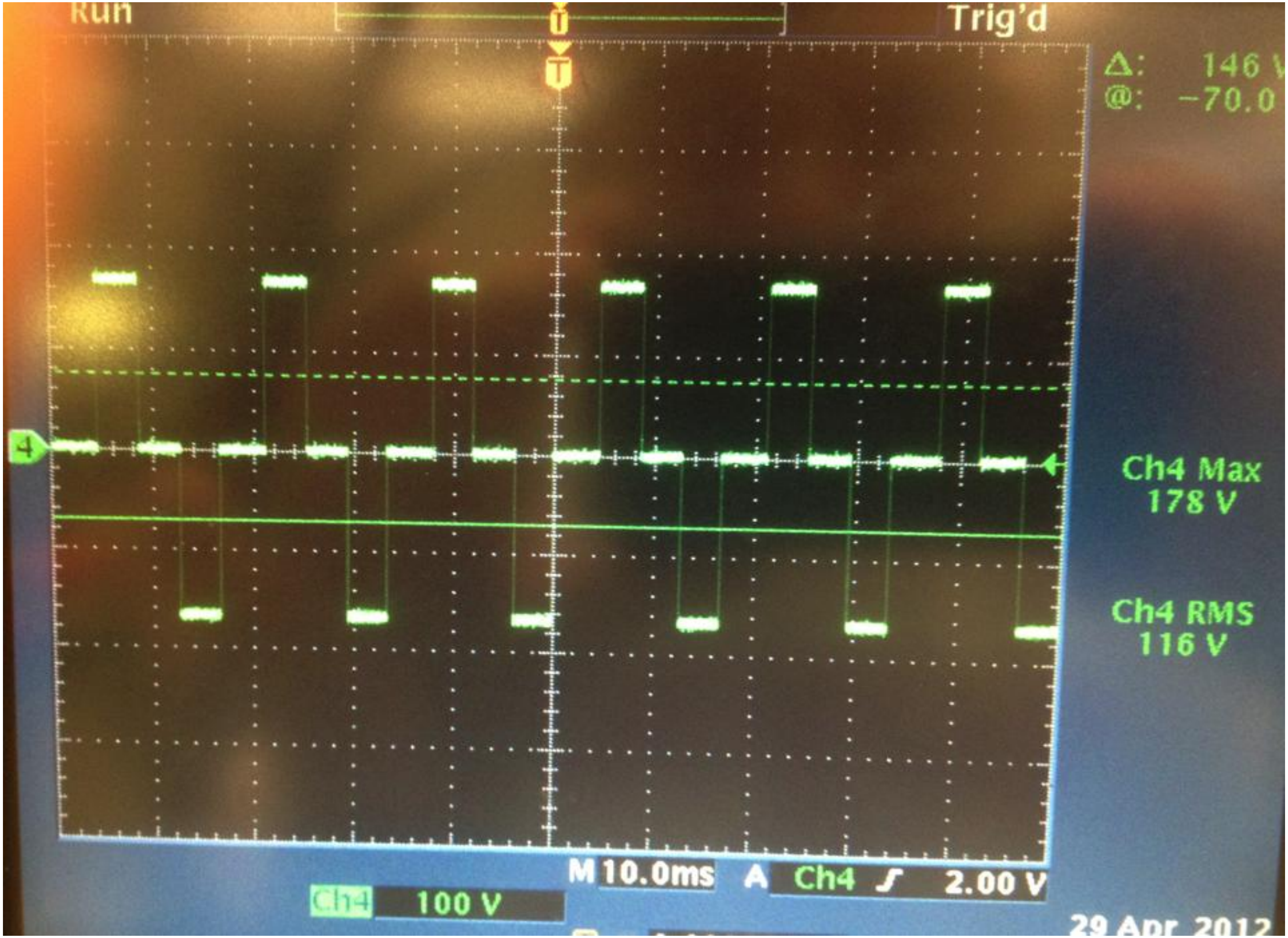
- If switching had 50% duty ratio, outputs would be 163Vrms and 325Vrms

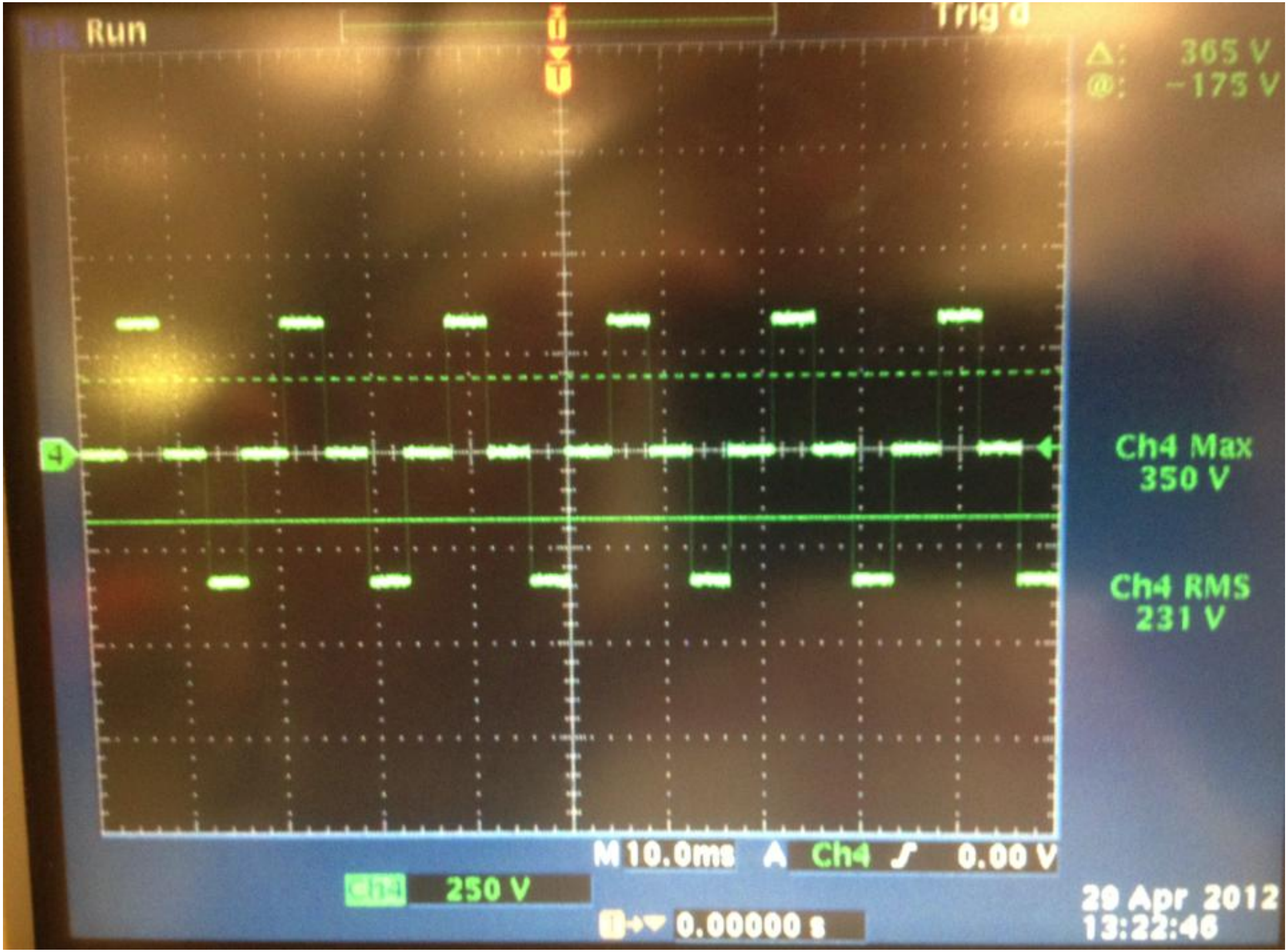
- To achieve outputs of 115Vrms and 230Vrms, dead time between switches must be introduced

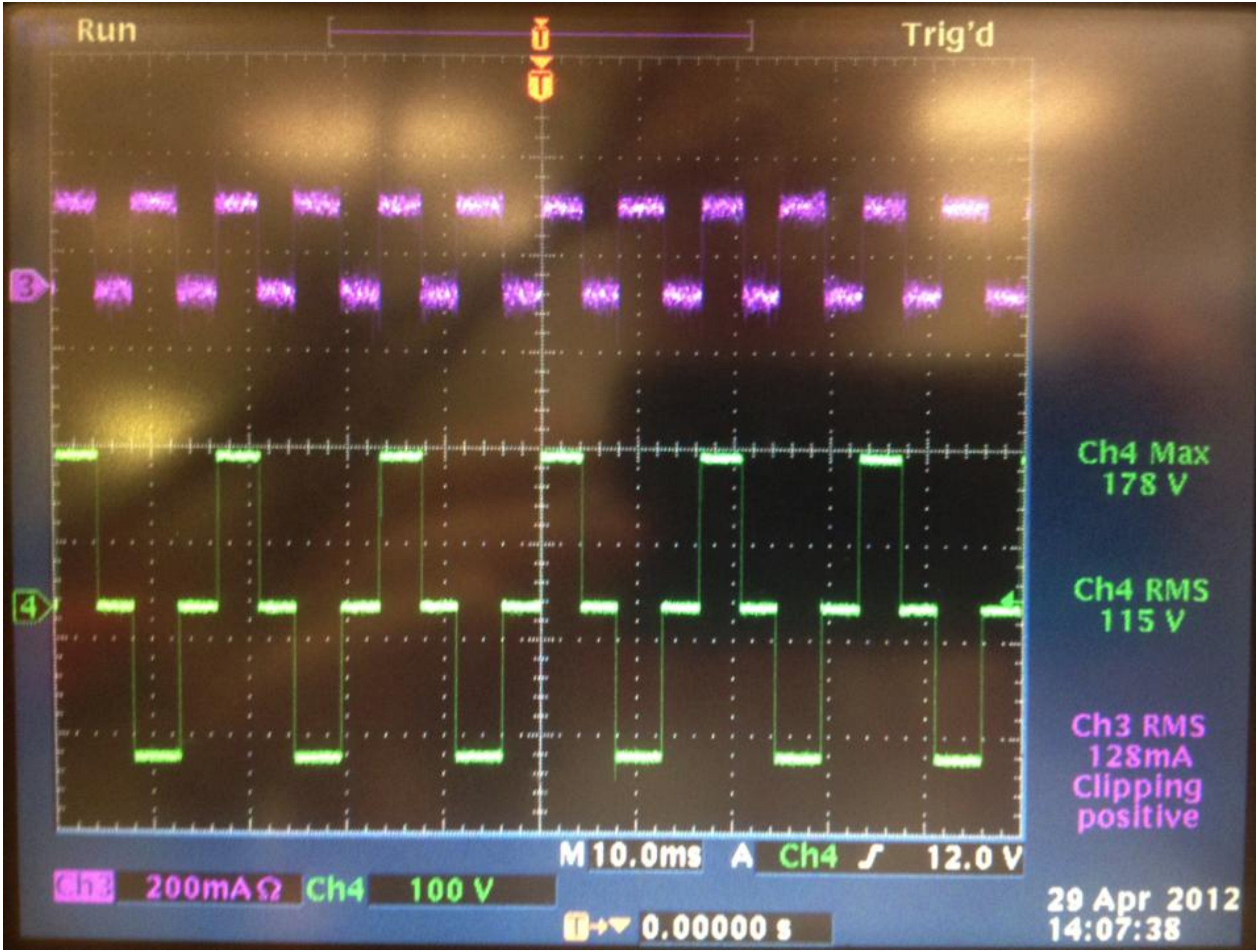
- Switching signals need 25% duty ratio


2-POLE SWITCH
2-POLE SWITCH

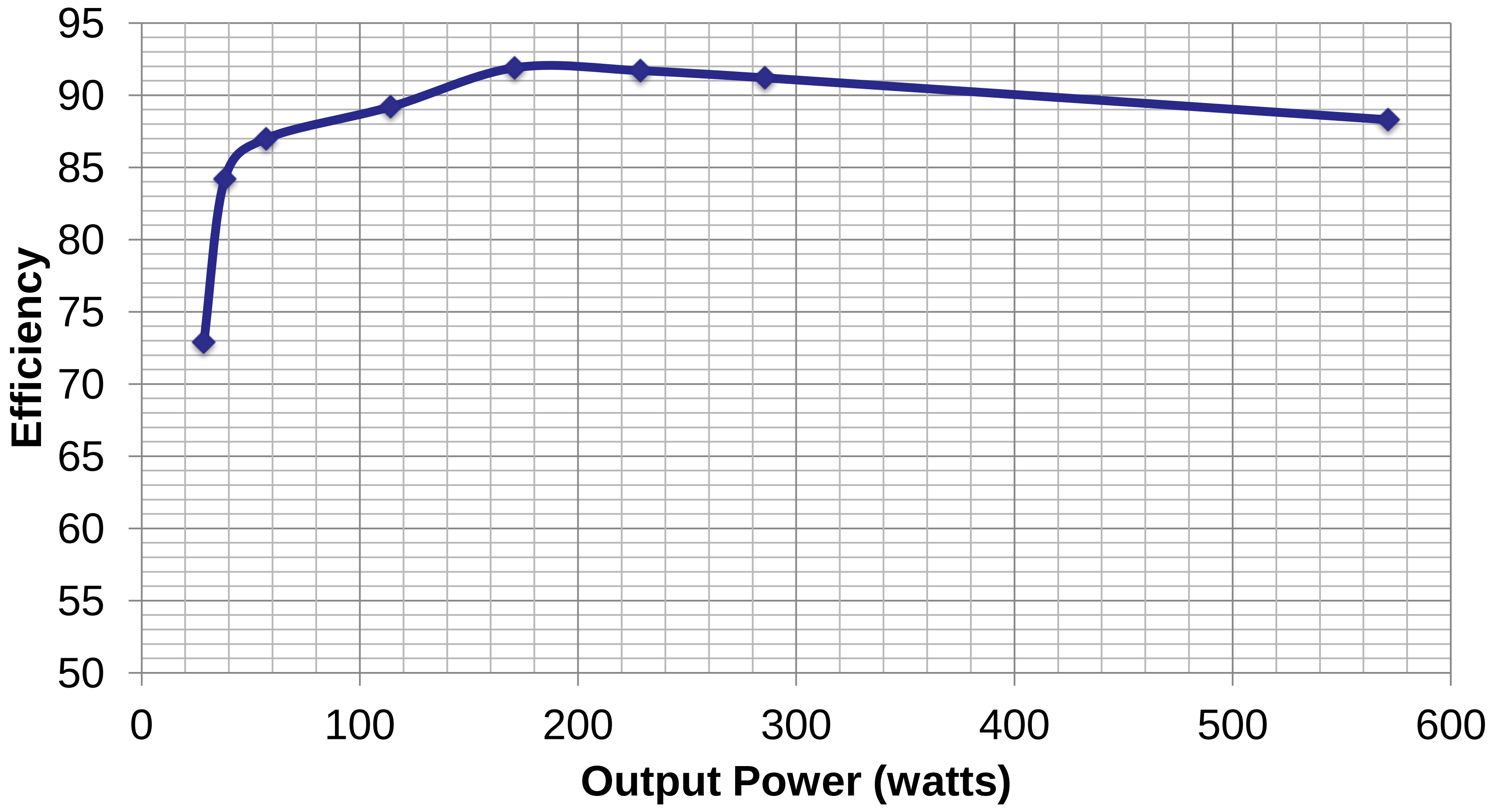

Tek Run
Trig'd
Δ: 2.92 V
@: −3.68 V
Ch2 Freq
59.10 Hz
Ch2 +Duty
23.17 %
Ch1 +Duty
24.53 %
Ch1 Freq
59.10 Hz
Ch1 2.00 V
Ch2 2.00 V
M 10.0ms
A Ch2 1.84 V
Ch4 2.50 V
0.00000 s
29 Apr 2012
12:08:28


Run
Trig'd
Δ: 146
@: −70.0
Ch4 Max
178 V
Ch4 RMS
116 V
M 10.0ms
A Ch4
2.00 V
Ch4
100 V
29 Apr 2012

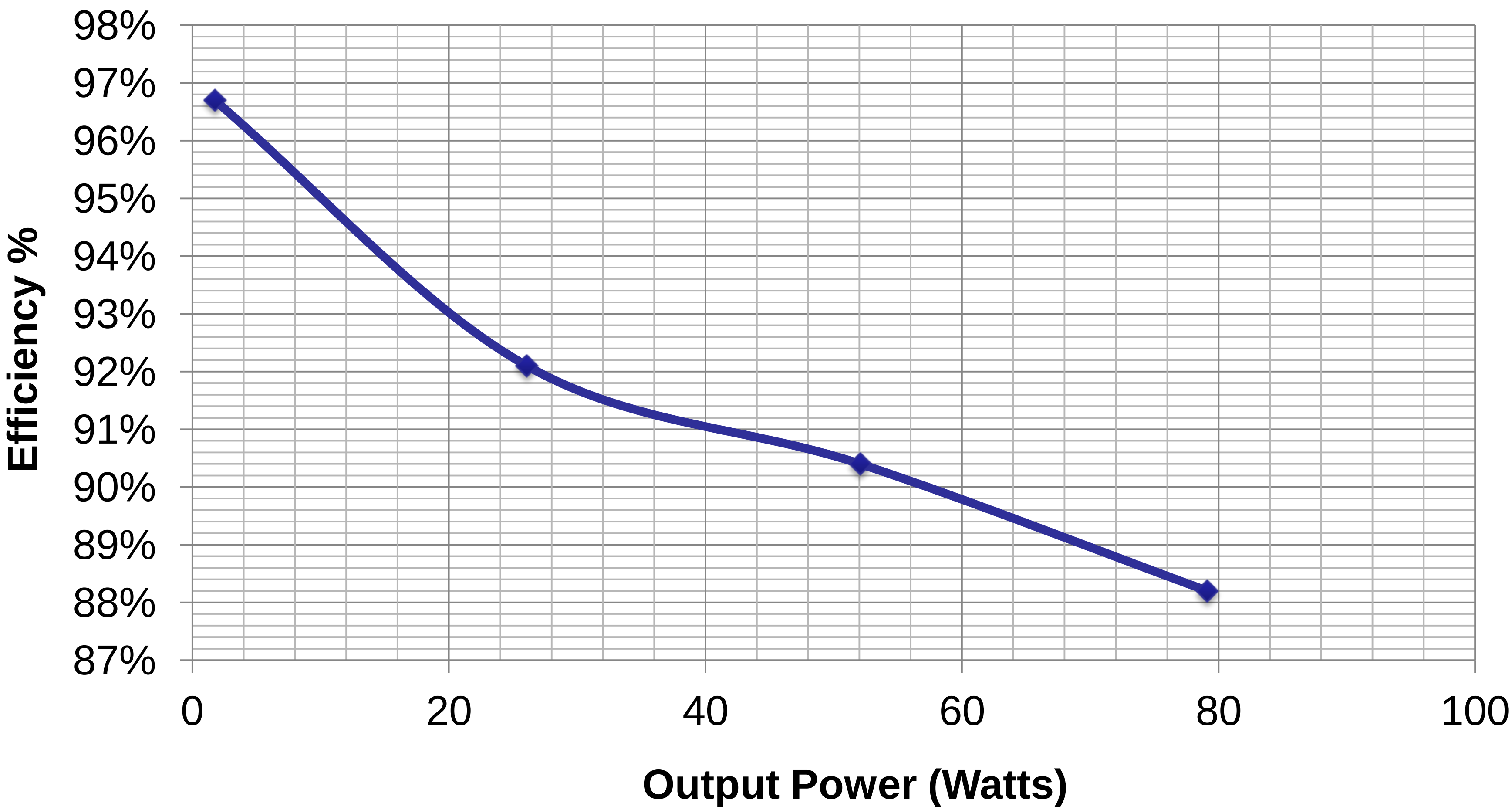

Run
Trig'd
Δ: 365 V
@: −175 V
Ch4 Max
350 V
Ch4 RMS
231 V
M 10.0ms A Ch4 0.00 V
Ch4 250 V
0.00000 s
29 Apr 2012
13:22:46


Run
Trig'd
Ch4 Max
178 V
Ch4 RMS
115 V
Ch3 RMS
128mA
Clipping
positive
M 10.0ms A Ch4 12.0 V
200mA Ω Ch4 100 V
0.00000 s
29 Apr 2012
14:07:38

Rectifier Efficiency



MOSFET Bridge Efficiency



Overall Efficiency

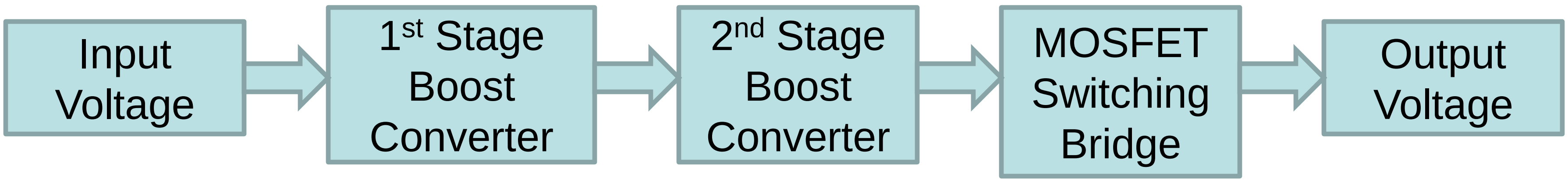
- Initial targeted efficiency = 80% (Proposal)

- Targeted efficiency after simulations = 70% (Design Review)

- Rectifier efficiency = 72.9%-91.9%
- H-bridge efficiency = 88.2%-96.7%

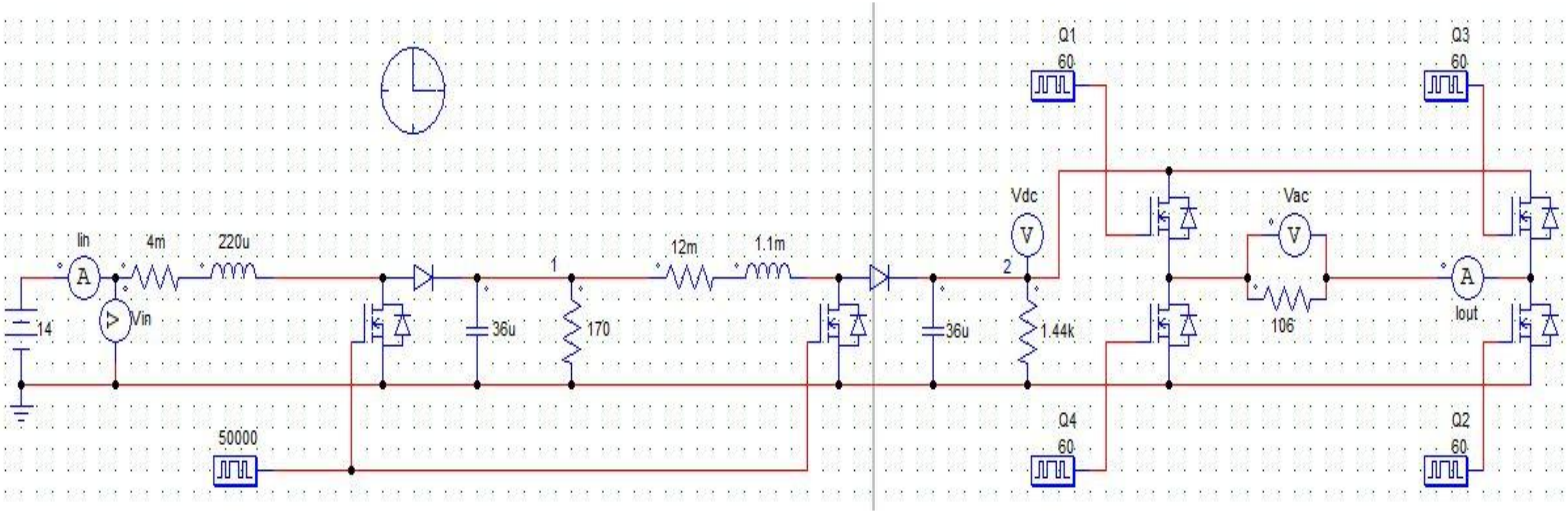
- Overall efficiency = 64.3%-88.9%

DC/AC Circuit: General Topology

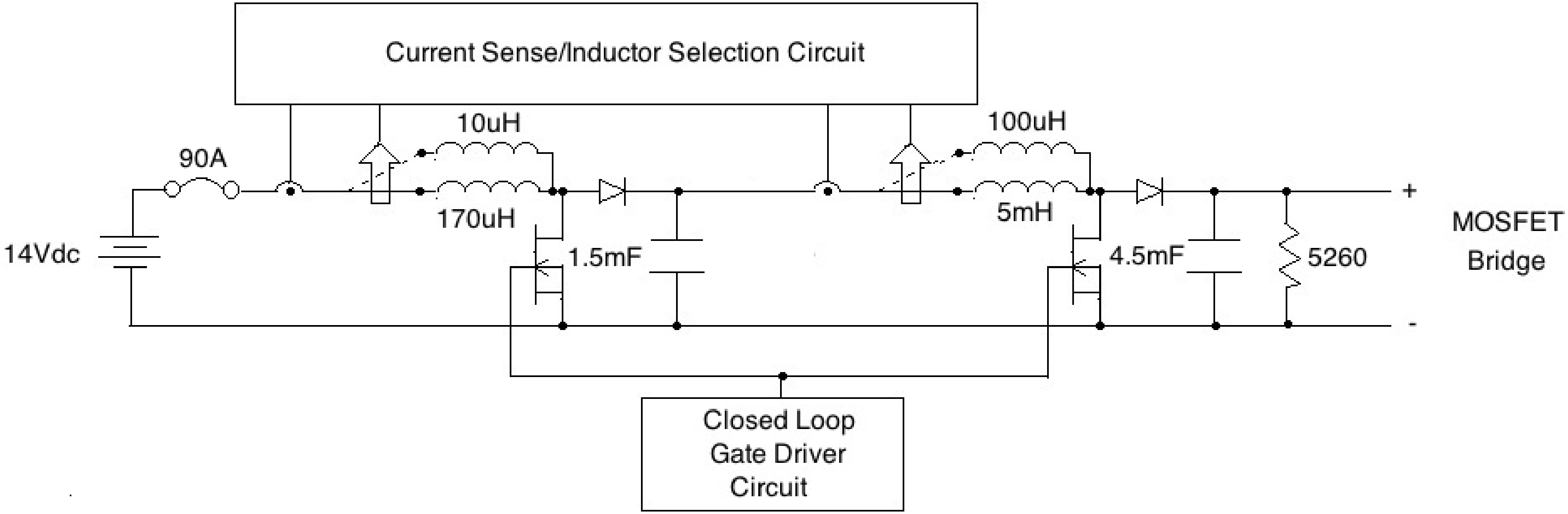


- DC input voltage is fed into 1st stage of DC-DC boost converter and is stepped up to 4x
- DC signal is then channeled through 2nd stage DC-DC boost converter and is stepped up to the appropriate amount (115V or 230V)
- The signal is then switched at the appropriate frequency (60Hz or 50Hz) using the same MOSFET bridge as the AC/AC circuit
- A square wave is received at the output

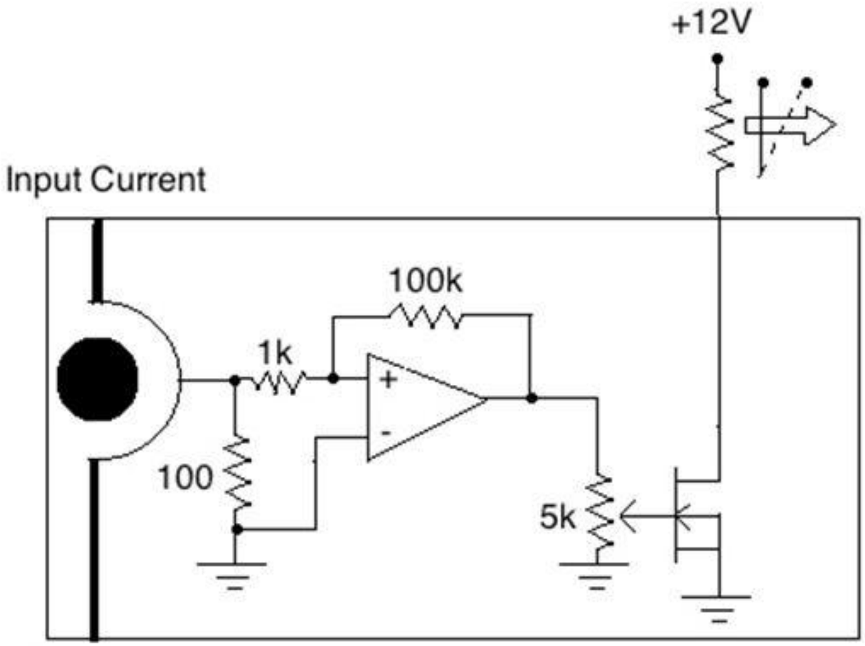
DC/AC Converter: Initial Design



DC/AC Converter: Actual Implementation

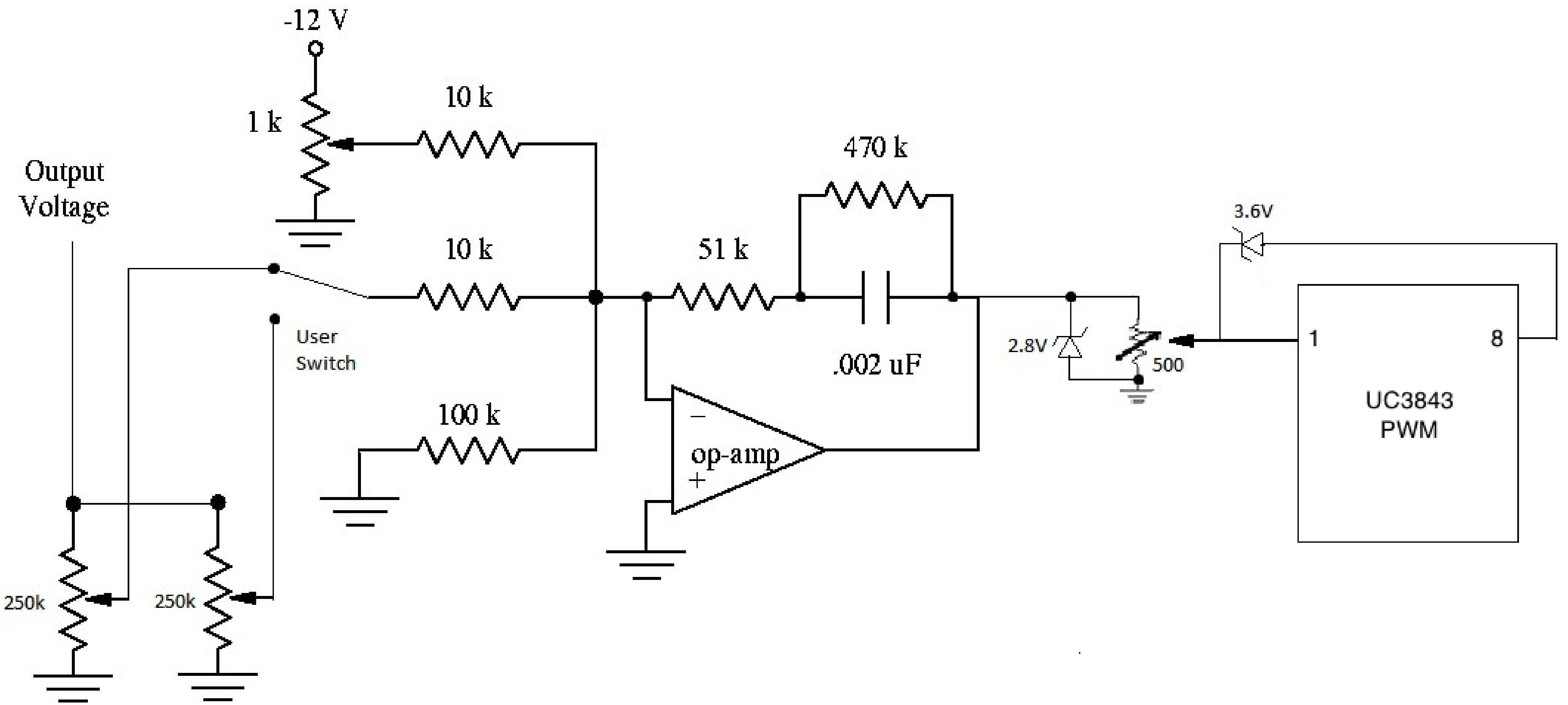


Current Sensing Circuit



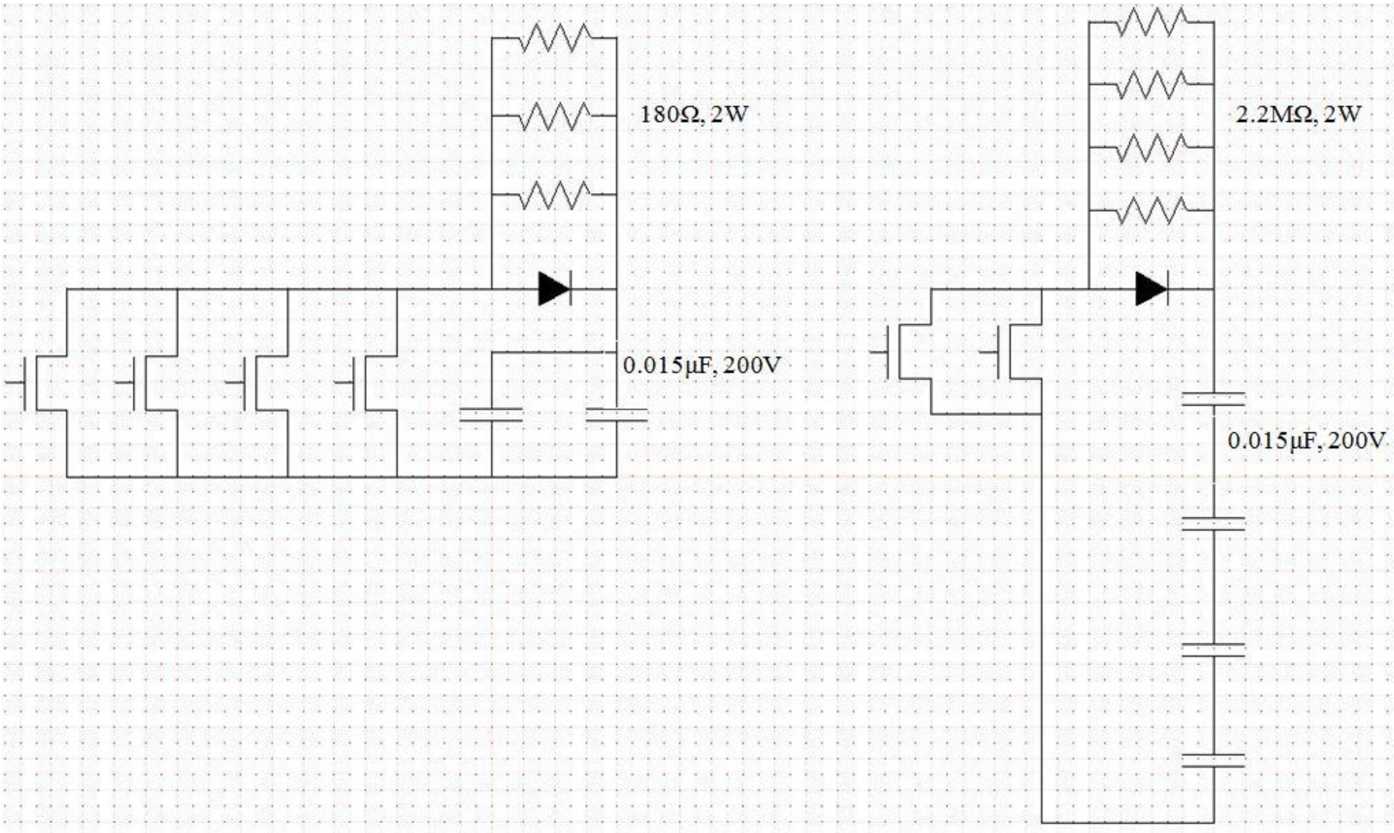
- Hall effect sensor creates an output voltage based on input current
- Non-inverting amplifier increases sensitivity
- Output voltage of amplifier controls gate voltage of N-channel MOSFET
- SPDT relay switches when sensed current is high enough

Closed Loop Control Circuit

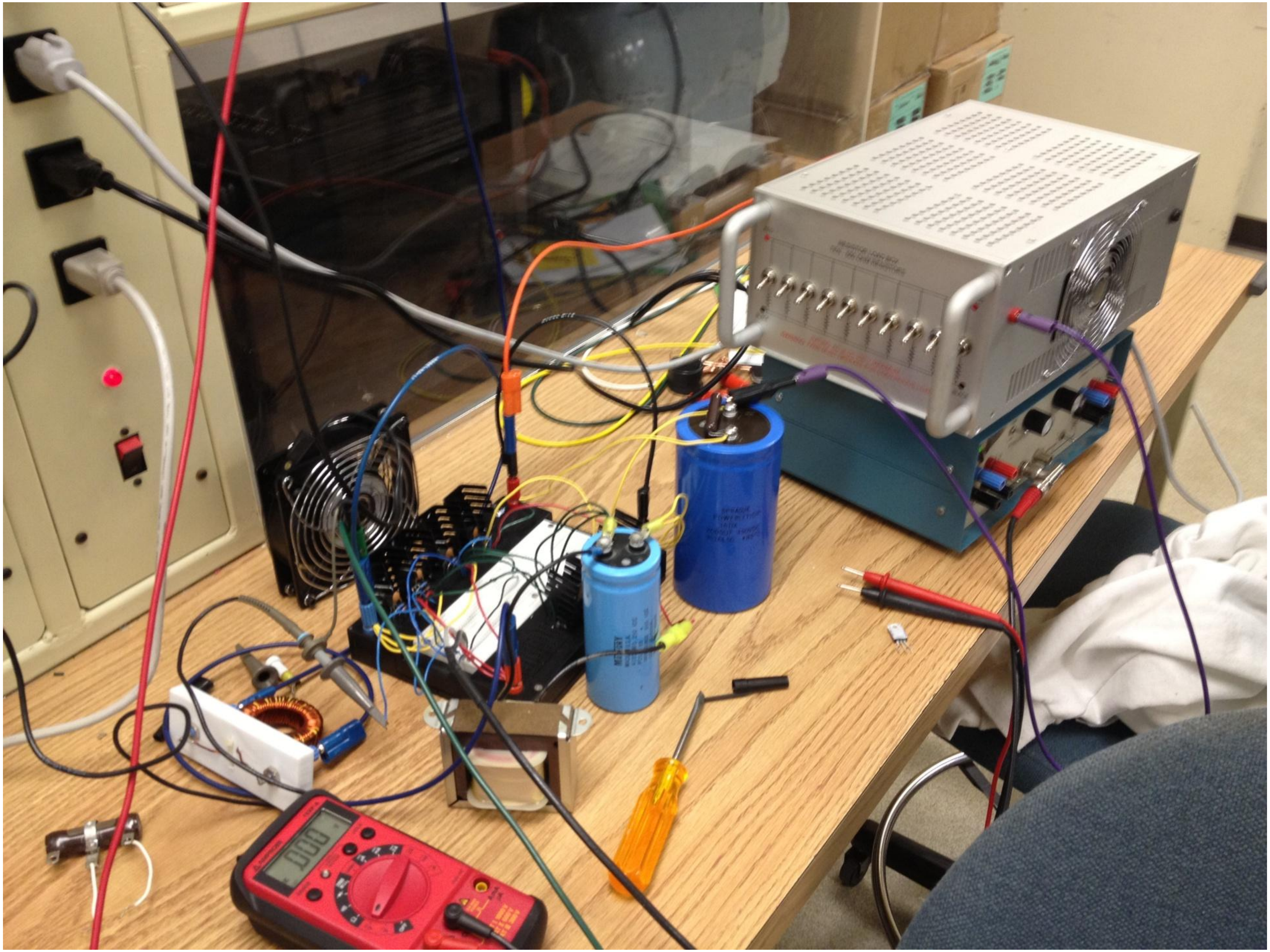


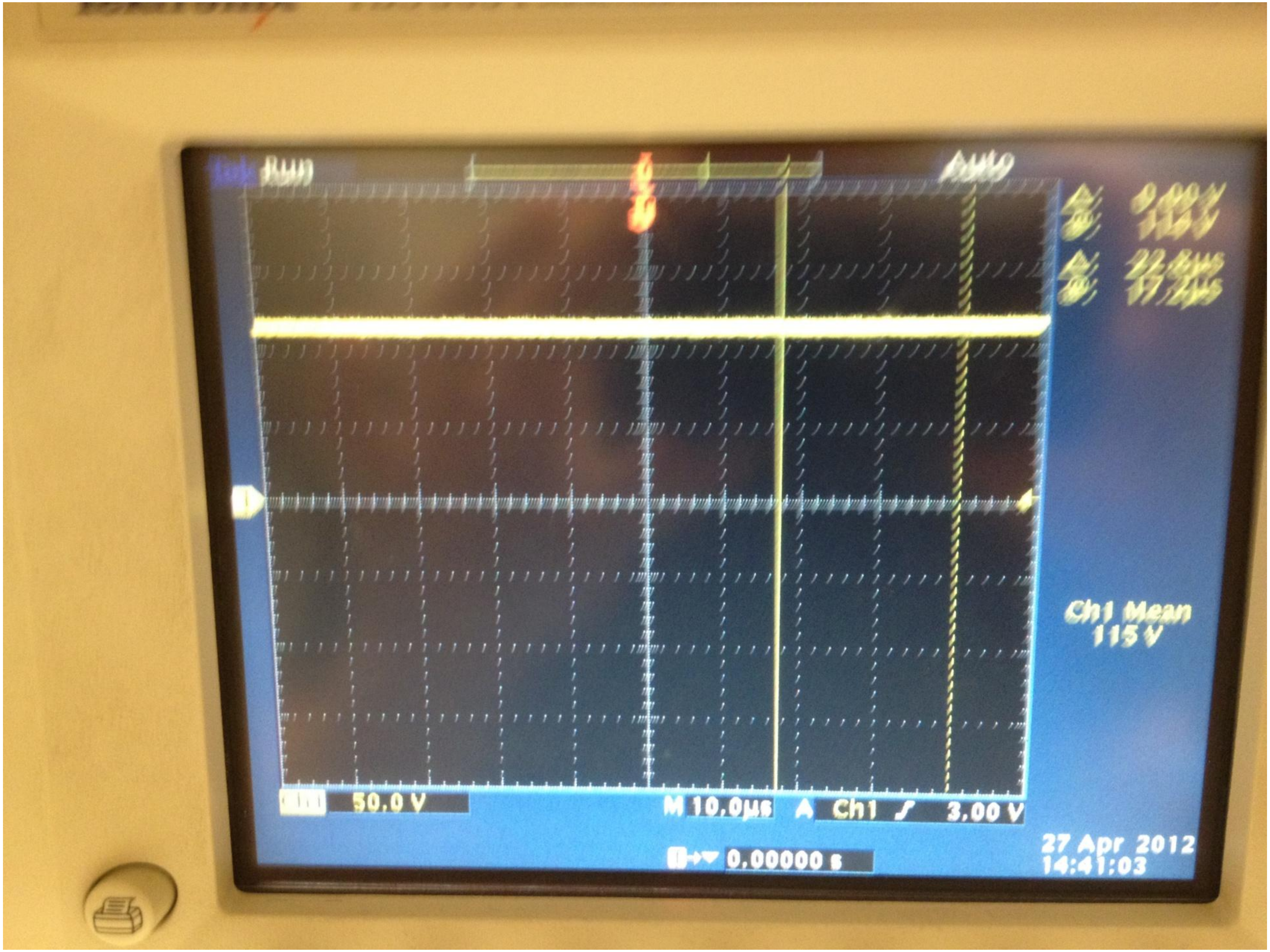
- PI control creates signal voltage based on output voltage of boost converter
- User switch determines output of 115Vdc or 230Vdc
- Zener diodes limit duty ratio to between 50%-90%

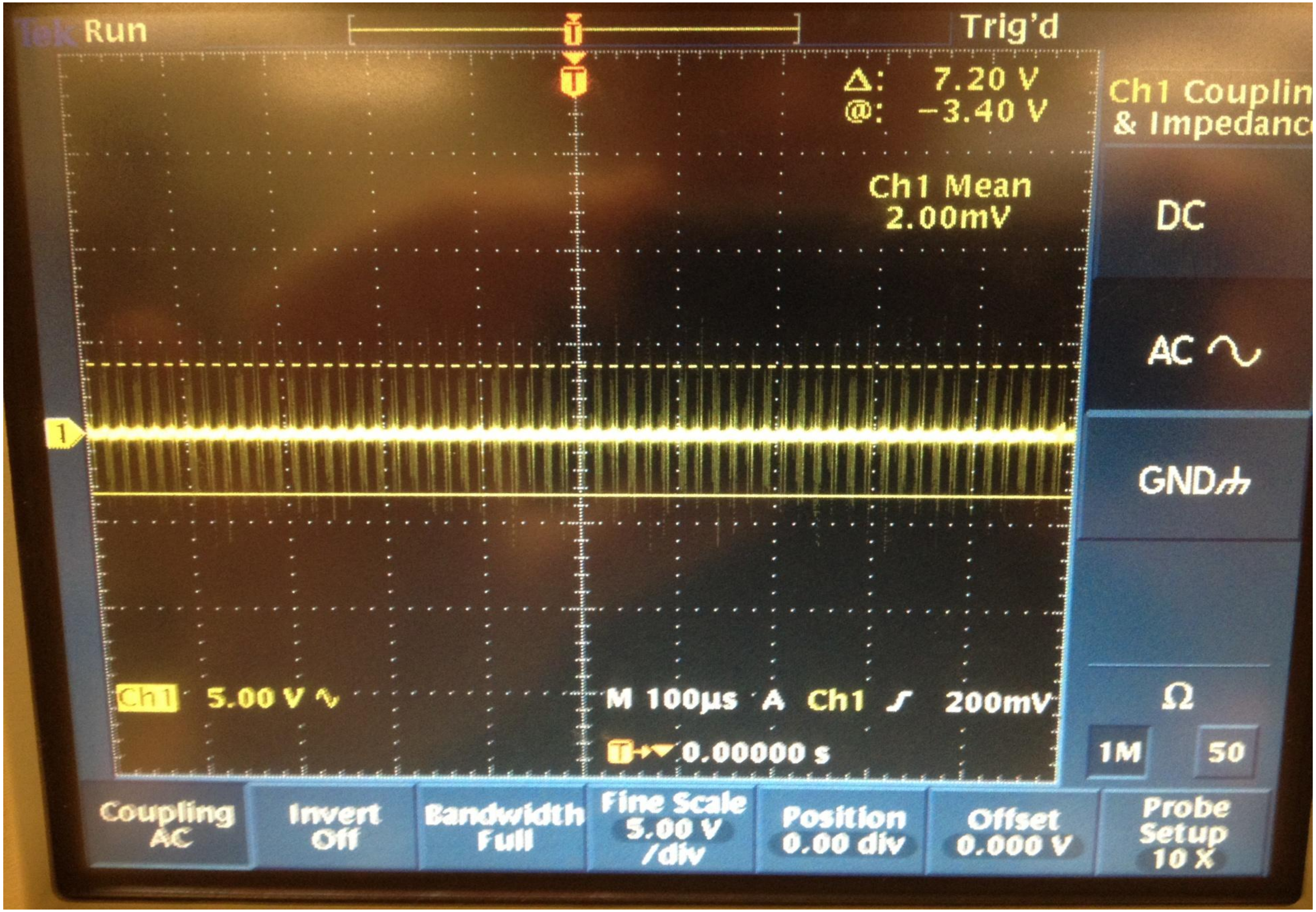
Snubber Circuit



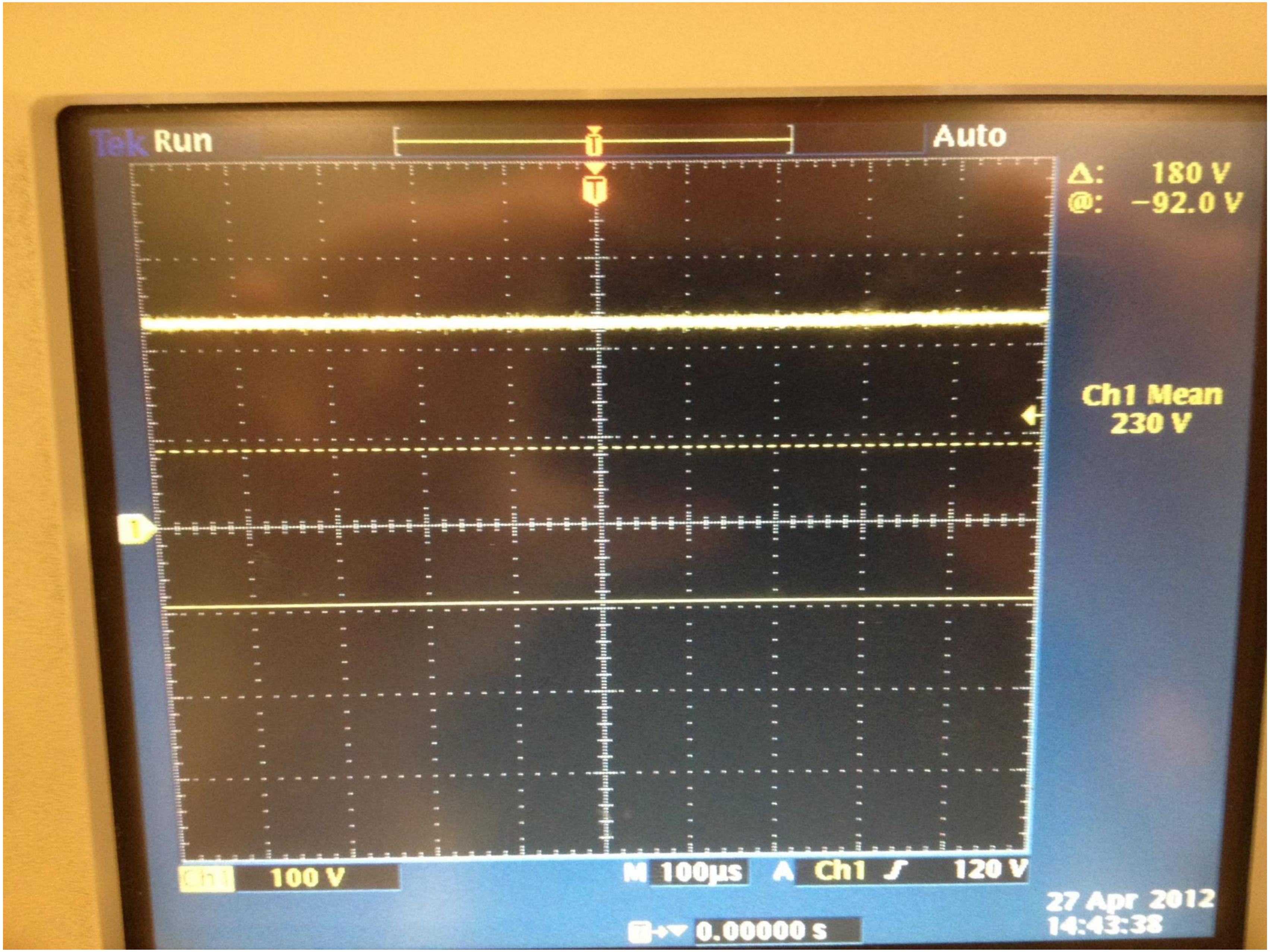
- To dissipate power when switches are off
- To reduce switching losses at high frequencies (50kHz)

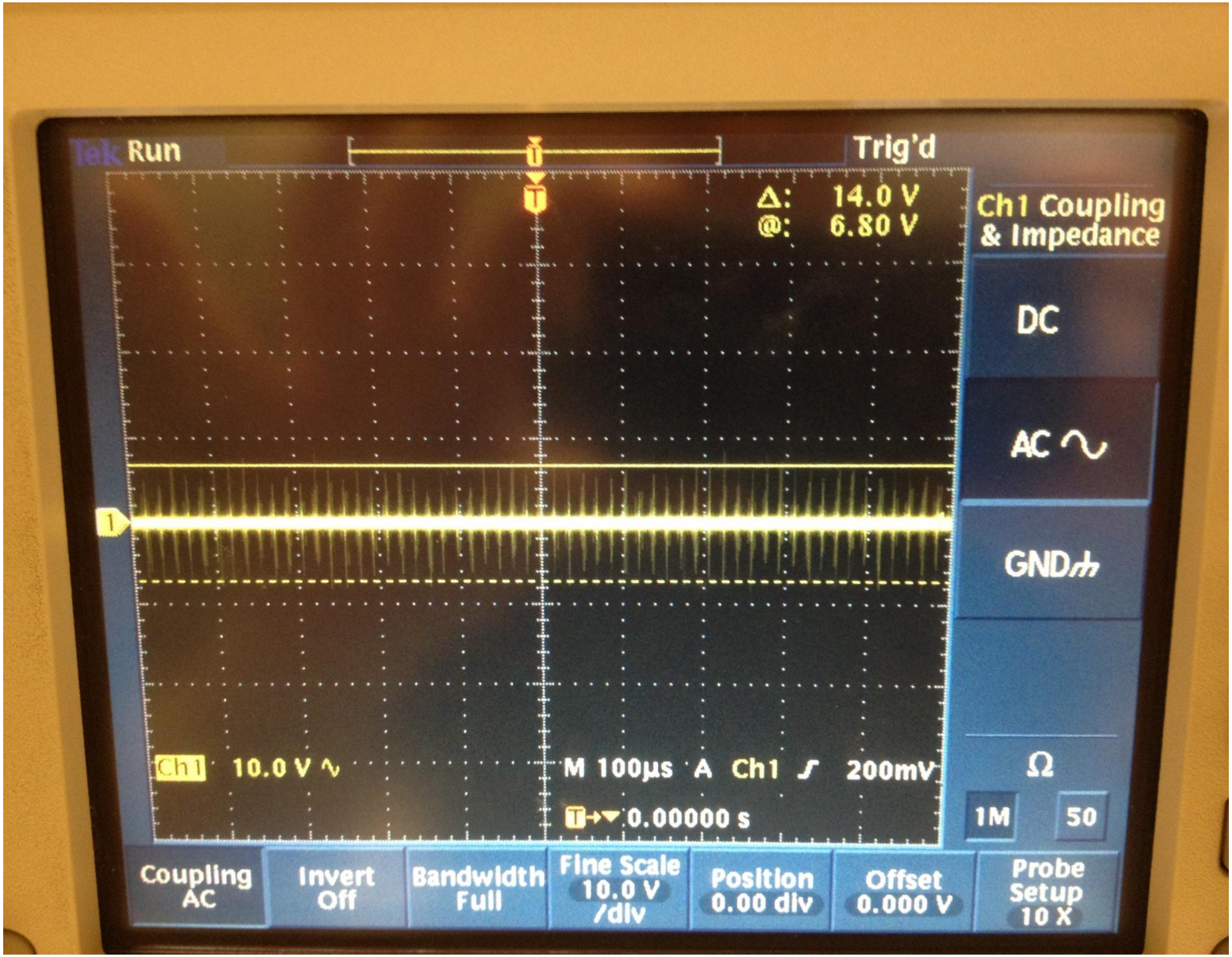



Auto
Ch1 Mean
115 V
50.0 V
M 10.0µs
A Ch1
3.00 V
0.00000 s
27 Apr 2012
14:41:03



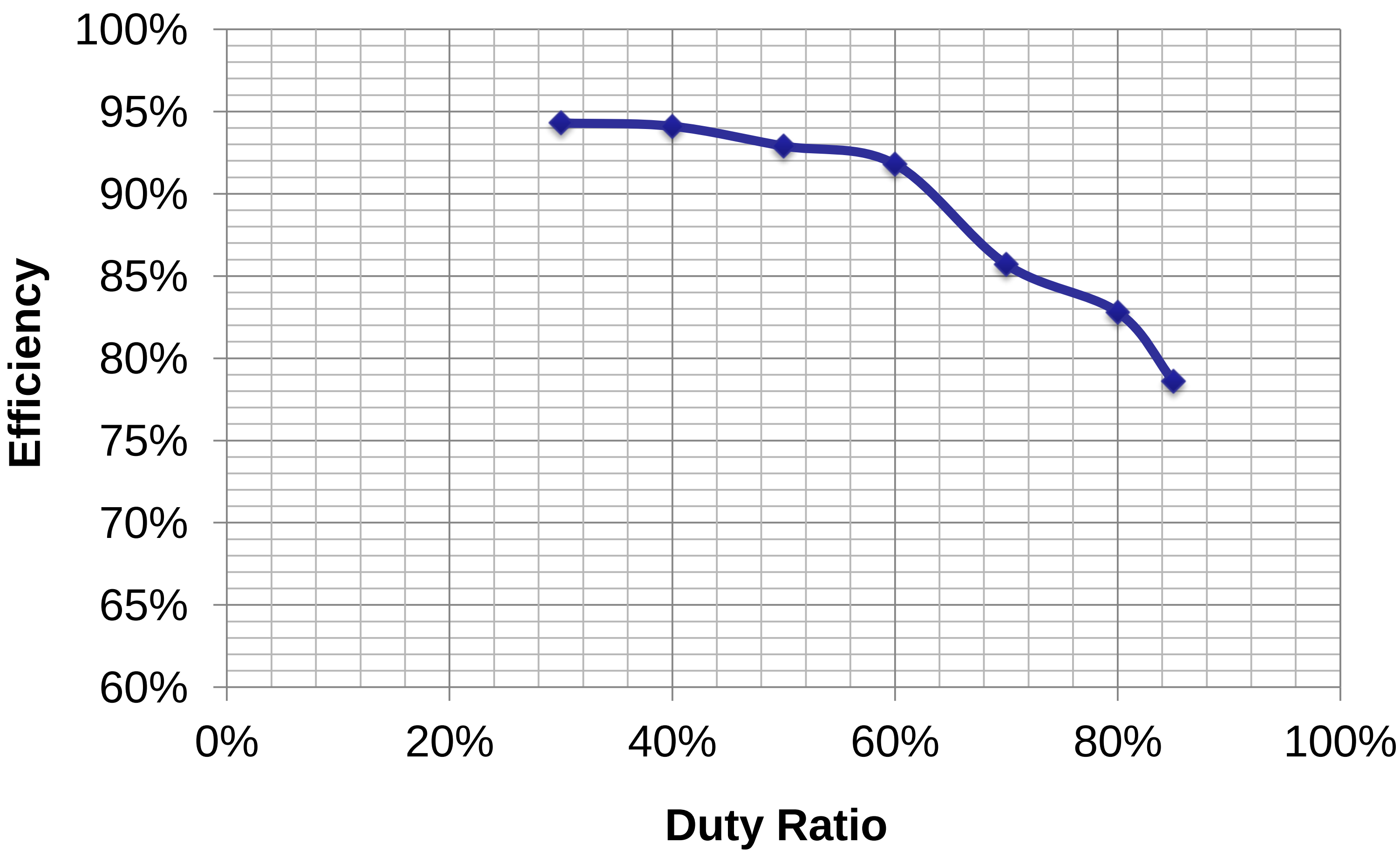
115V ripple measurement = 7.2Vpp = ± 3.1%


Tek Run
Auto
Δ: 180 V
@: −92.0 V
Ch1 Mean
230 V
Ch1 100 V
M 100µs A Ch1 ∫ 120 V
0.00000 s
27 Apr 2012
14:43:38

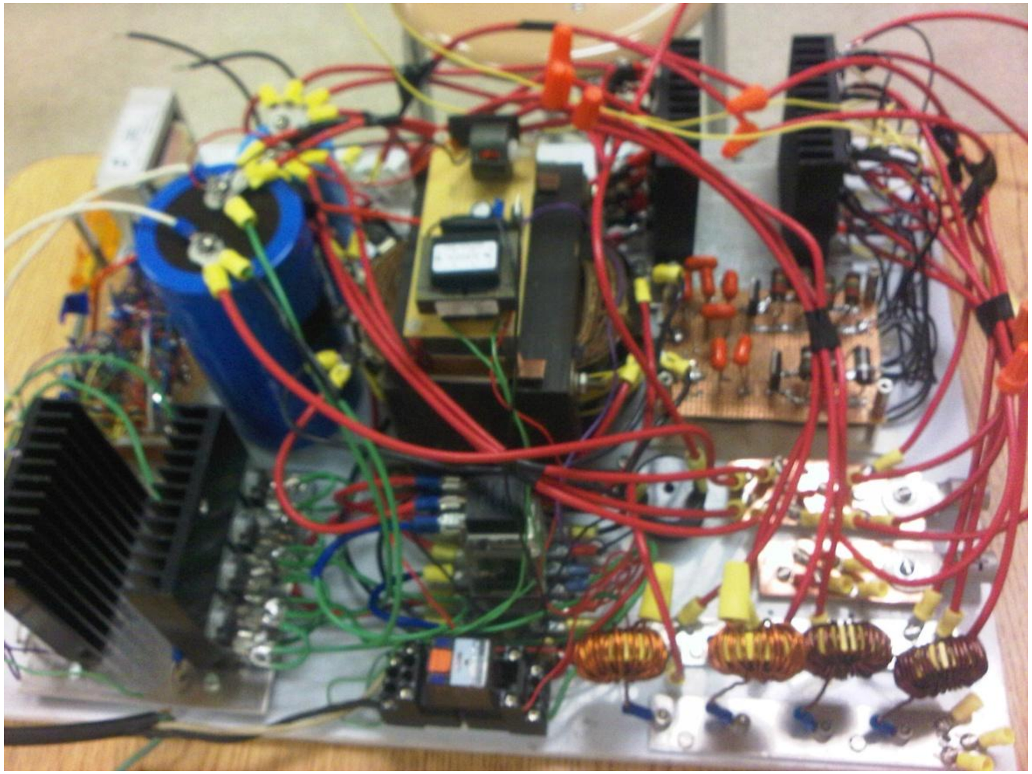


230V ripple measurement = 14Vpp = ± 3.0%

DC/AC Converter Efficiency



Overall Physical Circuit Layout



Challenges

AC/AC Design

- Needed to build a VSI waveform circuit (instead of original 50% DR)
- Power supply of 12Vdc for digital components
- High-side and low-side gate drivers
- No mains ground (isolated)

DC/AC Design

- Boost converter voltage regulation
- In depth magnetics design
- PWM reliability
- High input current (~90A)

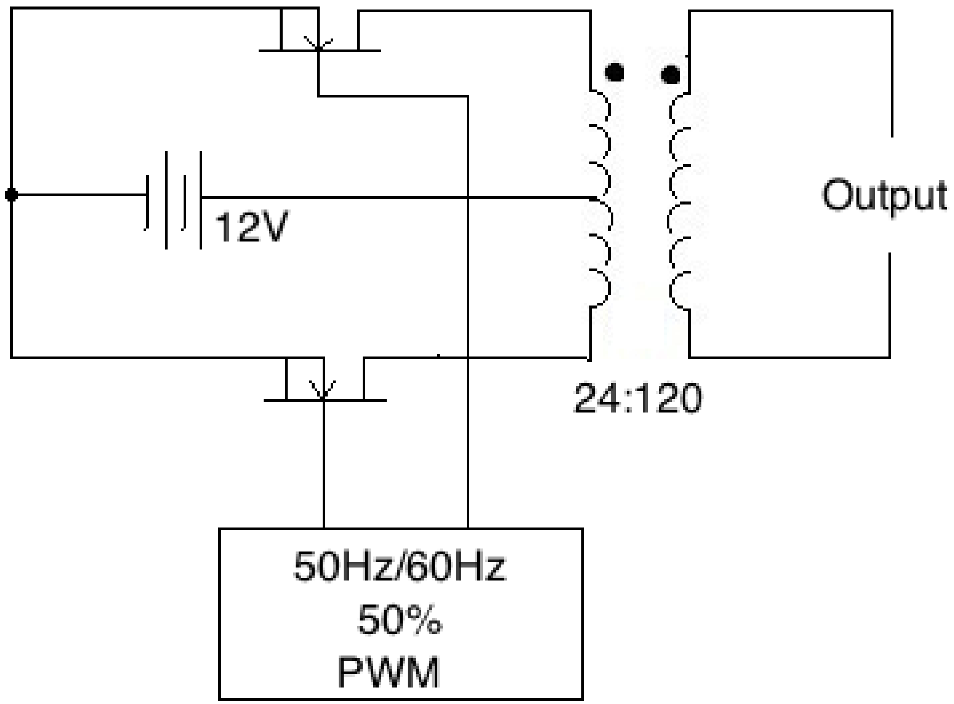
Reasons For Failure

- Hard Start – voltage and current immediately seen by MOSFETs
- Power Resistors – Wire wound and can act like inductor causing initial current spike
- PWM signal oscillation – Witnessed in video, dangerous to MOSFETs, causes quick changes in inductor current
- Rapid inductor current variation causes voltage spikes
- Analog circuits cause cascading problems

Recommendations

- Use a 3-stage boost converter instead of a 2-stage
- Implement slow start circuits
- Micro controller for PWM signal and closed loop control
- Use a center tap transformer circuit (shown on next slide) instead of a boost converter
- Use high power MOSFETs instead of parallel combination
- Micro controller for VSI waveform
- Opto-coupler to isolate digital components from power components
- Create a pure sine wave output

Inverter Design II



Special Thanks To

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Ryan May

ECE Machine Shop

ECE Parts Shop

Thank You

Questions?