

TI Designs: TIPD205

オープン・ループのフラックスゲート・センサを使用した±100Aバス バー電流センサのリファレンス・デザイン

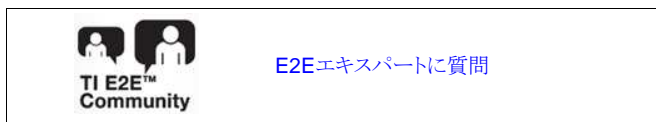


概要

この完全なバスバー・アセンブリ・リファレンス・デザインは、最大±100Aの非侵襲性(絶縁され、損失のない)電流測定ソリューションです。このアセンブリには、円形切り欠き、挿入、プリント基板(PCB)、絶縁スタンドオフ、端子ブロック、およびインターフェイス・ケーブル・アセンブリを持つバスバーが含まれており、そのまま大電流の測定に使用できます。

リソース

- TIPD205 デザイン・フォルダ
- DRV425 プロダクト・フォルダ
- OPA320 プロダクト・フォルダ

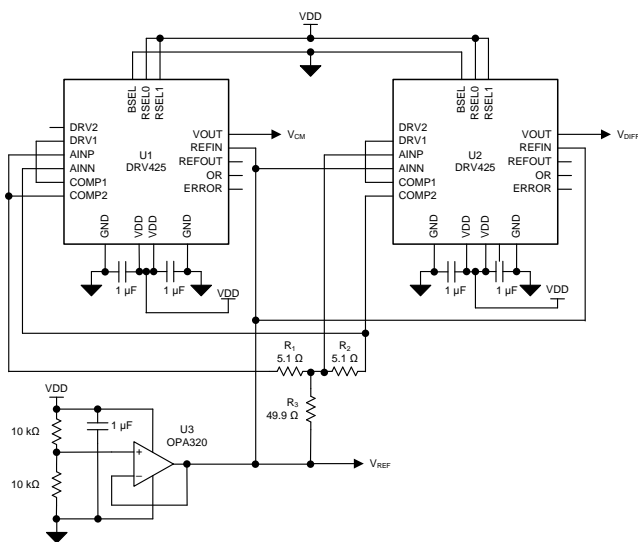


特長

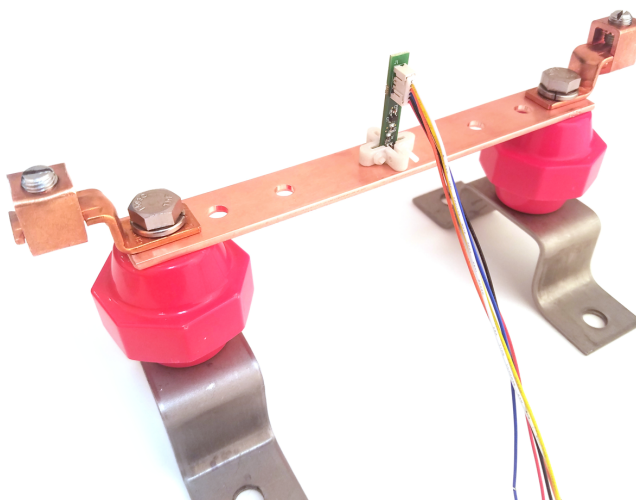
- 最大100Aの電流範囲
- 非侵襲性の(絶縁され、損失のない)測定
- 完全なアセンブリ
- オープン・ループの電流センサ
- DCおよびAC電流を正確に測定

アプリケーション

- バッテリー管理システム(BMS)
- ACドライブ制御モジュール
- サーボ・ドライブ制御モジュール
- ブラシレスDCモータ・ドライブ
- サージ保護デバイス



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1 System Description

A variety of methods are available for measuring current. One method is to measure the magnetic field generated by the current source, which creates an isolation between the current and the measurement system. This method eliminates some of the concerns normally associated with a typical current shunt monitor by removing the shunt resistor, which can cause unwanted power loss. This method also eliminates high-voltage concerns due to isolating through the magnetic field. This reference design provides instruction for measuring current through a busbar by measuring the magnetic field generated using two DRV425 devices. Using the DRV425 fluxgate sensor to measure the magnetic field has the benefit of low drift and low noise, which are often larger when using typical Hall effect sensors. This reference design provides two PCB orientations that can be used to measure the current. The TIPD205 design allows for quick evaluation of both PCB orientations (horizontal and vertical). See [Bus Bar Theory of Operation](#) (SLOA237) for further detailed information regarding busbar operation. This busbar measures ± 100 A using a 5-V supply. This design is scalable to measure higher or lower current.

1.1 Key System Specifications

表 1. Key System Specifications

PARAMETER	SPECIFICATIONS
Current range	± 100 A
Supply voltage	5.0 V
Magnetic field orientation	Horizontal and vertical

2 System Overview

2.1 Block Diagram

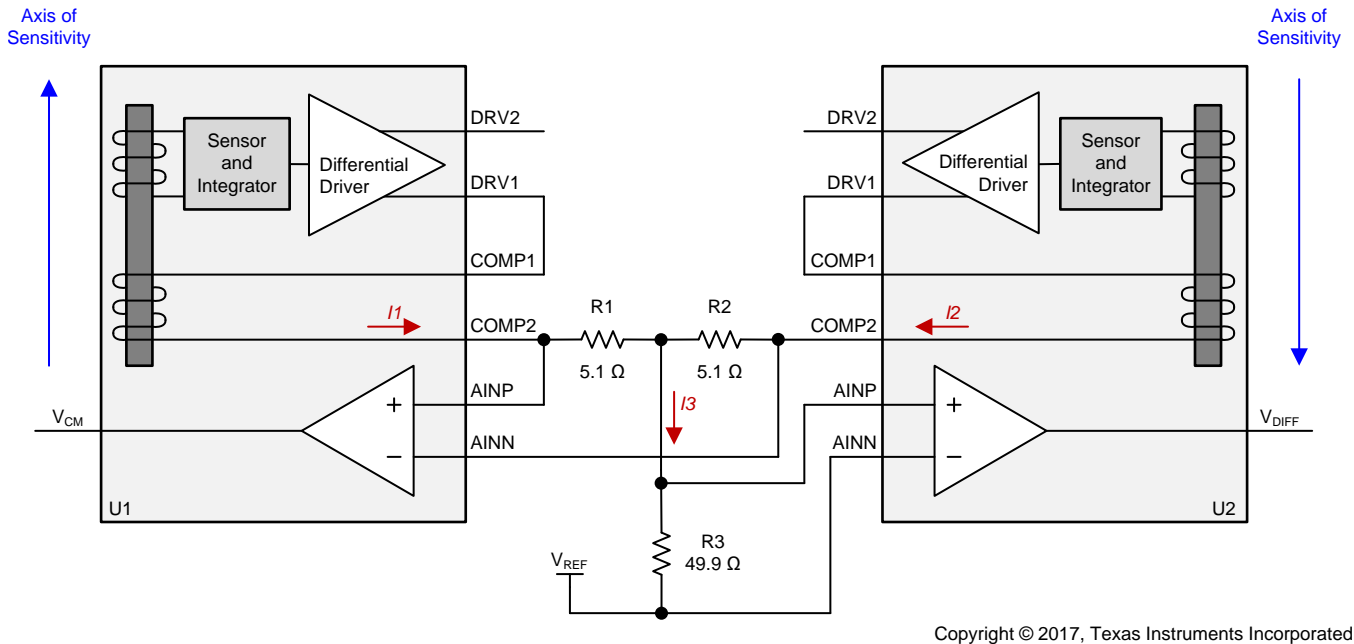


図 1. TIPD205 Block Diagram

2.2 Highlighted Products

2.2.1 DRV425

The DRV425 is designed for single-axis magnetic field sensing and enables electrically-isolated, high-sensitivity, and precise DC- and AC-field measurements. The device provides a proprietary, integrated fluxgate sensor (IFG) with an internal compensation coil to support a high-accuracy sensing range of ± 2 mT with a measurement bandwidth of up to 47 kHz. The low offset, offset drift, and noise of the sensor, combined with the precise gain, low gain drift, and very-low nonlinearity provided by the internal compensation coil result in unrivaled precision for magnetic field measurement. The output of the DRV425 is an analog signal which is proportional to the sensed magnetic field. The DRV425 offers a complete set of features, including an internal difference amplifier, on-chip precision reference, and diagnostic functions to minimize component count and system-level cost. The DRV425 is available in a thermally-enhanced, non-magnetic, thin WQFN package with a PowerPAD™ integrated circuit package for optimized heat dissipation. The device is specified for operation over the extended industrial temperature range of -40°C to $+125^{\circ}\text{C}$.

2.2.2 OPA320

The OPA320 amplifier in a buffer configuration drives the reference pin along with the output current from the DRV pins of the DRV425 pairs. The OPA320 is selected as the buffer for the reference voltage because of its very-low offset voltage, low quiescent current, low input bias current, and low noise. Use the small SOT-23 package to enable the size constraint of the PCB.


2.3 System Design Theory

Traditional busbar current measurement techniques use closed-loop current modules to accurately measure and control current. While these modules are accurate, they usually require a large magnetic core and often dissipate several watts of power. An alternative approach is to use two DRV425 devices connected for a differential measurement, mounted on a printed circuit board which is then placed into a hole drilled in the center of the busbar. When a hole is drilled into the center of the busbar, the current is split into two equal parts that generate magnetic field gradients with opposite directions inside the hole. The opposing fields cancel each other out in the center of the hole. The high sensitivity and linearity of the DRV425 devices positioned equidistant from the center of the hole allow small opposing fields to be sensed and current to be measured with a high degree of accuracy.

The busbar design has two different orientations available for evaluation. The two PCB orientations are very similar and the most significant reason to choose one version over the other is due to stray magnetic fields. Neighboring currents typically cause these stray fields, which can either be in the vertical or horizontal axis. Adding these stray fields to the desired field being measured can cause a situation that saturates the DRV425 devices. The user must use a perpendicular (or normal) orientation for the DRV425 axis of sensitivity in relation to these stray fields to avoid saturation.

This system is designed for current measurements up to 100 A by measuring the magnetic field generated by the current through the busbar. See [Bus Bar Theory of Operation](#) (SLOA237) for a more detailed explanation on the system design theory.

2.3.1 Busbar Design

The measured current and the amount of temperature from which the busbar can increase from the ambient temperature determine the busbar dimensions. The bar has a cutout which increases the power dissipated through the busbar and must be taken into account for the temperature rise. The design of the bar enables a very-low temperature rise when 100 A passes through it. All the dimensions and the type of cutout affect the magnetic field monitored by the DRV425 devices. Use the [DRV425 Bus Bar Application Magnetic Field Calculator](#) to calculate the dimensions required for the current measurement.  2 shows a screenshot from the calculator used in the design. A design must attempt to get the highest magnetic field to improve the signal-to-noise (desired field-to-stray field) performance. The highest field is limited by the DRV425 saturation of 2 mT.

Bus Bar Parameter Input	
Design Configuration	
PCB Device Configuration:	Vertical
Bus Bar Cutout Configuration:	Hole
Application Specific Parameters	
Current (I):	100.00 A
Bus Bar Width (x-dimension):	25.40 mm
Bus Bar Height (y-dimension):	3.18 mm
Hole Size (circle diameter, slot width):	10.16 mm
Sensor Spacing:	2.30 mm
Calculated Magnetic Field (Primary)	
Calculated Parameter	
Magnetic Field at DRV425-1 (B ₁):	0.4707 mT
Magnetic Field at DRV425-2 (B ₂):	0.4707 mT
Differential Magnetic Field (B _{DIFF}):	0.9414 mT
DRV425 Parameter Input	
Application Specific Parameters	
Rshunt (R3):	49.90 Ohm
Reference Voltage (Vref):	2.50 V
Calculated DRV425 Output	
Calculated Parameter	
Vout (Vdiff):	4.7923 V

Bus Bar Parameter Input	
Design Configuration	
PCB Device Configuration:	Horizontal
Bus Bar Cutout Configuration:	Hole
Application Specific Parameters	
Current (I):	100.00 A
Bus Bar Width (x-dimension):	25.40 mm
Bus Bar Height (y-dimension):	3.18 mm
Hole Size (circle diameter, slot width):	10.16 mm
Sensor Spacing:	2.00 mm
Calculated Magnetic Field (Primary)	
Calculated Parameter	
Magnetic Field at DRV425-1 (B ₁):	0.3931 mT
Magnetic Field at DRV425-2 (B ₂):	0.3931 mT
Differential Magnetic Field (B _{DIFF}):	0.7861 mT
DRV425 Parameter Input	
Application Specific Parameters	
Rshunt (R3):	49.90 Ohm
Reference Voltage (Vref):	2.50 V
Calculated DRV425 Output	
Calculated Parameter	
Vout (Vdiff):	4.4143 V

図 2. DRV425 Busbar Application Magnetic Field Calculator for Vertical and Horizontal Design

2.3.2 Circuit Design

The circuit must produce an output that represents the current through the busbar and reduces any stray magnetic fields. Achieve this output by measuring the difference in magnetic fields from the two DRV425 devices. The circuit provides an output that represents the magnetic field produced by the current being measured and the common magnetic field. The designer is not required to use the output of the V_{CM} (common magnetic field); however, this output can be useful to determine if the DRV425 devices are close to saturation. *Bus Bar Theory of Operation* provides a circuit analysis for this circuit with multiple examples on the expectations and the DRV425 limitations. Rshunt determines the gain of the circuit and the user can adjust this for the desired gain. The TIPD205 reference design has an Rshunt of 49.9Ω (see 図 2).

2.3.3 Insert Design

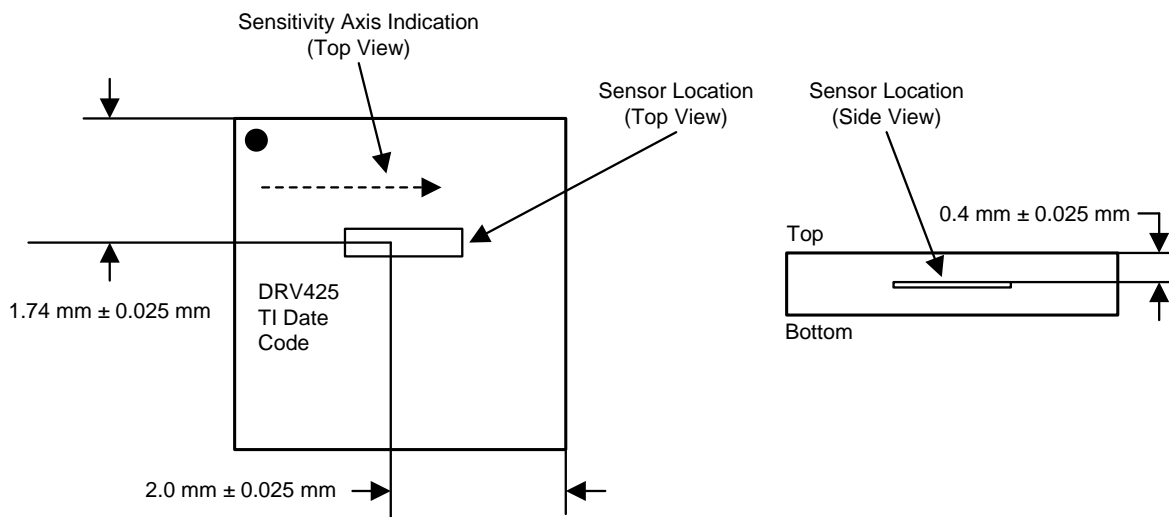
The insert to place the PCB is designed to place both versions of the PCB into the busbar. The insert is polarized and the holes for the nylon screws only align if the user has correctly placed the PCB inside the insert. The purpose of the provided nylon screws is to secure the PCB to the insert and limit the movement of the PCB board. Nylon screws are non-magnetic and do not disturb the magnetic flux. The alignment is structured such that the DRV425 devices are equidistant from the center depending on the PCB orientation. The insert also has alignment pins that match up with the busbar to prevent users from incorrectly placing it. The material is selected for cost and ease of use and is not designed for high-temperature applications; however, the designer can change the material to meet a variety of requirements. Measuring the current through the magnetic flux automatically creates an isolation barrier between the current and the measurement system. The insert provides separation from the PCB to the busbar, which creates a limited physical isolation. This design of the insert is not intended for significant isolation but instead to visually determine the location of the DRV425 devices relative to the busbar and to allow the flexibility of using both orientations. The insert limits the voltage isolation with a clearance and creepage of 1.524 mm (60 mils). Increase the clearance and creepage by redesigning the insert to meet isolation requirements.

2.3.4 Error Sources

The designer must account for some of the error sources. Calibrate some of these errors out of the system by simply measuring the known currents like 0 A and 100 A against the accuracy required. Use these two values to calculate the offset and gain of the system and obtain a low measurement error.

2.3.4.1 Physical Construction

The physical construction of the busbar, placement of the sensors, as well as the sensor separation causes errors. The silicon placement (sensor location) in the package of the DRV425 has a tolerance of 0.025 mm in all directions, which only accounts for some of the error because of the sensor separation (see [Fig 3](#)). The majority of the error regarding the separation of the two DRV425 sensors is due to the assembly and manufacturing of the PCB. Sensor separation that varies from the intended distance produces a gain error and the user can simulate this using the [DRV425 Bus Bar Application Magnetic Field Calculator](#) by changing the sensor spacing input field and comparing the output values. A 1% error in placement typically equates to an approximate 1% error in gain error, but this varies depending on the dimensions of the busbar. This gain error is consistent and the user can calibrate for this.



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Fig 3. Sensor Location Inside DRV425

2.3.4.2 Fluxgate Sensor Offset

The DRV425 is an open-loop magnetic field sensor; however, the internal closed-loop nature of the device compensates for any nonlinearities of the fluxgate sensor. A small offset error of the fluxgate remains which can impact system performance. The typical offset error of the DRV425 is $2\text{ }\mu\text{T}$. For this design, the full-scale value for one DRV425 device in vertical orientation is $470.7\text{ }\mu\text{T}$ and the offset error calculates to a 0.43% error of full scale. Calibrate this error by measuring the output voltage with zero current.

2.3.4.3 Sense Amplifier and External Reference

The sense amplifier offset voltage (V_{OS}) is another source of offset error. The magnitude of offset error at the output equals the product of the amplifier gain and input-referred offset voltage along with the offset voltage from the fluxgate sensor. The reference is derived from a resistor divider on the supply voltage and is buffered before being sent to the sense amplifier. Many implementations use a difference amplifier to sense the voltage across R_{SENSE} , in those cases the exact voltage reference level does not play a role in the system error because the reference voltage is used for the reference input of the difference amplifier and the transducer output is measured as V_{OUT} with respect to V_{REF} .

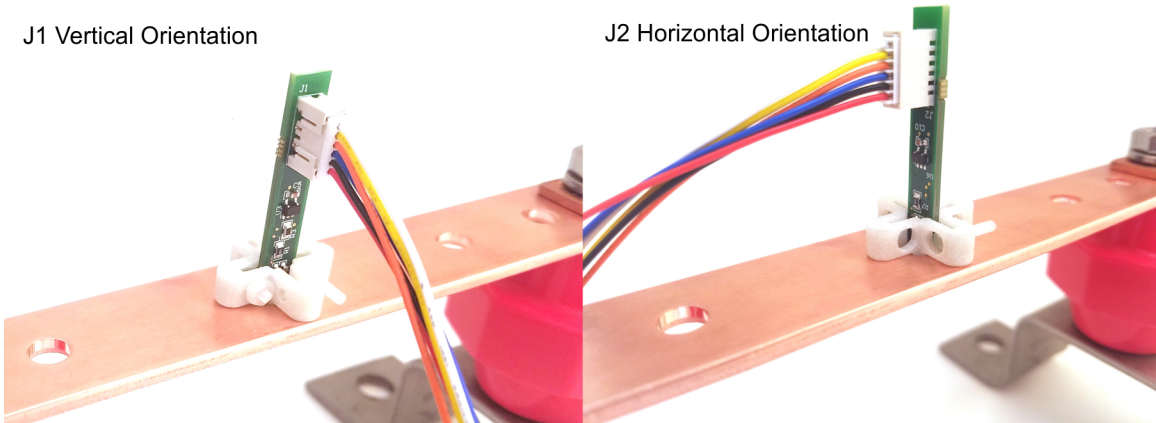
2.3.4.4 Shunt Resistor

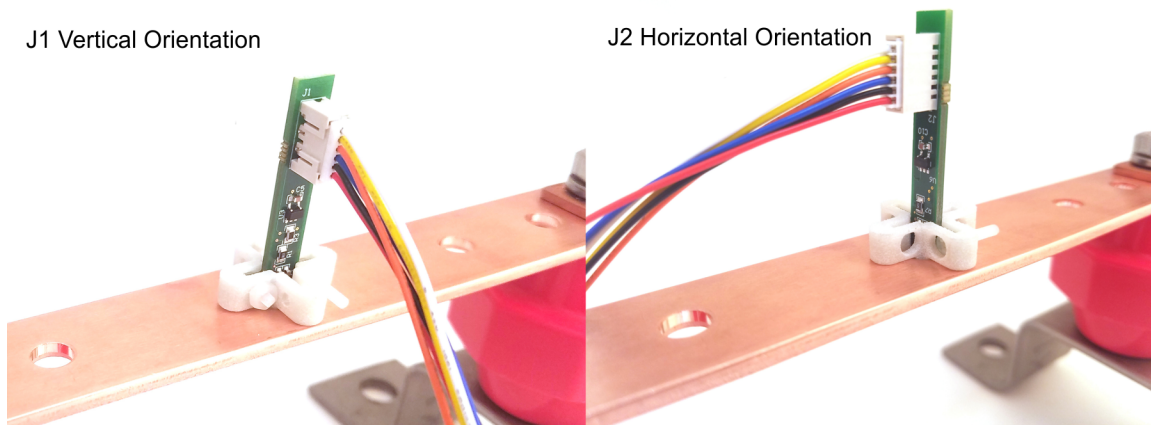
The shunt or sense resistor has a direct impact on the overall gain of the design. This design supports ± 100 A. Reducing the size of the shunt resistor allows the designer to measure a higher current range. The schematic, which is available in [Schematics](#), uses a $49.9\text{-}\Omega$ shunt which yields an output voltage of 2.5 ± 2.2923 V in the vertical orientation and 2.5 ± 1.9143 V in the horizontal orientation at ± 100 -A busbar current.

3 Getting Started Hardware

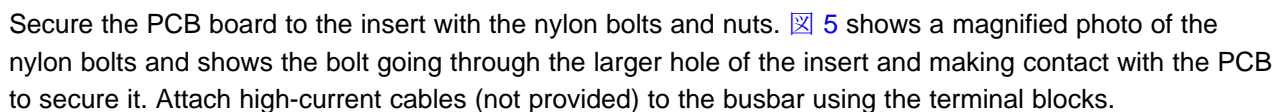
3.1 Hardware

Secure the terminal block to the busbar and isolation standoffs. When assembling the hardware, all high-current connections must be tight and secure, as any loose connections create a high-resistance path. When dealing with high currents, a small increase in resistance creates an increase in power dissipation and temperature. With time the copper can build an oxide layer and create a higher resistance path between the terminal blocks and the busbar, which the user can eliminate by scraping off the oxide with an abrasive material, adding NO OX-ID-A, using an electrical contact grease that prevents formation of oxides, or any combination thereof.

Decide which orientation to use and place the board inside the insert. J1 is the connector for the vertical orientation and J2 is the connector for the horizontal orientation. Another way to determine the orientation of the PCB section is by noting that the vertical version of the DRV425 devices are aligned and the horizontal version of the DRV425 devices are offset.  4 shows the PCB inserted in both orientations.



 4. PCB Orientation

Secure the PCB board to the insert with the nylon bolts and nuts.  5 shows a magnified photo of the nylon bolts and shows the bolt going through the larger hole of the insert and making contact with the PCB to secure it. Attach high-current cables (not provided) to the busbar using the terminal blocks.

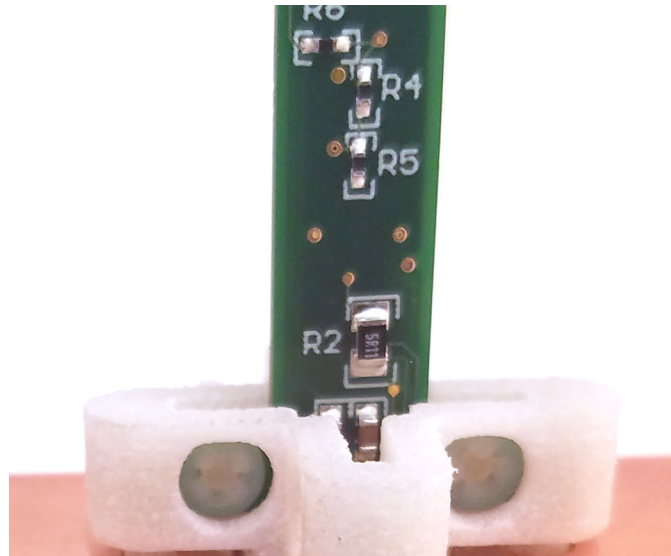


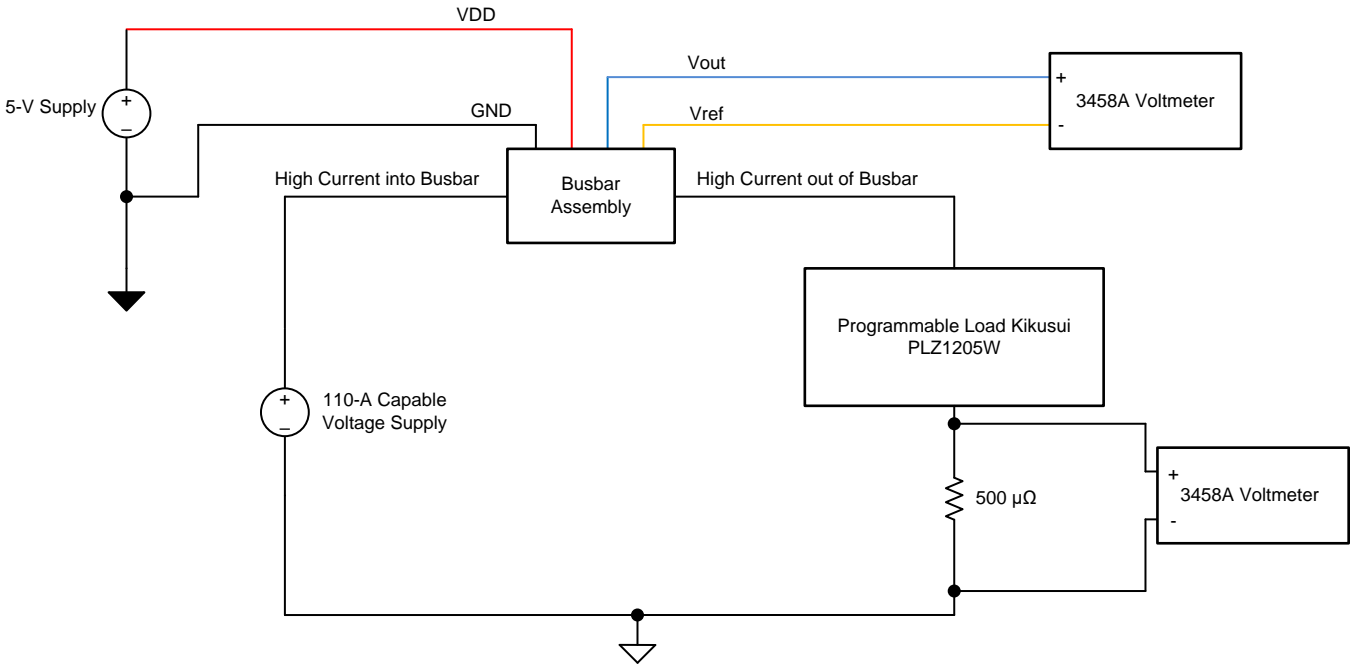
図 5. Zoomed-In Photo of Nylon Bolts Securing PCB

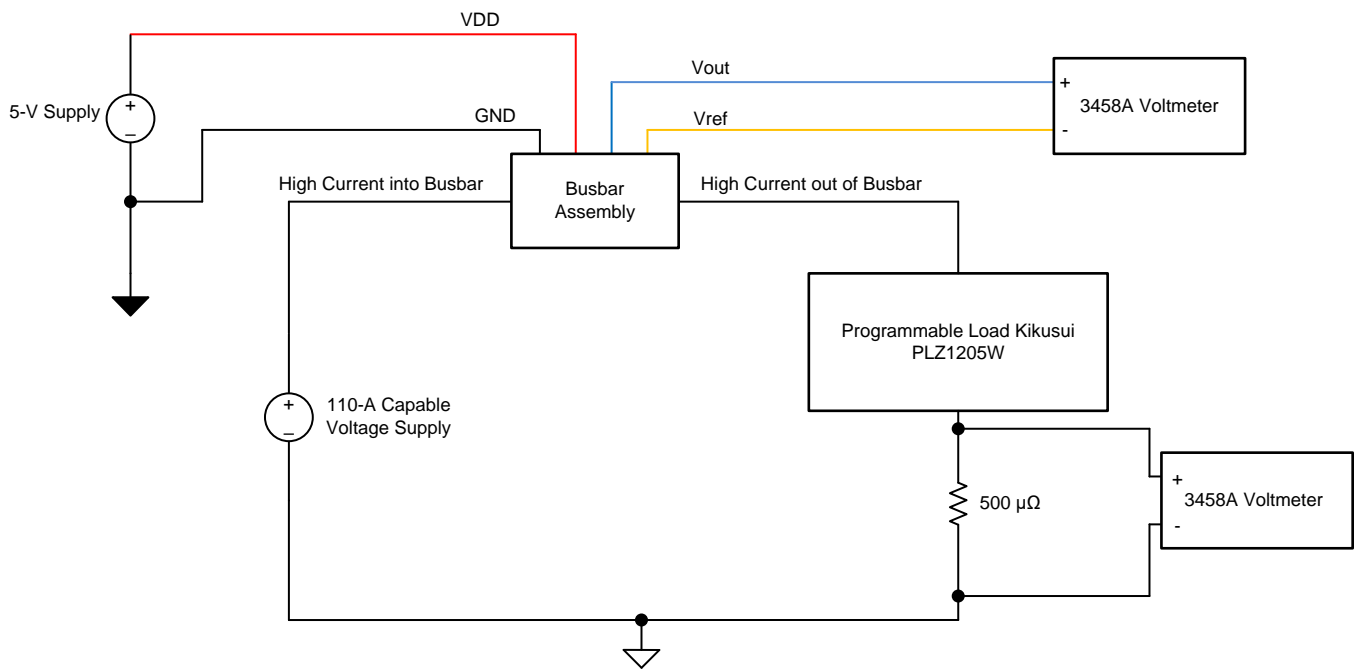
Place the connector on the board to J1 or J2 and connect the power supply and measurement instruments based on 表 2.

表 2. Connection Table

COLOR	I/O	NAME	DESCRIPTION
Red	Input	VDD	Input power 5 V
Black	Input	GND	Ground
Blue	Output	Vout	Output voltage referenced to V_{REF}
Orange	Output	Vref	Voltage reference $VDD/2$
Yellow	Output	VCM	Common field output
White	Output	Alert	Diagnostic flag active low

4 Testing and Results

The test setup consists of the TIPD205 assembly (busbar, standoffs, insert, vertical and horizontal PCB boards, and terminal blocks), two DC supplies, two 3458A digital multimeters (DMM), a programmable load, and a 500- $\mu\Omega$ shunt resistor. One of the DC supplies must be able to provide a current higher than 100 A with the full circuit load. To control the current through the busbar, a programmable load (Kikusui PLZ1205W) was used to control the current and to be able to sweep it from 0 A to 100 A. An accurate, 500- $\mu\Omega$ shunt resistor was used to obtain an accurate measurement.  shows a block diagram with all the required connections for the measurements. Note that the alert pin and the VCM pins have not been used in this setup. The function of the alert pin is to help determine if either of the DRV425 devices are saturated. The function of the VCM pin is to determine if the setup has a high external stray field, which is not an issue in this setup.



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図 6. Test Setup Diagram

The TIPD205 setup was used for both orientations and produced the following transfer curves in [図 7](#) and [図 8](#).

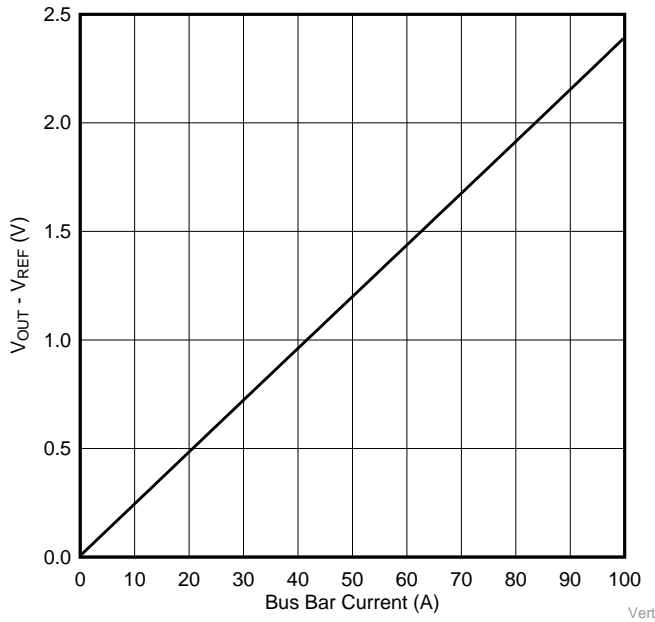


図 7. V_{OUT} versus Input Current for Vertical Orientation (J1)

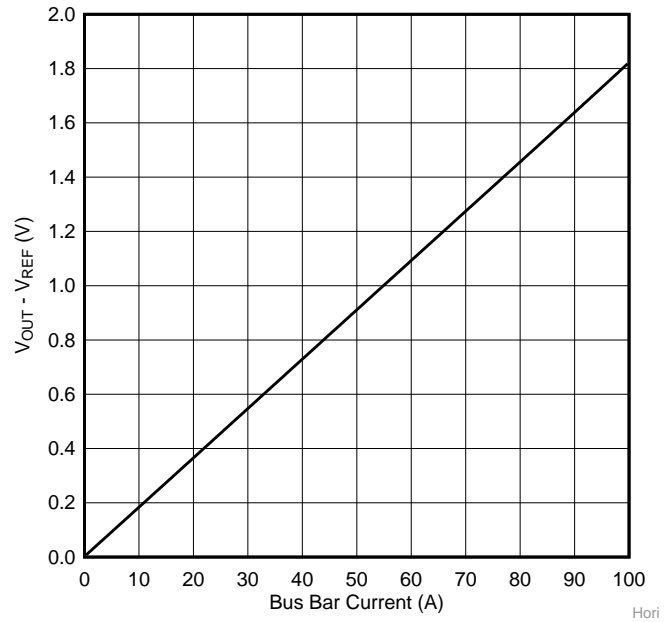


図 8. V_{OUT} versus Input Current for Horizontal Orientation (J2)

The gain and offset were calculated to increase accuracy. Calibrate the gain using [式 1](#) for the vertical orientation and [式 2](#) for the horizontal orientation. The offset is the measured V_{OUT} to V_{REF} when the current is 0 A.

$$\text{Gain}_{\text{Meas}} = \frac{(V_{\text{OUT}} - V_{\text{REF}}) 100 \text{ A} - (V_{\text{OUT}} - V_{\text{REF}}) 0 \text{ A}}{100 - 0} = \frac{2.396 \text{ V} - (0.00606 \text{ V})}{100} = \frac{23.9 \text{ mV}}{\text{A}} \quad (1)$$

$$\text{Gain}_{\text{Meas}} = \frac{(V_{\text{OUT}} - V_{\text{REF}}) 100 \text{ A} - (V_{\text{OUT}} - V_{\text{REF}}) 0 \text{ A}}{100 - 0} = \frac{1.8232 \text{ V} - (0.00258 \text{ V})}{100} = \frac{18.21 \text{ mV}}{\text{A}} \quad (2)$$

After completing these calculations, calculate the complete the full-scale error using [式 3](#).

$$\text{Full - ScaleError (\%)} = \frac{I_{\text{BUSBAR}} - \frac{V_{\text{OUT}} - V_{\text{REF}}}{\text{Gain}_{\text{Meas}}}}{200 \text{ (A)}} \quad (3)$$

図 9 and 図 10 show the calculated full-scale error from 0 A to 100 A.

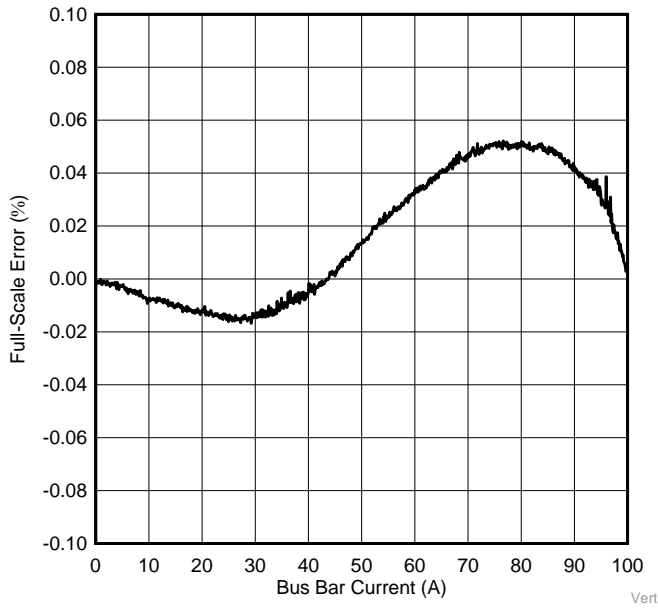


図 9. Full-Scale Error versus Current
Vertical Orientation (J1)

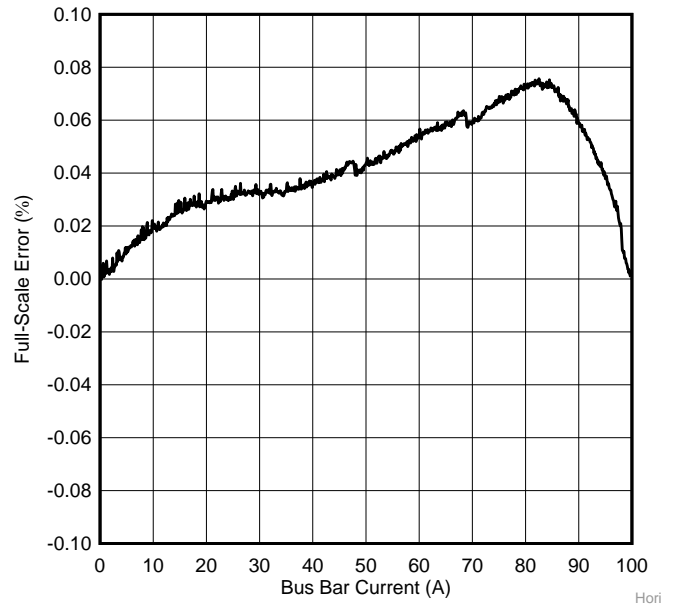


図 10. Full-Scale Error versus Current
Horizontal Orientation (J2)

5 Design Files

5.1 Schematics

To download the schematics, see the design files at [TIPD205](#).

5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIPD205](#).

5.3 Altium Project

To download the Altium project files, see the design files at [TIPD205](#).

5.4 Gerber Files

To download the Gerber files, see the design files at [TIPD205](#).

5.5 Assembly Drawings

To download the assembly drawings, see the design files at [TIPD205](#).

6 Related Documentation

1. Texas Instruments, [Bus Bar Theory of Operation](#), Application Report (SLOA237)
2. Texas Instruments, [Design Considerations for Dual DRV425 Bus Bar Application](#), TI TechNote (SBOA185)

6.1 商標

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改訂履歴

資料番号末尾の英字は改訂を表しています。その改訂履歴は英語版に準じています。

2015年10月発行のものから更新	Page
• 基板の画像を変更	1
• 「概要」、「特長」、「アプリケーション」を表紙に追加	1
• <i>System Description</i> and <i>Key System Specifications</i> 追加	2
• <i>System Overview</i> section featuring <i>Block Diagram</i> , <i>Highlighted Products</i> , and <i>System Design Theory</i> 追加	3
• Updated former <i>Theory of Operation</i> section and changed title to <i>System Design Theory</i>	4
• Updated former <i>Verification & Measured Performance</i> section to <i>Testing and Results</i> with revised content	10

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お客様は、個別のTIリソースにつき、当該TIリソースに記載されているTI製品を含むアプリケーションの開発に関連する目的でのみ、使用、コピー、変更することが許可されています。明示的または黙示的を問わず、禁反言の法理その他どのような理由でも、他のTIの知的所有権に対するその他のライセンスは付与されません。また、TIまたは他のいかなる第三者のテクノロジーまたは知的所有権についても、いかなるライセンスも付与されるものではありません。付与されないものには、TI製品またはサービスが使用される組み合わせ、機械、プロセスに関連する特許権、著作権、回路配置利用権、その他の知的所有権が含まれますが、これらに限られません。第三者の製品やサービスに関する、またはそれらを参照する情報は、そのような製品またはサービスを利用するライセンスを構成するものではなく、それらに対する保証または推奨を意味するものでもありません。TIリソースを使用するため、第三者の特許または他の知的所有権に基づく第三者からのライセンス、あるいはTIの特許または他の知的所有権に基づくTIからのライセンスが必要な場合があります。

TIのリソースは、それに含まれるあらゆる欠陥も含めて、「現状のまま」提供されます。TIは、TIリソースまたはその仕様に関して、明示的か暗黙的にかかわらず、他のいかなる保証または表明も行いません。これには、正確性または完全性、権原、続発性の障害に関する保証、および商品性、特定目的への適合性、第三者の知的所有権の非侵害に対する黙示的保証が含まれますが、これらに限られません。

TIは、いかなる苦情に対しても、お客様への弁済または補償を行う義務はなく、行わないものとします。これには、任意の製品の組み合わせに関連する、またはそれらに基づく侵害の請求も含まれますが、これらに限られず、またその事実についてTIリソースまたは他の場所に記載されているか否かを問わないものとします。いかなる場合も、TIリソースまたはその使用に関連して、またはそれらにより発生した、実際の、直接的、特別、付随的、間接的、懲罰的、偶発的、または、結果的な損害について、そのような損害の可能性についてTIが知らされていたかどうかにかかわらず、TIは責任を負わないものとします。

お客様は、この注意事項の条件および条項に従わなかったために発生した、いかなる損害、コスト、損失、責任からも、TIおよびその代表者を完全に免責するものとします。

この注意事項はTIリソースに適用されます。特定の種類の資料、TI製品、およびサービスの使用および購入については、追加条項が適用されます。これには、半導体製品(<http://www.ti.com/sc/docs/stdterms.htm>)、評価モジュール、およびサンプル(<http://www.ti.com/sc/docs/sampterm.htm>)についてのTIの標準条項が含まれますが、これらに限られません。