TI Designs

Low-Cost, Flexible Voltage Supervisor and Battery Tester Reference Design

TI Designs

This is a low-cost, flexible voltage supervisor that uses a voltage reference to test the voltage of a battery. This solution can also be used as a voltage rail monitor for many applications that require accurate power delivery with multiple rails. This design utilizes TI's ultra-low power voltage references, reducing the overall system power consumption while maintaining a low BOM cost. Testing and displaying the battery voltage in this design shows how easy this system can be designed and implemented in comparable applications.

Design Resources

TIDA-00670	Tool Folder Containing Design Files
ATL431	Product Folder
LM339	Product Folder
TPS27081A	Product Folder
TLV61225	Product Folder
TPD1E10B06	Product Folder

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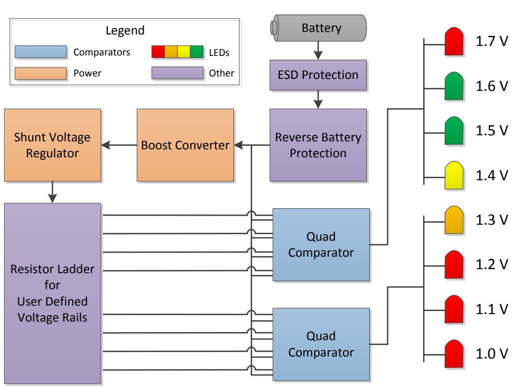
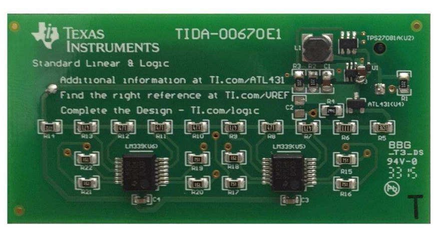
Design Features

- The ATL431 Shunt Regulator Allows for Voltage Regulation With Minimal Current Consumption (60 µA)
- TLV61225 Boost Converter Enables the Entire Circuit to be Powered from a AA Battery (0.8 V to 3.3 V Input)
- User Configurable Resistor Ladder Creates Customizable Number of Voltage Rails for Supervision
- Low Cost to Design for Customized Voltage Supervision
- Footprint Can Fit on Backside of Single AA Battery Voltage Holder
- No Firmware or Software Required

Featured Applications

- Power Supply
- Industrial Battery Chargers
- Renewable Fuel Cell
- Renewable Energy Storage
- Power Rail Control for PLCs
- Uninterrupted Power Supply





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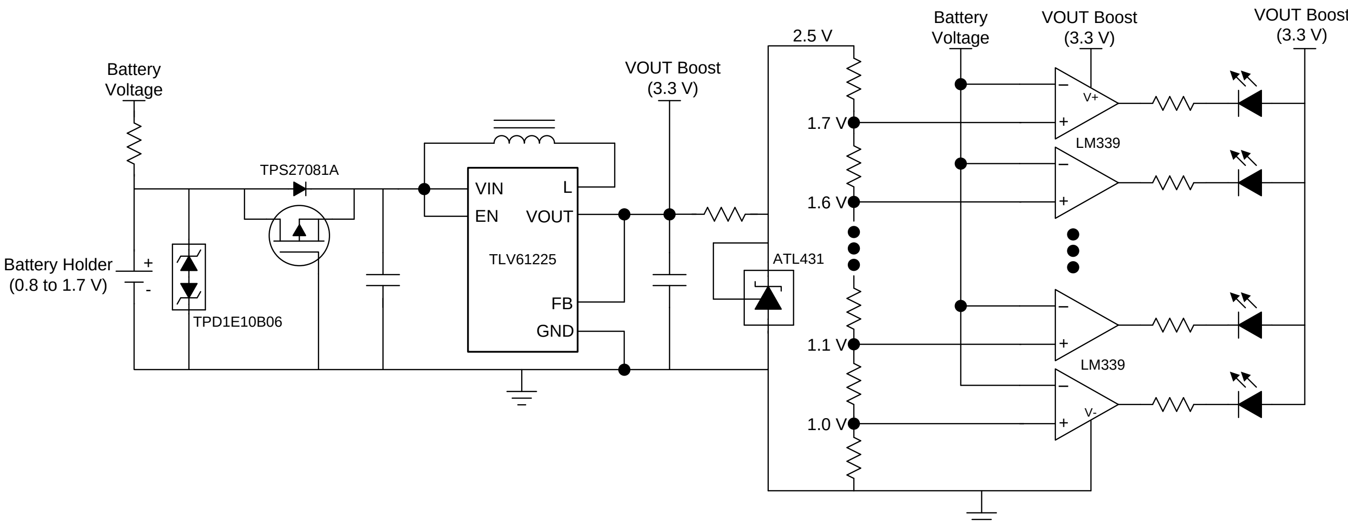
1 System Description

The TIDA-00670 reference design provides an easy-to-design solution that implements the monitoring of multiple, user-defined voltage rails while reducing the overall system cost. The battery voltage tester design provides a way to test the voltage of a single cell AA battery over a range of 1.0 V to 1.7 V. This solution is a simple example of this voltage supervision application, but can be used in more complex applications where monitoring multiple voltage rails is necessary. The design is especially applicable in situations where customization in number and reference voltage of the rails is necessary or where system costs must be reduced.

2 Application Block Diagram



When a user places a battery in the battery slot, the TLV61225 boost converter generates a 3.3-V rail from the 1.0- to 1.7-V battery to power the entire circuit. The 3.3-V rail provides a voltage that enables the ATL431 device to provide an accurate 2.5-V output with minimal current consumption. The resistor ladder is used to create multiple, customizable voltage rails from which the two LM339 devices can compare the rail voltages to the voltage of the battery. If the voltage of the battery is greater than any of the 8 voltages generated from the resistor ladder, then the comparator drives the cathode of the light-emitting diode (LED) to ground, which turns the LED on and indicates the battery voltage.

Additionally, the TPD1E10B06 and TPS27081A devices provide the appropriate electrostatic discharge (ESD) and reverse polarity protection. The TPD1E10B06 device provides the ESD protection at the site of the battery holder. The TPS27081A device is used as a switch that turns on when the battery polarity is correct and turns off when the battery has been placed into the battery holder incorrectly.

3 Highlighted Products

3.1 ATL431

3.1.1 Description

The ATL431 device is a low quiescent current, adjustable, precision shunt regulator with a specified thermal stability over automotive, commercial, and industrial temperature ranges. The output can be adjusted between 2.5 V and 36 V by using two external resistors. The ATL431 device has a greater than twenty times improvement in cathode current over its TL431 predecessor. The active circuitry of the ATL431 device provides a very sharp turn-on characteristic that makes this device an excellent replacement for Zener diodes in many applications.

3.1.2 Features

- Adjustable regulated output of 2.5 V to 36 V
- Very-low operating current
  - $I_{KA(min)}$ = 35 µA (max)
  - I_{REF} = 150 nA (max)
- Internally compensated for stability
  - Stable with no capacitive load
- Reference voltage tolerances at 25°C
  - 0.5% for ATL431B
  - 1% for ATL431A
- Typical temperature drift
  - 5 mV (–40°C to 85°C); I Version
  - 6 mV (–40°C to 125°C); Q Version
- Extended cathode current range 35 µA to 100 mA
- Low output impedance of 0.3 Ω (max)

3.1.3 Implementation

The ATL431 device is a critical component for this design as it provides a low-power consumption, stable reference from which the resistor ladder can operate. The ATL431 device only consumes 60 µA to provide the 2.5-V rail for the resistor ladder to have an accurate reference for voltage division.

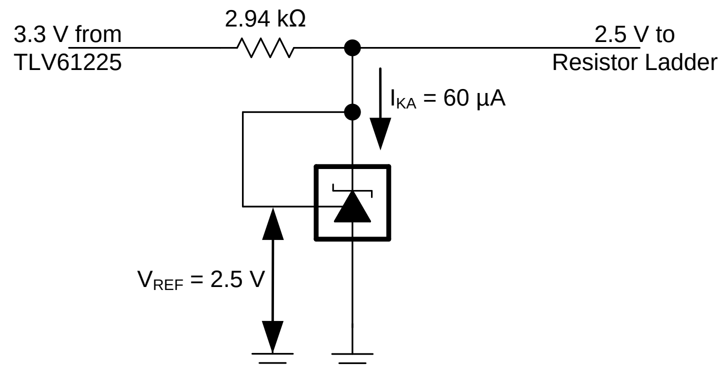


Figure 1. ATL431 Application Schematic

3.2 *LM339*

3.2.1 Description

The LM339 device consists of four independent voltage comparators that are designed to operate from a single power supply over a wide range of voltages. The current drain is independent of the supply voltage. The LM339 device is characterized for operation from 0°C to 70°C.

3.2.2 Features

- Wide supply ranges
  – Single supply: 2 V to 36 V
  – Dual supplies: ±1 V to ±18 V
- Low supply-current drain independent of supply voltage: 0.8 mA (typical)
- Low input bias current: 25 nA (typical)
- Low input offset voltage: 2 mV (typical)
- Common-mode input voltage range includes ground
- Differential input voltage range equal to maximum-rated supply voltage: ±36 V
- Low output saturation voltage
- Output compatible with TTL, MOS, and CMOS

3.2.3 Implementation

Two LM339 devices are used to compare the eight voltage rails (set by the resistor ladder) to the battery voltage. When the battery voltage exceeds the voltage rail, the comparator pulls the cathode of the LED to ground, which turns on the LED.

When considering the implementation of hysteresis, please refer to the *Comparator with Hysteresis Reference Design* (TIDU020).

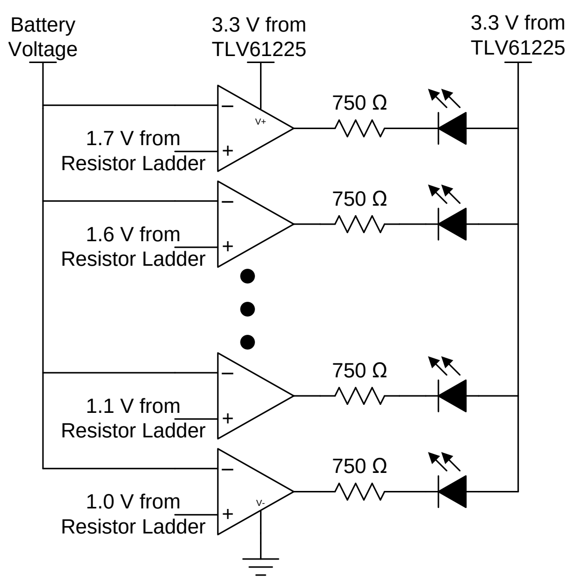


Figure 2. LM339 Application Schematic

3.3 *TPS27081A*

3.3.1 Description

The TPS27081A device is a high-side load switch that integrates a power PFET and a control NFET in a tiny package.

The TPS27081A features industry-standard ESD protection on all pins to provide better ESD compatibility with other onboard components.

The TPS27081A level shifts the ON/OFF logic signal to VIN levels and supports as low as 1-V CPU or MCU logic to control higher-voltage power supplies without requiring an external level-shifter.

3.3.2 Features

- Low ON-resistance, high-current PFET
  - $R_{DS(on)}$ = 32 mΩ at V_{GS} = –4.5 V
  - $R_{DS(on)}$ = 44 mΩ at V_{GS} = –3 V
  - $R_{DS(on)}$ = 82 mΩ at V_{GS} = –1.8 V
  - $R_{DS(on)}$ = 93 mΩ at V_{GS} = –1.5 V
  - $R_{DS(on)}$ = 155 mΩ at V_{GS} = –1.2 V
- Adjustable turnon and turnoff slew rate control through external R1, R2, and C1
- Supports a wide range of 1.2-V to 8-V supply inputs
- Integrated NMOS for PFET control
- NMOS ON/OFF supports a wide range of 1-V to 8-V control logic interface
- Full ESD protection (all pins)
  - HBM 2 kV, CDM 500 V
- Ultra-low leakage current in standby (typical 100 nA)
- Available in tiny six-pin package
  - 2.9 mm × 2.8 mm × 0.75 mm SOT (DDC)

3.3.3 Implementation

In this application, the TPS27081A device is used for reverse battery protection. When the battery is placed into the battery holder appropriately, the switch is activated and allows current to flow. When the battery is inverted, the switch is turned off to prevent damage to other devices. The low turnon resistance of the TPS27081A allows for minimal voltage dropout as well as power consumption.

Please refer to *Reverse Current/Battery Protection Circuits* (SLVA139) for additional information on the implementation of reverse protection circuitry.

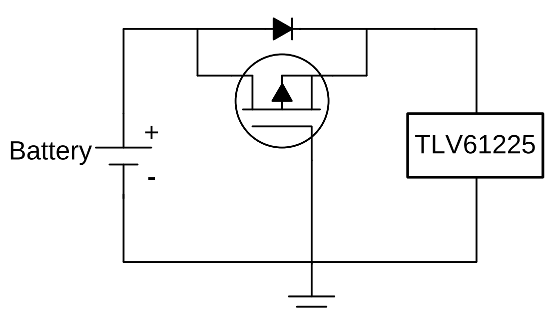


Figure 3. TPS27081A Application Schematic

3.4 TLV61225

3.4.1 Description

The TLV61225 device provides a power-supply solution for products powered by either a single-cell or dual-cell alkaline or nickel-metal hydride (NiMH) battery, in addition to a single cell Li-primary battery. The boost converter is based on a hysteretic controller topology using synchronous rectification to obtain maximum efficiency at minimal quiescent currents. The output voltage of this device is set internally to a fixed output voltage of 3.3 V.

3.4.2 Features

- Up to 94% efficiency at typical operating conditions
- 5-µA quiescent current
- Operating input voltage from 0.7-V to 3.3-V
- Pass-through function during shutdown
- Output current of more than 40 mA from a 1.2-V input
- Typical switch current rating 400 mA
- Output overvoltage protection
- Overtemperature protection
- Fixed 3.3-V output voltage
- Small six-pin SC-70 package

3.4.3 Implementation

The TIDA-00670 reference design utilizes the TLV61225 device to power the entire circuit from the battery. The boost converter takes the 0.8- to 1.7-V battery input voltage and generates a 3.3-V rail to power the comparators and create a voltage rail, from which the ATL431 device can operate to create the stable 2.5-V reference.

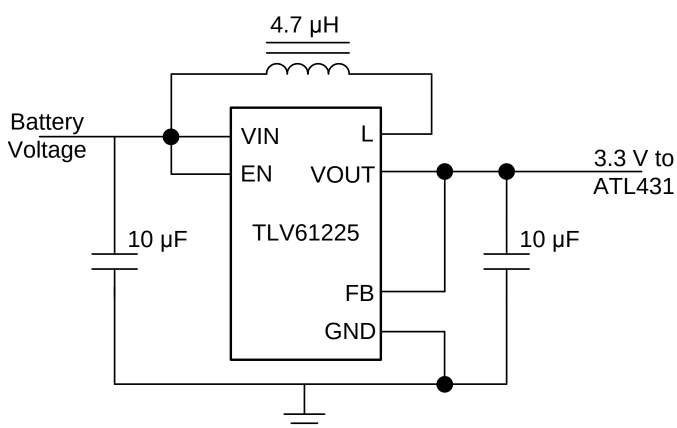


Figure 4. TLV61225 Application Schematic

3.5 TPD1E10B06

3.5.1 Description

The TPD1E10B06 device is a single-channel ESD transient voltage suppression (TVS) diode in a small 0402 package. This TVS protection device offers ±30-kV contact ESD, ±30-kV IEC air-gap protection, and has an ESD clamp circuit with a back-to-back TVS diode for bipolar or bidirectional signal support. The 12-pF line capacitance of this ESD protection diode is suitable for a wide range of applications supporting data rates up to 400 Mbps.

3.5.2 Features

- Provides system-level ESD protection for low-voltage I/O interface
- IEC 61000-4-2 Level 4 ESD protection
  - ±30 kV contact discharge
  - ±30 kV air-gap discharge
- IEC 61000-4-5 Surge: 6 A (8/20 µs)
- I/O capacitance 12 pF (typical)
- R_{DYN} 0.4 Ω (typical)
- DC breakdown voltage ±6 V (minimum)
- Ultralow leakage current 100 nA (maximum)
- 10-V clamping voltage (max at I_{PP} = 1 A)
- Industrial temperature range: –40°C to 125°C
- Space-saving 0402 footprint

3.5.3 Implementation

The TPD1E10B06 device provides ESD protection to the board from hazardous situations, such as a strike at the input voltage terminals.

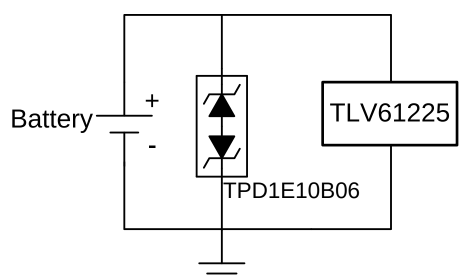


Figure 5. TPD1E10B06 Application Schematic

4 Getting Started

The reference design hardware does not require any external software or firmware to operate. The hardware only requires a single AA battery to operate the circuitry.

Simply plug any AA battery into the AA battery holder and the circuitry powers up immediately. The appropriate LEDs illuminate to indicate the battery voltage.

4.1 Hardware–Board Circuitry

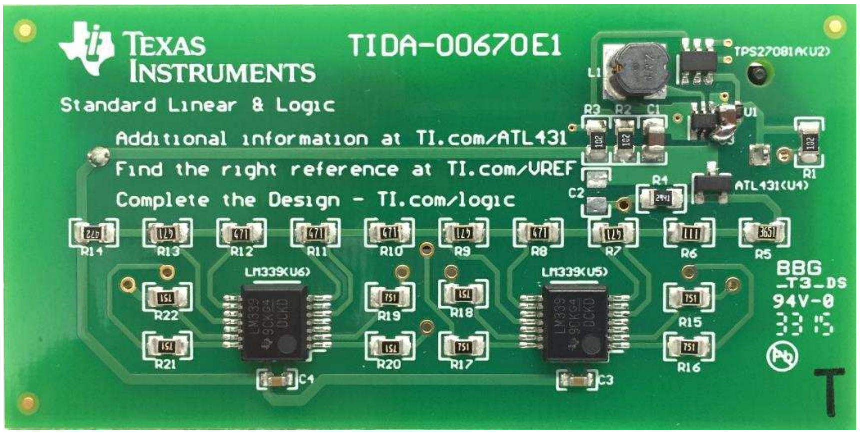


Figure 6. Top View of AA Battery Tester

4.2 Hardware–AA Battery Tester

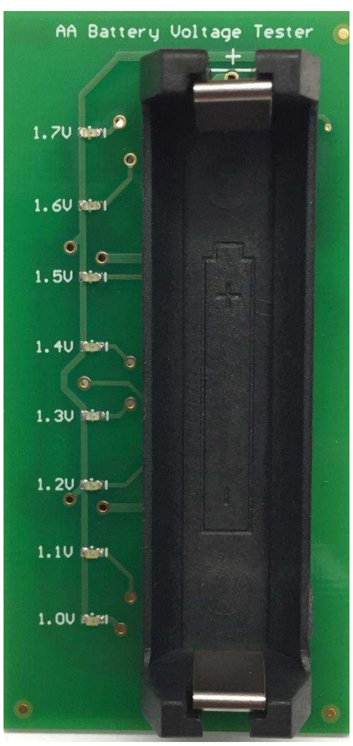


Figure 7. AA Battery Tester Without Battery

Figure 8. AA Battery Tester With Battery

5 Test Data

5.1 Device Current Consumption

Figure 9 shows the current consumption of the battery tester as a function of input voltage. A voltage supply was attached to the terminals of the battery holder and swept over the full range of the TLV61225 boost converter. Note the following characteristics of the plot:

- The current rises from about 0.5 V until about 0.7 V, when the current drops quickly. The increase in current consumption is leakage current moving through the entire board until the TLV61225 boost converter turns on and begins to regulate at an input voltage near 0.7 V.
- As the input voltage rises, the curve displays a trend indicating lower current consumption. This consistent decay-type decrease occurs because of the efficiency of the TLV61225 boost converter as the input voltage increases. As the input voltage increases, the efficiency of the boost converter increases, as Figure 3 of the TLV61225 datasheet notes.
- There are steps in the current consumption at 0.1-V intervals between 1.0 V and 1.7 V that occur when each LED indicator turns on. Each of the LEDs consume 2 mA to 3 mA of current. A combination of the higher input voltage and the higher current consumption increases the efficiency of the TLV61225 device, thereby decreasing the magnitude of each step as the LEDs turn on.

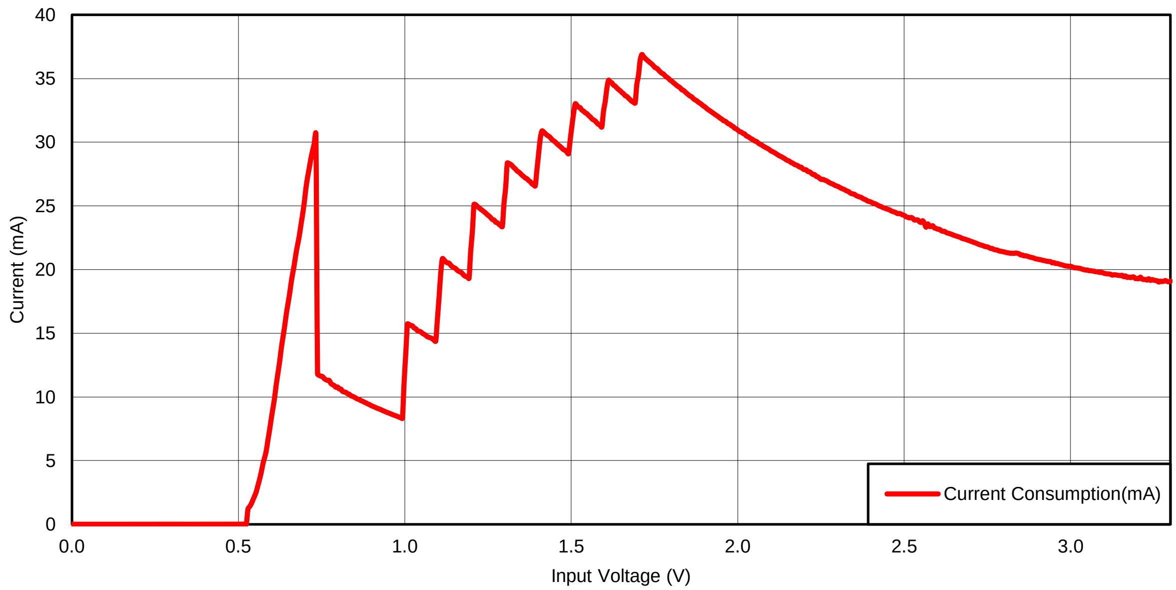


Figure 9. Total Current Consumption Versus Input Voltage

5.2 Device Voltage Rails

Figure 10 shows the voltage rails of the battery tester as a function of input voltage. A voltage supply was attached to the terminals of the battery holder and swept over the full range of the AA battery tester. Note the following characteristics of the plot:

- The moment the boost converter begins to regulate at the 0.7-V input, each of the other voltage rails begins to regulate immediately.
- Even as the output voltage of the boost converter begins to rise above 3.3 V at an input voltage greater than 2.8 V, the ATL431 device continues to consistently regulate at 2.5 V.
- Each of the eight rails generated using a resistor ladder are very accurate and consistent over the full input voltage range.

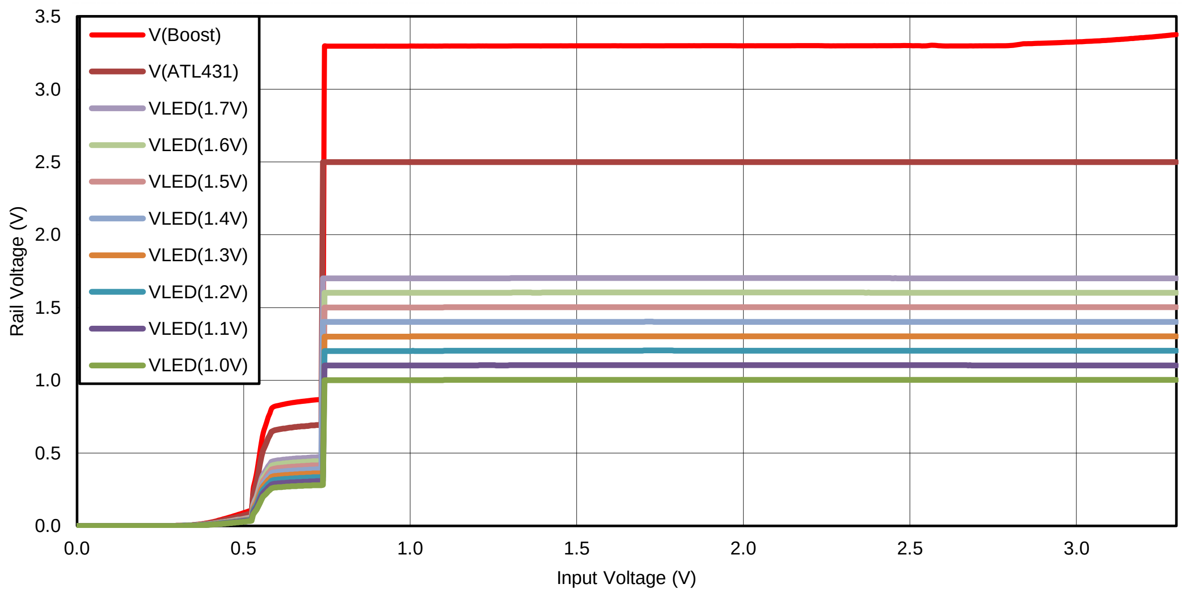


Figure 10. Device Voltage Rails Versus Input Voltage

6 Design Files

6.1 Schematic

To download the schematic, see the design files at TIDA-00670.

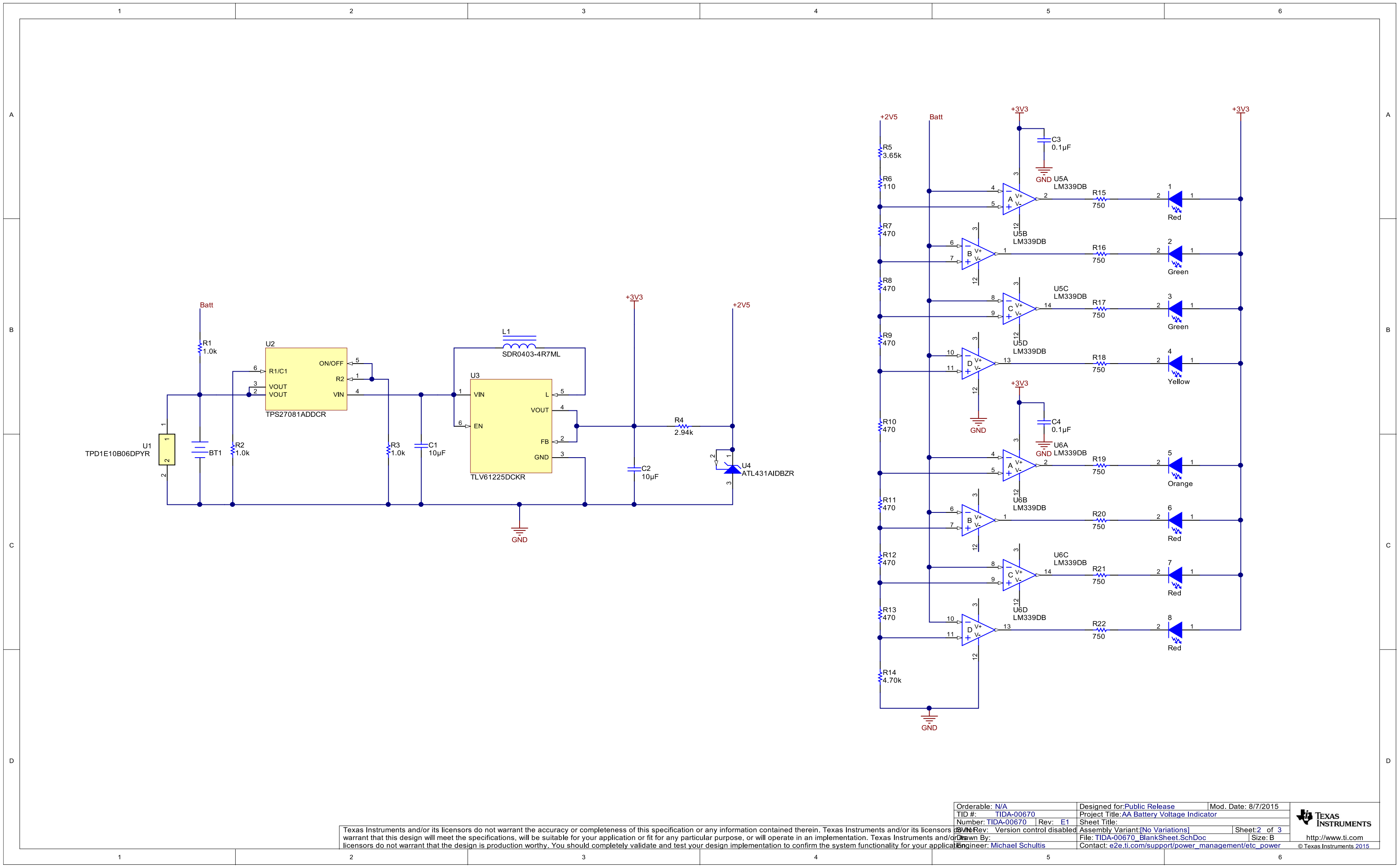


Figure 11. AA Battery Tester Schematic

6.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00670.

ITEM	QTY	REFERENCE	VALUE	PART DESCRIPTION	MANUFACTURER	MANUFACTURER PART NUMBER	PCB FOOTPRINT
1	1	!PCB1		Printed Circuit Board	Any	TIDA-00670	
2	4	1, 6, 7, 8	Red	LED, Red, SMD	OSRAM	LS L29K-G1J2-1-Z	SMD, 2-Leads, Body 1.3x0.8mm
3	2	2, 3	Green	LED, Green, SMD	OSRAM	LG L29K-G2J1-24-Z	1.7x0.65x0.8mm
4	1	4	Yellow	LED, Yellow, SMD	OSRAM	LY L29K-H1K2-26-Z	LED, 1.3x0.65x0.8mm
5	1	5	Orange	LED, Orange, SMD	OSRAM	LO L29K-J2L1-24-Z	SMD, 2-Leads, Body 1.3x0.8mm
6	1	BT1		AA Battery Holder, Through-hole mount	Keystone	1015	AA Battery Holder, Through-hole mount
7	2	C1, C2	10uF	CAP, CERM, 10 µF, 6.3 V, +/- 20%, X5R, 0805	TDK	C2012X5R0J106M	0805
8	2	C3, C4	0.1uF	CAP, CERM, 0.1 µF, 6.3 V, +/- 10%, X7R, 0603	MuRata	GRM188R70J104KA01D	0603
9	6	FID1, FID2, FID3, FID4, FID5, FID6		Fiducial mark. There is nothing to buy or mount.	N/A	N/A	Fiducial
10	1	L1	4.7uH	Inductor, Drum Core, Ferrite, 4.7 µH, 1.7 A, 0.094 ohm, SMD	Bourns	SDR0403-4R7ML	4.5x3.2x4mm
11	3	R1, R2, R3	1.0k	RES, 1.0 k, 5%, 0.125 W, 0805	Panasonic	ERJ-6GEYJ102V	0805
12	1	R4	2.94k	RES, 2.94 k, 1%, 0.125 W, 0805	Panasonic	ERJ-6ENF2941V	0805
13	1	R5	3.65k	RES, 3.65 k, 0.5%, 0.1 W, 0805	Susumu Co Ltd	RR1220P-3651-D-M	0805
14	1	R6	110	RES, 110, 0.5%, 0.1 W, 0805	Susumu Co Ltd	RR1220P-111-D	0805
15	7	R7, R8, R9, R10, R11, R12, R13	470	RES, 470, 0.5%, 0.1 W, 0805	Susumu Co Ltd	RR1220P-471-D	0805
16	1	R14	4.70k	RES, 4.70 k, 0.5%, 0.1 W, 0805	Susumu Co Ltd	RR1220P-472-D	0805
17	8	R15, R16, R17, R18, R19, R20, R21, R22	750	RES, 750, 5%, 0.125 W, 0805	Panasonic	ERJ-6GEYJ751V	0805
18	1	U1		ESD in 0402 Package with 10 pF Capacitance and 6 V Breakdown, 1 Channel, -40 to +125 degC, 2-pin X2SON (DPY), Green (RoHS & no Sb/Br)	Texas Instruments	TPD1E10B06DPYR	DPY0002A
19	1	U2		1.2V - 8V, 3A PFET High Side Load Switch with Level Shift & Adjustable Slew Rate Control, DDC0006A	Texas Instruments	TPS27081ADDCR	DDC0006A
20	1	U3		SINGLE CELL HIGH EFFICIENT STEP-UP CONVERTER, DCK0006A	Texas Instruments	TLV61225DCKR	DCK0006A
21	1	U4		2.5V Low Iq Adjustable Precision Shunt Regulator, DBZ0003A	Texas Instruments	ATL431AIDBZR	DBZ0003A
22	2	U5, U6		Quad Comparator, DB0014A	Texas Instruments	LM339DB	DB0014A

Figure 12. BOM

6.3 Layer Plots

To download the layer plots, see the design files at TIDA-00670.

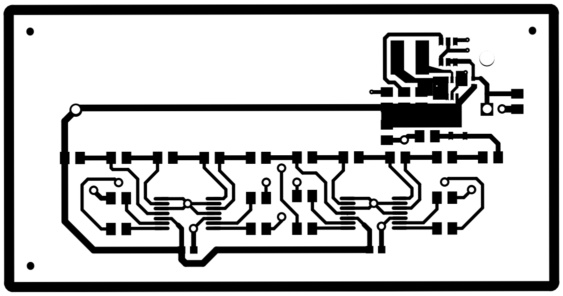


Figure 13. Top Layer

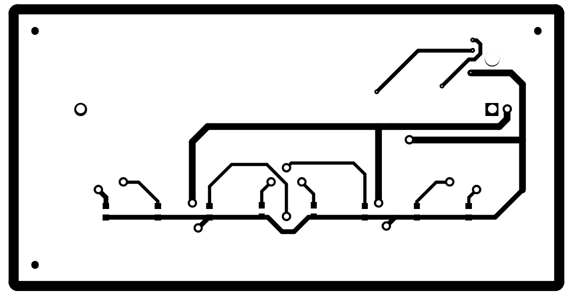


Figure 14. Bottom Layer

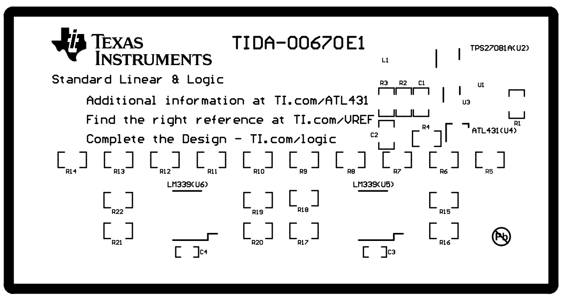


Figure 15. Top Overlay

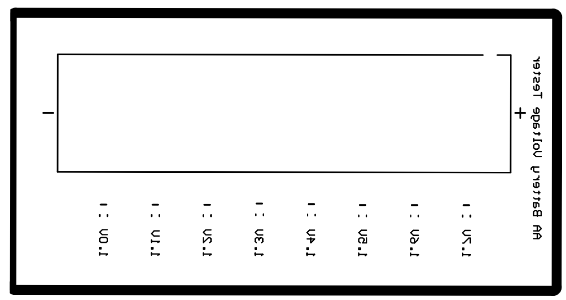


Figure 16. Bottom Overlay

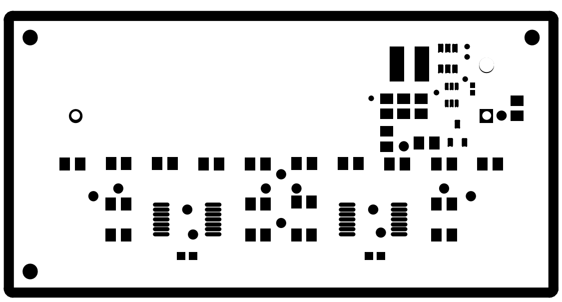


Figure 17. Top Solder Mask

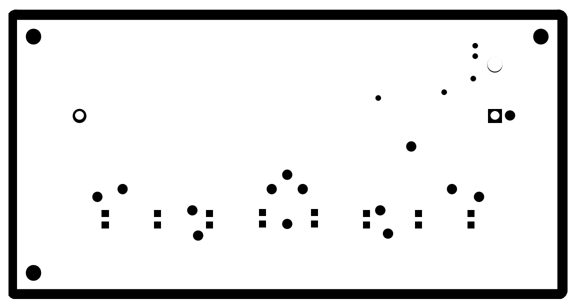
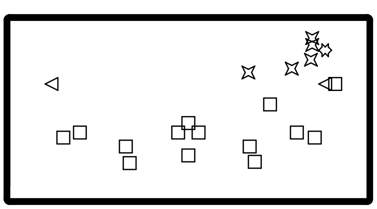


Figure 18. Bottom Solder Mask



Symbol	Quantity	Finished Hole Size	Plated	Hole Type
✡	1	77.95mil (1.980mm)	NPTH	Round
⌘	5	8.00mil (0.203mm)	PTH	Round
□	14	28.00mil (0.711mm)	PTH	Round
▽	2	46.85mil (1.190mm)	PTH	Round
	22 Total			

Figure 19. Drill Drawing

Figure 20. Board Dimensions

6.4 Altium Project

To download the Altium project files, see the design files at TIDA-00670.

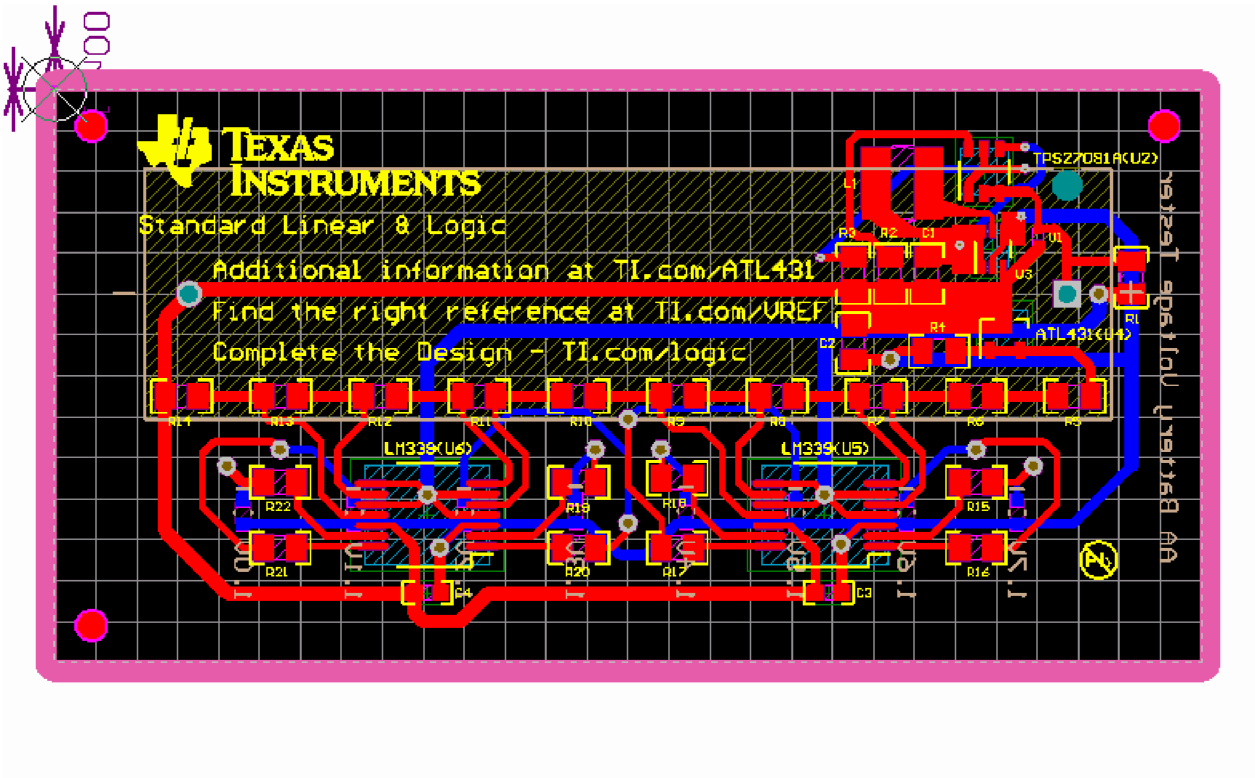


Figure 21. Board Layers Full View

6.5 Layout Guidelines

The most critical layout guideline to consider when using the design consists of the TLV61225 switching regulator. Similar to all switching power supplies, the layout is an important step in the design. If the layout is not carefully executed, the regulator can show instability as well as EMI problems. Use wide and short traces for the main current path and for the power ground paths. The input capacitor, output capacitor, and inductor must be placed as close as possible to the IC. Figure 22 provides a good layout example for the TLV61225 device.

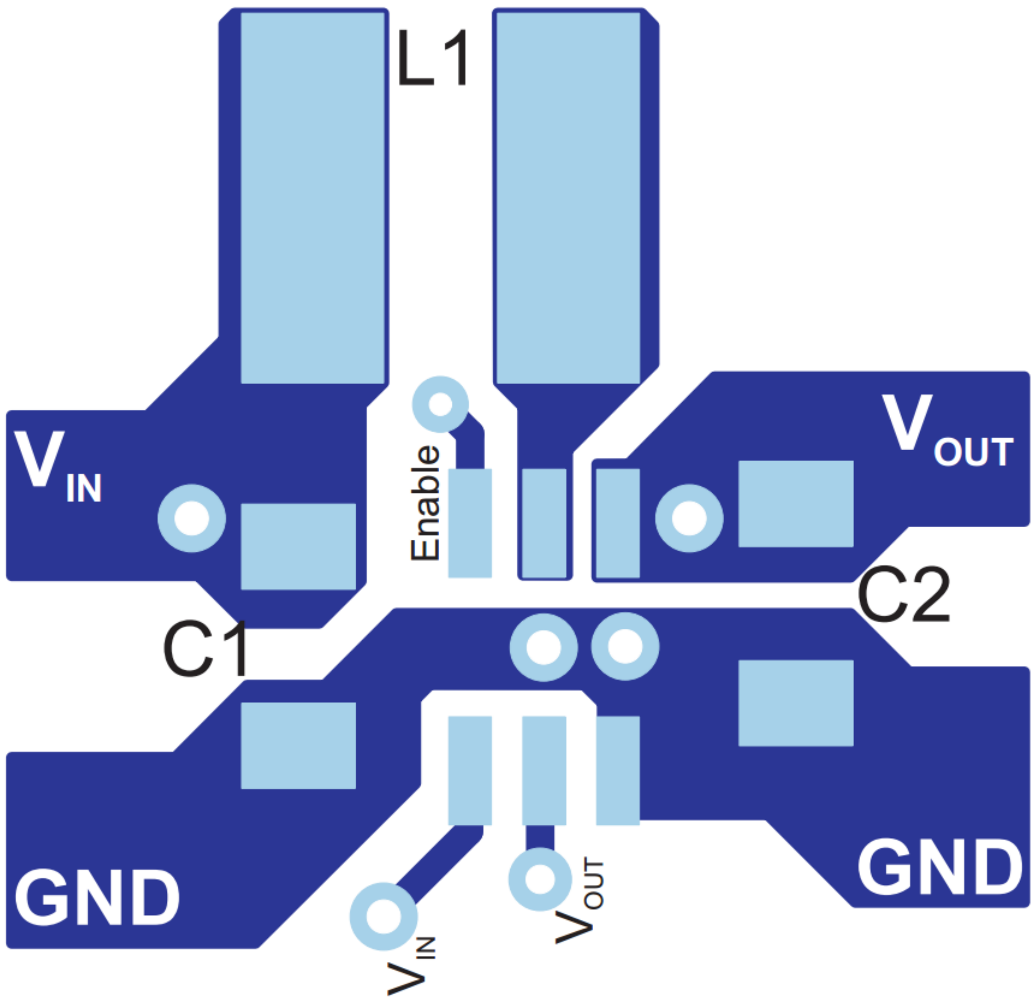


Figure 22. TLV61225 Layout Example

6.6 Gerber Files

To download the Gerber files, see the design files at TIDA-00670.

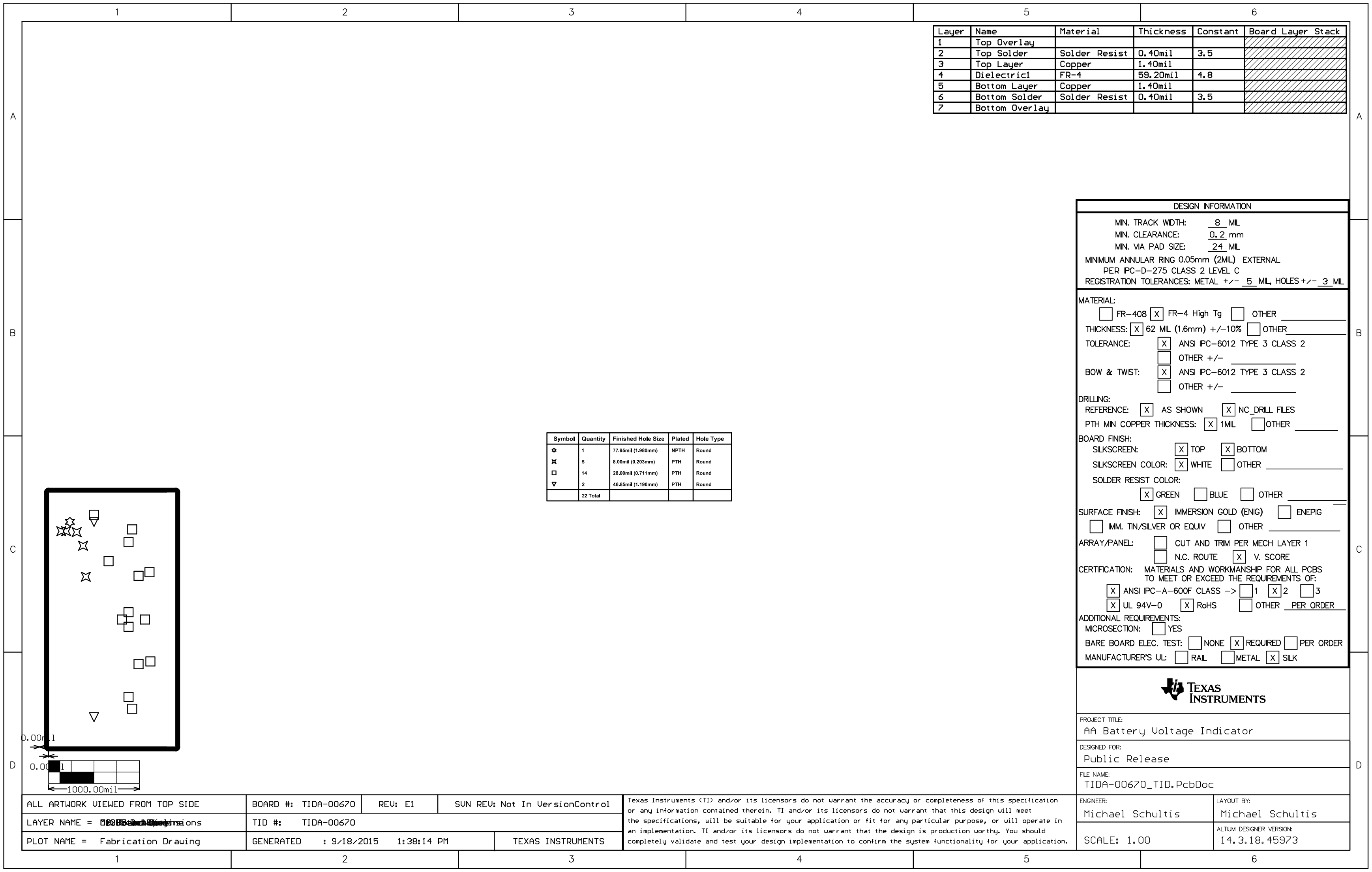


Figure 23. Fabrication Drawing

6.7 Assembly Drawings

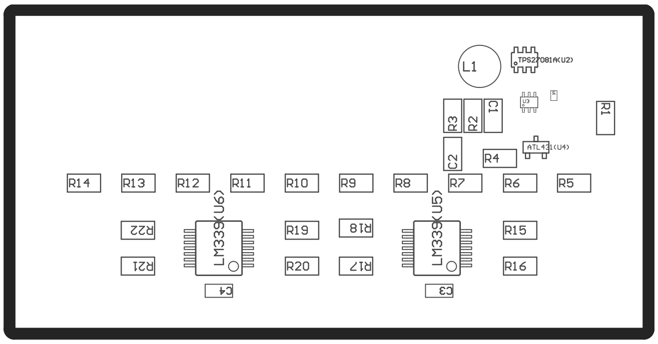


Figure 24. Top Assembly Drawing

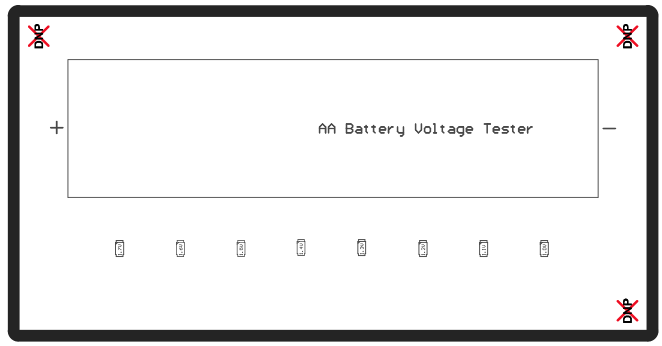


Figure 25. Bottom Assembly Drawing

7 References

1. Texas Instruments, *Reverse Current/Battery Protection Circuits*, Application Report (SLVA139)
2. Texas Instruments, *Comparator with Hysteresis Reference Design*, TI Designs (TIDU020)
3. Texas Instruments, *ATL43x 2.5-V Low Iq Adjustable Precision Shunt Regulator*, ATL431 Datasheet (SLVSCV5)
4. Texas Instruments, *LMx39x, LM2901xx Quad Differential Comparators*, LM339 Datasheet (SLCS006)
5. Texas Instruments, *TPS27081A 1.2V - 8V, 3A PFET High Side Load Switch With Level Shift & Adjustable Slew Rate Control*, TPS27081A Datasheet (SLVSBE9)
6. Texas Instruments, *TLV61225 Single-Cell High-Efficient Step-Up Converter in 6 pin SC-70 Package*, TLV61225 Datasheet (SLVSAF0)
7. Texas Instruments, *TPD1E10B06 Single-Channel ESD Protection Diode in 0402 Package*, TPD1E10B06 Datasheet (SLLSEB1)

8 About the Author

MICHAEL SCHULTIS is an Applications Engineer at Texas Instruments and is part of the Standard Linear and Logic Business Unit where he is responsible for the linear power portfolio including developing reference designs and supporting customers regarding voltage references, linear voltage regulators, switching voltage regulators, and peripheral drivers. Michael earned his B.E. in Biomedical and Electrical Engineering from Vanderbilt University in Nashville, TN.

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