Isolated 70-W Streetlight LED Driver Using UCC28810

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Power Management

ABSTRACT

LED lighting is being used for residential, commercial and industrial applications. It offers various advantages over incandescent bulbs, such as lower energy consumption, longer life, attainment of full brightness without need for a warmup time, and so forth. With the advent of these lights in large numbers, regulations in a few countries require LED drivers with high power factor (greater than 0.9) and low current THD (less than 10 per cent), to have minimum effect on the grid.

Conventionally, UCC28810 operates in critical conduction mode, resulting in a high value of current THD. This application report describes use of UCC28810 in a single-stage 70-W streetlight LED driver in AC/DC Flyback topology with fixed-frequency and constant on-time switching, to achieve power factor greater than 0.9 and current THD less than 10 percent. CD74HCT14 Schmitt-triggered inverter is used to implement external oscillator, feedback sawtooth generator and short-circuit protection circuit. Output current regulation and output open-circuit protection are implemented with both secondary-side and primary-side regulation circuits. Implementation with single stage helps to reduce number of components, system size and cost.

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1 Design Specifications

Table 1 lists the UCC28810-based 70-W streetlight LED driver design specifications.

Table 1. UCC28810-based 70-W Streetlight LED Driver Design Specifications

Design Specifications	
Input voltage range (V_{IN})	Universal, 90 V–265 V AC RMS
Output voltage (V_{OUT})	106 V
Load current (I_{OUT})	600 mA
Power factor	Greater than 0.9 in V_{IN} range
Current total harmonic distortion (I_{THD})	Less than 10%
Output short-circuit protection	Yes
Output open-circuit protection	Yes

2 Application Schematic

2.1 Secondary-Side Output Current Regulation

Figure 1 and Figure 2 illustrate the secondary-side output current regulation schematics.

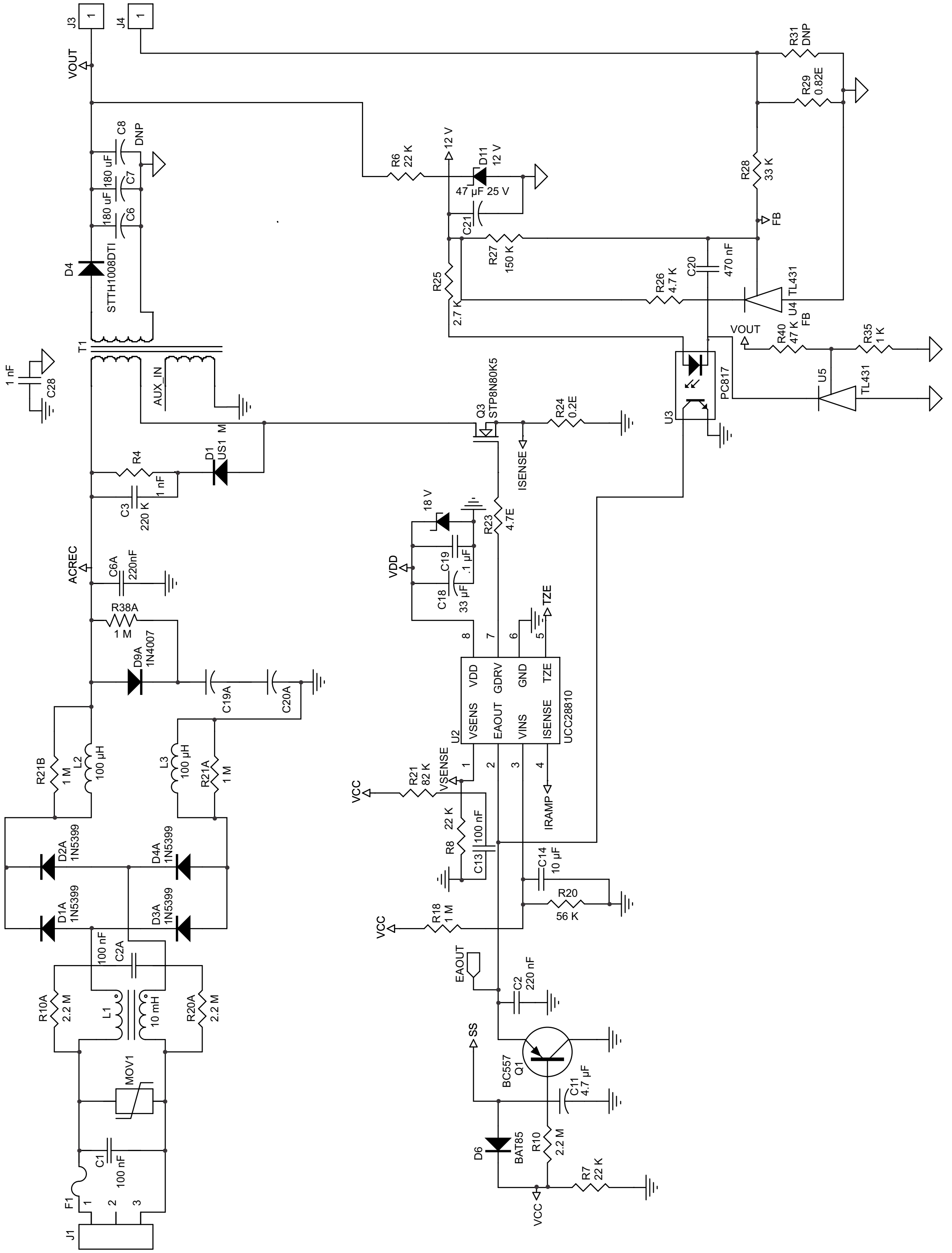


Figure 1. Schematic for 70-W Streetlight LED Driver With Secondary-Side Regulation (Part 1)

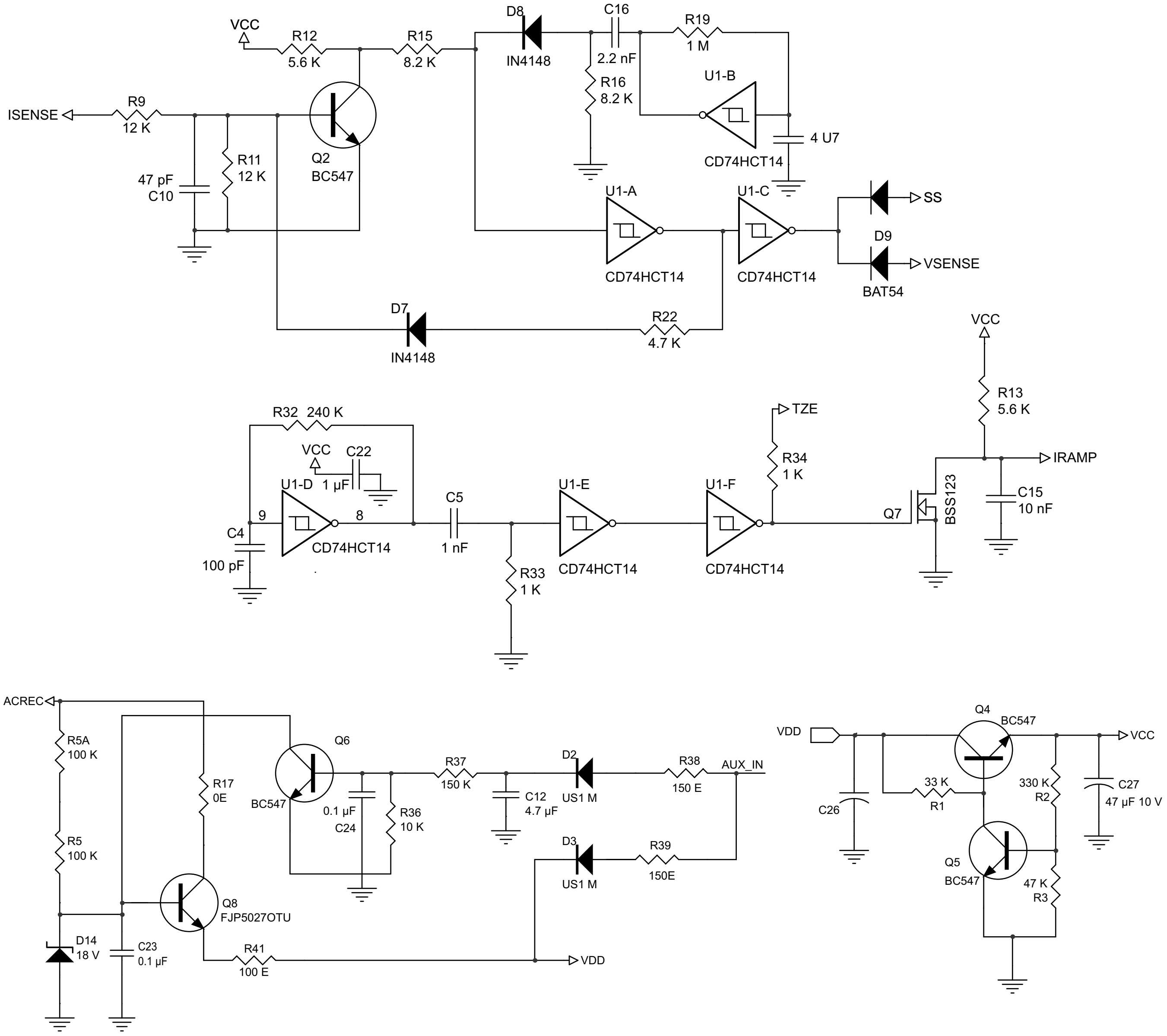


Figure 2. Schematic for 70-W Streetlight LED Driver with Secondary-Side Regulation (Part 2)

2.2 Primary-Side Output Current Regulation

Figure 3 and Figure 4 illustrate the primary-side output current regulation schematics.

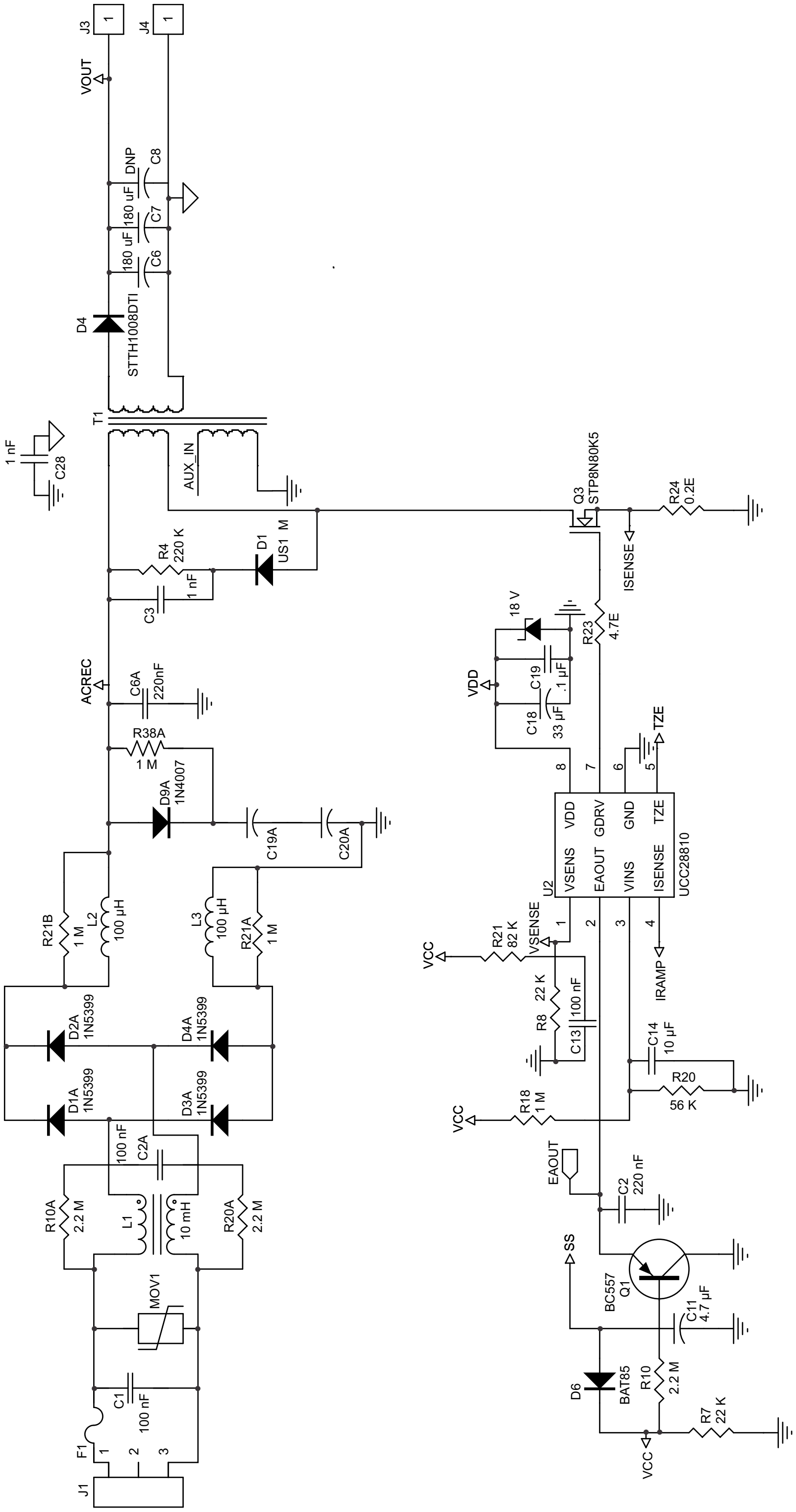


Figure 3. Schematic for 70-W Streetlight LED Driver with Primary-Side Regulation (Part 1)

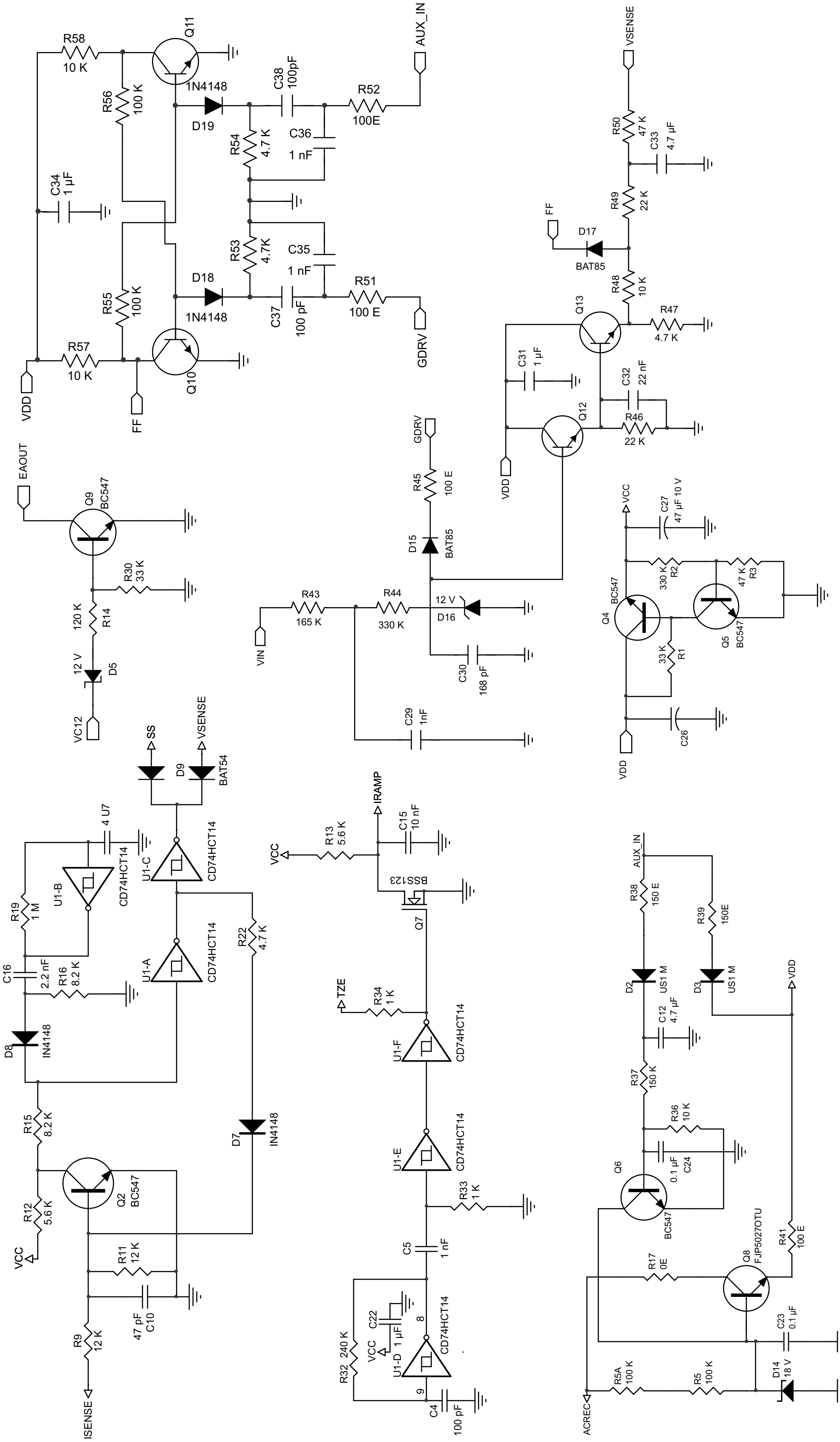


Figure 4. Schematic for 70-W Streetlight LED Driver with Primary-Side Regulation (Part 2)

3 Principle of Operation

The UCC28810 is an off-line AC/DC controller specifically designed to drive high power LEDs for lighting applications requiring power factor correction and EMC compliance. It is designed for controlling a Flyback, single-ended primary-inductance converter (SEPIC), or Boost converter operating in critical conduction mode. The UCC28810 features a transconductance amplifier for feedback error processing, a simple current reference generator for generating a current command proportional to the input voltage, a current-sense (PWM) comparator, PWM logic, and a totem-pole driver for driving an external FET. To overcome the issue of high I_{THD}, these subsystems internal to low-cost UCC28810 are used here to operate at fixed switching frequency with constant on-time, and achieve high power factor and low I_{THD}, less than 10 percent.

Figure 1 depicts a reference schematic describing key components in the Flyback stage. Input AC voltage is rectified using full bridge rectifier (D_{1A}–D_{4A}) to obtain a unidirectional AC bus. It may be noted that the input capacitor is so small (220 nF) that the input voltage is close to a rectified sinusoid, as also required to obtain high power factor. This rectified V_{IN} is connected through transformer primary winding to the drain of switching FET Q_3, whose source is connected to ground return through the current-sensing resistor R_{24}.

The transformer primary inductance, L_p is related to the switching frequency f_{sw}, converter output power P_{out}, system efficiency η, maximum on-time, $t_{on\text{-}max}$ at minimum input line voltage $V_{in\_rms(min)}$ according to the equation:

$$Lp = \frac{\eta \times V_{in\_rms(min)}^2 \times t_{on-max}^2}{2\ P_{out} \times \dfrac{1}{f_{sw}}}$$

$$Lp = \frac{(0.9) \times (90)^2 \times (7.5\ \mu s)^2}{2 \times 66 \times \dfrac{1}{(60{,}000)}} \Rightarrow Lp = 186.4\ \mu H \tag{1}$$

Primary inductance, L_p is chosen as 200 µH for this design. Maximum on-time at minimum input voltage is chosen as 7.5 µsec, considering maximum duty cycle of 45% at 60 kHz switching frequency.

For L_p=200 µH, peak input voltage at minimum AC input $V_{in\_min(pk)}$ and maximum on-time at minimum V_{in}, $t_{on\text{-}max}$, peak current in primary winding, $I_{p,pk}$ is calculated as:

$$I_{p,pk} = \frac{V_{in\_min(pk)} \times t_{on-max}}{L_p}$$

$$I_{p,pk} = \frac{\left(90\sqrt{2}\right) \times (7.5\ \mu s)}{200\ \mu H} = 4.77\ A \tag{2}$$

Due to large output voltage (106 V), and limitations of FET maximum drain-source voltage rating (800 V), turns ratio is selected as 1 (that is, N = 1). Hence, secondary peak current $I_{s,pk}$ is equal to 4.77 A, and minimum secondary rectifier diode reverse voltage rating is 585 V. Thus, STTH1008 (800 V, 10-A rating) is selected as secondary rectifier for this design.

3.1 Active Startup Circuit

Figure 5 illustrates the active startup circuit.

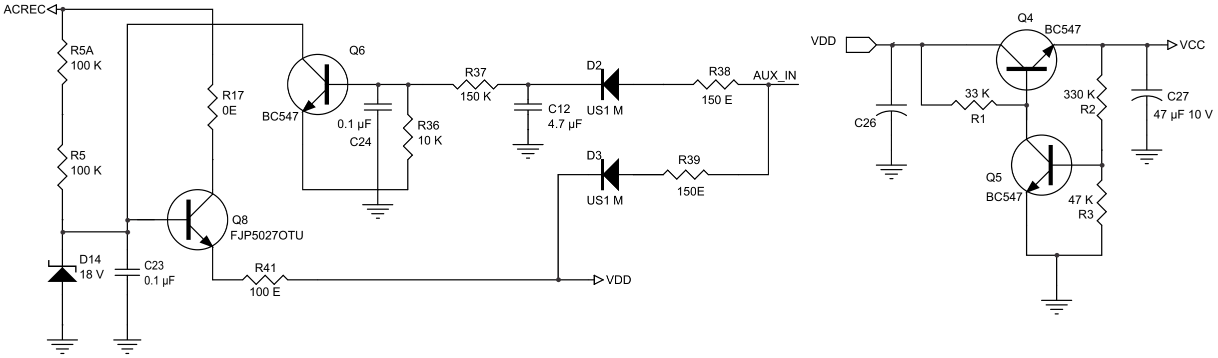


Figure 5. Active Startup Circuit

It is not possible to supply bias voltage while meeting IC current requirements for both UCC28810 and CD74HCT14 together using the resistive startup technique. In Figure 5, transistor Q8 as emitter-follower sources 17.4 V V_{DD} startup bias for UCC28810 at its emitter, which is converted to 5 V for CD74HCT14 supply using discrete, low-IQ linear regulator. Once switching begins and output voltage ramps-up, bias voltage for these ICs is sourced from primary-side auxiliary winding, which is also used to disable active-startup circuit with Q_6. Once in steady state, it is required to disable active-startup circuit in order to minimize efficiency loss due to large voltage drop across Q_8 and IC supply current flowing through it.

3.2 Switching Oscillator

Figure 6 shows the switching oscillator circuit.

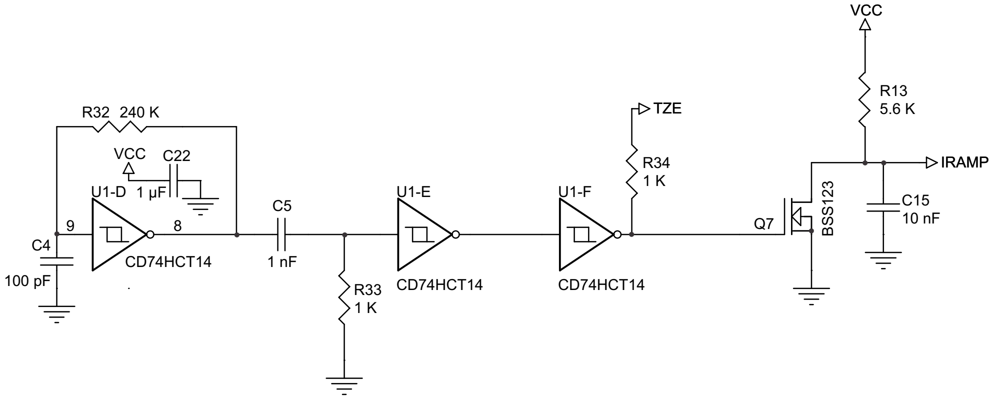


Figure 6. Switching Oscillator

The flyback stage is operating at a constant 60-kHz switching frequency, generated using CD74HCT14, Schmitt-triggered inverter, as shown in Figure 6. Equation 3 is used to calculate oscillator frequency of a Schmitt inverter-based oscillator. For C_4 = 100 pF, feedback resistance R_{32} is obtained as 248 kΩ:

$$f_{sw} = \frac{1}{0.67\ RC} \Rightarrow R = \frac{1}{(0.67)f_{sw} \times C} = \frac{1}{(0.67)(60{,}000)(0.1\ nf)} = 248\ k\Omega \tag{3}$$

This 60-kHz square-pulse output of U_{1D} is given to an RC high-pass filter, inverted, and fed as input to UCC28810 TZE pin to initiate the next switching cycle (t_{on}). A transition is detected when TZE input goes low, which sets the gate drive to HIGH. This pulse also discharges RC ramp generator capacitor C_{15} at the start of t_{on}, using Q_7. Gate drive turn-on edge is triggered with 60-kHz square-pulse input to the TZE pin from the above oscillator, while gate DRV turn-off edge is determined by the output current regulation circuit (when IRAMP voltage exceeds internal multiplier output voltage). In Figure 16, frequency of waveform 2 governs f_{sw}, while the on-time of this waveform (determined by values of C_5 and R_{33}) is the time-period for which FET Q_7 discharges capacitor C_{15}.

3.3 Soft-Start Circuit

At startup, the 60-kHz switching begins as soon as bias on UCC28810 exceeds its V_{DD} turn-on threshold (15.8 V). Due to the use of the 470-nF capacitor C_{20} to slow down loop response, it is required to have soft-start operation, such that the duty cycle increases gradually from its minimum value at startup. The circuit in Figure 7 shows this implementation. As V_{CC} bias voltage (5 V) is formed during startup, RC low-pass filter (R_{10} = 2.2 M, C_{11} = 4.7 µF) charges slowly to input peak value, resulting in Q_1 pulling down error amplifier output (EAOUT) low, initially, and allowing it to reach its final value after approximately a 1-second delay. Diode D_6 helps to discharge C_{11} for next soft-start initiation on V_{DD} / system reset.

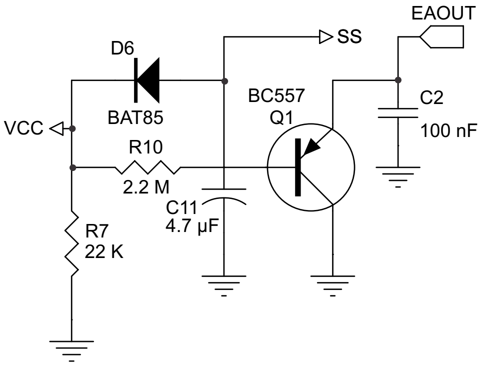


Figure 7. Soft-Start Circuit

Additionally, duty cycle limiting at nearly 45% is incorporated to mitigate stability issues, by providing DC voltage on the VINS pin as UCC28810 internal multiplier output clamp. For 60-kHz switching frequency, the feedback ramp on C_{15} reaches a level of 0.53 V at 45% duty cycle. Since UCC28810's internal multiplier has a fixed gain of 2, an input of 0.26 V DC on the VINS pin helps clamp the duty cycle at maximum 45%.

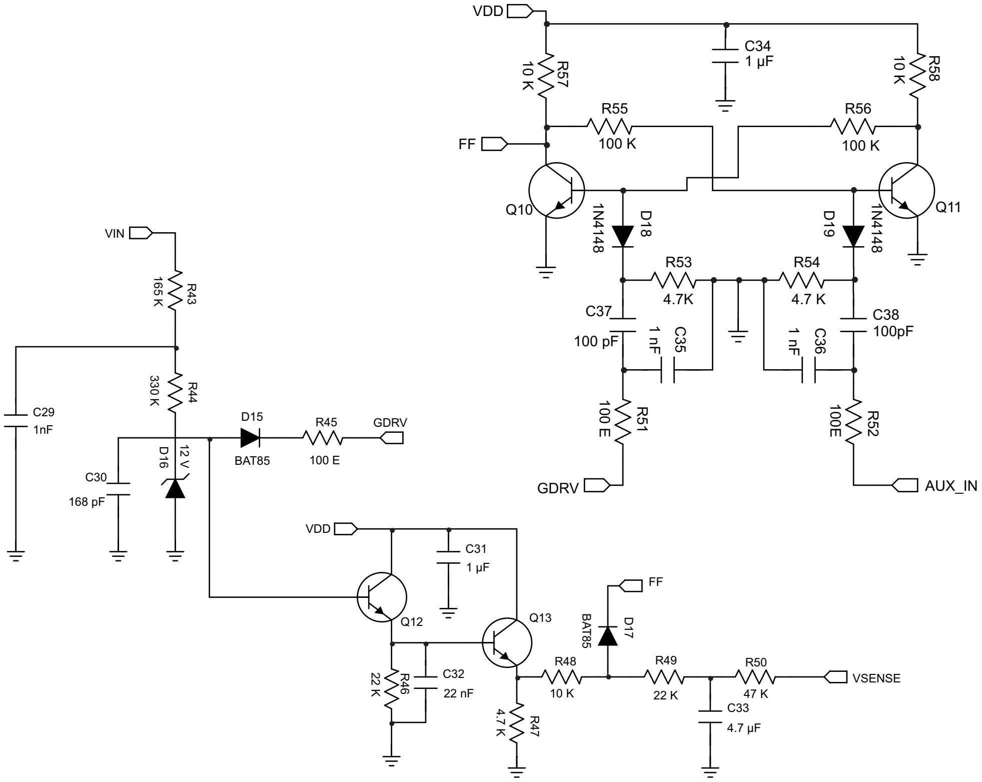
3.4 Output Current Regulation

We need to regulate constant 600-mA output current though the LEDs. This is achieved using both secondary-side and primary-side regulation circuits. With **secondary-side output current regulation**, current through the LEDs is measured as a voltage on very small current sense resistors (R_{29} and R_{31}), and regulated with TL431's 2.495 V feedback reference. This circuit is shown in Figure 1. V_{DD} voltage for the optocoupler and TL431s is generated with a 12-V zener biased from the 106-V output voltage. During the process of locking of loop to reach regulation, when the voltage on U4 REF pin exceeds 2.495 V, the cathode of U_4 pulls down optocoupler U_3 cathode to 2.495 V, which reduces voltage on the EAOUT pin of UCC28810. Since EAOUT pin of UCC28810 is output of internal error amplifier, this pulldown with optocoupler helps to maintain duty cycle optimum for output current regulation point. Further, power loss on sense resistors is proportional to voltage across them and the current flowing through them:

$$P_{loss} = V_{sense} \times I_{LED} \tag{4}$$

The U4 feedback reference of 2.495 V results in a power loss of 1.497 W for 600-mA current through sense resistors. To minimize this loss and make the system more efficient, a 2-V DC offset is added to the U4 feedback (using resistors R_{27} and R_{28}) from the 12-V zener voltage, such that sense resistor drops only 0.5 V due to the current flowing through it.

Alternatively, primary-side output current regulation within ±2.5 percent of intended output current has been achieved with the circuit in Figure 8:



(Circuit used in only-primary-side output current regulation scheme.)

Figure 8. Alternate Implementation for Primary-Side Output Current Regulation

For transformer T_1 primary winding,

$$V_{in(inst)} = L_p \times \frac{dI_p}{dt} \Rightarrow I_{p,pk} = \frac{V_{in(inst)} \times t_{on}}{L_p} \tag{5}$$

Where:

$V_{in(inst)}$ = instantaneous input voltage
L_p = Transformer primary inductance
t_{on} = On-time during time period T

Further, output current in flyback converter is given by:

$$I_{out} = \frac{I_{s,pk}}{2} \times \frac{t_{off}}{T} \Rightarrow I_{out} = \frac{NI_{p,pk}}{2} \times \frac{t_{off}}{T} \Rightarrow I_{out} = \frac{N \times V_{in(inst)} \times t_{on}}{2\ L_p} \times \frac{t_{off}}{T} \Rightarrow I_{out} \alpha I_{p,pk} \times \frac{t_{off}}{T} \tag{6}$$

Where:

I_{out} = Current through LEDs
$I_{s,pk}$ = Secondary-side peak current
t_{off} = Off-time during time period T
N = transformer turns ratio
$I_{p,pk}$ = primary-side peak current

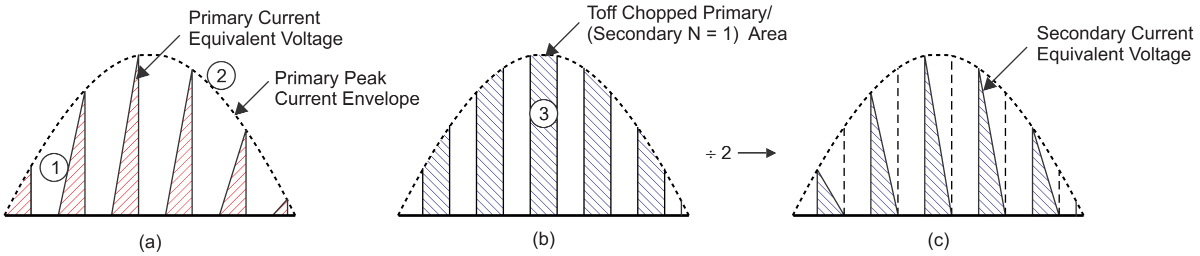
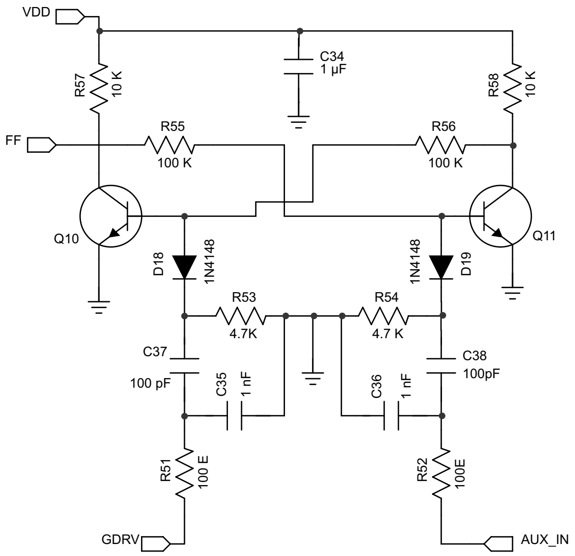


Figure 9. Primary-Side Output Current Regulation Logic

From Equation 5 and Equation 6, since primary-side peak current is sinusoidal in nature, varying in proportion to instantaneous V_{in} and T_{on}, if we generate a voltage proportional to V_{in} and t_{on}, and calculate the average for time period t_{off} (over total time T), we get a DC voltage which is proportional to output LED current.

Here, a ramp voltage (proportional to instantaneous V_{in} amplitude and t_{on}) is generated using R_{43}, R_{44}, and C_{30} during on-time, and discharged with the gate drive signal using D_{15} during t_{off}. Consecutively, this ramp is peak detected using emitter-follower transistor Q_{12}. This envelope varying in proportion to V_{in} is again buffered to obtain low output impedance using emitter-follower transistor Q_{13}, and chopped during time-interval t_{off} (to obtain a time-average over t_{off}) using flip-flop circuit as shown in Figure 10.



(Circuit used in only-primary-side output current regulation scheme.)

Figure 10. Flip-Flop Circuit to Extract T_{off}

This flip-flop used for T_{off} chopping is implemented using transistors Q_{10} and Q_{11}, with T_{off} waveform edges triggered by negative going transitions of FET gate drive (GDRV) and primary-side auxiliary winding (AUX_IN) waveforms, thus generating square pulse of duration T_{off}, as also depicted in Figure 19.

This resulting waveform chopped for T_{off} is averaged using RC (R_{49} = 22 kΩ, C_{33} = 4.7 µF) averaging circuit. Since the control loop needs to have a narrow bandwidth, for output current to be less sensitive to the twice mains frequency ripple, cut-off frequency for this RC low-pass filter is selected much less than 100 Hz. It may be noted that this average is two-times of that obtained from Equation 6, and this doubling factor needs to be accounted for by scaling resistor values. UCC28810 has an internal 2.5 V referenced error amplifier with VSENSE inverting input. This error amplifier is used for primary-side output current regulation. Since voltage from the primary-side current regulation circuit (output of RC averaging circuit) is less than 2.5 V (1.85 V), superposition of a DC offset from 5-V supply and RC averaging circuit output is undertaken to regulate at 2.5 V.

3.5 Output Short-Circuit Protection

At the instant of output LEDs being short-circuited, U4 immediately detects a voltage feedback greater than 2.5 V, and engages U3 to reduce duty cycle to minimum value. The 12-V bias of optocoupler and U4 (and U5) reduces to zero during this period and secondary loop loses control. Voltage on current sense resistor R_{24} is continuously monitored to detect short-circuit at output.

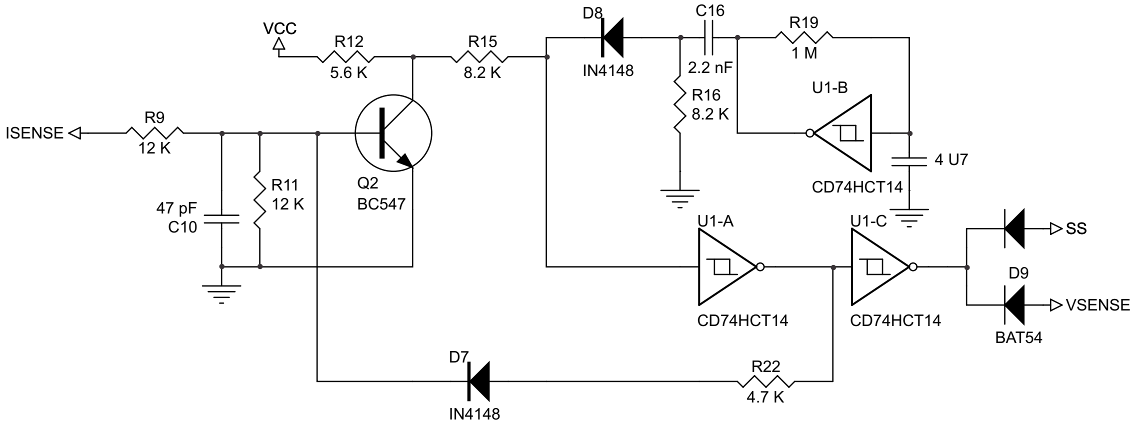


Figure 11. Output Short-Circuit Protection

For 64-W output power, primary peak current reaches a maximum of nearly 1 V (see Figure 17). Short-circuit detection threshold is thus set with sufficient margin (to avoid false triggering) at 1.4 V. This sub-system is shown in Figure 11. As the voltage on R_{24} reaches 1.4 V or greater, a latch including Q_2 and U_{1A} is enabled. The 5-V output of this latch is inverted using U_{1C} to form logic LOW level at output which then pulls down voltage on capacitors C_{13} and C_{11} attached to the VSENS and EAOUT pins of UCC28810, respectively. This short-circuit protection is auto-retry type, with Schmitt inverter oscillator (U_{1B}) generating a reset pulse every 3 seconds. This auto-retry interval may be modified by adjusting R_{19}.

3.6 Output Open-Circuit Protection

In case of absence of LEDs at output (Output Open-Circuit), this design reduces power being delivered to the secondary, to prevent voltage on output capacitors from exceeding their ratings. This feature is implemented in different ways for the case of Primary-Side and Secondary-Side Output current regulation schemes.

For a **secondary-side regulated system**, output voltage is divided using resistors R_{35} and R_{40}, and fed to the REF pin of TL431 (U_5), as shown in Figure 1. These resistors are selected such that in case of an open-circuit, output voltage reaches a maximum of 110% of its nominal value. For V_{out} = 106 V, $V_{out(open)}$ ≈120 V.

From Equation 7, R_{35} and R_{40} is obtained as 1 kΩ and 47 kΩ to get 2.495 V level at the U5 REF pin.

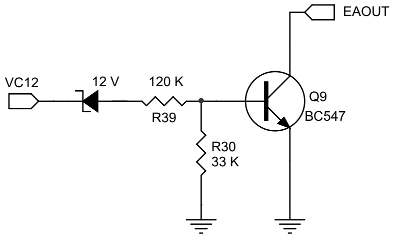
$$V_{REF(U5)} = \frac{V_{out(open)}}{R_{35} + R_{40}} \times R_{35} \tag{7}$$

Where:

$V_{REF(U5)}$ = TL431 reference pin 2.495-V regulation voltage
$V_{out(open)}$ = maximum voltage at output when open-circuited

In case of an output open-circuit, U5 enables the optocoupler, pulling the EAOUT pin of UCC28810 low, limiting duty cycle to its minimum value, and preventing voltage on output capacitors from exceeding their ratings or reaching dangerously high values.

Open-circuit protection with primary-side output current regulation is shown in Figure 12. Voltage (VC12) formed on C_{12} from primary auxiliary winding is used to detect open-circuit at output. This voltage on C_{12} (VC12) is stepped down using a zener and resistance divider (R_{39}, R_{30}), enabling transistor Q_{11} in case of open-circuit. Transistor Q_{11}, when active, pulls down the EAOUT pin of UCC28810 (which is the error amplifier output), and reduces duty cycle to its minimum value.



(Circuit used in only-primary-side output current regulation scheme.)

Figure 12. Output Open-Circuit Protection in Primary-Side Regulated System

4 Performance Data and Typical Characteristic Curves

Figure 13 through Figure 19 present some typical performance curves for the UCC28810-based 70-W LED driver design.

4.1 Output Current Variation with Respect to Input Voltage

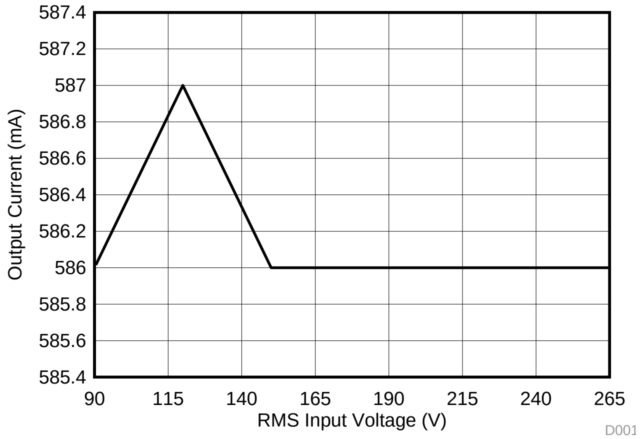


Figure 13. Output Current Variation with Respect to Input Voltage

4.2 Power Factor Variation With Respect to Input Voltage

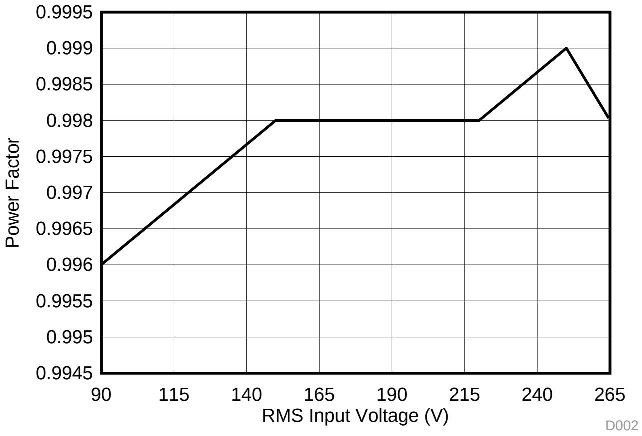


Figure 14. Power Factor Variation With Respect to Input Voltage

4.3 Variation of Current THD with Input Voltage

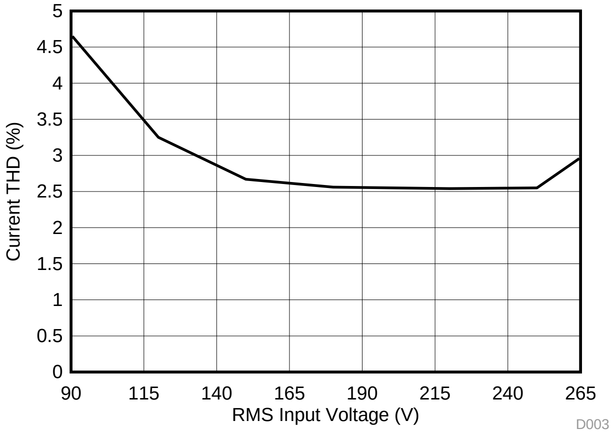
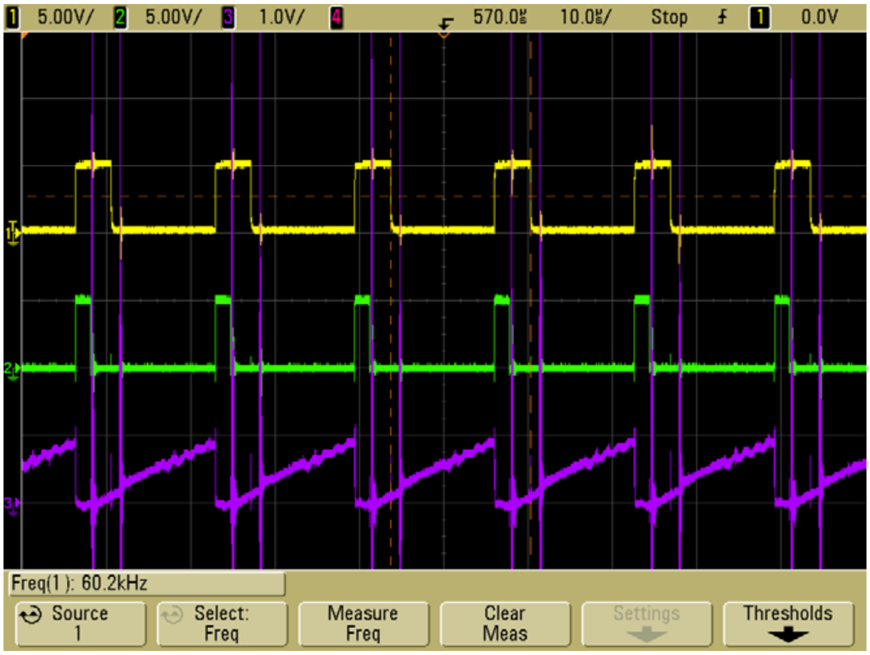


Figure 15. Variation of Current THD with Input Voltage

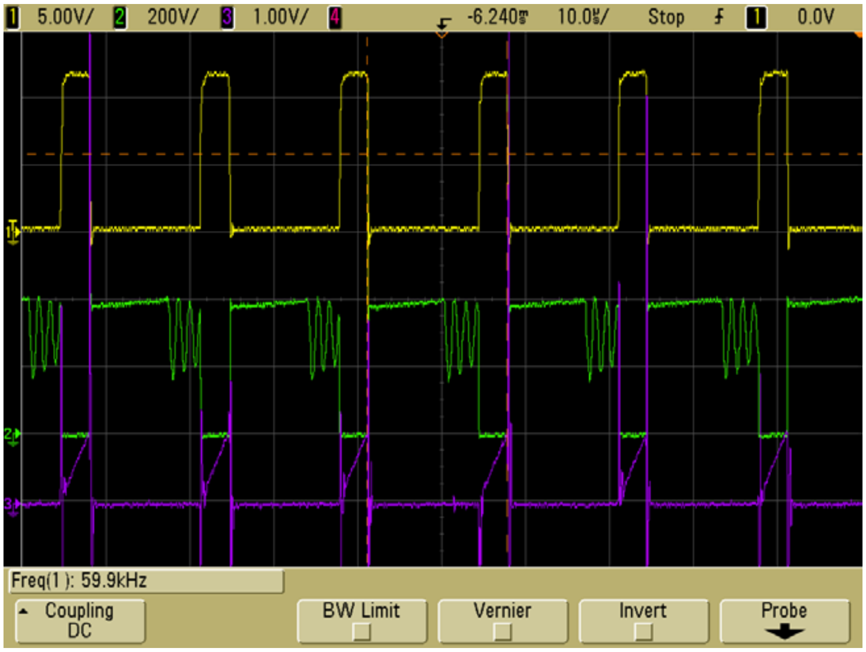
4.4 External Oscillator and Feedback Ramp



Ch1: CD74HCT14 Inverting Schmitt 60kHz Oscillator, Ch2: 60kHz Square Pulses input to UCC28810 TZE pin, Ch3: Regulation Feedback Ramp

Figure 16. External Oscillator and Feedback Ramp

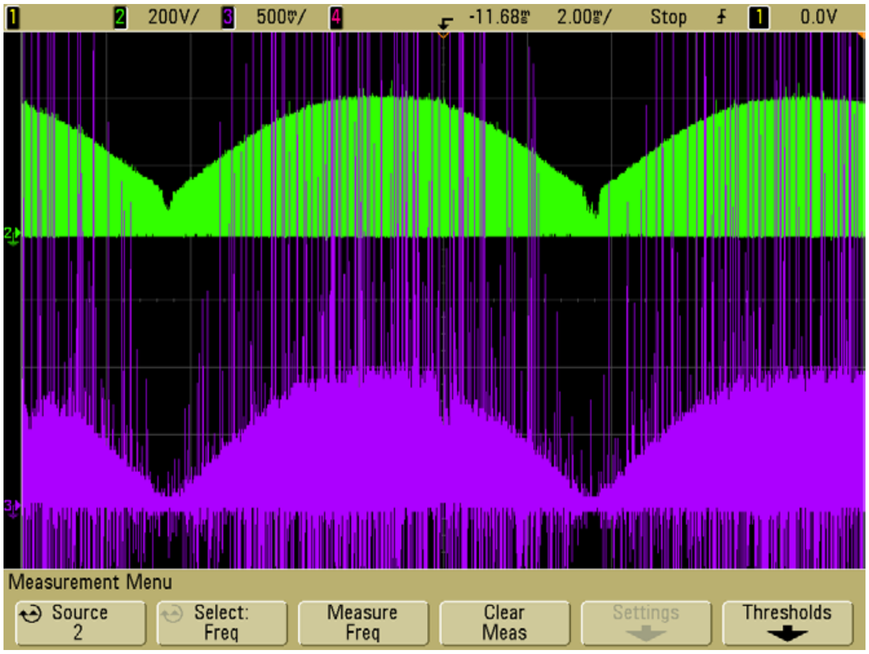
4.5 Primary-Side FET Gate Drive, Drain, and Current-Sense Waveforms



Ch1: Primary-Side FET Gate Drive, Ch2: Primary-Side FET Drain Waveform,
Ch3: Primary-Side Current Sense Waveform

Figure 17. Primary-Side FET Gate Drive, Drain, and Current-Sense Waveforms

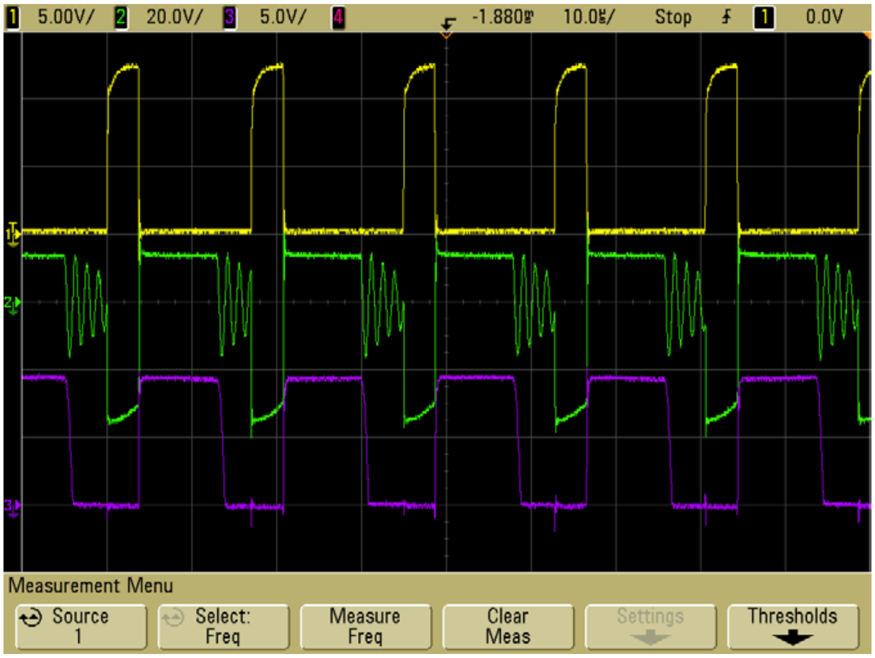
4.6 MOSFET Drain and Primary-Side Current Sense Voltage Envelope



Ch2: Primary-Side FET Drain, Ch3: Primary-Side Current Sense Waveform

Figure 18. Primary-Side FET Drain and Current Sense Voltage Envelope

4.7 Gate Drive, Auxiliary Winding, and Flip-Flop T_{off} Detector Waveforms



Ch1: Primary-Side FET Gate Drive, Ch2: Transformer Auxiliary Winding, Ch3: Flip-Flop based Toff Detector

Figure 19. Primary-Side FET Gate Drive, Auxiliary Winding, and Flip-Flop Toff Detector

5 Bill of Materials

Table 2 lists the bill of materials (BOM) for the secondary-side output current regulation circuit.

5.1 Secondary-Side Output Current Regulation

Table 2. Bill of Materials for Circuit with Secondary Side Regulation

Count	RefDes	Value	Description	Size	Part Number	MFR.
1	C1	100nF	Capacitor, Film, 100nF, 300VAC	Radial	B32023A3104M	Epcos
1	C2	220nF	Capacitor, ceramic, 220nF, 10V	805	Std	Std
2	C3,C28	1nF	Capacitor, ceramic, 1nF, 2kV	Radial	DEBE33D102ZB2B	Murata
1	C4	100pF	Capacitor, ceramic, 100pF, 10V	805	Std	Std
2	C5,C22	1nF	Capacitor, ceramic, 1nF, 10V	805	Std	Std
2	C6,C7	220µF	Capacitor, electrolytic, 220µF, 160V	Radial	UVR2C221MHA	Nichicon
1	C6A	220nF	Capacitor, Film, 220nF, 305VAC	Radial	B32922C3224M189	Epcos
DNP	C8	220µF	Capacitor, electrolytic, 220µF, 160V	Radial	UVR2C221MHA	Nichicon
1	C10	47pF	Capacitor, ceramic, 47pF, 6.3V	805	Std	Std
1	C11	4.7µF	Capacitor, electrolytic, 4.7µF, 25V	Radial	UVR1E4R7MDA	Nichicon
2	C12,C17	4.7µF	Capacitor, ceramic, 4.7µF, 25V	805	Std	Std
2	C13,C24	100nF	Capacitor, ceramic, 100nF, 6.3V	805	Std	Std
1	C14	10µF	Capacitor, ceramic, 10µF, 6.3V	805	Std	Std
1	C15	10nF	Capacitor, ceramic, 10nF, 10V	805	Std	Std
1	C16	2.2nF	Capacitor, ceramic, 2.2nF, 10V	805	Std	Std
1	C18	33µF	Capacitor, electrolytic, 33µF, 25V	Radial	UVR1E330MDA	Nichicon
2	C19,C23	100nF	Capacitor, ceramic, 100nF, 35V	805	Std	Std
2	C19A,C20A	10µF	Capacitor, electrolytic, 10µF, 315V	Radial	UVR2F100MPA	Nichicon
1	C20	470nF	Capacitor, ceramic, 470nF, 25V	Radial	Std	Std
1	C21	47µF	Capacitor, electrolytic, 47µF, 25V	Radial	UVR1E470MDA	Nichicon
DNP	C25	47µF	Capacitor, electrolytic, 47µF, 25V	Radial	UVR1E470MDA	Nichicon
1	C26	10µF	Capacitor, electrolytic, 10µF, 25V	Radial	UVR1E100MDA	Nichicon
1	C27	47µF 10V	Capacitor, electrolytic, 47µF, 10V	Radial	UVR1A470MDA	Nichicon
DNP	C2A	100nF	Capacitor, Film, 100nF, 300VAC	Radial	B32023A3104M	Epcos
3	D1, D2, D3	US1M	Diode, rectifier, 1000V, 1A	DIODE0.4	US1M	Diodes Inc.
4	D1A, D2A, D3A, D4A	1N5399	Diode, rectifier, 1000V, 1.5A	DIODE0.6	1N5399-E3/54	Vishay
1	D4	STTH1008DTI	Diode, hyperfast, 800V, 10A	TO220AC	STTH1008DTI	STMicro
1	D11	12V	Diode, Zener, 12V, 1W	DIODE0.4	1N4742A-TP	MCC
1	D6	BAT85	Diode, Schottky, 30V, 200mA	DO-34	BAT85,113	NXP
2	D7,D8	IN4148	Diode, rectifier, 75V, 150mA	SOD523	1N4148X-TP	MCC
1	D9	BAT54	Diode, Schottky 30V, 200mA	SOT-23	BAT54S-TP	MCC
1	D9A	1N4007	Diode, rectifier, 1000V, 1A	DIODE0.4	1N4007-TP	MCC
1	D10	18V	Diode, Zener, 18V, 1W	SMA	SMAZ18-13-F	Diodes Inc.
DNP	D12	68V	Diode, Zener, 68V, 1/2W	SOD123	MMSZ5266BT1G	On Semi
DNP	D13	56V	Diode, Zener, 56V, 1/2W	SOD123	MMSZ5263BT1G	On Semi
1	D14	18V	Diode, Zener, 18V, 1W	DIODE0.4	1N4746A-TP	MCC
1	F1	39213150000	Fuse, 3.15A, 250V	Radial, Box	39213150000	Littelfuse
1	J1	TC03236200J0G	Terminal Block, 15A, 5.1mm	200-3	TC03236200J0G	FCI
1	J3	5010	Test point, red, thru hole	0.125 × 0.125 in	5010	Keystone
1	J4	5011	Test point, black, thru hole	0.125 × 0.125 in	5011	Keystone
1	L1	10mH	Inductor, Common-Mode, 10mH, 3A, TH	UU10.5	Custom	Custom
2	L2,L3	100uH	Inductor, Differential, 100µH, 3A, TH	TH	Custom	Custom
1	MOV1	B72207S271K321	MOV, 387V, 1.2kA	Disc 7mm	B72207S271K321	Epcos
1	Q1	BC857	Transistor, PNP, 45V, 100mA	SOT-23	BC857BLT3G	On Semi
3	Q2,Q4,Q5	BC847	Transistor, NPN, 45V, 100mA	SOT-23	BC847CLT3G	On Semi

Table 2. Bill of Materials for Circuit with Secondary Side Regulation (continued)

Count	RefDes	Value	Description	Size	Part Number	MFR.
1	Q3	STP8N80K5	Transistor, N-ch FET, 800V, 6A	TO-220-3	STP8N80K5	STMicro
1	Q6	BC547	Transistor, NPN, 45V, 100mA	TO-92	BC547CZL1G	On Semi
1	Q7	BSS123	Transistor, N-ch FET, 100V, 170mA	SOT-23	BSS123LT1G	On Semi
1	Q8	FJP5027OTU	Transistor, NPN, 800V, 3A	TO-220-3	FJP5027OTU	Fairchild
2	R1,R28	33K	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R2	330K	Resistor, chip, 1/4W, 1%	1206	Std	Std
2	R3,R40	47kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R4	220kΩ	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
DNP	R4A	220kΩ	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R5	100K	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R5A	100K	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R6	22kΩ	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
2	R7,R8	22kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R9	12kΩ	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R10	2.2MΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
DNP	R10A,R20A	2.2MΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R11	12kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
2	R12,R13	5.6kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R15	8.2kΩ	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R16	8.2kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R17	0E	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
2	R18,R19	1MΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R20	56kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R21	82kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
DNP	R21A,R21B	1MΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
2	R22,R26	4.7kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R23	4.7E	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R24	0.2Ω	Resistor, chip, 1/2W, 1%	1206	Std	Std
1	R25	2.7kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
2	R27,R37	150kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R29	0.82Ω	Resistor, axial,1W, 1%	AXIAL0.4	Std	Std
DNP	R31	1Ω	Resistor, axial,1W, 1%	AXIAL0.4	Std	Std
1	R32	240kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
3	R33, R34, R35	1kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R36	10kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R38	150Ω	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R38A	1MΩ	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R39	150Ω	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R41	100E	Resistor, chip, 1/4W, 1%	1206	Std	Std
DNP	R42	0.5Ω	Resistor, chip, 1/4W, 1%	1206	Std	Std
	T1	200µH	Transformer, Custom	PQ3230	Std	Std
DNP	T1A	200µH	Transformer, Custom	PQ2625	Std	Std
1	U1	CD74HCT14M	IC, High Speed CMOS Logic Hex Schmitt-Triggered Inverters	SOIC-14	CD74HCT14M	TI
1	U2	UCC28810	IC, LED Lighting Power Controller	SOIC-8	UCC28810DR	TI
1	U3	PC817B	IC, Optocoupler	DIP4	PC817B	Sharp
2	U4,U5	TL431	Adjustable Precision Shunt Regulator	TO-92	TL431CLPM	TI

5.2 *Primary-Side Output Current Regulation*

Table 3 lists the BOM for the primary-side output current regulation circuit.

Table 3. Bill of Materials for Circuit with Primary Side Regulation

Count	RefDes	Value	Description	Size	Part Number	MFR
1	C1	100nF	Capacitor, Film, 100nF, 300VAC	Radial	B32023A3104M	Epcos
1	C2	220nF	Capacitor, ceramic, 220nF, 10V	805	Std	Std
2	C3,C28	1nF	Capacitor, ceramic, 1nF, 2kV	Radial	DEBE33D102ZB2B	Murata
1	C4	100pF	Capacitor, ceramic, 100pF, 10V	805	Std	Std
2	C5,C22	1nF	Capacitor, ceramic, 1nF, 10V	805	Std	Std
2	C6,C7	220µF	Capacitor, electrolytic, 220µF, 160V	Radial	UVR2C221MHA	Nichicon
1	C6A	220nF	Capacitor, Film, 220nF, 305VAC	Radial	B32922C3224M189	Epcos
DNP	C8	220µF	Capacitor, electrolytic, 220µF, 160V	Radial	UVR2C221MHA	Nichicon
1	C10	47pF	Capacitor, ceramic, 47pF, 6.3V	805	Std	Std
1	C11	4.7µF	Capacitor, electrolytic, 4.7µF, 25V	Radial	UVR1E4R7MDA	Nichicon
2	C12,C17	4.7µF	Capacitor, ceramic, 4.7µF, 25V	805	Std	Std
2	C13,C24	100nF	Capacitor, ceramic, 100nF, 6.3V	805	Std	Std
1	C14	10µF	Capacitor, ceramic, 10µF, 6.3V	805	Std	Std
1	C15	10nF	Capacitor, ceramic, 10nF, 10V	805	Std	Std
1	C16	2.2nF	Capacitor, ceramic, 2.2nF, 10V	805	Std	Std
1	C18	33µF	Capacitor, electrolytic, 33µF, 25V	Radial	UVR1E330MDA	Nichicon
2	C19,C23	100nF	Capacitor, ceramic, 100nF, 35V	805	Std	Std
2	C19A,C20A	10µF	Capacitor, electrolytic, 10µF, 315V	Radial	UVR2F100MPA	Nichicon
DNP	C25	47µF	Capacitor, electrolytic, 47µF, 25V	Radial	UVR1E470MDA	Nichicon
1	C26	10µF	Capacitor, electrolytic, 10µF, 25V	Radial	UVR1E100MDA	Nichicon
1	C27	47µF 10V	Capacitor, electrolytic, 47µF, 10V	Radial	UVR1A470MDA	Nichicon
DNP	C2A	100nF	Capacitor, Film, 100nF, 300VAC	Radial	B32023A3104M	Epcos
1	C29	1nF	Capacitor, ceramic, 1nF, 2kV	Radial	DEBE33D102ZB2B	Murata
1	C30	168pF	Capacitor, ceramic, 168pF, 25V	805	Std	Std
1	C31	1µF	Capacitor, electrolytic, 1µF, 25V	Radial	Std	Std
1	C32	22nF	Capacitor, ceramic, 22nF, 25V	805	Std	Std
1	C33	4.7µF	Capacitor, ceramic, 4.7µF, 6.3V	805	Std	Std
1	C34	1µF	Capacitor, electrolytic, 1µF, 25V	Radial	Std	Std
2	C35,C36	1nF	Capacitor, ceramic, 1nF, 35V	805	Std	Std
2	C37,C38	100pF	Capacitor, ceramic, 100pF, 35V	805	Std	Std
3	D1, D2, D3	US1M	Diode, rectifier, 1000V, 1A	DIODE0.4	US1M	Diodes Inc.
4	D1A, D2A, D3A, D4A	1N5399	Diode, rectifier, 1000V, 1.5A	DIODE0.6	1N5399-E3/54	Vishay
1	D4	STTH1008DTI	Diode, hyperfast, 800V, 10A	TO220AC	STTH1008DTI	STMicro
1	D5	12V	Diode, Zener, 12V, 1W	DIODE0.4	1N4742A-TP	MCC
1	D6	BAT85	Diode, schottky, 30V, 200mA	DO-34	BAT85,113	NXP
2	D7,D8	IN4148	Diode, rectifier, 75V, 150mA	SOD523	1N4148X-TP	MCC
1	D9	BAT54	Diode, Schottky 30V, 200mA	SOT-23	BAT54S-TP	MCC
1	D9A	1N4007	Diode, rectifier, 1000V, 1A	DIODE0.4	1N4007-TP	MCC
1	D10	18V	Diode, Zener, 18V, 1W	SMA	SMAZ18-13-F	Diodes Inc.
1	D14	18V	Diode, Zener, 18V, 1W	DIODE0.4	1N4746A-TP	MCC
2	D15,D17	BAT85	Diode, schottky, 30V, 200mA	DO-34	BAT85,113	NXP
1	D16	12V	Diode, Zener, 12V, 1W	DIODE0.4	1N4742A-TP	MCC
2	D18,D19	IN4148	Diode, rectifier, 75V, 150mA	SOD523	1N4148X-TP	MCC
1	F1	39213150000	Fuse, 3.15A, 250V	Radial, Box	39213150000	Littelfuse
1	J1	TC03236200J0G	Terminal Block, 15A, 5.1mm	200-3	TC03236200J0G	FCI
1	J3	5010	Test point, red, thru hole	0.125 × 0.125 in	5010	Keystone
1	J4	5011	Test point, black, thru hole	0.125 × 0.125 in	5011	Keystone
1	L1	10mH	Inductor, Common-Mode, 10mH, 3A, TH	UU10.5	Custom	Custom

Table 3. Bill of Materials for Circuit with Primary Side Regulation (continued)

Count	RefDes	Value	Description	Size	Part Number	MFR
2	L2,L3	100uH	Inductor, Differential, 100uH, 3A, TH	TH	Custom	Custom
1	MOV1	B72207S271K321	MOV, 387V, 1.2kA	Disc 7mm	B72207S271K321	Epcos
1	Q1	BC857	Transistor, PNP, 45V, 100mA	SOT-23	BC857BLT3G	On Semi
3	Q2,Q4,Q5	BC847	Transistor, NPN, 45V, 100mA	SOT-23	BC847CLT3G	On Semi
1	Q3	STP8N80K5	Transistor, N-ch FET, 800V, 6A	TO-220-3	STP8N80K5	STMicro
2	Q6,Q9	BC547	Transistor, NPN, 45V, 100mA	TO-92	BC547CZL1G	On Semi
1	Q7	BSS123	Transistor, N-ch FET, 100V, 170mA	SOT-23	BSS123LT1G	On Semi
1	Q8	FJP5027OTU	Transistor, NPN, 800V, 3A	TO-220-3	FJP5027OTU	Fairchild
4	Q10, Q11, Q12, Q13	BC847	Transistor, NPN, 45V, 100mA	SOT-23	BC847CLT3G	On Semi
2	R1,R30	33K	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R2	330K	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R3	47kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R4	220kΩ	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
DNP	R4A	220kΩ	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R5	100K	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R5A	100K	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R7	22kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R8	82kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R9	12kΩ	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R10	2.2MΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
DNP	R10A,R20A	2.2MΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R11	12kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
2	R12,R13	5.6kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R14	120kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R15	8.2kΩ	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R16	8.2kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R17	0E	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
2	R18,R19	1MΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R20	56kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R21	68kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
DNP	R21A,R21B	1MΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R22	4.7kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R23	4.7E	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R24	0.2Ω	Resistor, chip, 1/2W, 1%	1206	Std	Std
1	R37	150kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R32	240kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
2	R33,R34	1kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R36	10kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R38	150Ω	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R38A	1MΩ	Resistor, axial,1/4W, 1%	AXIAL0.4	Std	Std
1	R39	150Ω	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R41	100E	Resistor, chip, 1/4W, 1%	1206	Std	Std
DNP	R42	0.5Ω	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R43	165kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	R44	330kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
3	R45, R51, R52	100Ω	Resistor, chip, 1/4W, 1%	1206	Std	Std
2	R46 ,R49	22kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
3	R47, R53, R54	4.7kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
3	R48, R57, R58	10kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std

Table 3. Bill of Materials for Circuit with Primary Side Regulation (continued)

Count	RefDes	Value	Description	Size	Part Number	MFR
1	R50	47kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
2	R55, R56	100kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
2	R57, R58	10kΩ	Resistor, chip, 1/4W, 1%	1206	Std	Std
1	T1	200µH	Transformer, Custom	PQ3230	Std	Std
DNP	T1A	200µH	Transformer, Custom	PQ2625	Std	Std
1	U1	CD74HCT14M	IC, High Speed CMOS Logic Hex Schmitt-Triggered Inverters	SOIC-14	CD74HCT14M	TI
1	U2	UCC28810	IC, LED Lighting Power Controller	SOIC-8	UCC28810DR	TI

6 Test Results

6.1 *Secondary-Side Output Current Regulation*

Table 4 lists the performance characteristics of a 70-W LED driver design with secondary-side output current regulation.

Table 4. Performance Characteristics of 70-W LED Driver Design With Secondary-Side Output Current Regulation

Input RMS Voltage (V)	Input Power (W)	Output Voltage (V)	Output Current (mA)	Output Power (W)	Efficiency (%)	Power Factor	Current THD (%)
90	71.35	105.8	586	61.99	86.89	0.996	4.67
120	69.55	106	587	62.22	89.46	0.997	3.25
150	68.85	106.1	586	62.17	90.30	0.998	2.67
180	68.68	106.1	586	62.17	90.52	0.998	2.56
220	67.91	106.1	586	62.17	91.55	0.998	2.54
250	68.12	106.2	586	62.23	91.35	0.999	2.55
265	68.17	106.2	586	62.23	91.29	0.998	2.97

6.2 *Primary-Side Output Current Regulation*

Table 5 lists the performance characteristics of a 70-W LED driver design with primary-side output current regulation.

Table 5. Performance Characteristics of 70-W LED Driver Design with Primary-Side Output Current Regulation

Input RMS Voltage (V)	Input Power (W)	Output Voltage (V)	Output Current (mA)	Output Power (W)	Efficiency (%)	Power Factor	Current THD (%)
90	79.41	112.6	621	69.92	88.05	0.999	3.88
120	78.25	112.3	622	69.85	89.26	0.999	3.58
150	75.3	111.0	611	67.82	90.06	0.999	2.12
180	73.57	109.9	605	66.48	90.37	0.999	1.92
220	69.37	107.5	595	63.96	92.20	0.998	2.80
250	70.69	108.3	599	64.87	91.77	0.998	2.26
265	70.93	108.4	598	64.82	91.39	0.997	2.25

7 Conclusion

This application report describes design details and test results for a fixed-frequency, single-stage 70-W AC/DC flyback LED driver for streetlight applications, both with primary-side and secondary-side output current regulation circuits. Due to constant on-time and fixed switching-frequency operation, power factor greater than 0.9, and current THD less than 10 percent, is easily achieved. This design meets all the necessary performance specifications, including output open-circuit and short-circuit protections.

8 References

1. UCC28810 LED lighting power controller: http://www.ti.com/product/ucc28810.
2. CD74HCT14M High Speed CMOS Logic Hex Schmitt-Triggered Inverter: http://www.ti.com/product/cd74hct14.
3. TL431 Adjustable Precision Shunt Regulator: http://www.ti.com/product/tl431.
4. TPS92314 Off-Line Primary Side Sensing Controller with PFC: http://www.ti.com/product/tps92314

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