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230V_{AC} Off-line LED Driver with Dimming and Short-Circuit Load Protection using the HV9805 Controller

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INTRODUCTION

This application note provides a 230V_{AC} off-line LED driver, three steps dimming solution with load-side short-circuit protection using the HV9805 device. Based on a boost topology with power factor correction (PFC) and output overvoltage protection (OVP) followed by a linear output current regulator, this solution also offers soft enable-disable control.

HV9805 DEVICE GENERAL DESCRIPTION

The HV9805 driver integrated circuit (IC) is targeted at general LED lighting products, such as LED lamps and LED lighting fixtures with a maximum power rating of about 25W at 120V_{AC} and 50W at 230V_{AC}.

A two-stage topology provides true constant current drive for the LED load while drawing mains power with high power factor. The first stage, a boundary conduction mode boost converter, transfers power from the AC line to a second stage linear current regulator with high power factor and high efficiency. The linear current regulator, arranged for operation with low overhead voltage, transfers power from the first stage to the LED load with true constant current (no ripple) and protects the LED load from the overvoltage that may pass from mains to the output of the first stage.

The IC is particularly geared to drive a high voltage LED load. An LED load arranged as a high-voltage load is capable of offering cost advantages in terms of heat management and optics. The boost converter employs a cascode switch for high-speed switching and convenient generation of the V_{DD} supply. The control device of the cascode switch is an integral part of the HV9805 and is rated at 700 mA peak. Current for powering the V_{DD} supply is derived by means of an internal connection to the cascode switch.

The main characteristics and features of the HV9805 LED driver include a two Stage Driver Topology:

- 1st Stage with:
  - Boundary Conduction Mode (BCM) boost with power factor correction
  - High power factor (0.98 typical)
  - High efficiency (90% typical)
  - Simple V_{DD} supply: no auxiliary winding required
  - Boost converter cascode switch: internal switch rated at 700 mA peak
  - Supports up to 25W at 120V_{AC}
  - Supports up to 50W at 230V_{AC}
- 2nd Stage:
  - Linear post-regulator with low overhead voltage
  - Zero LED current and brightness ripple
  - Provides true DC light and protects load from line voltage transients
  - Output load open circuit protection
  - High efficiency
  - ±4% reference over temperature

Applications:

- LED Lamps
- LED Lighting Fixtures
- Low Output Voltage Applications, SEPIC Topology

Note:	For the complete list of characteristics, refer to the HV9805 Data Sheet.

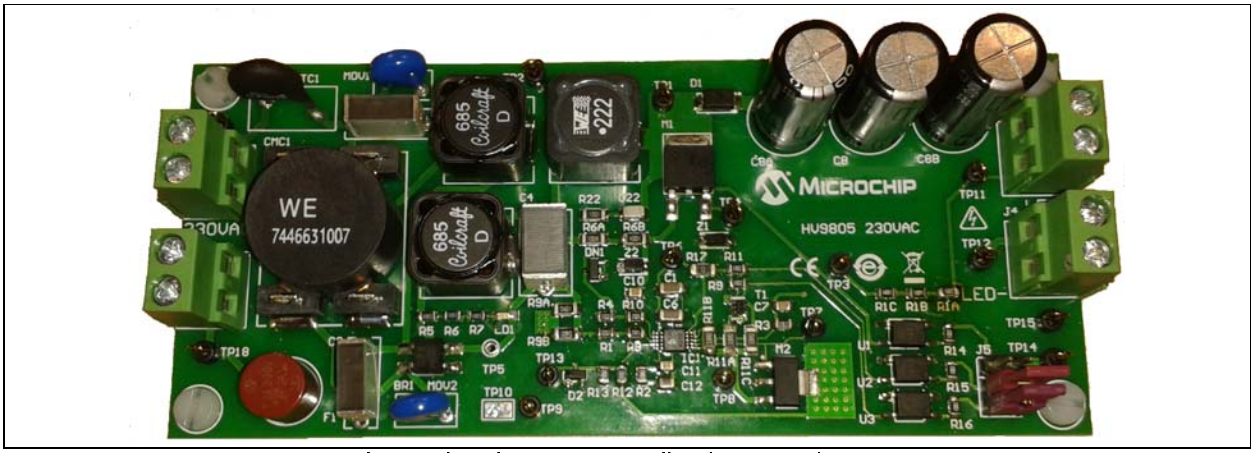

FIGURE 1: HV9805 Three Dimming Steps Application Board.

Figure 2 shows a typical boost application circuit combined with the block diagram of the IC.

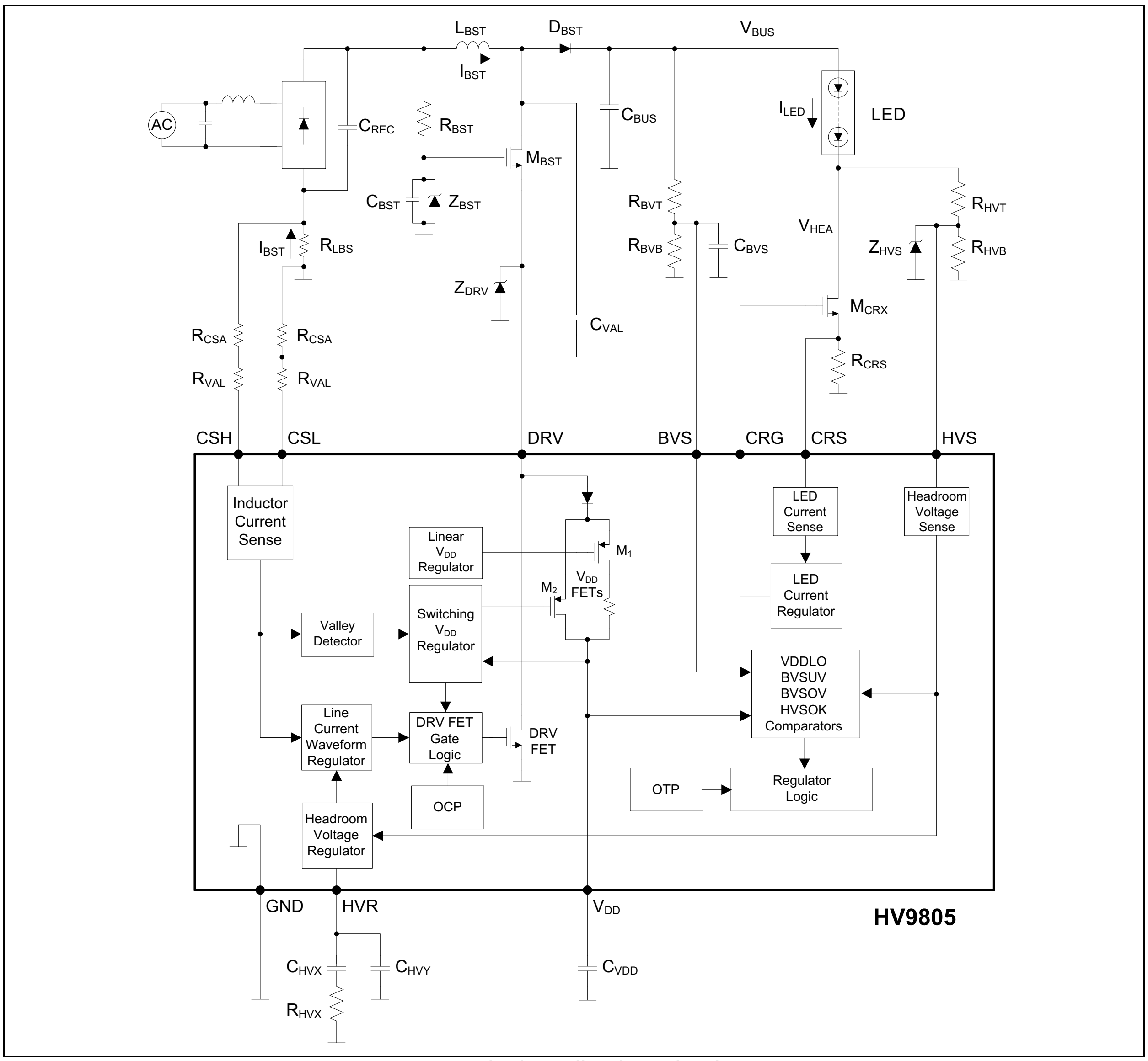

FIGURE 2: HV9805 Boost-Type Typical Application Circuit.

APPLICATION'S INPUT-OUTPUT PARAMETERS

For the boost application, the design parameters can be observed in Table 1.

TABLE 1: DESIGN PARAMETERS

Parameter	Value
Input Voltage	190 - 265 V_{AC} @ 50 Hz
LED String Voltage	415 V_{DC}
LED String Current	90 mA
	60 mA
	30 mA
Overvoltage Protection Threshold	435 V_{DC}

THREE-STEP DIMMING – DESCRIPTION AND OPERATION

The HV9805 LED driver was targeted specifically for streetlights. Initially there was no need of dimming for such an application. However, today's regulations request some level of dimming to reduce energy consumption during the late night periods. Considering the market needs, a three-step dimming application was developed around the HV9805. See Appendix A for the full schematic.

The principle of operation is simple and relies on the modification of the resistor R_{CRS} in series with M_{CRX} in the output linear regulator of HV9805 (see Figure 2).

To obtain the three levels of dimming, the R_{CRS} resistor was split into three parts connected in parallel. Figure 3 depicts a section of the general schematic, representing the resistors involved in the dimming: R11A, R11B, R11C. Two of them, R11C and R11A, are each connected in series with a small MOSFET transistor, M3 and M4 respectively, to GND.

Initially, the two MOSFETs are conducting (ON) since their gates are biased with 7.5V from the V_{DD} pin of the HV9805. Because of the high level output voltages specific for such applications (above 400 V_{DC}), the control signal must be optically isolated. When one or both of the two gate control signals (U2 and U3) are activated through the input optocouplers, either M3 or M4 or both in the same time will turn off. As a result, the linear output regulator series-equivalent resistor (R_{CRS}) will be modified, thus adjusting the LED load current.

In our case, the R11A/B/C each have 33Ω and the equivalent R_{CRS} value can be 11Ω, 16.5Ω or 33Ω. Consequently, the output LED load current of the three-step dimming will be 90 mA, 60 mA or 30 mA.

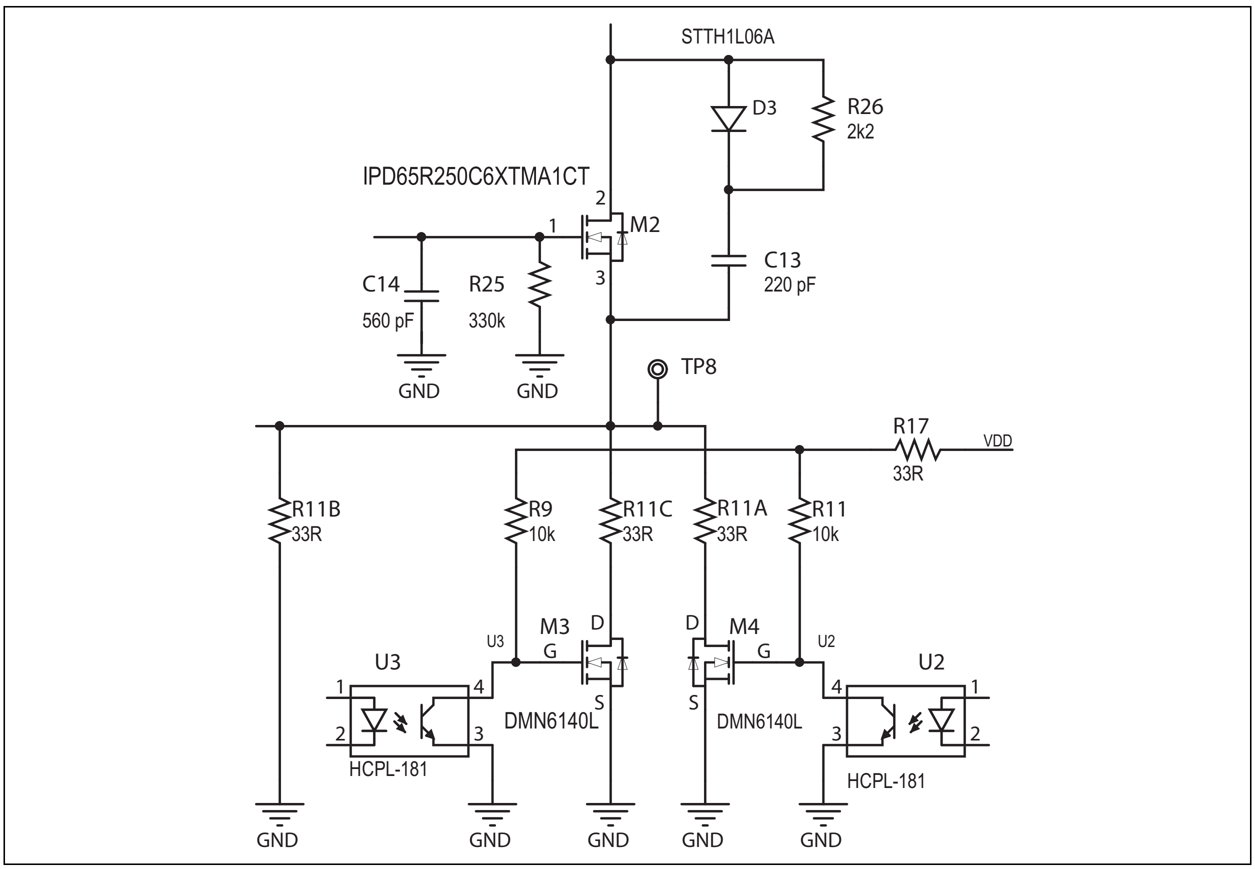

FIGURE 3: Three-Step Dimming Circuit used with the HV9805 Application.

The triggering voltage levels for the dimming steps are related to the input control voltage (0-10V) applied between test points TP14 and TP15 that can be adjusted using Zener diodes Z5 and Z4 (see Figure 4). To activate the dimming, J5 header must be populated with jumpers on 3-4 and 5-6 positions (see Appendix E for triggering voltage levels).

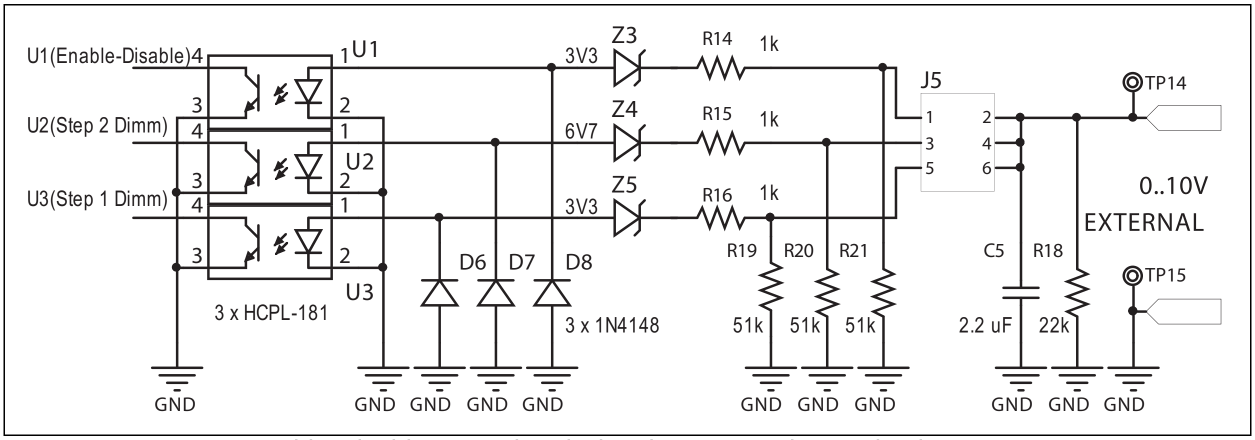

FIGURE 4: Enable-Disable Control and Dimming Steps Trigger Circuit.

ENABLE-DISABLE CONTROL – DESCRIPTION AND OPERATION

To activate the board's Enable-Disable Control, J5 must be populated with a jumper set on position 1-2 (as seen in Figure 4). In a similar manner as in the case of dimming, the Enable-Disable Control becomes active in Disable mode when, depending on the Z3 Zener diode value, the external control voltage exceeds this value (e.g. 3.3V) and the input optocoupler U1 turns off the M1 MOSFET (see Figure 5). In this moment, the board is disabled and the output load current becomes zero. The Z3 diode must not be chosen under 2.7V because of M1's safe operation gate control characteristics. To enable the board, the external control voltage must decrease under the Z3 voltage (see Appendix E for details).

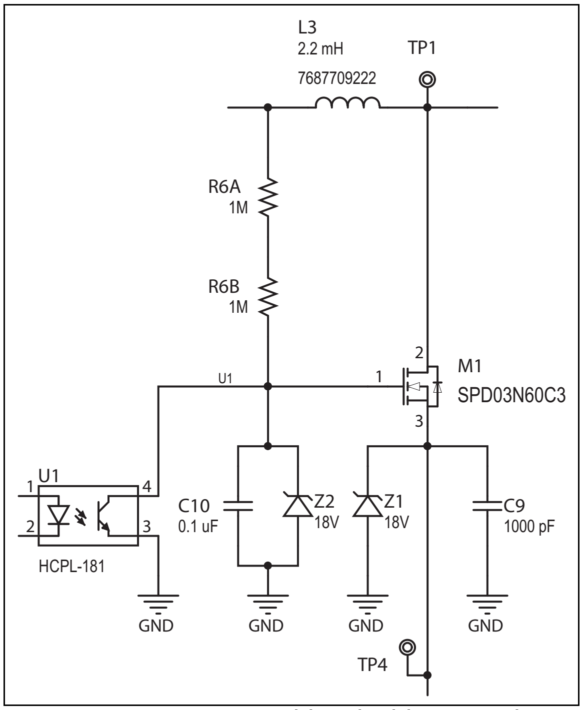

FIGURE 5: Enable-Disable Control Circuit.

SHORT-CIRCUIT PROTECTION – DESCRIPTION AND OPERATION

The working principle of the short-circuit protection (SCP) is that when TP11 and TP12 (see Figure 6 and the schematic in Appendix A) are accidentally connected (producing LED load short circuit), M2 will be turned OFF immediately and the controller will go into an open-circuit condition. In that moment, the TP11 voltage will be charged and discharged between the preset Overvoltage Protection values (e.g. 410V and 435V, see TP11 wave in Figure 19). Note that the short period charging procedure is to provide energy to the HV9805 controller right after V_{DD} hits the lowest threshold. The M2 transistor must be rated for more than 500V, which is above the OVP threshold. The current schematic uses a 650V rated MOSFET. An RCD snubber network was added across M2 (R26, C13, D3, see Figure 6) to limit overshoot voltages during short-circuit conditions. The triggering voltage (V_{TRIG}) of TP12 cannot be too low (not lower than 60V) for determining the SCP condition. Too low triggering voltage will make the system unable to startup or, when powering off, unable to immediately power up again. The triggering voltage can be roughly calculated as follows:

EQUATION 1:

When M2 turns off:

$$V_{R23} \approx 0.6V$$
$$V_{D2} \approx 4.7V$$
$$V_{R13} \approx 5.3V$$

At room temperature:

$$I_{R13} = \frac{5.3V}{82\ k\Omega} = 65\ \mu A$$

$$I_{D2} = \frac{0.6V}{3.9\ k\Omega} = 154\ \mu A$$

Then:

$$V_{TRIG} = (I_{R13} + I_{D2}) \times (R12 + R12A + R12B) + V_{R13}$$
$$= \sim 104V$$

Setting the V_{TRIG} to approximately 100V will ensure enough margin for the temperature change, as V_{BE} voltage decreases with increased temperature.

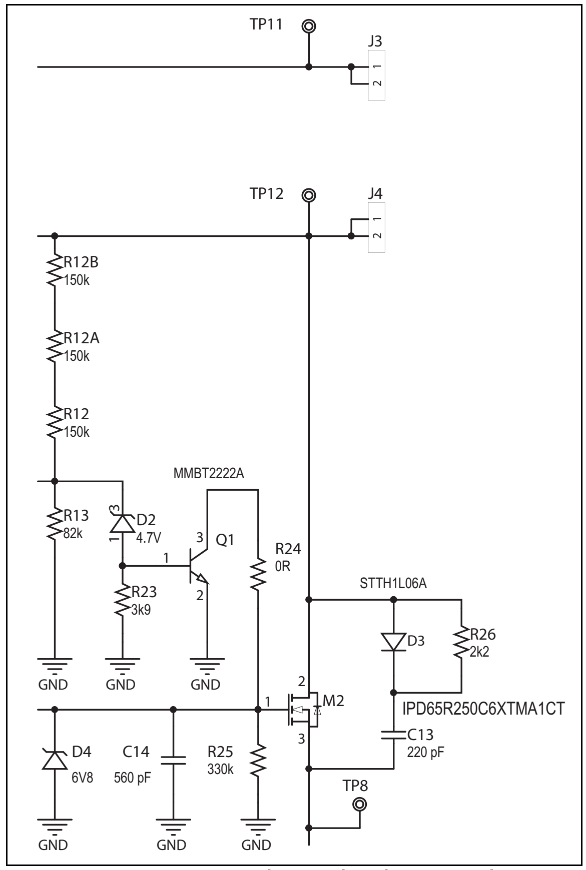

FIGURE 6: *Short-Circuit Protection.*

The open-circuit protection (OCP) may not function in some conditions, such as non-optimal PCB layout. Since the internal FET turns off during OCP, M1 is biased at the common gate amplifier condition; any ringing that occurs at the M1's source node will make the M1's drain node ring too. In the same time, L3 will be charging and discharging, and V_{BUS} might reach dangerous levels. An example can be observed in Figure 18 on M1's source waveform (TP4).

To solve this possible problem, the current design schematic offers a solution for the most effective circuit changes (see TP11 wave in Figure 19). They are as follows (see Figure 7):

- choose the C22 value from 15 pF to 20 pF for increased damping effect on M1's drain node.
- choose the C9 value between 1000 pF to 3000 pF to M1's source terminal to stabilize this node.

After these modifications are done, the OCP condition will work properly (see Figure 19). This method has the drawback of around 1 to 3% increase of the total harmonic distortion (THD).

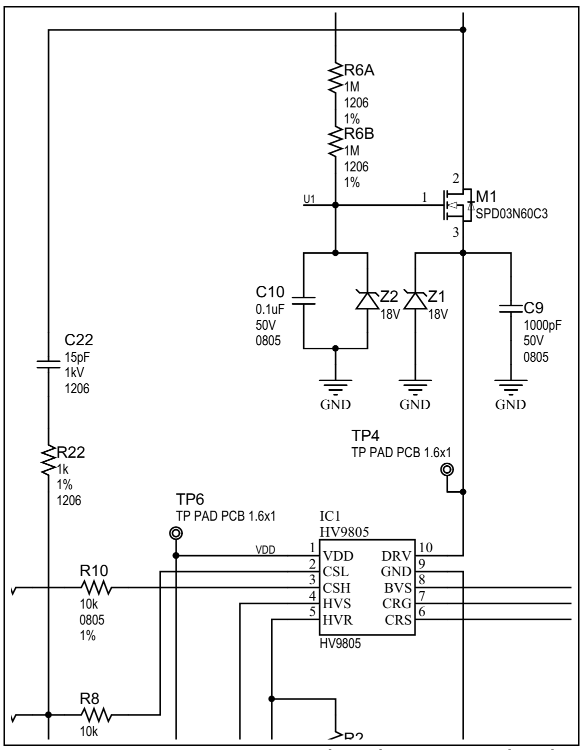

FIGURE 7: Improving the Open Circuit Protection.

WAVEFORMS

Figures 8 to 13 show the actual waveforms for measured dimming steps and enable/disable controls. Figures 14 to 19 depict Start-up, Stop, Short Circuit and Open-Circuit Protection waves.

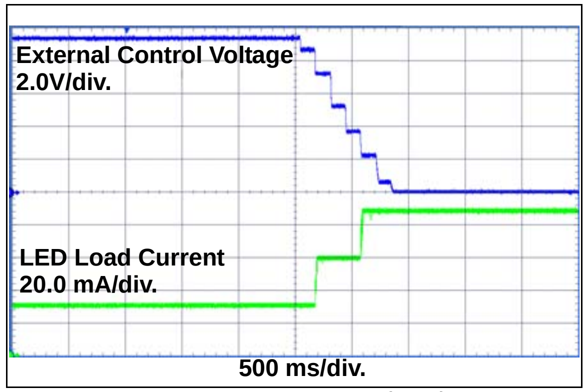

FIGURE 8: Ramp Up Dimming: 30-60-90 mA.

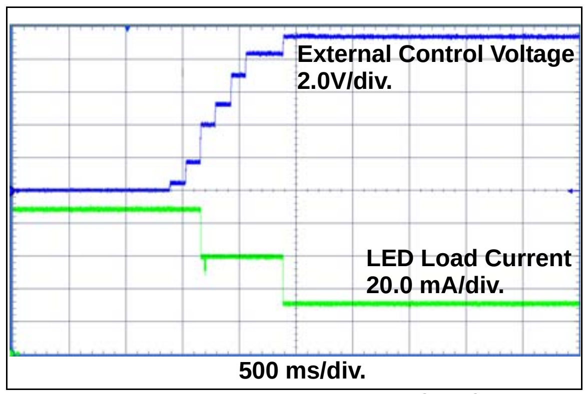

FIGURE 9: Ramp Down Dimming: 90-60-30 mA.

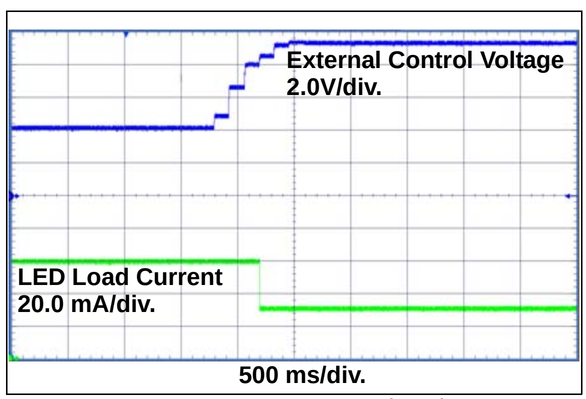

FIGURE 10: One-Step Dimming: 60-30 mA.

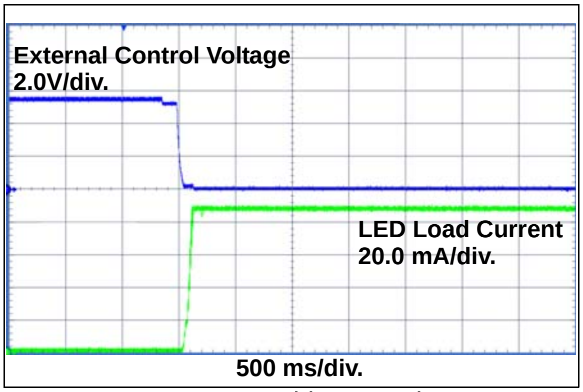

FIGURE 11: *Enable Control: 0-90 mA.*

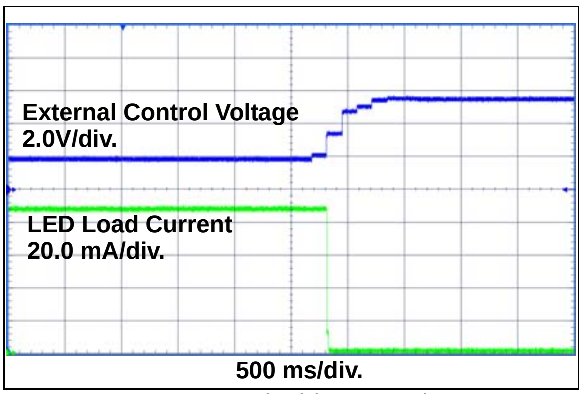

FIGURE 12: *Disable Control: 90-0 mA.*

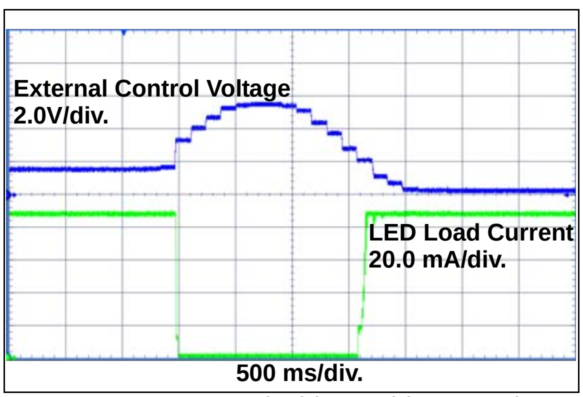

FIGURE 13: *Disable-Enable Control: 90-0-90 mA.*

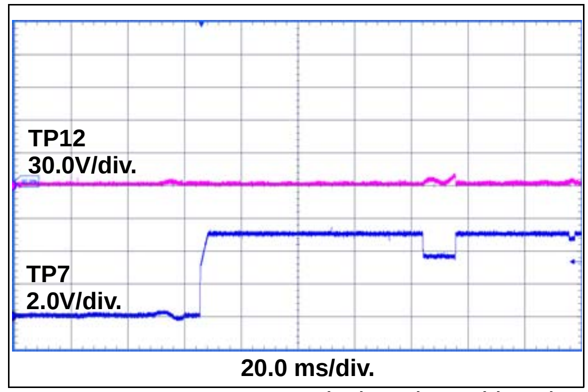

FIGURE 14: *TP12 (up) and TP7(down) Voltage on Start-Up.*

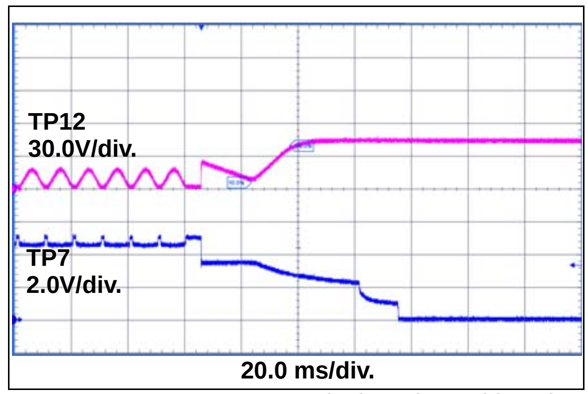

FIGURE 15: *TP12 (up) and TP7(down) Voltage on Stop.*

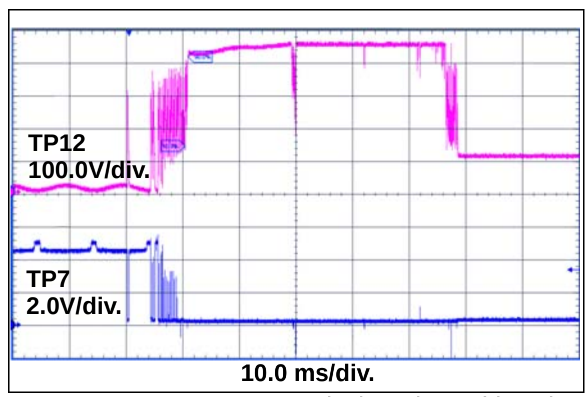

FIGURE 16: *TP12 (up) and TP7(down) Voltage when LED Load Short Circuit Occurs.*

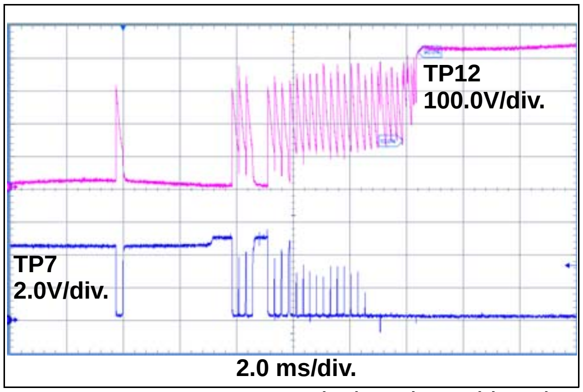

FIGURE 17: *TP12 (up) and TP7(down) Voltage on LED Load Short Circuited, Starting Stage.*

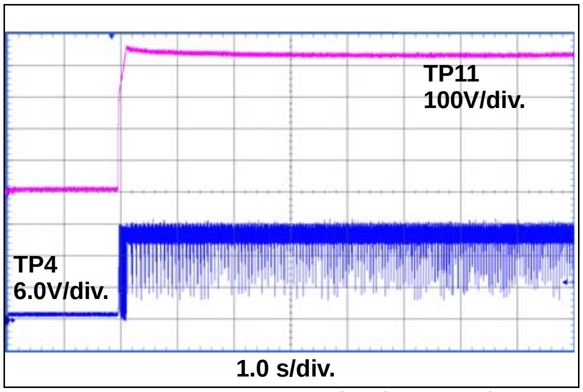

FIGURE 18: *Open-Circuit Protection Circuit.*

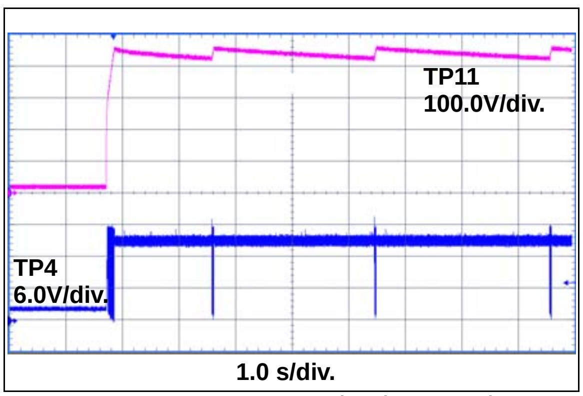

FIGURE 19: *Open-Circuit Protection, Safe Operation.*

CONCLUSIONS

This application note demonstrates a practical solution to perform simple dimming, soft enable-disable control and full protection on load side using the HV9805 LED driver controller. The design has been realized in a simple manner with ordinary extra components, preserving all known features of an HV9805 application: high efficiency, high power factor and low THD. The external control is simple, optically isolated and can be adapted to different types of interfaces. The design is not fitted for high-accuracy dimming applications where trigger steps must occur on certain control levels, due to the characteristic dispersion of Zener diodes.

APPENDIX A: BOARD SCHEMATIC

Figure 20 shows the complete schematic of a 230V_{AC} Three-Step Dimming application using the HV9805 device.

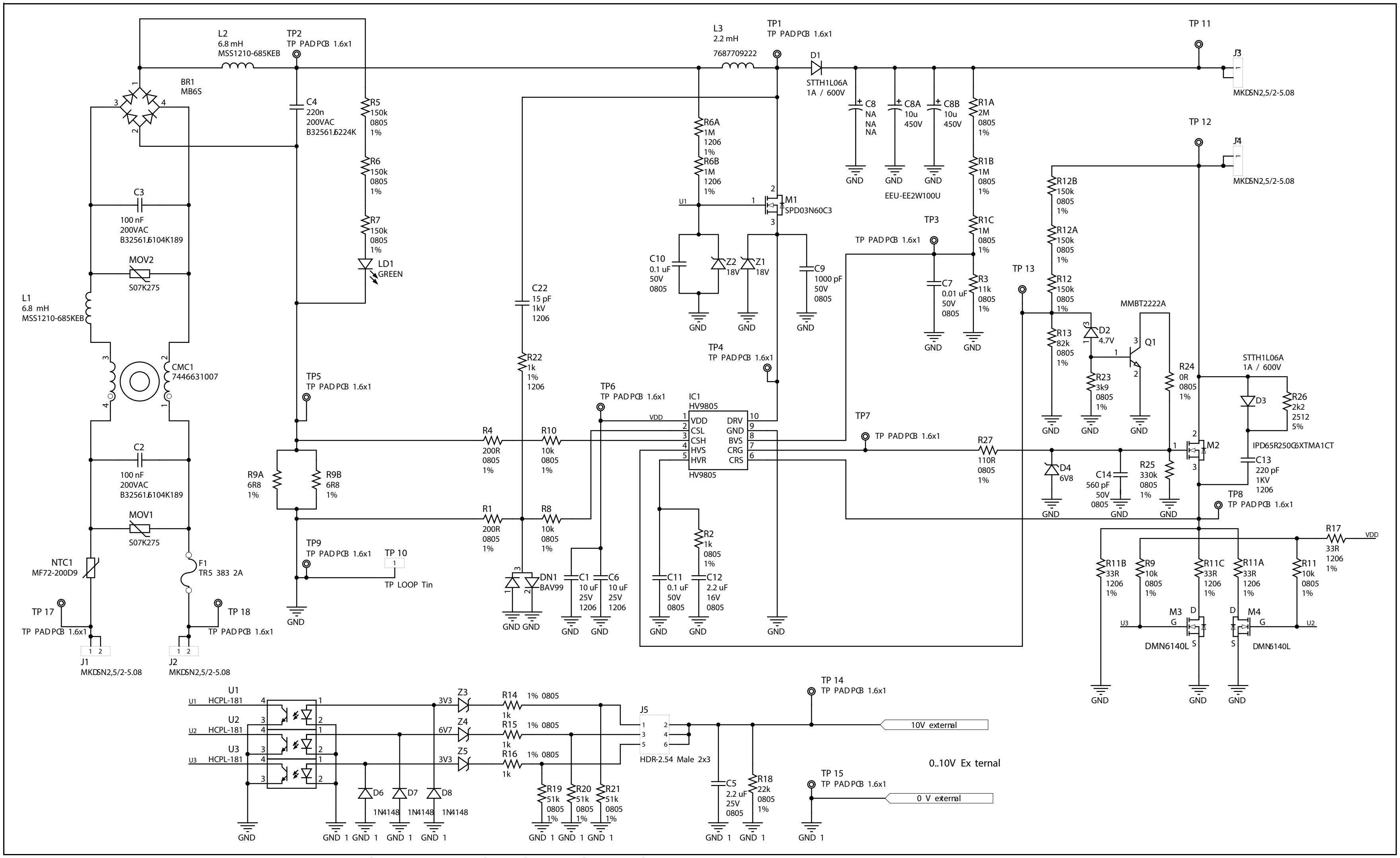

FIGURE 20: *HV9805 230V_{AC} Three-Step Dimming Schematic.*

APPENDIX B: BOARD LAYOUTS

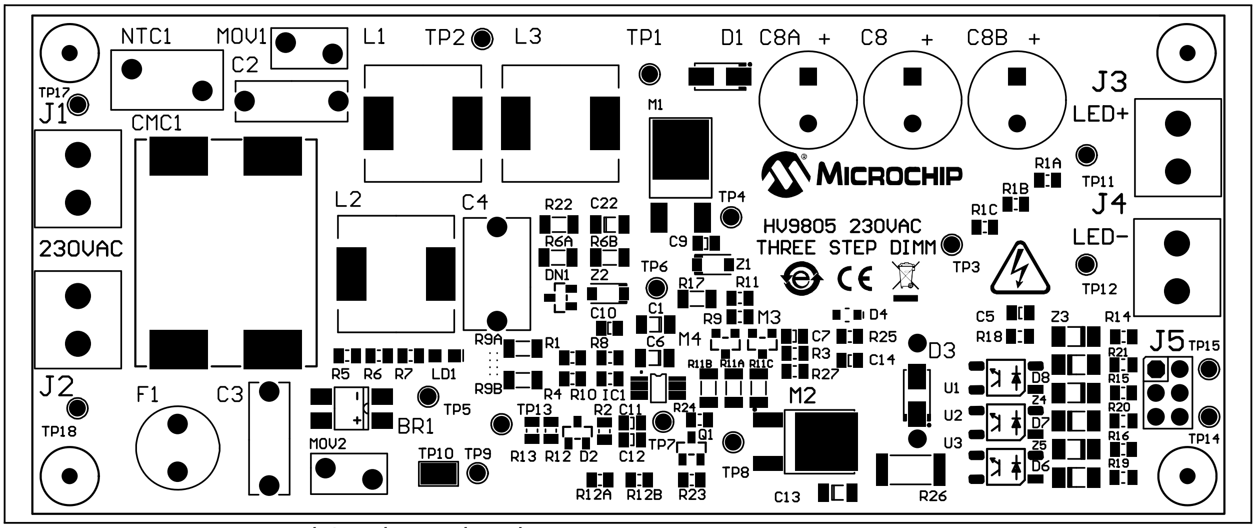

FIGURE 21: Board Overlay and Pads.

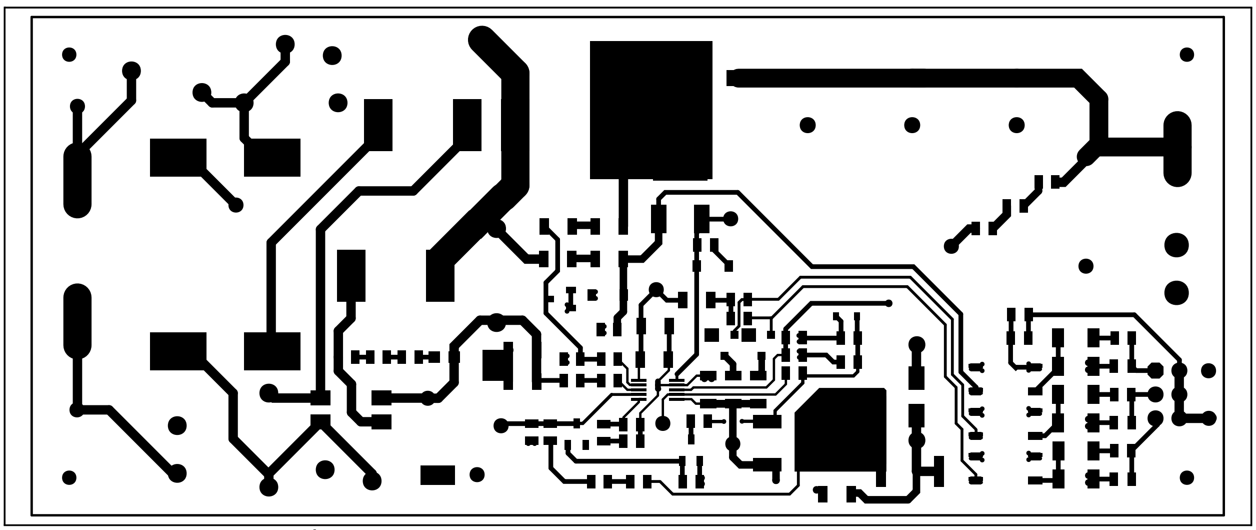

FIGURE 22: Board Top Copper.

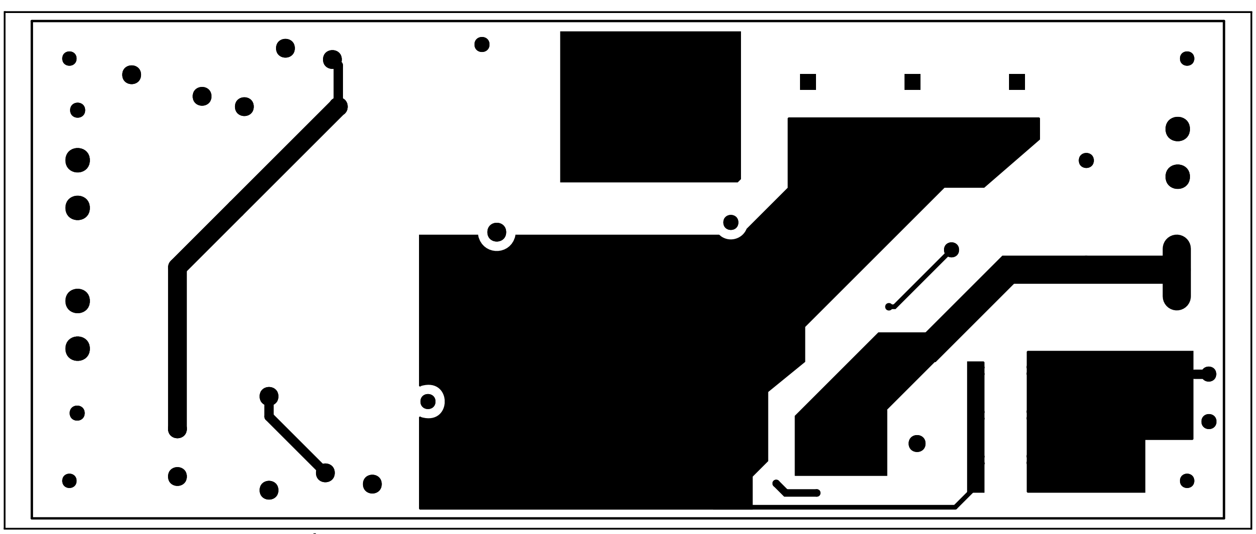

FIGURE 23: Board Bottom Copper.

APPENDIX C: BILL OF MATERIALS (BOM)

Qty.	Reference	Description	Manufacturer	Part Number
1	BR1	IC Rectifier Bridge 0.5A 600V 4SOIC	Fairchild Semiconductor®	MB6S
2	C1,C6	Cap. ceramic 10 µF 25V 10% X7R SMD1206	Samsung Electro-Mechanics America, Inc.	CL31B106KAHNFNE
2	C2,C3	Film Capacitors 0.1 µF 400V 10%	EPCOS AG	B32561J6104K
1	C4	Film Capacitors 0.22 µF 400V 10%	EPCOS AG	B32561J6224K
1	C5	Cap. ceramic 2.2 µF 25V X7R 0805	TDK Corporation	CGA4J3X7R1E225K125AB
1	C7	Cap. ceramic 10 nF 50V 10% X7R SMD 0805	KEMET®	C0805C103K5RACTU
2	C8, C8A	Cap. aluminum 10 µF 450V 20%	Panasonic – ECG®	EEUEE2W100U
1	C9	Cap. ceramic 1000 pF 50V 10% X7R SMD 0805	KEMET	C0805C102K5RACTU
2	C10, C11	Cap. ceramic 0.1 µF 50V 10% X7R SMD 0805	Yageo Corporation	CC0805KRX7R9BB104
1	C12	Cap. ceramic 2.2 µF 16V 10% X7R SMD 0805	TDK Corporation	C2012X7R1C225K125AB
1	C13	Cap. ceramic 220 pF 1 kV U2J 1206	Murata Electronics®	GRM31A7U3A221-JW31D
1	C14	Cap. ceramic 560 pF 50V 10% X7R SMD 0805	KEMET	C0805C561K5RACTU
1	C22	Cap. ceramic 15 pF 1 kV U2J 1206	Murata Electronics	GRM31A7U3A150-JW31D
1	CMC1	Inductor Common Mode 6800 µH 1.4A,2x0.30 Ohm	Wurth® Group	7446631007
2	D1,D3	Diode UltraFast 1A 600V 80 ns SMA	STMicroelectronics	STTH1L06A
1	D2	Diode Zener 4.7V 350 mW SOT-23-3	Fairchild Semiconductor®	BZX84C4V7
1	D4	Diode Zener 6.8V 300 mW SOD323	NXP Semiconductors	BZX384-C6V8,115
1	DN1	Diode Array GP 70V 200 mA SOT23-3	Fairchild Semiconductor	BAV99
1	F1	Fuse Board Mount 2A 300V_{AC} RAD	Littelfuse®	38312000000
1	IC1	HV9805 High Voltage LED Driver	Microchip Technology Inc.	**HV9805MG-G**
4	J1, J2, J3, J4	Conn. Terminal 5.08 mm 16A	PHOENIX CONTACT	MKDSN2,5/2-5.08
1	J5	Header 2 row, Pitch 2.54, through hole	TE Connectivity, Ltd.	5-146256-5
2	L1, L2	Power Inductor 6800 µH, 0.39A, 5.85Ω	Coilcraft	MSS1210-685KEB
1	L3	WE-PD HV SMD Power Inductor 2200 µH, 0.65A, 3.1Ω	Wurth Group	7687709222
1	LD1	Diode LED GREEN 2V 30 mA 120 mcd Diffuse SMD 0805	Avago Technologies	HSMM-C170
1	M1	MOSFET N-CH 550V 9A TO-252	Infineon Technologies AG	IPD50R399CP
1	M2	MOSFET N-CH 650V 16.1A TO-252	Infineon Technologies AG	IPD65R250C6XT-MA1CT
2	M3, M4	MOSFET N-CH 60V 1.6A SOT-23	Diodes® Incorporated	DMN6140L-7
2	MOV1, MOV2	Varistor 243V 1.2 kA DISC 7MM	EPCOS AG	S07K175
1	NTC1	Current Limiter INRSH 200OHM 20%	Cantherm	MF72-200D9

Note: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

APPENDIX C: BILL OF MATERIALS (BOM) (CONTINUED)

Qty.	Reference	Description	Manufacturer	Part Number
1	PCB	HV9805 230V_{AC} Three Step Dimming - Printed Circuit Board	—	04-10469-R1
2	R1, R4	Res. 200R 1% 1/8W SMD 0805	Yageo Corporation	RC0805FR-07200RL
4	R2, R14, R15, R16	Res. 1 kΩ 1% 1/10W SMD 0805	Yageo Corporation	RC0805FR-071KL
1	R3	Res. TKF 11k 1% 1/8W SMD 0805	Yageo Corporation	RC0805FR-0711KL
6	R5, R6, R7, R1, R12A, R12B	Res. 150 kΩ 1% 1/8W SMD 0805	Yageo Corporation	RC0805FR-07150KL
1	R12	Res. 22 kΩ 1% 1/8W SMD 0805	Yageo Corporation	RC0805FR-0722KL
5	R8, R9, R10, R11	Res. 10 kΩ 1% 1/16W SMD 0805	Yageo Corporation	RC0805FR-0710KL
4	R11A, R11B, R11C, R17	Res. SMD 33Ω 1% 1/4W 1206	Yageo Corporation	RC1206FR-0733RL
1	R13	Res. 82 kΩ 1% 1/16W SMD 0805	Yageo Corporation	RC0805FR-0782KL
1	R18	Res. 22 kΩ 1% 1/16W SMD 0805	Yageo Corporation	RC0805FR-0722KL
3	R19, R20, R21	Res. 51 kΩ 1% 1/16W SMD 0805	Yageo Corporation	RC0805FR-0751KL
1	R22	Res. 1 kΩ 1% 1/4W SMD 1206	Yageo Corporation	RC1206FR-071KL
1	R23	Res. SMD 3.9 kΩ 1% 1/8W 0805	Yageo Corporation	RC0805FR-073K9L
1	R24	Res. SMD 0.0Ω JUMPER 1/8W 0805	Yageo Corporation	RC0805FR-070RL
1	R25	Res. SMD 330 kΩ 1% 1/8W 0805	Yageo Corporation	RC0805FR-07330KL
	R26	Res. SMD 2.2 kΩ 5% 1W 2512	Vishay/Dale	CRCW25122K20JNEG
1	R27	Res. SMD 110Ω 1% 1/8W 0805	Yageo Corporation	RC0805FR-07110RL
1	R1A	Res. 2 MΩ 1% 1/8W SMD 0805	Yageo Corporation	RC0805FR-072ML
4	R1B, R1C, R6A, R6B	Res. 1 MΩ 1% 1/8W SMD 0805	Yageo Corporation	RC0805FR-071ML
2	R9A, R9B	Res. SMD 6.8Ω 1% 1/4W 1206	Yageo Corporation	RC1206FR-076R8L
1	TP10	PC Test Point Miniature SMT	Keystone Electronics Corp.	5015
14	TP1-9, TP11-15	PC Test Point Miniature 040"D BLACK	Keystone Electronics Corp.	5001
3	U1, U2, U3	Phototransistor Optocupler SMD Mini-Flat Type, 3750 V_{RMS} , V_{CEO} = 80V, I_C = 50 mA	Avago Technologies	HCPL-181
2	Z1, Z2	Diode Zener 18V 500 mW SOD123	Fairchild Semiconductor	MMSZ5248B
2	Z3,Z5	Diode Zener 3.3V 1.5W SMA	ON Semiconductor®	1SMA5913BT3G
1	Z4	Diode Zener 6.8V 1.5W SMA	ON Semiconductor	1SMA5921BT3G

Note: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

APPENDIX D: MEASURED INPUT - OUTPUT PARAMETERS

Input Current (mA)	Output Current (mA)	Input Power (W)	Output Power (W)	Efficiency (%)	Power Factor	A_{THD} (%)
60	31	13	11.6	89	0.883	16.3
110	58	25	22.7	91	0.962	8.25
160	86	38	34.9	92	0.975	5.86

APPENDIX E: CONFIGURATION TABLE FOR ENABLE-DISABLE AND LED LOAD LIGHT LEVEL RELATED TO EXTERNAL CONTROL VOLTAGE

External Control Voltage (V)	J5 - Jumper Position			LED Load Light Level (%)			Disable
	1-2	3-4	5-6	100	66	33	
0-10				●			
<3.3	✓	✓	✓	●			
>3.3	✕						ON
			✕		●		
>6.7		✕			●		
		✕	✕			●	

Legend: blank = unpopulated/not active
✕ = populated jumper (position short-circuited)
✓ = either populated or unpopulated
● = actual light level

NOTES:

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
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ISBN: 978-1-5224-0261-9

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