

TI Designs: TIDA-01600

サーボ・ドライブおよびロボティクス用のスマート・ブレーキ制御および診断のリファレンス・デザイン

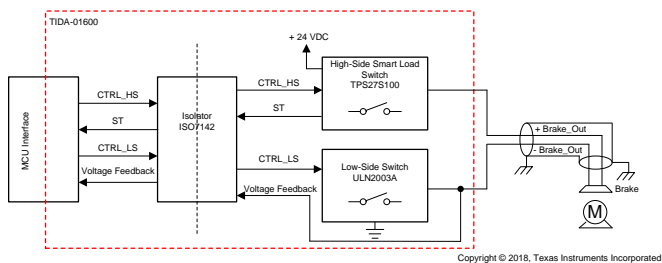
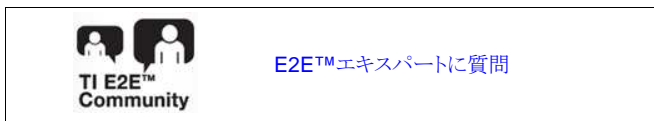


概要

このリファレンス・デザインは、外部の保持ブレーキを制御するために2チャンネルの出力信号を供給し、IEC EN 61800-5-2に従って、サーボ・ドライブに安全なブレーキ制御機能を実装します。保持ブレーキは、電源がオフになったときはラッチされ、コイルに電圧が印加されると解放されます。このセットアップは、コイルに電力を供給するスマート電子負荷スイッチのイネーブルとディスエーブルによって実現されます。また、このリファレンス・デザインには各種のフォルトを検出する診断機能も含まれており、安全な動作を保証し、保持ブレーキ出力の電圧を下げて消費電力を低減できます。このデザインは、C2000™ LaunchPad™を使用してブレーキ制御信号を生成し、診断機能を実行します。

リソース

- TIDA-01600 デザイン・フォルダ
- ISO7142CC プロダクト・フォルダ
- TPS27S100 プロダクト・フォルダ
- ULN2003A プロダクト・フォルダ
- LMZ14201 プロダクト・フォルダ
- TPS7B69-Q1 プロダクト・フォルダ
- TVS3300 プロダクト・フォルダ



特長

- EN 61800-5-2に規定されている要件を満たす、安全なブレーキ制御を実装
- 24V定格、最大2Aの電流の保持ブレーキを、絶縁制御信号により制御
- デュアル・スイッチ制御により安全な動作を強化
- 自己診断機能に開放負荷検出と過電流保護を含む
- ハイサイド・スイッチの障害検出
- 保持ブレーキ電流の高速な減少により、保持ブレーキを迅速に適用
- オプションとして、保持ブレーキ出力の電圧低減により消費電力を削減可能

アプリケーション

- サーボ・ドライブ、ロボティクス、CNC
- 保持ブレーキ・コントローラ






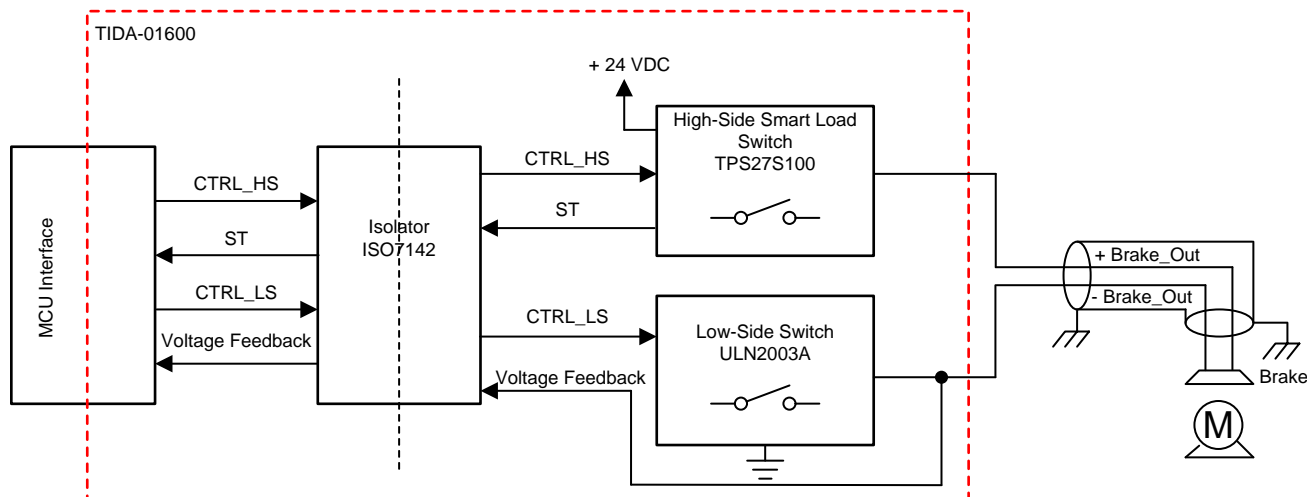
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1 System Description

Variable speed drives are used in a wide range of applications, including robotics and computer numeric control (CNC) machines. Safety is a constant concern because holding and motion controls are always present in these systems involving humans. The recent development of drives with built-in safety-related features eliminates the conventional methods of using standstill and speed monitors, limit switches, position cameras, contactors, and so on, which highly improves the reliability of the system. There is an enormous amount of danger in automated production, particularly from gravitational forces in the case of vertical movements, if a power failure occurs or a braking device fails. The "safe brake control" (SBC) function enables brakes to be controlled safely, thereby preventing suspended loads from falling. In CNC machines, SBC prevents movement of work due to external force.

SBC comes under the standard EN 61800-5-2: 2007 functional safety for speed variable drives. SBC supplies a safe output signal to drive an external mechanical brake. The brakes used must be *safety brakes*, in which a quiescent current operates against a spring. If the current flow is interrupted, the brake engages. Control modules frequently include a power reduction feature when the brake is released to reduce energy consumption or brake heating. Holding brakes and service brakes are often used on axes with suspended loads. The SBC function is generally used to control the holding brake and is activated once an axis is at standstill.

This reference design implements the SBC function for holding brakes rated up to the current rating of 2 A. This design uses the TPS27S100 as a high-side smart switch and the ULN2003A as a low-side switch. Dual switch control is implemented to ensure safe brake operation. The brake control signals are isolated from the controller through the digital isolator ISO7142. The TPS27S100 enables the design to detect open circuit and short circuit conditions at the brake output, enhancing safety of the system. Output voltage from the brake coil is reduced through the PWM on the low-side switch, reduces power consumption while the brake is energized. The load switch eliminates the discrete elements, which improves system reliability.  1 shows the block diagram of this reference design.



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図 1. Block Diagram of TIDA-01600

1.1 Key System Specifications

表 1 shows the key system specifications for this reference design.

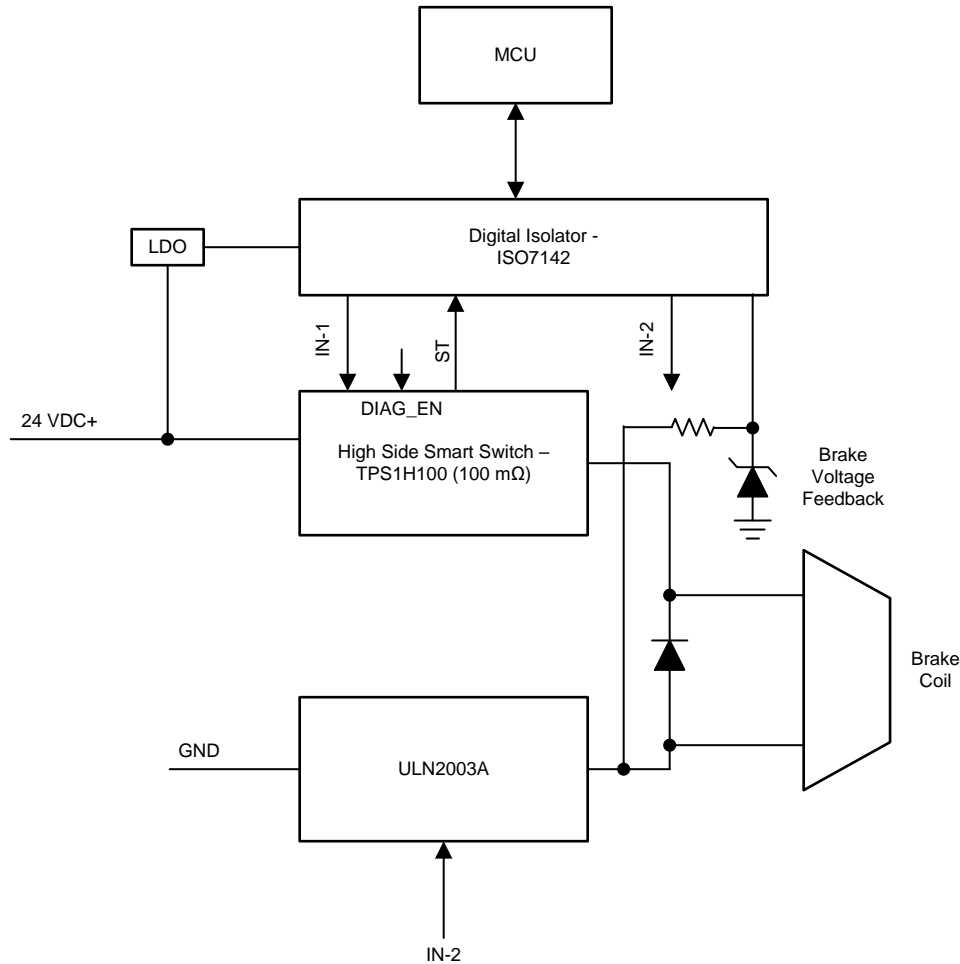
表 1. Key System Specifications

PARAMETER	SPECIFICATIONS
Nominal input voltage	+24 V (+15%)
Output voltage without voltage reduction	Input – 1 V (nominal)
Output voltage with voltage reduction	0 V to 23 V
Brake current	Up to 2 A
Switching frequency	10 kHz
Hardware redundancy	1
Protection features	Open load detection
	Overcurrent protection
	False brake activation detection
Release time	< 100 ms
Applying time	< 200 ms
Time to voltage reduction	Programmable through MCU (up to 1 s)

2 System Overview

2.1 Block Diagram

Figure 2 shows the system level block diagram for this reference design.



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Figure 2. System Level Block Diagram of TIDA-01600

This design provides a reference solution for implementing SBC in servo drives. The SBC function provides safe output signals to control the external brake. Holding brakes with a current rating of up to 2 A can be controlled. The main parts of the design include the ISO7142 digital isolator, the high-side smart switch TPS27S100, and the low-side switch ULN2003A. The brake coil is connected between the two switches. The switches are enabled and disabled by the digital input signal generated by the microcontroller (MCU) through the digital isolator.

The board is powered by two external 24-V power supplies. The MCU and VCC1 of the digital isolator are powered using the 3.3 V generated from a 24-V supply using the LMZ14201 SIMPLE SWITCHER®. The high-side switch and VCC2 of the digital isolator are powered using the 3.3 V generated from a 24-V supply using the TPS7B6933 LDO.

The system is designed to be protected against overload, short-circuit, and overtemperature and also detects when there is an open load. The status output pin of the TPS27S100 generates a fault signal that corresponds to the open load detection and short-circuit and overtemperature protection, when it is accounted. This fault signal is fed to the MCU through the isolator. Voltage feedback from the brake coil is taken to monitor the unintentional turnon and also to adjust the voltage from the brake coil. Optional PWM operation can be implemented to the ULN2003A low-side switch to control the peak and hold currents of the brake coil.

2.2 Highlighted Products

2.2.1 ISO7142

The ISO7142CC provides galvanic isolation up to 2500- V_{RMS} for 1 minute per UL and 4242-VPK per VDE. The ISO7142CC is a quad-channel isolator with two forward- and two reverse-direction channels. This device is capable of a maximum data rate of 50 Mbps with 5-V supplies and 40 Mbps with 3.3-V or 2.7-V supplies. The ISO7142CC has integrated filters on the inputs to support noise-prone applications. [Figure 3](#) shows the pin diagram of the device.

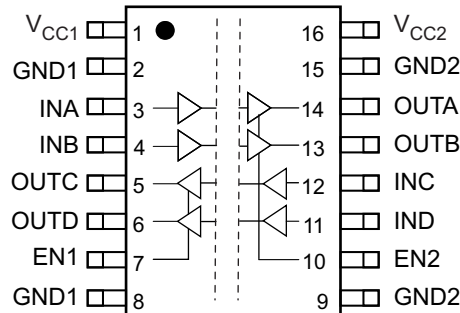

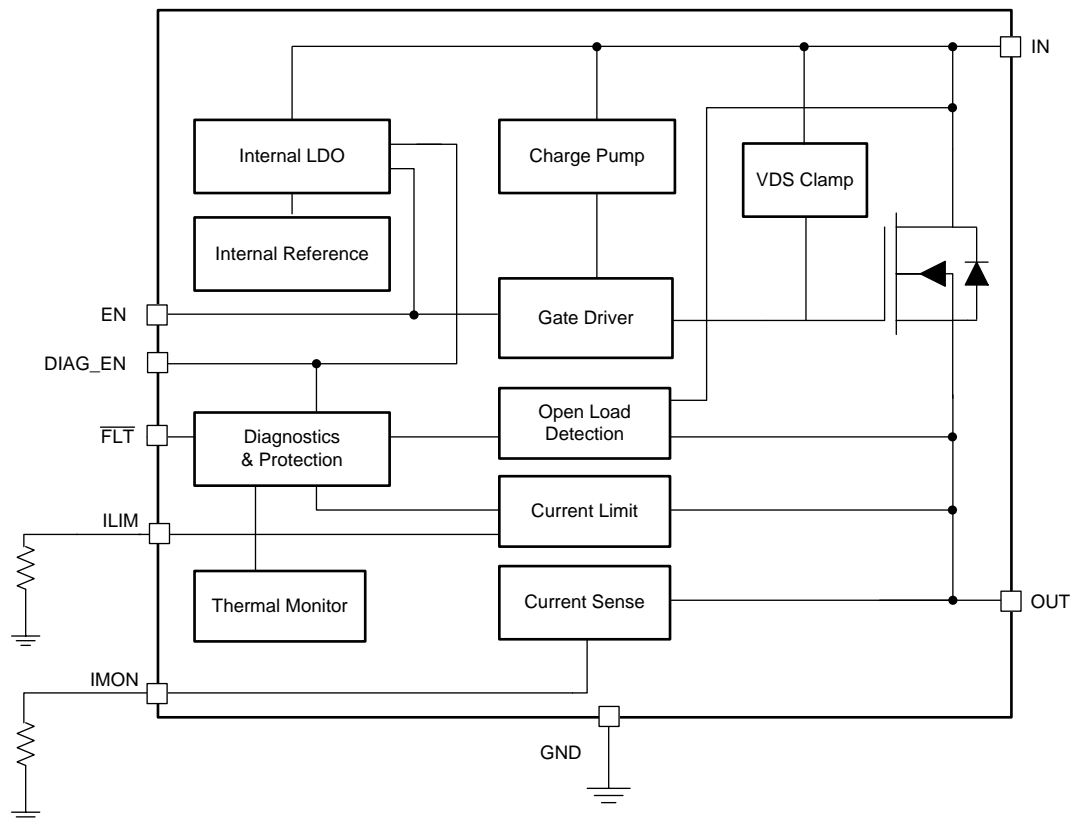


Figure 3. Pin Diagram of ISO7142

2.2.2 TPS27S100

The TPS27S100 is a single-channel, fully-protected, high-side switch with an integrated NMOS and charge pump. Full diagnostics and high-accuracy current-monitor features enable intelligent control of the load. An adjustable current-limit function greatly improves the reliability of the whole system. The device diagnostic reporting has two versions to support both digital fault status and analog current monitor output. Accurate current monitor and adjustable current limit features differentiate it from the market.  4 shows the functional block diagram of the TPS27S100.



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 4. Functional Block Diagram of TPS27S100

2.2.3 ULN2003A

The ULN2003A device is a high-voltage, high-current Darlington transistor array. This device has seven NPN Darlington pairs that feature high-voltage outputs with common-cathode clamp diodes for switching inductive loads. The collector-current rating of a single Darlington pair is 500 mA. The Darlington pairs can be paralleled for higher current capability. The ULN2003A device has a 2.7-k Ω series base resistor for each Darlington pair to operate directly with TTL or 5-V CMOS devices. [Figure 5](#) shows the block diagram of the ULN2003A.

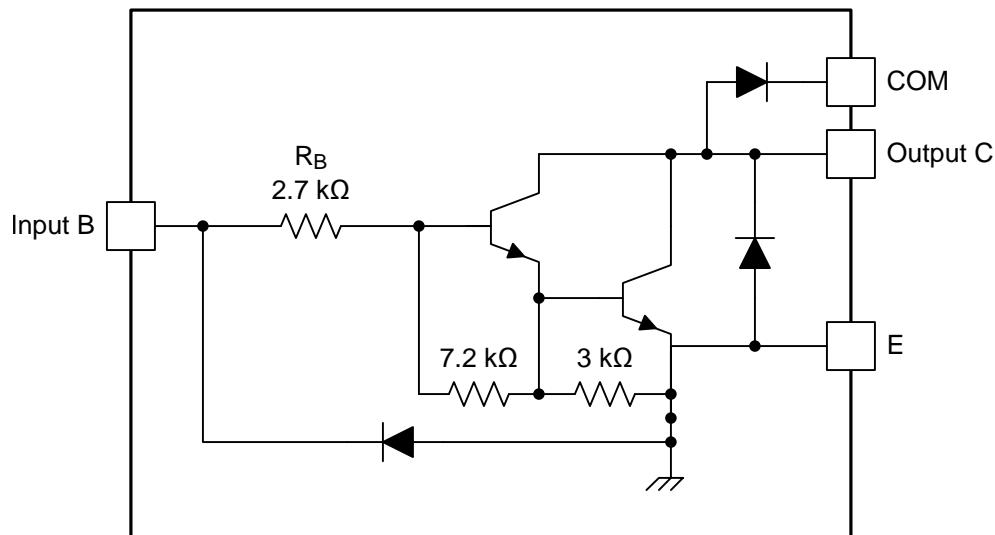


図 5. Block Diagram of ULN2003A

2.2.4 LMZ14201

The LMZ14201 SIMPLE SWITCHER power module is an easy-to-use, step-down, DC/DC solution that can drive up to a 1-A load with exceptional power conversion efficiency, line and load regulation, and output accuracy. The LMZ14201 can accept an input voltage rail between 6 V and 42 V and deliver an adjustable and highly accurate output voltage as low as 0.8 V.

2.2.5 TPS7B6933

The TPS7B6933-Q1 high-voltage linear regulator operates over a 4-V to 40-V input voltage range. The device has an output current capability of 150 mA and offers fixed output voltage of 3.3 V. The device features a thermal shutdown and short-circuit protection to prevent damage during overtemperature and overcurrent conditions.

2.2.6 TVS3300

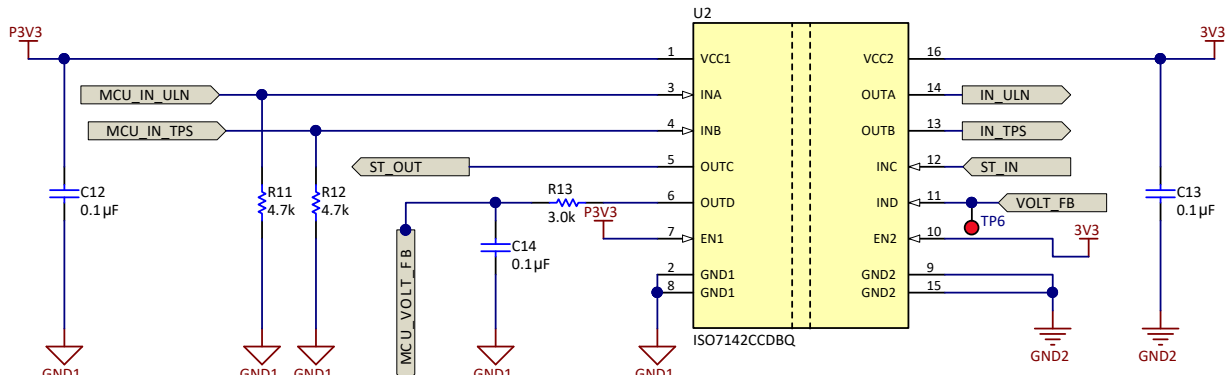
The TVS3300 is a unidirectional precision surge protection clamp with a 33-V working voltage designed specifically to protect systems with mid-voltage rails in industrial, communication, and factory automation applications. The TVS3300 has a fast response time when surge current is applied so there is no overshoot voltage during clamping, making it ideal to replace traditional TVS and Zener diodes.

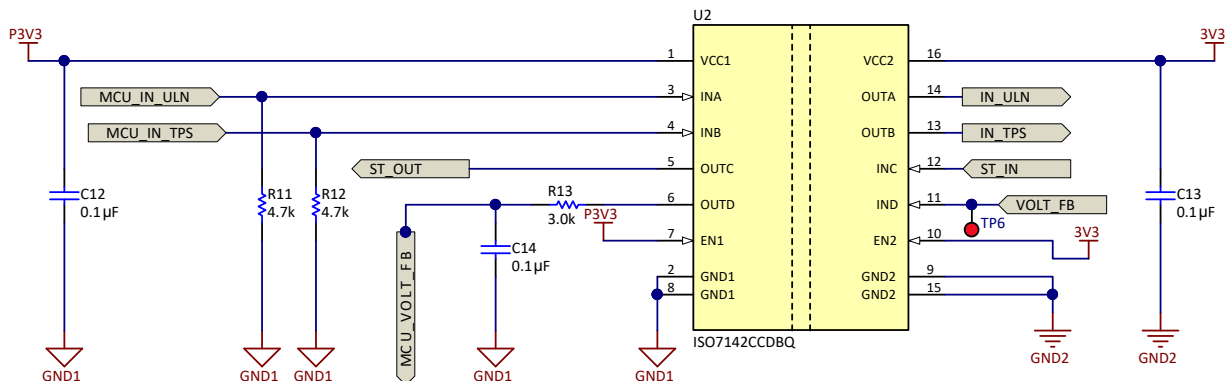
2.3 System Design Theory

2.3.1 DC Voltage Input

This reference design is designed to operate for a DC voltage of 24 V (+15 %). The board has two separate connectors to supply 24 V to the primary and secondary sides. J1 is the input connector for supplying the 24-V DC to the primary side. The DC voltage can be applied to the reference design at connector J2. The TVS3300 is a 33-V precision clamp that is connected in a bidirectional configuration for protection against high-voltage transients. Inductor L1 and capacitor C8 form the power filter.

2.3.2 Low-Power, Quad-Channel Digital Isolator

The MCU sends the control signals through the ISO7142 digital isolator to drive the high-side and the low-side switches independently. Also, the Status pin output from the high-side switch, which gives the diagnostic coverage against fault conditions, and the voltage feedback from the brake coil is fed back to the MCU through the digital isolator.  shows the circuit for the ISO7142.



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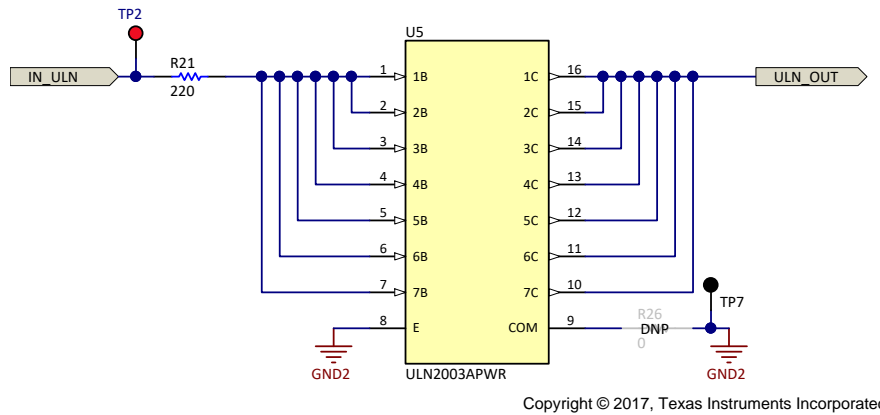
 6. Schematic of Digital Isolator ISO7142 and Circuit

The VCC1 pin is supplied with 3.3 V generated using the LMZ14201 SIMPLE SWITCHER (as explained in 2.2.4). C12 (0.1 µF) is used as a local decoupling capacitor for the VCC1 pin. The EN1 pin of the isolator is tied high to enable the output channels in the primary side.

The VCC2 pin is supplied with 3.3 V generated using the TPS7B6933 LDO (as explained in 2.2.5). C13 (0.1 µF) is used as a local decoupling capacitor for the VCC2 pin. The EN2 pin of the isolator is tied high to enable the output channels in the secondary side.

2.3.4 Low-Side Switch

This reference design uses the ULN2003A as a low-side switch that is a high-current Darlington transistor arrays. 8 shows the circuit for the low-side switch.

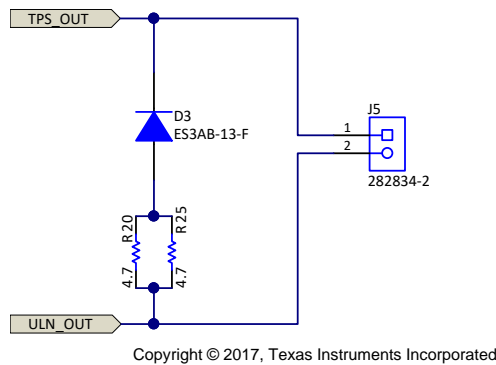


8. Schematic of Low-Side Switch ULN2003A Circuit

The ULN2003A consists of seven Darlington pairs each having a current rating of 500 mA. All the pairs are paralleled for higher current capability. The input signal for activating the switch is given from the MCU. The output of the switch is given to another terminal of the brake coil through connector J5.

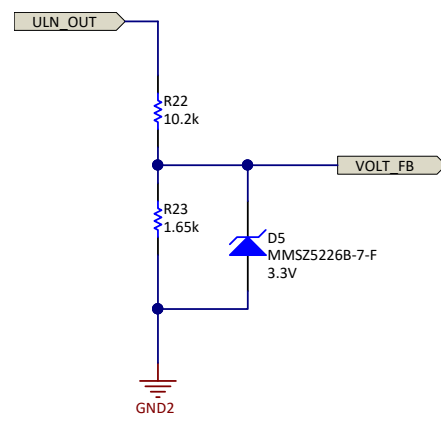
2.3.5 Snubber Circuit

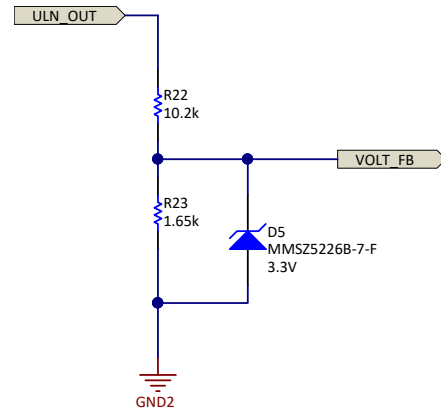
9 shows the snubber circuit connected across the brake coil. When the switch is opened, the coil's inductance responds to the decrease in current by inducing a voltage of reverse polarity, which damages the switch. Resistors R20 and R25 are placed in series with the commutating diode D3 connected in parallel to the brake coil to demagnetize the brake coil faster, thus protecting the switch from a high reverse voltage transient.



9. Schematic of Snubber Circuit

2.3.6 Voltage Feedback From Brake Coil

Voltage feedback from the brake coil is taken from the low-side switch and fed to the MCU through the digital isolator. This feedback is done to monitor the output voltage and adjust the input PWM signal to the low-side switch accordingly. A resistor divider is used to step down the voltage from 24 V to 3.3 V to feed it to MCU.  shows the circuit for brake voltage feedback.

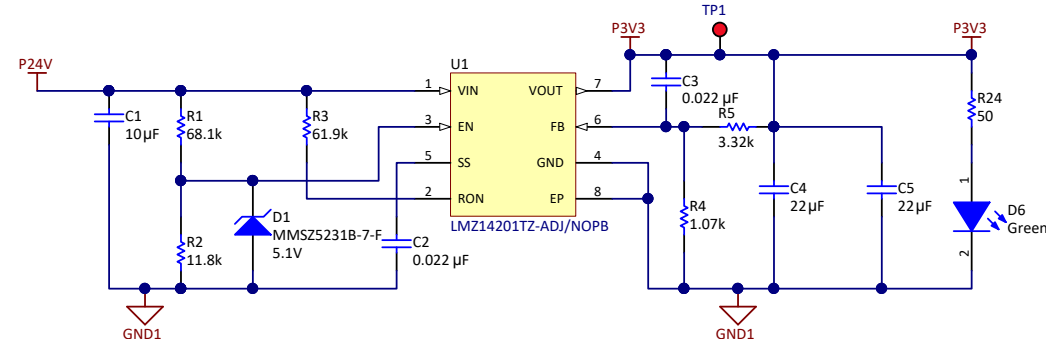


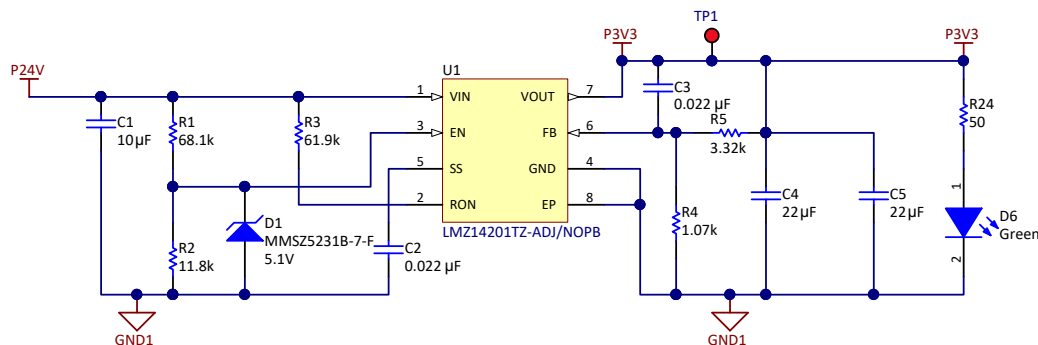
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 10. Schematic of Circuit for Brake Voltage Feedback

2.3.7 Power Supplies

2.3.7.1 3.3-V Generation Using LMZ14201

The LMZ14201 is a step-down, DC/DC power module used to power the primary side. This device is typically used to convert a higher DC voltage to a lower DC voltage with a maximum output current of 1 A. This design uses the LMZ14201 to convert the 24-V input to 3.3 V to supply power the primary side of the isolator and MCU.  shows the circuit for the LMZ14201.



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 11. Schematic of 3.3-V Generation Using LMZ14201

Output voltage is determined by a divider of two resistors connected between VO and ground. The midpoint of the divider is connected to the FB input. The voltage at FB is compared to a 0.8-V internal reference. In normal operation, an ON-time cycle is initiated when the voltage on the FB pin falls below 0.8 V. The main MOSFET ON-time cycle causes the output voltage to rise and the voltage at the FB to exceed 0.8 V. As long as the voltage at FB is above 0.8 V, ON-time cycles will not occur.

The regulated output voltage determined by the external divider resistors R5 and R4 is:

$$V_O = 0.8 \text{ V} \times \left(1 + \frac{R5}{R4} \right) \quad (2)$$

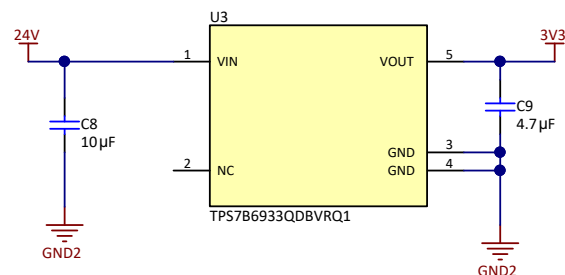
Rearranging terms, the ratio of the feedback resistors for a desired output voltage is:

$$\frac{R5}{R4} = \frac{V_O}{0.8 \text{ V}} - 1 \quad (3)$$

These resistors must be chosen from values in the range of 1.0 k Ω to 10.0 k Ω . This reference design uses R5 as 3.32k and R4 as 1.07k to generate an output voltage of 3.3 V.

2.3.7.2 3.3-V Generation Using TPS7B6933

A 3.3-V supply is needed to power digital isolator on the secondary side. Here, the TPS7B6933 is used to convert 24 V to 3.3 V to supply power the secondary side of the isolator and the high-side switch. [Figure 12](#) shows the circuit of the TPS7B6933.



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Figure 12. Schematic of 3.3-V Generation Using TPS7B6933

3 Hardware, Testing Requirements, and Test Results

3.1 Required Hardware

This section explains the top and bottom views of the PCB for this reference design. This section also explains the power supply requirement and connectors used to connect the external world.

3.2 PCB Overview

Figure 13 shows the top view of the PCB. The high-side and low-side switches are highlighted in the figure.

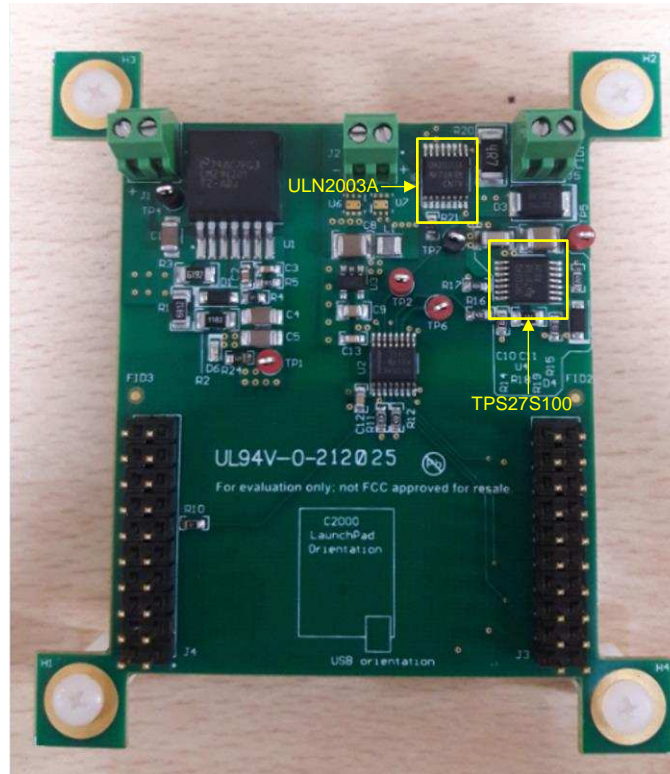


Figure 13. Top View of PCB

3.2.1 Connectors

Table 2. Connectors

CONNECTOR	PURPOSE
J1	24 V_VIN power supply to power the primary side of the board
J2	24 V_VIN power supply to power the secondary side of the board
J3	20-pin connector to connect to the C2000 LaunchPad
J4	20-pin connector to connect to the C2000 LaunchPad
J5	Output connector for connecting the Brake coil

3.3 Testing and Results

This section shows the test results that evaluate the functionality and the performance as specified in the design. This reference design used a 1-kW servo motor with a brake coil for testing. The brake coil is powered by a 24-V DC, and the current rating of the coil is about 0.81 A. The inductance of the coil is measured to be about 65.35 mH and the resistance is about 30.8 Ω .

3.3.1 Test Results

3.3.1.1 Functional Tests

Figure 14 shows the brake coil current, output voltage across brake coil, and the enable PWM signal given to the low-side switch. Figure 15 and Figure 16 show the rising and falling edges of the brake coil current, respectively. When the enable PWM signal becomes high, brake current ramps from zero to reach the maximum current of 740 mA. When the enable signal goes low, the current starts to decay and then it reaches zero. Faster decay of the brake coil current is determined by the diode and resistor connected across the brake coil.

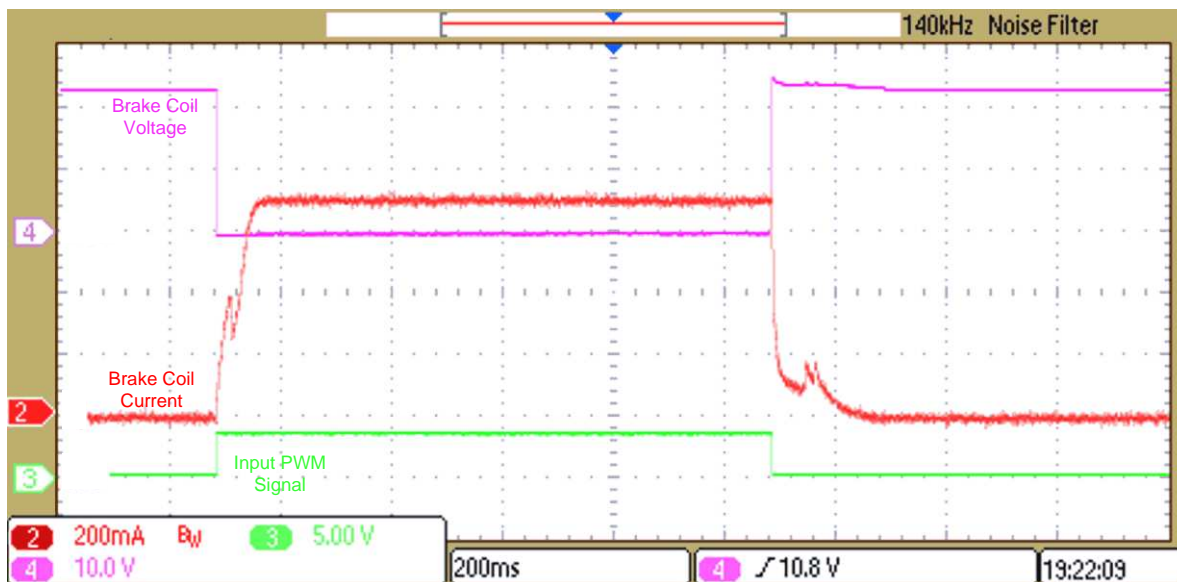


Figure 14. Waveform of Brake Coil Current

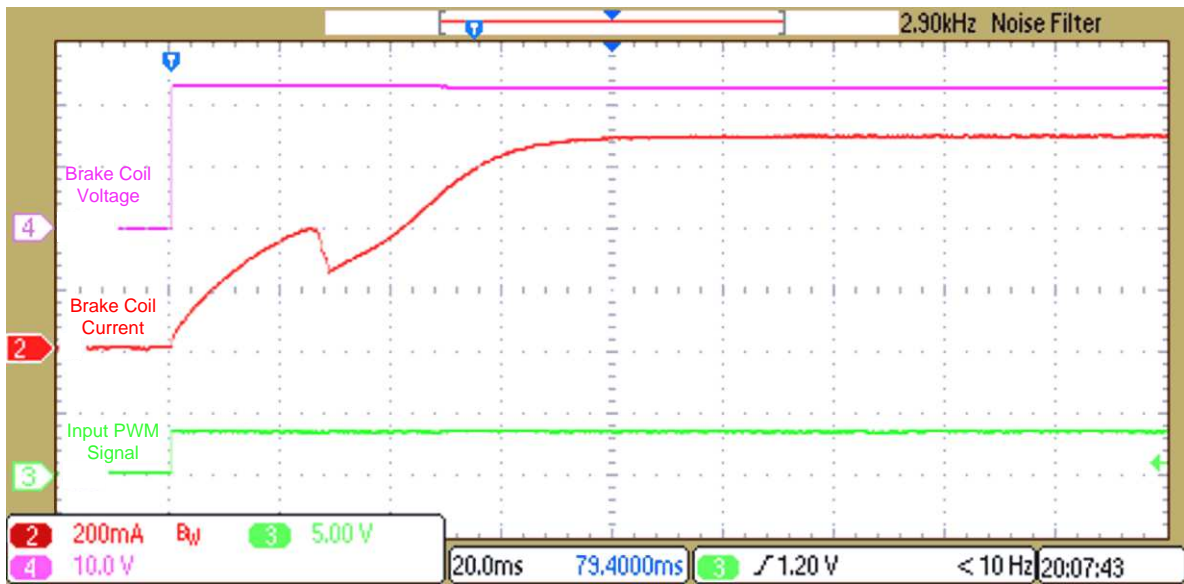


図 15. Rising Edge of Brake Coil Current

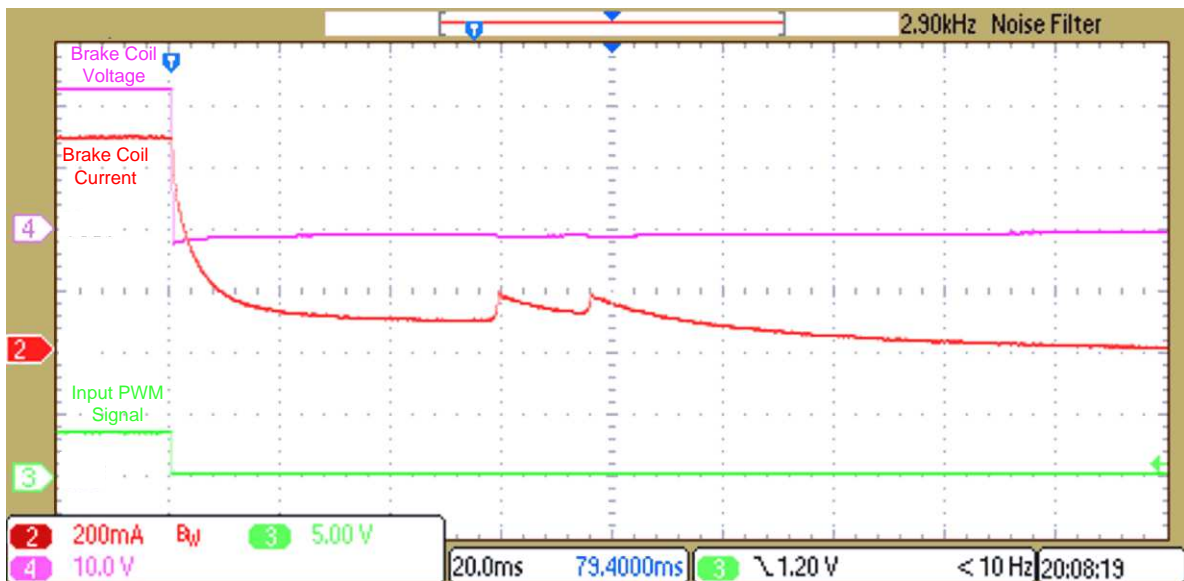



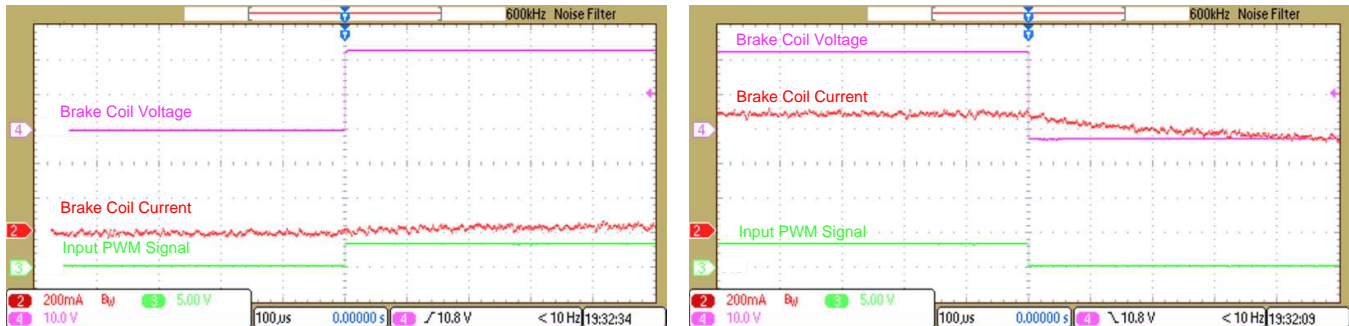


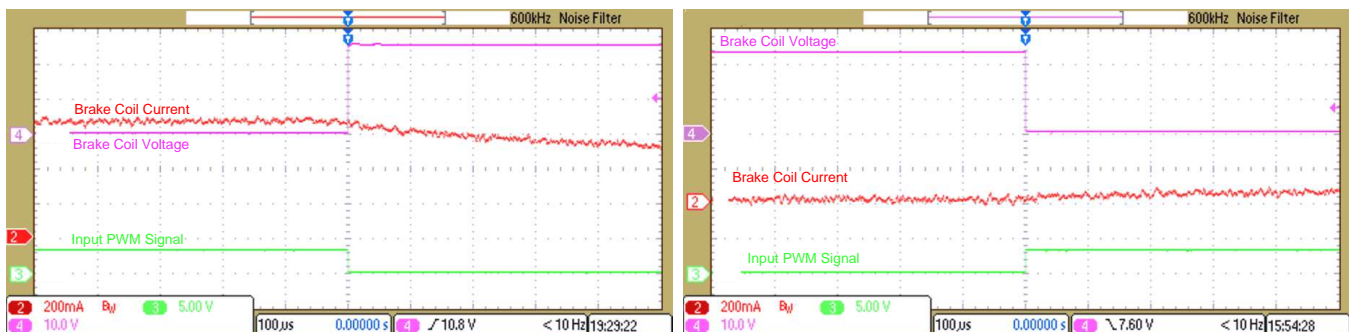
図 16. Falling Edge of Brake Coil Current

3.3.1.2 Output Voltage Measured Across Coil and Switches

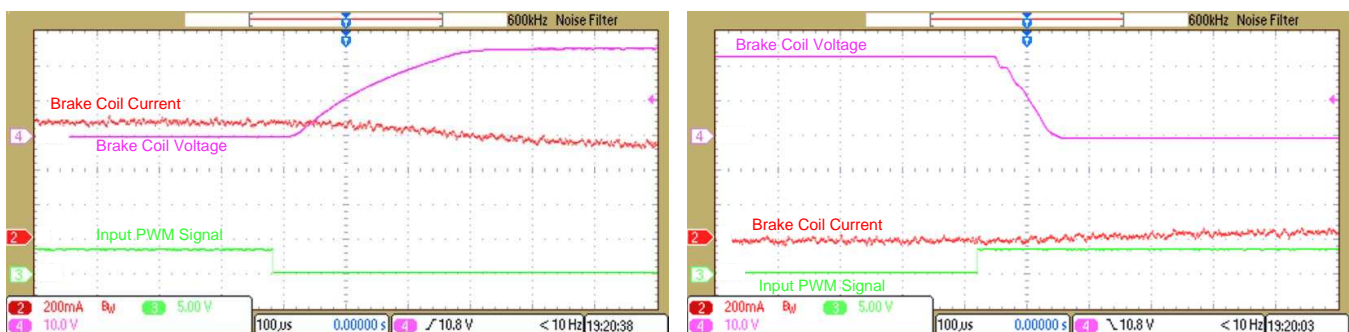
This test checks the overvoltage across the brake coil when it is turned off. The voltage is measured across the coil and independently across the both switches. The voltage increases proportional to the enable input PWM signal and drops to zero when the enable signal goes low. No overvoltage condition occurs when the brake coil is turned off. , , and  show the output voltage measured across the coil, low-side switch, and the high-side switch, respectively.



 17. Output Voltage Across Brake Coil



 18. Output Voltage Across Low-Side Switch



 19. Output Voltage Across High-Side Switch

3.3.1.3 No Load Detection

The TPS27S100 high-side switch has a built-in diagnostic feature covering no load detection. When the enable signal input to the switch is high and if the current flowing through the output is less than $I_{(ol,on)}$, which is typically less than 6 mA, the device recognizes an open-load fault. The status pin signal goes low to indicate the fault. When the enable input signal is low and if an open load occurs, the output voltage is close to the supply voltage ($V_{IN} - V_{OUT} < V_{(ol,off)}$), typically less than 1.8 V, the status pin signal goes low indicating no load detected. [Fig 20](#) and [Fig 21](#) show the no load detection waveforms captured. This functionality helps in identifying open cable and coil detection, thereby enhancing the safety of the design.

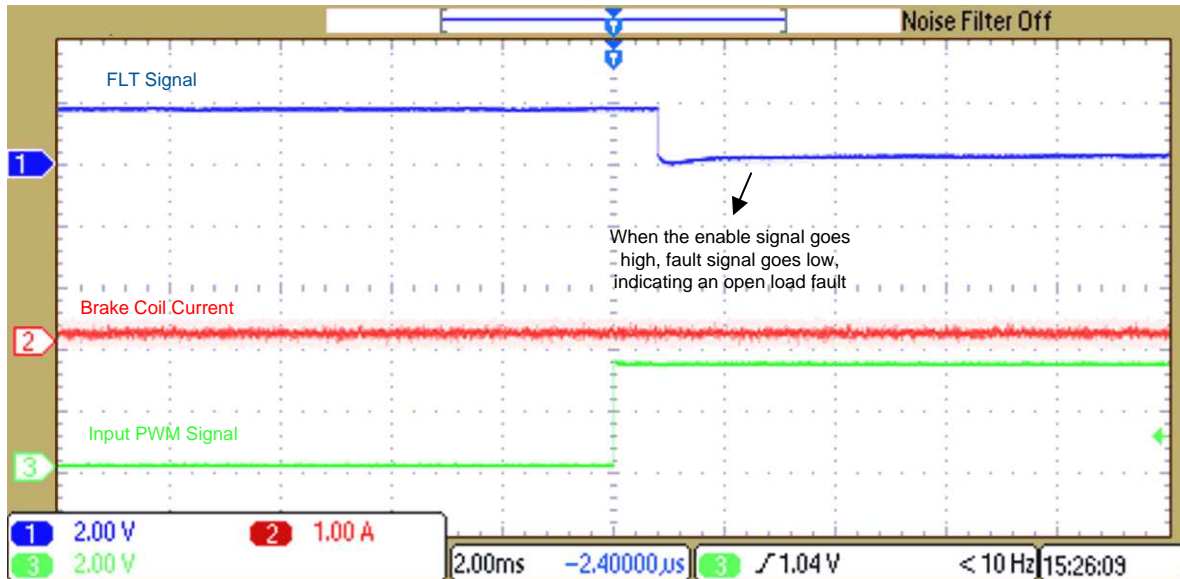


Fig 20. No Load Detection, IN Pin High

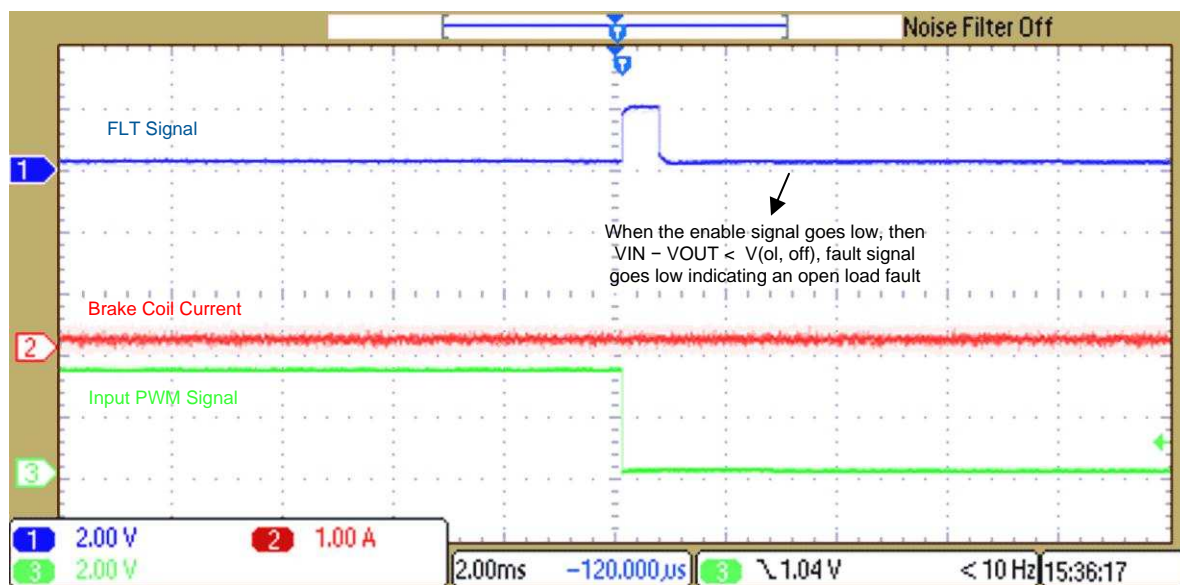


Fig 21. No Load Detection, IN Pin Low

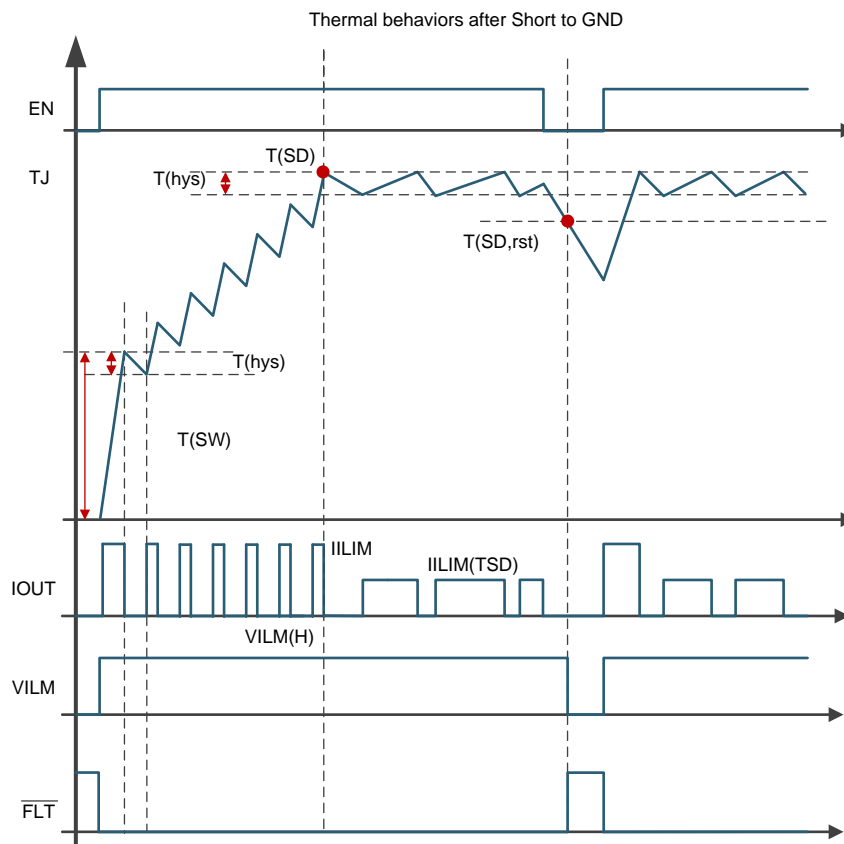
3.3.1.4 Short-Circuit, Overcurrent, and Thermal Shutdown Protection

Another built-in diagnostic feature of the TPS27S100 is the short-circuit and thermal shutdown protection. When the switch is on, a short to GND or an overload condition causes overcurrent. If the overcurrent triggers the current-limit threshold (I_{lim}), the fault condition is reported out. The current limit threshold is set to 2 A for this reference design. The device starts to heat up due to severe power stressing on the power FET. To protect the device in cases of severe power stressing, the device implements two types of thermal fault detection: absolute temperature protection (thermal shutdown) and dynamic temperature protection (thermal swing).

Thermal swing activates when the power FET temperature is increasing sharply (that is, when $\Delta T = T_{(FET)} - T_{(Logic)} > T_{(sw)}$). Then the output turns off. The output automatically recovers and the fault signal clears when $\Delta T = T_{(FET)} - T_{(Logic)} < T_{(sw)} - T_{(hys)}$. The thermal swing function improves the device reliability when subjected to repetitive fast thermal variation.

Multiple thermal swings are triggered before thermal shutdown happens. Thermal shutdown is active when absolute temperature $T_J > T_{SD}$. When active, the output is shut down, and the ST pin goes low. The output is auto-recovered when $T_J < T_{SD} - T_{hys}$; the current limit is reduced to $I_{lim,tsd}$, or half of the programmable current limit value, to avoid repeated thermal shutdown. However, the thermal shutdown fault signal and half current limit value are not cleared until the junction temperature decreases to less than $T_{SD,rst}$.

☒ 22 shows the thermal behavior after a short circuit happens.



☒ 22. Thermal Behavior of TPS27S100

Figure 23 and Figure 24 show the short-circuit and thermal shutdown response of the high-side switch. When the output is short to GND, the current limit is triggered to 2 A and the fault signal goes low to indicate a short-circuit fault. Due to the thermal shutdown, the current limit is reduced to half the programmed value as shown in Figure 22.

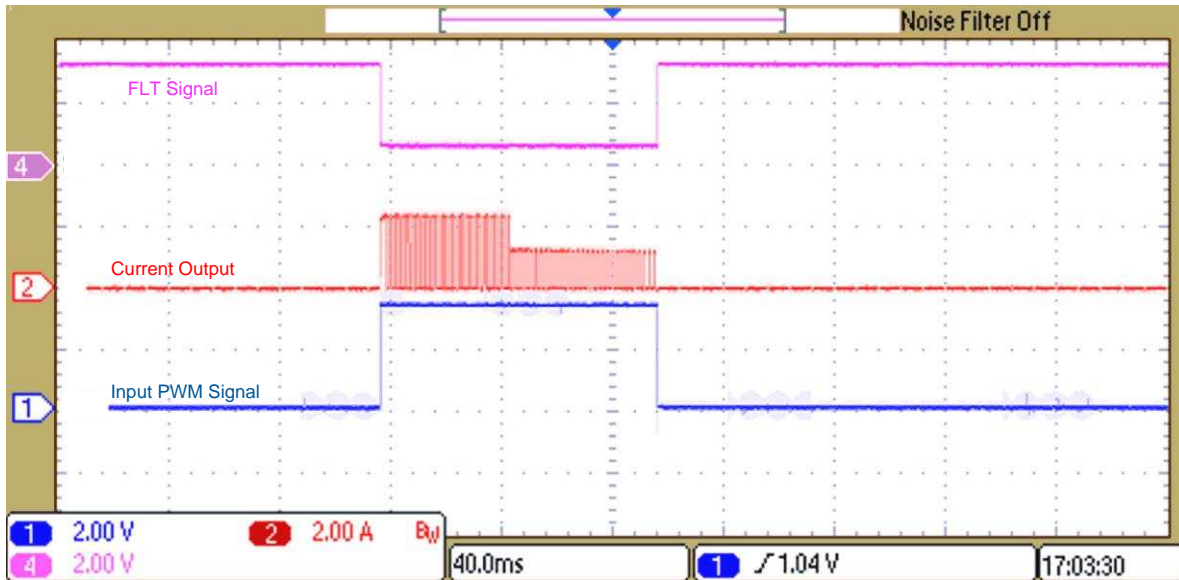


Figure 23. Short-Circuit Protection

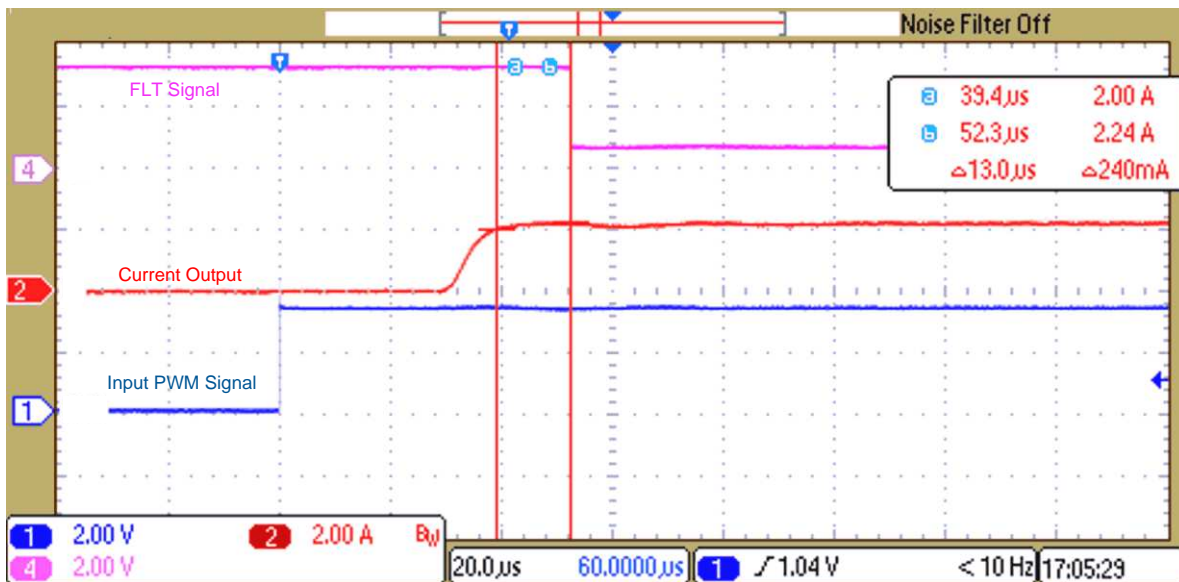
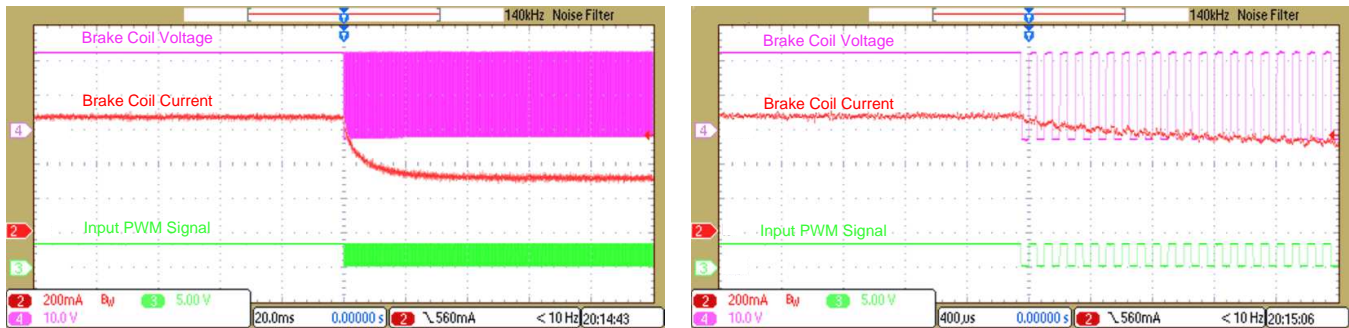


Figure 24. Short-Circuit Protection Delay Measurement

3.3.1.5 PWM Waveforms From Operational Mode to Hold Mode

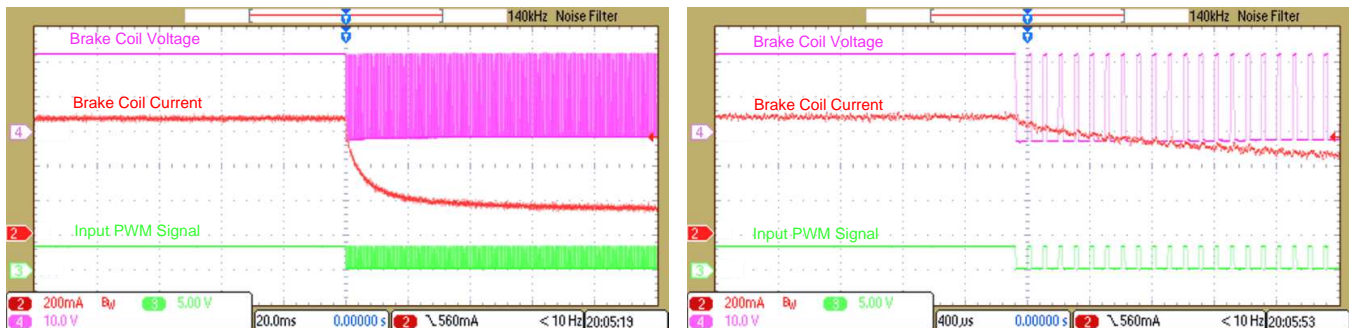
This reference design has a feature that reduces voltage at the holding brake output to reduce power consumption. The PWM signal given to the low-side switch is controlled to reduce the voltage at the holding brake output. To activate the brake coil, a 100% duty cycle is applied. Once the brake gets activated, the voltage can be reduced to the holding level to reduce the power consumption. When the voltage drops below the holding level, the brake gets latched holding the load. The following figures show the waveforms captured from operational mode to hold mode. The PWM frequency is set to 10 kHz. At a 100% duty cycle, the brake coil current is measured to be 0.71 A.

☒ 25 shows the waveforms captured reducing the PWM signal from a 100% duty cycle to a 50% duty cycle. The brake coil current is measured to be 0.36 A. The brake is still holding and the power consumption is saved to around 76%.



☒ 25. PWM Duty Cycle Reduced From 100% to 50% at 10 kHz

☒ 26 shows the waveforms captured when the PWM duty cycle is reduced from 100% to 25% without the brake latching. The brake coil current is measured to be 0.18 A. The power consumption is saved to around 90%. The brake is latched at a 20% duty cycle where the brake coil current is around 0.15 A. The safe threshold is to operate the brake at a 25% duty cycle.



☒ 26. PWM Duty Cycle Reduced From 100% to 25% at 10 kHz

Now, the PWM frequency is set to 1 kHz and the PWM duty cycle is applied to the low-side switch. At a 100% duty cycle, the brake coil current measured is about 0.71 A. 図 27 shows the waveforms captured when the duty cycle is reduced from 100% to 75% without the brake latching. The current goes down to 0.35 A. The power consumption is saved to around 65%.

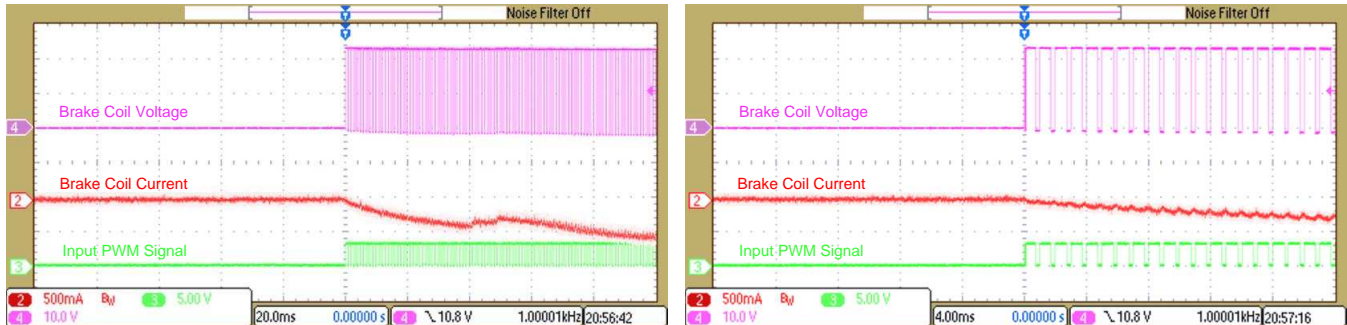


図 27. PWM Duty Cycle Reduced From 100% to 75% at 1 kHz

図 28 shows the waveforms captured when the PWM duty cycle is reduced from 100% to 50% without brake latching. The current goes down to 0.19 A. The power consumption is saved to around 86%. The brake got latched at a 20% duty cycle. The safe threshold to operate the brake is at a 25% duty cycle.

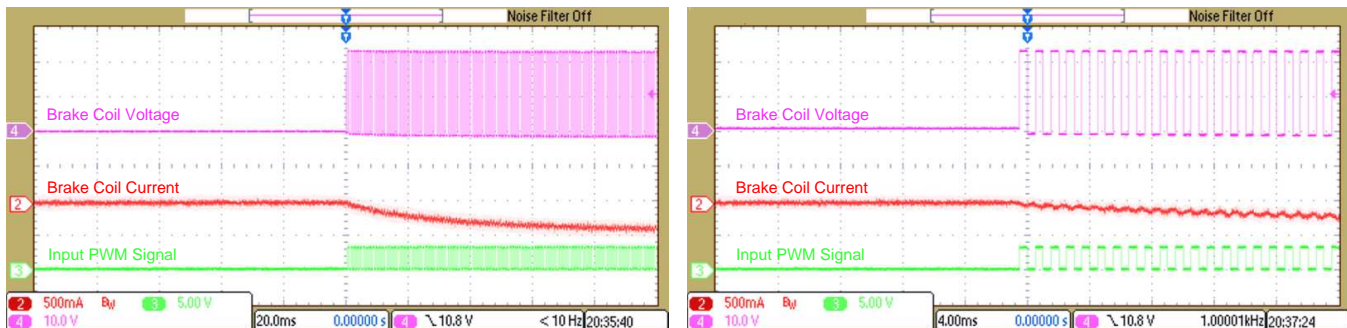


図 28. PWM Duty Cycle Reduced From 100% to 50% at 1 kHz

3.3.1.6 Brake Voltage Feedback Waveforms

図 29 shows the waveforms taken of the brake voltage feedback. The output brake voltage is converted to 3.3 V using the resistor divider, is fed to the MCU through the digital isolator for monitoring the brake coil voltage, and adjusts the input PWM signal to the low-side switch accordingly to reduce voltage to the brake output and save power.

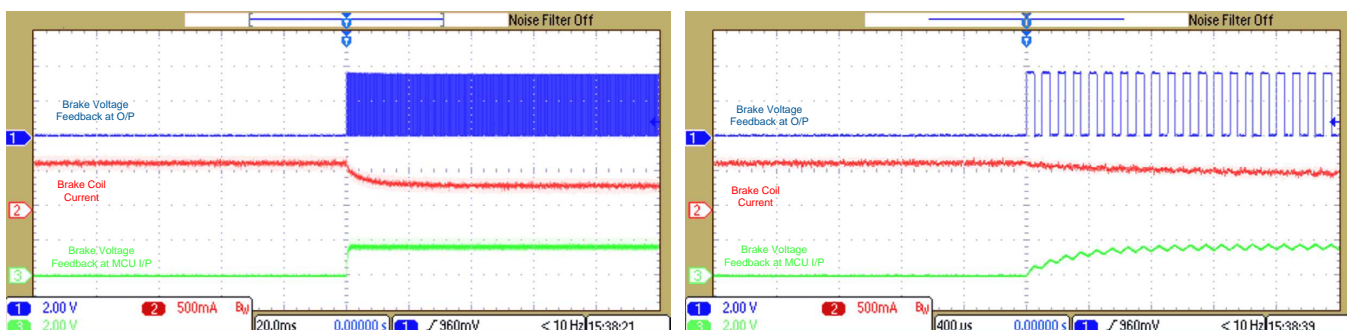


図 29. Waveform of Brake Voltage Feedback

3.3.1.7 Voltage Drop Across Switches

Figure 30 shows the voltage drop taken across the low-side switch, which is measured to be 780 mV. Figure 31 shows the voltage drop taken across the high-side switch, which is measured to be 60 mV.

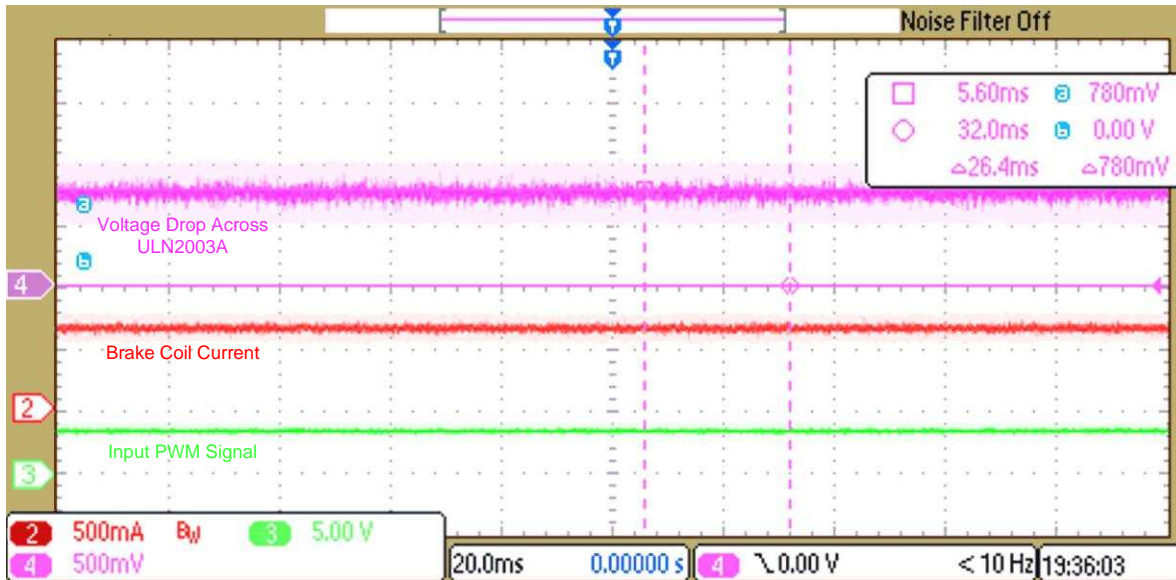


Figure 30. Voltage Drop Across Low-Side Switch

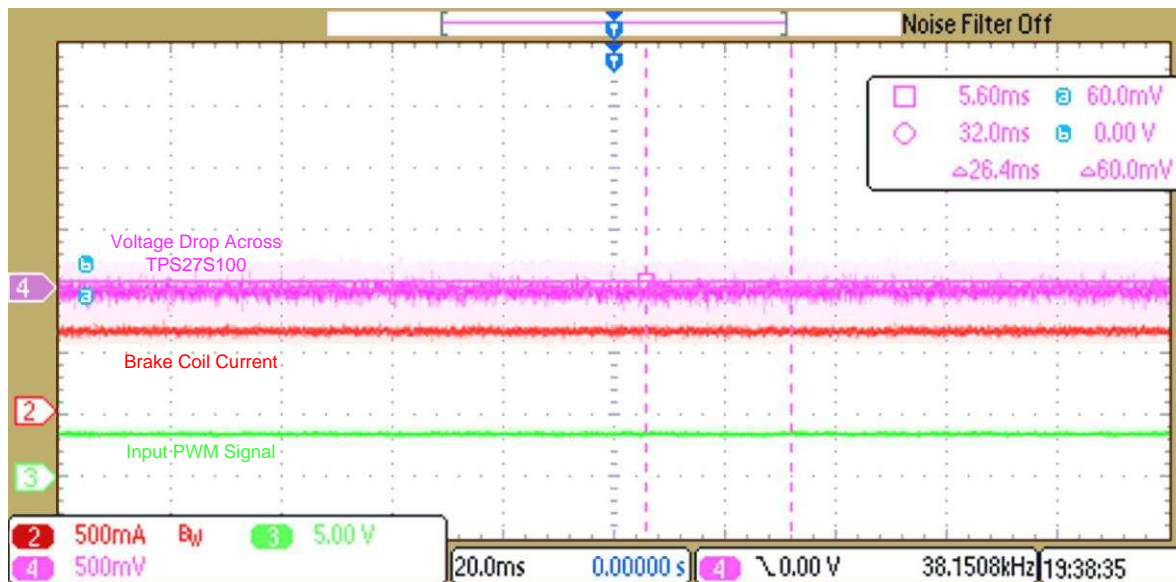


Figure 31. Voltage Drop Across High-Side Switch

3.3.1.8 Thermal Image

Figure 32 to Figure 35 show the thermal images of the board captured at different duty cycles. The reference design board is powered. The test condition is that the high-side switch is kept always on and the PWM signal is given to the low-side switch. The board is operated for 15 minutes for each duty cycle. Images are taken before coil excitation and after coil excitation with a 100% duty cycle, 50% duty cycle, and 25% duty cycle, respectively. The ambient temperature when making these measurements is 25°C.

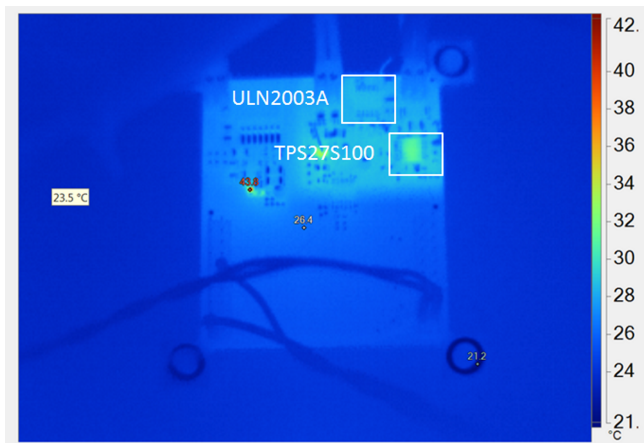


Figure 32. Temperature at No Load

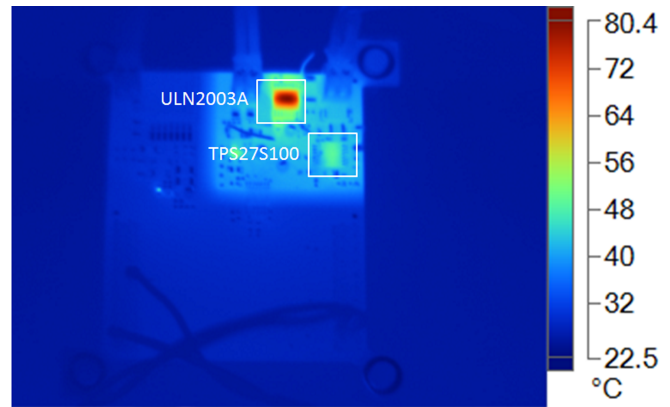


Figure 33. Temperature at 100% Duty Cycle

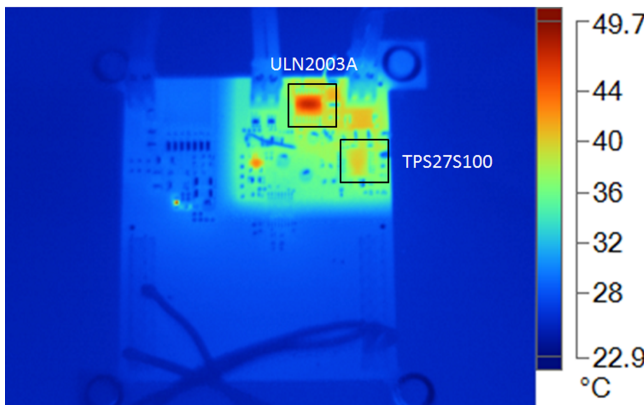


Figure 34. Temperature at 50% Duty Cycle

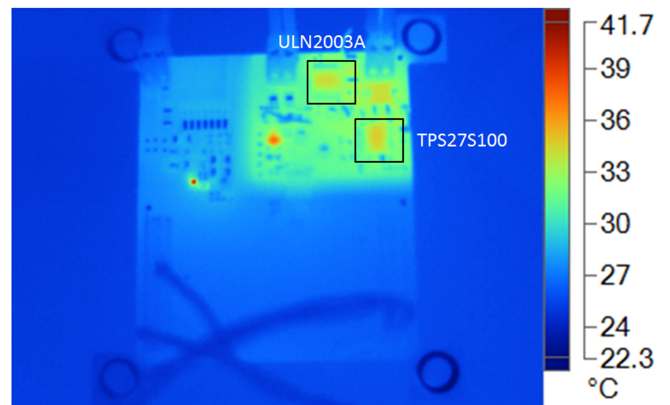


Figure 35. Temperature at 25% Duty Cycle

The low-side switch gets much hotter than the high-side switch because the voltage drop across the ULN2003A is 780 mV whereas the voltage drop across the TPS27S100 is 60 mV. The temperature is reduced when a 5-V LDO is used because the power dissipation is lesser when compared with the power dissipation when a 3.3-V LDO is used. The temperature in the low-side switch can be improved by using the FET-based switch TPL7407L as there is no dependency of base current in FET, which makes it thermally stable as compared to BJT.

4 Design Files

4.1 Schematics

To download the schematics, see the design files at [TIDA-01600](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-01600](#).

4.3 PCB Layout Recommendations

図 36. Isolation Barrier and Power Plane of Layout

The ground is split into two planes: GND1 and GND2. GND1 serves as a ground for the primary side of the ISO7142 and LM14201 devices. GND2 serves as a ground for the secondary side of the ISO7142, TPS27S100, ULN2003A, and TPS7B6933 devices.

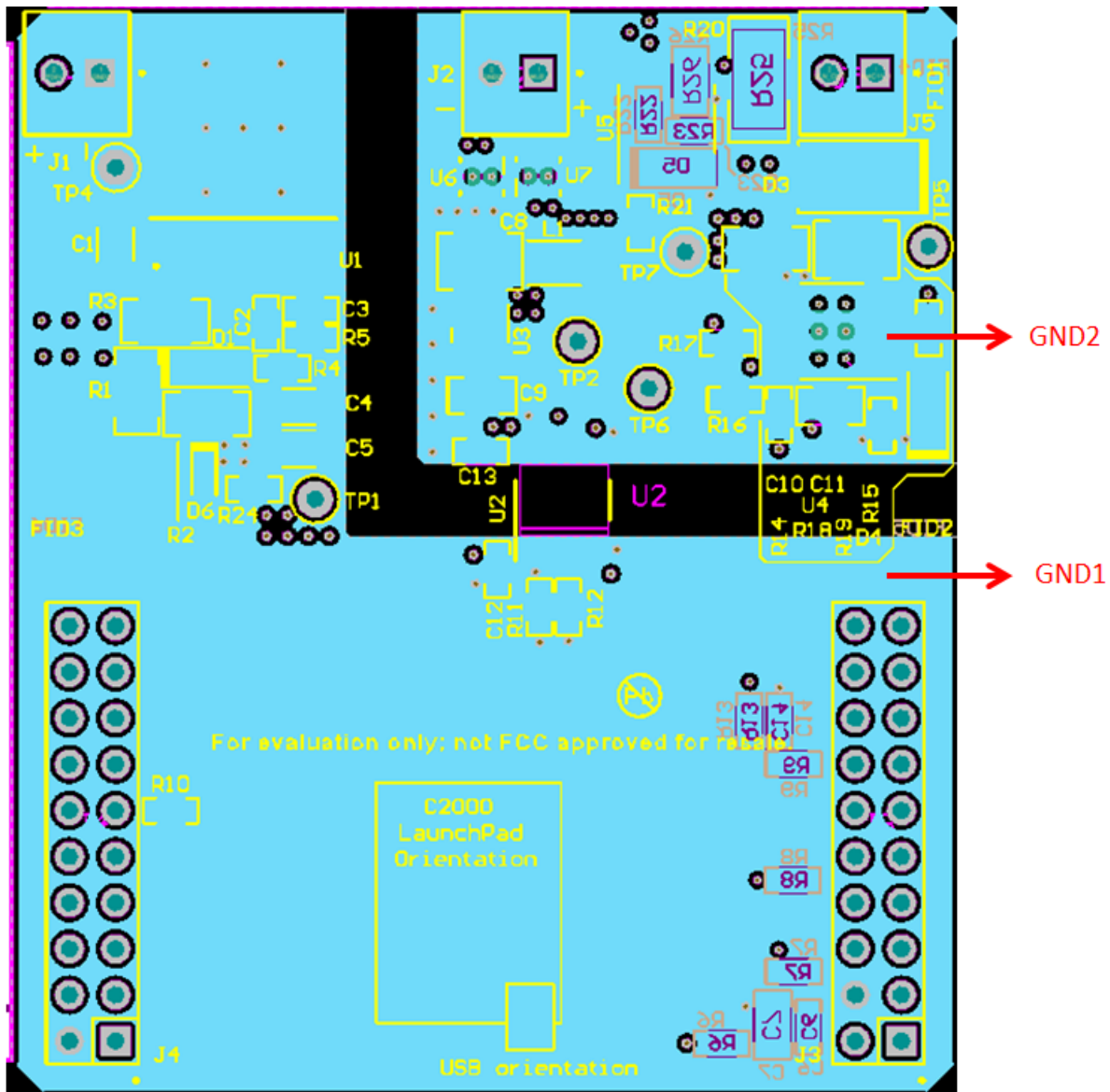


図 37. Split in Ground Plane of Layout

4.3.1 Layout Prints

To download the layer plots, see the design files at [TIDA-01600](#).

4.4 Altium Project

To download the Altium project files, see the design files at [TIDA-01600](#).

4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-01600](#).

4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-01600](#).

5 Related Documentation

1. IEC - International Electrotechnical Commission, [IEC 61800-5-2:2016 RLV: Adjustable speed electrical power drive systems - Part 5-2: Safety requirements - Functional](#) , 18 April 2016

5.1 商標

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6 Terminology

PWM— Pulse width modulation

MCU— Microcontroller unit

7 About the Author

MEGA PRIYA GANESAN is a systems engineer at Texas Instruments, where she is responsible for developing subsystem design solutions for the Industrial Motor Drive segment. Mega Priya earned her bachelor of engineering in electrical and electronics engineering at PSG College of Technology, Coimbatore.

7.1 Recognition

The author would like to recognize the excellent contributions from **PAWAN NAYAK** during the design, test, and documentation phases of the TIDA-01600 reference design.

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