

# ON Semiconductor

## Is Now

The logo for onsemi, featuring the word "onsemi" in a dark teal, lowercase, sans-serif font. The letter "i" is stylized with a white dot and a teal vertical bar. A small orange triangle is positioned above the top right of the "i". A trademark symbol (TM) is located to the right of the logo.

To learn more about onsemi™, please visit our website at  
[www.onsemi.com](http://www.onsemi.com)

---

**onsemi** and **onsemi** and other names, marks, and brands are registered and/or common law trademarks of Semiconductor Components Industries, LLC dba "**onsemi**" or its affiliates and/or subsidiaries in the United States and/or other countries. **onsemi** owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of **onsemi** product/patent coverage may be accessed at [www.onsemi.com/site/pdf/Patent-Marking.pdf](http://www.onsemi.com/site/pdf/Patent-Marking.pdf). **onsemi** reserves the right to make changes at any time to any products or information herein, without notice. The information herein is provided "as-is" and **onsemi** makes no warranty, representation or guarantee regarding the accuracy of the information, product features, availability, functionality, or suitability of its products for any particular purpose, nor does **onsemi** assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. Buyer is responsible for its products and applications using **onsemi** products, including compliance with all laws, regulations and safety requirements or standards, regardless of any support or applications information provided by **onsemi**. "Typical" parameters which may be provided in **onsemi** data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. **onsemi** does not convey any license under any of its intellectual property rights nor the rights of others. **onsemi** products are not designed, intended, or authorized for use as a critical component in life support systems or any FDA Class 3 medical devices or medical devices with a same or similar classification in a foreign jurisdiction or any devices intended for implantation in the human body. Should Buyer purchase or use **onsemi** products for any such unintended or unauthorized application, Buyer shall indemnify and hold **onsemi** and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that **onsemi** was negligent regarding the design or manufacture of the part. **onsemi** is an Equal Opportunity/Affirmative Action Employer. This literature is subject to all applicable copyright laws and is not for resale in any manner. Other names and brands may be claimed as the property of others.

# CCRACGEVB

## An AC LED Lighting Evaluation Board Using Constant Current Regulators (CCR) Evaluation Board User's Manual



ON Semiconductor®

[www.onsemi.com](http://www.onsemi.com)

### EVAL BOARD USER'S MANUAL

Six Different Circuit Topologies Covering Smallest Bill of Materials to Widest Input Voltage: 12 VAC to 250 VAC.

#### Introduction

Engineers developing solid-state lighting control systems need to balance circuit efficiency, power factor (PF), total harmonic distortion (THD), total cost of bill of materials (BOM) and input voltage range to cover large geographic regions and aesthetics to satisfy different customer requirements. The CCRACGEVB allows engineers to evaluate six different topologies as they approach this difficult balancing act.

The CCRACGEVB (see Figure 1) has an input voltage range of 12 VAC to 250 VAC and showcases the NSIC20x0JBT3G series of 120 V CCRs and the NSI50150ADT4G (150 – 350 mA Adjustable) CCR. It has circuit topologies for “Straight LED Driving”, “Capacitive Drop LED Driving” and “Chopper LED Driving”, all with and without dimming by typical triac dimmers. It has a simple current inrush limiting circuit to suppress the impact of initial high inrush currents and power spikes.

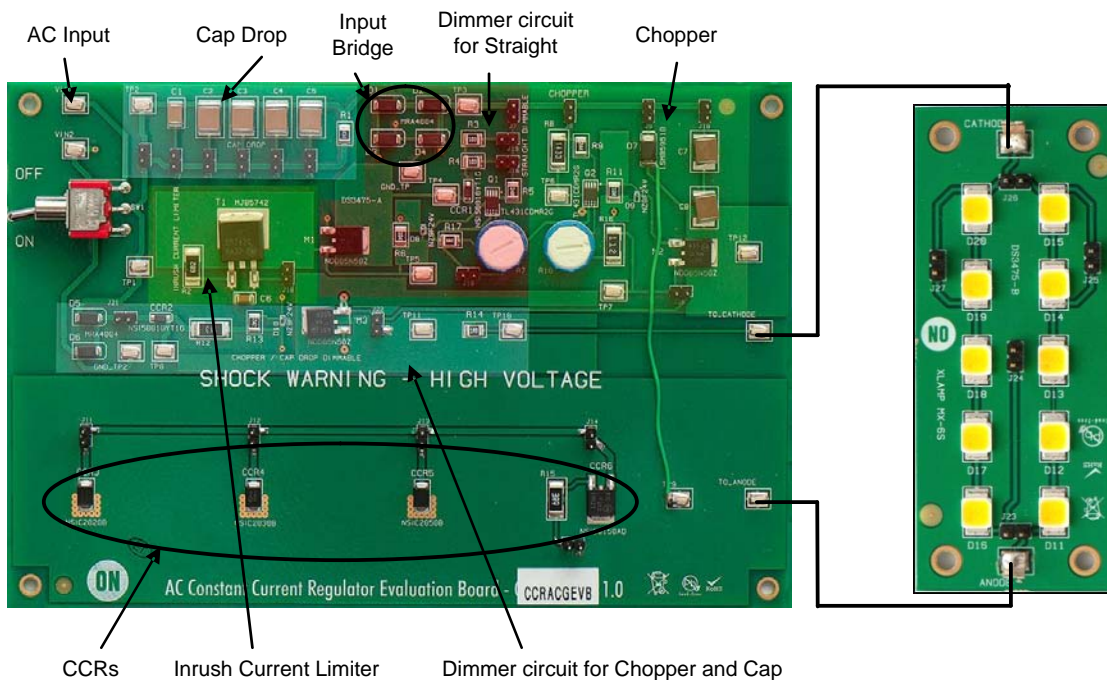


Figure 1. CCR AC Evaluation Board – CCRACGEVB

# CCRACGEVB

The CCRACGEVB is set up with multiple jumpers to allow reuse of circuit components in the different topologies. There are test points at all the major nodes to enable the collection of circuit performance data and also allow engineers to insert their own components for circuit variations.

The components for CCRACGEVB were selected to allow evaluation over a large input voltage range. Designers should review their specific application requirements and determine if smaller or lower cost parts could be selected in place of those used here.

The application note is broken up into sections covering the different circuits. A brief circuit description for each topology will be provided with the jumpers selected together with data collected at multiple voltages.

## CCRACGEVB Features:

### Input Voltage

- 12 VAC to 250 VAC

### CCRs

- NSIC2020JBT3G 120 V 20 mA SMB
- NSIC2030JBT3G 120 V 30 mA SMB
- NSIC2050JBT3G 120 V 50 mA SMB
- NSI50150ADT4G 50 V 150–350 mA DPAK

### Topologies

- Straight No Dimming, With Output Capacitance, With Triac Dimming
- Cap-Drop No Dimming, With Triac Dimming
- Chopper No Dimming, With Triac Dimming

### Inrush Current Limiter

### LED Board (supplied with CCRACGEVB)

- 10x XLAMP MX-6S LEDs

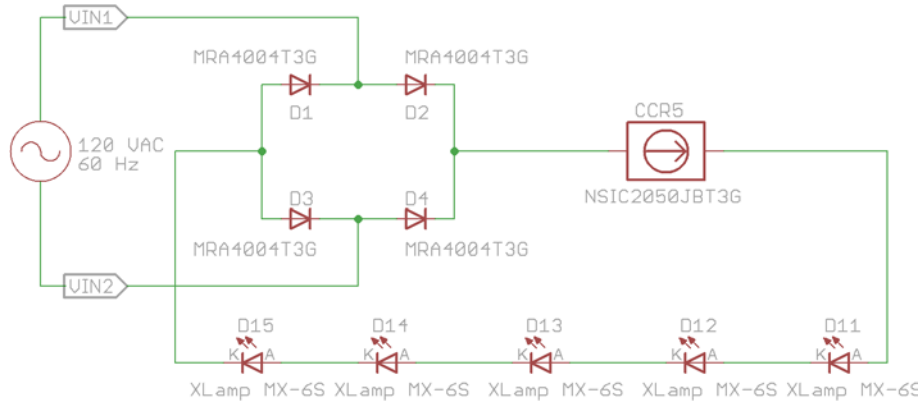


Figure 2. Straight Non-dimmable LED Driver (120 VAC example)

### Straight LED Driver, Non-dimming (120 VAC Example):

The Straight LED driver circuit is the simplest with the lowest BOM and highest PF.

To setup the CCRACGEVB for the Straight LED driver non-dimming topology, place jumpers according to Table 1.

Table 1. JUMPERS PLACED ONTO THE EVB

Jumpers in Place	Reference Data
J1, J13, J18, J19, J20, J22, J26	Appendix A

The AC input is rectified using an AC bridge (D1 – D4). A CCR (CCR3, 4, 5 or 6) controls the current through the LED string. The LEDs will be turned on at double the AC mains frequency (120 Hz in the USA). The duty cycle is about 60%. Figure 2 depicts the schematic with the evaluation board reference designators.

### V<sub>F-Total</sub> LEDs

The maximum forward voltage drop across the LED string is determined by the minimum input peak voltage minus the minimum regulating voltage for the CCR.

Assuming –10% tolerance of AC mains:

$$\text{MAX}V_{F-\text{Total LEDs}} = \text{AC } V_{\text{inMINPeak}} - V_{\text{AKMIN}} \quad (\text{eq. 1})$$

$$\begin{aligned} \text{MAX}V_{F-\text{Total LEDs}} &= 120 \text{ V} \times 1.414(-10\%) - 3 \text{ V} = \\ &= 150 \text{ V} \end{aligned}$$

The minimum forward voltage drop across the LED string is determined by the maximum input peak voltage minus the breakdown voltage of the CCR.

Assuming +10% tolerance of AC mains:

$$\text{MIN}V_{F-\text{Total LEDs}} = \text{AC } V_{\text{inMAXPeak}} - V_{\text{AKMAX}} \quad (\text{eq. 2})$$

$$\begin{aligned} \text{MIN}V_{F-\text{Total LEDs}} &= 120 \text{ V} \times 1.414(+10\%) - 120 \text{ V} = \\ &= 67 \text{ V} \end{aligned}$$

# CCRACGEVB

## Conduction Time (T<sub>ON</sub>)

The conduction time (on time) of the LED string is based on the V<sub>F-TotalLEDs</sub>. The rectified voltage needs to rise above the forward voltage of the LEDs before they begin to conduct and the CCR regulates the current through them. The T<sub>ON</sub> conduction time (%) calculation for the typical 120 VAC is the following:

$$T_{ON}(\%) = 100 \left[ 1 - \left( 2 \sin^{-1} \frac{1}{\pi} \frac{V_{F-TotalLEDs}}{ACV_{in\_TYPPeak}} \right) \right] \quad (\text{eq. 3})$$

When using 5 x Cree XLamp MX-6S in series providing a V<sub>F-TotalLEDs</sub> = 100 V, conduction time equals:

$$T_{ON}(\%) = 100 \left[ 1 - \left( 2 \sin^{-1} \frac{1}{\pi} \frac{100 \text{ V}}{120 \text{ V} \times 1.414} \right) \right] = 62.3\%$$

## Design Trade-off

- The lower the V<sub>F-TotalLEDs</sub>:
  - ◆ Higher %T<sub>ON</sub> conduction time , more light output
  - ◆ Lower efficiency due to higher power lost across CCR
- The higher the V<sub>F-TotalLEDs</sub>:
  - ◆ Higher efficiency due to less power lost across CCR
  - ◆ Lower %T<sub>ON</sub> conduction time, less light output

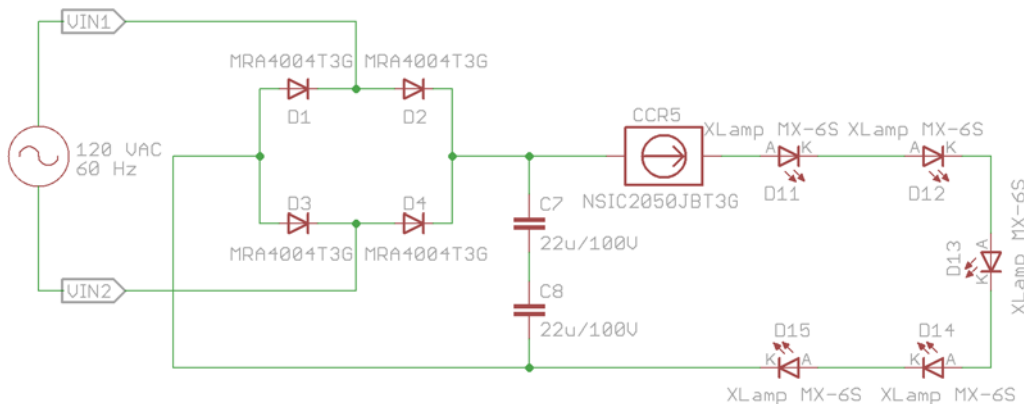


Figure 3. Straight Non-dimmable LED Driver with Output Capacitor (120 VAC example)

## Straight LED Driver, with Triac Dimming (120 VAC Example):

This circuit incorporates an additional circuit to provide a minimum load for the Triac dimmer.

To set up the CCRACGEVB for the Straight LED driver dimming topology, place jumpers according to Table 3. Figure 4 depicts the schematic with the evaluation board reference designators.

Table 3. JUMPERS PLACED ONTO THE EVB

Jumpers in Place	Reference Data
J1, J7, J13, J15, J16, J18, J20, J22, J26	Appendix C

## Straight LED Driver. Non-dimming, with Output Capacitor (120 VAC Example):

This circuit will have a higher efficiency compared to the straight LED driver.

To set up the CCRACGEVB for the Straight LED driver non-dimming topology with output Capacitor, place jumpers according to Table 2. Figure 3 depicts the schematic with the evaluation board reference designators.

Table 2. JUMPERS PLACED ONTO THE EVB

Jumpers in Place	Reference Data
J1, J10, J13, J18, J19, J20, J22, J26	Appendix B

The AC input is rectified using an AC bridge (D1 – D4) and charges the capacitor (C7 & C8 in series). The voltage on the capacitor will be equal to or a little below the peak rectified voltage. A CCR (CCR3, 4, 5 or 6) controls the current through the LED string. The charge on the capacitor allows the CCR to continue providing current to the LED string when the rectified AC voltage is below the V<sub>F-TotalLEDs</sub>. The Inrush current limiter (T1, R2 & C6) can be employed to limit the inrush current or current spike from a power surge. As the capacitor C6 charges, T1 will turn on and provide a low impedance bypass.

This circuit comprises R3 – R7, R17, CCR1, M1, Q1 and D8. The selection of R3/4 and the value of R7 are based on the Triac dimmer. The selection of R3 & R4 in parallel (5.0 KΩ) and R7 & R17 in series (50 Ω) have produced good results.

# CCRACGEVB

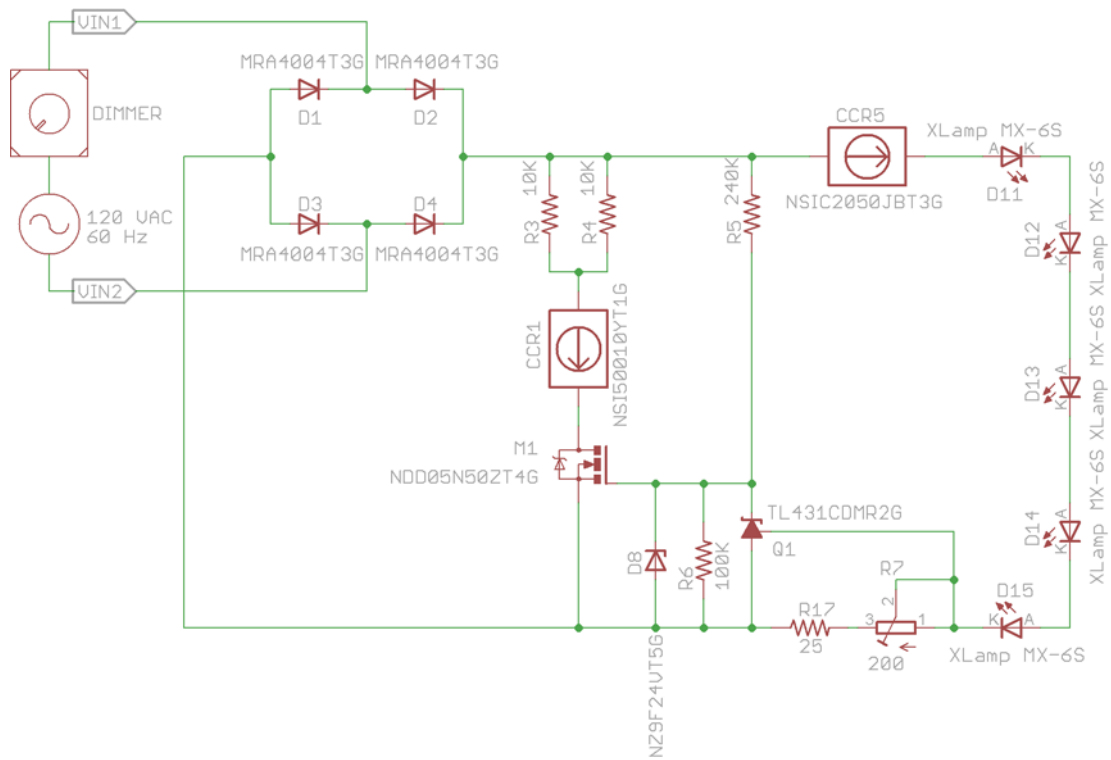


Figure 4. Straight Dimmable LED Driver (120 VAC example)

## Cap-Drop LED Driver Topology, Non-dimming (120 & 230 VAC Example):

The Cap-Drop circuit is selected for high efficiency and a low BOM cost.

To set up the CCRACGEVB for the Cap-Drop LED driver non-dimming topology, place jumpers according to Table 4. Figure 6 & Figure 7 depict the schematics with the evaluation board reference designators. Appendix D shows the 120 VAC example and Appendix E provides its 230 VAC counterpart.

Table 4. JUMPERS PLACED ONTO THE EVB

Jumpers in Place	Reference Data
J2, J13, J19, J20, J25, J22, J26	Appendix D (120 VAC)
J2, J13, J19, J20, J22, J24	Appendix E (230 VAC)

The operation of the Cap-Drop circuit is very similar to the straight LED circuit with the advantage of improved efficiency because the AC voltage is reduced to be a little over the forward voltage of the LED string.

## Inrush Current Limiter

The Inrush Current Limiter (Figure 5) is incorporated to reduce the surge current if power is connected at the peak of the AC input. At turn on, the 6.8 KΩ resistor will limit the current as the Darlington MJB5742 will be off and the 33 μF capacitor will appear as a short. As the capacitor charges the Darlington will turn on and provide a low impedance bypass.

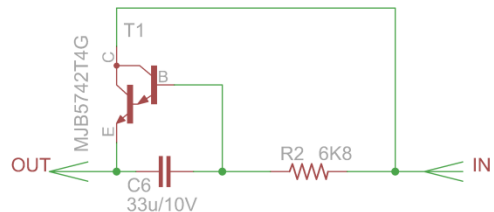


Figure 5. Inrush Current Limiter

# CCRACGEVB

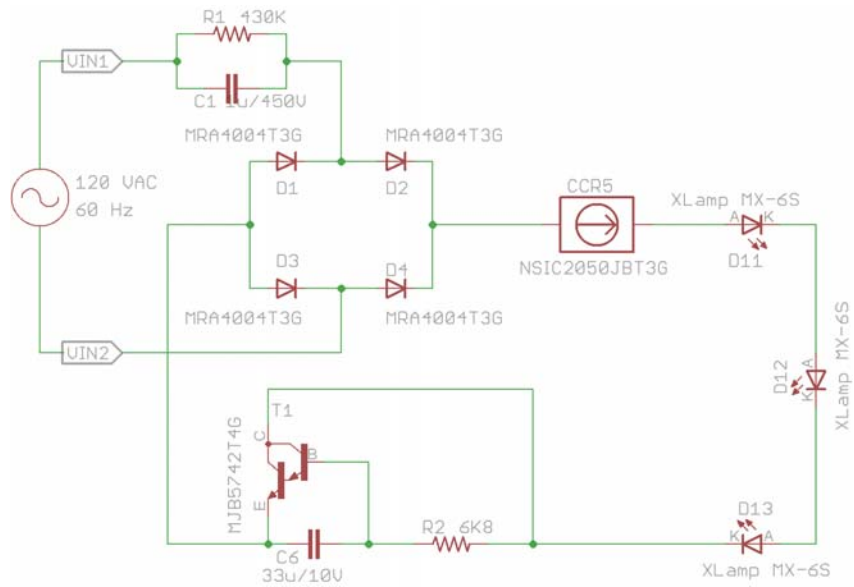


Figure 6. Cap-Drop LED Driver, Non-dimming (120 VAC example)

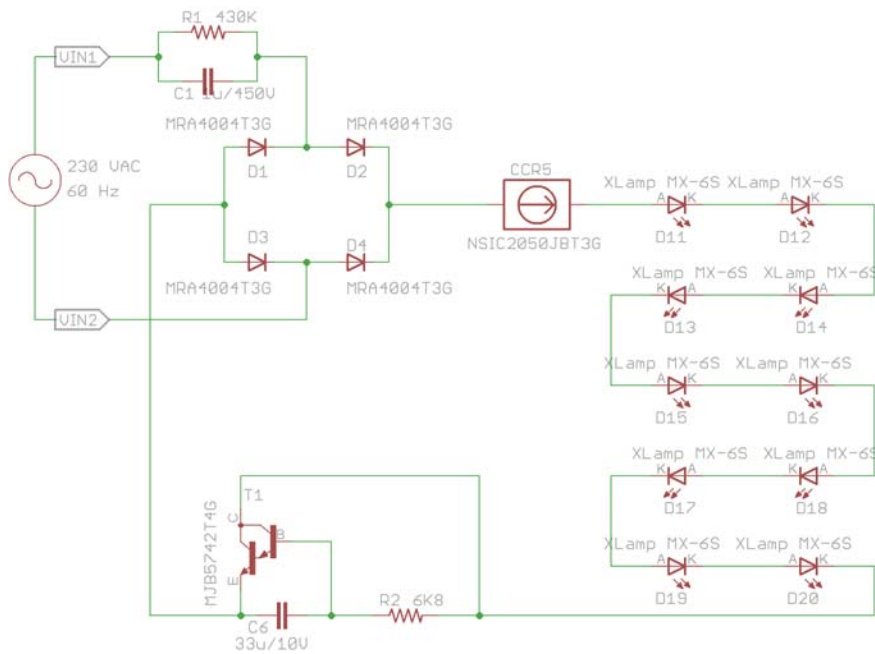


Figure 7. Cap-Drop LED Driver, Non-dimming (230 VAC example)

## Cap-Drop LED Driver Topology with Triac Dimming (120 VAC Example):

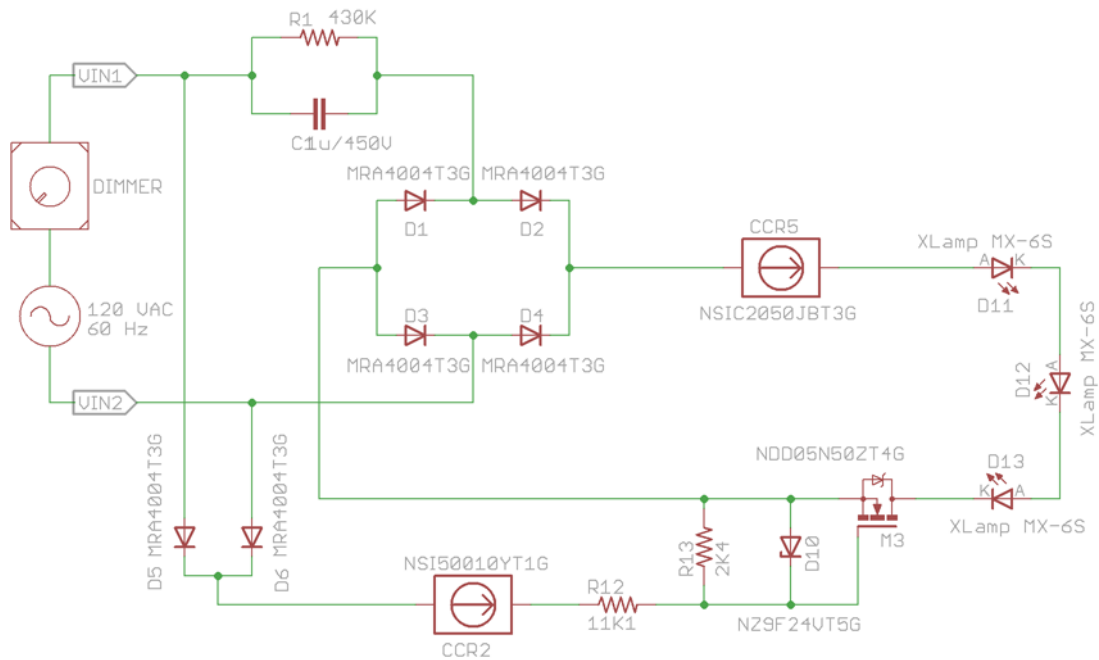
To set up the CCRACGEVB for the Cap-Drop LED driver dimming topology, place jumpers according to Table 5. Figure 8 depicts the schematic with the evaluation board reference designators.

Table 5. JUMPERS PLACED ONTO THE EVB

Jumpers in Place	Reference Data
J2, J13, J18, J19, J20, J21, J25, J26	Appendix F

This circuit has the addition of a Triac Edge Detect circuit to switch the LED string on and off. The circuit is comprised of: D5, D6, D10, CCR2, R12, R13 & M3. The circuit detects the triac waveform and turns the MOSFET M3 on. CCR2 provides a basic load to the triac to keep it functioning correctly.

# CCRACGEVB



**Figure 8. Cap-Drop LED Driver with Triac Dimming (120 VAC example)**

## **Chopper LED Driver Topology 85 VAC to 250 VAC, Non-dimming:**

The Chopper circuit is selected for high efficiency and a wide input voltage range.

To set up the CCRACGEVB for the Chopper LED driver non-dimming topology, place jumpers according to Table 6. Figure 9 depicts the schematic with the evaluation board reference designators.

**Table 6. JUMPERS PLACED ONTO THE EVB**

Jumpers in Place	Reference Data
J1, J8, J10, J13, J19, J22, J25, J26	Appendix G

The operation of the Chopper circuit can be broken into two sub-circuits; a simple buck and a straight LED driver with output capacitance. The AC is then rectified using an AC bridge (D1 – D4).

A CCR (CCR3, 4, 5 or 6) controls the current through the LED string.

The Buck circuit is comprised of a voltage divider R8 & R16/R10 that are used to set the voltage through TL431, that the MOSFET switch M2 turns off. When the output from the bridge is below the set voltage, M2 is ON and capacitor C7/C8 is charged. If the voltage is above the threshold voltage  $V_f$  of the LED string, then the CCR will limit the current through the LEDs. When the voltage is above the set voltage, the MOSFET is turned OFF. The LEDs then draw current from the charge on capacitor C7/C8 which is limited by the CCR.

## **Chopper LED Driver Topology 85 VAC to 250 VAC, with Triac Dimming:**

This circuit is the same as Figure 9 with the addition of the Triac Dimming Detect circuit as described in the Cap-Drop description above (Figure 8).

To setup the CCRACGEVB for the Chopper LED driver non-dimming topology, place jumpers according to Table 7.

Figure 10 depicts the schematic with the evaluation board reference designators.

**Table 7. JUMPERS PLACED ONTO THE EVB**

Jumpers in Place	Reference Data
J1, J8, J13, J10, J19, J21, J25, J26	Appendix H



# CCRACGEVB

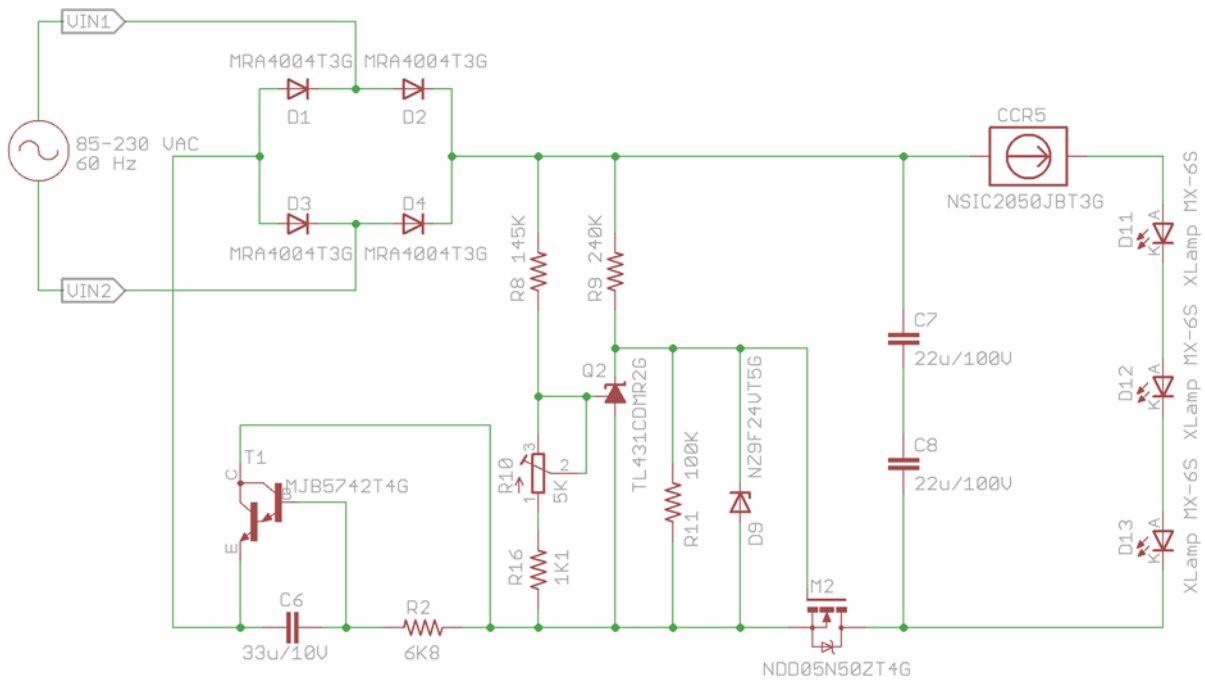


Figure 9. Chopper Non-dimming LED Driver (85 VAC to 230 VAC example)

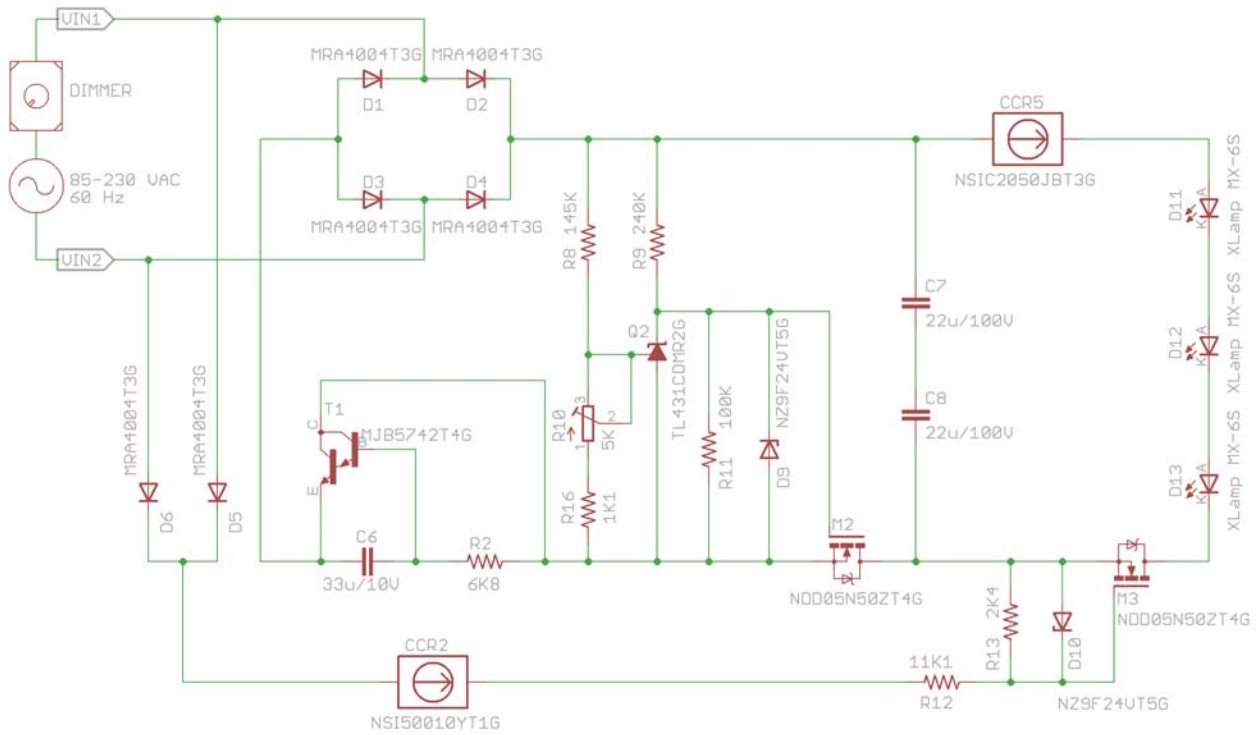


Figure 10. Chopper LED Driver with Dimming (85 VAC to 230 VAC example)



# CCRACGEVB

## APPENDIX A

### Straight LED Driver, Non-dimming (120 VAC Example)

Table 8. PERFORMANCE EVALUATION

Power Factor	THD [%]	Efficiency [%]	Input Power [W]
0.96	26.7	62.7	5.5

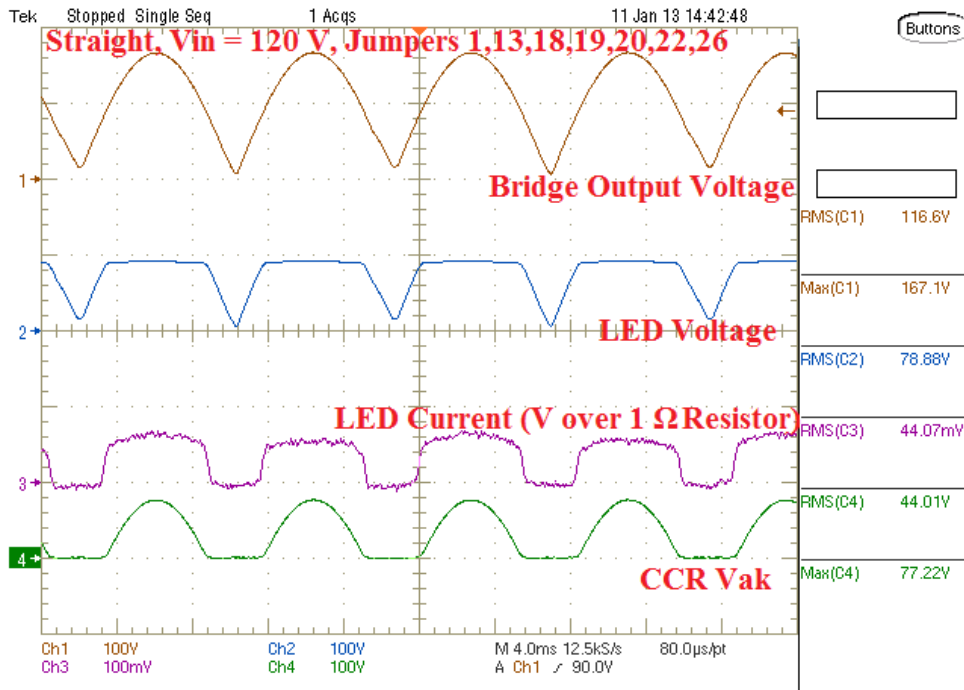


Figure 11. Bridge Output, LED, LED Current and CCR V<sub>AK</sub> Waveforms

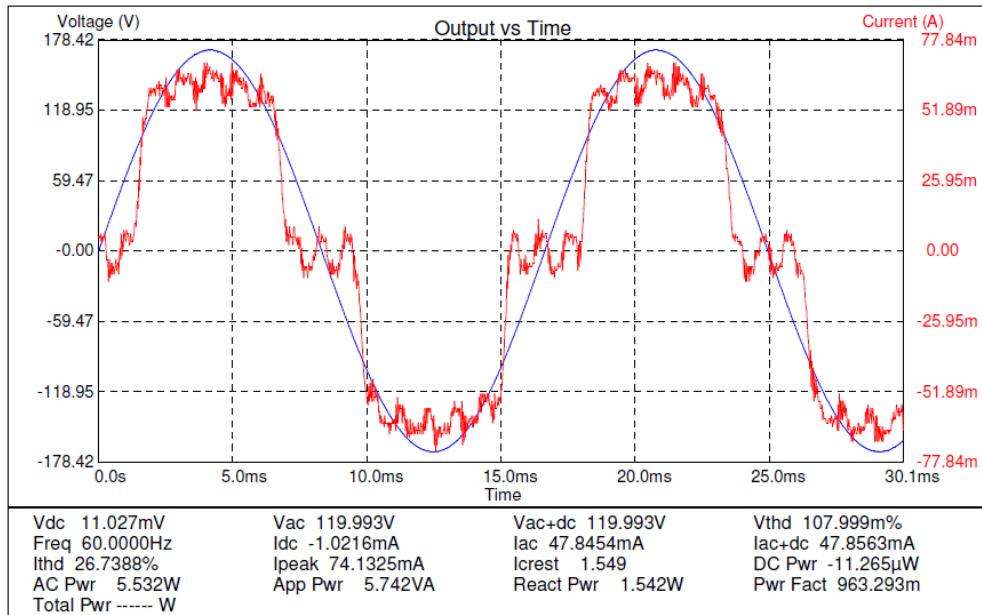


Figure 12. Input Current and Voltage Waveforms from Power Main

# CCRACGEVB

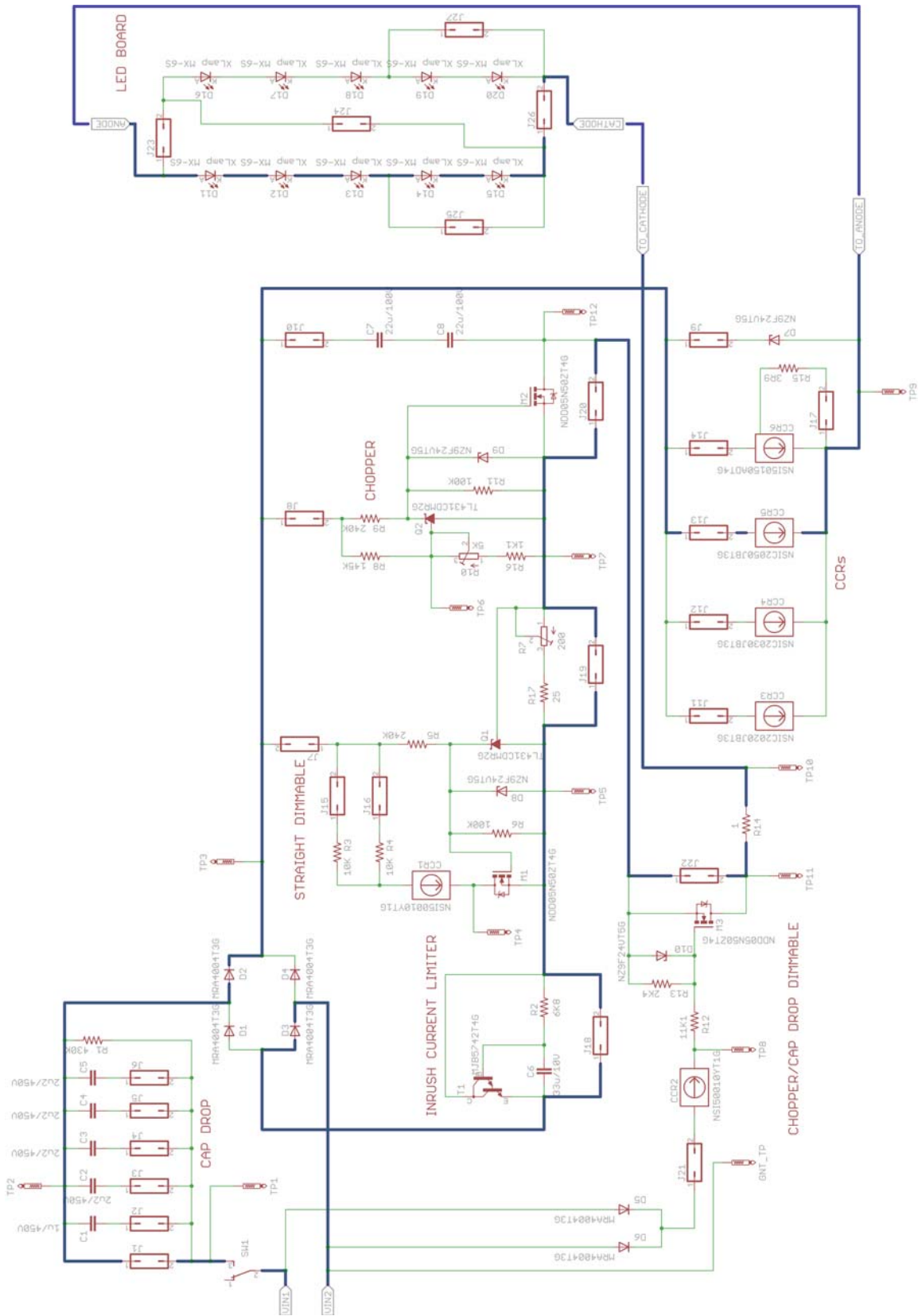


Figure 13. Straight LED Driver, Non-dimming Circuitry Flow (120 VAC)

# CCRACGEVB

## APPENDIX B

### Straight LED Driver, Non-dimming, with Output Capacitor (120 VAC Example)

Table 9. PERFORMANCE EVALUATION

Power Factor	THD [%]	Efficiency [%]	Input Power [W]
0.63	65.9	68.2	6.8

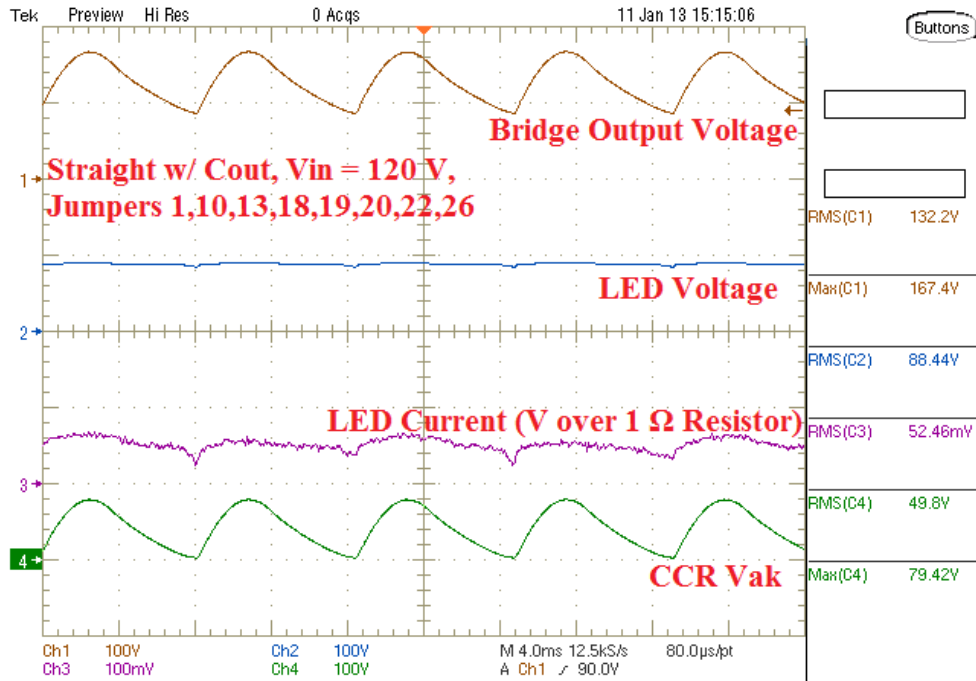


Figure 14. Bridge Output, LED, LED Current and CCR  $V_{AK}$  Waveforms

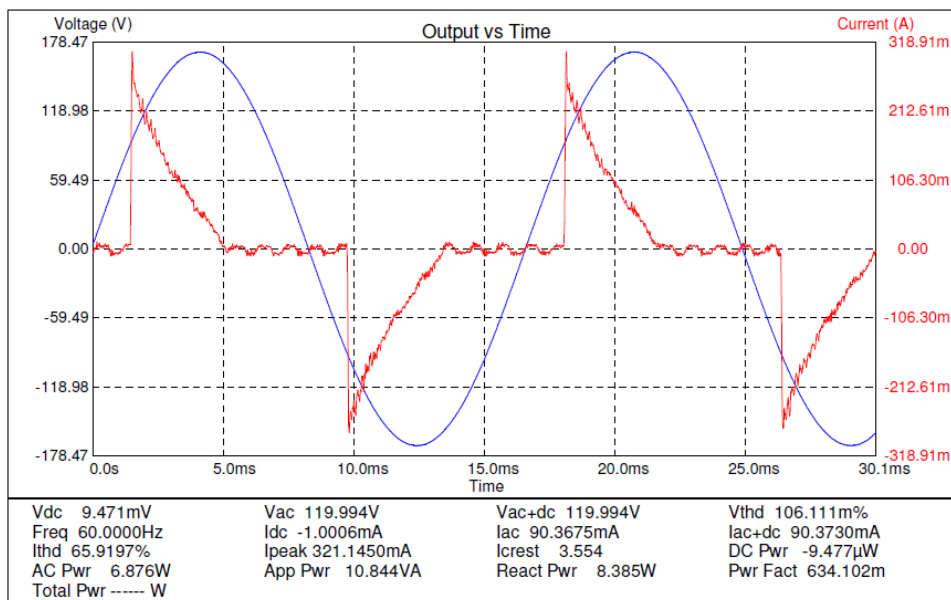


Figure 15. Input Current and Voltage Waveforms from Power Main

# CCRACGEVB

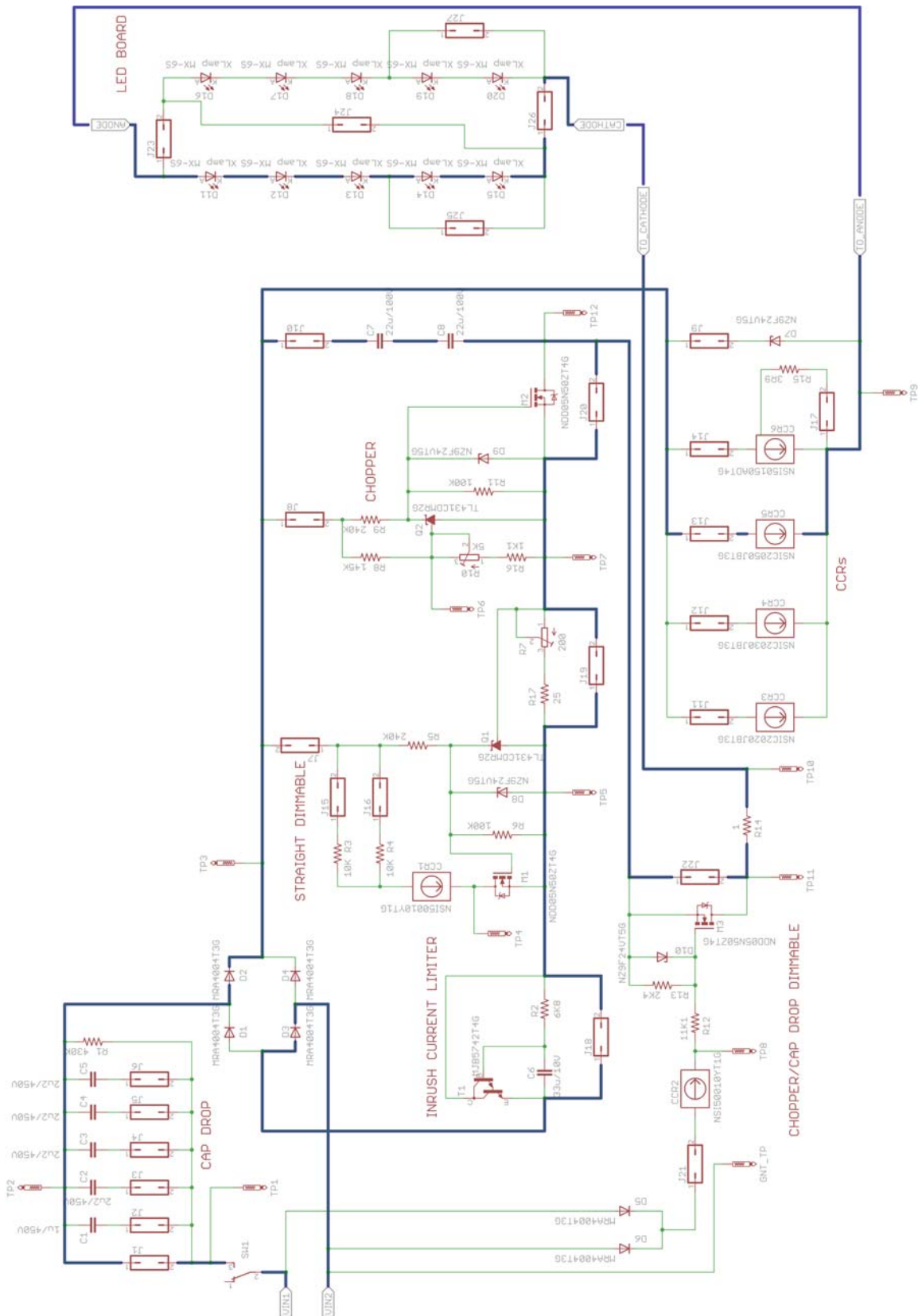


Figure 16. Straight LED Driver, Non-dimming w/Cap Circuitry Flow (120 VAC)

# CCRACGEVB

## APPENDIX C

### Straight LED Driver, with Triac Dimming (120 VAC Example)

Table 10. PERFORMANCE EVALUATION

Power Factor	THD [%]	Efficiency [%]	Input Power [W]
0.93	36.1	59.4	4.3

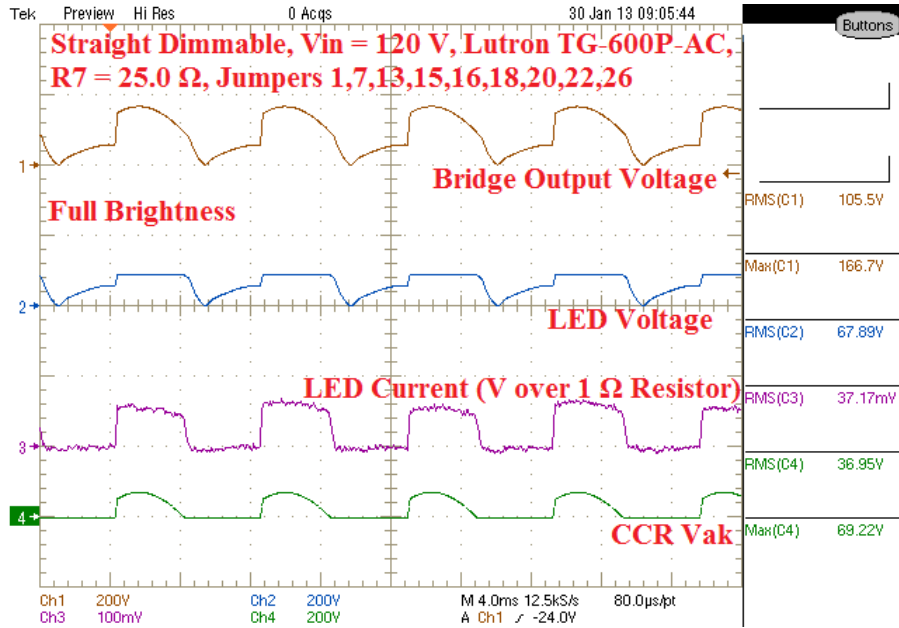


Figure 17. Bridge Output, LED, LED Current and CCR  $V_{AK}$  Waveforms (Full Brightness)

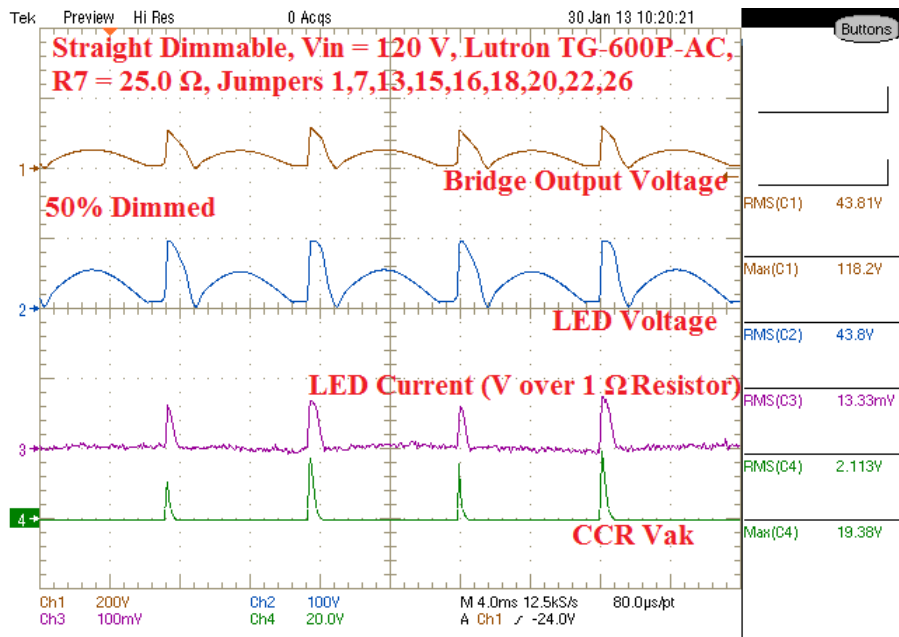


Figure 18. Bridge Output, LED, LED Current and CCR  $V_{AK}$  Waveforms (50% Dimmed)

# CCRACGEVB

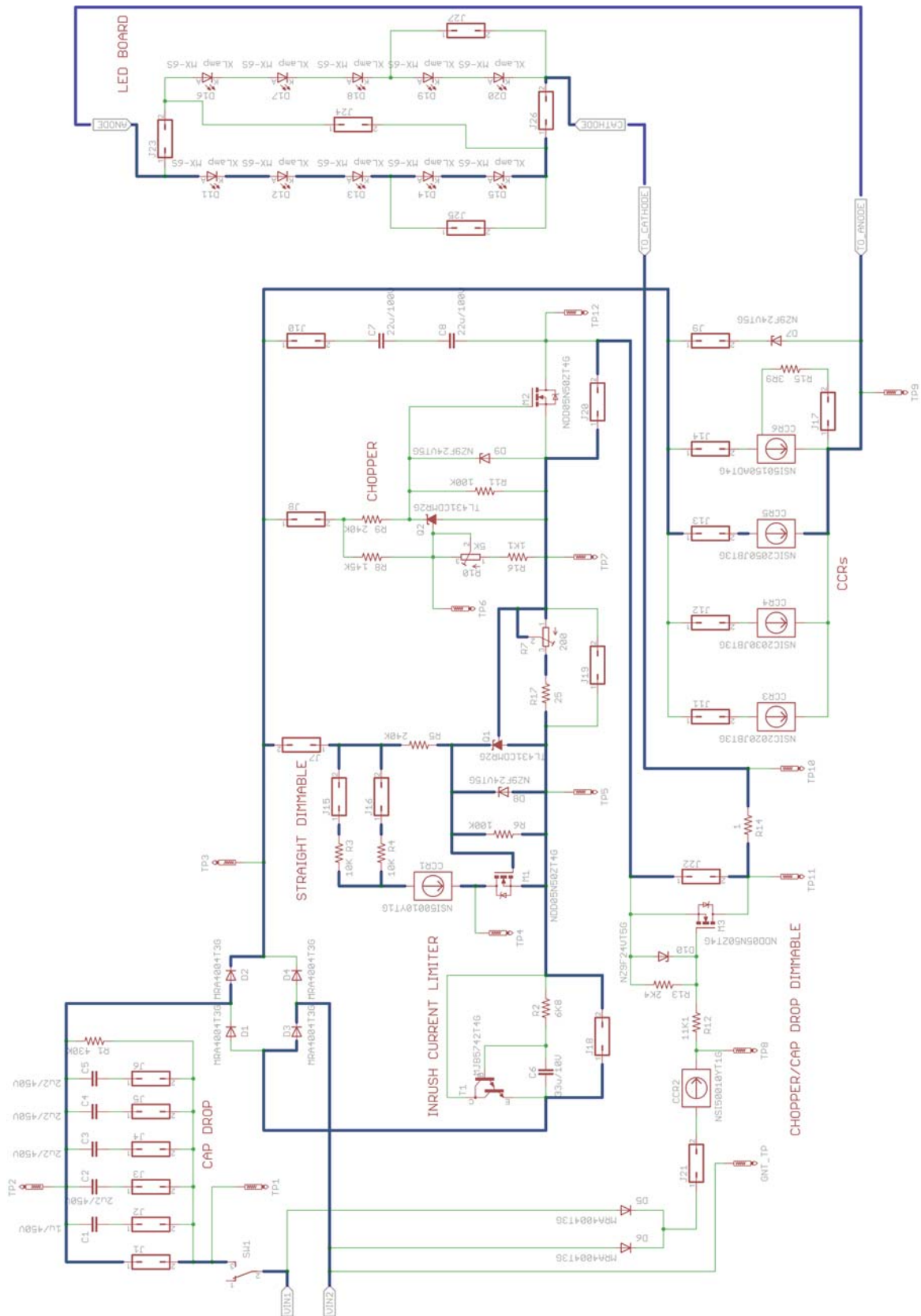


Figure 19. Straight LED Driver, with Triac Dimming Circuitry Flow (120 VAC)

# CCRACGEVB

## APPENDIX D

### Cap-Drop LED Driver Topology, Non-dimming (120 VAC Example)

Table 11. PERFORMANCE EVALUATION

Power Factor	THD [%]	Efficiency [%]	Input Power [W]
0.76	41.24	54.6	3.47

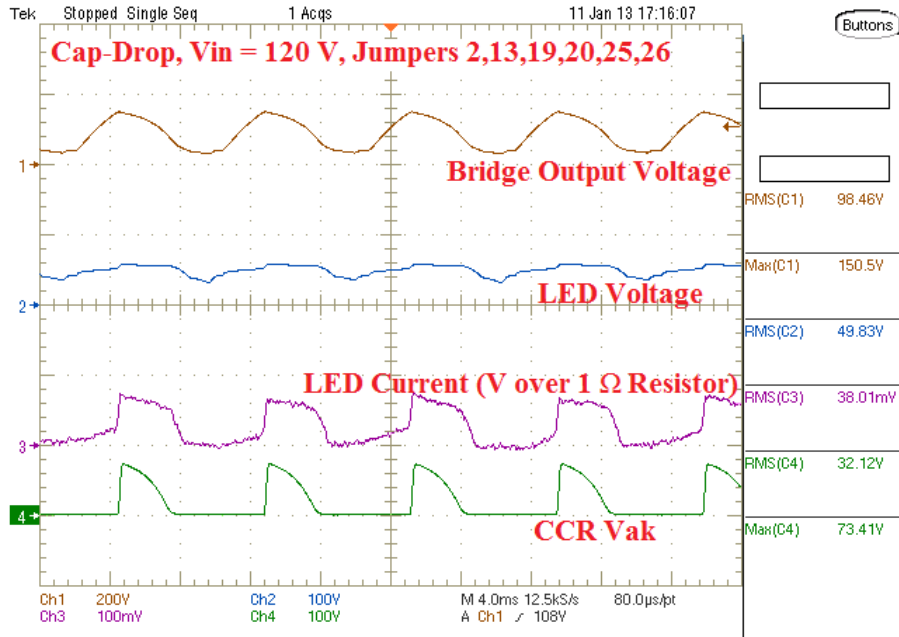


Figure 20. Bridge Output, LED, LED Current and CCR V<sub>AK</sub> Waveforms

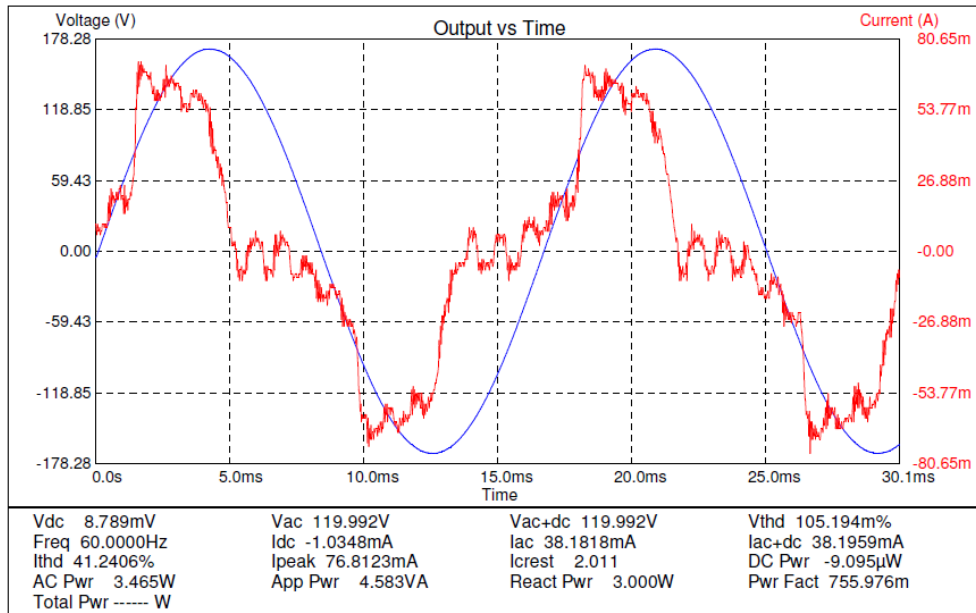


Figure 21. Input Current and Voltage Waveforms from Power Main



# CCRACGEVB

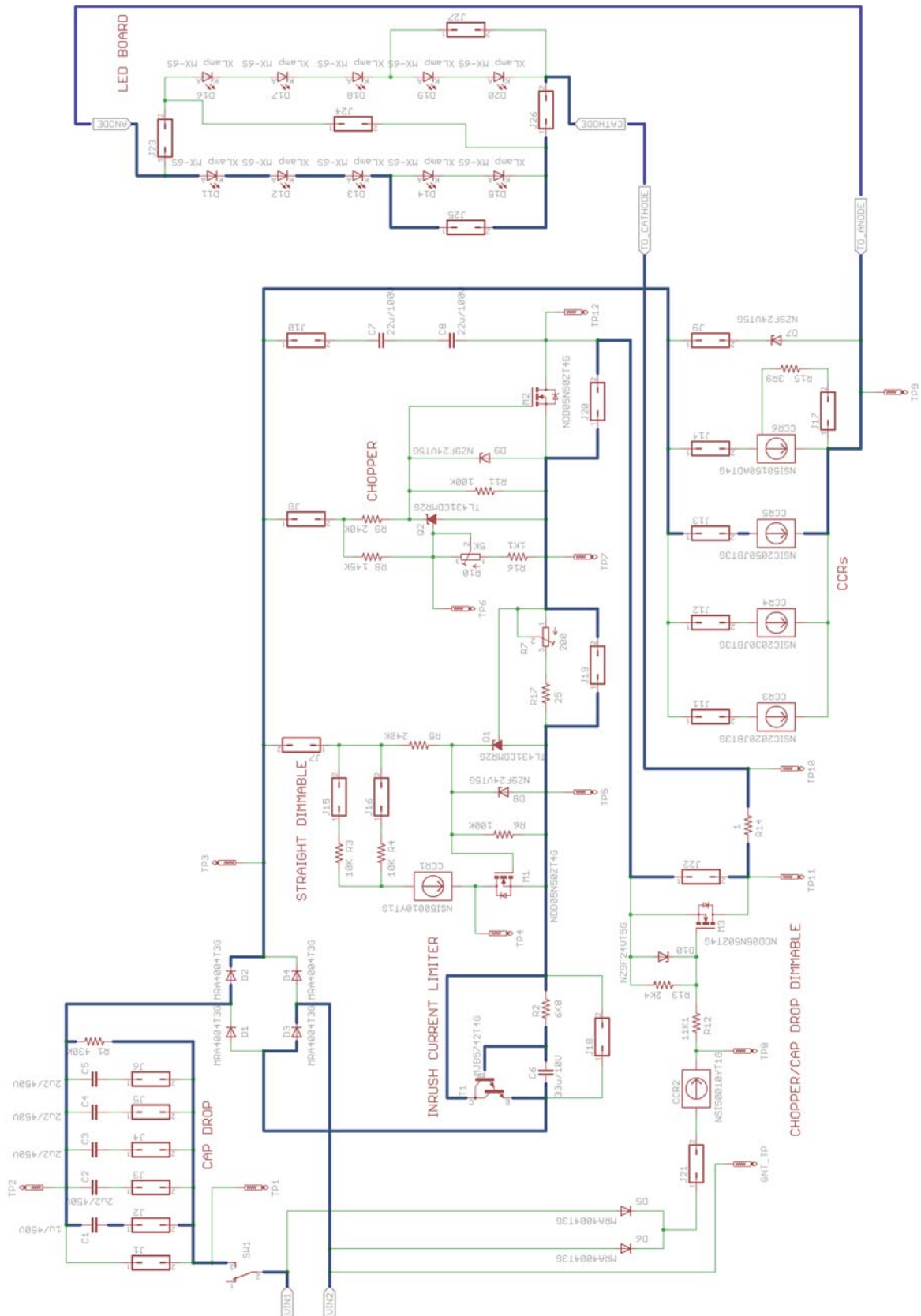


Figure 22. Cap-Drop LED Driver Topology, Non-dimming Circuitry Flow (120 VAC)

# CCRACGEVB

## APPENDIX E

### Cap-Drop LED Driver Topology, Non-dimming (230 VAC Example)

Table 12. PERFORMANCE EVALUATION

Power Factor	THD [%]	Efficiency [%]	Input Power [W]
0.88	41.6	74.6	7.76

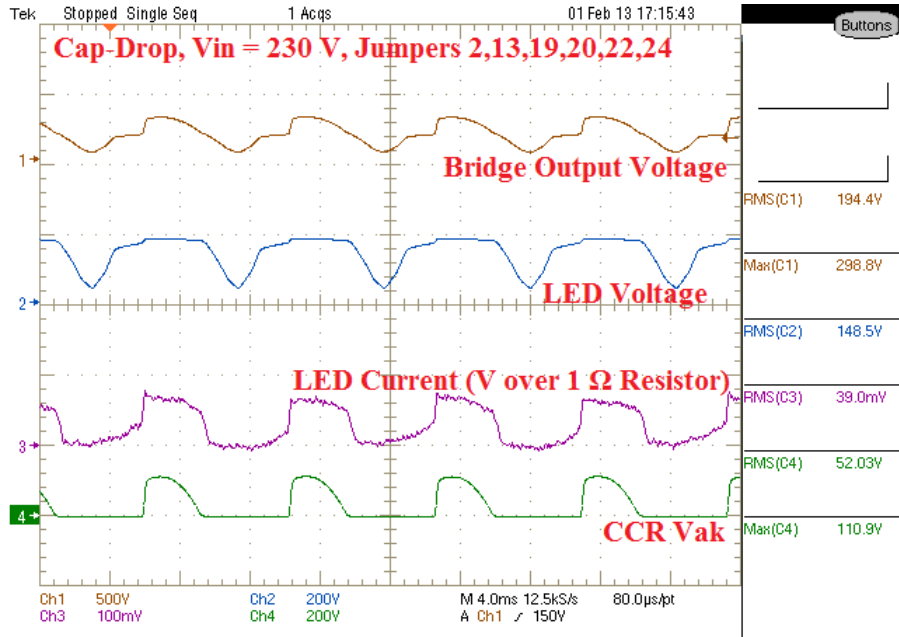


Figure 23. Bridge Output, LED, LED Current and CCR  $V_{AK}$  Waveforms

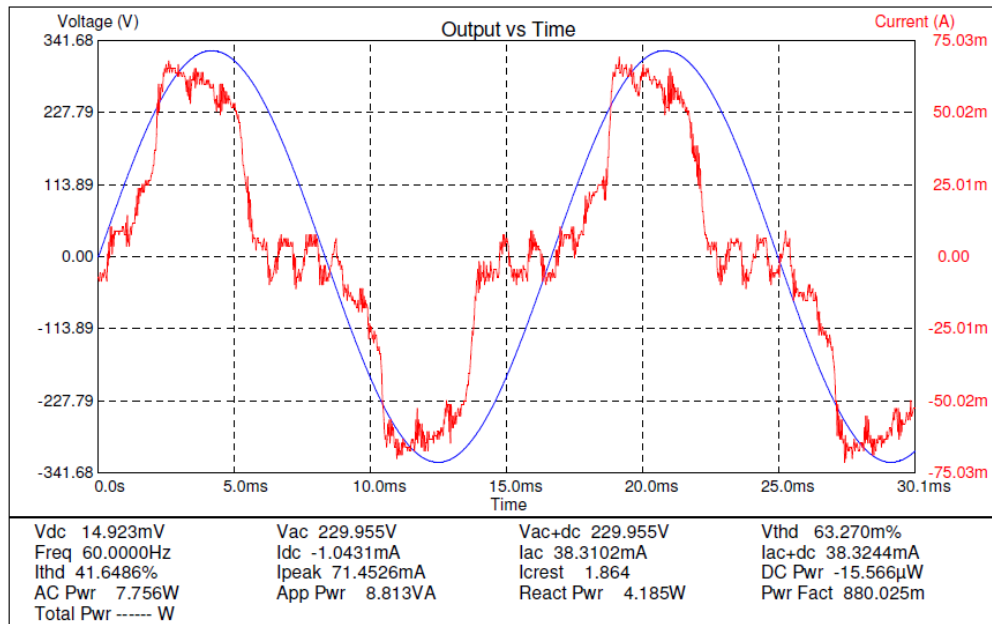


Figure 24. Input Current and Voltage Waveforms from Power Main

# CCRACGEVB

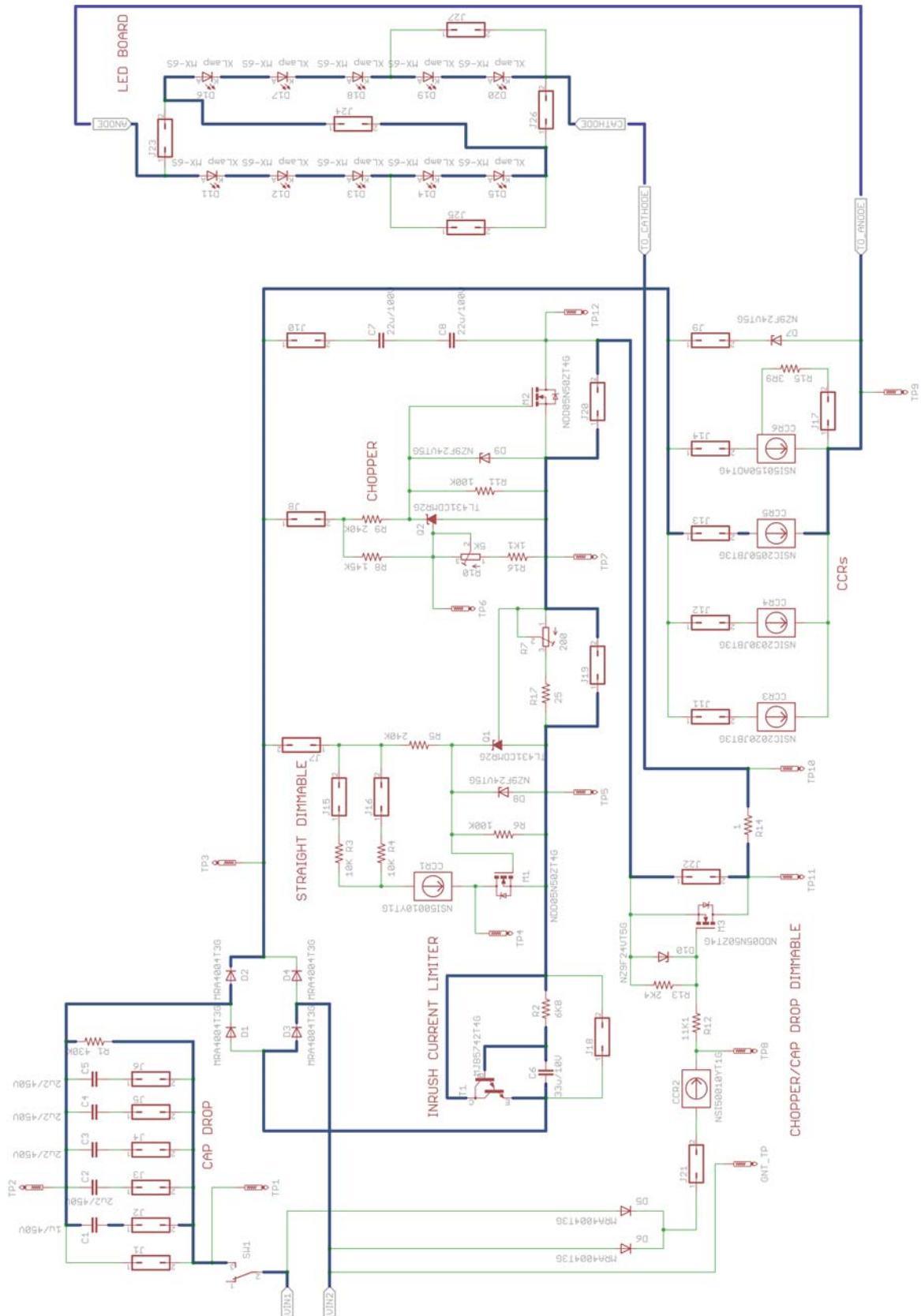


Figure 25. Cap-Drop LED Driver Topology, Non-dimming Circuitry Flow (230 VAC)

# CCRACGEVB

## APPENDIX F

### Cap-Drop LED Driver Topology with Triac Dimming (120 VAC Example)

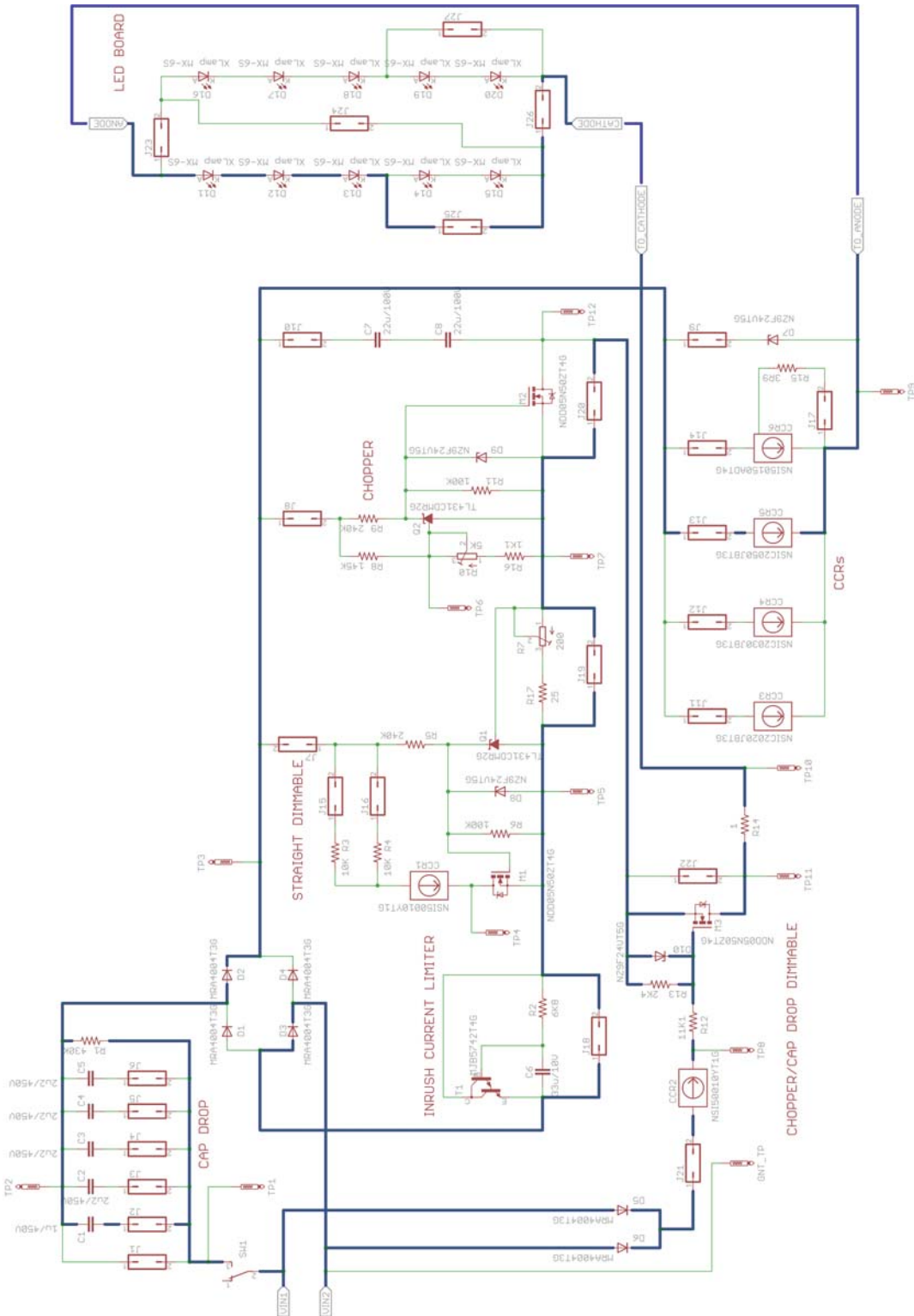


Figure 26. Cap-Drop LED Driver Topology with Triac Dimming Circuitry Flow (120 VAC)

# CCRACGEVB

## APPENDIX G

### Chopper LED Driver Topology 85 VAC to 250 VAC, Non-dimming

Table 13. PERFORMANCE EVALUATION (85 VAC)

Power Factor	THD [%]	Efficiency [%]	Input Power [W]
0.48	83.6	82.4	3.6

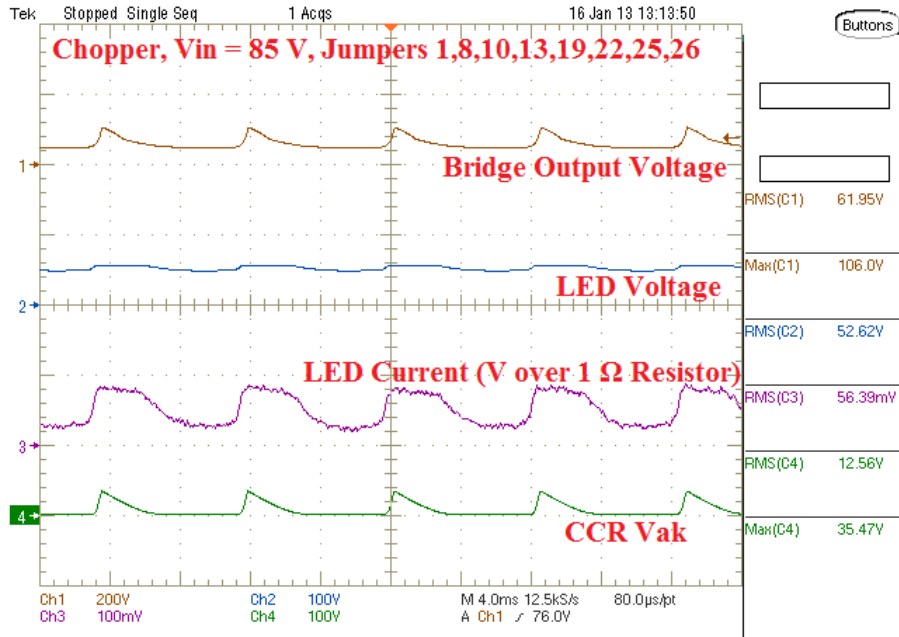


Figure 27. Bridge Output, LED, LED Current and CCR  $V_{AK}$  Waveforms (85 VAC)

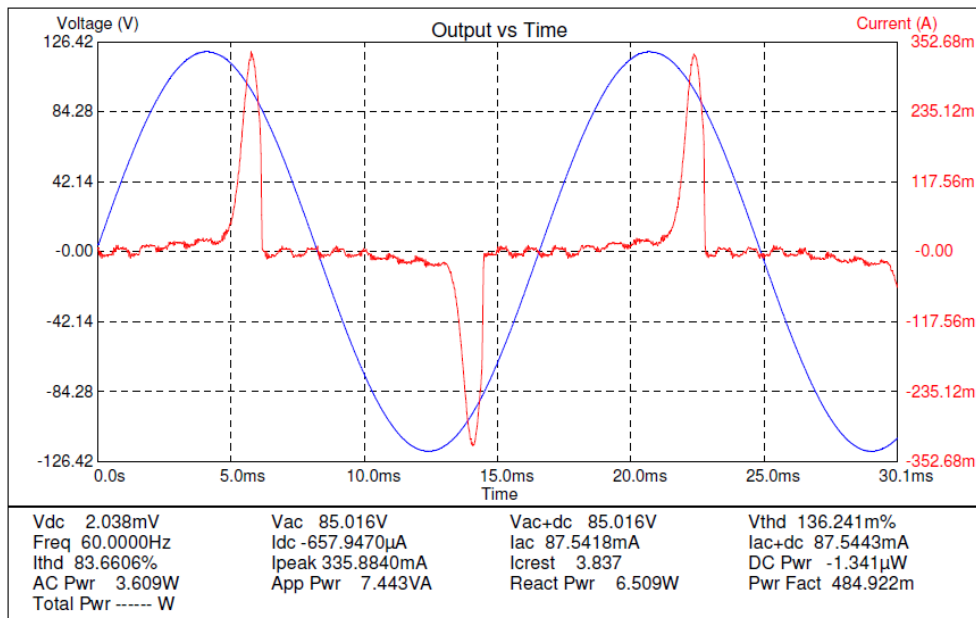


Figure 28. Input Current and Voltage Waveforms from Power Main (85 VAC)

# CCRACGEVB

Table 14. PERFORMANCE EVALUATION (230 VAC)

Power Factor	THD [%]	Efficiency [%]	Input Power [W]
0.2	96.78	32.4	10.3

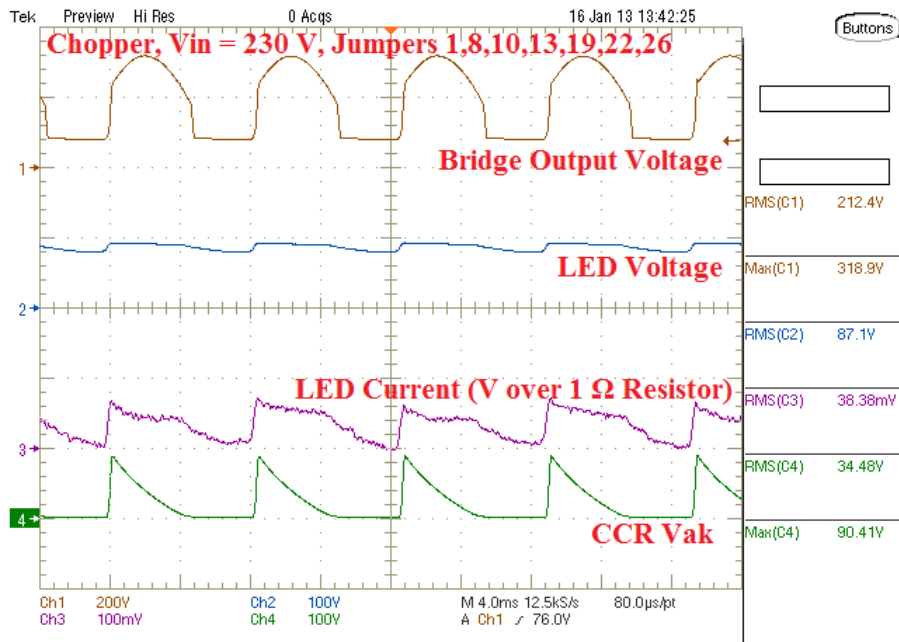


Figure 29. Bridge Output, LED, LED Current and CCR  $V_{AK}$  Waveforms (230 VAC)

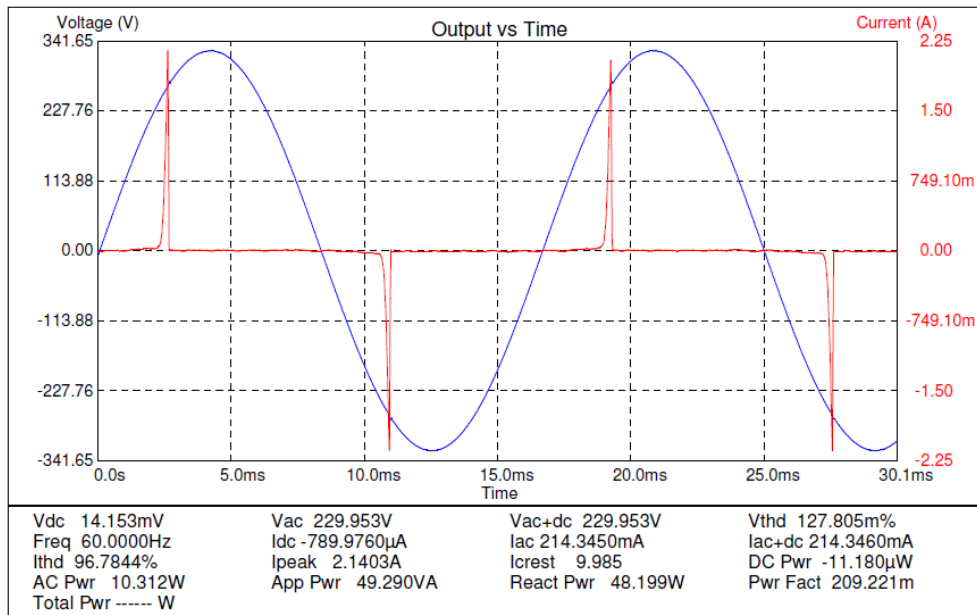


Figure 30. Input Current and Voltage Waveforms from Power Main (230 VAC)

# CCRACGEVB

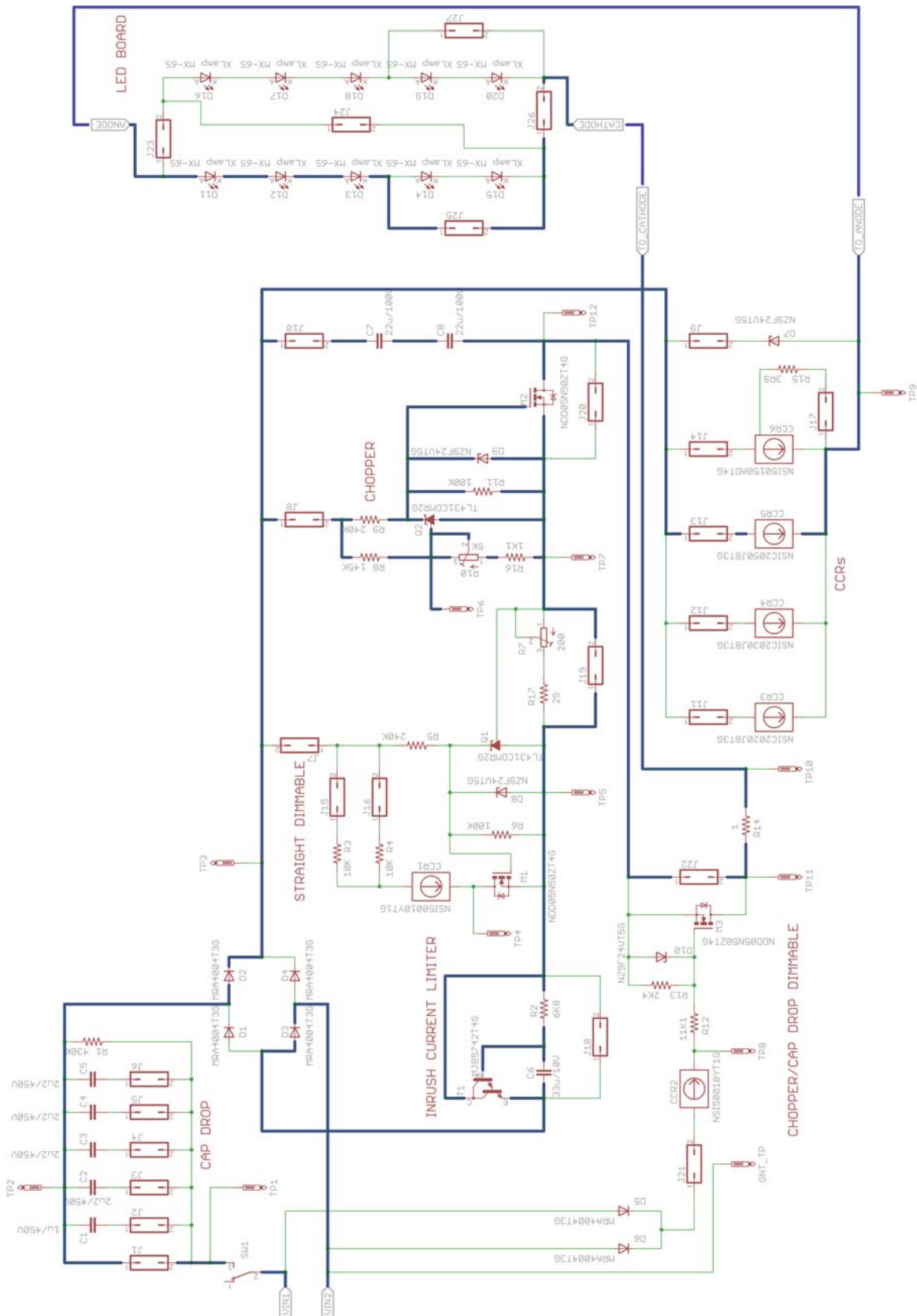


Figure 31. Chopper LED Driver Topology 85 VAC to 250 VAC, Non-dimming Circuitry Flow



# CCRACGEVB

## APPENDIX H

### Chopper LED Driver Topology 85 VAC to 250 VAC, with Triac Dimming

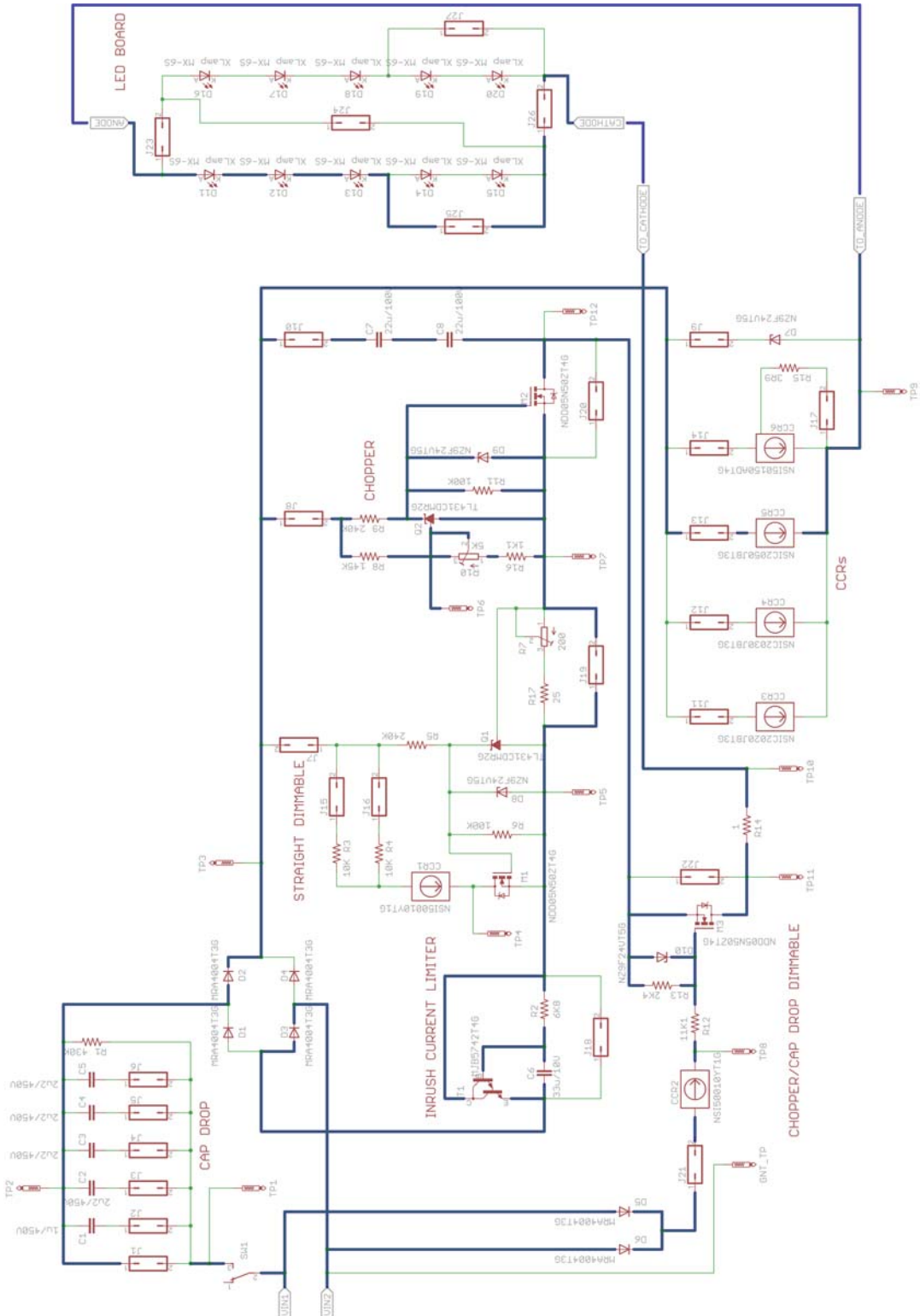


Figure 32. Chopper LED Driver Topology 85 VAC to 250 VAC, with Triac Dimming Circuitry Flow