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LDO regulator as a Post AC DC Rectifier Ripple Cleaner Reference Design for Industrial Applications

TEXAS INSTRUMENTS

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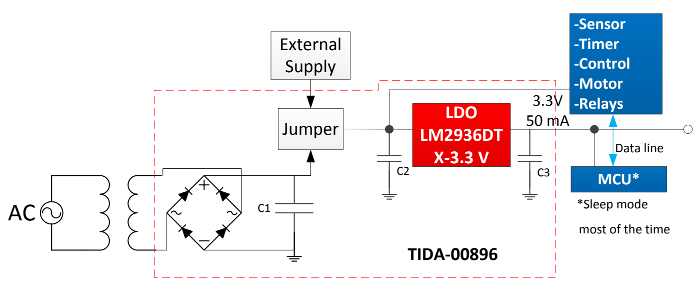
Design Resources

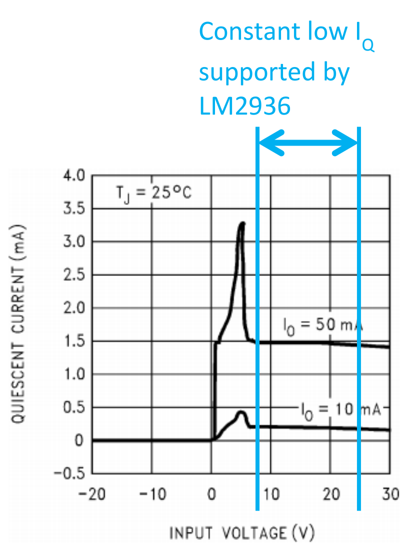
TIDA-00896	www.ti.com/tool/TIDA-00896
LM2936DTX-3.3	www.ti.com/product/LM2936

TI E2E™ Community

Ask the Analog Experts
WEBENCH® Design Center

Block Diagram





Design Features

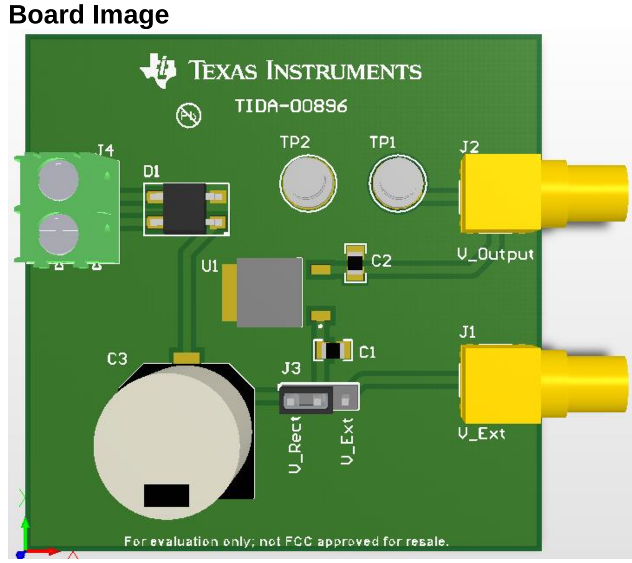
- Low stand by current regulator (I_Q < 20uA at 100 µA load)
- Easy to implement AC to DC rectification and regulation
- AC grid power to 3.3V regulated DC voltage
- -30 mV maximum load regulation from nominal output voltage
- 27 mV> load transient with a 30 mA/10 µs load step
- 50 mA maximum output current, with short circuit current limit protection
- Input and transient voltage protection
- TIDA-00896 provides: design guide, test data and design files for the post AC to DC rectification linear regulator

Featured Applications

Smart grid and building automation applications:

- Smoke detector
- Heat detector
- Wall dimmer
- Wall timer
- Humidity and condensation monitor fan switch

Board Image



1 System Description

TIDA-00896 reference design provides an easy to implement, low standby current and isolated AC to DC rectification. The AC input voltage is regulated to a ripple free 3.3V using LM2936 a low dropout (LDO) linear regulator. The 3.3V voltage rail is ideal to power microcontrollers which are intended to operate in a low power standby mode most of the time. The low standby quiescent current consumption of LM2936 minimizes the power consumption during the long low power cycles of the system.

Many applications can benefit from this easy to implement low stand by current approach, below is a list of some of the building automation and smart grid applications, which may benefit from this solution:

- Humidity and condensation monitor fan switch
- Motion Detectors
- Smoke detectors
- Heat detectors
- Wall dimmers
- Thermostats
- Wall timers

The TIDA-00896 reference design provides test data, schematic, BOM and PCB layout files; all the files can be obtain at www.ti.com/tool/TIDA-00896

2 Block Diagram

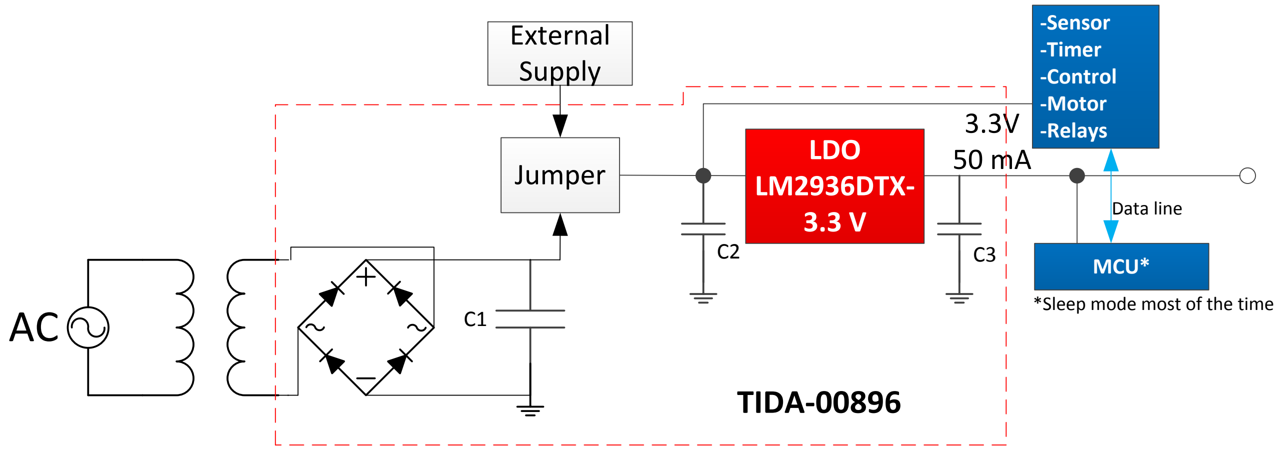


Figure 1: TIDA-00896 High Level Block Diagram

Figure 1 is a conceptual block diagram of the TIDA-00896 design. The red blocks represent the focus design component. The blue blocks show the scalability of the TIDA-00896 power management design. Jumper block is to select between the output of the full bridge rectifier or external power supply

2.1 LM2936

The LM2936 ultra-low quiescent current regulator features low dropout voltage and low current in the standby mode. With less than 15-µA quiescent current at a 100-µA load, the LM2936 is ideally suited for automotive and other battery operated systems. The LM2936 retains all of the features that are common to low dropout regulators including a low dropout PNP pass device, short circuit protection, reverse battery protection, and thermal shutdown. The LM2936 has a 40-V maximum operating voltage limit, a −40°C to 125°C operating temperature range, and ±3% output voltage tolerance over the entire output current, input voltage, and temperature range. The LM2936 is available in a TO-92 through-hole package, as well as SOIC-8, VSSOP, SOT–223, and TO-252 surface mount packages.

LM2936 has various design support tools, the tools can be obtained at LM2936 online product folder

- A behavioral simulation TINA-TI model
- WEBENCH® Model for instantly view reference schematic, charts, BOM, and operating values

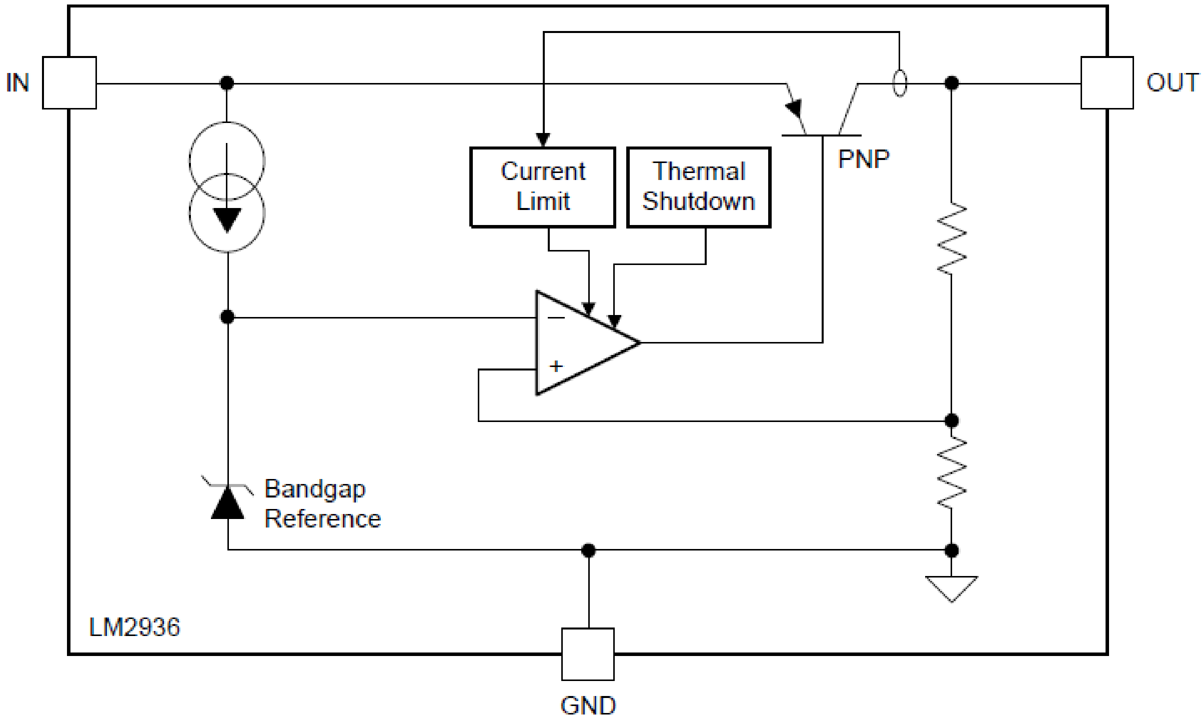


Figure 2 LM2936 Functional Block Diagram

3 Design description

There are numerous methods to rectify the alternating current (AC) main grid power to direct current (DC) power; the methods vary in cost, complexity, galvanic isolation, size, ripple voltage, standby current consumption and efficiency. TIDA-00896 emphasis is on an isolated easy to implement, ripple free, low cost and low standby current consumption AC rectification to 3.3 V DC output.

3.1 AC Power Rectification:

The 120V AC voltage is stepped down to ~10V using a 12:1 turn ratio step down transformer, then four diodes in the famous bridge configuration (Shown in **Figure 1**) rectify the negative swings of the sinusoidal signal.
A smoothing capacitor is placed after the full bridge rectifier diodes to linearize and smooth the rectified waveform. The smoothing capacitor value can be approximated using **Equation 1**.

$$\boldsymbol{C1} = \frac{\boldsymbol{Q}}{\boldsymbol{V_{OUT(Ripple)}}} = \frac{\boldsymbol{I \times t}}{\boldsymbol{V_{OUT(Ripple)}}} = \frac{\boldsymbol{I_{LOAD}}}{\boldsymbol{f \times V_{OUT(Ripple)}}} \tag{1}$$

f = 1/t for a full bridge rectifier circuit the frequency is twice of the input frequency (120Hz)
t = discharge time
C1 = Smoothing capacitor value
Q = Capacitor Charge

The LM2936 Linear regulator further regulates the output of the smooth capacitor to 3.3V. The LM2936 high ripple rejection capability minimizes the voltage ripple by 60 dBs from low frequency up to 10 kHz

3.2 LM2936 Compensation Components

The minimum output capacitance required to maintain stability is 10 µF for the LM2936 5-V option, and at least 22 µF for the 3.3-V and 3-V options. The output capacitor value may be increased without limit as long as it meets the ESR specifications shown in **Figure 3**. Larger values of output capacitance will give improved transient response.

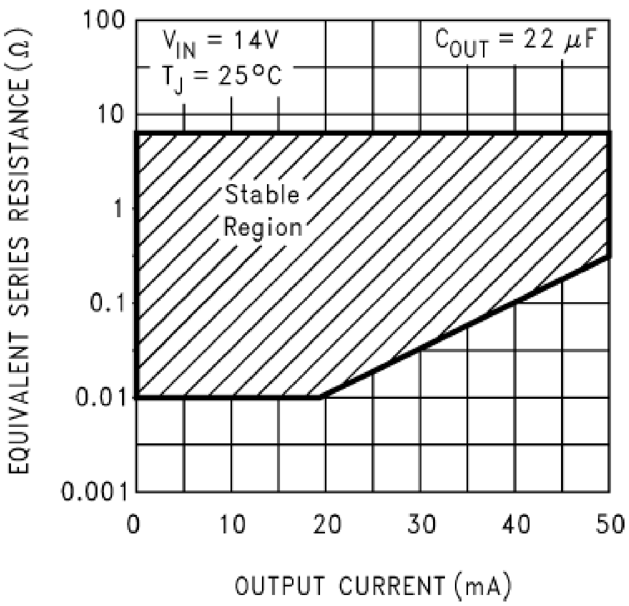


Figure 3: Output Capacitor ESR Stable Region

3.3 Benefits of LM2936DTX-3.3 as a Post Rectification Regulator:

High power supply rejection ratio

The LM2936DTX-3.3 linear regulator has a high PSRR (~60db from 1Hz 10 kHz), this feature enable the LDO to minimize the ripple from the smoothing capacitor. **Figure 7** in Section 6 of this document shows a comparison between PSRR and frequency, **Figure 8** of the same section highlights the filtering capabilities of the LM2936.

Low standby power consumption

The ultra-low standby quiescent current is typically less than 20µA minimizing the power consumption during low current cycles. For example if the LM2936 is operating from 10 V input voltage and the load is 100µA or less (i.e. microcontroller) the LM2936 only consumes 150 µW

Additional LM2936 benefits and features:

- Internal Short Circuit Current Limit,
- Internal Thermal Shutdown Protection,
- ±3% Output Tolerance Over Line, Load, and Temperature,
- 24-V Input Voltage Protection
- –50-V Input Transient Protection

4 Alternative AC/DC Methods

The following methods provide higher efficiency, but require a more complex configuration and may present ripple and switching noise at the output. A High current and high PSRR LDOs like the LP38502 can be implemented to further regulate and rectify output voltage to a low noise and ripple free voltage supply for devices sensitive to input voltage fluctuation like MCUs, amplifiers and sensors among many others.

4.1 Isolated Flyback

The Flyback configuration is derived from to a buck-boost topology. The compensating inductor is replaced by coupled inductors which work as a transformer giving the advantage of galvanic isolation.
The flyback converter controls a high voltage MOSFET. The drain of the MOSFET is connected to the rectified AC line and the gate is controlled by the flyback control system, **Figure 4** shows a comprehensive schematic of a typical flyback controller the UCC28710.
When the MOSFET switches ON the primary coil is charged and when the MOSFET switches OFF the stored magnetized energy is transferred to the secondary coil. To complete the feedback loop an optocoupler is used to maintain the isolation between input and output.

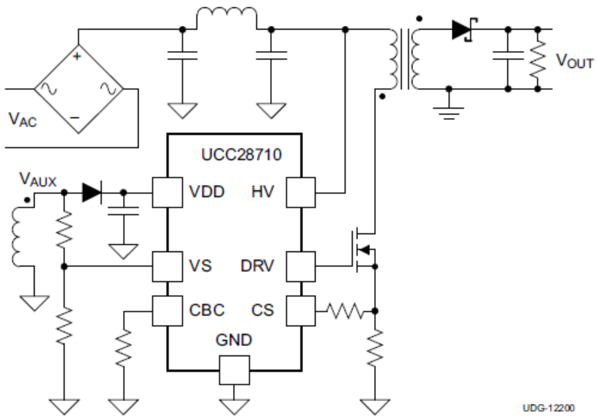


Figure 4 UCC28710 Flyback Controller

The output voltage of this approach may have output switching ripple voltage around ~20mV, if lower ripple voltage is required and LDO should be placed at the flyback's output.

For more detail information on flyback topologies and reference design examples, please refer to the following links:
www.ti.com/tool/pmp9202
www.ti.com/tool/pmp9203
www.ti.com/tool/pmp9204

4.2 Transformer-less

None isolated AC to DC rectification and regulation using a full bridge rectifier and step down controller. **Figure 5** is the schematic from the PMP5412 transformer-less reference design.
The line voltage is rectified with a full bridge diode configuration then a FET controller TPS64203 is used to control high voltage MOSFETs to efficiently step down the rectified voltage.

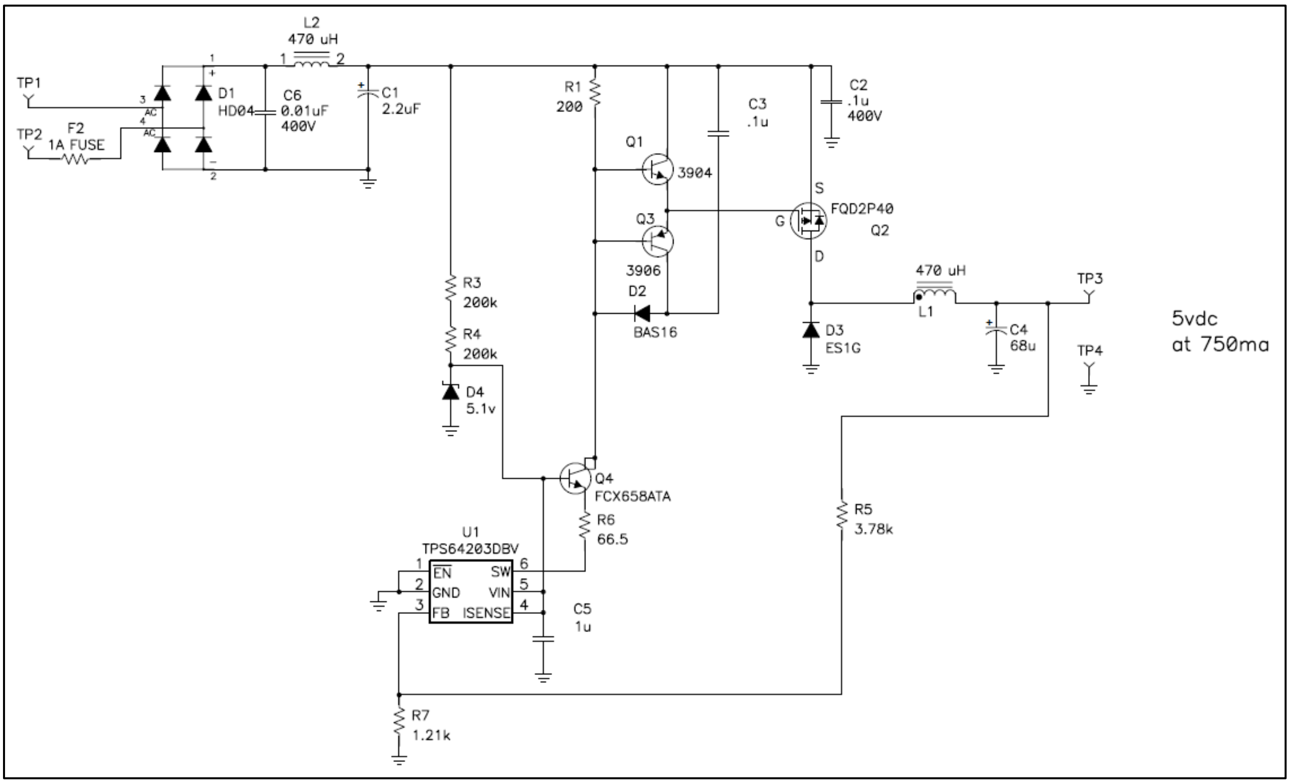


Figure 5: PMP5412 transformer-less reference schematic

For more information bout the PMP5412 design visit the design folder at www.ti.com/tool/pmp5412

5 Test Data

Before applying power to the TIDA-00896 board, all external connections should be verified. The external power supply must be turned off before being connected. Confirm proper polarity to the VIN and output terminals before turning the external power supply on.

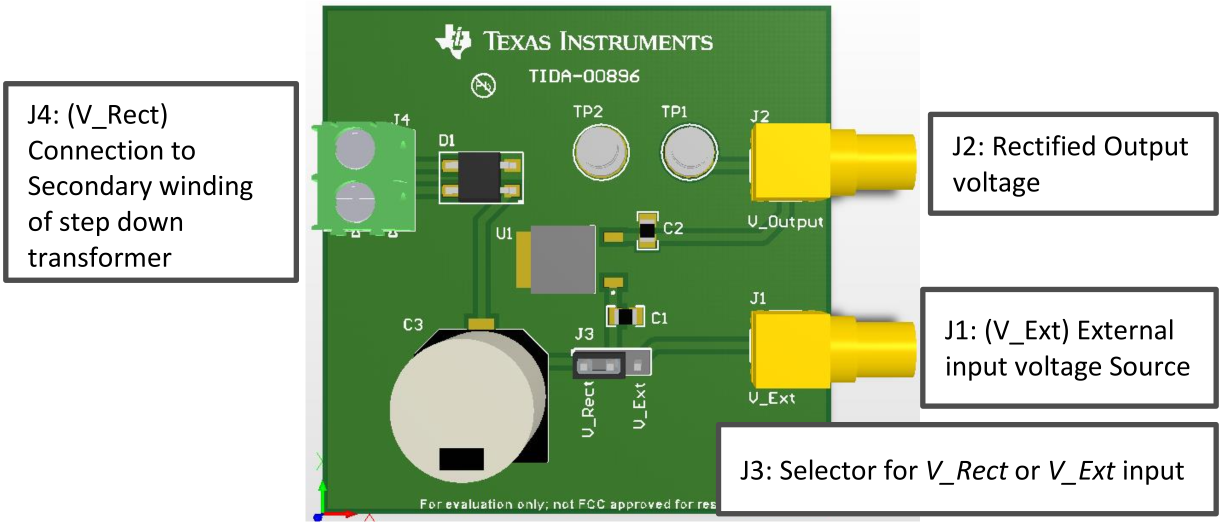


Figure 6: TIDA-00896 Board

Note

The TIDA-00896 board was developed for testing and performance validation only and is not available for sale; however, reference design files can be downloaded at http://www.ti.com/tool/tida-00896

5.1 Test Equipment

The following table shows the test equipment used.

Table 1 Test Equipment

Test equipment	Part number
Oscilloscope	Agilent DPO4014B
DC voltage supply	Agilent E3631A
Multimeter	Agilent E34401A
Network Analyzer	Agilent E5061B ENA

5.2 Test Results

5.2.1 LM2936 Power Supply Ripple Rejection

The output voltage ripple rejection ratio is calculated by comparing the regulated output voltage of the device under test (DUT) with the input voltage ripple over a frequency range of 1Hz to 1MHz.

Test parameters:

V_{IN_AC} = Sweep from 1Hz to 1MHz

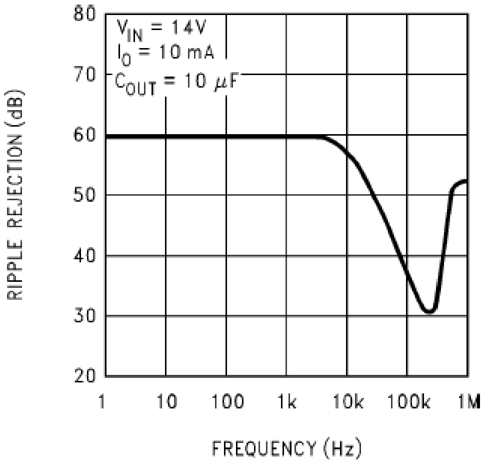


Figure 7: Ripple Rejection vs. Frequency

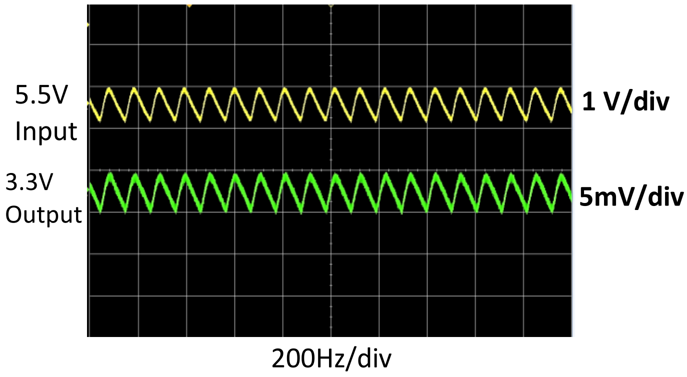


Figure 8: Comparison Between V_{IN} With Coupled AC Signal And regulated LM2936 V_{OUT}

Figure 7 shows how the input voltage ripple of 1V at 120 Hz was greatly minimized by the LDO.

5.2.2 Load Transient and Regulation

The load transient test is defined as the change in output voltage from nominal value resulting from a change in load current.

Test Parameters
C_{IN} = 0.22µF
C_{OUT} = 22µF
Load = 30mA
Load step edge time = 10µs
Input Voltage = 10V
Output Voltage = 3.3V

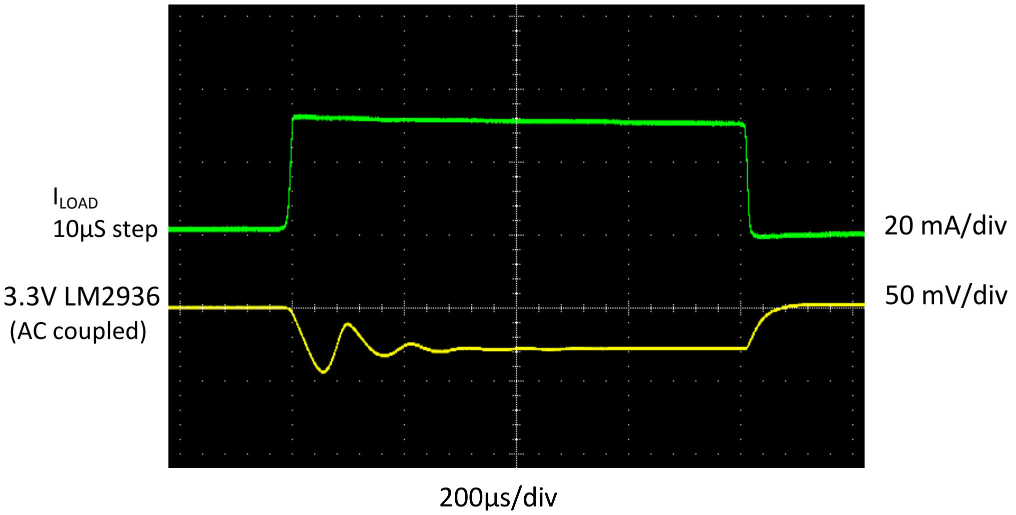


Figure 9 LM2936 3.3V

Test results:
Undershoot
Undershoot voltage measured from load regulation to lower peak = 15mV
Load regulation
Measured from no load nominal voltage to steady state output voltage under load = 27 mV

The transient response can improve by adding more capacitors between the output pin and ground.

5.3 Quiescent current

The quiescent current is the current drawn by the LM2936 to operate the internal circuit architecture. Figure 9 and figure 10 shows the LM2936 quiescent current at various scenarios combinations of input voltage and output current.

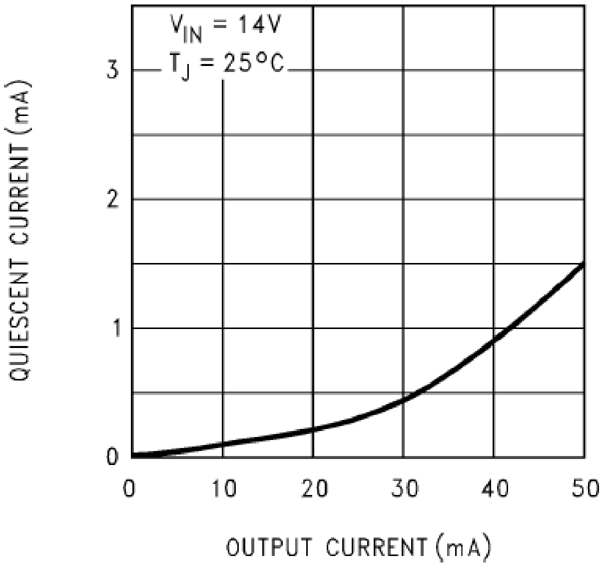


Figure 10: Comparison between Quiescent Current and Output Current

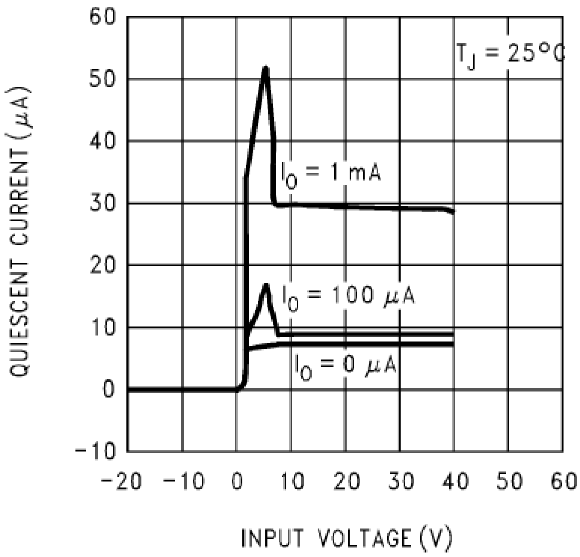


Figure 11: Comparison between Quiescent Current and Input Voltage

6 Design Files

6.1 Schematics

To download the Schematics for each board, see the design files at http://www.ti.com/tool/TIDA-00896

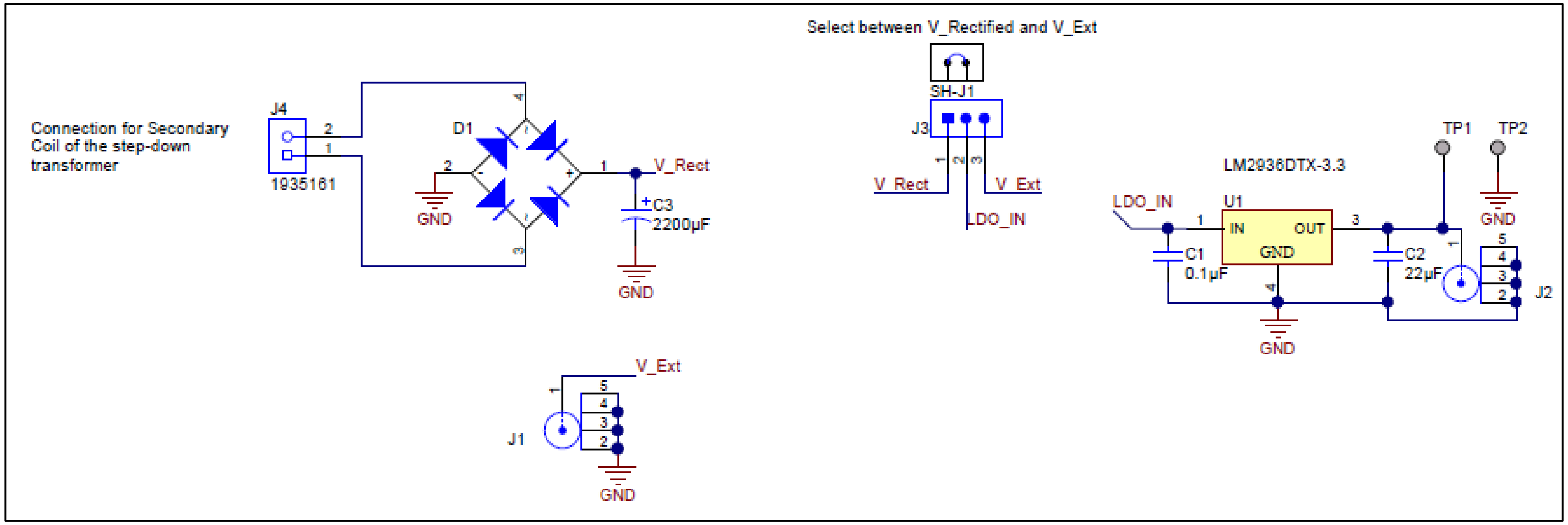


Figure 12: TIDA-00896 Schematic

6.1.1 Altium Project

The Altium project files can be downloaded at the link below.
http://www.ti.com/tool/TIDA-00896

- Gerber and NC-drills
- Bill of Materials (BOM)
- Assembly Drawings

6.2 PCB Layout Recommendations

- As a rule of thumb avoid connections using long trace lengths and narrow trace widths. These will add parasitic inductances and resistance that resulting in inferior performance especially during transient conditions
- Avoid any sharp 90^0 angles traces, electric fields tend to build up on corners increasing EMI coupling.
- Connect Input and output capacitors close to the LDO pins
- Include a solid ground area for thermal dissipation

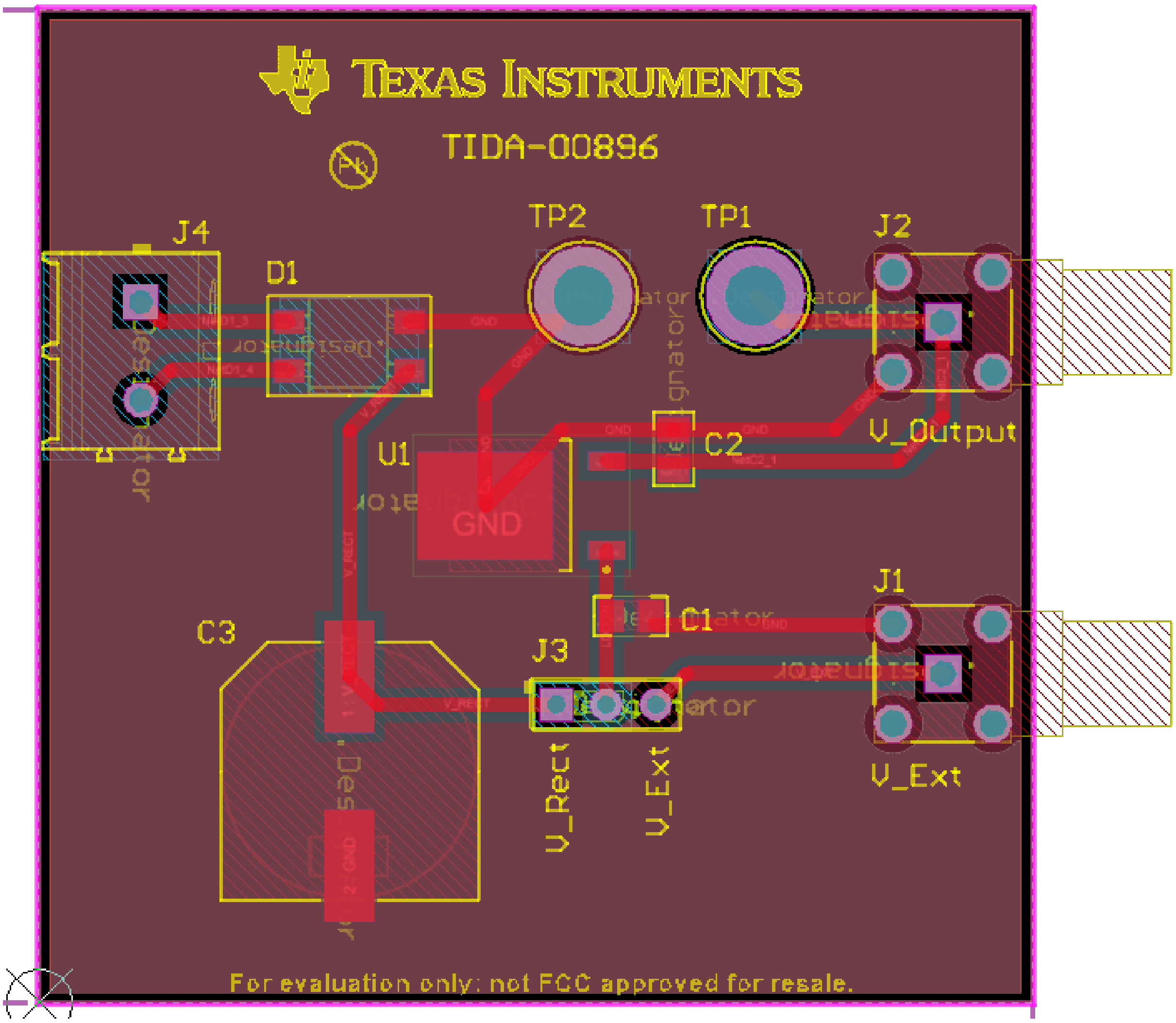


Figure 13: TIDA-00896 Layout Guidelines

7 References

1. Texas Instruments TI Designs: Power Supply Design Seminar
   http://www.ti.com/lit/ml/slup224/slup224.pdf
2. Texas Instruments TI Designs: Overview for Linear Regulator (LDO)
   http://www.ti.com/lsds/ti/power-management/linear-regulators-ldo-overview.page
3. Texas Instruments Application note: A Topical Index of TI LDO Application Notes
   http://www.ti.com/lit/an/sbva026e/sbva026e.pdf

8 Terminology

TI Glossary: SLYZ022 This glossary lists and explains terms, acronyms, and definitions.

9 About the Author

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