TI Designs
Automotive Reverse Polarity Protection Reference Design

Description

Reverse polarity is the typical protection required in an automotive environment. During maintenance or service, the battery of the car are typically detached and reconnected. There is a probability of connecting the wires to wrong terminals of the battery. This error can be fatal and damage the components in electronic control units. To avoid any such damages, there is a need for reverse polarity protection. Schottky diodes will have high power loss. The LM5050-1-Q1 along with N-channel MOSFET can be used to reduce the power dissipation.

Resources

TIDA-00992	Design Folder
LM5050-1-Q1	Product Folder

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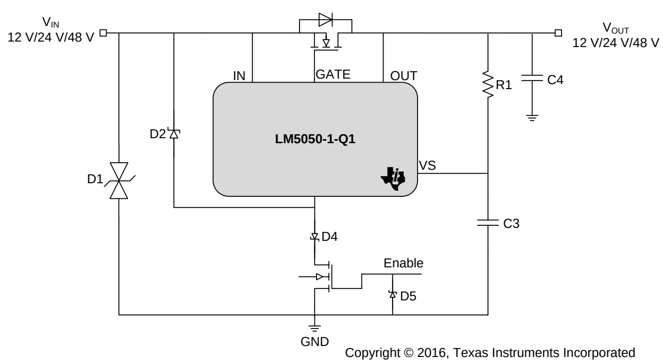
Features

- Reverse Polarity Protection for 12 V, 24 V, 48 V
- ORing Controller to Connect Multiple Batteries
- Replaces the Schottky Diode and Reduces Power Dissipation
- Less or No Overheads for Heat Sink and Housing Design for Control Units
- Improves System Efficiency With Very Low Quiescent Current
- Compliance to ISO7637-2, ISO16750-2

Applications

- Electronic Control Units
- Body Control Module



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1 System Overview

1.1 System Description

Reverse polarity is the typical protection required in an automotive environment. During maintenance or service, the battery of the car are typically detached and reconnected. There is a probability of connecting the wires to wrong terminals of the battery. This error can be fatal and damage the components in electronic control units. To avoid any such damages, there is a need for reverse polarity protection. Schottky diodes will have high power loss. The LM5050-1-Q1 along with N-channel MOSFET can be used to reduce the power dissipation.

1.2 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATION	MIN	TYP	MAX	UNIT
V_{INPUT}	DC input voltage	–60	—	60	V
Output current	Q1 configurable	—	5	—	A
Gate voltage (turnon time)	12 V	—	460	—	µs
	24 V	—	368	—	µs
	48 V	—	317	—	µs
Gate voltage (turnoff time)	12 V	—	9.5	—	ms
	24 V	—	2.95	—	ms
	48 V	—	2.06	—	ms
Operating current	12 V: Jumper J5 closed	—	1.8	—	mA
	24 V: Jumper J5 closed	—	3.4	—	mA
	48 V: Jumper J5 closed	—	6.92	—	mA
Quiescent current	12 V: Jumper J5 open	—	< 10	—	nA
	24 V: Jumper J5 open	—	< 10	—	nA
	48 V: Jumper J5 open	—	< 10	—	nA

1.3 Block Diagram

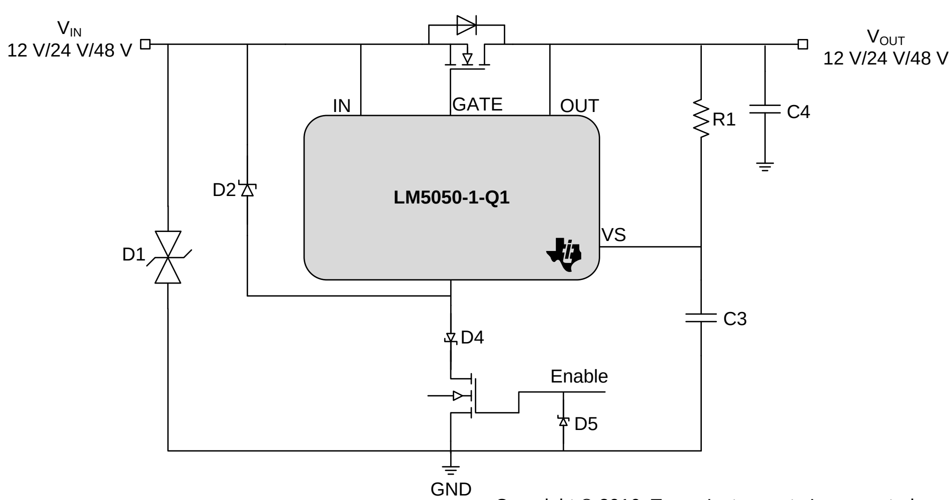


Figure 1. Block Diagram

1.4 Highlighted Products

1.4.1 LM5050-1-Q1

The LM5050-1/LM5050-Q1 High-Side ORing FET Controller operates in conjunction with an external MOSFET as an ideal diode rectifier when connected in series with a power source. This ORing controller allows MOSFETs to replace diode rectifiers in power distribution networks thus reducing both power loss and voltage drops.

The LM5050-1/LM5050-Q1 controller provides charge pump gate drive for an external N-channel MOSFET and a fast response comparator to turn off the FET when current flows in the reverse direction. The LM5050-1/LM5050-Q1 can connect power supplies ranging from 5 to 75 V and can withstand transients up to 100 V.

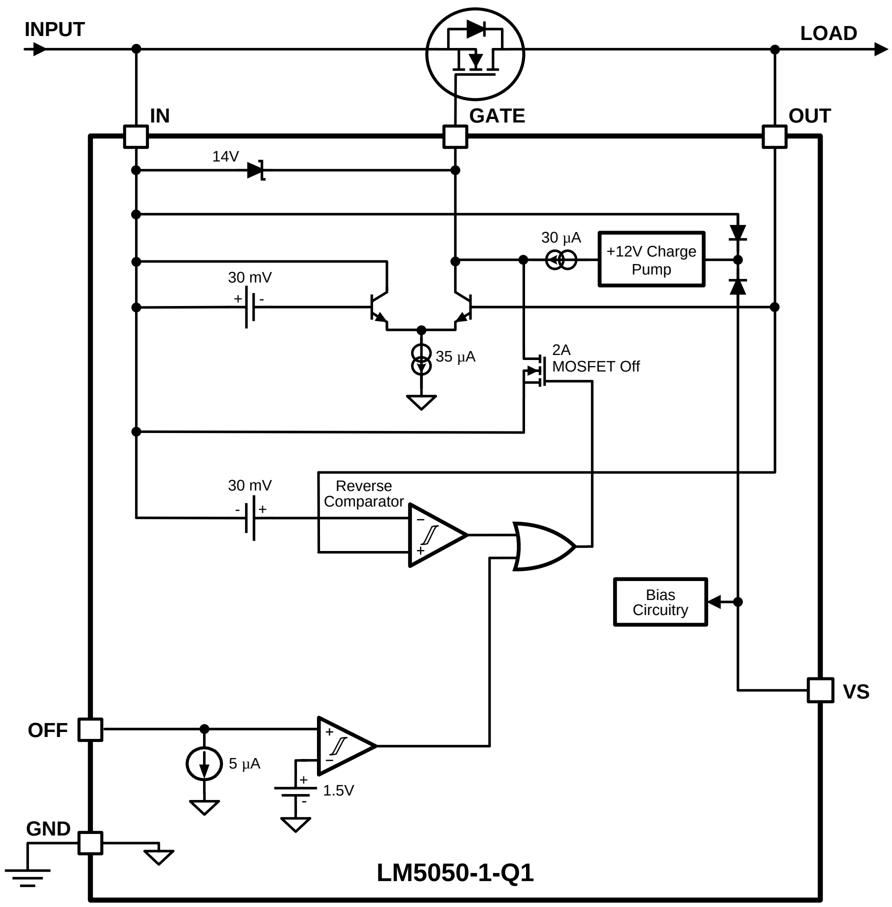


Figure 2. LM5050-1-Q1 Functional Block Diagram

Key features include:

- Available in standard and AEC-Q100 qualified versions LM5050Q0MK-1 (up to 150°C T_J) and LM5050Q1MK-1 (up to 125°C T_J)
- Wide operating input voltage range, V_{IN}: 1 to 75 V (V_{BIAS} required for V_{IN} < 5 V)
- 100-V transient capability
- Charge pump gate driver for external N-channel MOSFET
- Fast 50-ns response to current reversal
- 2-A peak gate turnoff current
- Minimum V_{DS} clamp for faster turnoff

2 System Design Theory

2.1 Automotive Conducted Transients

In an automotive environment, batteries are connected to various electronic control units, loads, and sensor and load systems. Due to several parameters, conducted transients are seen on power lines for electronic control units. A short overview of such electrical transients are shown in Figure 3.

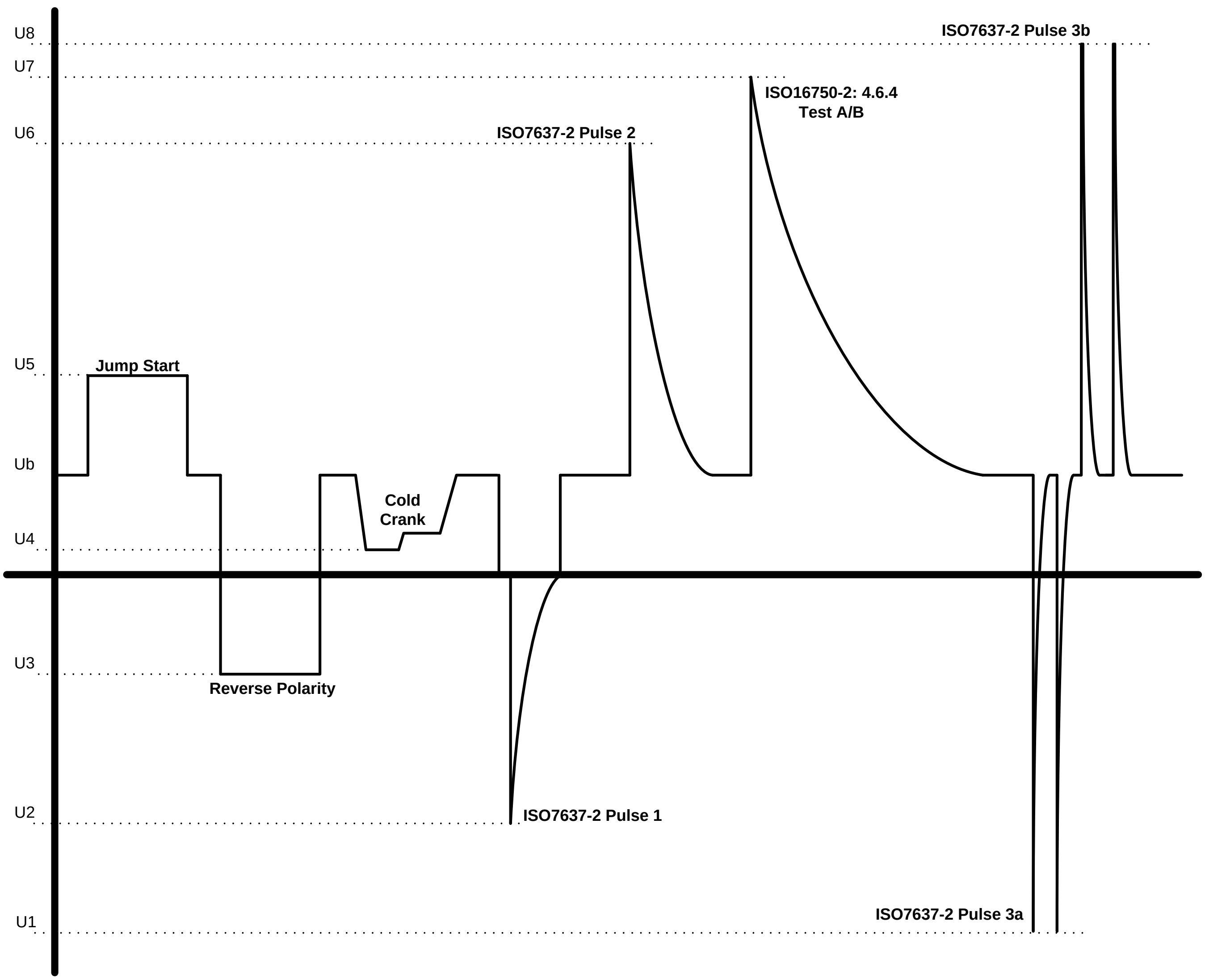


Figure 3. Overview of Transients

Description, behavior and impact of automotive power line electrical transients are specified/defined in standards listed in Table 2.

Table 2. List of Automotive Electrical Transients Standards

STANDARD OR SPECIFICATION	INSTITUTE OR COMPANY
ISO 7637-2	Road vehicles: Electrical disturbances from conduction and coupling
ISO 16750-2	Road vehicles: Environmental conditions and testing for electrical and electronic equipment
LV124	Group of OEMS (Audi, BMW, Porsche, VW, and so on)
SAEJ1113-11	USA Standard by the Society of Auto Engineers
JASO A-1	Japanese automobile standard

Specification of these standards are not limited to this list; auto manufacturers have their own internal standards. Although changes are typically only in a few parameters of different tests or limits, the essence of the requirements are the same.

ISO 7637 is titled *Road vehicles – Electrical disturbances from conduction and coupling*, and part 2 is specifically "Electrical transient conduction along supply lines only". The standard defines a test procedure, including the description of test pulses, to test the susceptibility of an electrical subsystem to transients, which could potentially be harmful to its operation. Each pulse is modeled to simulate a transient that could be created by a real event in the car. This design mainly focus for reverse polarity protection and ORing applications, which is predominantly placed next to battery.

ISO 16750 is titled *Road vehicles – Environmental conditions and testing for electrical and electronic equipment*, and part 2 is specifically "Electrical loads." An easy way to think of this standard is that it essentially defines a series of "supply voltage quality" events—variations of the battery supply voltage under various conditions. For the most part, these conditions are not harmful to the electrical subsystem, but can affect its state of operation. The tests in this standard are designed to see how the subsystem behaves before, during, and after these events.

2.1.1 ISO 7637-2 Pulse 1

This test is a simulation of transients due to supply disconnection from inductive loads. It is applicable to DUTs which, as used in the vehicle, remain connected directly in parallel with an inductive load.

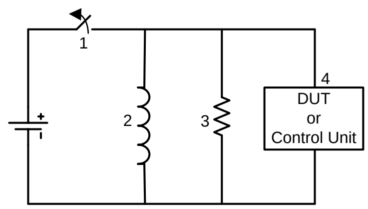


Figure 4. ISO 7637-2 Pulse 1

Key features include:

- Ignition switch and main relay or relevant
- Inductive load (relays, solenoids or motors, and so on)
- Load resistance (effective load on the power supply)
- Control Unit or DUT (exposed to transients)
- Battery

Pulse 1 occurs when switch(1) is open. The pulse itself, simulating an inductive kick in a parallel system, is a high-voltage, negative-going transient. The waveform and its parameters are given in Figure 5 and Table 3:

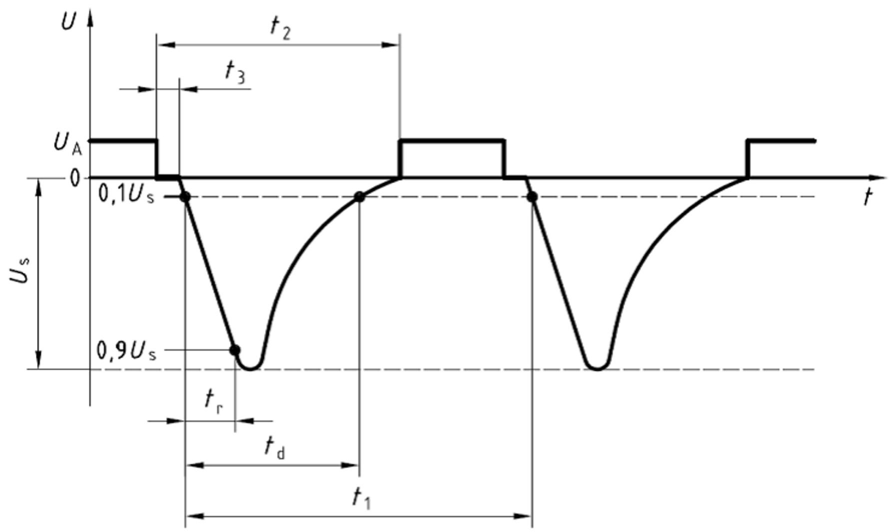


Figure 5. ISO 7637-2 Pulse 1 Waveform

Table 3. ISO 7637-2 Pulse 1 Parameters

PARAMETER	12-V SYSTEM	24-V SYSTEM
U_S	–75 to –100 V	–450 to –600 V
R_i	10 Ω	50 Ω
t_d	2 ms	1 ms
t_r	$\left(1_{-0.5}^{\ 0}\right)$µs	$\left(3_{-1.5}^{\ 0}\right)$µs
t_1 (1)	0.5 to 5 s	
t_2	200 ms	
t_3 (2)	< 100 µs	

(1) t1 must be chosen such that the DUT is correctly initialized before the application of the next pulse.
(2) t3 is the smallest possible time necessary between the disconnection of the supply source and the application of the pulse.

Pulse specification and parameters might vary based on OEM and vehicle configuration.

2.1.2 ISO 7637-2 Pulse 2a

Pulse 2a simulates transients due to sudden interruption of currents in a device connected in parallel with DUT due to inductance of the wiring harness.

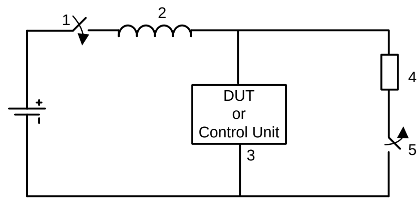


Figure 6. ISO 7637-2 Pulse 2a Simulation Picture

Key features include:

- Ignition switch and main relay or relevant
- Inductance (wiring harness)
- Control Unit or DUT (exposed to transients)
- Load resistance (effective load on the power supply)
- Load switch
- Battery

The pulse itself, simulating an inductive kick from the wiring harness, is a high-voltage, positive-going transient. The waveform and its parameters are given in Figure 7 and Table 4:

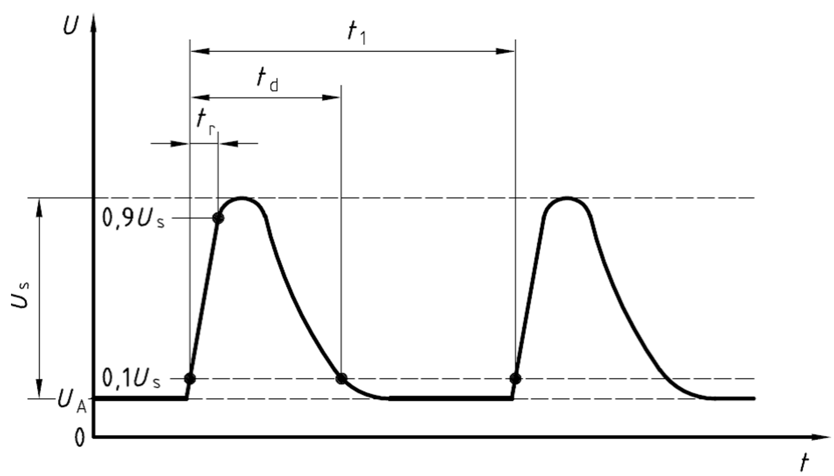


Figure 7. ISO 7637-2 Pulse 2a Waveform

Table 4. Pulse 2a Parameters

PARAMETER	12-V SYSTEM	24-V SYSTEM
U_S	37 to 50 V	
R_i	2 Ω	
t_d	0.05 ms	
t_r	$\left(1^{\ 0}_{-0.5}\right)\mu s$	
t_1 (1)	0.2 to 5 s	

(1) The repetition time t_1 can be short, depending on the switching. The use of a short repetition time reduces the test time.

Pulse specification and parameters might vary based on OEM and vehicle configuration.

2.1.3 ISO 7637-2 Pulses 3a and 3b

These test pulses are a simulation of transients that occur as a result of the switching processes. The characteristics of these transients are influenced by distributed capacitance and inductance of the wiring harness.

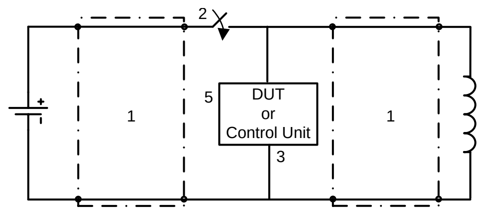


Figure 8. ISO 7637-2 Pulse 3a and 3b Simulation Picture

Key features include:

- Wiring harness with distributed inductance and capacitance
- Ignition switch and main relay or relevant
- Control Unit or DUT (exposed to transients)
- Inductive load (relays, solenoids or motors, and so on)
- Battery

Pulse 3a is seen in control unit or DUT when supply is turned ON or load is switched before the control unit. A burst of negative arching transients are seen due to relay on and off.

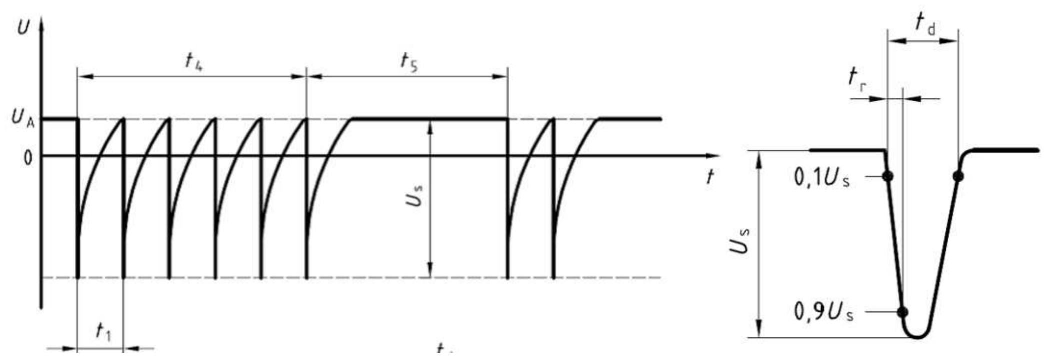


Figure 9. ISO 7637-2 Pulse 3a Waveform

Table 5. ISO 7637-2 Pulse 3a Parameters

PARAMETER	12-V SYSTEM	24-V SYSTEM
U_S	112 to 150 V	150 to 200 V
R_i	50 Ω	
t_d	$\left(0.1^{+0.1}_{0}\right)$ µs	
t_r	5 ns ± 1.5 ns	
t_1	100 µs	
t_4	10 ms	
t_5	90 ms	

Pulse 3a is seen in control unit or DUT when load is switched after the control unit. A burst of positive arching transients are seen due to relay on and off.

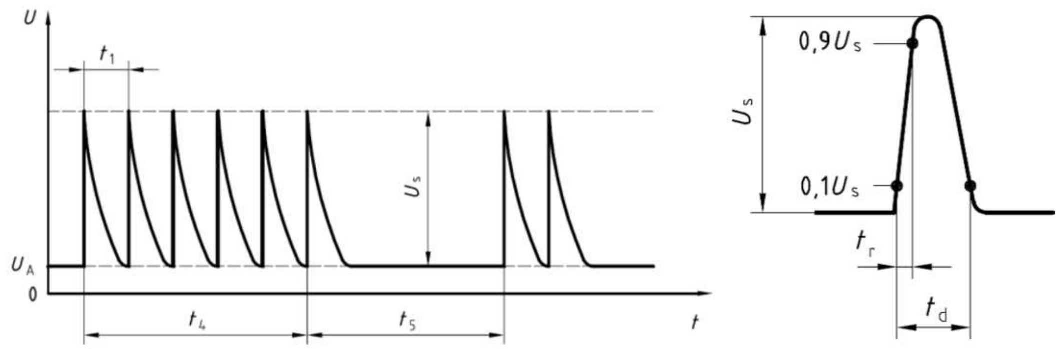


Figure 10. ISO 7637-2 Pulse 3b Waveform

Table 6. ISO 7637-2 Pulse 3b Parameters

PARAMETER	12-V SYSTEM	24-V SYSTEM
U_S	75 to 100 V	150 to 200 V
R_i	50 Ω	
t_d	$\left(0.1^{+0.1}_{0}\right)\mu s$	
t_r	5 ns ± 1.5 ns	
t_1	100 µs	
t_4	10 ms	
t_5	90 ms	

Pulse specification and parameters might vary based on OEM and vehicle configuration.

2.1.4 ISO 16750-2 4.6.4 Load Dump

This test is a simulation of load dump transient, occurring in the event of a discharged battery being disconnected while the alternator is generating charging current and with other loads remaining on the alternator circuit at this moment. Load dump may occur on account of a battery being disconnected as a result of cable corrosion, poor connection or of intentional disconnection with the engine running. This pulse was actually moved from ISO 7637 to ISO 16750.

The actual load dump event is extremely high energy and high voltage, which would be very difficult (and expensive) to protect against on every subsystem in the vehicle. Instead, every OEM installs a clamping circuit to the alternator, which limits the voltage to a more manageable level for the subsystem. This clamped voltage varies from OEM to OEM, but is typically in the range of 30 to 40 V.

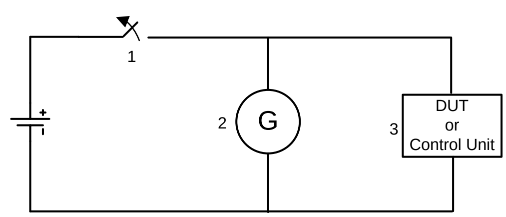


Figure 11. ISO 16750-2 Test B Simulation Picture

Key features include:

- Battery connection (loose contact or disconnection)
- Alternator with internal clamping
- Control Unit or DUT (exposed to transients)
- Battery

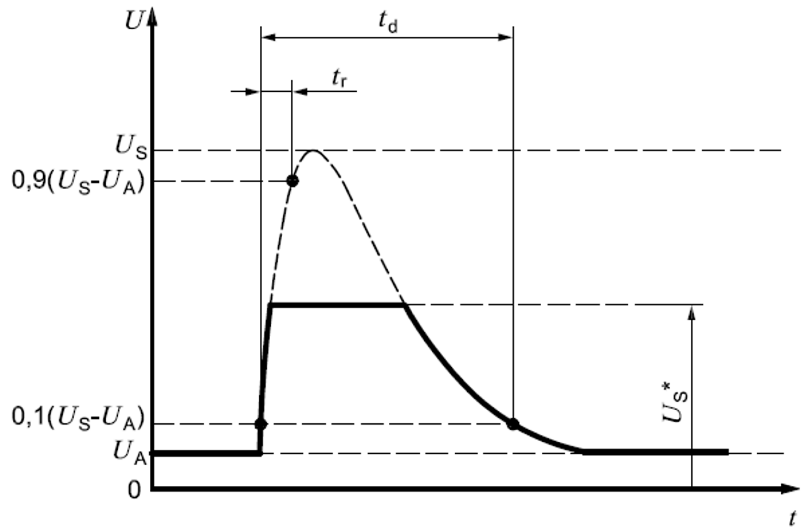


Figure 12. ISO16750-2 Test B Waveform

Table 7. ISO16750-2 Test B Parameters

PARAMETER	TYPE OF SYSTEM	
	U_N = 12 V	U_N = 24 V
U_S[a] (V)	79 ≤ U_S ≤ 101	151 ≤ U_S ≤ 202
U_S^* (V)	35	65
R_i (Ω)	0.5 ≤ R_i ≤ 4	1 ≤ R_i ≤ 8
t_d (ms)	40 ≤ t_d ≤ 400	100 ≤ t_d ≤ 350
t_r (ms)	$10\binom{0}{-5}$	

Pulse specification and parameters might vary based on OEM and vehicle configuration.

2.1.5 ISO 16750-2 4.7 Reverse Voltage

This test checks the ability of a control unit to withstand against the connection of a reversed battery when using an auxiliary starting device. During the service or while repairing the car, there is a possible risk of mis wire or wrong connections of system wiring harness to battery. In such case electronic control units needs to have protection for reverse battery voltage.

In automotive systems, the alternator is directly connected to battery without any fuse. Rectifier diodes in the alternator can withstand the reverse voltage for 60 s. If the diodes in alternator are damaged, then there is a scope for damage of wires and possible fire inside the system. Once the fuses or alternator are replaced, the rest of the devices are expected to run with class A. So the control units are expected to withstand the reverse voltage for at least 60 s ± 6 s.

Table 8. ISO16750-2 Reverse Voltage Parameters

NOMINAL VOLTAGE U_N (V)	TEST VOLTAGE U_A (V)
12	14
24	28

Pulse specification and parameters might vary based on OEM and vehicle configuration.

3 Getting Started Hardware

3.1 Undervoltage (V_{IN} < 5 V)

When the battery voltage is less than 5 V, the LM5050-1-Q1 is in undervoltage mode, and the gate voltage of Q1 will follow the source. The body diode of Q1 is in forward conduction, V_{OUT} will follow the V_{IN} voltage with the voltage drop of body diode in Q1. Behavior of the LM5050-1-Q1 is same irrespective of the state of Enable pin.

3.2 Normal Operation (5 V ≤ V_{IN} ≤ 75 V)

Status of the Enable pin will have an impact on the state of the LM5050-1-Q1 in normal operation mode. If the Enable pin is high, the ground pin of the LM5050-1-Q1 is connected to system ground. VFD_D4 and RDS_ON_Q2 will have an impact on offset voltage between the ground of the LM5050-1-Q1 and system ground. T_{OFFSET} voltage is negligible based on the operating voltage of the battery. As the Enable pin is high, Q2 will turn ON, and the LM5050-1-Q1 ground pin is above the system ground with an offset. The VS pin is around 5 V above the ground pin, and the gate pin of the LM5050-1-Q1 will start charging the gate of Q1 with 32 μA through an internal charge pump current source. Select Q1 based on the battery and type of system. Load current and maximum reverse voltage are the key parameters.

If Enable is low, the gate of Q2 is low or less than the turnon gate-to-source threshold voltage of Q2. If Q2 is turned off, the voltage difference between the VS pin to ground of the LM5050-1-Q1 is low. The internal biasing circuit will be in an OFF state, resulting the LM5050-1-Q1 gate pin to follow the source pin due to internal diode. Q1 will be turned OFF due to low or basing voltage. Normally, V_{OUT} will follow the input voltage with the body diode of Q1. So, if the Enable pin is high, there is less voltage drop and power dissipation in Q1. If the Enable pin is low, Q1 will act as simple diode with high power dissipation.

3.3 Reverse Protection

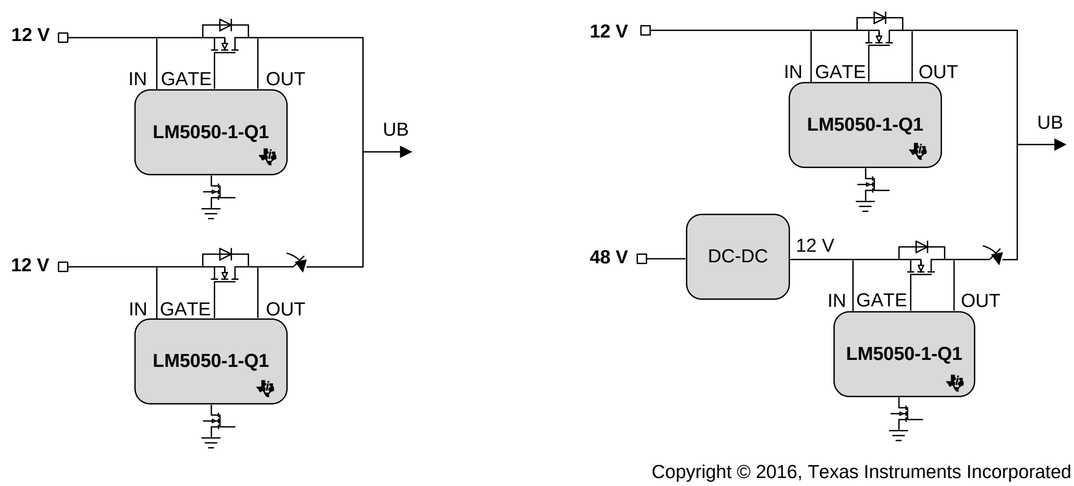


Figure 13. Typical Applications

When the OUT pin voltage is higher than V_{IN} + threshold, then the LM5050-1-Q1 will quickly discharge the gate of Q1 with a strong drive strength, which could be minimum of 1.8 A. Typical reverse threshold voltage to turn OFF Q1 is on average –28 mV. Connections of IN and OUT pins must be short and close to the source and drain pins of Q1.

4 Testing and Results

Test setup for automotive polarity protection has been done as shown in Figure 14.

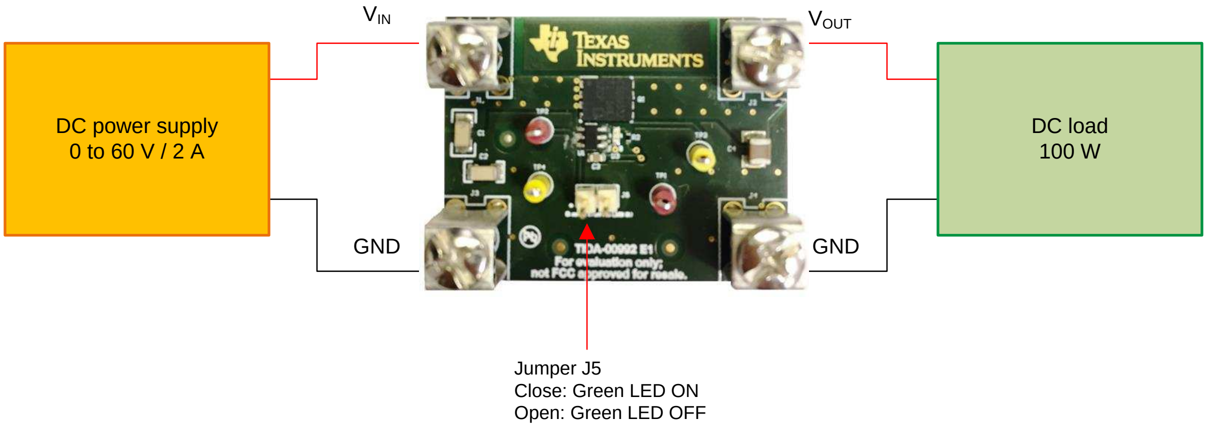


Figure 14. Test Setup

To check the performance of the LM5050-1-Q1, the TIDA-00992 board has been tested until 60-V DC. Thermal performance of the designs are checked with 5 A flowing through Q1. To simulate diode behavior, Jumper J5 has been removed. Figure 7 and Table 4 shows the difference in thermal behavior of the TIDA-00992.

The CSD19532Q5B has been used for Q1.

- R_{DSON_Q1} = 4 mΩ
- Load current = 5 A
- Power dissipation in Q1 = 5 × 5 × 4 m = 0.1 W
- $R_{\theta JA\_Q1}$ = 50°C/W
- $T_J = T_A + R_{\theta JA\_Q1}$ × Power dissipation = T_A + 50°C/W × 0.1 W = T_A + 5°C

As per Figure 15, ambient temperature on the board is around 31°C, whereas temperature of Q1 is around 5°C higher.

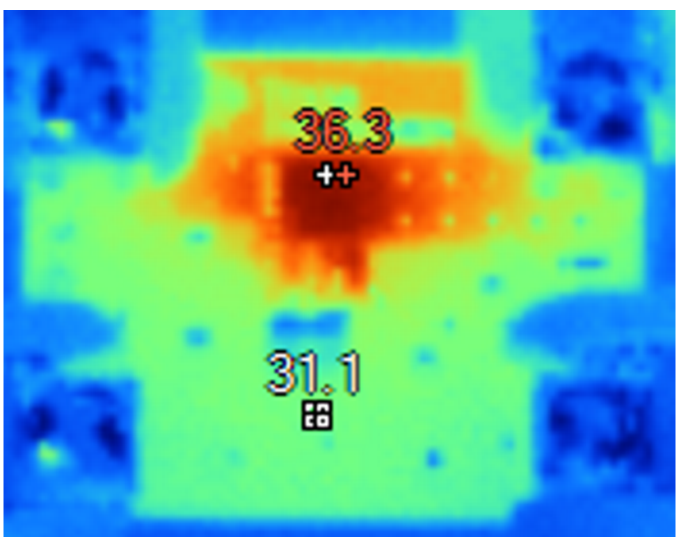


Figure 15. LM5050-1-Q1 at 5-A Load Current

When Q1 is turned OFF, current flows through diode of Q1. Forward voltage drop of the diode is in range of 0.4 V. For the load current of 5 A, power dissipation of the diode will be around 2 W. Power dissipation in the diode is around 20 times higher than the power dissipation in Q1, as is the delta temperature in Q1. As per Figure 16, 138.1°C is observed during the temperature tests with body diode in the TIDA-00992.

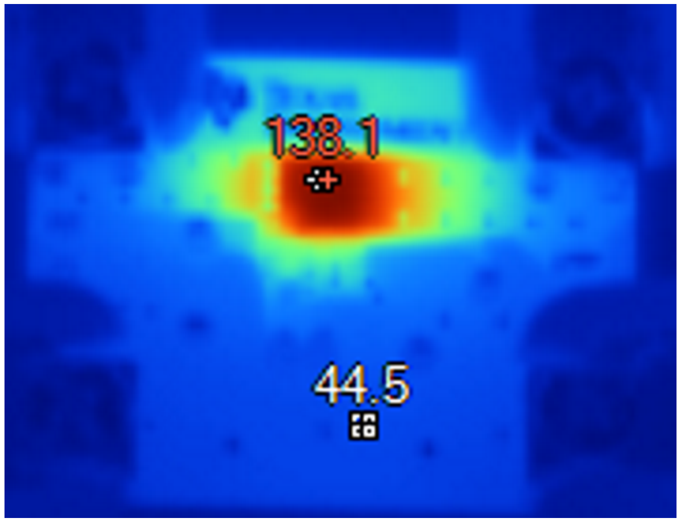
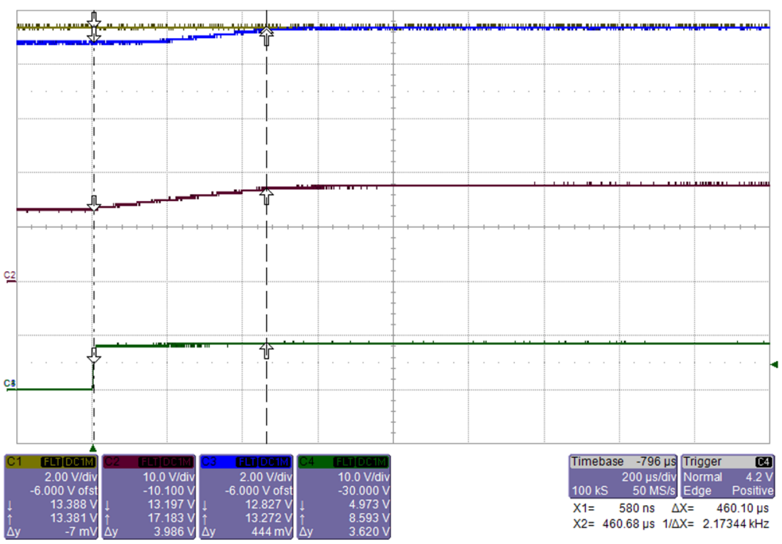


Figure 16. Diode at 5-A Load Current

4.1 Operational Tests



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage
CH3: Gate (TP2)
CH4: Enable (TP4)

Battery input voltage = 12 V
Turnon time: 460 µs

Figure 17. Turnon Behavior

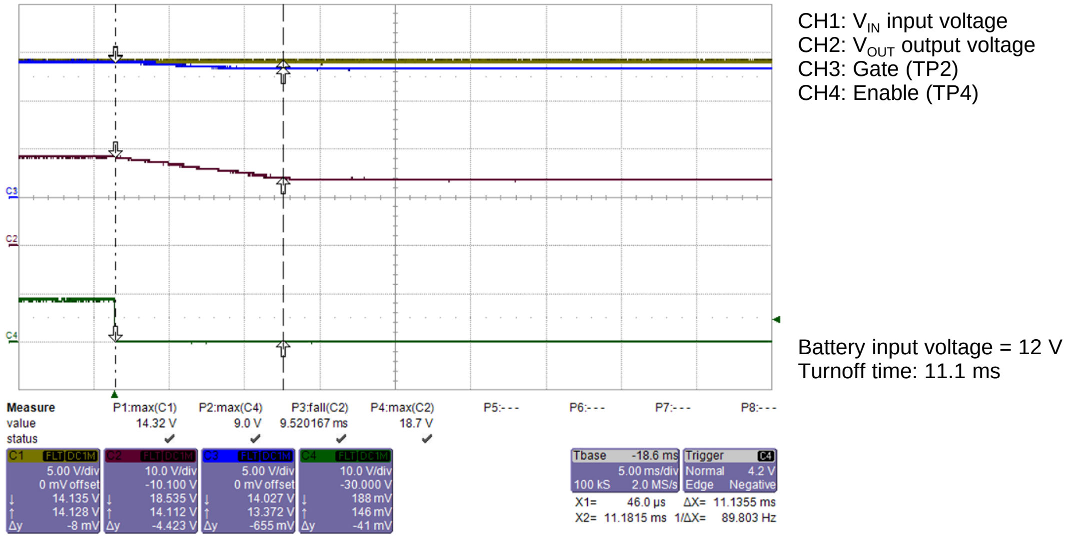


Figure 18. Turnoff Behavior

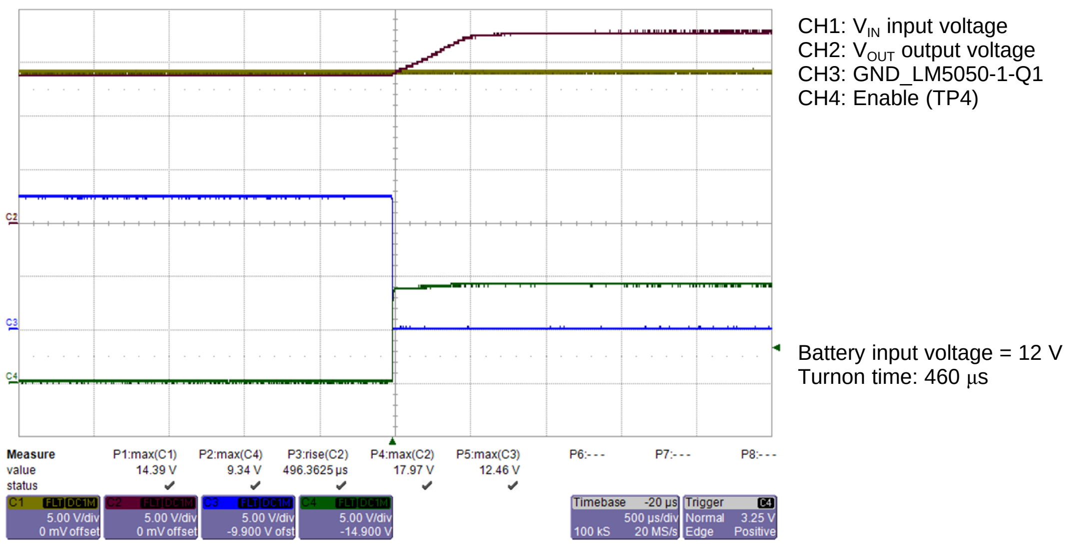
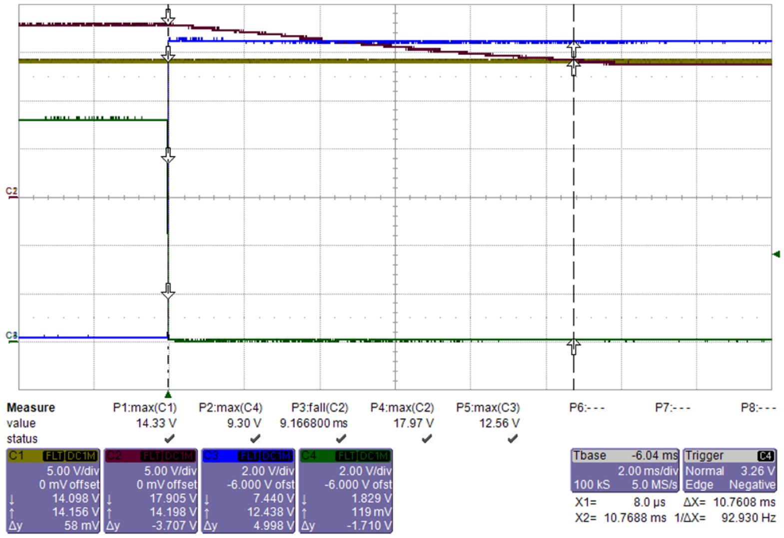


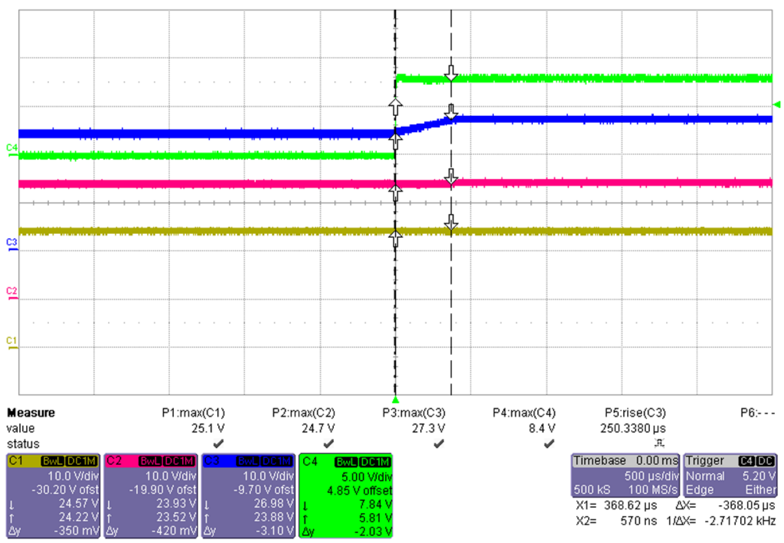
Figure 19. Turnon Behavior With GND



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage
CH3: GND_LM5050-1-Q1
CH4: Enable (TP4)

Battery input voltage = 12 V
Turnoff time: 10.76 ms

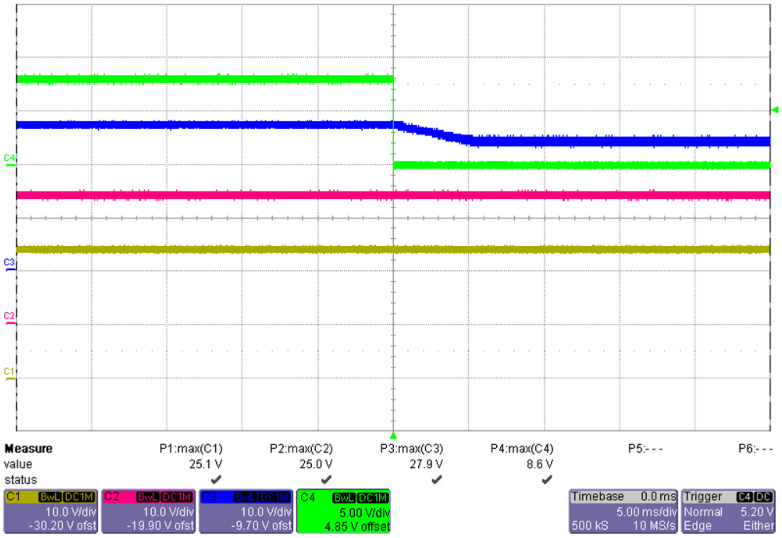
Figure 20. Turnoff Behavior With GND



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage
CH3: Gate (TP2)
CH4: Enable (TP4)

Battery input voltage = 24 V
Turnon time: 368 µs

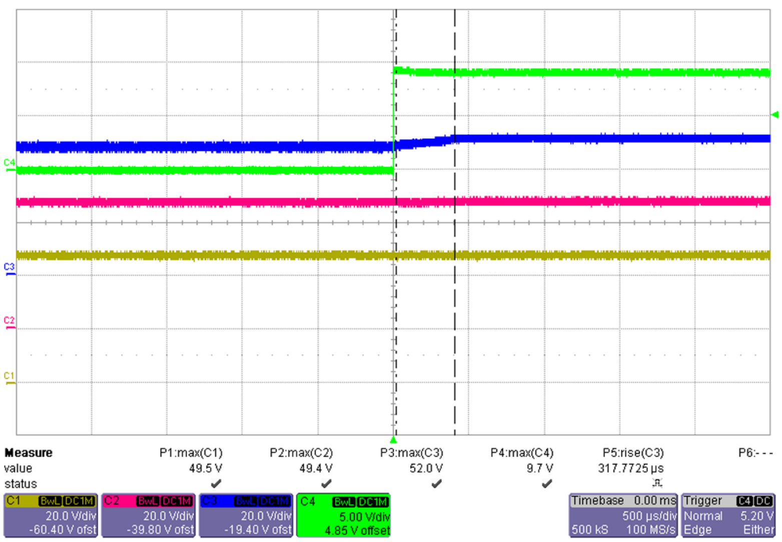
Figure 21. Turnon Behavior at 24 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage
CH3: Gate (TP2)
CH4: Enable (TP4)

Battery input voltage = 24 V
Turnoff time: 5 ms

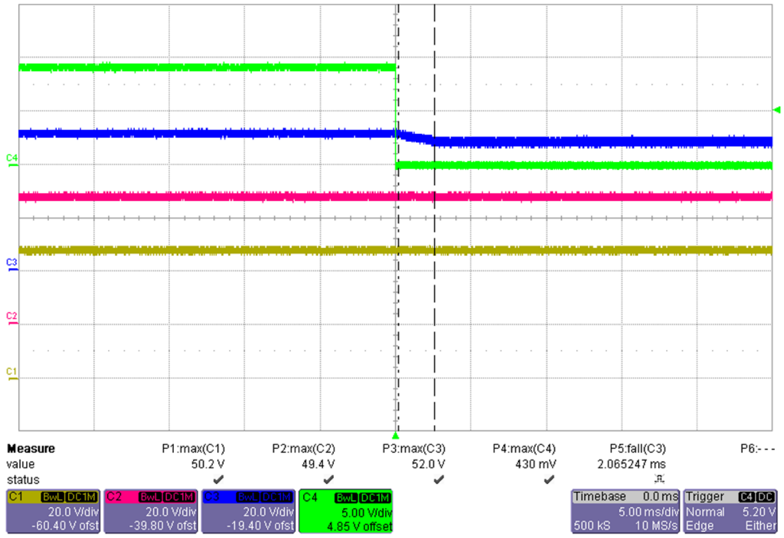
Figure 22. Turnoff Behavior at 24 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage
CH3: Gate (TP2)
CH4: Enable (TP4)

Battery input voltage = 48 V
Turnon time: 317 µs

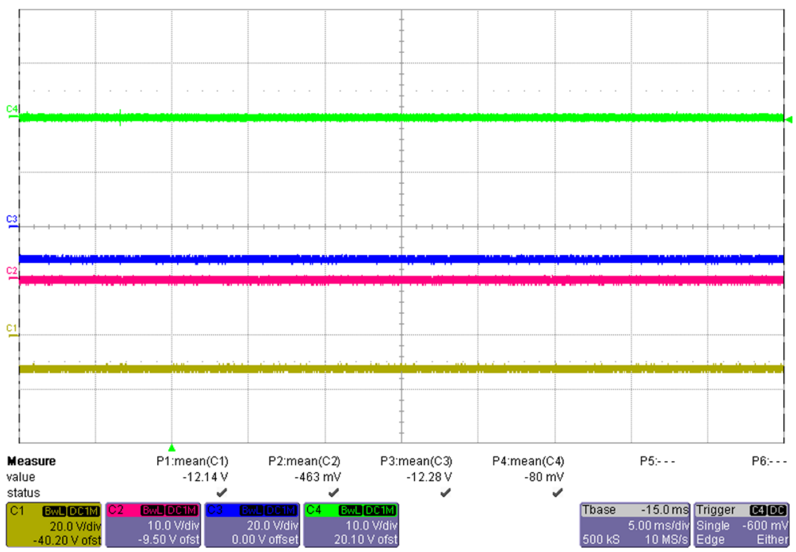
Figure 23. Turnon Behavior at 48 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage
CH3: Gate (TP2)
CH4: Enable (TP4)

Battery input voltage = 48 V
Turnoff time: 2.06 ms

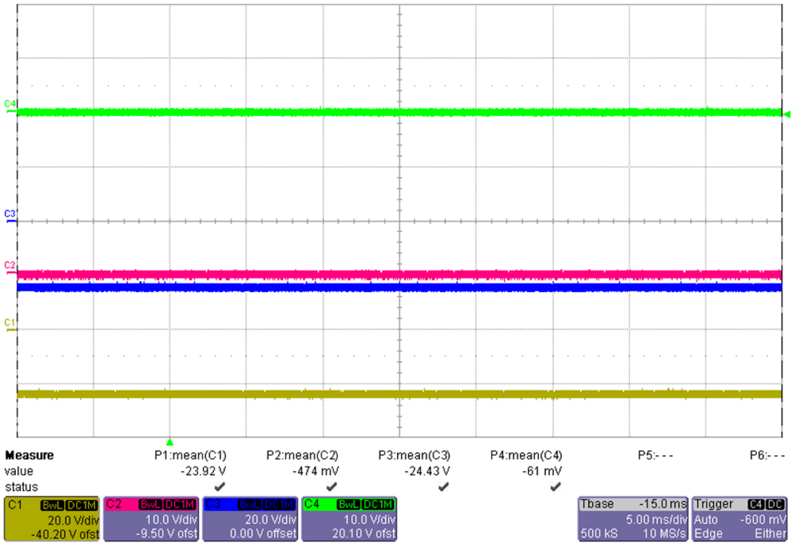
Figure 24. Turnoff Behavior at 48 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage
CH3: Gate (TP2)
CH4: Enable (TP4)
Battery input voltage = 12 V
Reverse polarity

No output voltage and zero output current

Figure 25. Reverse Polarity at 12 V

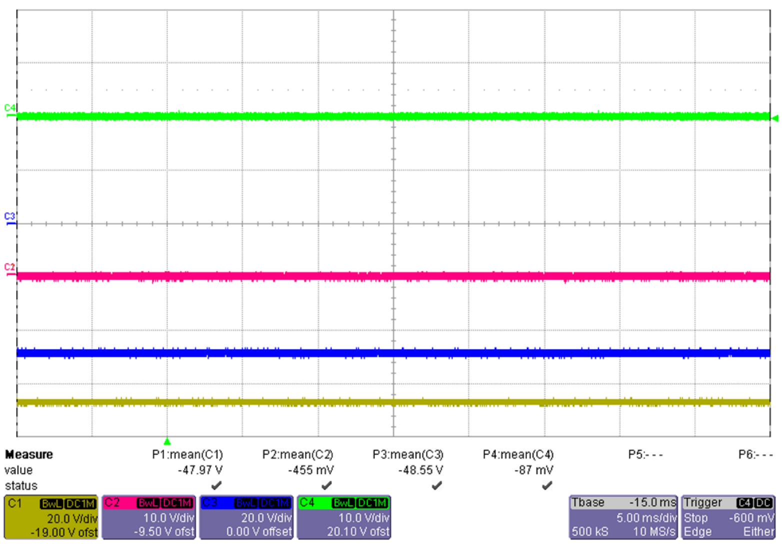


CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage
CH3: Gate (TP2)
CH4: Enable (TP4)

Battery input voltage = 24 V
Reverse polarity

No output voltage and zero output current

Figure 26. Reverse Polarity at 24 V



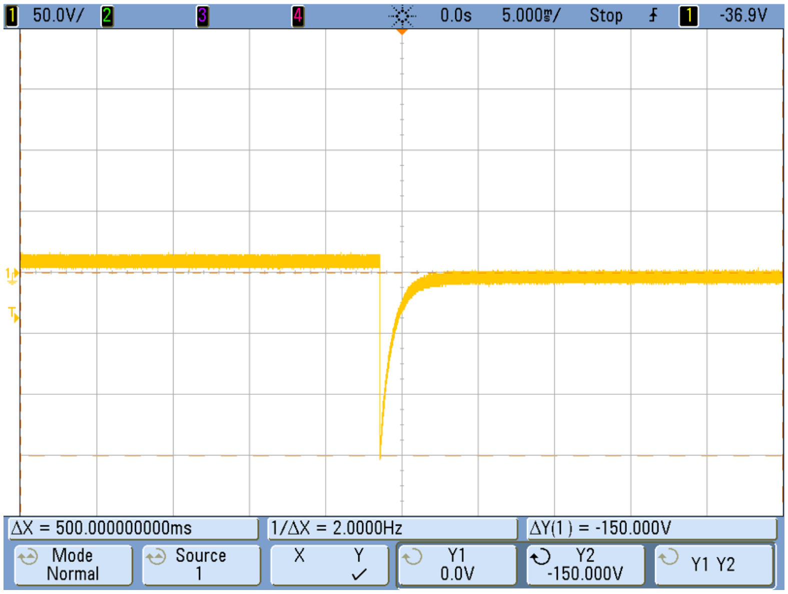
CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage
CH3: Gate (TP2)
CH4: Enable (TP4)

Battery input voltage = 48 V
Reverse polarity

No output voltage and zero output current

Figure 27. Reverse Polarity at 48 V

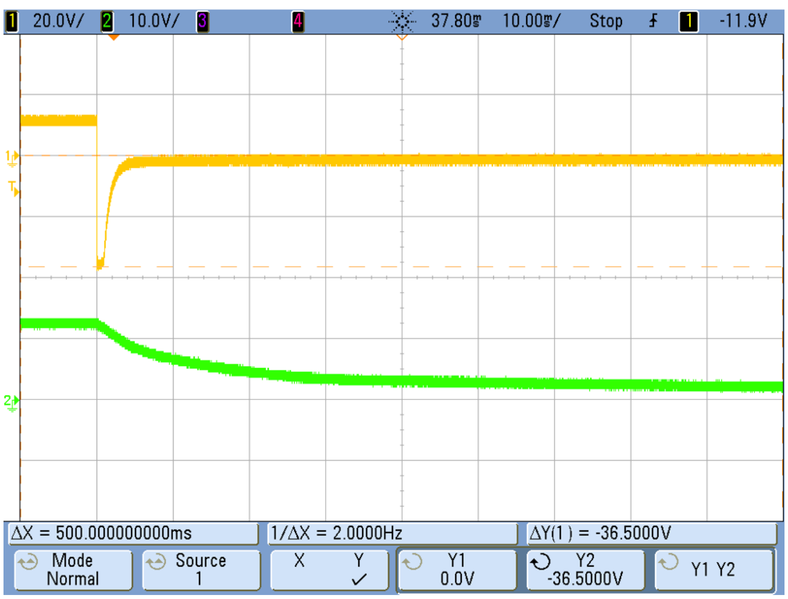
4.2 Transient Tests



CH1: Generator pulse waveform

Battery input voltage = 12 V
ISO 7637-2 Pulse 1.1

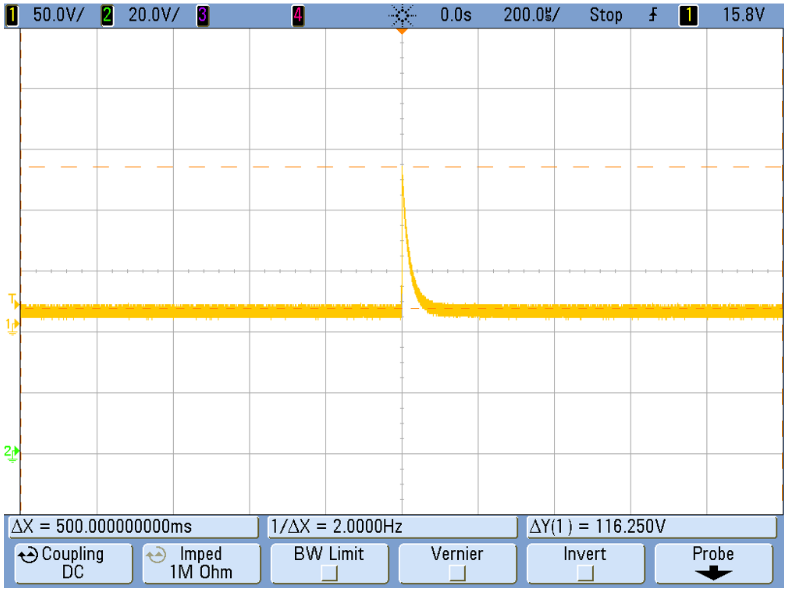
Figure 28. ISO 7637-2 Generator Pulse 1.1 at 12 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage

Battery input voltage = 12 V
ISO 7637-2 Pulse 1.1

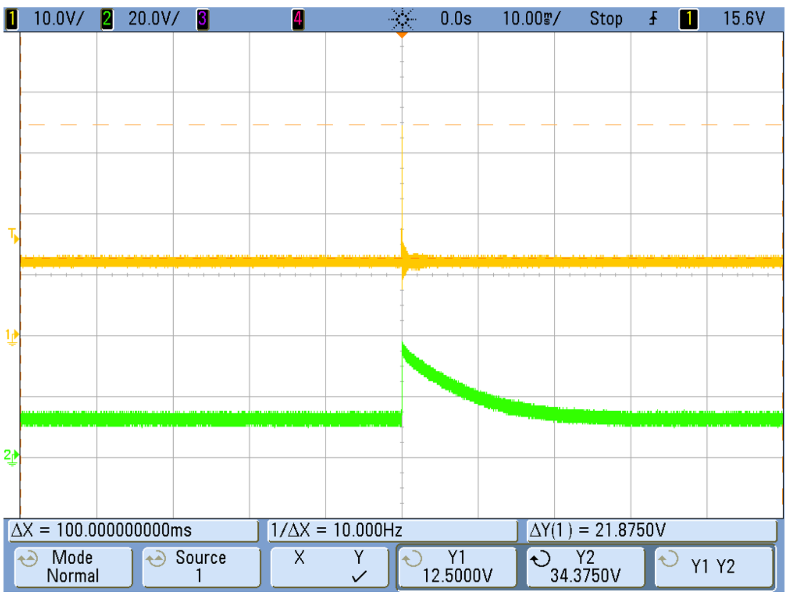
Figure 29. TIDA-00992 Pulse 1.1 at 12-V Behavior



CH1: Generator pulse waveform

Battery input voltage = 12 V
ISO 7637-2 Pulse 2a

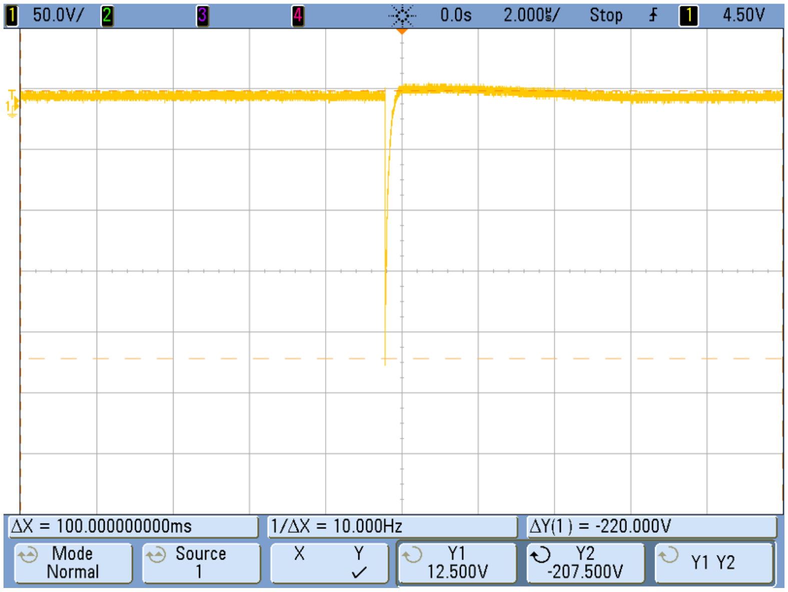
Figure 30. ISO 7637-2 Generator Pulse 2a at 12 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage

Battery input voltage = 12 V
ISO 7637-2 Pulse 2a

Figure 31. TIDA-00992 Pulse 2a at 12-V Behavior



CH1: Generator pulse waveform

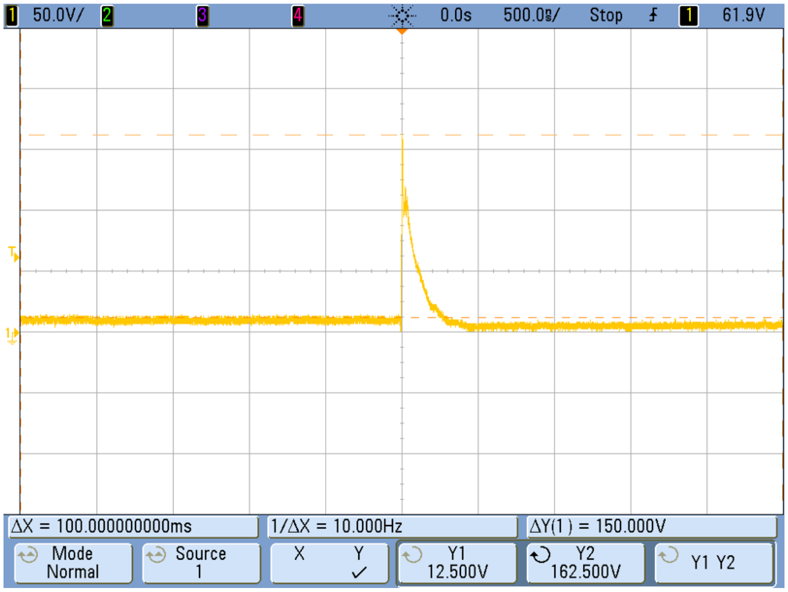
Battery input voltage = 12 V
ISO 7637-2 Pulse 3a

Figure 32. ISO 7637-2 Generator Pulse 3a at 12 V

CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage

Battery input voltage = 12 V
ISO 7637-2 Pulse 3a

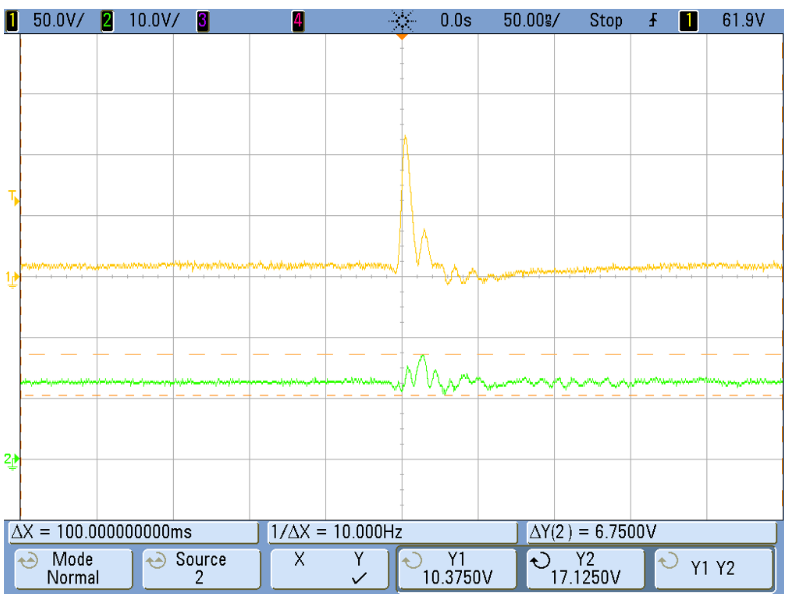
Figure 33. TIDA-00992 Pulse 3a at 12-V Behavior



CH1: Generator pulse waveform

Battery input voltage = 12 V
ISO 7637-2 Pulse 3b

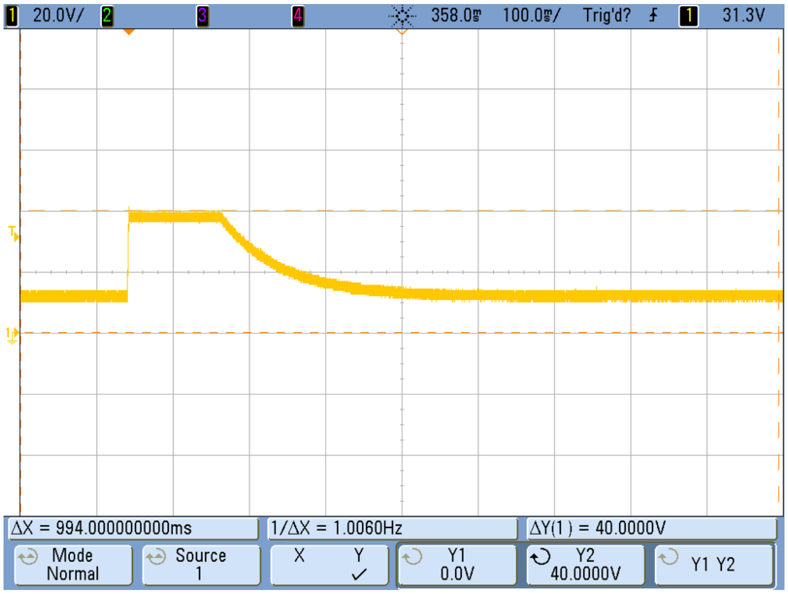
Figure 34. ISO 7637-2 Generator Pulse 3b at 12 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage

Battery input voltage = 12 V
ISO 7637-2 Pulse 3b

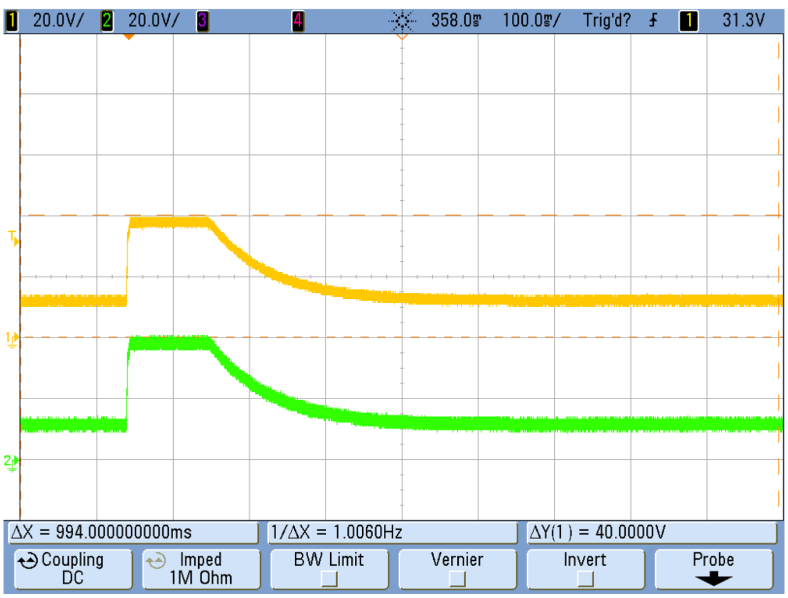
Figure 35. TIDA-00992 Pulse 3b at 12-V Behavior



CH1: Generator pulse waveform

Battery input voltage = 12 V
ISO 16750-2 4.6.4 load dump

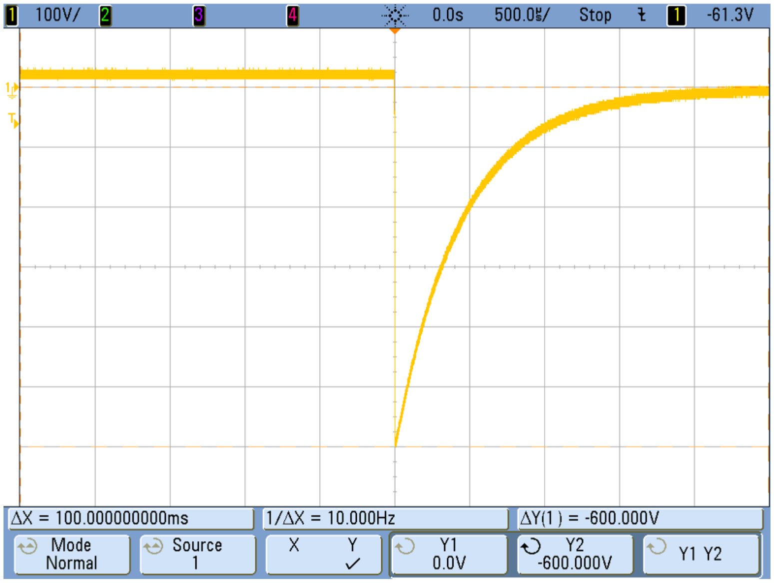
Figure 36. ISO 16750-2 Generator Pulse Load Dump at 12 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage

Battery input voltage = 12 V
ISO 16750-2 4.6.4 load dump

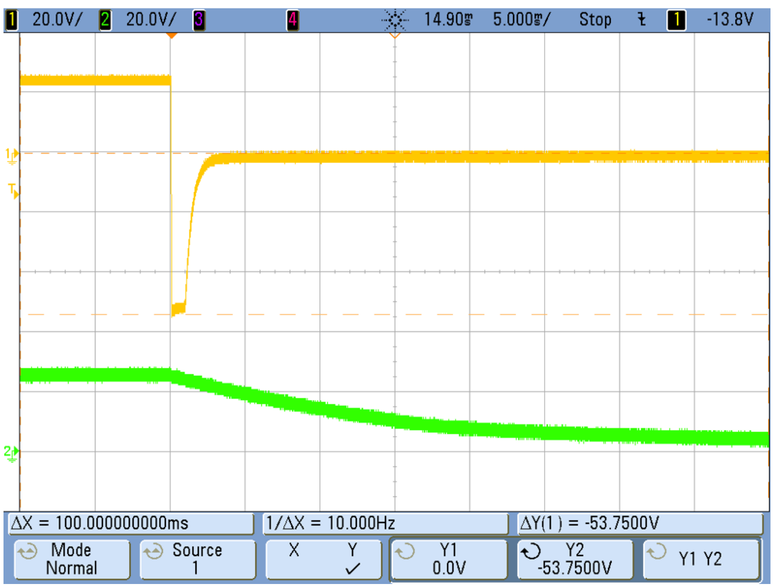
Figure 37. TIDA-00992 Load Dump at 12-V Behavior



CH1: Generator pulse waveform

Battery input voltage = 24 V
ISO 7637-2 Pulse 1.1

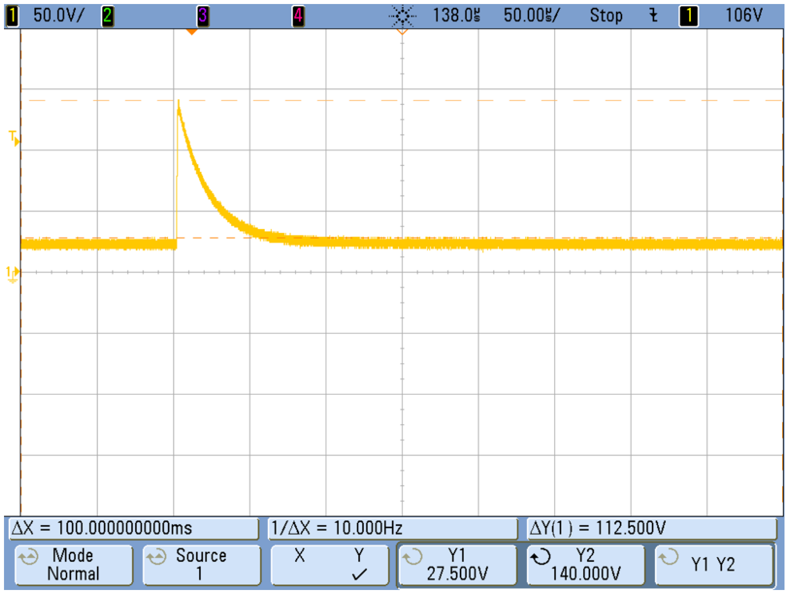
Figure 38. ISO 7637-2 Generator Pulse 1.1 at 24 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage

Battery input voltage = 24 V
ISO 7637-2 Pulse 1.1

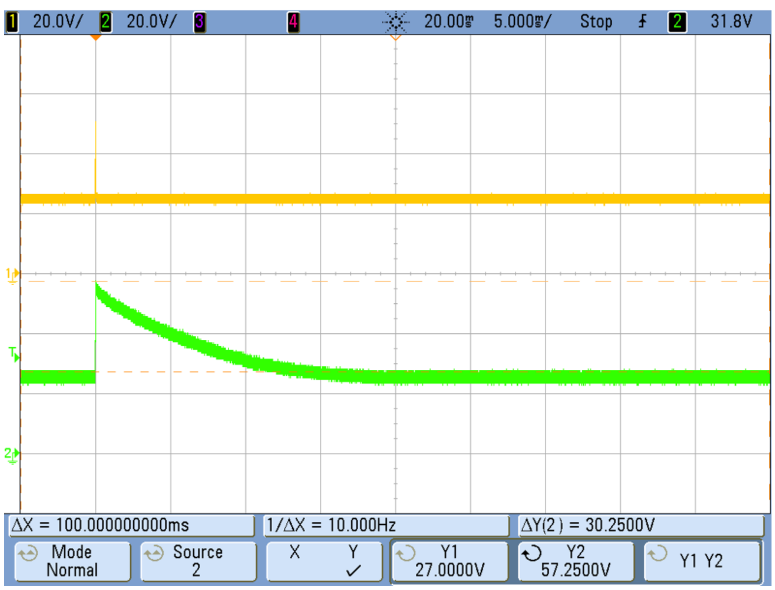
Figure 39. TIDA-00992 Pulse 1.1 at 24-V Behavior



CH1: Generator pulse waveform

Battery input voltage = 24 V
ISO 7637-2 Pulse 2a

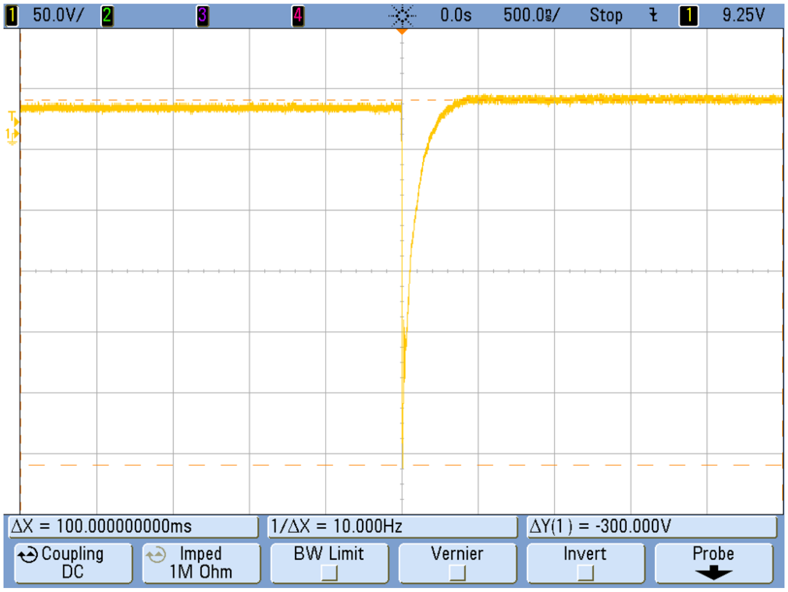
Figure 40. ISO 7637-2 Generator Pulse 2a at 24 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage

Battery input voltage = 24 V
ISO 7637-2 Pulse 2a

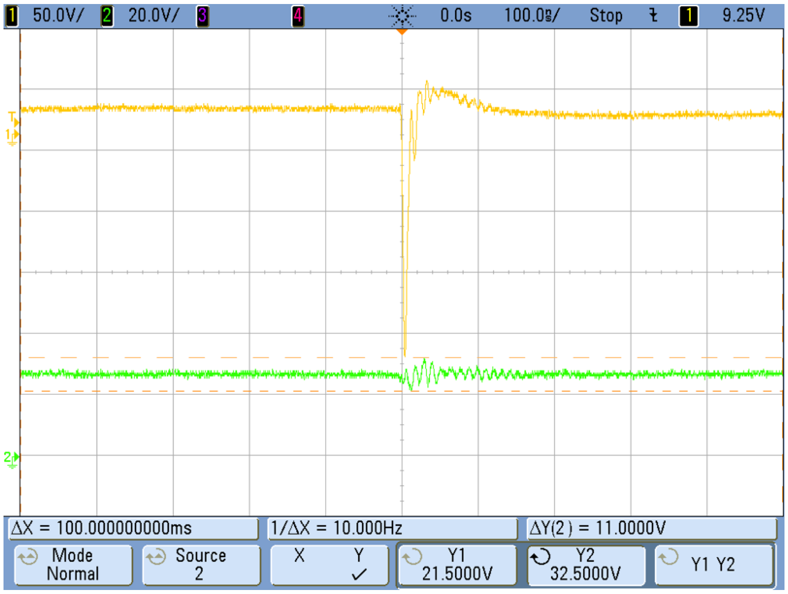
Figure 41. TIDA-00992 Pulse 2a at 24-V Behavior



CH1: Generator pulse waveform

Battery input voltage = 24 V
ISO 7637-2 Pulse 3a

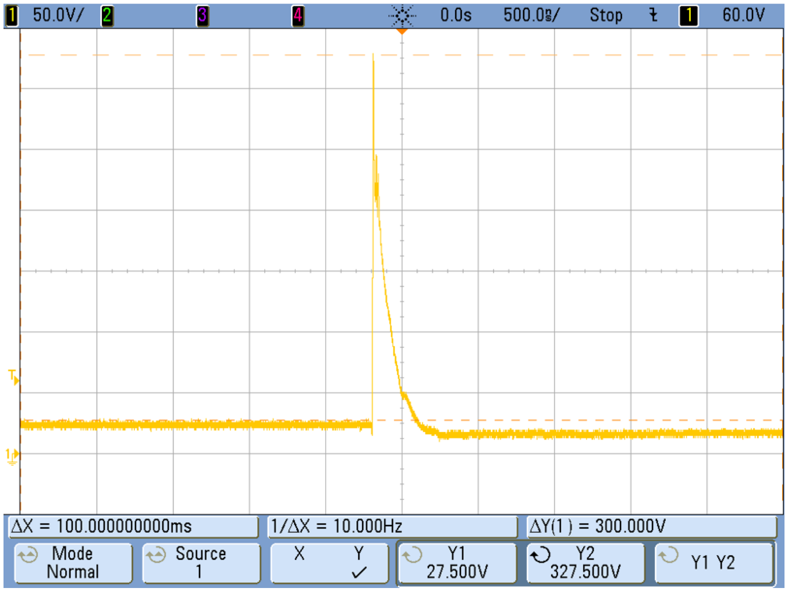
Figure 42. ISO 7637-2 Generator Pulse 3a at 24 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage

Battery input voltage = 24 V
ISO 7637-2 Pulse 3a

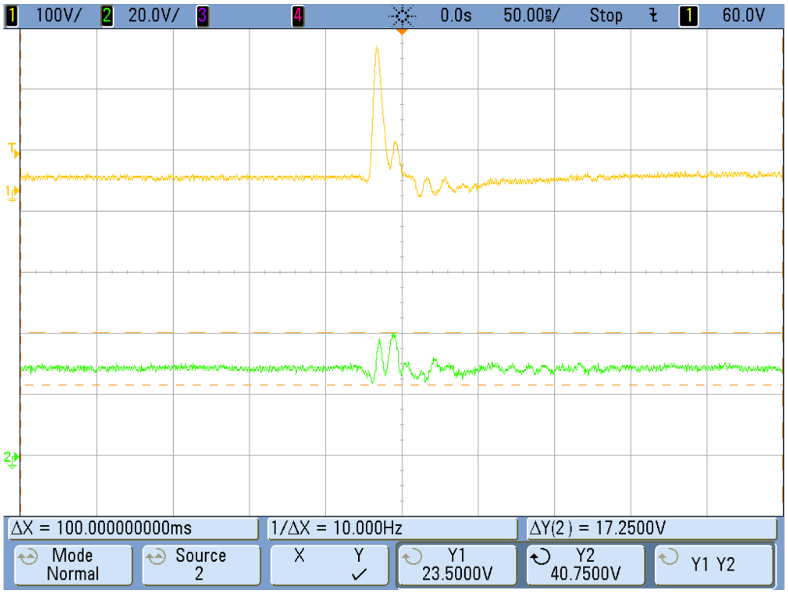
Figure 43. TIDA-00992 Pulse 3a at 24-V Behavior



CH1: Generator pulse waveform

Battery input voltage = 24 V
ISO 7637-2 Pulse 3b

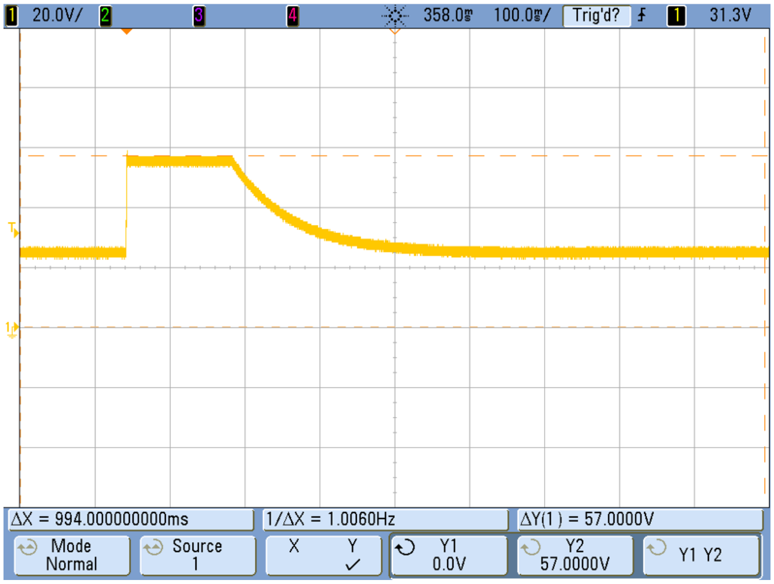
Figure 44. ISO 7637-2 Generator Pulse 3b at 24 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage

Battery input voltage = 24 V
ISO 7637-2 Pulse 3b

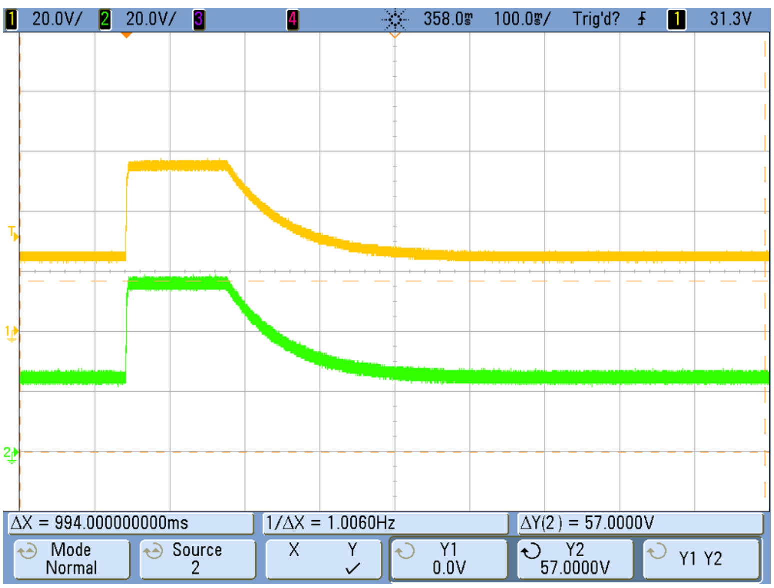
Figure 45. TIDA-00992 Pulse 3b at 24-V Behavior



CH1: Generator pulse waveform

Battery input voltage = 24 V
ISO 16750-2 4.6.4 load dump

Figure 46. ISO 16750-2 Generator Pulse Load Dump at 24 V



CH1: V_{IN} input voltage
CH2: V_{OUT} output voltage

Battery input voltage = 24 V
ISO 16750-2 4.6.4 load dump

Figure 47. TIDA-00992 Load Dump at 24-V Behavior

5 Design Files

5.1 Schematics

To download the schematics, see the design files at TIDA-00992.

5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00992.

5.3 PCB Layout Recommendations

PCB layout has to be done with appropriate measures to ensure the smooth operation of functionality of LM5050-1-Q1 and support reverse polarity protection

1. Check the Q1 for power dissipation, and set the layer thickness and area appropriately.
2. Place vias appropriately to share the current on both sides of PCB.
3. Place minimum length tracks for voltage sense pins of IN and OUT(4 and 6 of LM5050-1-Q1) to drain and source pins of Q1.

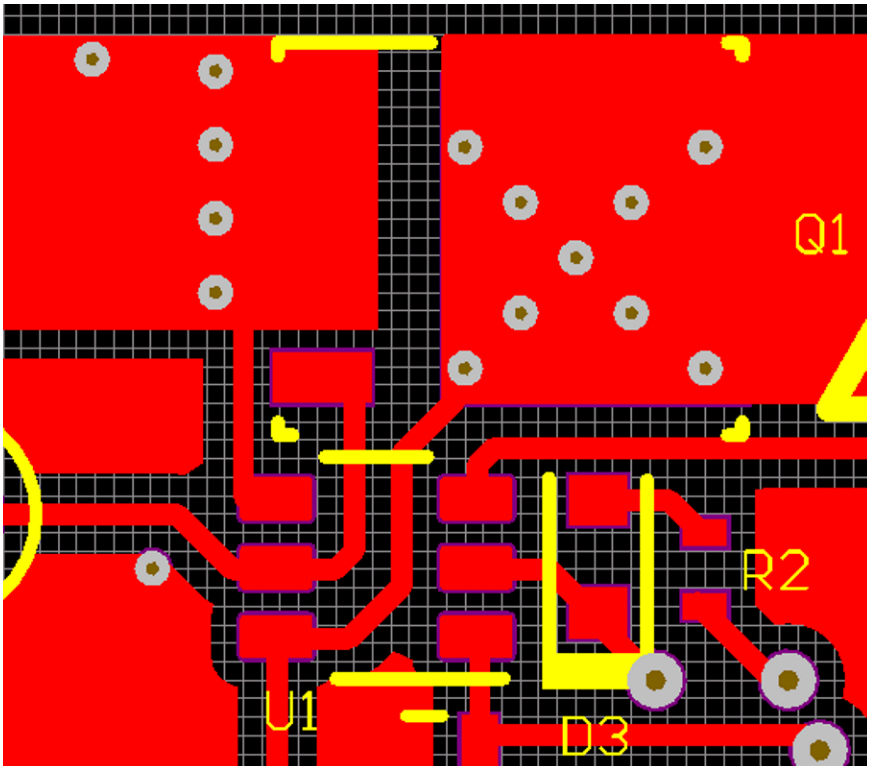


Figure 48. LM5050-1-Q1 Layout

4. Place Q2 and D4 in a short length to GND pin of the LM5050-1-Q1.

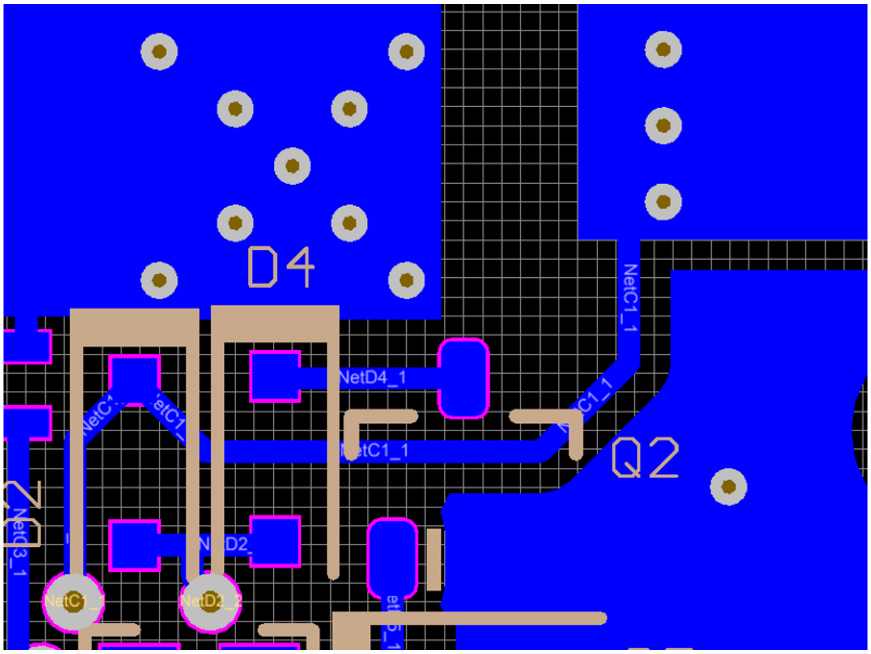


Figure 49. Ground Switch LM5050-1-Q1

5. Place D1, C1, and C2 very near to connector pins.

5.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-00992.

5.4 Gerber Files

To download the Gerber files, see the design files at TIDA-00992.

5.5 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00992.

6 Related Documentation

1. Texas Instruments, *AN-2087 LM5050-1EVAL Evaluation Board*, LM5050-1 User's Guide (SNVA458)

6.1 Trademarks

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7 About the Author

RAMA KAMBHAM (Rama Chandra Reddy) is an automotive system engineer working in Texas Instruments Deutschland. Rama brings to this role his extensive experience in Battery Management Systems and Engine Management Systems in the automotive domain. Rama earned his bachelor of engineering degree from Osmania University Hyderabad, India.

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