Application Report
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Implementing Voltage References and Supervisors Into Your Traction Inverter Design

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ABSTRACT

The focus of this application note will be demonstrating how voltage references and supervisors fit into the success of designing a high performance, traction inverter design.

Contents

List of Figures

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1 Introduction

Many automotive systems implement some form of voltage supervision or monitoring. Voltage supervision can allow for additional safety in ensuring the power domains contained in the system are well-regulated. Additionally, several automotive systems need to provide precision voltage references for the high performance, analog signal conditioning, voltage and current morning, and power delivery sub-systems.

Voltage supervisors and references can be something that isn't well designed into systems due to improper part selection or incorrect design practices. The focus of this application note will be demonstrating how voltage references and supervisors fits into the success of designing a high performance, mixed-signal design. The system that will be highlighted will be a traction inverter, as it is an excellent example of a system whose performance can be hugely impacted by proper component selection and design of voltage reference and supervisor products.

2 Traction Inverter Designs

A traction inverter's goal in a hybrid (or electric) vehicle, for example, is to convert the DC battery power efficiently to AC power to drive an electric motor. The torque generated from this electric motor will in turn lead to the rotation of the drive shaft, with the end result being the turning of the wheels that are connected to the drive shaft. It is evident that automotive OEMs would like to make the energy transfer process as efficient as possible to achieve the most eco-friendly car. This application note will focus on ensuring that this goal can be met by designing in Texas Instruments' voltage reference and supervisor products into a hybrid or electric vehicle's traction inverter's system.

Highlighted below (Figure 1, Figure 2) are two traction inverter block diagrams that need to implement several instances of voltage supervision and references. These implementations can allow for high performance and additional safety, with very little additional board space consumption and component cost.

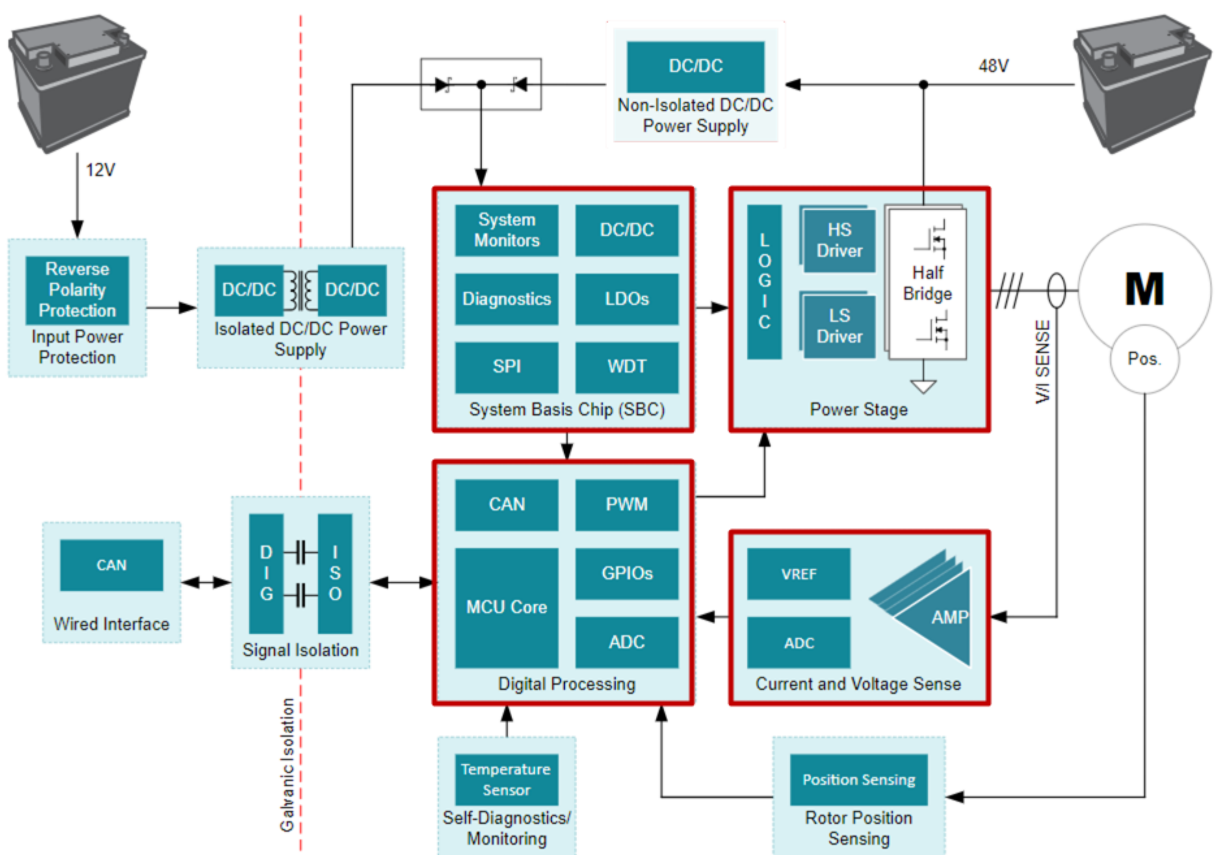

Figure 1. Starter Generation Unit Block Diagram

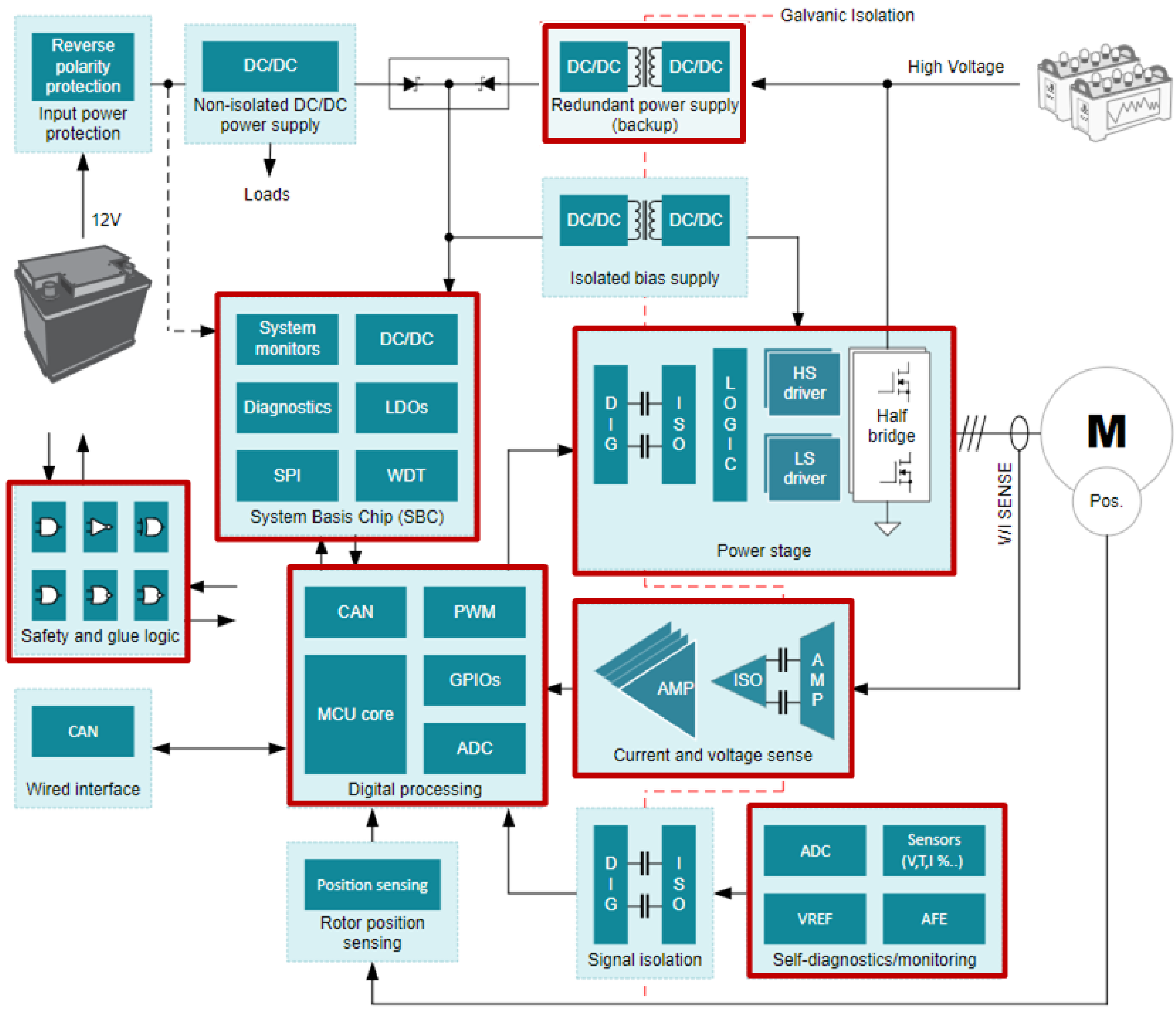

Figure 2. High Voltage Traction Inverter Block Diagram

Outlined in red are the sub-systems that can use voltage supervision and/or voltage references to achieve certain functionality. These specific functionalities could range from over (or under) voltage detection to designing a type 2/3 compensation network of a flyback converter.

This application note will go over design considerations for achieving the specific functionalities required by each sub-system of the traction inverter block diagram. Shown will be how to properly select Texas Instrument's voltage supervision and reference solutions and how to design them into your system correctly for additional safety and high system performance.

3 Design Example: Traction Inverter

3.1 System Basis Chip

The system basis chip(Figure 3) serves as the generator of the microcontroller (MCU) and its peripherals power. To ensure that the MCU does not enter an invalid logic state, or incorrect operation with its peripherals, voltage supervision must be performed. Additionally, to provide a mechanism to determine if the MCU's code is executing properly, a watchdog timer needs to be implemented into the system design.

Figure 3. System Basis Chip Entities And Functional Blocks

3.1.1 MCU and Transceiver/Controller Supply Monitoring

The supplies of the MCU must be monitored. This can be achieved by implementing a voltage detector/supervisor (Figure 4). This will ensure that the system will know when this power supply reaches its nominal value, such that, the devices it powers (MCU, SPI controller, CAN controller, etc.) can be properly sequenced. This can be accomplished quickly and accurately, with supplies of 1.8V and lower, with the low V_{POR} specification of TPS3840-Q1, as example. To learn more about the importance of V_{POR} on voltage supervisor performance, please read SNVA845: Mitigating the Indeterminate Output of a Voltage Supervisor (Reset IC) During Power Up/Down .

Most often DC/DC regulators have a “power good” signal to let the system know that it is properly regulating. While this might not always be the case, having a voltage supervisor additional to the “power good” signal could provide added safety and flexibility in the design. This additional safety comes from often having higher accuracy and being able to adjust the threshold, time delay, and hysteresis of the voltage supervisor.

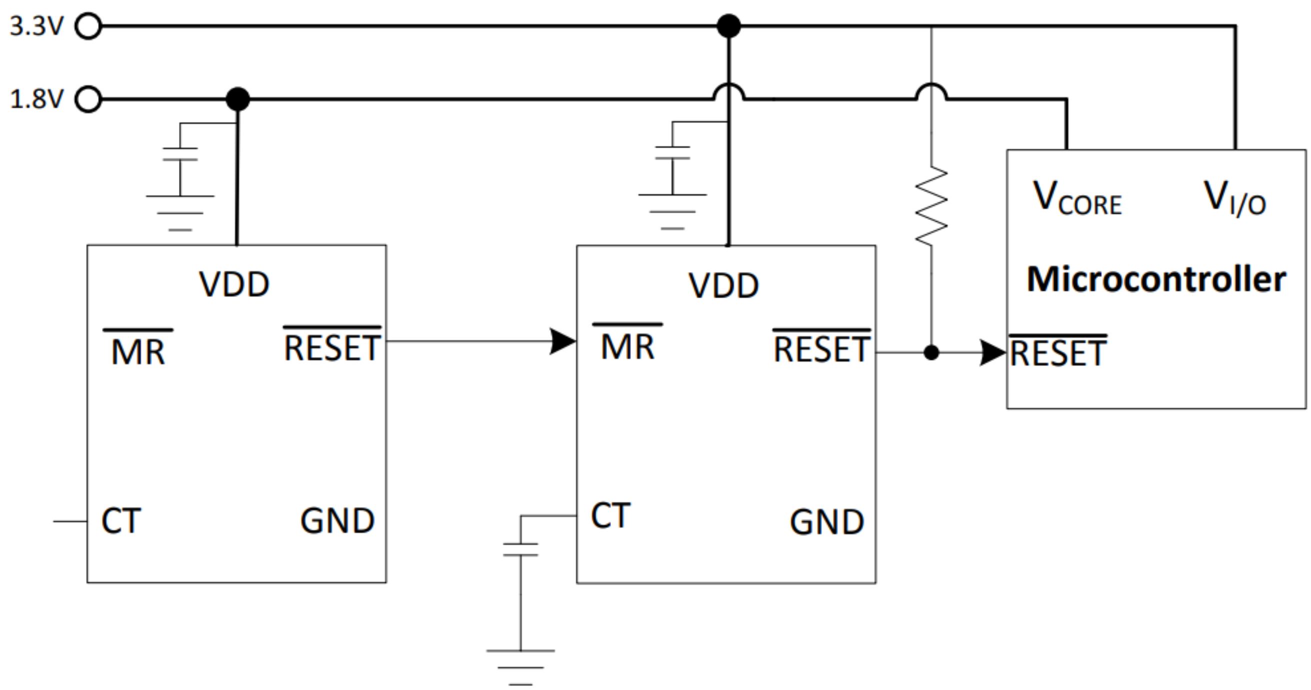

Figure 4. Micrcontroller Supply Monitoring With Voltage Supervisor(s)

3.1.2 MCU Watchdog Timer

Determining that the MCU is executing its code properly is with out a doubt of high importance to a mixed-signal design. Using the classic watchdog timer, the system can reset the MCU if it becomes "hung-up" in its execution. Without implementing a watchdog timer into a design, a manual reset would be required to restart the system.

While MCUs often have an embedded watchdog timer, these timers can be constrained in customization, or come with the required customization at a large price tag. TPS3430-Q1 and TPS3431-Q1 are excellent examples of watchdog timers whose programmable timeout and low quiescent current make it very appealing. Even if your design chooses to implement the embedded watchdog of the MCU, choosing to implement an external watchdog, as well, allows for additional safety, especially when implementing a window watchdog that catches early and late faults. Window watchdogs are often required to fulfill certain safety standards for automotive and industrial applications.

Additional to providing watchdogs with low power consumption, Texas Instruments provide watchdogs in two different variants, that is, windowed and standard. The difference between these two watchdogs is the detection method of determining a fault. Like the name sounds, a window watchdog will signal a "fault" if a valid input pulse is not received within a certain window, or time frame. A standard watchdog will only alert if a valid input pulse is not received before a certain period of time. This difference is illustrated below. The type of watchdog that should be chosen needs to be done to fit the individual system requirements.

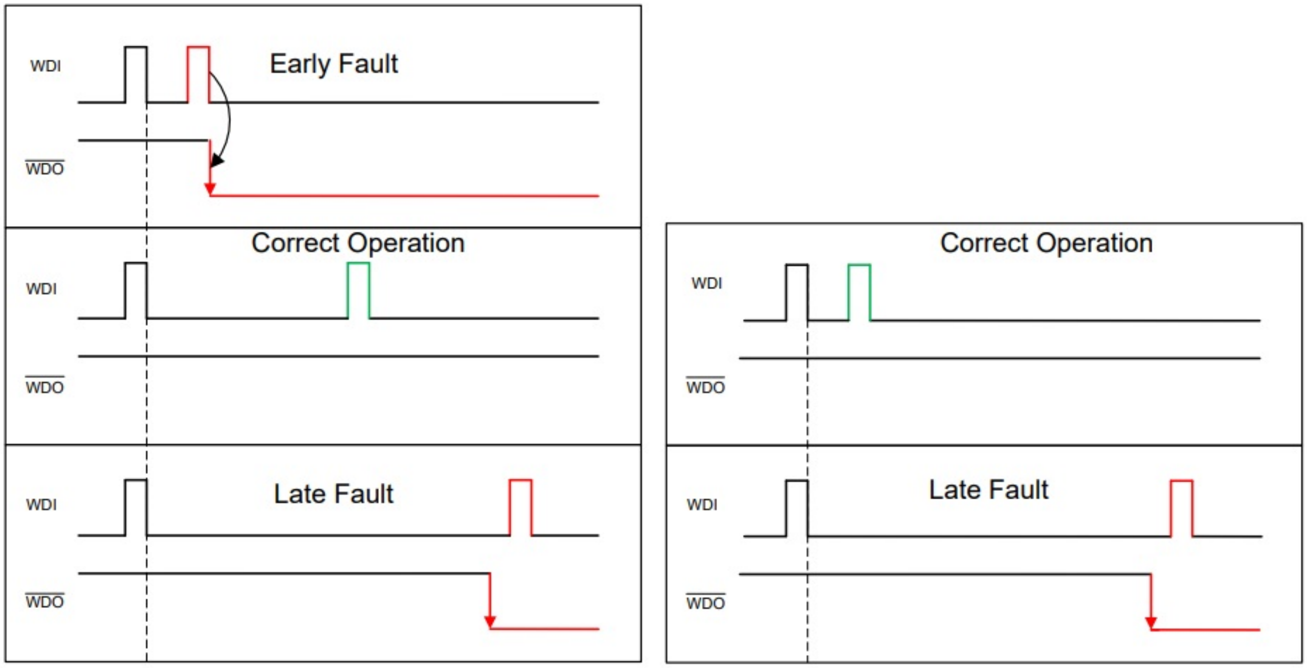

Figure 5. Window Watchdog (Left) Vs. Standard Watchdog (Right)

3.2 Safety and Glue Logic

Automotive safety is continuing to advance and requirements are becoming more stringent. Designers are always thinking about the "what if" situations and the "safety and glue logic" block is an example of this. This block serves as backup diagnostics for the system in case the main processor fails. With that being said, major items that should be monitored include the power domains contained in the system.

Figure 6. Safety And Glue Logic Entities And Functional Blocks

3.2.1 Off-Battery Monitoring

The need for off-battery monitoring stems from needing the ability to detect and alert the system of transients on the battery, or anomalies with the battery voltage.

Using the TL431LI-Q1 as a voltage comparator is one way to achieve this type of voltage monitoring. This use case with the TL431LI-Q1 has found to be well accepted by many designers due to TL431LI-Q1's accuracy/performance. Below is an example circuit topology for using TL431LI-Q1 as a window comparator.

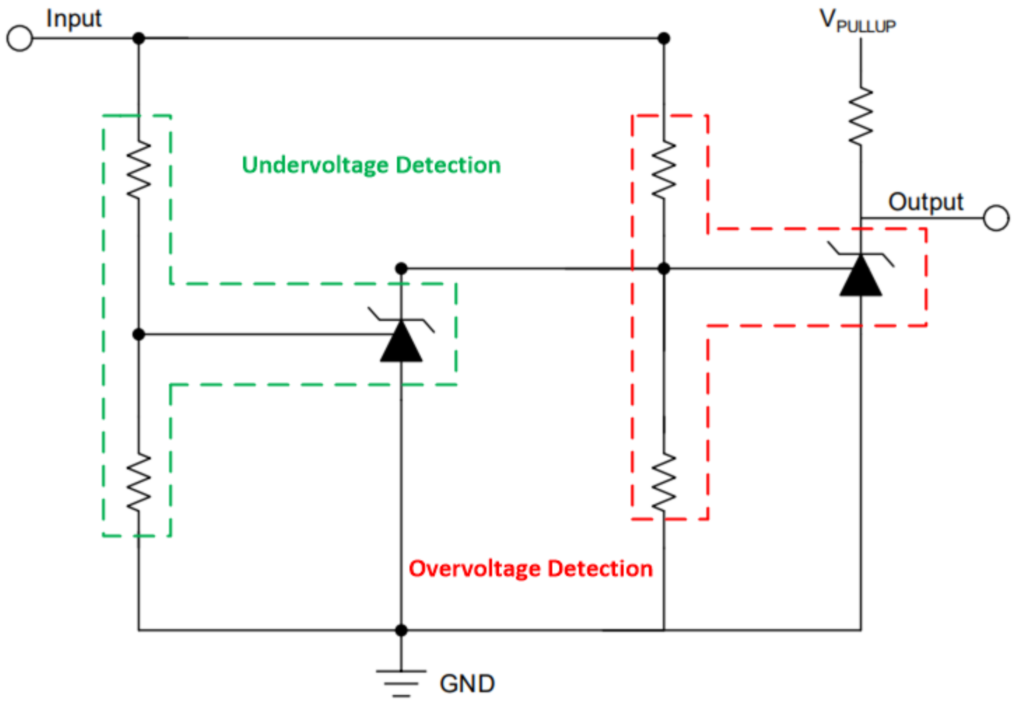

Figure 7. Circuit Topology for TL431 as a Window Comparator

NOTE: The overvoltage or undervoltage detection sections of the window comparator may be removed if functionality is not needed.

To better understand how TL431LI-Q1 can be used for voltage monitoring, please read SLVA987: Using the TL431 as a Voltage Comparator.

Another way battery voltage can be monitored is by using a discrete comparator and voltage reference, such as the ATL431LI-Q1 (or TL431LI-Q1). The selection of your reference should be dictated by overall system cost and performance requirements. Below is an example schematic that illustrates how measuring off-battery voltage can be achieved.

To better understand the differences between TI's 431 series devices, please consult the 431-Q1 selection guide.

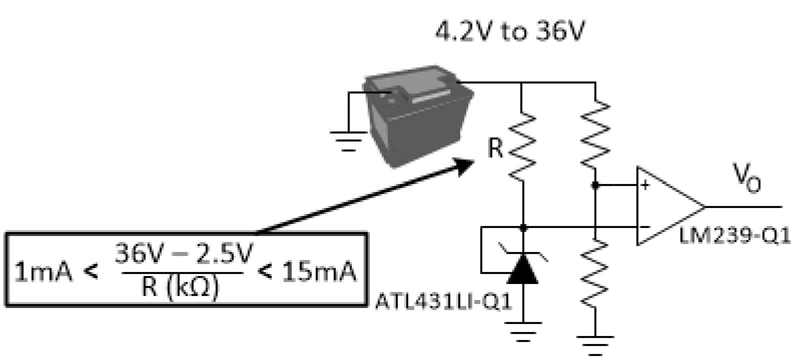

Figure 8. Detecting Off-Battery Fault With Comparator and TL431LI-Q1

One last example on how to achieve off-battery voltage monitoring is by using a voltage supervisor. This approach will call for the lowest, quiescent current requirement, with proper supervisor selection. This will be especially beneficial for "always-on," battery applications, where low standby current is extremely important. To better understand the transients and/or anomalies the car battery might experience, as well, hints on designing a supervisor for off-battery monitoring, please read application note SNVA864: Achieving Nano Amp I_Q in Automotive, Wide-V_{IN} Applications. Figure 9 is a design highlighted in the application note SNVA864, where undervoltage supervision is designed for a voltage range from 4.2V to 42V, while maintaining a high efficiency figure.

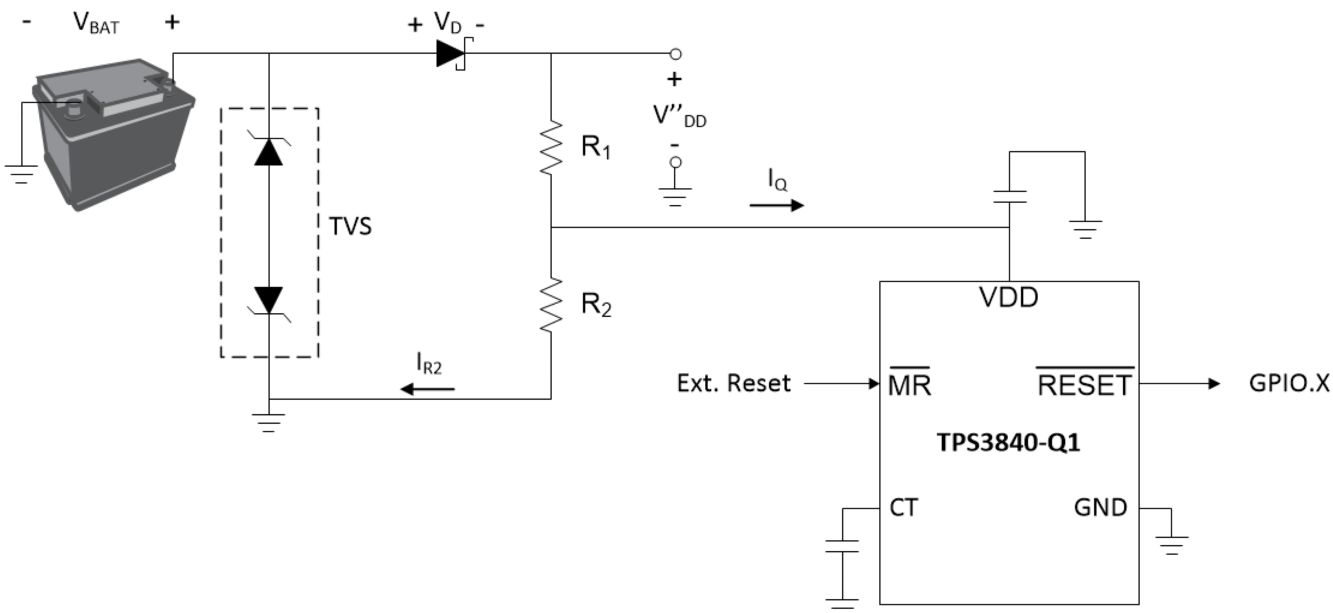

Figure 9. Illustrating TPS3840-Q1 Implementation For Wide-V_{IN} Designs

3.3 *Digital Processing*

The digital processing block in a traction inverter design is tasked with quite a few items, including, but not limited to: communicating with other sub-systems, monitoring the angular position and acceleration of the motor, controlling the motor drive, and monitoring the current/voltage drive on the motor.

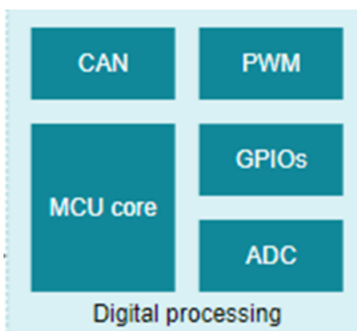

Figure 10. Digital Processing Entities And Functional Blocks

3.3.1 ADC Voltage Referencing

A precision voltage reference is needed to correctly diagnosis the state of the motor. The motor's position and speed can be sensed by a resolver-based control device, such as the PGA411. This device will provide an accurate measurement of the position and in turn, speed of the device, which will be outputted as a digital word. That being said, no analog to digital conversion will be needed on the motor control data. Analog to digital conversion will be need to be performed on the current and voltage sense data (of the motor). To accurately measure this data, the data converter will need a high precision reference.

Voltage referencing is critical for the performance of data converters. The reference is important for the resolution of data converters as any short or long term drift on the reference will directly impact the correctness of the conversion.

REF34-Q1 is an example of a product whose output tolerance and temperature coefficient of 0.05% and 10ppm/°c, respectively, can provide superior converter performance at little extra system cost. To learn more about the impact of reference selection on converter performance, please read SNVA842: Choosing the Voltage Reference for Your Automotive Application.

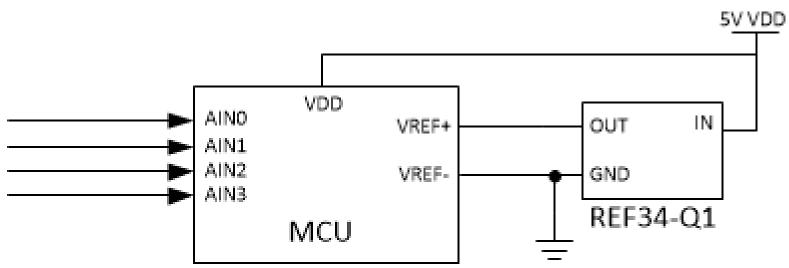

Figure 11. External ADC Referencing With REF34-Q1

3.4 Current/Voltage Sense

The current and voltage being used to drive the electric motor must be accurately monitored. This information (in combination with the angular position) will provide the system with knowledge regarding the current state of the motor and perhaps, its health.

3.4.1 Current Sensing

A shunt based current approach is usually taken for monitoring motor current drive. Isolation needs to occur between the sense point (motor) and the transmission point (ADC). This can be achieved with an isolation amplifier, such as the AMC1301-Q1. This will allow for the likelihood of the low-power digital hardware from getting damaged due to seeing large voltage transients. Below is an example implementation with this device, which can be used to achieve a precise current measurement, while providing excellent isolation from input to output and supporting large peak currents through the device.

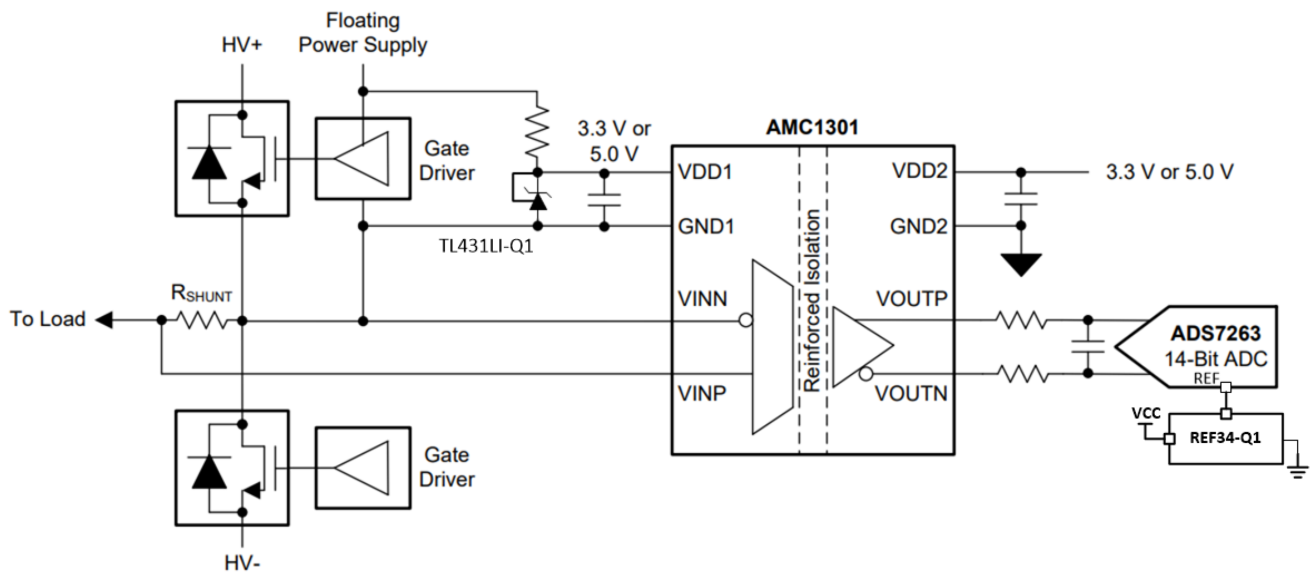

Figure 12. High Voltage Current Monitoring Application Design

3.4.2 Low-Side Voltage Sense

Low-side voltage sense requires galvanic isolation to occur between the sense point and where the output is transmitted.

Application note SBAA289: High-Accuracy Isolated Voltage Measurements in HEV/EV Subsystems Using AMC1311-Q1 and AMC1211-Q1, highlights a few different approaches for low-side voltage measurements.

3.4.3 High-Side Voltage Sense

High-side voltage sense is done a little differently, typically, than how low-side voltage sensing is done. Below is an example block diagram of how the high voltage battery can be sensed effectively at a low cost.

One typical approach for this application is to divide the voltage of the high-side battery down to be within the voltage range of the ADC and to utilize as much as possible of its dynamic range. This implementation can be illustrated below. To ensure high precision, a series voltage reference, such as, REF34-Q1 should be implemented.

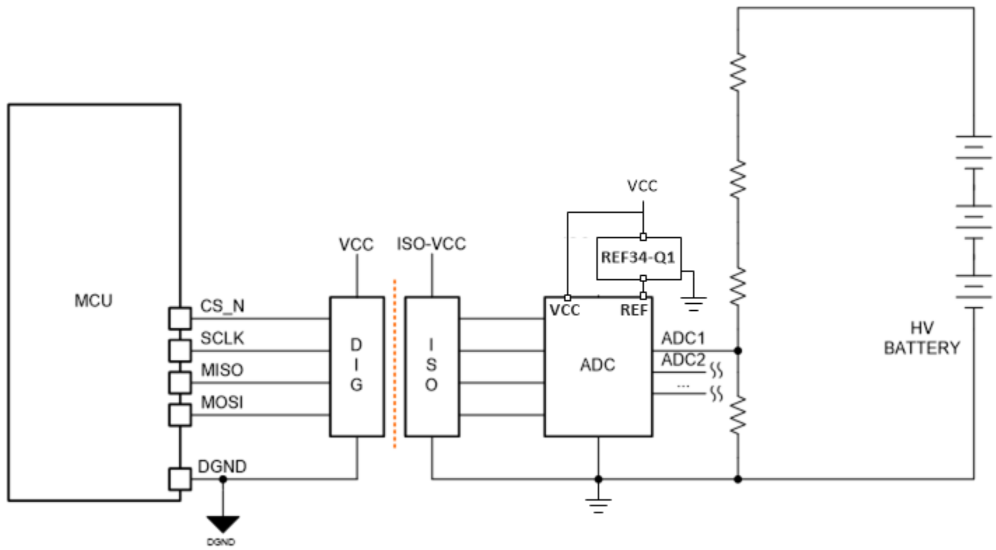

Figure 13. High-Side Voltage Sense Design Approach

3.5 *Self-Diagnostics/Monitoring*

Safety of the system can be furthered by accurately measuring system "health" or ambient conditions such as temperature and pressure.

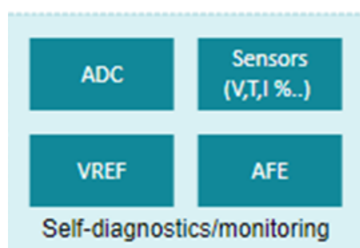

Figure 14. Self-Diagnostics/Monitoring Entities And Functional blocks

3.5.1 ADC Voltage Referencing

Analog to digital conversion may need to be performed on the sensed measurements. To perform this conversion accurately, a precision voltage reference will be needed.

3.5.2 Low-Power Current Supply Monitoring

Current monitoring can provide additional information with what is going on in the system. This information can range from knowing how much battery life you have left to knowing a part is beginning to fail. To get this information, current monitoring must be done accurately. The Texas Instruments voltage supervisor and reference product portfolio can make this happen!

If an absolute value of the current being drawn from a power supply needs to be measured (for example), a current sense amplifier may need to be implemented. Please read application note SBOA211: Low-Cost Bidirectional Current Sensing Using INA181 to get an idea for the challenges faced in current monitoring. The design highlighted in this application note (Figure 15) implements TL431LI for the most accurate current measurement. This example use-case would be done for a "divided-down" voltage of the motor voltage, such that, the INA181-Q1's input voltage is not exceeded.

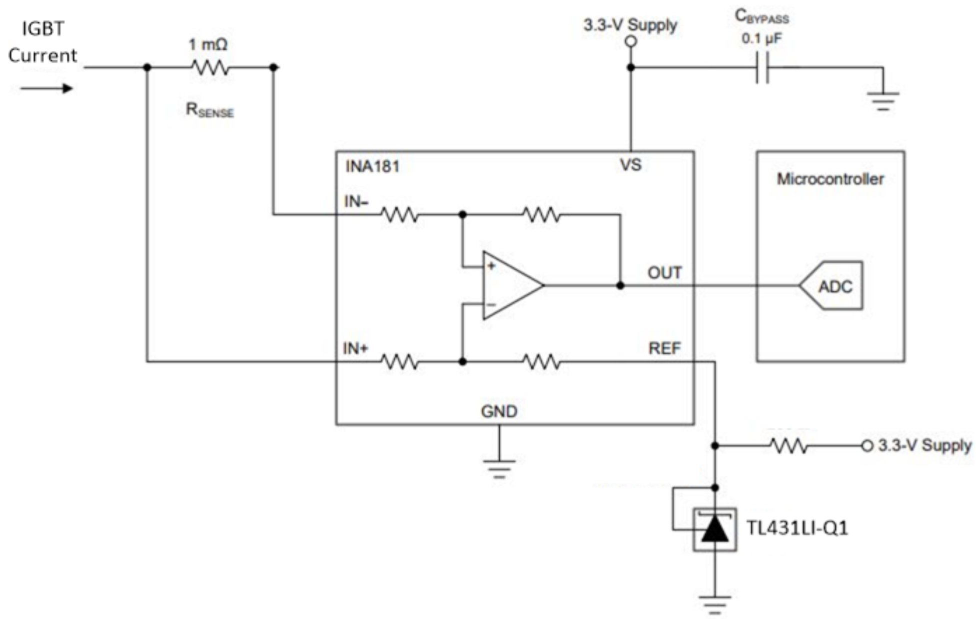

Figure 15. Current Sensing With INA181-Q1 and TL431LI-Q1

3.6 Power Stage

The IGBTs that drive the electric motor in a traction inverter requires a negative supply to do so. The TL431-Q1 can be used to derive the negative supply. Having a negative supply is critical for ensuring that the minimal conduction loss occurs through the IGBT. To better understand supply generation for IGBTs, please reference SLLA354: Is Your IGBT Gate-Driver Power Supply Optimized?

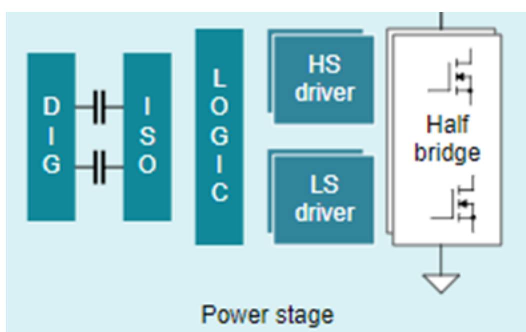

Figure 16. Power Stage Entities And Functional Blocks

3.6.1 Negative Voltage Supply Generation

TIDA-020014 is a design example that implements the TL431-Q1 to derive the negative supply for base (or gate) driving the transistors that control the electric motor in a traction inverter. TIDA-020014: HEV/EV traction inverter power stage with 3 types of IGBT/SiC bias-supply solutions reference design.

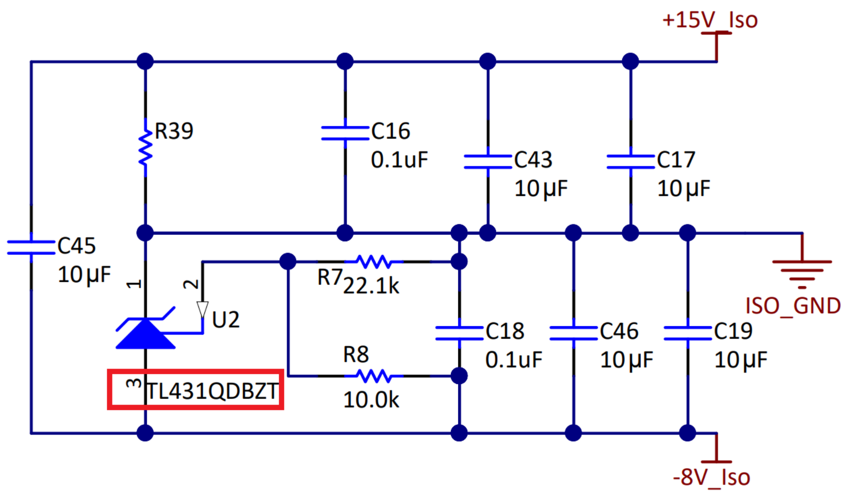

Figure 17. Negative Voltage Supply Generation With TL431LI-Q1 in TIDA-020015

3.7 Redundant Power Supply

A high voltage power supply (battery) is required to drive the electric motor in a traction inverter design. This battery can often be in the 400V range and is used to derive lower voltage power domains in the system. This is achieved through switching power converters, whom must have isolation between input and output to prevent the potential of arcing. This isolation can often be achieved in the feedback/ compensation network of the flyback converter (as example) through an optocoupler.

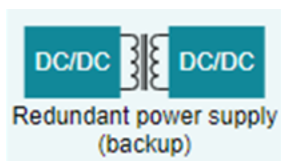

Figure 18. Redundant Power Supply Entities And Functional blocks

3.7.1 Isolated Feedback with Optocoupler

The TL431-Q1 is vital to the compensation network design with isolation through an optocoupler. To learn more, please read SLUP340: Switch-Mode Power Converter Compensation Made Easy, pp.19, section “Isolated feedback with optocoupler.” Additionally, an example reference design that implements TL431-Q1 with an optocoupler for isolated feedback can be found here: TIDA-01505, Automotive 40V to 1kV Input Flyback Reference design Supporting Regenerative Braking Test.

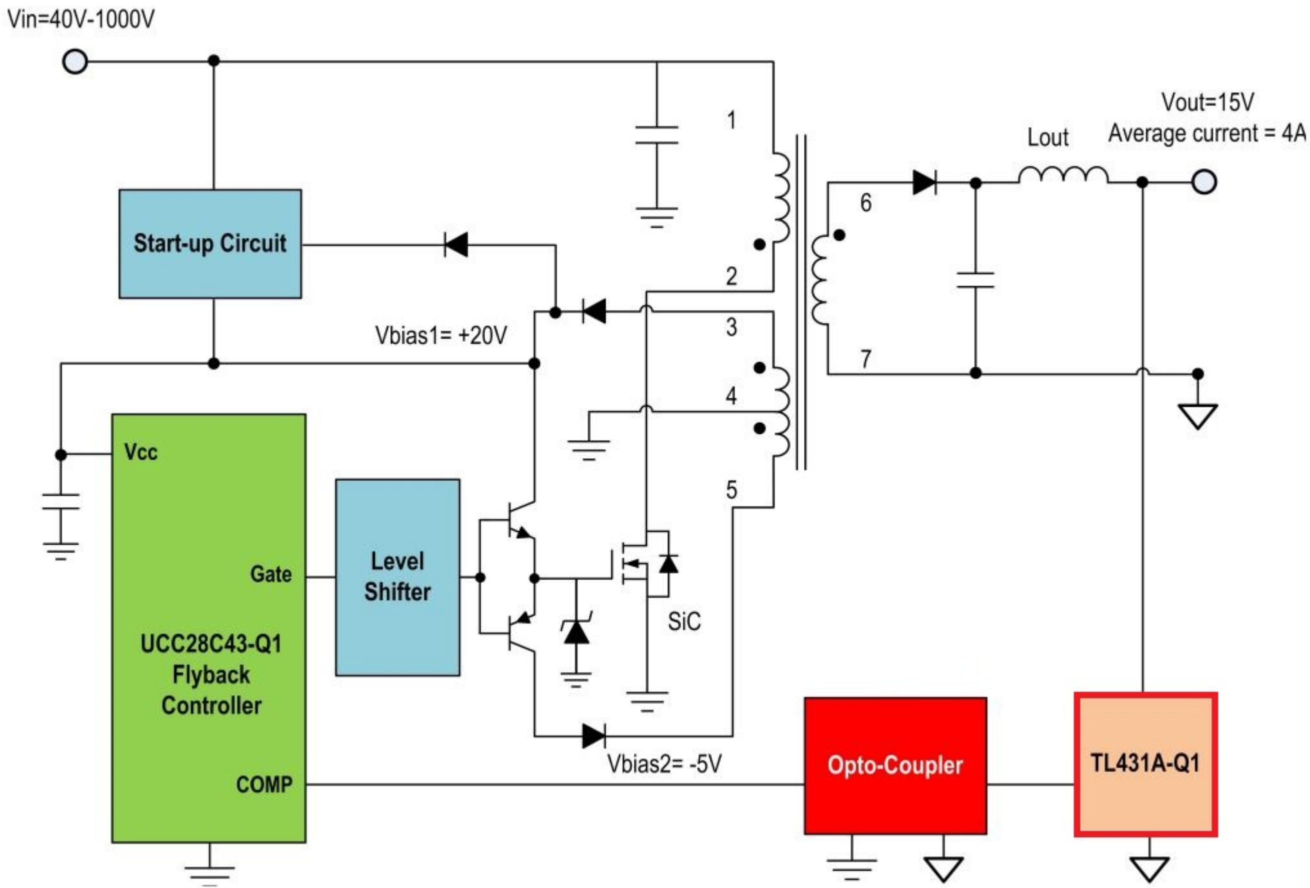

Figure 19. Isolation Compensation with TL431A-Q1 in TIDA-01505

4 Summary

It can be seen from the traction inverter example, though often overlooked, voltage supervision and references are critical to the success in electronic designs. Texas Instruments' voltage supervisor and reference portfolio makes it especially easy in finding a product that will fit the system's needs. Please visit TI.com/svs to learn more about Texas Instruments' voltage supervisor and reference products, by viewing all the available support documents and designs that can be found on the site.