Battery Control Unit Reference Design for Energy Storage Systems

Description

This reference design is a central controller for a high-voltage Lithium-ion (Li-ion), lithium iron phosphate (LiFePO4) battery rack. This design provides driving circuits for high-voltage relay, communication interfaces, (including RS-485, controller area network (CAN), daisy chain, and Ethernet), an expandable interface to humidity sensor, high-voltage analog-to-digital converter (ADC), and current sensor. This design uses a high-performance microcontroller to develop and test applications. These features make this reference design applicable for a central controller of high-capacity battery rack applications.

Resources

TIDA-010253	Design Folder
TMDSCNCD263, LMR51440, TPS7A16	Product Folder
TPS7B81, TPS62913, TPS4H160-Q1	Product Folder
ULN2803C, ISO1042, UCC12050, ISO1410	Product Folder
SN6505B, BQ32002, HDC3020, TPS3823	Product Folder
DP83826E, TPS763, LM74701-Q1, TSD05C	Product Folder

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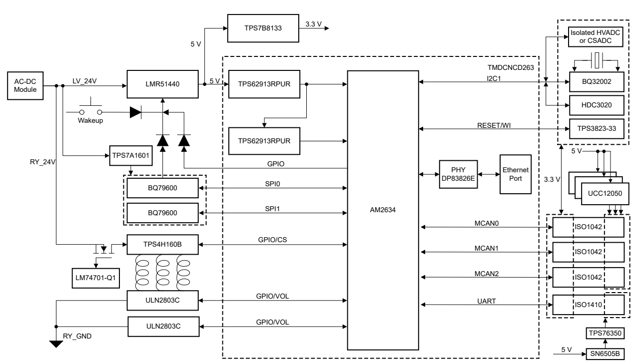
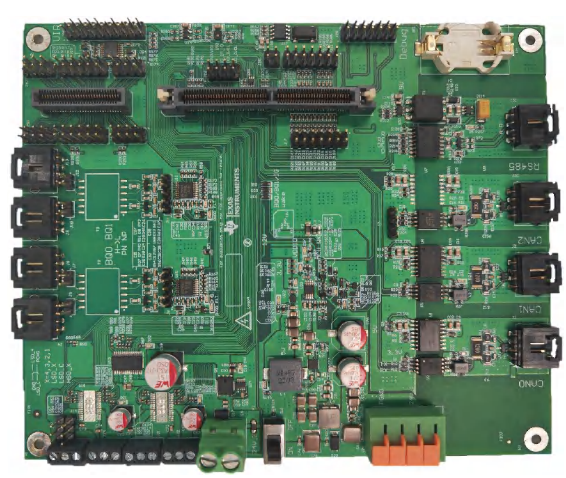
Features

- Interface complies with Sitara™ MCU controlCARD
- Full communication interface including isolated CAN, RS-485, and Ethernet
- Robust drive channels for relay coils
- Robust daisy-chain communication channels
- Comprehensive interface with humidity sensor, real-time clock, watchdog, and high voltage ADC
- Power supply reverse-polarity protection

Applications

- Battery energy storage system





1 System Description

Currently, a battery energy storage system (BESS) plays an important role in residential, commercial and industrial, grid energy storage and management. BESS has various high-voltage system structures. Commercial, industrial, and grid BESS contain several racks that each contain packs in a stack. A residential BESS contains one rack.

A rack is a integrated module to compose the BESS. A rack consists of packs in a matter of parallel connection. Since battery cells require a proper working and storage temperature, voltage range, and current range for lifecycle and safety, it is important to monitor and protect the battery cell at the rack level.

A battery control unit (BCU) is a controller designed to be installed in the rack to manage racks or single pack energy. The BCU performs the following:

- Communicates with the battery system management unit (BSMU), battery power conversion system (PCS), high-voltage monitor unit (HMU), and battery monitor unit (BMU)
- Estimates *Pack* or *Rack* state of charge (SOC) and state of health (SOH)
- Battery cluster balancing, thermal management, power (relay) *ON* and *OFF*
- Limits charging and discharging current
- Power supply to other systems

An HMU is a controller designed to be installed in the rack to keep monitoring racks and single pack status including rack voltage, current, single or accumulated charging and discharging, cycle time, and insulation. The BCU is used with the HMU to complete a full function of protection and energy management in at the rack level. The BMU is a controller designed to be installed in the pack to keep monitoring voltage and temperature of each battery cell for the total lifecycle.

The information collected by the HMU and BMU is transmitted to the BCU for safety and energy management. A robust and fast-speed communication is also required between the BMU and BCU or the HMU and BCU. A CAN is traditionally and widely used for robustness of communication. A CAN structure controller needs a MCU, a digital isolator, and an isolated power module to operate CAN communication functions. Efficient power consumption management of the isolated interface and MCU on the pack-side is crucial for CAN.

A daisy chain is offered as an optional plan to replace CAN. Compared with a CAN interface, only a couple of transformers are needed in BMU, HMU, and BCU. Thus, daisy chain provides an advantage in cost over CAN especially in high-capacity battery pack applications since cost is a concern for CAN structure in large-capacity BESS which consists of lots of BMU nodes and CAN interface devices. The insulation requirement also increases cost. Using reinforced insulation between BMU, HMU, and BCU communication interfaces increases the cost in the digital isolator and isolated power module.

The BCU needs to transmit the SOC, SOH, and rack status to the PCS and BSMU to operate the whole energy storage function. CAN, RS-485, and Ethernet is widely used in the communication interface.

The BCU switches relays *ON* or *OFF* to keep the rack works safely based on the SOC, SOH, and rack status like rack current, voltage, temperature and insulation status. SOC and SOH is estimated from the accurate information of pack and rack.

This design focuses on large capacity battery rack applications and applications that can be applied in residential, commercial, and industrial, grid BESS and more. The design uses a connector interface to the TMDSCNCD263 (AM263x general-purpose controlCARD development kit Arm® based MCU) to test all the functions. The external watchdog TPS3823 is employed to make sure the MCU operates reliably. The design contains one TPS4H160 and two ULN2803 devices to switch the power supply of the relay coils *ON* or *OFF* and make a full diagnostics and high-accuracy current sense of relay coils. The design contains three ISO1042 devices, one ISO1410, one DP83826E, and two BQ79600 devices for the communication interface. The UCC12050 and SN6505 devices are used for isolated power supply. The design also connects the real-time clock BQ32002 to log data and the humidity sensor HDC3020 to monitor the condensation status of rack or pack.

2 System Overview

2.1 Block Diagram

Figure 2-1 shows the system diagram.

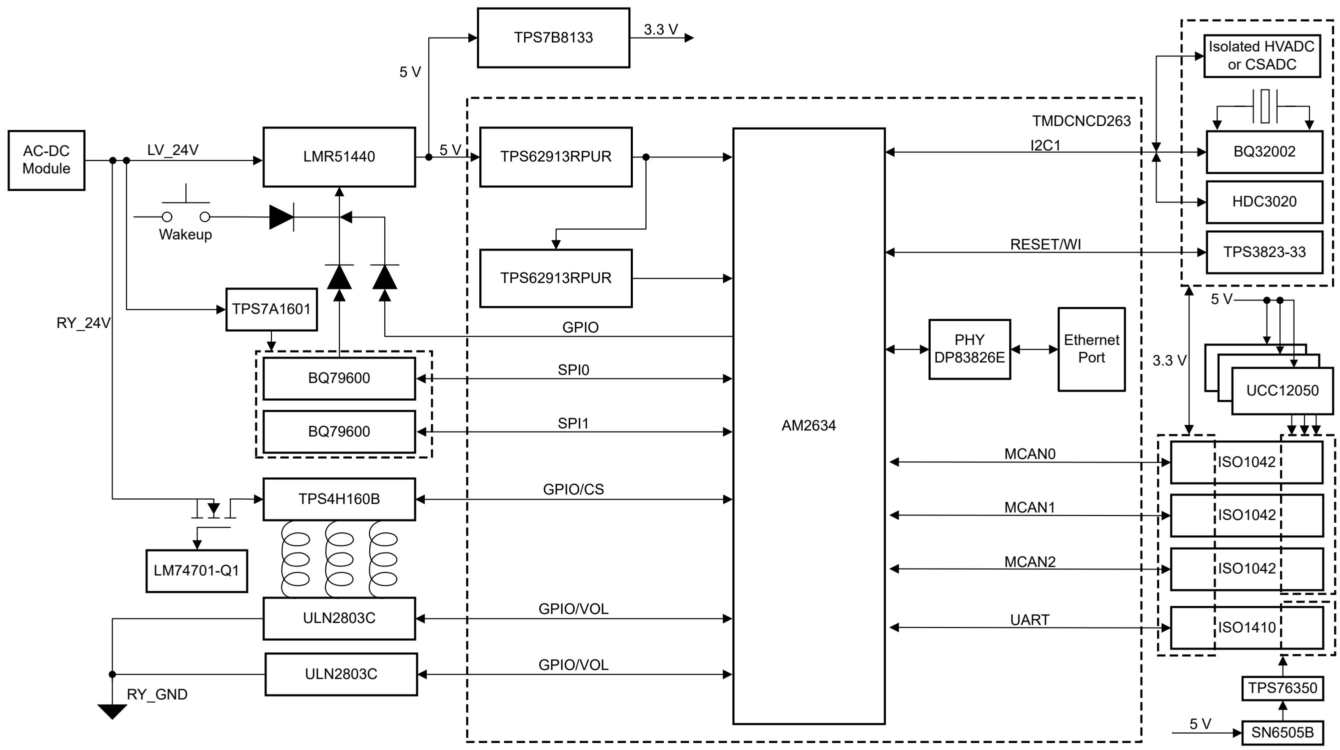


Figure 2-1. TIDA-010271 Block Diagram

The design uses the TMDSCNCD263 as a general-purpose MCU to operate and test all the functions including the power rail monitor, wakeup, relay switch, watchdog (WTD), real-time clock (RTC), humidity sensor, isolated CAN, isolated RS-485, Ethernet, and daisy chain communication.

The design uses the LMR51440 buck converter to convert the 24-V to 5-V power rail to supply the TMDSCNCD263, isolated power module UCC12050, and transformer driver SN6505B with a maximum 4-A capacity. A wakeup trigger circuit is designed to enable the LMR51440 from shutdown mode. The BQ79600 is supplied from TPS7A1601 in 12 V to support the reverse wakeup. The TPS7B8813 is used to convert the 5-V to 3.3-V power rail for VIO and power supply of peripheral devices.

The design uses an I2C bus to connect peripheral devices including humidity sensor, RTC and optional isolated high-voltage ADC or current ADC. The HDC3020 is used to measure the humidity to assess the possibility of dew formation in an IP67 BESS container. The BQ32002 backed up with a coin cell battery is used to generate a local time to the MCU.

Basic insulation is required for CAN and RS-485. The UCC12050 and ISO1042 devices are used to implement the isolated CAN communication function. The SN6505B and ISO1410 devices are used to implement the isolated RS-485 communication function. The ISO1410 can support up to 500Kbps data rates.

The design uses TPS3823-33 for timing supervision with a watchdog time out of 1.6 s.

2.2 Design Considerations

2.2.1 Power Tree and Wakeup

Figure 2-2 shows the BCU power tree.

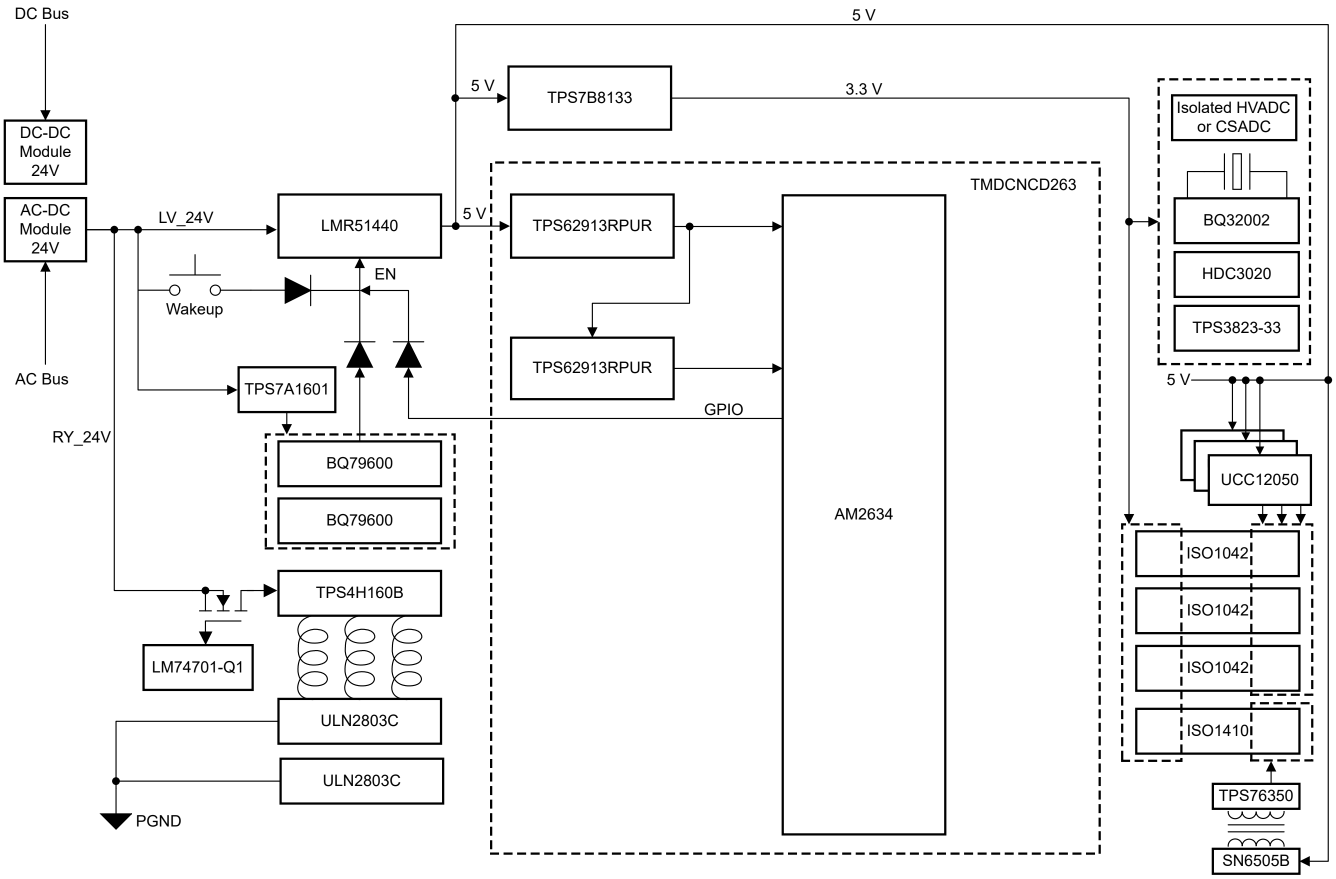


Figure 2-2. BCU Power Tree

The BCU is supplied in a rated 24 V with a range of 18 V to 32 V. The 24-V power supply can be from AC-DC module or DC-DC module with 70-W minimum power.

There are two 24-V input supply paths (LV_24V and RY_24V). LV_24V is used to supply all the control functions of the devices. The LM51440 is used to convert the LV_24V to 5 V with 4-A maximum current. The 5-V power rails are used to provide the supply voltage to the TMDCNCD263, UCC12050, and SN6505B. The UCC12050 provides transceiver-side supply 5-V voltage for the isolated CAN. The SN6505B, transformer and TPS76350 provides transceiver-side supply 5-V voltage for the isolated RS-485. The low-dropout (LDO) TPS7A1601 converts LV_24V to 12 V. The 12-V power rails can enable the reverse wakeup feature of the BQ79600. The LDO TPS7B8133 converts 5 V to 3.3 V. The 3.3-V power rail is used to provide the digital-side supply voltage of the isolated CAN or isolated RS-485, BQ32002, HDC3020, and TPS3823. RY_24V is used to supply the relay coils independently from LV_24V.

There are two wakeup paths to wake LMR51440 through the EN pin. One is a button trigger using LV_24V, another is a reverse wakeup from BQ79600-Q1. The BQ79600-Q1 supports automatic host wakeup through the INH pin when an unmask fault is detected in the battery pack. The MCU gives an IO voltage to the LMR51440, holds the LMR51440 through the EN pin when the wakeup trigger voltage fluctuates.

2.2.2 Insulation Requirement for Isolated Interface

Table 2-1 shows the insulation requirement in 1500-V BESS by the IEC 60664-1-2020.

Table 2-1. IEC 60664-1-2020 1500-V BESS Insulation Requirements

PARAMETER	CLEARANCE		CREEPAGE	
Altitude	Basic	Reinforced	Basic	Reinforced
≤ 4000 m	7.1 mm	10.4 mm	8 mm	16 mm
5000 m	8.14 mm	11.84 mm	8 mm	16 mm

A basic insulation is required between the BCU and PCS or the BCU and BSMU. For an altitude of 4000 m, the minimum clearance is 7.1 mm and the creepage is 8 mm. For an altitude of 5000 m, the minimum clearance is 8.14 mm and the creepage is 8 mm. This design follows the requirement from an altitude of 4000 m. For CAN, UCC12050 and ISO1042DWV are used. For RS-485, transformer 750315371 and ISO1410DWR are used.

A reinforced insulation is required between the BCU and BMU. The minimum clearance is 10.4 mm and the creepage is 16 mm. To meet the minimum clearance and creepage requirements, a transformer for daisy chain or a digital isolator for CAN is necessary.

Consider using a more appropriate device or connecting the devices in series for altitudes above 4000 m.

2.2.3 Robust Relay Driver

The coil is a crucial component of high-voltage relays because the coil provides the driving force to close the contacts. The current through the coil generates a magnetic field which attracts the moving core to close the contacts, and on the contrary open the contacts. Even though there are several high-voltage relay vendors in the market, such as TE, Panasonic, GIGAVIC, HF, and so on, the driving current requirements of all the relay coils are similar. The current profile can be divided into three phases, as shown in Figure 2-3. The first phase is known as pickup phase, the current needs to be large enough and keep long enough to make sure the relay is closed during the phase. The second phase is the hold phase, where a smaller current is kept to efficiently close the relay and keep the relay closed. The last phase is current fast decay, during this phase the current drops very quickly to quench the contacts opening. Figure 2-3 shows the three phases requirement of the current curve, the actual currents in the pickup phase and hold phase can be PWM signals with maximum and minimum values.

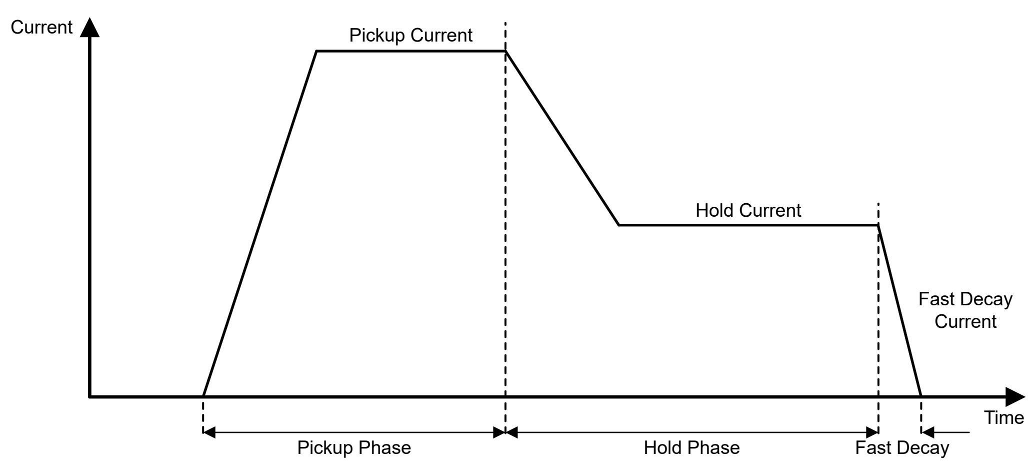


Figure 2-3. Three Phases of the Relay Current Curve

Generally, the relay vendors provide two relay coil types, one is an economized coil with an internal economizer and the other is a non-economized coil that requires external economization. The economized coil integrates an internal economizer with one of several methods such as a two-coil economizer, pulse-width modulation with voltage feedback, and pulse-width modulation with current feedback. Powering the two terminals of the coil alone is sufficient, and the desired current waveform is generated by itself with this internal economizer. The non-economized coil refers to a coil without any internal circuitry, requiring external circuits to produce the desired current waveform.

It is more preferable from the system perspective to use both high-side and low-side switches to drive the relay coil for safety reasons. The coil is always energized and cannot be shut off when a short-circuit failure happens if only the high- or low-side switch is used. The failure is in line with a short circuit to input on the high-side switch and short circuit to ground on the low-side switch. A large current flows through the coil and cannot be switched off, thus the coil can be damaged due to high power dissipation.

Implementing an elaborate design is indispensable to achieve the current profile. Otherwise, the current through the coil reaches the maximum value determined by the applied voltage divided by coil resistance. Generally, the maximum and minimum current for both the pickup phase and the hold phase are stipulated in each specification to provide the proper operation of the relay. Some vendors prefer to stipulate the minimum effective current in each phase. These currents are much smaller than the current determined by the supply voltage and coil resistance. This not only helps save energy consumption, but also extends relay operation lifetime.

Figure 2-4 shows relay driver circuit.

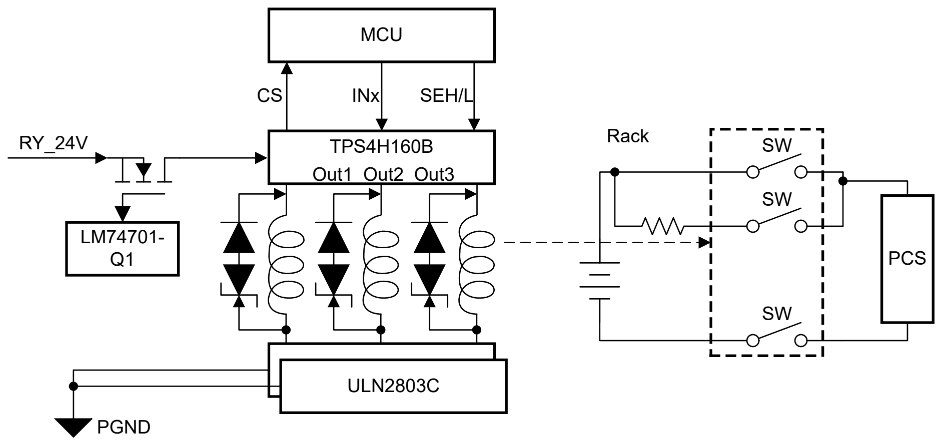


Figure 2-4. Relay Driver Circuit

RY_24V provides power supply to relay coils. The design uses LM74701-Q1 for reverse polarity protection and a low forward voltage drop regulation. TPS4H160-Q1 is used to switch the RY_24V to coils positive terminal. TPS4H160-Q1 provides a current limit of 8 A which is large enough to cover the pickup phase current with a sufficient margin. Version B of TPS4H160-Q1 is used for the load current monitor function feature. For version B, SEL and SEH are two pins to multiplex the shared current-sense function among the four channels. ULN2803C is used to switch the GND to coils negative terminal. ULN2803C consists of eight NPN Darlington pairs that feature high-voltage outputs with common-cathode clamp diodes for switching inductive loads. The collector-current rating of each Darlington pair is 500 mA. The Darlington pairs are connected in parallel for higher current capability up to 4 A.

Here the high-side switch TPS4H160-Q1 acts as ON and OFF control and protects the coil while short-circuit failures happen at the low-side terminal. A freewheeling circuit is optional for TPS4H160-Q1, because the current through the coil must not interrupt suddenly while turning off the high-side switch. Otherwise, there can be a very large voltage spike due to the coil inductance and probably damage the components. Meanwhile, diagnosis features at both high- and low-side terminals are a benefit for BESS applications.

2.2.4 Stackable Daisy Chain Communication

Figure 2-5 shows the BMU and BMU ring communication.

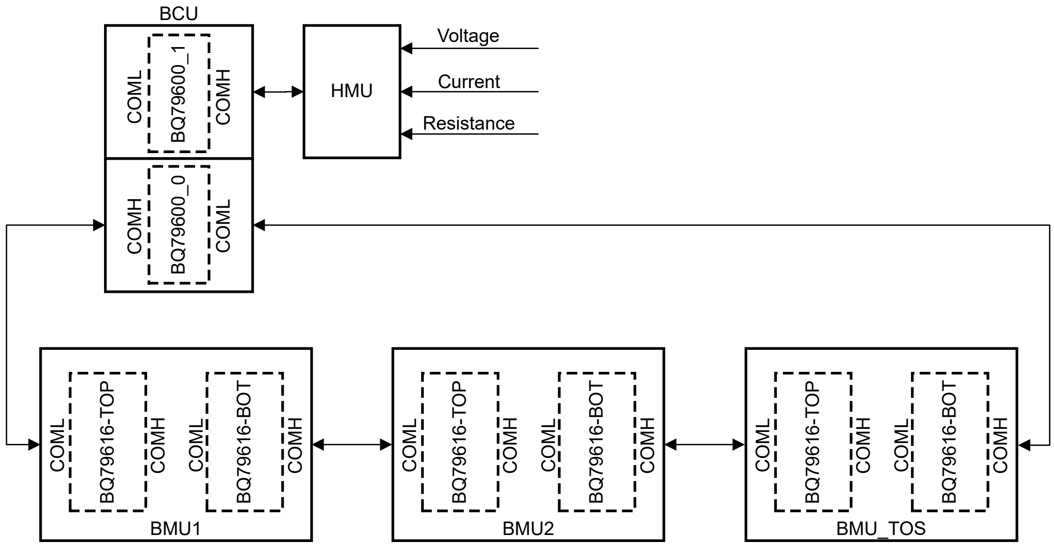


Figure 2-5. Ring Communication Structure

The BCU collects the rack information including voltage, current, and insulation resistance from HMU or the high-voltage-side ADC in a duty cycle to protect the system from overcurrent and estimate an accurate SOC. This duty cycle can be as short as 1 ms for some certain filtering algorithms. The BCU collects the cell information from the BMU including cell voltage, cell temperature in a duty cycle of 100 ms. A bidirectional communication is required for a robust communication structure. Considering that the communication period is different, it is more preferable for HMU to use an single daisy chain than to use a shared daisy chain with BMU.

2.3 Highlighted Products

2.3.1 TMDSCNCD263

The TMDSCNCD263 is an HSEC180 controlCARD-based evaluation and development tool for the AM263x series Sitara™ high-performance microcontrollers. This board is an excellent choice for initial evaluation and prototyping because the board provides a standardized and easy-to-use platform to develop future applications. The AM263 controlCARD is equipped with a Sitara AM2634 processor along with additional components to allow the user to make use of the various device interfaces including industrial Ethernet, standard Ethernet, fast serial interface (FSI) and others to easily develop and test applications. The AM2634 supports a variety of Industrial Ethernet protocols like EtherCAT, Ethernet/IP, and PROFINET.

The TMDSCNCD263 can be used standalone or paired with a controlCARD Baseboard Docking Station.

Features:

- Standard 180-pin HSEC interface
- Onboard XDS110 debugger and test automation header
- Onboard 128MB QSPI Flash and current monitoring
- CAN transceiver, FSI header, three RJ-45 Ethernet jacks

2.3.2 LMR51440

The LMR514x0 is a wide-V_{IN}, easy-to-use synchronous buck converter capable of driving up to 4-A or 5-A load current. With a wide input range of 4 V to 36 V, the device is an excellent choice for a wide range of industrial applications for power conditioning from an unregulated source.

The LMR514x0 features adjustable switching frequency from 200 kHz to 1.1 MHz with an external resistor, which provides the flexibility to optimize either efficiency or external component size. The device has a pulse frequency modulation (PFM) mode version to realize high efficiency at light load and a forced pulse-width modulation (FPWM) version to achieve constant frequency, and small output voltage ripple over the full load range. Soft-start and compensation circuits are implemented internally which allows the device to be used with minimum external components.

The device has built-in protection features, such as cycle-by-cycle current limit, hiccup mode short-circuit protection, and thermal shutdown in case of excessive power dissipation. The LMR514x0 is available in a WSON-12 package.

2.3.3 TPS7A16

The TPS7A16 family of ultra-low power, low-dropout (LDO) voltage regulators offers the benefits of ultra-low quiescent current, high input voltage and miniaturized, high thermal-performance packaging.

The TPS7A16 family is designed for continuous or sporadic (power backup) battery-powered applications where ultra-low quiescent current is critical to extending system battery life.

The TPS7A16 family offers an enable pin (EN) compatible with standard CMOS logic and an integrated open drain active-high power good output (PG) with a user-programmable delay. These pins are intended for use in microcontroller-based, battery-powered applications where power-rail sequencing is required.

In addition, the TPS7A16 is an excellent choice for generating a low-voltage supply from multicell designs ranging from high cell-count power-tool packs to automotive applications; not only can this device supply a well-regulated voltage rail, but the device can also withstand and maintain regulation during voltage transients. These features translate to simpler and more cost-effective, electrical surge-protection circuitry.

2.3.4 TPS7B81

The TPS7B81 is a low-dropout (LDO) linear regulator that operates from input voltages up to 40 V and can supply up to 150 mA in current. With only 2.7 μA of quiescent current at light loads, the device is an excellent choice for wide input supply designs and high cell count battery applications that need very low standby power consumption. The 45-V transient tolerance provides additional headroom for applications where inductive kickback can be present, thereby reducing external circuitry for voltage suppression.

With integrated short-circuit and overcurrent limiting, the TPS7B81 protects the system during fault conditions. In addition to the low standby power consumption, the very low dropout voltage in light load conditions helps maintain regulation even when powered by depleted batteries.

The TPS7B81 is available in thermally enhanced, 8-pin HVSSOP and 6-pin WSON packages. Both packages offer high thermal conductivity, and their small size supports compact design, making them well designed for space-limited applications such as power tools or motor drive modules and battery packs.

2.3.5 TPS62913

The TPS6291x devices are a family of high-efficiency, low noise, and low ripple current mode synchronous buck converters. The devices are an excellent choice for noise-sensitive applications that normally use an LDO for post regulation such as high-speed ADCs, clock and jitter cleaner, serializer, de-serializer, and radar applications.

The devices operate at a fixed switching frequency of 2.2 MHz or 1 MHz, and can be synchronized to an external clock.

To further reduce the output voltage ripple, the device integrates loop compensation to operate with an optional second-stage ferrite bead L-C filter. This allows an output voltage ripple below 10 μV_{RMS}.

Low-frequency noise levels, similar to a low-noise LDO, are achieved by filtering the internal voltage reference with a capacitor connected to the NR/SS pin.

The optional spread spectrum modulation scheme spreads the DC/DC switching frequency over a wider span, which lowers the mixing spurs.

2.3.6 TPS4H160-Q1

The TPS4H160-Q1 device is fully protected quad-channel smart high-side switch with four integrated 160-mΩ NMOS power field-effect transistors (FETs).

Full diagnostics and high-accuracy current sense enable intelligent control of the load.

An external adjustable current limit improves the reliability of whole system by limiting the inrush or overload current.

2.3.7 ULN2803C

The ULN2803C device is a 50-V, 500-mA Darlington transistor array. The device consists of eight NPN Darlington pairs that feature high-voltage outputs with common-cathode clamp diodes for switching inductive loads. The collector-current rating of each Darlington pair is 500 mA. The Darlington pairs can be connected in parallel for higher current capability.

Applications include relay drivers, hammer drivers, lamp drivers, display drivers (LED and gas discharge), line drivers, and logic buffers. The ULN2803C device has a 2.7-kΩ series base resistor for each Darlington pair for operation directly with TTL or 5-V CMOS devices.

2.3.8 ISO1042

The ISO1042 device is a galvanically-isolated controller area network (CAN) transceiver that meets the specifications of the ISO11898-2 (2016) standard. The ISO1042 device offers ±70-V DC bus fault protection and ±30-V common-mode voltage range. The device supports up to 5-Mbps data rate in CAN FD mode allowing much faster transfer of payload compared to classic CAN. This device uses a silicon dioxide ($SiO2$) insulation barrier with a withstand voltage of 5000 V_{RMS} and a working voltage of 1060 V_{RMS}. Electromagnetic compatibility has been significantly enhanced to enable system-level ESD, EFT, surge, and emissions compliance. Used in conjunction with isolated power supplies, the device protects against high voltage, and prevents noise currents from the bus from entering the local ground. The ISO1042 device is available for both basic and reinforced isolation (see Reinforced and Basic Isolation Options). The ISO1042 device supports a wide ambient temperature range of –40°C to +125°C. The device is available in the SOIC-16 (DW) package and a smaller SOIC-8 (DWV) package.

2.3.9 UCC12050

The UCC12050 is an automotive qualified DC/DC power module with 5-kV_{RMS} reinforced isolation rating designed to provide efficient, isolated power to isolated circuits that require a bias supply with a well-regulated output voltage. The device integrates a transformer and DC/DC controller with a proprietary architecture to provide 500 mW (typical) of isolated power with low EMI.

The UCC12050 integrates protection features for increased system robustness. The device also has an enable pin, synchronization capability, and regulated 5-V or 3.3-V output options with headroom. The UCC12050 is a low-profile, miniaturized design offered in a wide-body SOIC package with 2.65-mm height (typical).

2.3.10 ISO1410

The ISO14xx devices are galvanically-isolated differential line transceivers for TIA/EIA RS-485 and RS-422 applications. These noise-immune transceivers are designed to operate in harsh industrial environments. The bus pins of these devices can endure high levels of IEC electrostatic discharge (ESD) and IEC electrical fast transient (EFT) events which eliminates the need for additional components on bus for system-level protection. The devices are available for both basic and reinforced isolation (see Reinforced and Basic Isolation Options).

These devices are used for long-distance communications. Isolation breaks the ground loop between the communicating nodes, allowing for a much larger common-mode voltage range. The symmetrical isolation barrier of each device is tested to provide 5000 V_{RMS} of isolation for 1 minute per UL 1577 between the bus-line transceiver and the logic-level interface.

The ISO14xx devices can operate from 1.71 V to 5.5 V on side 1 which lets the devices be interfaced with low-voltage FPGAs and ASICs. The wide supply voltage on side 2 from 3 V to 5.5 V eliminates the need for a regulated supply voltage on the isolated side. These devices support a wide operating ambient temperature range from –40°C to +125°C.

2.3.11 SN6505B

The SN6505x is a low-noise, low-EMI push-pull transformer driver, specifically designed for small form factor, isolated power supplies. The device drives low-profile, center-tapped transformers from a 2.25-V to 5-V DC power supply. Ultra-low noise and EMI are achieved by slew rate control of the output switch voltage and through Spread Spectrum Clocking (SSC). The SN6505x consists of an oscillator followed by a gate drive circuit that provides the complementary output signals to drive ground-referenced N-channel power switches. The device includes two 1-A power-MOSFET switches to provide start-up under heavy loads. The switching clock can also be provided externally for accurate placement of switcher harmonics, or when operating with multiple transformer drivers. The internal protection features include a 1.7-A current limiting, undervoltage lockout, thermal shutdown, and break-before-make circuitry. The SN6505x includes a soft-start feature that prevents high inrush current during power up with large load capacitors. The SN6505A has a 160-kHz internal oscillator for applications that need to minimize emissions whereas the SN6505B has a 420-kHz internal oscillator for applications that require higher efficiency and smaller transformer size. The SN6505x is available in a small 6-pin SOT23 or DBV package. The device operation is characterized for a temperature range from –55°C to 125°C.

2.3.12 BQ32002

The BQ32002 device is a compatible replacement for industry standard real-time clocks.

The BQ32002 features an automatic backup supply that can be implemented using a capacitor or non-rechargeable battery. The BQ32002 has a programmable calibration adjustment from –63 ppm to +126 ppm. The BQ32002 registers include an OF (oscillator fail) flag indicating the status of the RTC oscillator, as well as a STOP bit that allows the host processor to disable the oscillator. The time registers are normally updated once per second, and all the registers are updated at the same time to prevent a timekeeping glitch. The BQ32002 includes automatic leap-year compensation.

2.3.13 HDC3020

The HDC302x is an integrated capacitive based relative humidity (RH) and temperature sensor. The device provides high accuracy measurements over a wide supply range (1.62 V – 5.5 V), along with ultra-low power consumption in a compact 2.5-mm × 2.5-mm package. Both the temperature and humidity sensors are 100% tested and trimmed on a production setup that is National Institute of Standards and Technology (NIST) traceable and verified with equipment that is calibrated to ISO/IEC 17025 standards.

Offset Error Correction reduces RH sensor offset due to aging, exposure to extreme operating conditions, and contaminants to return device to within accuracy specifications. For battery IoT applications, auto measurement mode and ALERT feature enable low system power by maximizing MCU sleep time. There are four different I2C addresses that support speeds up to 1 MHz. A heating element is available to dissipate condensation and moisture.

The HDC3020 is an open cavity package without protective cover. Two device variants have a cover option to protect the open cavity RH sensor: HDC3021 and HDC3022. HDC3021 has removable protective tape to allow conformal coatings and printed circuit board (PCB) wash. HDC3022 has a permanent IP67 filter membrane to protect against dust, water, and PCB wash.

2.3.14 TPS3823

The TPS382x family of supervisors provide circuit initialization and timing supervision, primarily for digital signal processors (DSP) and processor-based systems. During power on, $\overline{\text{RESET}}$ asserts when the supply voltage V_{DD} becomes greater than 1.1 V. Thereafter, the supply voltage supervisor monitors V_{DD} and keeps $\overline{\text{RESET}}$ active low as long as V_{DD} remains less than the threshold voltage, V_{IT-}. An internal timer delays the return of the output to the inactive state (high) to provide proper system reset. The delay time, t_d, starts after V_{DD} has risen above the threshold voltage (V_{IT-} + V_{HYS}). When the supply voltage drops below the threshold voltage V_{IT-}, the output becomes active (low) again. No external components are required. All the devices of this family have a fixed-sense threshold voltage, VIT–, set by an internal voltage divider. The TPS382x family also offers watchdog time out options of 200 ms (TPS3820) and 1.6 s (TPS3823, TPS3824, and TPS3828).

2.3.15 DP83826E

The DP83826 offers low and deterministic latency, low power, and supports 10BASE-Te, 100BASE-TX Ethernet protocols to meet stringent requirements in real-time industrial Ethernet systems. The device includes hardware bootstraps to achieve fast link-up time, fast link-drop detection modes, and dedicated reference CLKOUT to clock synchronize other modules on the systems.

The two configurable modes are BASIC standard Ethernet mode that uses a common Ethernet pinout, and ENHANCED Ethernet mode which supports standard Ethernet mode and multiple industrial Ethernet fieldbus applications with the additional features and hardware bootstraps configuration.

2.3.16 TPS763

The TPS763xx family of low-dropout (LDO) voltage regulators offers the benefits of LDO voltage, low-power operation, and miniaturized packaging. These regulators feature LDO voltages and quiescent currents compared to conventional LDO regulators. Offered in a 5-pin, small outline integrated-circuit SOT-23 package, the TPS763xx series devices are an excellent choice for cost-sensitive designs and for applications where board space is at a premium.

A combination of new circuit design and process innovation has enabled the usual PNP pass transistor to be replaced by a PMOS pass element. Because the PMOS pass element behaves as a low-value resistor, the dropout voltage is low [typically 300 mV at 150 mA of load current (TPS76333)] and is directly proportional to the load current. Because the PMOS pass element is a voltage-driven device, the quiescent current is low (140 µA maximum) and is stable over the entire range of output load current (0 mA to 150 mA). Intended for use in portable systems such as laptops and cellular phones, the LDO voltage feature and low-power operation result in a significant increase in system battery operating life.

The TPS763xx also features a logic-enabled sleep mode to shut down the regulator, reducing quiescent current to 1 µA maximum at T_J = 25°C. The TPS763xx is offered in 1.6-V, 1.8-V, 2.5-V, 2.7-V, 2.8-V, 3-V, 3.3-V, 3.8-V, and 5-V fixed-voltage versions and in a variable version (programmable over the range of 1.5 V to 6.5 V).

2.3.17 LM74701-Q1

The LM74701-Q1 is an automotive AEC Q100 qualified ideal diode controller which operates in conjunction with an external N-channel metal-oxide semiconductor field-effect transistor (MOSFET) as an ideal diode for low loss reverse polarity protection with a 20-mV forward voltage drop. LM74701-Q1 is an excellent choice for input protection of 12-V automotive systems. The 3.2-V input voltage support is particularly well designed for severe cold crank requirements in automotive systems.

The device controls the GATE of the MOSFET to regulate the forward voltage drop at 20 mV. The regulation scheme enables graceful turn-off of the MOSFET during a reverse current event and provides zero DC reverse current flow. Fast response (< 0.75 µs) to reverse current blocking makes the device an excellent choice for systems with output voltage holdup requirements during ISO7637 pulse testing as well as power fail and input micro-short conditions. The LM74701-Q1 has a unique integrated VDS clamp feature which enables users to achieve TVS-less input polarity protection design and save, on average, a typical 60% of PCB space in constrained automotive systems.

The LM74701-Q1 controller provides a charge pump gate drive for an external N-channel MOSFET. With the enable pin low, the controller is off and draws approximately 1 µA of current.

3 Hardware, Software, Testing Requirements, and Test Results

The key performances of the TIDA-010253 were tested in a TI lab, the end equipment used and test processes and results are described in this section.

Table 3-1 describes the connections for TIDA-010253 board.

Table 3-1. LV_24V Input Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J26-1	PGND	Negative terminal of power supply
J26-2	PGND	Negative terminal of power supply
J26-3	VBATI	Positive terminal of power supply, rated voltage is 24 V, working voltage is 18 V–32 V
J26-4	VBATI	Positive terminal of power supply, rated voltage is 24 V, working voltage is 18 V–32 V

Table 3-2. RY_24V Input Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J16-1	PGND	Negative terminal of relay power supply
J16-2	24V_CONN	Positive terminal of relay power supply, rated voltage is 24 V, working voltage is 18 V–32 V

Table 3-3. Relay Coil Driver Connector1

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J22-1	LS_OUT1	Reserved low side power switch terminal1 between PGND and coil
J22-2	LS_OUT_COM	Common low side power switch terminal between PGND and coil
J22-3	HS_OUT1	High-side power switch terminal1 between relay power supply and coil

Table 3-4. Relay Coil Driver Connector2

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J21-1	LS_OUT2	Reserved low side power switch terminal2 between PGND and coil
J21-2	LS_OUT_COM	Common low side power switch terminal between PGND and coil
J21-3	HS_OUT2	High side power switch terminal2 between relay power supply and coil

Table 3-5. Relay Coil Driver Connector3

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J24-1	LS_OUT3	Reserved low side power switch terminal3 between PGND and coil
J24-2	LS_OUT_COM	Common low side power switch terminal between PGND and coil
J24-3	HS_OUT3	High side power switch terminal3 between relay power supply and coil

Table 3-6. Relay Coil Driver Connector4

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J23-1	LS_OUT4	Reserved low side power switch terminal4 between PGND and coil
J23-2	LS_OUT_COM	Common low side power switch terminal between PGND and coil
J23-3	HS_OUT4	High side power switch terminal4 between relay power supply and coil

Table 3-7. DaisyChain0 (COMH) Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J4-3	BQ0_COMHP_ISO	COM high-side positive
J4-4	BQ0_COMHN_ISO	COM high-side negative

Table 3-8. DaisyChain0 (COML) Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J8-1	BQ0_COMLN_ISO	COM low-side negative
J8-2	BQ0_COMLP_ISO	COM low-side positive

Table 3-9. DaisyChain1 (COMH) Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J9-3	BQ1_COMHP_ISO	COM high-side positive
J9-4	BQ1_COMHN_ISO	COM high-side negative

Table 3-10. DaisyChain1 (COML) Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J13-1	BQ1_COMLN_ISO	COM low-side negative
J13-2	BQ1_COMLP_ISO	COM low-side positive

Table 3-11. I2C Peripheral Device Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J19-1	GND	BCU ground
J19-2	VDDIO	3.3 V for I/Os and power supply for peripheral device
J19-3	EXT_I2C2_GPIO	GPIO for I2C2 control
J19-4	EXT_I2C1_GPIO	GPIO for I2C1 control
J19-5	I2C2_SDA	Serial Data Line for I2C2, connected to HDC3020
J19-6	I2C2_SCL	Serial Clock Line for I2C2, connected to HDC3020
J19-7	I2C1_SDA	Serial Data Line for I2C1, connected to BQ32002
J19-8	I2C1_SCL	Serial Clock Line for I2C1, connected to BQ32002

Table 3-12. SPI Peripheral Device (HV ADC and Current Sensor) Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J25-1	VDDIO	3.3 V for I/Os and power supply for peripheral device
J25-2	VDDIO	3.3 V for I/Os and power supply for peripheral device
J25-3	UIR_OC1	Overcurrent alarm1
J25-5	UIR_OC2	Overcurrent alarm2
J25-7	UIR_nFAULT	SPI peripheral device fault alarm
J25-8	VCC5V	5-V power supply for peripheral device
J25-9	VCC5V	5-V power supply for peripheral device
J25-10	VCC5V	5-V power supply for peripheral device
J25-11	UIR_SPI_MOSI	SPI Master Output, Slave Input
J25-13	UIR_SPI_MISO	SPI Master Input, Slave Output
J25-15	UIR_SPI_CS	SPI Chip Select
J25-17	UIR_SPI_CLK	SPI Clock
J25-18	UIR_SN65_EN	Enable pin to additional power supply for peripheral device
J25-19	GND	BCU ground

Table 3-12. SPI Peripheral Device (HV ADC and Current Sensor) Connector (continued)

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J25-20	GND	BCU ground

Table 3-13. CAN0 Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J1-2	CANH0	CAN0_High
J1-3	CANL0	CAN0_Low
J1-4	GND0	CAN0_GND

Table 3-14. CAN1 Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J2-2	CANH1	CAN1_High
J2-3	CANL1	CAN1_Low
J2-4	GND1	CAN1_GND

Table 3-15. CAN2 Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J30-2	CANH2	CAN2_High
J30-3	CANL2	CAN2_Low
J30-4	GND4	CAN4_GND

Table 3-16. RS-485 Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J30-2	RS485_B	RS-485 Negative
J30-3	RS485_A	RS485_Positive
J30-4	GND2	RS485_GND

3.1 Hardware Requirements

Table 3-17 summarizes the equipment used for testing.

Table 3-17. Test Equipment Summary

EQUIPMENT	MODEL OR DESCRIPTION
Multimeter	Agilent 34401A
Oscilloscope	RIGOL MISO5152-E
DC source	Chroma 6204P-600-8
Relay	EVC500
High Voltage Differential Probe	Micsig DP10013
CAN tools	USBCANFD-200U

3.2 Software Requirements

For testing and demonstration purposes, a relatively simple software including relay driving, transmission of the CAN message, and daisy chain communication is implemented with the HSEC180 controlCARD TMDSCNCD263.

3.3 Test Setup

Use the following procedures before running this design board. The design was constructed with rack configurations. The board was tested using 32S-BMU (TIDA-010271) to simulate a pack. USBCANFD-200U is used to send the CAN messages in a duty cycle to simulate PCS and BSMU. The relay uses EVC500 of TE. DC source supplies input VDC to power and relay driver circuit.

Figure 3-1 shows the relay driver circuit.

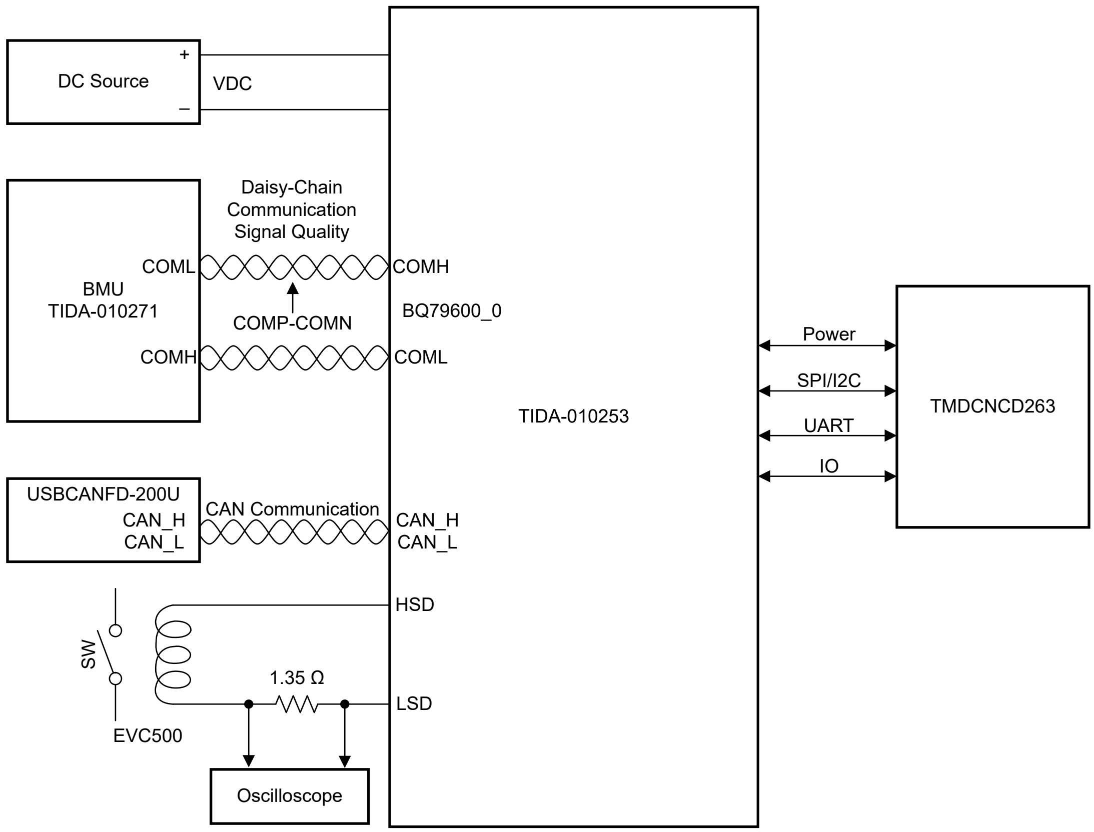


Figure 3-1. Test Setup

3.4 Test Results

3.4.1 Power Supply Testing

The power supply tests include testing to measure the variation of the 5-V supply when the input voltage (VDC) varies, and measuring the input current when input voltage is negative with respect to GND, which mimics a reverse input condition.

Figure 3-2 shows that the 5-V supply is active and well regulated for input voltages on VDC in the range of 2 V to 36 V. These measurements are recorded with no external load on the reference design board.

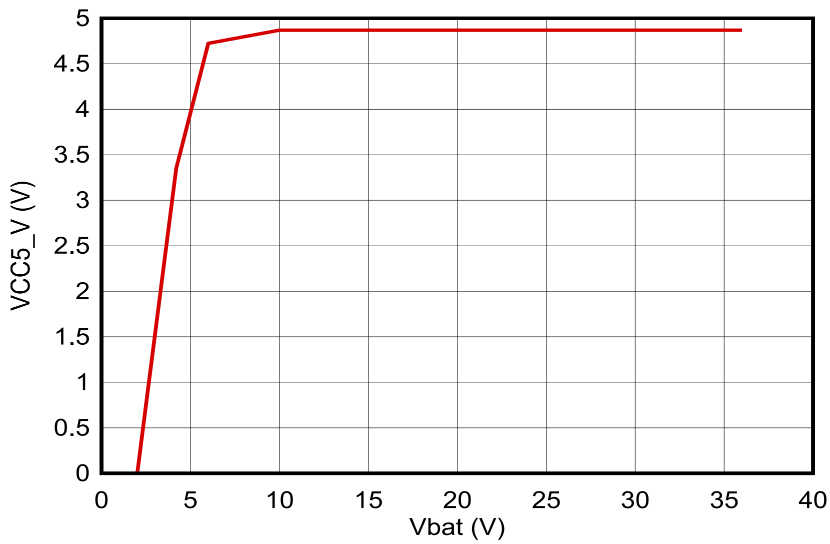


Figure 3-2. Measured 5-V Supply vs Applied Input Voltage

Figure 3-3 shows the input current under conditions of negative voltages applied to input with respect to GND. For applied voltages more negative than –5 V, the current increases linearly.

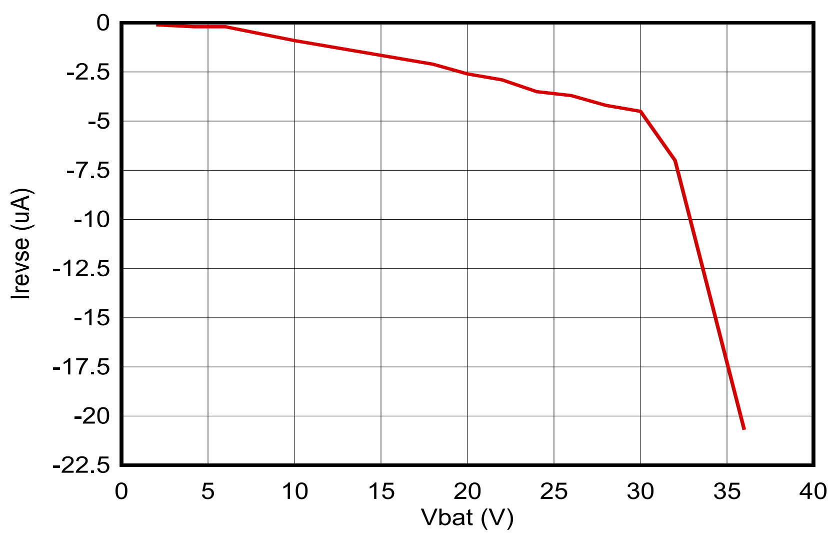


Figure 3-3. Input Current vs Applied Negative Input Voltage

For positive (normal polarity) applied Input voltages, Figure 3-4 shows the input current at input versus the applied input voltage. For a nominal 24-V supply level, the design has an input current of around 120 mA, including the controlCARD microcontroller board. This represents the idle current when no relay is actively driven, the CAN, RS-485, daisy chain, and Ethernet transceiver are idle. As the applied voltage is increased to 36 V, there is a slight increase in the input current, but no significant increase. This indicates there is no breakdown of any of the components connected to VDC, thus the design is not damaged by steady-state VDC voltages up to 36 V. The design is robust to load-dump conditions that can occur on the supply system.

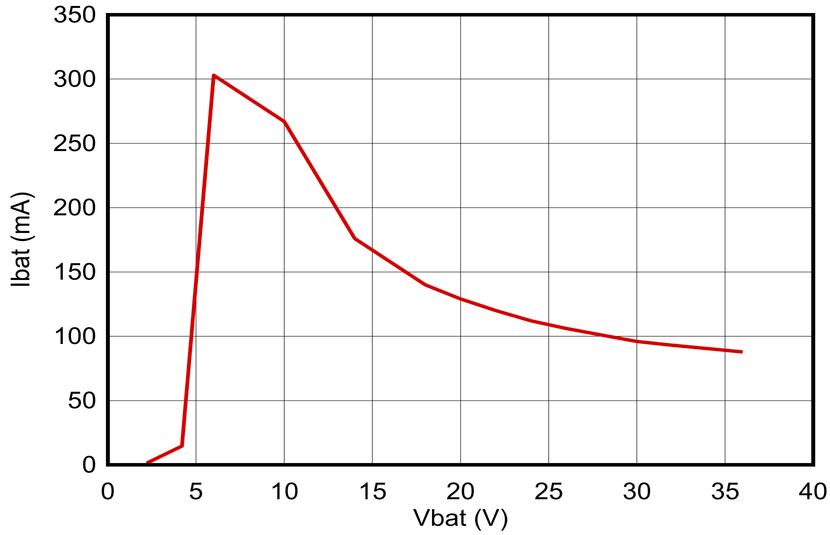


Figure 3-4. Input Current vs Applied Positive Input Voltage

3.4.2 Daisy Chain Signal Quality

This design uses a BMU (TIDA-010271) to communicate with BCU. The test point is in the BCU COMH port of BQ79600_0. The oscilloscope measures the COMP-COMN to check the positive pulse width, negative pulse width, rise slew rate, and fall slew rate.

Figure 3-5 through Figure 3-8 show the daisy chain waveforms.

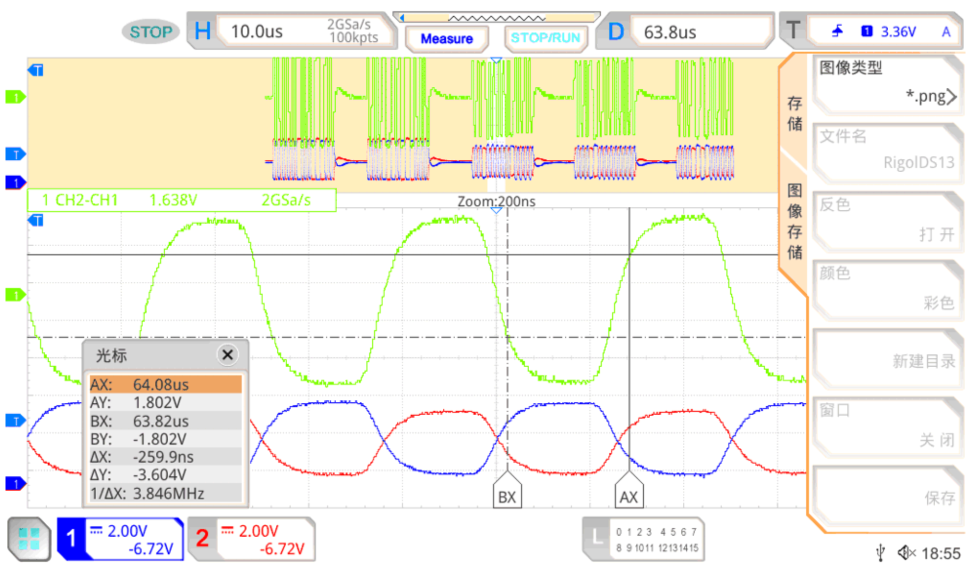


Figure 3-5. Positive Pulse-Width of Daisy Chain

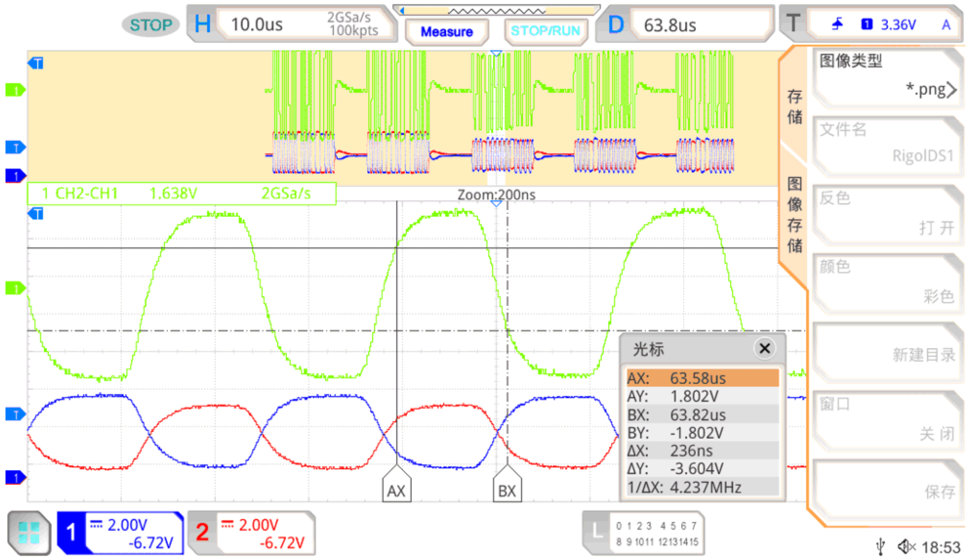


Figure 3-6. Negative Pulse-Width of Daisy Chain

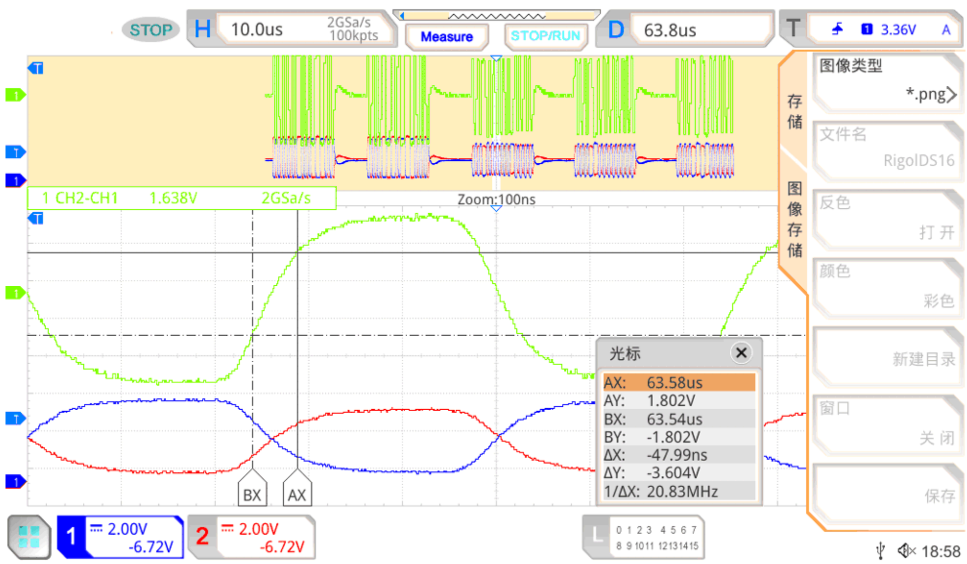


Figure 3-7. Raise Slew-Rate of Daisy Chain

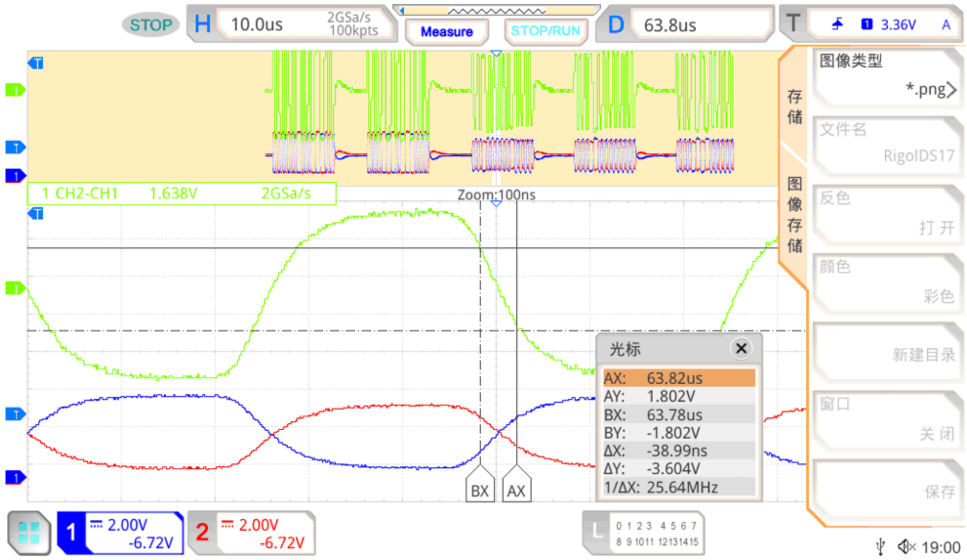


Figure 3-8. Fall Slew-Rate of Daisy Chain

Table 3-18 lists daisy chain signal performance data.

Table 3-18. Daisy Chain Signal Performance

PARAMETER	CONDITION	MIN	TEST DATA	MAX
Positive pulse width	Measure COMP-COMN from +1.8 V of rising edge to –1.8 V of next falling edge	230 ns	260 ns	270 ns
Negative pulse width	Measure COMP-COMN from –1.8 V of falling edge to +1.8 V of next rising edge	230 ns	236 ns	270 ns
Rise slew rate	Measure COMP-COMN from –1.8 V to +1.8 V of rising edge		50 ns	
Fall slew rate	Measure COMP-COMN from +1.8 V to –1.8 V of falling edge		39 ns	

3.4.3 Relay Driving

The coil driving circuit uses one channel of the smart high-side switch TPS4H160-Q1 and ULN2803 to implement a unidirectional drive, as Figure 2-3 shows. For testing this circuit, a high-voltage relay with economizer is used as the load, EVC500 is described in Table 3-19.

Table 3-19. Coil Data

OPERATING VOLTAGE RANGE / VDC	INRUSH CURRENT AT 23°C/A	MAXIMUM INRUSH TIME/ms	NOMINAL FREQUENCY/kHz	NOMINAL DUTY CYCLE/%
9 – 36	3.8	130	19.9	20

Figure 3-9 shows an oscilloscope plot of the signals during current pickup. Channel 1 shows the voltage on the relay coil; Channel 2 shows the shunt (1.35 Ω) voltage which corresponds to the shunt current through the high-side switch to the relay coil and economizer. Initially the current reaches a peak when the economizer operates in 100% duty cycle, and thus has only a small back electromotive force voltage. After the relay contacts close, the economizer operates in a nominal duty cycle. In the current pick-up process, the shunt voltage signal reaches peak of about 2.034 V. The scale factor for the shunt voltage signal is about 1.35 V/A of shunt current, so this signal indicates the peak current is about 1.507 A.

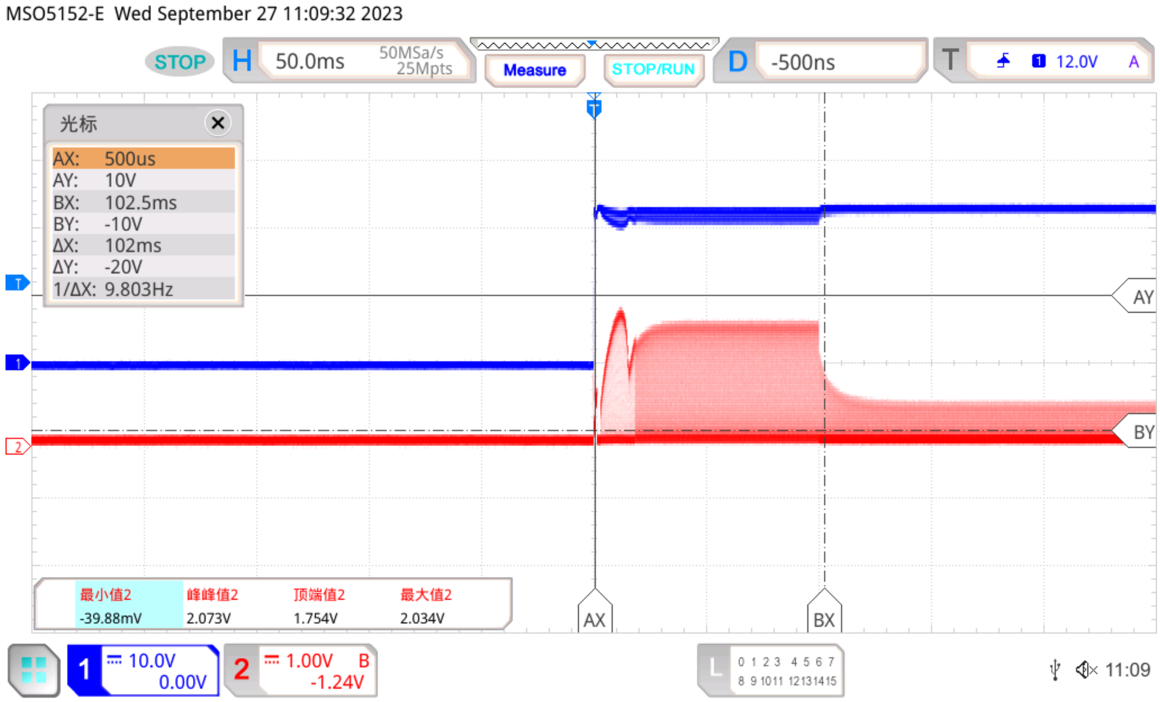


Figure 3-9. Current Pickup Phase

Figure 3-9 shows an oscilloscope plot of the current signals. Channel 1 shows the current sensing (CS) signal of TPS4H160B which corresponds to the current through the high-side switch to the relay coil and economizer. Channel 2 shows the shunt voltage. The shunt voltage signal is followed closely by the CS signal. The CS signal setting time from IN falling and the rising edge of TPS4H160 is a maximum 150 µs, which causes the CS signal to lose the PWM portion of the real shunt current.

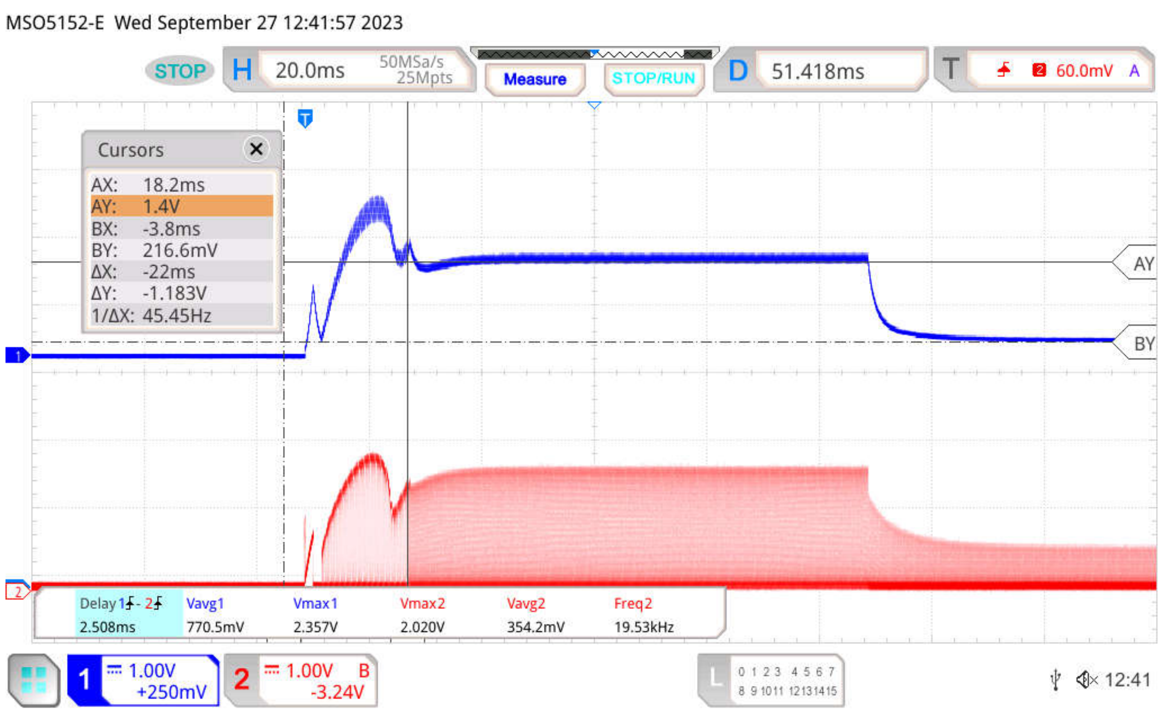


Figure 3-10. Current Measuring Performance

Figure 3-9 shows an oscilloscope plot of the signals during the current fast decay phase of the relay. Channel 1 shows the voltage on the relay coil; Channel 2 shows the shunt voltage. The voltage on Channel 1 reduces and the coil current begins to reduce. Due to the inductance of the coil, the coil current does not immediately drop to zero, but decays as the energy stored in the coil dissipates. The fast decay process lasts 3.14 ms.

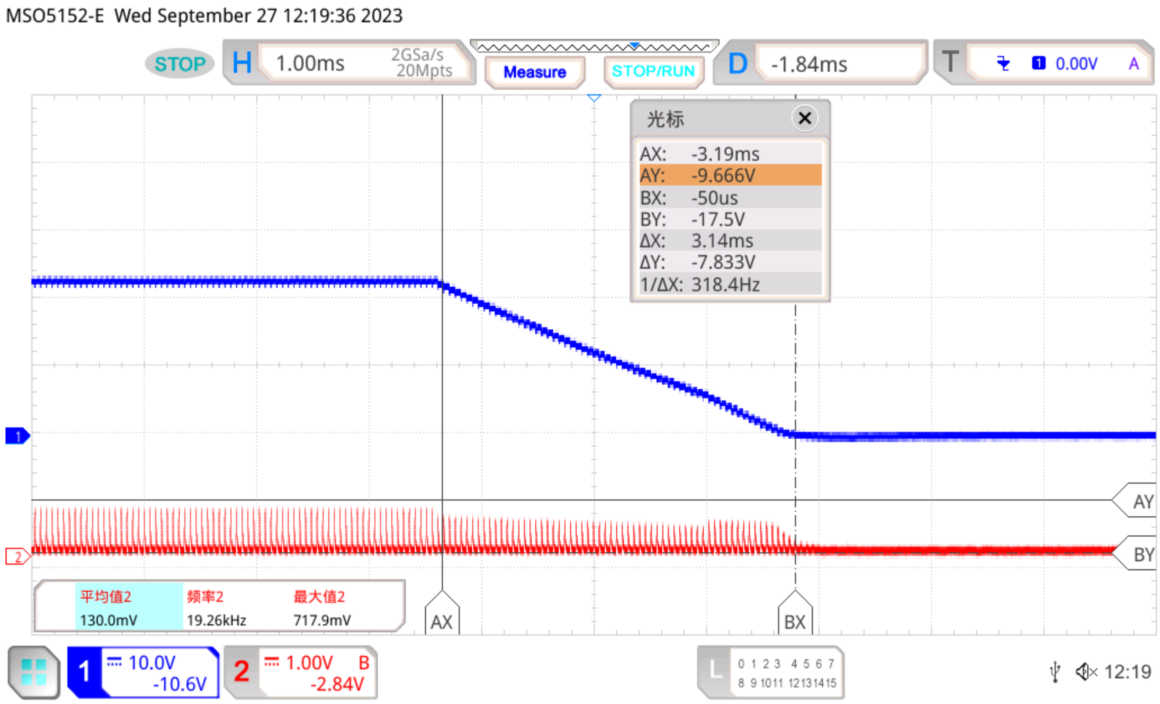


Figure 3-11. Current Fast Decay Phase

The TPS4H160-Q1 specifies an absolute maximum of 40 mJ for the *Inductive load switch-off energy dissipation, single pulse, single channel*, so this energy that must be dissipated each time the relay coil is turned off is significantly less than the specified value. Designers can use the TPS4H160-Q1 for this application without the need for protection diodes in parallel with relay coil, unless the coil is significantly larger than the model used for testing.

3.4.4 Isolated CAN Transceiver Operation

Figure 3-12 shows the signals during CAN transmitter operation. Channel 1 is the input to the transceiver on the TXD signal, changing state with a bit width of about 1 microsecond (1Mbps). Channel 2 is the CAN bus signal CANH-L which responds to the TXD signal.

At this scale, there is no observable time delay between transitions on the TXD pin and transitions on the CANH-L pin. The controlled slope of the CAN bus signals is also apparent.

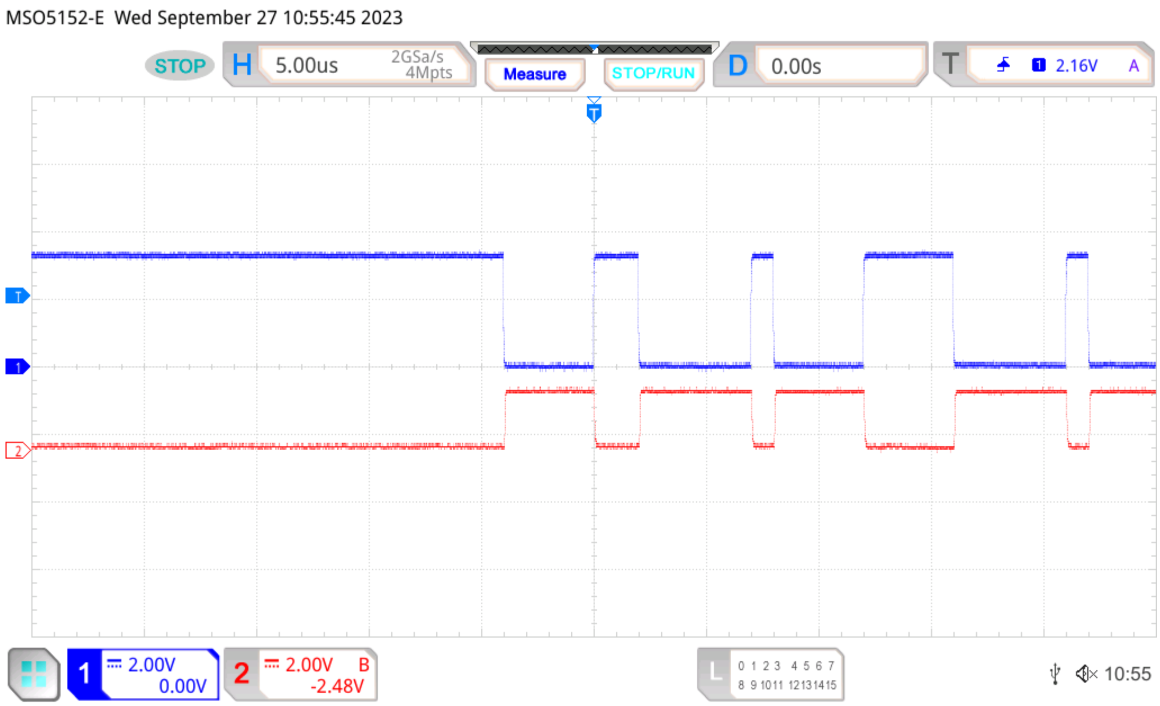


Figure 3-12. CAN Transceiver Operation Signals

4 Design and Documentation Support

4.1 Design Files

4.1.1 Schematics

To download the schematics, see the design files at TIDA-010253.

4.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-010253.

4.2 Tools and Software

Tools

USB2ANY The USB2ANY interface adapter is a tool intended to allow a computer to control an evaluation module (EVM) via a USB connection. USB2ANY supports multiple popular protocol interfaces and provides 3.3-V and 5-V power supplies.

Software

CCSTUDIO Code Composer Studio™ integrated development environment (IDE)

4.3 Documentation Support

1. Texas Instruments, *AM263x Control Card Hardware* User's Guide
2. Texas Instruments, *Driving High-Voltage Contactors in EV and HEVs* Technical White Paper
3. Texas Instruments, *AN-2162 Simple Success With Conducted EMI From DC-DC Converters* Application Note
4. Texas Instruments, *LMR51440-CALC* (LMR51440_Quick_Start_Tool_Rev1.0.xlsm) Calculation Tool

4.4 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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