Application Note

Grounding Considerations in Current-Sensing Applications

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Current and Position Sensing

ABSTRACT

To implement an optimal current-sensing circuit, an understanding of both the application and the current-sense amplifier is necessary. Grounding is also an important consideration, perhaps more so in certain applications than others. One such application is motor drive, where the switching nature of current and voltage makes it challenging to achieve a high-performance current sense function. Clean grounding and small current loops are key to reducing parasitic inductance and voltage spikes. Besides addressing some of the common issues associated with grounding for current sense in general, this application note analyzes some of the unique aspects to understand current sense for motor drive.

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1 Introduction

The term “ground” in the context of electrical engineering took shape with the invention of modern utility electricity and telegraph systems, where it was discovered that the Earth ground could be used to carry the return current.

In modern-day utility electricity standards, an uninterrupted Earth ground wire is required that runs from the source to the loads. This ground is also referred to as equipment ground. The purpose of the equipment ground is to prevent metal parts from being energized in situations such as broken insulation of the main conductors. Sometimes people also refer to the grounded neutral as “ground”. Strictly speaking, a distinction should be made between the two. Neutral completes the loop with “hot” or “line” and is the return path for the load current. Although it is connected to Earth ground at the main distribution panel, it is prohibited to do so at the point of load such as an outlet.

Figure 1-1 is a one-line wiring diagram for a typical household electrical system in the US. It shows the connection from the breaker panel to various loads, as well as how grounding should be connected for the loads. A load may be any common household appliance, as well as electrical outlet.

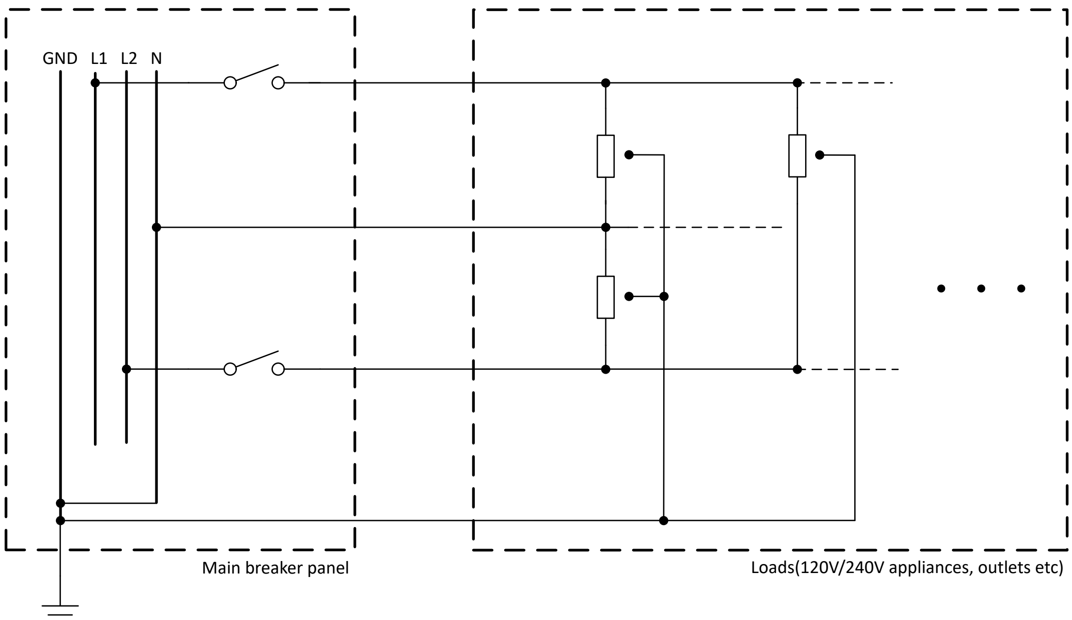

Figure 1-1. One-Line Diagram Of Utility Household Electric System in the US

In the semiconductor industry, the term “ground” is used even more loosely. Ground often simply refers to a common connection without any physical connection to Earth ground whatsoever. In other words, it has nothing to do with Earth ground. After all, electrical standards generally do not require Earth ground for low-voltage DC systems, a domain which a majority of semiconductor circuits fall into.

2 Grounding in DC Circuits

Ungrounded DC circuits are used on a daily basis. For example, a battery-powered system works just fine without any of the battery terminals being grounded. Simply put, the Earth ground is not needed for a DC circuit to function. However, safety is a concern for high-voltage systems (> 50 V).

In a grounded high-voltage DC system, if a person comes into contact with the power rail, electric shock can occur. While in an isolated DC system, such electrical shock should not occur. However, in reality either side of the power supply may become grounded due to a random first fault. A person will suffer electrical shock when coming into contact with the other side of the power supply in a second fault condition. Because such ground fault cannot be prevented in an isolated system, electrical standards such as NEC require high-voltage DC systems to be installed with proper Earth grounding. Ground fault, overcurrent, and overvoltage protection devices are then installed accordingly to ensure safety.

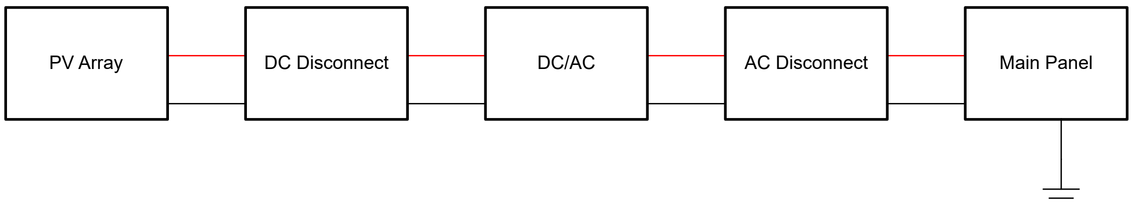

Figure 2-1. A Grounding Scheme of Grid-Tied PV System

Figure 2-1 shows one common grounding scheme of a grid-tied photovoltaic (PV) system which typically falls into the high-voltage category. The red lines connecting different components represent current-carrying conductors; the black lines represent uninterrupted grounding conductor or equipment ground conductor. In this grounding scheme, the DC grounding electrode is combined with the AC grounding electrode.

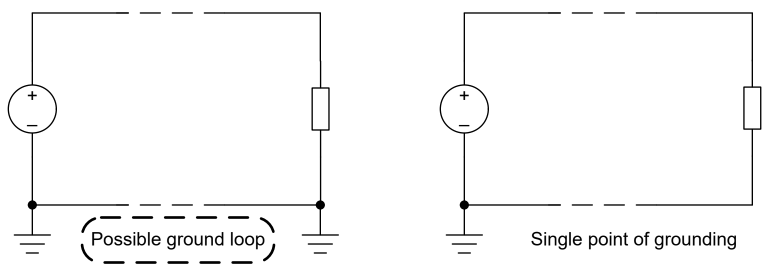

Figure 2-2. Ground Loop and its Prevention

Ground loops form when multiple grounding electrodes exist, and there is a voltage potential between any two. Figure 2-2 shows ground loops can form when multiple grounding electrodes are provided. To prevent ground loops, use a single grounding electrode wherever possible.

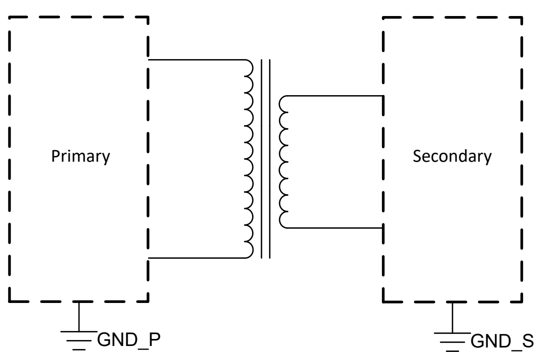

Figure 2-3. Isolated Grounds

While an Earth ground is not absolutely needed, a “ground” or “common” is. An exception are isolated circuits, such as those enabled by transformers and galvanic isolation barriers, where there could be two or more grounds defined by different voltage potentials. However, within each isolated domain, a single common ground still provides reference to all components. Such an isolated system is shown in Figure 2-3, where the primary side ground is separated from the secondary side ground. The two grounds can be defined by different potentials.

Multiple grounds are often defined even in a non-isolated circuit. An example is a typical mixed-signal system where analog ground and digital ground may be defined. To make matters more confusing, multiple grounds are often found for the seemingly identical ground. This type of ground partitioning is often found in applications where the exact same circuitry is cloned multiple times as shown in Figure 2-4. Schematic-wise, each clone might be put on a uniquely named ground which is typically designed to be one or multiple inter-connected ground planes in the PCB.

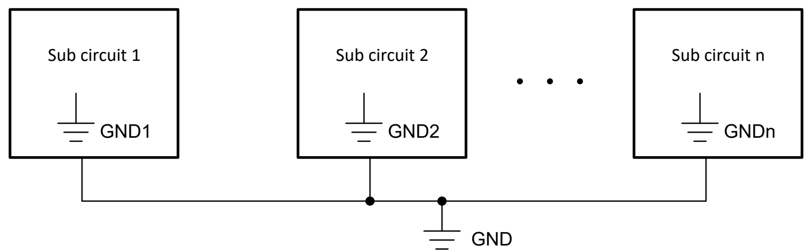

Figure 2-4. PCB STAR Grounding

However it is accomplished, the goal of ground partitioning is to minimize interference and keep noisy circuitry away from the sensitive one. Furthermore, regardless how the ground is partitioned, all grounds will eventually be electrically connected to a single common point. In essence, each of the grounds constitutes an island on which a subsystem operates. It is sometimes not possible to contain all recirculating current within the island. In these situations, the ground plane and traces must be routed such that the current path does not pose interference to other sensitive parts of the system.

3 Grounding in Isolated Current Sensing Applications

Three technologies stand out as integrated, isolated current sensors. They are shunt-based isolation amplifiers or modulators, fluxgate sensors, and in-package Hall-effect sensors.

Shunt-based isolation current sensing employs isolated amplifiers or modulators. Figure 3-1 illustrates an example. The AMC1300 input is similar to a non-isolated current-sense amplifier in that the small differential voltage, which rides on top of a large common-mode voltage, is extracted and amplified. The output is separated from the input circuitry by an isolation barrier that is highly resistant to magnetic interference. The input and output operate in different power domains, each with its own power supply and ground. From the point of view of downstream measuring circuit, the load current is completely isolated, and no return path is needed for the input bias current.

The isolation between the high and low sides are evident in the physical layout. The two sides are separated by an area void of any conductive material. There is no common ground connection between the two sides.

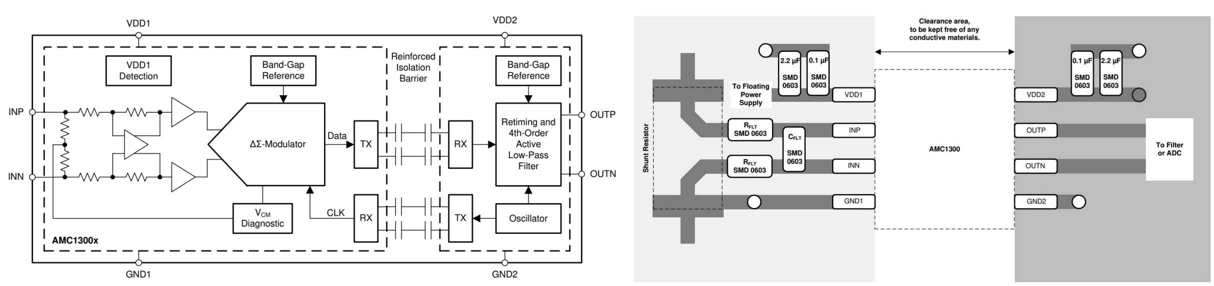

Figure 3-1. Isolated Amplifier AMC1300 Block Diagram and PCB Layout

Magnetic sensors work without making physical contact between the sensor IC and the current it is measuring, thanks to their inherent isolation through magnetic fields. A galvanically-isolated barrier is possible that can withstand very high common-mode voltages.

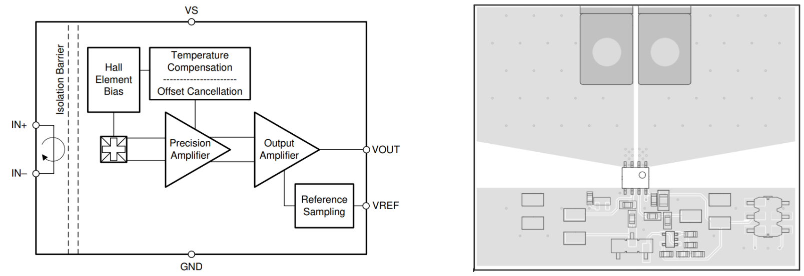

Figure 3-2. Hall-Effect Current Sensor TMCS1100 Block Diagram and PCB Layout

An example of in-package Hall sensor is the TMCS1100 family, shown in Figure 3-2. Within the device, the high-voltage side load current passes through the low-ohmic lead frame path. No external components, isolated supplies, or control signals are required on the high-voltage side. At the low-voltage side, the magnetic field generated by the input current is sensed by a Hall sensor and amplified by a precision signal chain.

Also shown in Figure 3-2 is a recommended layout of the TMCS1100. The layout is optimized for thermal performance while at the same time minimizes stray magnetic field interference. A large creepage area is visible between the high side and low side. There is no common connection between the two sides and they are physically isolated.

4 Working Principle of Non-isolated Current Sense Amplifiers

Shunt-based Current Sense Amplifiers (CSA), also known as current shunt monitors, measure current by amplifying the voltage drop across the shunt resistor while rejecting the influence from common-mode input voltage. Unless specifically noted, the term CSA represents non-isolated analog output current-sense amplifiers throughout this article.

Based on the location of the shunt resistor, current-sensing topologies are classified into three categories – high side, low side, and inline. While low side current sensing topology has the advantage of avoiding large common-mode voltage, it does come with drawbacks including ground disturbance. For high side, the CSA must solve the challenge of tolerating common-mode input voltage which is typically much higher than the power-supply voltage itself. Rather than working with constant common-mode input voltage, inline current sensing experiences PWM-type common-mode input which poses a unique set of challenges.

A general-purpose high-performance CSA that is suitable for high-side configuration must be capable of the following specifications: wide common-mode input range, high CMRR, low V_{OS}, high gain, and high bandwidth. There are numerous other specifications, which together with those listed can be tailored to target a specific segment of applications. It is rare, if possible at all, to create a CSA that is suitable for all applications. One of the first challenges in designing with a general purpose CSA is to choose one that strips the high common-mode voltage while amplifying the differential input with sufficiently large gain.

Although the selection of analog output CSA is quite large, most are classified into three categories based on topology.

4.1 Single or Multi-stage Difference Amplifier

This topology resembles the classical diff amp, designed as either single stage or a cascade of two. The total gain equals to the product of the gains of all stages. The CMRR of this topology depends on the matching of resistors. Some form of trimming is necessary to achieve high CMRR. Figure 4-1 shows a block diagram of a CSA based on diff amp topology.

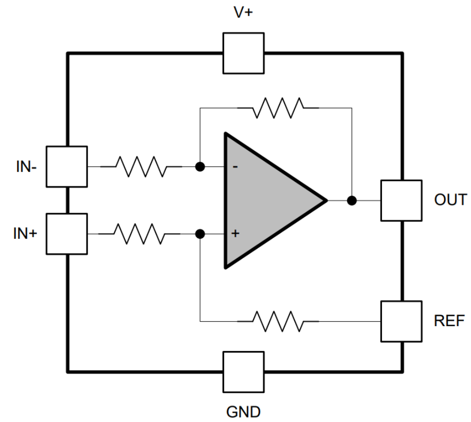

Figure 4-1. Single-Stage Diff Amp Based CSA

4.2 Current Feedback

In this topology, the differential input voltage is imposed on the input resistor, producing an output current that passes through the load resistor. The gain equals to the ratio between the load resistor and the input resistor. The main advantage of this topology is that the input bias current is decoupled from common-mode input voltage and is relatively constant. Unlike the diff amp topology where the common-mode voltage has direct resistive paths to ground through the gain setting resistors, the common-mode impedance can be very high. The only source for bias current is the input bias current of the op amp.

Figure 4-2 shows several variations of the current feedback topology. To the left is a basic form which is unidirectional and only works when the differential input voltage is positive. The basic form also has common-mode limitations and will not function near ground. To the right is a variation where an output buffer is integrated to provide an output voltage, and avoid loading by downstream circuitry. In the middle is a variation adapted from the basic form to accommodate bidirectional current sensing. A second input amplifier is integrated thereby extending the input common-mode range to include ground and negative voltages.

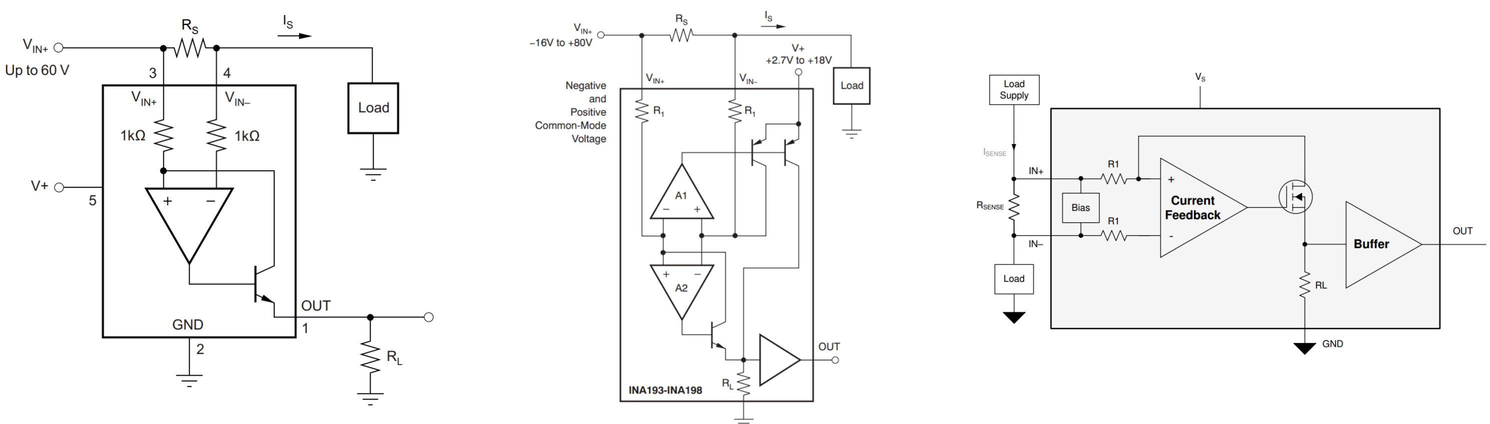

Figure 4-2. Current Feedback CSA

4.3 Switched Capacitor

Figure 4-3 shows a switched capacitor CSA. In this topology, flying capacitors are used to sample the voltage across the shunt resistor and stripping off the high-voltage common-mode component from the input. The input bias current can be very small when it is made up of only the capacitor charging and discharging current. A second stage is used to provide additional gain and accomplish differential to single-ended voltage conversion. The second stage is normally a simple diff amp.

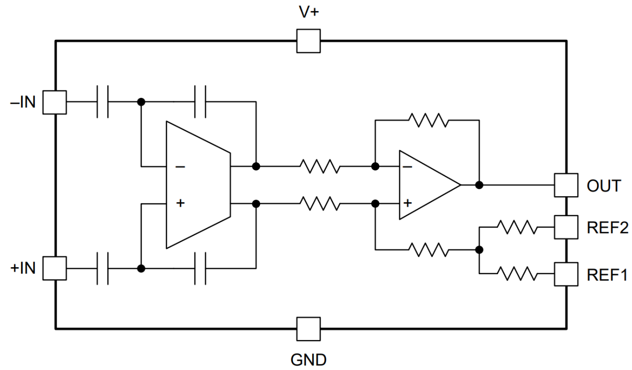

Figure 4-3. Switched Capacitor CSA

4.4 Input Stage and Input Bias Current

A general-purpose CSA must work with common-mode voltage that far exceeds the power supply. For example the common-mode voltage could be 80 V while the supply voltage is 5 V. This is achieved with transistors and capacitors that are capable of standing off high voltage, enabling the rest of the circuitry to employ low-voltage devices. A dominant input stage configuration is a common base or common gate where the input signal is coupled to the emitter or source of the transistor pair. The common-mode voltage is used to power the front end amplifier when it is sufficiently high, or higher than the power-supply voltage. A comparator and simple resistor-based common-mode sensing enables the transition between the two power rails. Bias current is drawn from the common-mode voltage source when it is used to power the front amplifier. Figure 4-4 shows a block enclosed by the red dashed box, which represents the common-mode sensing and supply function. This block is sometimes referred to as "Bias" in some data sheets. Normally a pair of resistors of larger value is used to sense the common-mode voltage level, which is passed onto the supply selection circuitry including the comparator. A second pair of much smaller value passes the common-mode voltage to the front amplifier when chosen as power source.

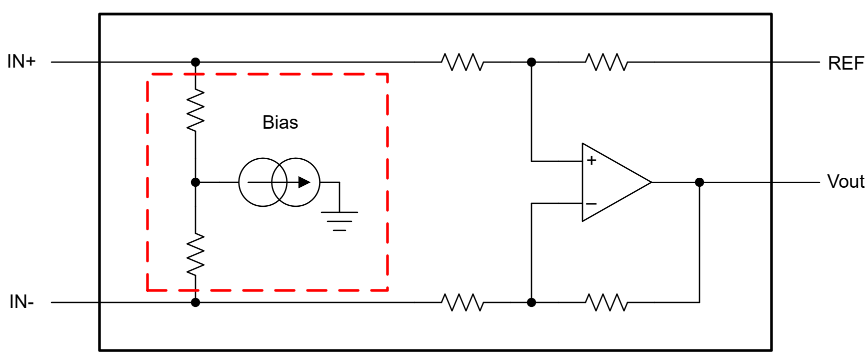

Figure 4-4. Bias and Common-Mode Sensing in CSA

The bias current for this type of input stage usually ranges from 10 μA to 100 μA under nominal working conditions and sets the low limit of the current to be measured. While this level of bias current is negligible in most power supply monitoring applications, it does pose a threshold in applications where small currents need to be measured accurately. When not distinguished, "bias current" refers to both the positive and negative input bias current associated with the positive and negative input pins respectively. Because of the structure of the common-mode sense resistor pair, the two input bias currents are equal only when the differential input voltage equals to zero. They start to diverge as the differential input voltage deviates from zero volts. The increase or decrease is generally linear. However, there are exceptions if there is clamping circuitry and such circuity is activated.

Switched-capacitor architecture offers an alternative in this situation because it eliminates DC bias current entirely. However, the bias current is not zero as a result of capacitor charging and discharging. In this category, it is routine to find CSA with I_b on the order of 10 μA. Recent development has pushed I_b lower considerably, with 1 nA specification commonplace.

Contrasting with CSA, digital power monitors measure both shunt voltage and bus voltage with an integrated ADC. An internal math engine converts these quantities and outputs a bit stream that represents current, voltage, and power. Some are able to keep time and therefore can calculate energy and charge. Most digital power monitors employ a hybrid ADC that samples the input voltage directly, though some comes with a front-end programmable gain amplifier to accommodate a wide input range. Similar to switched capacitor analog CSA, small input bias currents can be achieved with some on the order of 1 nA. However small, it is not zero and may need to be considered in an application circuit.

5 Grounding in Non-isolated Current-Sensing Applications

The input bias current constitutes a portion of the load current being measured and is supplied by the same supply. Although this current is normally negligible comparing to load current, it is nonzero. A return path must be provided for this current for the CSA to work properly. This is the fundamental reason a non-isolated CSA cannot be used in the same fashion as an isolated CSA.

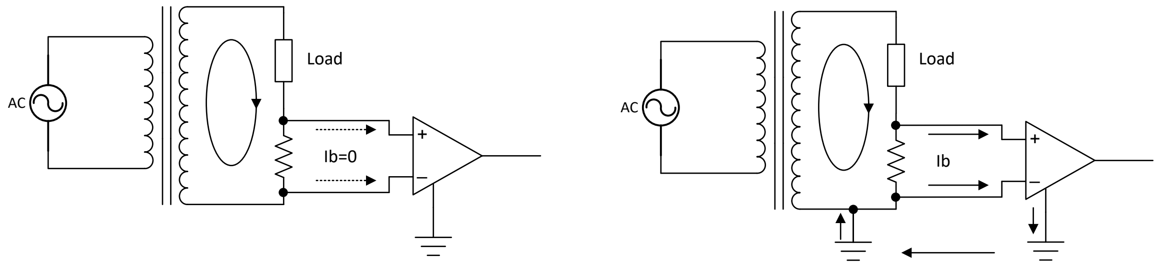

Figure 5-1. Without (Left) and With (Right) Return Path for Input Bias Current

Figure 5-1 shows an application where current in the secondary coil is measured. The primary side of the transformer is driven by an AC source; the secondary side is connected to a load. An AC recirculating current flows through both the load and the shunt resistor, and develops a small signal AC voltage across the shunt resistor. This AC shunt voltage in turn creates an AC input bias current that is equal but opposite in direction on the positive and negative input pins of the CSA. It is important to distinguish between the AC input bias current and the DC input bias current which is denoted by straight arrows in the graph. The AC bias current recirculates in the loop made up of the secondary coil and the common-mode sensing circuity inside the CSA. The DC bias current flows into the CSA and exits through the ground pin. On the left of Figure 5-1 is a setup where no return path is provided for the input bias current. Because the secondary coil is not connected to the same ground, the CSA is not able to draw DC current from the input pins, and it is effectively isolated from the secondary coil. The right side of the image is a setup where the secondary coil is connected to the same ground as the CSA, thereby completing the current return path.

If the shunt voltage is small, the AC input bias current approaches zero. Such scenario is depicted in Figure 5-2, where the shunt resistor is removed. The CSA is chosen to be bidirectional and the reference pin is set to 3.3 V; the power supply is set to 5 V. The absolute values for reference and supply are not critical, as long as they are allowed by the CSA, and they enable free movement of the output voltage under input disturbance. This experiment demonstrates the effect of return path for the DC bias current.

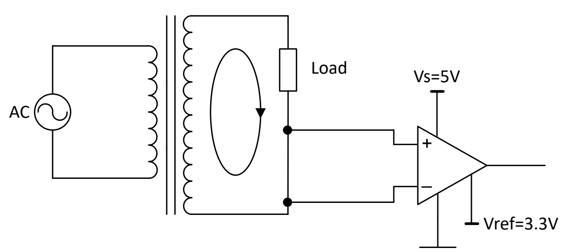

Figure 5-2. Experimental Setup

The secondary coil output is presented to the CSA as common-mode input voltage, as shown in Figure 5-3 (channel 2, red). The CSA output is measured by channel 1 (yellow). Because the input pins are shorted together, ideally the CSA output should be stable and equal to the 3.3-V reference voltage. Instead severe distortion up to a few hundred millivolts is observed. Such distortion will be a problem for accurate measurements.

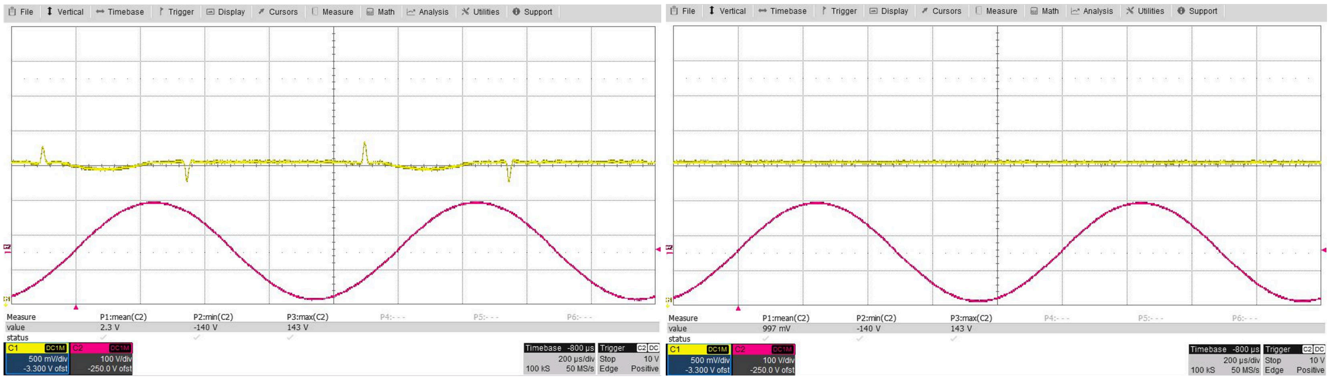

Figure 5-3. Output Waveform With Floating (Left) and Grounded (Right) Input

It is worth noting that even though the secondary coil output voltage is several hundred volts peak to peak, the CSA sustains no damage. This is because there is no current flowing into the CSA. In this case, isolation saves the CSA from physical destruction.

To prevent the distortion, a return path must be provided for the DC input bias current. The simplest approach is to ground the end of the coil where the shunt resistor is located, shown on the left side of Figure 5-4. This effectively turns the topology into a low-side sensing, where the CSA has a defined working common-mode voltage that is zero volts and within its specified range.

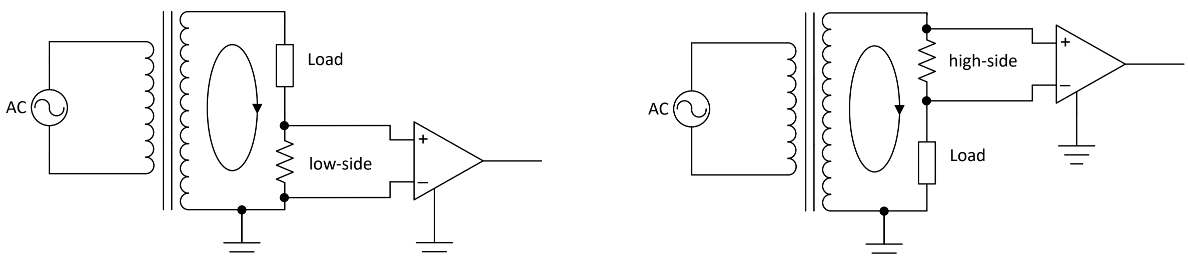

Figure 5-4. Grounded Secondary Coil for Low-Side (Left) or High-Side (Right) Current Sensing

Because most CSA have asymmetrical input common-mode input range, such as –4 V to 80 V, a high-side configuration may not be feasible for the circuit in Figure 5-4. Because the common-mode voltage detected by the CSA is the full-scale output of the secondary coil, and it may exceed the common-mode input range. Damage to the CSA is possible now that the current has a complete return path.

Now examine an example where a CSA is being used in AC-coupled configuration. As shown in Figure 5-5, the CSA input is coupled to the differential input voltage through a pair of capacitors. No external DC path for the input bias current is provided.

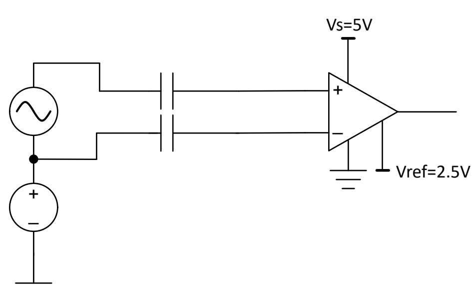

Figure 5-5. AC-Coupled CSA

Figure 5-6 shows a few screen shots of the output. It is evident that the DC level is random and the output is unpredictable. A pair of resistors to ground should provide the DC path for the input bias current. However, due to the relatively large input bias current, resistors of significant value may cause large offset, which may render the solution unviable.

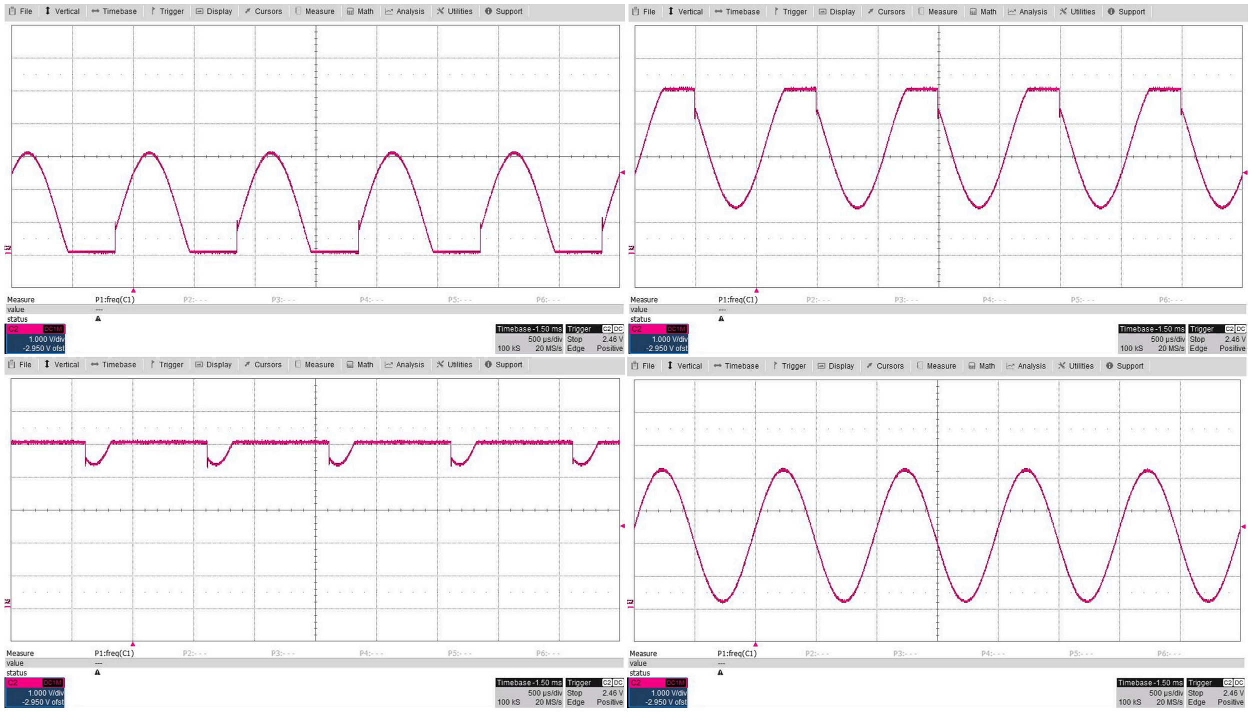

Figure 5-6. Unpredictable Output of AC-Coupled CSA

6 Level Shifting for High-Voltage Current-Sensing Applications

Voltage level shifting is a technique sometimes used to adopt a CSA even though the input common-mode voltage exceeds its specified range. This technique essentially floats the CSA relative to the common-mode voltage. Voltage level shifting takes advantage of the common-mode voltage source and uses it as one of the supply rails (that is, ground or supply) of the CSA depending on its polarity. The other corresponding supply rail is generated by an external circuitry. As a result, the CSA is operating in an environment that is voltage compliant.

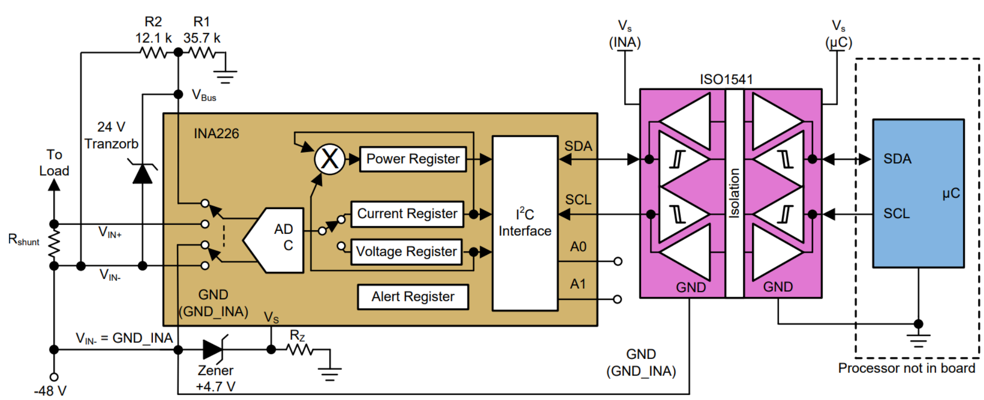

Figure 6-1. –48-V Power-Sensing Reference Design

Figure 6-1 shows a –48V power sensing reference design for telecom applications. This design can accurately measure current, voltage, and power on a –48-V bus. The INA226 device is selected to monitor the shunt voltage and the bus supply voltage. This information, together with calculated power is retrieved through the I2C interface. Because the INA226 is limited to a common-mode input voltage range of 0 V to 36 V, it cannot be used directly in the –48-V application. In this design the –48 V is used as the ground rail of INA226. A simple shunt regulator employing a Zener diode provides the necessary supply voltage relative to the –48-V ground. A voltage divider consisting of resistors R1 and R2 presents to the Vbus pin a scaled version of the –48 V. Doing so helps to limit the input voltage to within specified range.

The ISO1541 is a low-power, bidirectional I2C compatible bus isolator. The ISO1541 provides the necessary isolation between the high-voltage side and the low-voltage side.

Figure 6-2 shows a similar technique used to design an accurate current sensing solution for common-mode voltage of up to 400 V, which is limited by the PNP transistor breakdown voltage. Similar to the –48-V example, the 400 V is used as one of the power rails. Although instead of ground, it is used as the power-supply rail of the INA138. Similarly, a Zener shunt regulator is used to generate the device ground for INA138, creating the necessary working voltage for it.

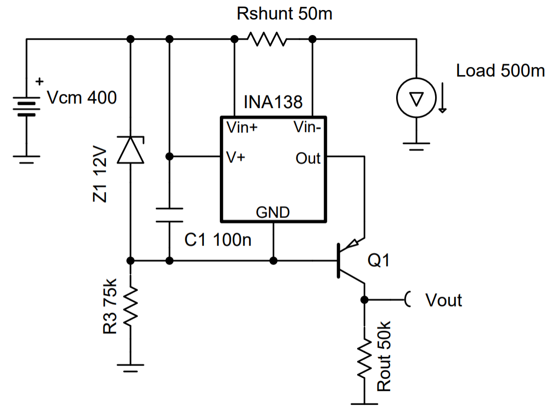

Figure 6-2. 400-V Current Sensing

7 Grounding in Motor Current-Sensing Applications

Accurate phase current sensing is critical in motor control applications. A poor current sensor may lead to large torque ripple, audible noise, and inefficiency. This section explores the origin of input voltage spikes experienced by CSA in typical motor applications. Explanations of some of the commonly-asked questions are provided, such as why the CSA needs to be able to withstand negative common-mode voltage even when it is used in the low side of the inverter; or why the CSA needs to be configured as bidirectional. Due to switching noise, component placement and layout is an integral part of a good motor drive design, an example of how to minimize interference and contain switching noise is provided.

Motor phase currents are measured in the following ways:

- DC link current, either high side or low side
- Inverter leg currents, either high side or low side
- Direct inline with the motor windings

Due to relaxed requirements for the CSA, low-side current sensing has been the most widely adopted topology, whether it is to sense the DC link (VBus) current or the inverter leg current. The current sensor can be either isolated or non-isolated. The selection is based on parameters such as performance, cost, and applicable end equipment standards. DC link voltage plays a large role in high-side current sensing, which ranges from a few volts to hundreds of volts. Figure 7-1 shows common current-sensing topologies in motor drive. Switches Q1 though Q6 make up the inverter output stage.

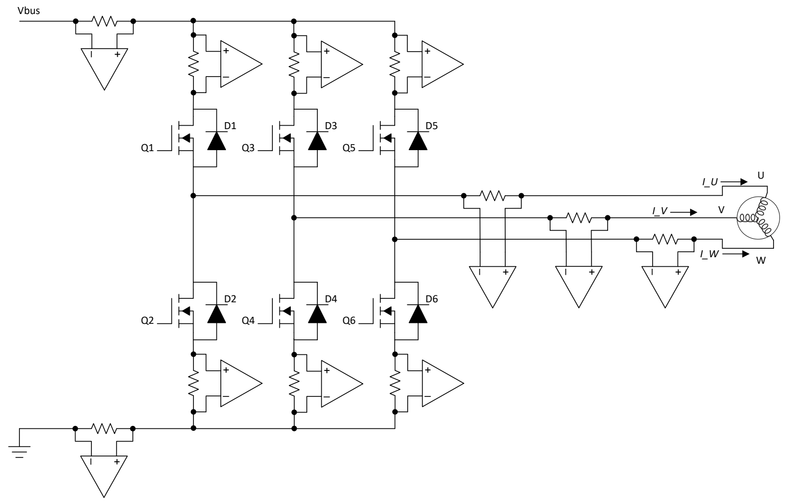

Figure 7-1. Common Motor Current-Sensing Topologies

Trapezoidal control of BLDC is a popular commutation method due to its simplicity. In trapezoidal control, the combination of the six switches defines six conduction zones. In each conduction zone one pair is turned on and rotates in the following order: (Q5, Q4), (Q1, Q4), (Q1, Q6), (Q3, Q6), (Q3, Q2), (Q5, Q2). The motor winding current in phase U is shown in Figure 7-2 for a complete electrical cycle. The other two phases are identical, except they are successively 120° out of phase.

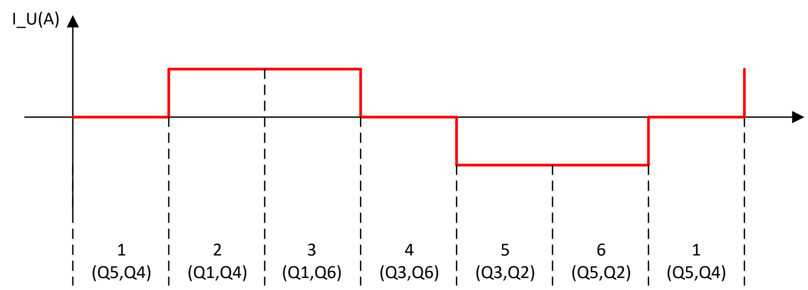

Figure 7-2. Ideal BLDC Motor Phase Current

In conduction zones 2 and 3, phase U current flows through Q1 and can be measured by high-side CSA; in conduction zones 5 and 6, phase U current flows through Q2 and can be measured by low-side CSA. An inline CSA can measure the current in both cases.

Figure 7-2 shows the DC current in its ideal form, ignoring the effect of motor inductance and switching. In reality, the instantaneous change of current is impossible, instead the vertical lines will resemble ramps. There are also glitches due to commutation and PWM duty cycle if the phase current is being modulated. For the purposes of this article, such ideal approximation is sufficient.

7.1 Common-Mode Voltage of Motor Current Sense Amplifiers

Figure 7-3 shows the current flow when the inverter switches from conduction zone (Q1, Q6) to (Q3, Q6). In zone (Q1, Q6), motor windings U and W are energized. Phase currents are indicated by the black dashed arrows. Next the inverter proceeds to zone (Q3, Q6) where windings V and W are energized. Phase currents are indicated by the red dashed arrows. At the transition between zones (Q1, Q6) and (Q3, Q6), Q1 turns off and Q3 turns on while Q6 is kept on. The current in winding U does not stop abruptly, instead it continues to flow through the freewheeling diode D2 and gradually decreases in magnitude.

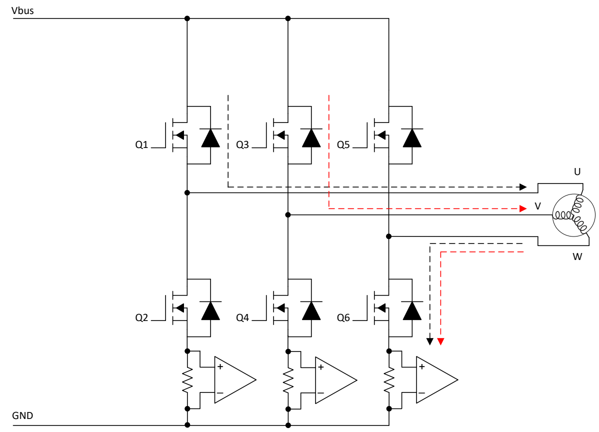

Figure 7-3. Switching of Motor Phase Currents

Figure 7-4 shows what occurs when the decay current flows through the low side diode. Inductance L represents parasitic inductance on PCB. There is no current flowing in L until the start of zone (Q3, Q6). At the moment when Q1 is turned off, current in L increases from zero to the initial value of the decay current instantaneously.

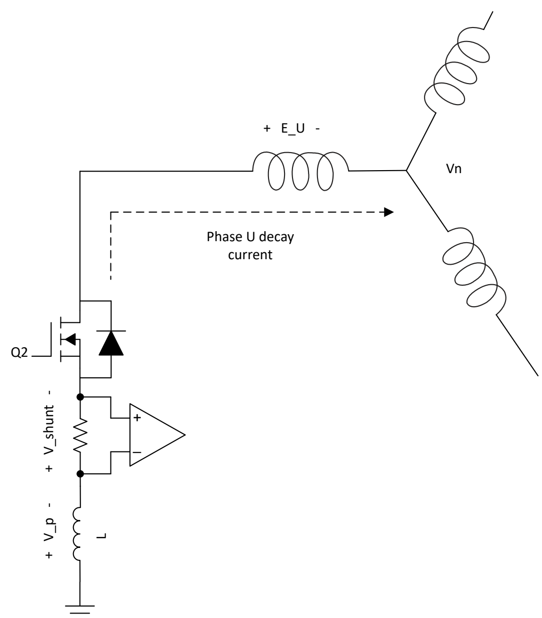

Figure 7-4. Freewheeling Current Though Low-Side Diode

The fast change in current induces an opposing voltage across L. To the CSA, this voltage appears as a negative common-mode voltage spike. This is illustrated in Figure 7-5 to the bottom. Such negative surge spike occurs at least once every electrical cycle and is repetitive in nature. If the spike's magnitude exceeds the input range of the CSA, it may weaken the physical structure of the CSA. This effect may need to be considered when selecting the CSA. Best practices in PCB layout should also be followed to minimized parasitic inductance.

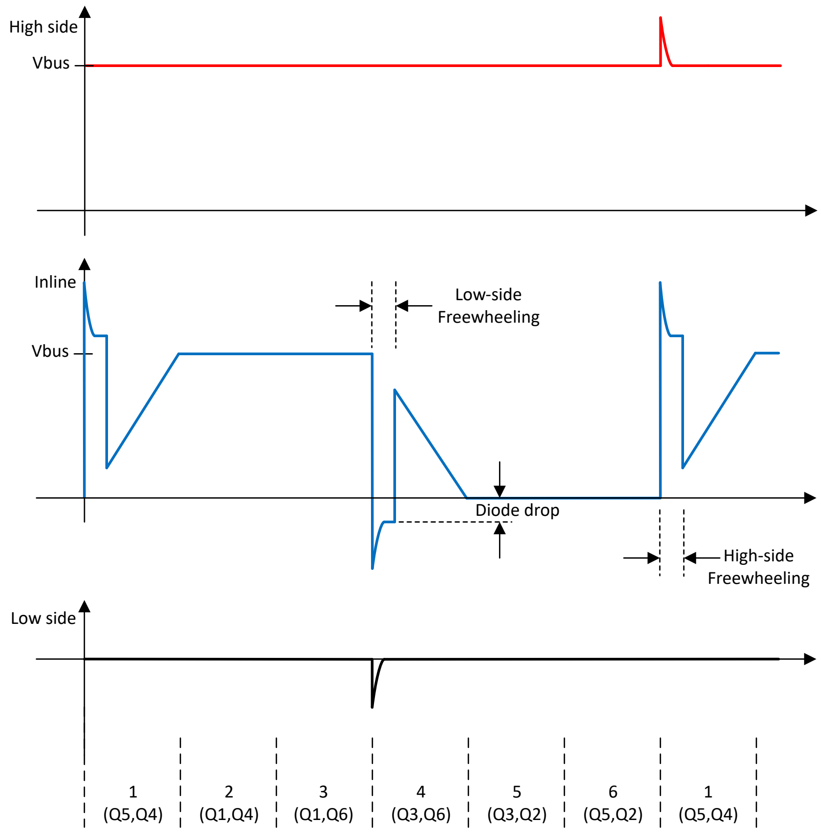

Figure 7-5. Common-Mode Voltage (Not to Scale)

In high-side current sensing, a similar effect is caused by parasitic inductances between the DC link and shunt resistor. It happens when motor winding switches from being driven with negative current to undriven, and the top side diode (D1 for example) conducts. However the surge is positive and adds to the DC link voltage, increasing the common-mode voltage burden of the CSA. This effect is shown in Figure 7-5 to the top. Similar to low-side, the surge is repetitive and occurs at least once every electrical cycle.

In inline current sensing, where the sense resistor is placed between the switching node and motor winding, the CSA experiences the full-scale ground to Vbus voltage as input common-mode while the inverter leg is being PWM modulated. The worst case occurs at the moment of commutation when either the top or bottom diode conducts. The diode drop is superimposed on ground or Vbus potential, as well as any spikes due to parasitic inductance. This situation is illustrated in Figure 7-5 to the middle. For better clarity, this plot is made assuming 100% PWM duty cycle.

7.2 Directionality of Motor Current-Sense Amplifiers

The conducting phase current and decay current flows in opposite directions. If the CSA input is connected such that conducting phase current develops a positive input voltage across the shunt resistor, the decay current will develop a negative input voltage for the CSA. The decay current will consequently push the CSA output toward ground. The negative input voltage due to decaying phase current is illustrated in Figure 7-6.

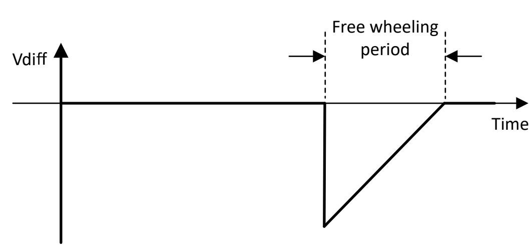

Figure 7-6. Negative Differential Input Voltage due to Decaying Phase Current

If a unidirectional CSA is used, it will be pushed into saturation by the negative shunt voltage. A deep saturation may take such a long time to overcome that the CSA is not ready to respond when the next conduction cycle comes, where it is tasked to provide a valid output value that is proportional to the phase current. For this reason, the CSA should be configured as bi-directional, so that it stays in linear operation region throughout the entire commutation cycle.

It should be noted that shunt resistor parasitic inductance can exacerbate the effect of decay current by creating a differential voltage spike, which adds to the negative differential voltage. For this reason, it is better to choose shunt resistors of low inductance. Smaller passive components tend to offer smaller parasitic inductance.

7.3 PCB Design for High-Performance Motor Drive

Similar to switched power supplies, the motor drive environment is inherently noisy and prone to Electromagnetic Interference (EMI), care must be taken in the PCB design phase. One critical aspect is the treatment of grounding, and layout practices that help minimize impact from grounding parasitics. Component placement and PCB layout play an important role in optimizing a motor drive design.

It is good practice to separate the inverter stage from the rest of the circuitry including the CSA. Grounding planes and power planes should be partitioned to achieve a minimum inductance design. Minimum current loop should be implemented for the switching nodes. Signal traces including those of current sensing should stay clear of the switching nodes. They should not run directly above or below the switching nodes and planes that carry recirculating current. Within the inverter stage, separate grounding islands can be created for each switching node to contain local recirculating current, this goes hand in hand with the goal of minimizing parasitic inductance.

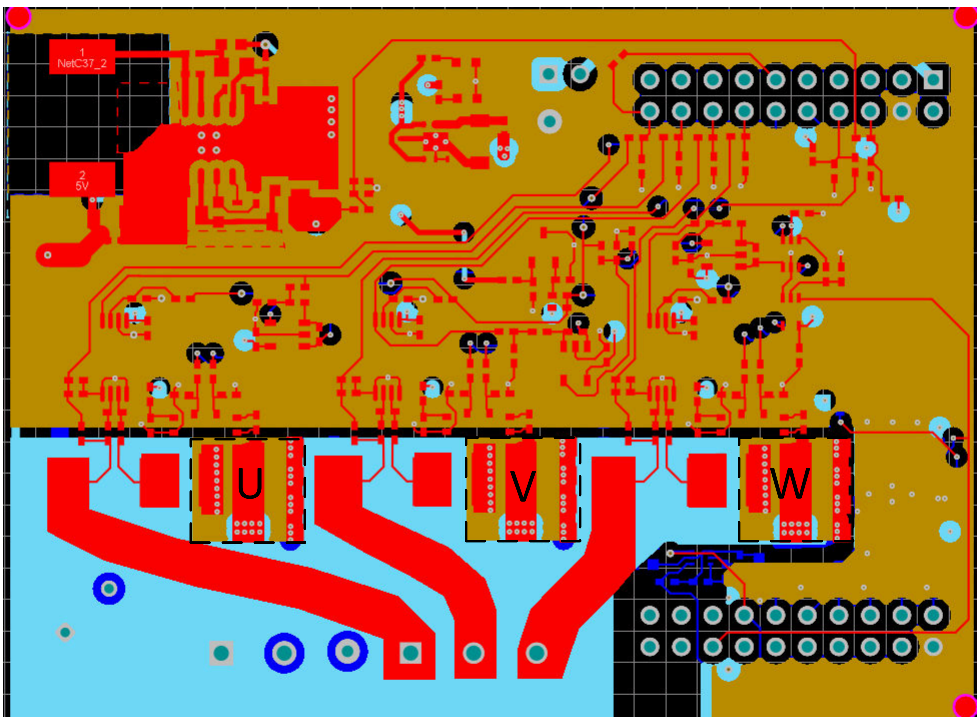

Figure 7-7. 48-V Motor Drive Design

Figure 7-7 is an example of a 48-V BLDC motor driver design with inline shunt based current sensing, it is implemented on a 4-layer PCB. The inverter stage including shunt resistors are located in the lower left part of the board, colored in light blue. The rest of the board is reserved for control circuitry and is located in the area colored yellow. Copper planes are created for power supplies and ground. A smaller ground plane is created for each of the switching nodes. These three smaller areas can be seen highlighted and noted as U, V and W in Figure 7-7. These local ground planes minimize current return loop for the switches and help contain switching noise.

8 Summary

A return path must be provided for the input bias current of non-isolated current sensors. This is normally done by sharing the same ground with the source being sensed. Through circuit techniques such as level shifting, it is possible to adopt current-sense amplifiers for high-voltage applications which are otherwise impossible. For motor drive current sensing, it is important to identify the suitable current sensor for the topology, recognizing voltage and timing requirements. PCB layout is just as important as the schematic design itself. It is critical to optimize component placement, minimized recirculating current loop, and provide solid ground planes. Follow best practices to reduce parasitic and interference, thereby reducing overvoltage and undervoltage spikes for the current sensor.

9 References

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- Texas Instruments, *BOOSTXL-3PhGaNInv Evaluation Module*
- Texas Instruments, *Simplifying Current Sensing* E-book
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