TI Designs
110-V AC to 5-V DC @ 30-mA Non-Isolated Power Supply Design Guide

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Design Resources

TIDA-00379	Tool Folder Containing Design Files
UCC28880	Product Folder
LMP2985-50	Product Folder

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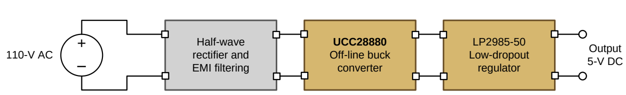
Design Features

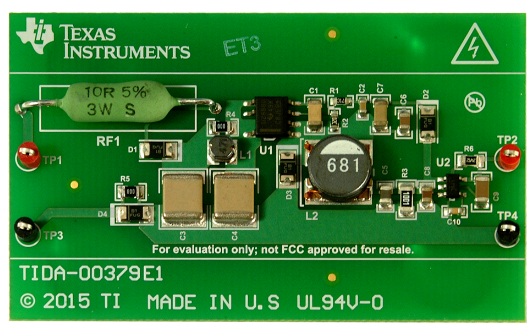
5-V DC/30-mA non-isolated power supply design for 110-V AC/60-Hz input with under 20-mV output ripple across no-load and full-load conditions.

- Does Not Require Custom Transformer
- Robust Performance With Inductor Current Runway Protection
- Protection: Current limit, Overload and Output Short Circuit, Over Temperature
- Optimized, Low-Cost BOM
- Input: 110-V AC (85-V to 130-V AC)
- Output Voltage: 5-V DC
- Load Current: 500 µA to 30 mA
- Output Ripple of Less Than 10 mV
- Conducted Emissions: CISPR 22, Class B
- Operating Conditions: –40°C to 85°C

Featured Applications

- Building Automation — Dimmers, Switches
- Smart Grid — Smart Plugs





An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATION	DETAILS
Input voltage	85-V to 130-V AC	See Section 4.1
Input line frequency	47 to 63 Hz	See Section 4.1
Output voltage	5-V DC	See Section 4.2
Load current, max	30 mA	See Section 4.1 and Section 4.2
Load current, min	500 µA	See Section 4.1 and Section 4.2
Output power, max	150 mW	See Section 4.1 and Section 4.2
Output ripple, max	20 mV	See Section 4.2 and Section 6.4
Converter efficiency, typical	55%	See Section 6.3
Conducted emissions	CISPR 22, Class B	See Section 6.7
Temperature rating	–40°C to 85°C	See Section 5.2
Dimensions	63.2 × 38.1 mm (1500 × 2490 mils)	See Section 7.3

2 System Description

The power supply is a key subsystem of many industrial, automotive, and consumer end-equipment products. The power supply subsystem is designed based on the operating voltage and current requirements of the system as well as the source from which power is derived. In some applications, power is derived directly from an existing AC power line through the use of an off-line AC-to-DC power converter.

The 110-V AC to 5-V DC @ 30-mA Non-Isolated Power Supply TI Design uses the UCC28880 low-power, low-cost, off-line buck converter and the LP2985-50 low-noise, low-dropout voltage regulator to generate a non-isolated 5-V/30-mA output directly from a 110-V AC line input. Off-line converters are powered directly from the AC line by using a rectifier and capacitive filter, and do not require a large 60-Hz transformer, thereby eliminating the heaviest and costliest component of a typical transformer-based power supply. The entire TI design is implemented on a single-sided, double-layer board size of just 63.2 × 38.1 mm with a build-of-materials (BOM) count of 19 devices.

This design guide addresses component selection, design theory, and test results of the entire TI Design system. The information provided in this design guide gives system designers a fully-tested reference design, which can be easily used as -is in existing systems or modified accordingly to meet different system requirements.

The following subsections describe the various blocks within the reference design system and the characteristics that are most critical to implementing the corresponding function.

2.1 AC-to-DC Buck Converter

Careful consideration is required when selecting an AC-to-DC converter for the power supply design. At a minimum, the power supply must meet the minimum voltage and current required to power the load. However, the power supply design must also be highly efficient to minimize power losses, and it must provide a stable output voltage to the rest of the system. The converter must also guard against failure conditions such as short circuits and high temperatures. The overall cost of the power supply design is also important.

The UCC28880 converter is at the center of the 110-V AC to 5-V DC @ 30-mA Non-Isolated Power Supply TI Design. The UCC28880 converter is configured as a traditional high-side buck, where the voltage feedback is sampled from the output voltage (V_{OUT}). The converter operates directly from the rectified mains AC line.

The UCC28880 converter incorporates a soft-start feature for controlled startup of the power stage and a special protection mechanism to avoid runaway of the inductor current when the converter operates with the output shorted or in other abnormal conditions. The UCC28880 device also includes thermal shutdown and undervoltage lockout protection features.

2.2 Low-Dropout Regulator

The low-dropout regulator delivers the final voltage and current to the load. As such, specifications such as output voltage tolerance and output noise level are key to ensuring the system performs as intended. The BOM count and cost of the discrete components required to operate the regulator are also important.

In the 110-V AC to 5-V DC @ 30-mA Non-Isolated Power Supply TI Design, the LP2985-50 low-dropout regulator provides the 5-V DC source to the load in the system. The LP2985-50 has an output voltage tolerance of 1.5%; however, other versions of this device are available, which can provide up to 1% output voltage tolerance. Other output voltages can also be achieved by selecting a different version of the LP2985 device.

The LP2985-50 device can be used with low-ESR capacitors, making it compatible with small, inexpensive ceramic capacitors. Its small SOT-23 package is ideal for most space-constrained applications. The LP2985-50 device also includes overcurrent and over-temperature protection features.

3 Block Diagram

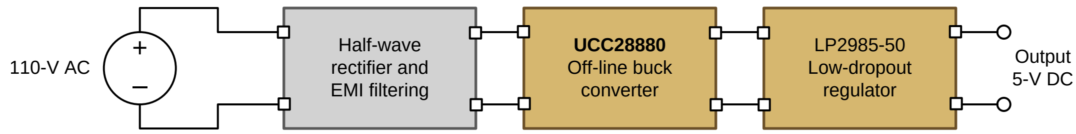


Figure 1. AC-DC Power Supply Block Diagram

3.1 Highlighted Products

The 110-V AC to 5-V DC @ 30-mA Non-Isolated Power Supply TI Design features the following devices:

- UCC28880 (Section 3.1.1): 700-V off-line switcher with a less than 100-µA device quiescent current
- LP2985-50 (Section 3.1.2): 150-mA low-noise, low-dropout voltage regulator

For more information on these devices, see their respective product folders at www.ti.com.

3.1.1 UCC28880 Description

The UCC28880 integrates a PWM controller and a 700-V power MOSFET into one monolithic device. The device also integrates a high-voltage current source, enabling start up and operation directly from the rectified mains voltage.

The low-quiescent current of the device enables excellent efficiency. The device is suitable for non-isolated AC-to-DC low-side buck and buck-boost configurations with level-shifted direct feedback, but also more traditional high-side buck, buck boost, and low-power flyback converters with low standby power can be built using a minimum number of external components.

The device generates its own internal low-voltage supply (5 V referenced to the device's ground, GND) from the integrated high-voltage current source. The PWM signal generation is based on a maximum constant ON-time, minimum OFF-time concept, with the triggering of the ON-pulse depending on the feedback voltage level. Each ON-pulse is followed by a minimum OFF-time to ensure that the power MOSFET is not continuously driven in an ON-state. The PWM signal is AND-gated with the signal from a current limit circuit. No internal clock is required as the switching of the power MOSFET is load dependent. A special protection mechanism is included to avoid runaway of the inductor current when the converter operates with the output shorted or in other abnormal conditions that can lead to an uncontrolled increase of the inductor current. This special protection feature keeps the MOSFET current at a safe operating level. The device is also protected from other fault conditions with thermal shutdown, undervoltage lockout and soft-start features.

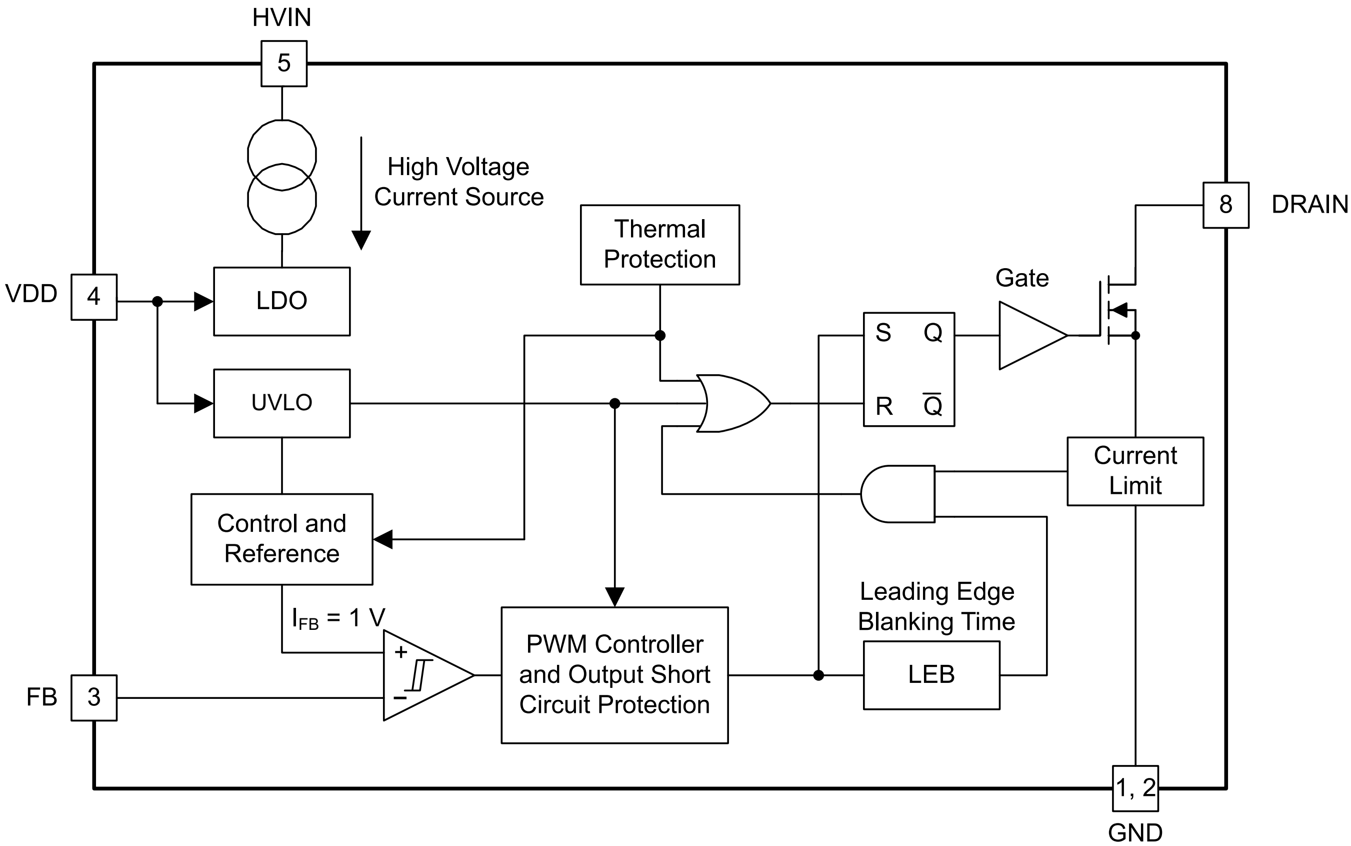


Figure 2. UCC28880 Functional Block Diagram

3.1.1.1 *UCC28880 Features*

- Integrated power MOSFET (Switch) rated to 700-V drain-to-source voltage
- Integrated high-voltage current source for internal low-voltage supply generation
- Soft start
- Self-biased switcher (start-up and operation directly from rectified mains voltage)
- Supports buck, buck-boost, and flyback topologies
- <100-µA device quiescent current
- Robust performance with inductor current
- Runaway prevention
- Protection
  - Current limit
  - Overload and output short circuit
  - Over temperature

3.1.2 LP2985-50 Description

The LP2985 family of fixed-output, low-dropout regulators offers exceptional, cost-effective performance for both portable and non-portable applications. Available in output voltages of 1.8, 2.5, 2.8, 2.9, 3, 3.1, 3.3, 5, and 10 V, the family has an output tolerance of 1% for the A version (1.5% for the non-A version) and is capable of delivering 150-mA continuous load current. Standard regulator features such as overcurrent and over-temperature protection are included.

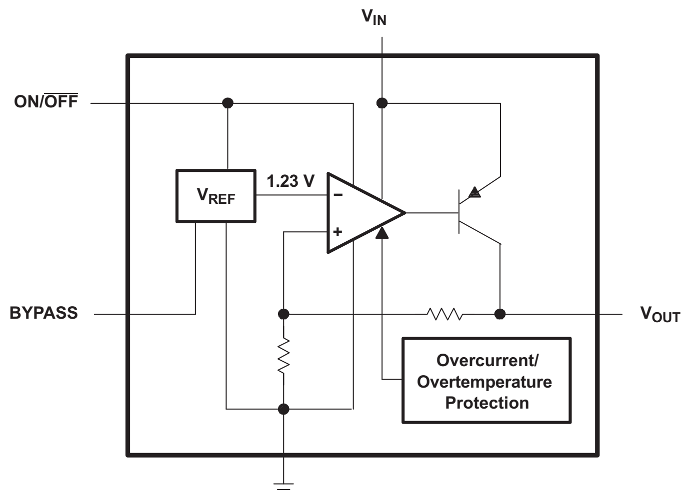


Figure 3. LP2985 Functional Block Diagram

3.1.2.1 LP2985-50 Features

The LP2985-50 has a host of features that makes the regulator an ideal candidate for a variety of applications:

- Low dropout: A PNP pass element allows a typical dropout of 280 mV at 150-mA load current and 7 mV at 1-mA load.
- Low quiescent current: The use of a vertical PNP process allows for quiescent currents that are considerably lower than those associated with traditional lateral PNP regulators.
- Shutdown: A shutdown feature is available, allowing the regulator to consume only 0.01-μA when the ON/OFF pin is pulled low.
- Low-ESR capacitor friendly: The regulator is stable with low-ESR capacitors, allowing the use of small, inexpensive, ceramic capacitors in cost-sensitive applications.
- Low noise: A BYPASS pin allows for low-noise operation with a typical output noise of 30-μV_{RMS} and the use of a 10-nF bypass capacitor.
- Small packaging: For the most space-constrained needs, the regulator is available in the SOT-23 package.

4 System Design Theory

The 110-V AC to 5-V DC @ 30-mA Non-Isolated Power Supply TI Design uses the UCC28880 converter and LP2985-50 low-dropout regulator to generate a non-isolated 5-V/30-mA output from a 110-V AC line input. The UCC28880 converter is configured as a traditional high-side buck, where the voltage feedback is sampled from the output voltage (V_{OUT}). The LP2985-50 regulator delivers the final output voltage and current to the load.

The TI design can be broken down into an input stage, an AC-to-DC conversion stage, and an output stage. The input stage provides short circuit protection, half-wave rectification, EMI filtering, and storage capacitance for the UCC28880 converter. The UCC28880 converts the AC voltage into a DC voltage source for the low-dropout regulator. At the output stage of the design, the low-dropout regulator delivers the final 5-V DC voltage to the load.

Table 2 lists the specifications for this TI design. The sections that follow document the selection process for the components used in the design.

Table 2. Power Supply Design Specifications

DESCRIPTION		MIN	MAX	UNIT
Design Input				
V_{IN}	AC input voltage	85	130	V_{RMS}
f_{LINE}	Line frequency	47	63	Hz
Design Requirements				
V_{OUT}	Output voltage	5		V
I_{OUT}	Output current	0	30	mA
ΔV_{OUT}	Output voltage ripple		20	mV
η	Converter efficiency	55%		

4.1 Off-Line Converter

4.1.1 Input Stage (RF1, D1, D4, C3, C4, L1)

Resistor RF1 is a flame-proof fusible resistor. RF limits the inrush current, and also provides protection in case any component failure causes a short circuit. Value for its resistance is generally selected between 4.7 to 15 Ω. A 10-Ω resistor was chosen for this design.

A half-wave rectifier is chosen and implemented by diode D1 (CD1408-FU1400). It is a general purpose 1-A, 400-V rated diode. It has a fast reverse recovery time (35 ns) for improved differential-mode-conducted EMI noise performance. Diode D4 (CD1408-FU1400) is added for improved common-mode-conducted EMI noise performance. D4 can be removed and replaced by a short if not needed.

EMI filtering is implemented by using a single differential-stage filter (C3-L1-C4), with L1 set to 470 μH. Capacitors C3 and C4 in the EMI filter also act as storage capacitors for the high-voltage DC input of the UCC28880. The required input capacitor size can be calculated according the formula given in the UCC28880 datasheet:

$$C_{BULK(min)} = \frac{\frac{2\,P_{IN}}{f_{LINE(min)}}\left\{\frac{1}{RCT} - \frac{1}{2\pi}\arccos\left(\frac{V_{BULK(min)}}{\sqrt{2} \times V_{IN(min)}}\right)\right\}}{\left(\sqrt{2} \times V_{IN(min)}\right)^2 - V_{BULK(min)}{}^2} \quad (1)$$

where

- $C_{BULK(min)}$ is the minimum value for the total capacitor value (C3 + C4 in the schematic).
- RCT = 1 in case of a single-wave rectifier and RCT = 2 in case of a full-wave rectifier (in this case, RCT = 1).
- P_{IN} is the converter input power.
- $V_{IN(min)}$ is the minimum RMS value of the AC input voltage.
- $V_{BULK(min)}$ is the minimum allowed voltage across the bulk capacitor during converter operation.
- $f_{LINE(min)}$ is the minimum line frequency when the line voltage is $V_{IN(min)}$.

The converter input power is calculated as follows:

- The converter maximum output power is

$$P_{OUT} = I_{OUT} \times V_{OUT} = 0.035\text{ A} \times 5.25\text{ V} = 0.184\text{ W} \quad (2)$$

- Assuming an efficiency of η = 55% the input power is

$$P_{IN} = \frac{P_{OUT}}{\eta} = \frac{0.184\text{ W}}{0.55} \approx 0.33\text{ W} \quad (3)$$

The following values were used for the other parameters.

- $V_{BULK(min)}$ = 80 V
- $V_{IN(min)}$ = 85 V_{RMS}
- $f_{LINE(min)}$ = 57 Hz

$$C_{BULK(min)} = \frac{\frac{2 \times 0.33\text{ W}}{57\text{ Hz}}\left\{\frac{1}{1} - \frac{1}{2\pi}\arccos\left(\frac{80\text{ V}}{\sqrt{2} \times 85\text{ V}}\right)\right\}}{\left(\sqrt{2} \times 85\text{ V}\right)^2 - (80\text{ V})^2}$$

$$C_{BULK(min)} = 1.25\ \mu\text{F} \quad (4)$$

Assuming a 20% tolerance for the bulk capacitors, the minimum required value is:

$$C_{BULK(min)} > \frac{C_{BULK(min)}}{(1 - \text{tolerance})} = \frac{1.25\ \mu\text{F}}{1 - 0.20} = 1.56\ \mu\text{F} \quad (5)$$

C3 and C4 were selected to be 1 μF each (C_{BULK} = 1 μF + 1 μF = 2.00 μF).

If the input EMI filter is not needed, L1 can be removed and the C3-C4 caps can be replaced by a single capacitor.

4.1.1.1 Regulator Capacitor (C1)

Capacitor C1 acts as the decoupling capacitor and storage capacitor for the internal regulator. Per the UCC28880 datasheet, a 100-nF, 10-V rated ceramic capacitor is enough for proper operation of the device's internal LDO. In this design, a 100-nF, 50-V rated capacitor was selected for C1.

4.1.1.2 Freewheeling Diode (D3)

The freewheeling diode has to be rated for high-voltage with as short as possible reverse-recovery time (t_{rr}). The maximum reverse voltage that the diode should experience in the application, during normal operation, is given by:

$$V_{D1(max)} = \sqrt{2} \times V_{IN(max)} = \sqrt{2} \times 130 = 184 \text{ V} \tag{6}$$

A margin of 20% is generally considered.

The chosen freewheeling diode for the application example is a 400-V, 1-A rated diode with $t_{rr} \leq 35$ ns. Using a diode with a higher t_{rr} leads to higher switching losses and lower efficiency.

4.1.1.3 Inductor (L2)

Per the UCC28880 datasheet, the minimum inductance value should satisfy both of the following equations:

$$L2 > \frac{V_{OUT} + V_d}{\Delta I_L \times f_{SW\_VIN(max)}} = \frac{7.0 \text{ V} + 1.05 \text{ V}}{240 \text{ mA} \times 66 \text{ kHz}} \approx 508 \ \mu\text{H} \tag{7}$$

$$L2 > \left[\frac{L_{MIN}}{V_{IN}}\right]_{min} \times V_{IN(max)} = 2.65 \frac{\mu\text{H}}{\text{V}} \times \left(\sqrt{2} \times 130 \text{ V}\right) \approx 490 \ \mu\text{H} \tag{8}$$

ΔI_L was calculated as $\Delta I_L < 2(I_{LIMIT} - I_{OUT}) = 2(150 \text{ mA} - 30 \text{ mA}) = 240$ mA. For full details on these equations, refer to the UCC28880 datasheet. The 7.0-V target was chosen to ensure the converter output voltage stayed above the output voltage of the low-dropout regulator.

This design uses a 680-µH inductor for L2.

4.1.1.4 Output Capacitor (C5)

The equivalent series resistance (R_{ESR}) of the output capacitor (C5) directly affects the performance of the switching regulator. If the R_{ESR} increases (as it does with low operating temperatures), the output ripple will increase accordingly. Also, a high R_{ESR} reduces overall regulator efficiency as power is dissipated when current flows in and out of the capacitor. It is important to select a capacitor with a low R_{ESR} at the intended operating frequency.

For this design, a 22-µF capacitor with a very low R_{ESR} at the 66-kHz target switching frequency was selected. The final capacitance value was selected based on measurements of the output ripple.

4.1.1.5 Feedback Path (C2, R1, and R2)

In high-side buck converter applications, the information on the output voltage value is stored on feedback capacitor (C1). This information is not updated in real-time. The information on the feedback capacitor is updated just after the MOSFET turn-off event. When the MOSFET is turned off, the inductor current forces the freewheeling diode (D3) to turn on and the GND pin of UCC28880 goes negative at $-V_{d3}$ (where V_{d3} is the forward drop voltage of diode D3) with respect to the negative terminal of bulk capacitor (C3). When D3 is on, through diode D2, the C1 capacitor is charged at $V_{OUT} - V_{d2} + V_{d3}$. The output voltage regulation level and time constant, τ_{FB} , is set using the following equations:

$$\frac{R_1}{R_2} = \frac{V_{OUT(T)} - V_{d4} + V_{d1} - V_{FB\_TH}}{V_{FB\_TH}} \cong \frac{V_{OUT(T)} - V_{FB\_TH}}{V_{FB\_TH}} \tag{9}$$

$$\tau_{FB} = C_2 \times \left(R_1 + R_2\right) \cong \frac{1}{10} C_5 R_3$$

where

- V_{FB_TH} is the FB pin reference voltage
- $V_{OUT(T)}$ is the target output voltage
- R1 and R2 are the resistor dividers connected to the FB pin (10)

The initial R1 and R2 ratio was calculated as follows:

$$\frac{R_1}{R_2} = \frac{V_{OUT(T)} - V_{FB\_TH}}{V_{FB\_TH}} \cong \frac{7.0\ \text{V} - 1.02\ \text{V}}{1.02\ \text{V}} = 5.86 \tag{11}$$

After performance testing, the design was adjusted such that R1 = 61.9 kΩ and R2 = 10.2 kΩ, giving R1/R2 = 6.07. The 7.0-V target was chosen to ensure the converter output voltage stayed above the output voltage of the low-dropout regulator.

For this design, a 0.22-µF capacitor was used as C2. The final capacitance value was selected based on measurements of the output voltage.

4.2 Low-Dropout Regulator

4.2.1 Input Capacitor (C8)

A minimum value of 1-µF (over the entire operating temperature range) is required at the input of the LP2985-50. There are no equivalent series resistance (ESR) requirements for this capacitor, and the capacitance can be increased without limit.

4.2.2 Output Capacitor (C9)

As an advantage over other regulators, the LP2985-50 permits the use of low-ESR capacitors at the output, including ceramic capacitors that can have an ESR as low as 5 mΩ.

As with other PNP LDOs, stability conditions require the output capacitor to have a minimum capacitance and an ESR that falls within a certain range. See the device datasheet for details.

A 2.2-µF capacitor is used in this design. Other capacitor values can be used, but it is critical that both the minimum capacitance and ESR requirement be met over the entire operating temperature range. Depending on the type of capacitors used, both these parameters can vary significantly with temperature.

4.2.3 Load Resistance (R3 and R6)

The output current in any standby or no-load condition should always be higher than the leakage current through the integrated power MOSFET of the UCC28880. A 24.9-kΩ resistance (R6) is placed at the output of the LDO to ensure a 200-µA load when V_{OUT} = 5 V. This resistor can be removed if the load of the system is always guaranteed to be above 200 µA. An additional load resistance can be placed on R3, which is not populated by default.

5 Getting Started Hardware

5.1 Hardware Overview

The 110-V AC to 5-V DC @ 30-mA Non-Isolated Power Supply TI Design hardware is shown in Figure 4. There are two pairs of test points for connecting the board to the input AC voltage and to the load. Test points TP1 and TP3 are used to connect the board to the input AC voltage. Test points TP2 and TP4 are used to connect the board to the load.

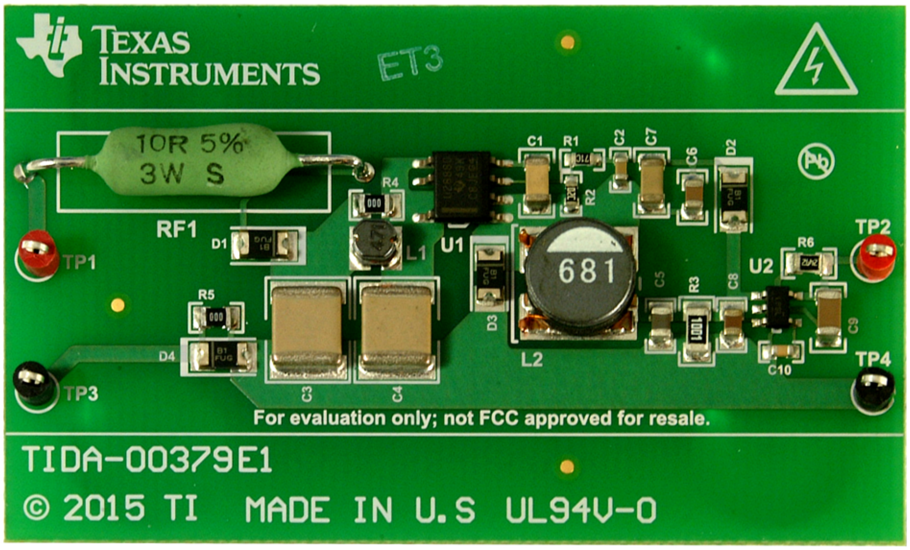


Figure 4. 110-V AC to 5-V DC @ 30-mA Non-Isolated Power Supply Reference Design Hardware

CAUTION

Electric shock is possible when connecting the board to a live wire. The board should be handled with care by a professional. For safety, use isolated test equipment with overvoltage and overcurrent protection.

CAUTION

Do not leave the EVM powered when unattended.

5.2 Operating Conditions

The 110-V AC to 5-V DC @ 30-mA Non-Isolated Power Supply TI Design should always be used within the operating conditions outlined in Table 3.

Table 3. Hardware Operating Conditions

DESCRIPTION		MIN	TYP	MAX	UNIT
T_A	Operating ambient temperature	–40	25	85 (1)	°C
V_{IN}	AC input voltage	85		130	V_{RMS}
f_{LINE}	Line frequency	47		63	Hz
V_{OUT}	Output voltage	4.5		5.5	V
I_{OUT}	Output current	0		30	mA

(1) Upper range limited by operating temperature of discrete components. With higher temperature-rated components, ambient operating temperature range can be extended to the range supported by the UCC28880 (–40°C to 105°C).

6 Test Data

6.1 Overview

The 110-V AC to 5-V DC @ 30-mA Non-Isolated Power Supply TI Design has been fully characterized. The results of testing and characterization are shown in the following sections.

6.2 Startup

The output voltage waveform at startup is shown in the following figures. The input voltage has been set to 85-V and 130-V AC. In each case, the output was loaded with a 35-mA constant current and with no load.

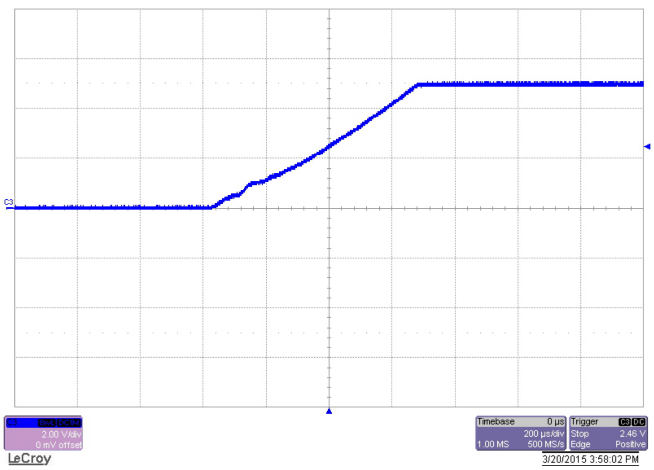


Figure 5. Startup Time: 85-V AC, 35-mA Load

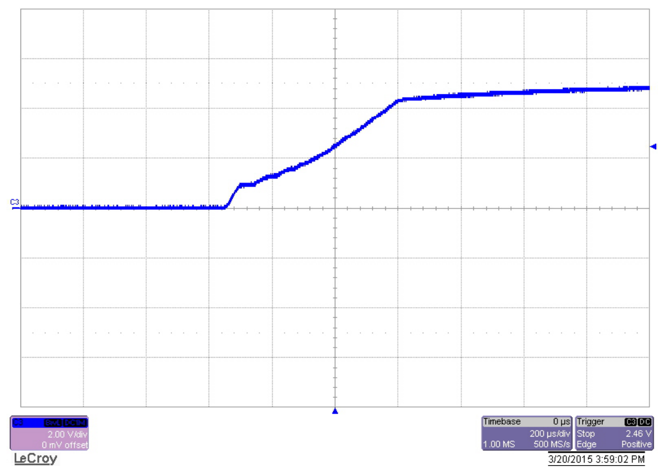


Figure 6. Startup Time: 85-V AC, No Load

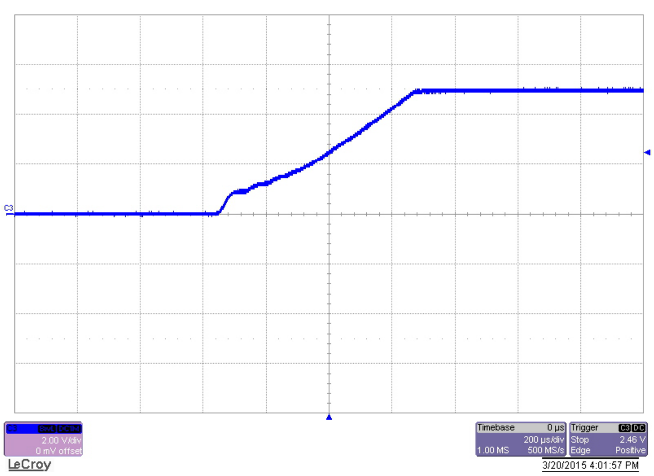


Figure 7. Startup Time: 120-V AC, 35-mA Load

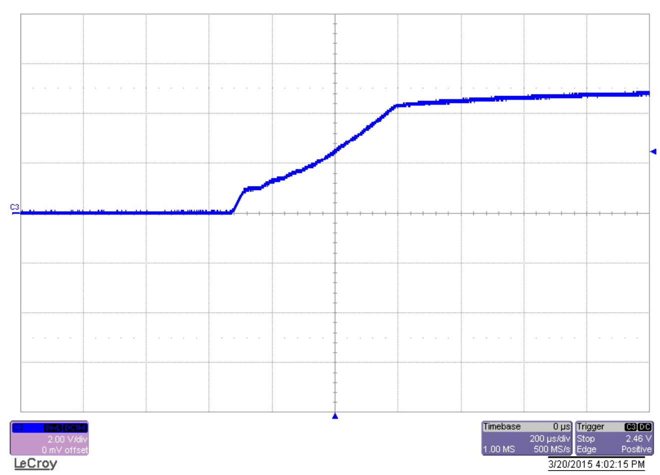


Figure 8. Startup Time: 120-V AC, No Load

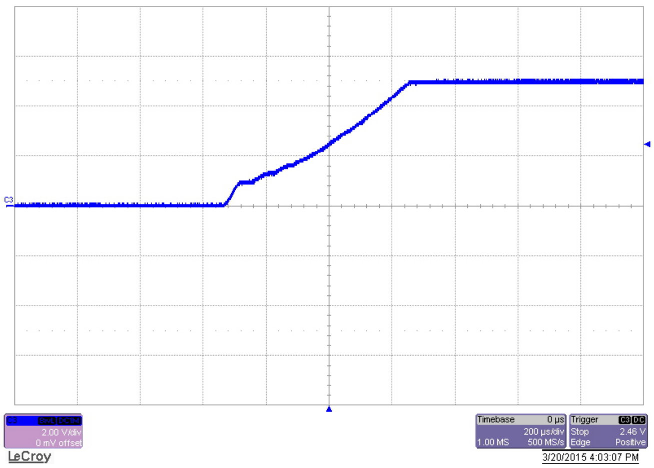


Figure 9. Startup Time: 130-V AC, 35-mA Load

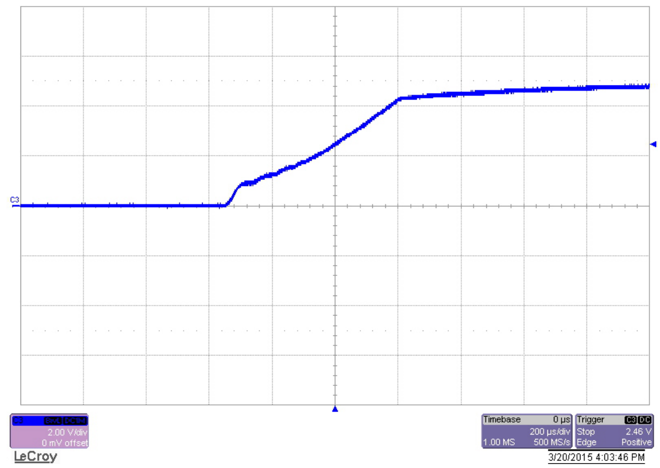


Figure 10. Startup Time: 130-V AC, No Load

6.3 *Efficiency*

The efficiency data versus output current is shown in Figure 11 and Table 4 through Table 7. The converter has been supplied with 85-V, 110-V, 120-V, and 130-V AC input voltages.

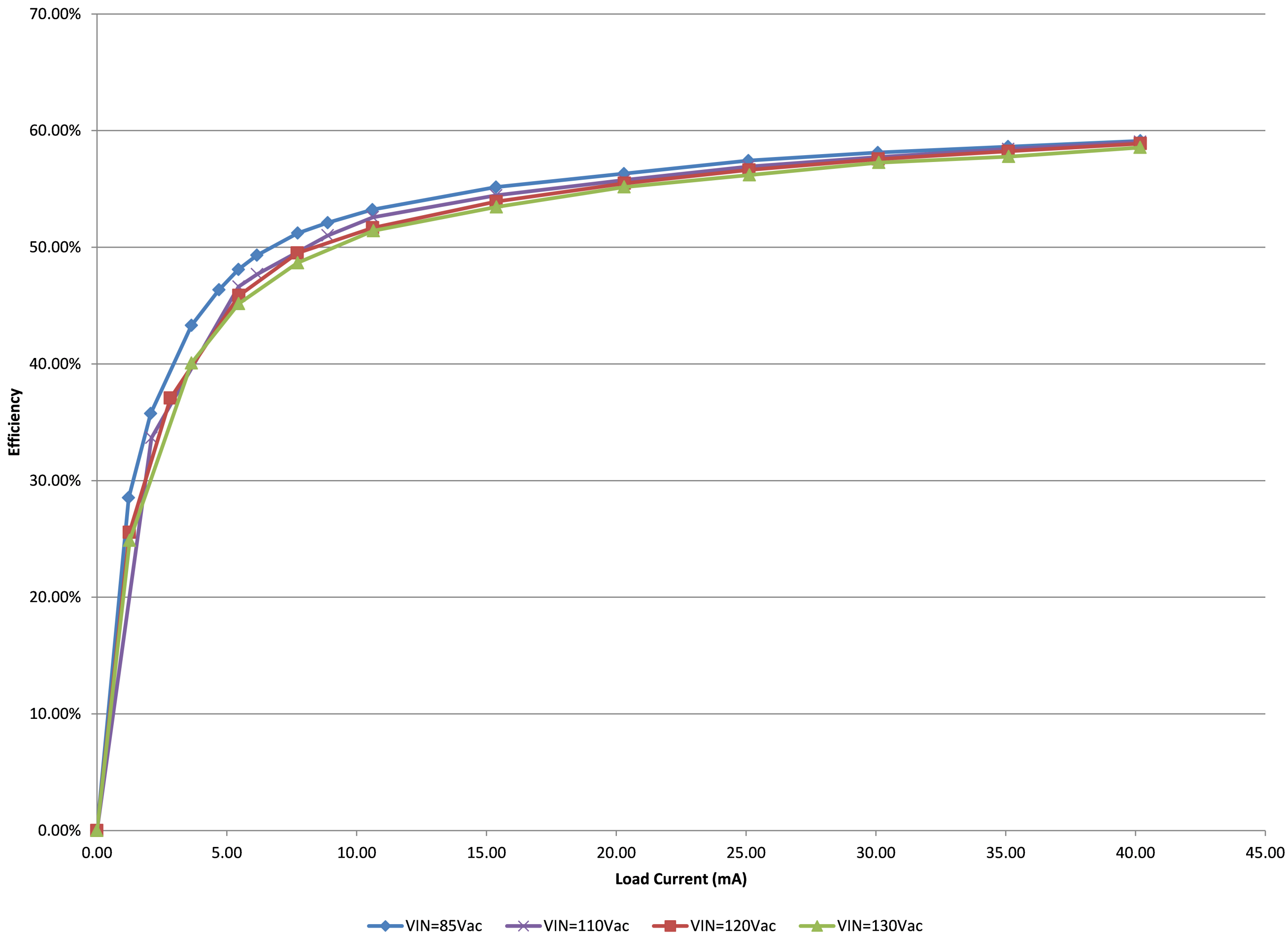


Figure 11. Efficiency versus Output Current

Table 4. Efficiency versus Output Current For V_{IN} = 85-V AC

V_{IN} (AC)	I_{IN} (mA)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (mW)	EFFICIENCY (%)
85.03	10.31	336.50	4.95	40.19	198.94	59.12%
85.02	9.17	296.30	4.95	35.09	173.70	58.62%
85.03	8.04	256.70	4.96	30.08	149.20	58.12%
85.02	6.90	216.70	4.96	25.09	124.45	57.43%
85.03	5.84	178.80	4.96	20.30	100.69	56.31%
85.03	4.70	138.21	4.96	15.37	76.24	55.16%
85.03	3.55	99.08	4.97	10.61	52.73	53.22%
85.03	3.14	84.80	4.97	8.89	44.18	52.10%
85.03	2.85	75.02	4.97	7.73	38.42	51.21%
85.03	2.46	62.08	4.97	6.16	30.62	49.32%
85.03	2.27	56.32	4.97	5.45	27.09	48.09%
85.03	2.08	50.40	4.97	4.70	23.36	46.35%
85.03	1.78	41.86	4.98	3.64	18.13	43.30%
85.03	1.32	28.84	4.98	2.07	10.31	35.74%
85.03	1.07	21.30	4.98	1.22	6.08	28.52%
85.03	0.06	11.60	4.99	0.00	0.00	0.00%

Table 5. Efficiency versus Output Current For V_{IN} = 110-V AC

V_{IN} (AC)	I_{IN} (mA)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (mW)	EFFICIENCY (%)
110.00	8.24	336.90	4.95	40.18	198.89	59.04%
110.00	7.36	297.40	4.95	35.10	173.75	58.42%
110.00	6.50	258.60	4.96	30.10	149.30	57.73%
110.00	5.64	218.70	4.96	25.10	124.50	56.93%
110.00	4.77	180.67	4.96	20.31	100.74	55.76%
110.00	3.39	140.10	4.96	15.38	76.28	54.45%
110.00	2.97	100.49	4.97	10.63	52.83	52.57%
110.00	2.62	86.60	4.97	8.89	44.18	51.02%
110.00	2.07	64.30	4.97	6.17	30.66	47.69%
110.00	1.92	58.20	4.97	5.46	27.14	46.63%
110.00	1.16	31.06	4.98	2.10	10.46	33.67%
110.00	0.61	13.60	4.99	0.00	0.00	0.00%

Table 6. Efficiency versus Output Current For V_{IN} = 120-V AC

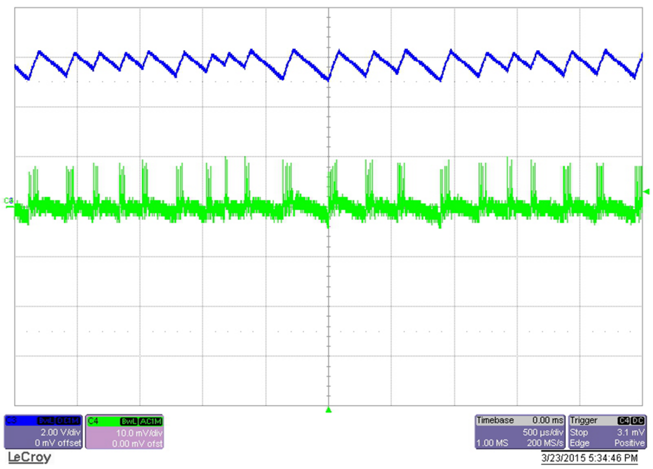
V_{IN} (AC)	I_{IN} (mA)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (mW)	EFFICIENCY (%)
120.05	7.66	337.80	4.95	40.19	198.94	58.89%
120.05	6.84	298.40	4.95	35.10	173.75	58.23%
120.05	6.07	259.30	4.96	30.09	149.25	57.56%
120.05	5.28	220.00	4.96	25.12	124.60	56.63%
120.05	4.48	181.63	4.96	20.32	100.79	55.49%
120.05	3.64	141.48	4.96	15.38	76.28	53.92%
120.05	2.79	102.15	4.97	10.62	52.78	51.67%
120.05	2.26	77.50	4.97	7.72	38.37	49.51%
120.06	1.82	59.27	4.97	5.47	27.19	45.87%
120.05	1.27	38.01	4.98	2.83	14.09	37.08%
120.05	0.92	24.34	4.98	1.25	6.23	25.58%
120.05	0.60	0.60	4.98	0.00	0.00	0.00%

Table 7. Efficiency versus Output Current For V_{IN} = 130-V AC

V_{IN} (AC)	I_{IN} (mA)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (mW)	EFFICIENCY (%)
130.07	7.17	339.00	4.94	40.18	198.49	58.55%
130.05	6.42	300.90	4.95	35.12	173.84	57.77%
130.06	5.70	260.90	4.96	30.12	149.40	57.26%
130.06	4.97	221.80	4.96	25.13	124.64	56.20%
130.06	4.22	182.60	4.96	20.31	100.74	55.17%
130.06	3.44	142.80	4.96	15.39	76.33	53.46%
130.06	2.64	102.95	4.97	10.65	52.93	51.41%
130.06	2.14	78.94	4.97	7.73	38.42	48.67%
130.06	1.73	60.08	4.97	5.46	27.14	45.17%
130.06	1.37	45.24	4.98	3.64	18.13	40.07%
130.06	0.90	25.22	4.98	1.26	6.27	24.88%
130.06	0.59	15.27	4.99	0.00	0.00	0.00%

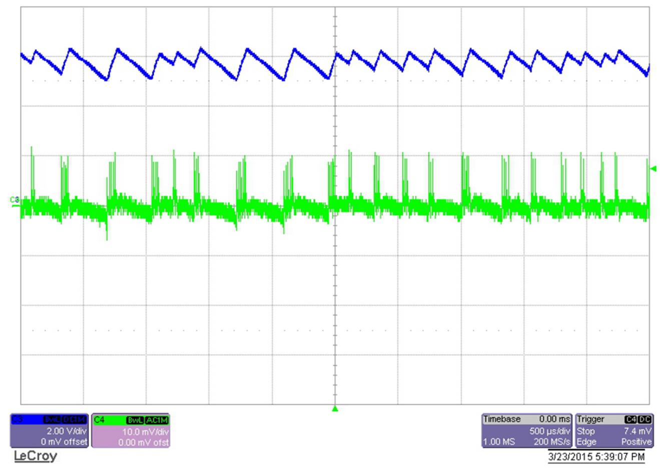
6.4 Output Ripple Current

The output ripple voltage plots are shown in the following figures. An AC source set between 85-V and 130-V AC has been connected to input terminals.



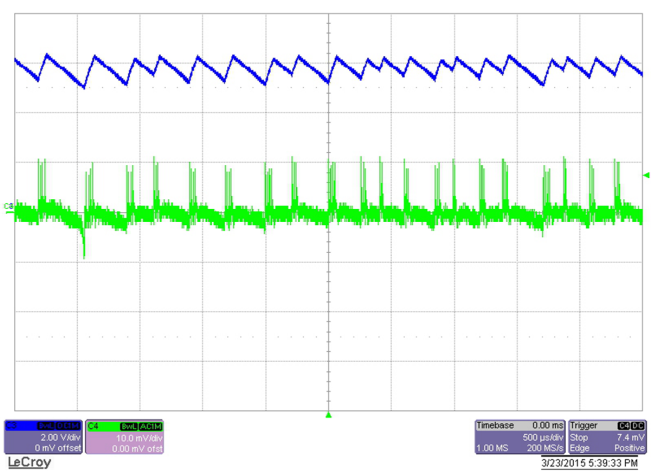
Ch3: LDO input voltage (2.0 V/div, 500 µs/div, DC coupling)
Ch4: LDO output voltage (10 mV/div, 500 µs/div, AC coupling)

Figure 12. Output Ripple Voltage With V_{IN} = 85-V AC, 5-V DC/30-mA Load



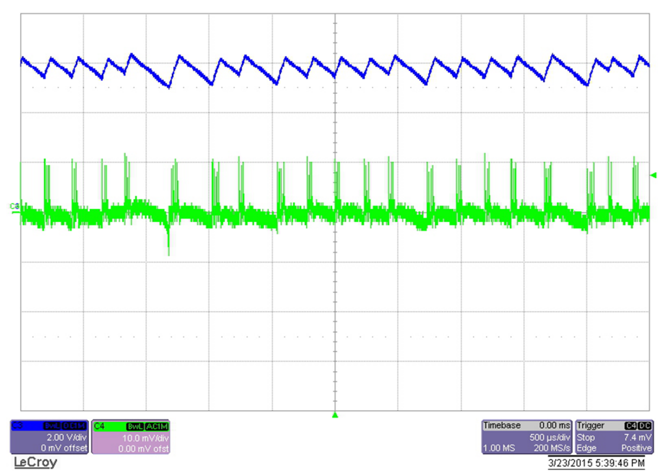
Ch3: LDO input voltage (2.0 V/div, 500 µs/div, DC coupling)
Ch4: LDO output voltage (10 mV/div, 500 µs/div, AC coupling)

Figure 13. Output Ripple Voltage With V_{IN} = 110-V AC, 5-V DC/30-mA Load



Ch3: LDO input voltage (2.0 V/div, 500 µs/div, DC coupling)
Ch4: LDO output voltage (10 mV/div, 500 µs/div, AC coupling)

Figure 14. Output Ripple Voltage With V_{IN} = 120-V AC, 5-V DC/30-mA Load

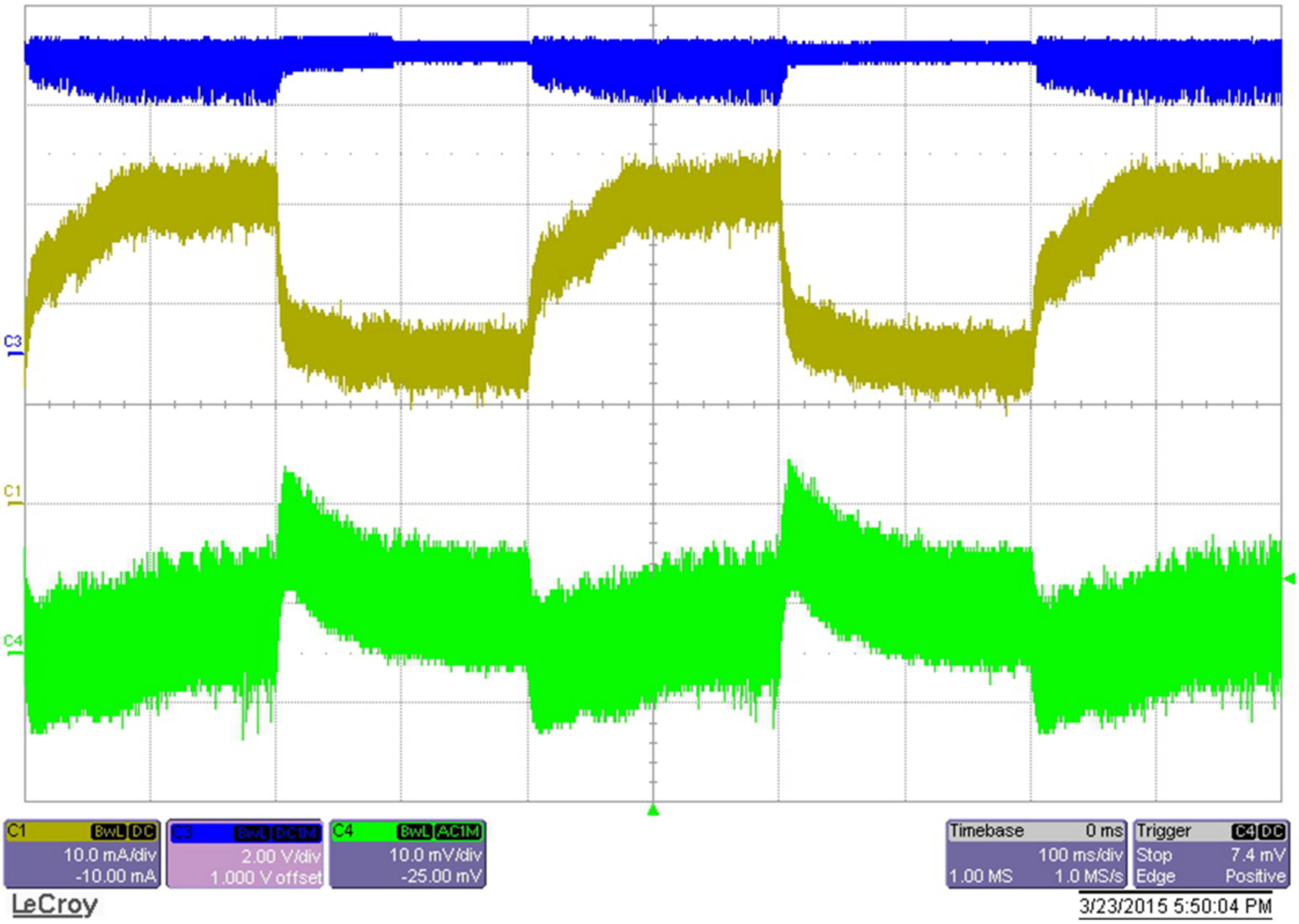


Ch3: LDO input voltage (2.0 V/div, 500 µs/div, DC coupling)
Ch4: LDO output voltage (10 mV/div, 500 µs/div, AC coupling)

Figure 15. Output Ripple Voltage With V_{IN} = 130-V AC, 5-V DC/30-mA Load

6.5 Transient Response

Figure 16 shows the transient response of the output voltage while the load has been switched from 10 to 30 mA with an input voltage source of 120-V AC.



Ch1: Output current (10 mA/div, 100 ms/div, DC coupling)
Ch4: Output voltage (10 mV/div, 100 ms/div, AC coupling)

Figure 16. Output Voltage Transient Response

6.6 Thermal Analysis

Figure 17 shows the thermal images of the prototype during a full load condition and 120-V AC input. The air temperature (still air condition) was 23.9°C.

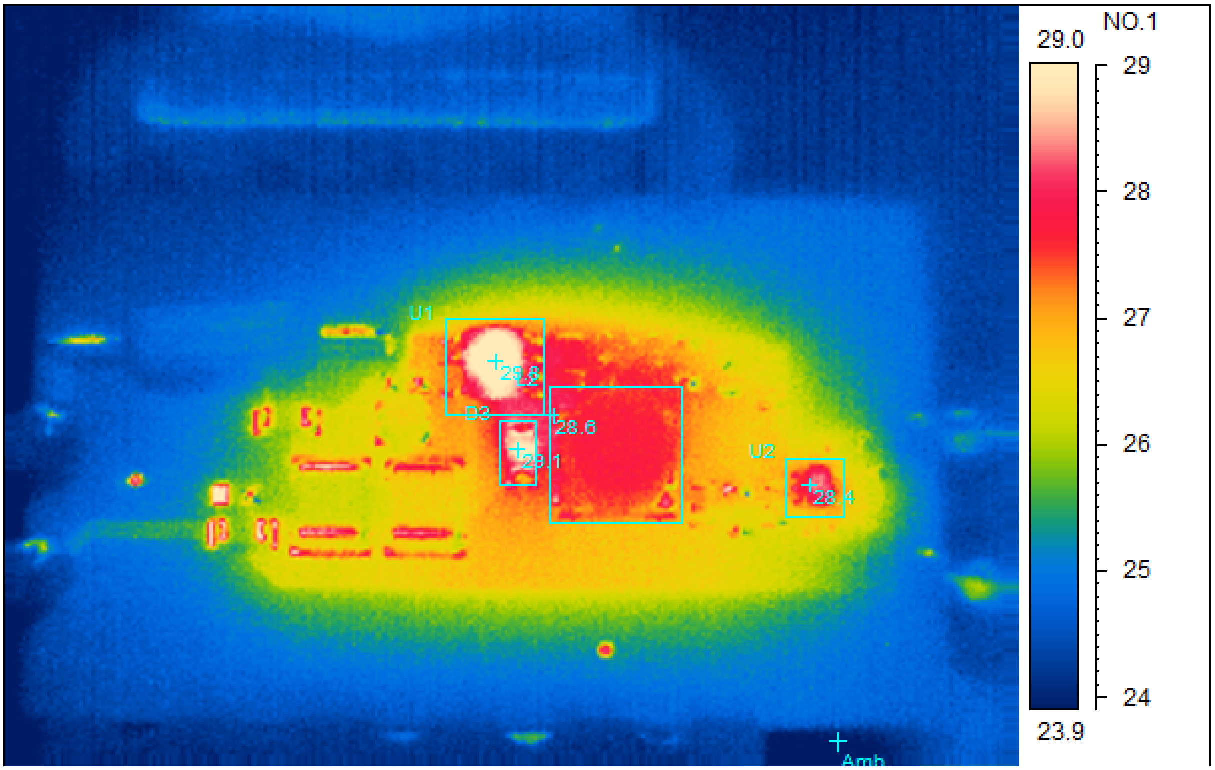


Figure 17. Thermal Analysis

Table 8. Thermal Analysis

SPOT ANALYSIS	TEMPERATURE
Ambient temperature	23.9°C
U1, max temp	29.8°C
D3, max temp	29.1°C
L2, max temp	28.6°C
U2, max temp	28.4°C

6.7 EMI Measurement

Figure 18 and Figure 19 show the EMI measurement taken at 120-V AC (Phase and Neutral). The line indicates the CISPR 22 Class B Limit.

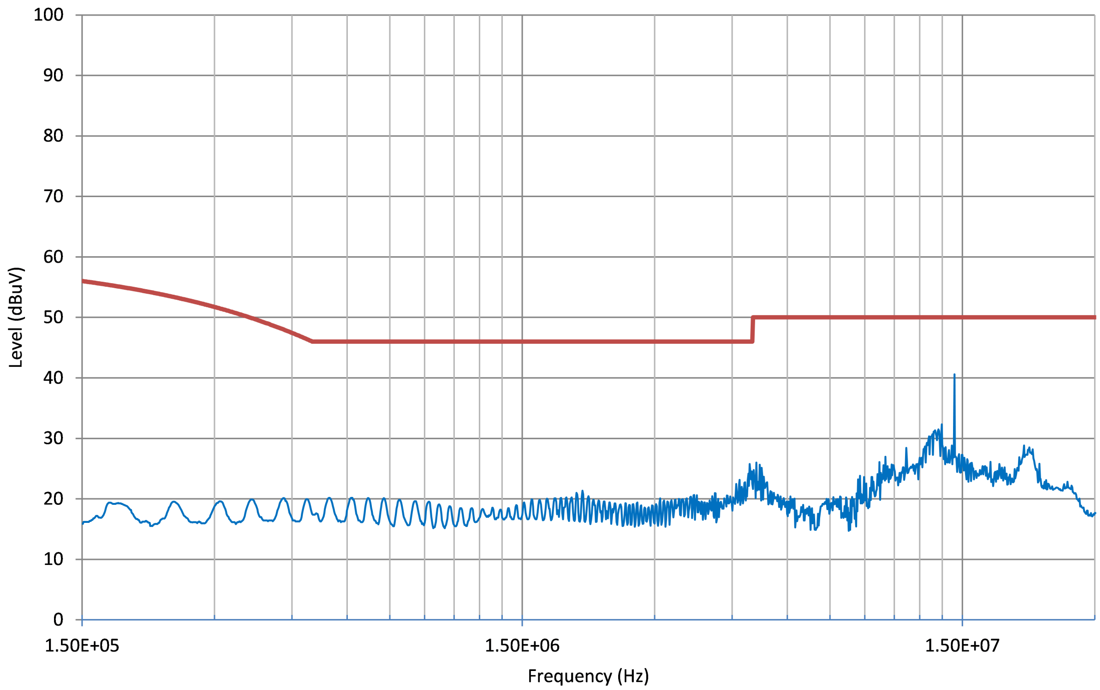


Figure 18. EMI Results: 120-V AC/60-Hz Line, 5-V DC/40 mA

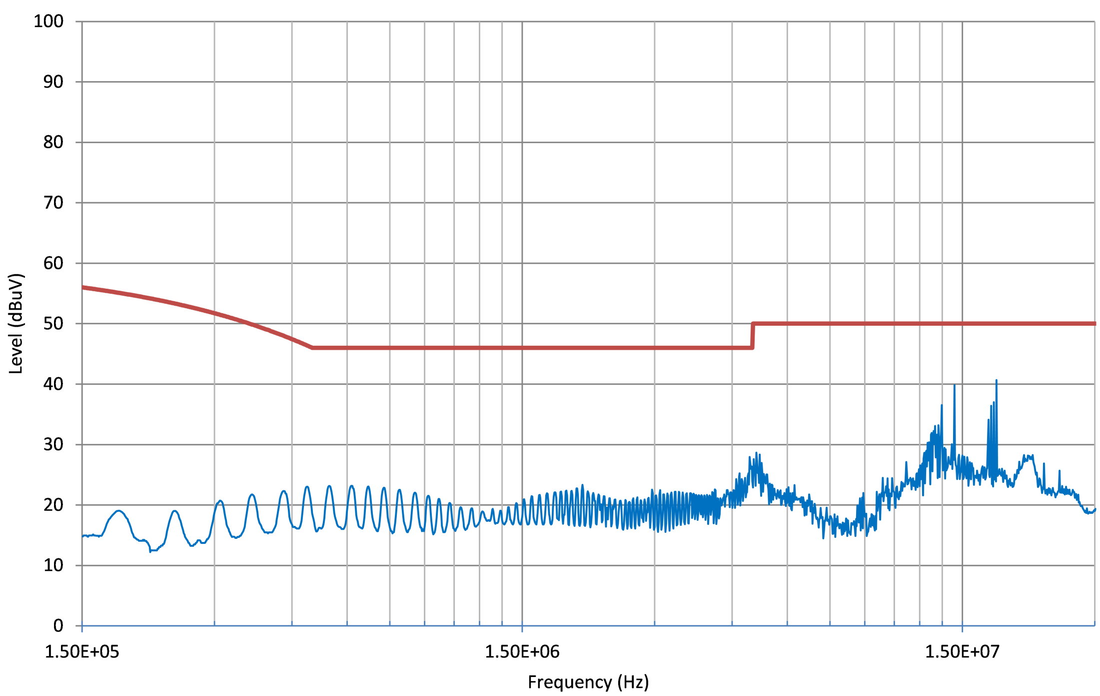


Figure 19. EMI Results: 120-V AC/60-Hz Neutral, 5-V DC/40 mA

7 Design Files

7.1 *Schematics*

To download the schematics, see the design files at TIDA-00379.

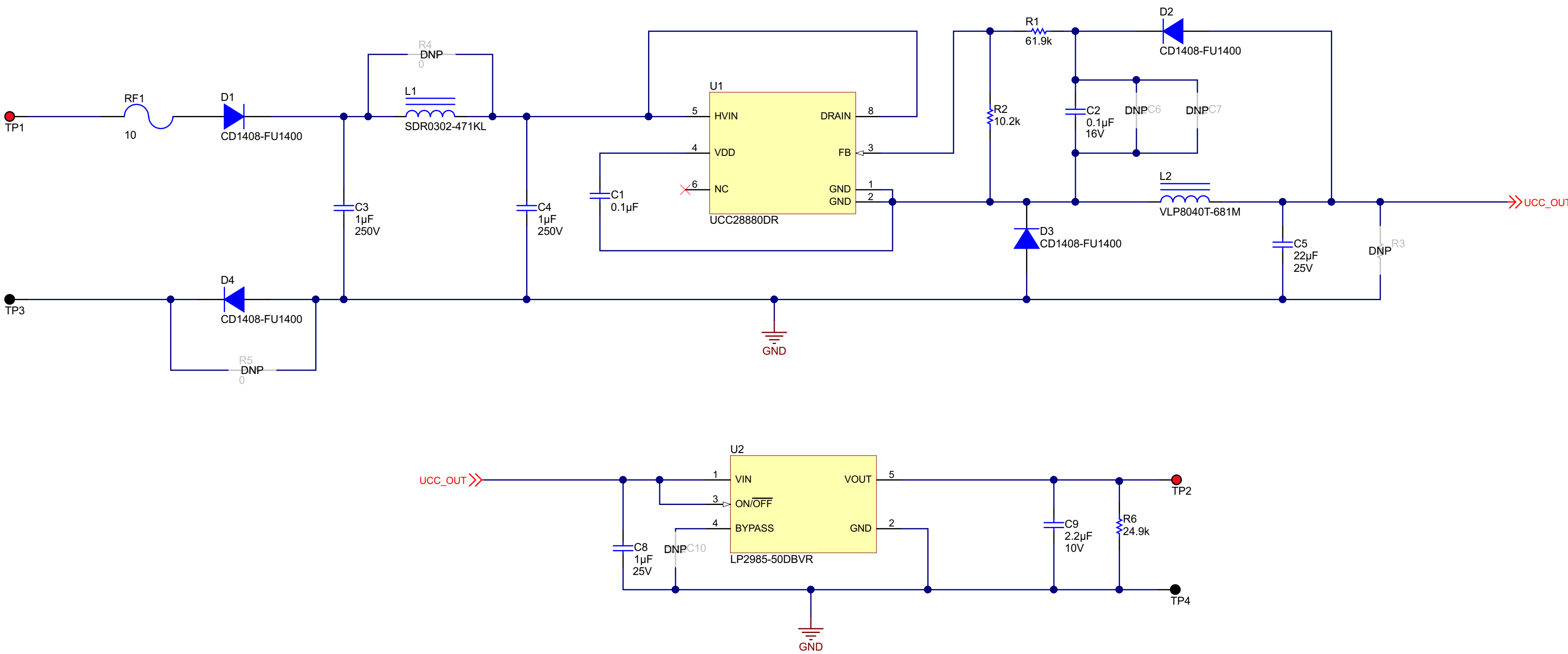


Figure 20. AC-to-DC Power Supply Schematics

7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00379.

Table 9. BOM

DESIGNATOR	DESCRIPTION	MANUFACTURER	PARTNUMBER	QUANTITY
!PCB	Printed Circuit Board	Any	TIDA-00379	1
C1	CAP, CERM, 0.1 µF, 50 V, +/- 10%, X7R, 1206	AVX	12065C104KAT2A	1
C2	CAP, CERM, 0.1 µF, 16 V, +/- 10%, X7R, 0603	Kemet	C0603C104K4RACTU	1
C3, C4	CAP, CERM, 1 µF, 250 V, +/- 10%, X7R, 2220	MuRata	GRM55DR72E105KW01L	2
C5	CAP, CERM, 22 µF, 25 V, +/- 20%, X5R, 0805	MuRata	GRM21BR61E226ME44	1
C6	CAP, CERM, 0.22 µF, 50 V, +/- 10%, X7R, 0805	Kemet	C0805C224K5RACTU	1
C7	CAP, CERM, 0.22 µF, 50 V, +/- 10%, X7R, 1206	Kemet	C1206C224K5RACTU	1
C8	CAP, CERM, 1 µF, 25 V, +/- 10%, X7R, 0805	TDK	C2012X7R1E105K	1
C9	CAP, CERM, 2.2 µF, 10 V, +/- 10%, X7R, 1206	MuRata	GRM31MR71A225KA01L	1
C10	CAP, CERM, 0.01 µF, 50 V, +/- 10%, X7R, 0603	MuRata	GRM188R71H103KA01D	1
D1, D2, D3, D4	Diode, Ultrafast, 400 V, 1 A, 1408 Diode	Bourns	CD1408-FU1400	4
H9, H10, H11, H12	Bumpon, Hemisphere, 0.44 X 0.20, Clear	3M	SJ-5303 (CLEAR)	4
L1	Inductor, Drum Core, Ferrite, 470 µH, 0.11 A, 14.3 ohm, SMD	Bourns	SDR0302-471KL	1
L2	Inductor, Unshielded Drum Core, Ferrite, 680 µH, 0.3 A, 2.2 ohm, SMD	TDK	VLP8040T-681M	1
R1	RES, 53.6 k, 1%, 0.1 W, 0603	Yageo America	RC0603FR-0753K6L	1
R2	RES, 10.2 k, 1%, 0.1 W, 0603	Yageo America	RC0603FR-0710K2L	1
R3	RES, 1.0 k, 5%, 0.25 W, 1206	Vishay-Dale	CRCW12061K00JNEA	1
R4, R5	RES, 0, 5%, 0.333 W, 0805	Vishay-Dale	CRCW08050000Z0EAHP	2
R6	RES, 24.9 k, 1%, 0.125 W, 0805	Vishay-Dale	CRCW080524K9FKEA	1
RF1	RES, 10, 5%, 3 W, Fusible, TH	Vishay-Bccomponents	AC03000001009JACCS	1
TP1, TP2	Test Point, Miniature, Red, TH	Keystone	5000	2
TP3, TP4	Test Point, Miniature, Black, TH	Keystone	5001	2
U1	700-V Lowest Quiescent Current Off-Line Switcher, D0007A	Texas Instruments	UCC28880DR	1
U2	150-mA Low-noise Low-dropout Regulator With Shutdown, DBV0005A	Texas Instruments	LP2985-50DBVR	1

7.3 Layer Plots

To download the layer plots, see the design files at TIDA-00379.

7.3.1 Layout Guidelines

The 110-V AC to 5-V DC @ 30-mA Non-Isolated Power Supply TI Design was laid out using a two-layer PCB with all components placed on the top-side. The PCB size is 63.2 × 38.1 mm (1500 × 2490 mils). All signal routing is carried out in the top layer.

As required by the UCC28880 device datasheet, the copper area connecting the GND, VDD, and FB pins is minimized because these pins are part of the switching node in the high-side buck configuration.

As recommended by the LP2985-50 datasheet, the input pin is bypassed to ground with a bypass-capacitor. The bypass capacitor is placed close to the VIN of the device and GND of the system. The loop area formed by the bypass-capacitor connection, the VIN pin, and the GND pin of the system is minimized.

7.4 Altium Project

To download the Altium project files, see the design files at TIDA-00379.

7.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00379.

7.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00379.

8 References

1. Texas Instruments, *UCC28880 700-V Lowest Quiescent Current Off-Line Switcher*, Datasheet (SLUSC05)
2. Texas Instruments, *LP2985 150-mA Low-noise Low-dropout Regulator With Shutdown*, Datasheet (SLVS522)
3. Texas Instruments, *Linear and Switching Voltage Regulator Fundamental Part 2*, Application Report (SNVA559)

9 About the Author

GUSTAVO MARTINEZ is a senior systems architect at Texas Instruments where he is responsible for developing reference designs for industrial applications. Gustavo has ample experience developing system reference designs for the Smart Grid and home automation segments that include high-performance application processors, floating-point digital signal processors, and RF technology. Gustavo obtained his Bachelor of Science degree from the University of Texas at El Paso.

Revision C History

Changes from B Revision (June 2015) to C Revision	Page
• Changed device name from UCC2880	1
• Changed device name from UCC2880	3
• Changed device name from UCC2880	3
• Changed device name from UCC2880	4
• Changed unit of measurement from Watts	15
• Changed unit of measurement from Watts	15
• Changed unit of measurement from Watts	16
• Changed unit of measurement from Watts	16

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Revision B History

Changes from A Revision (April 2015) to B Revision	Page
• Changed capacitor value from 0.68 µF	8

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Revision A History

Changes from Original (March 2015) to A Revision	Page
• Changed from preview page	1

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

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