TI Designs：TIDA-020019
汽车隔离式 CAN 和电源前端参考设计

说明

此参考设计演示了广泛应用于汽车环境且采用小型封装的增强型隔离式 CAN 通信。在混合动力车辆和电动车辆 (HEV/EV) 中，完整的高电压网络会相对于机箱接地浮动。对于连接在高电压到低电压浮动系统之间的电源和通信通道，则需要使用隔离。此 TI 设计具有低传输延迟，可降低环路延迟并支持较高的 CAN 波特率。

资源

TIDA-020019	设计文件夹
ISO1042-Q1	产品文件夹
SN6505A-Q1	产品文件夹
LMR23610-Q1	产品文件夹
TPS763-Q1	产品文件夹

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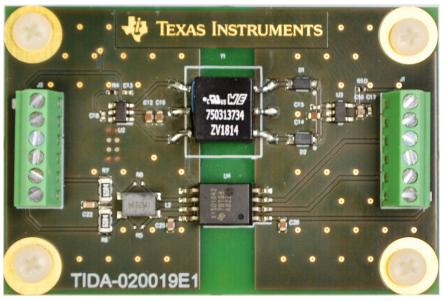
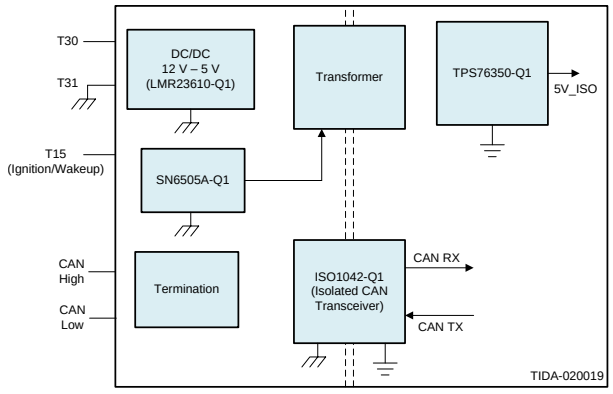
特性

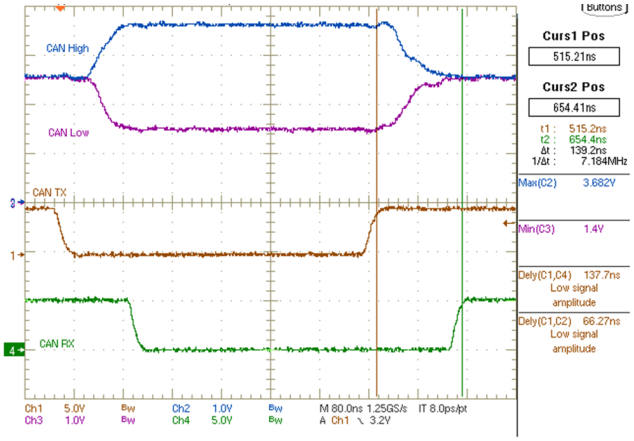
- 集成 CAN 和数字隔离器 (ISO1042-Q1)
- 低环路延迟（通常为 139ηs），支持高仲裁速率
- 内置增强型数字隔离
- ±70V 总线故障保护
- 成本敏感型终端，具有内部 ESD 保护功能
- 符合 ISO 11898-2 CAN 标准

应用

- 起动机/发电机
- 电池管理系统
- 直流/直流转换器
- 车载充电器







1 System Description

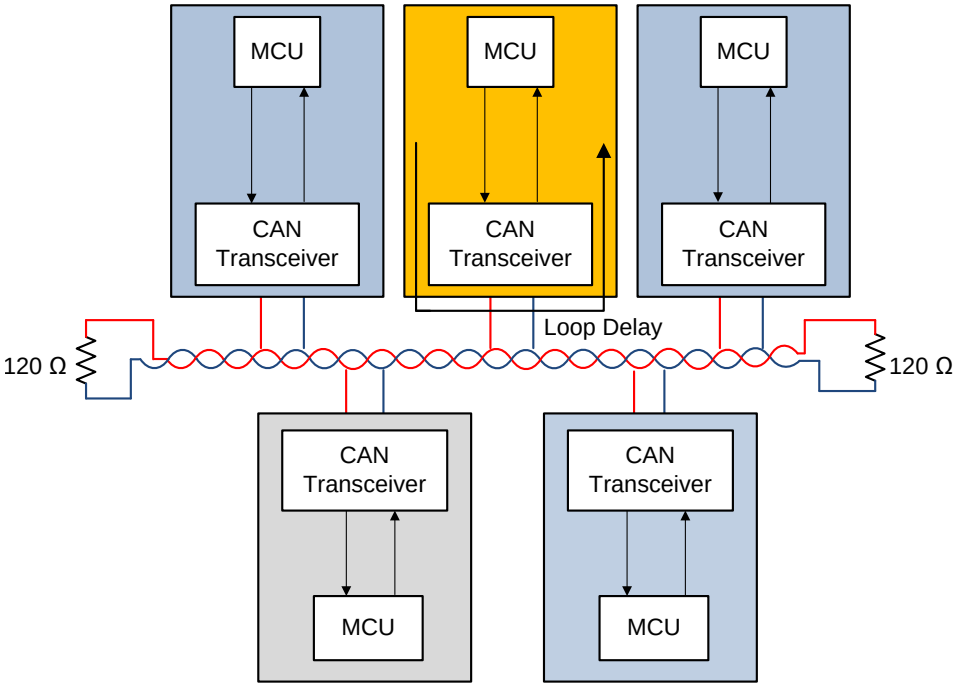
A *Controller Area Network* (CAN) is widely used in the automotive industry to replace the complex wiring harness with a two-wire bus. It is highly immune to electrical interference and it has the ability to self-diagnose and repair data errors. These features have led to the popularity of the CAN and extended its application in building automation, medical, and manufacturing. The TIDA-020019 integrated CAN, digital isolator reference design is targeted to improve the system and CAN performance for automotive isolated ground applications such as cell supervision units, battery control units, inverters, chargers, and so on.

CAN manages message collision and provides a unique proving ground for protocol compliance in any application. Any CAN node may begin to transmit when the bus is free, and two or more nodes may begin to transmit simultaneously. Arbitration is the process by which these nodes battle for control of the bus. Proper arbitration is critical to CAN performance because this is the mechanism that guarantees that message collisions do not reduce bandwidth or cause messages to be lost. Each data or remote frame begins with an identifier, which assigns the priority and content of the message. As the identifier is broadcast, each transmitting node compares the value received on the bus to the value being broadcast. The higher priority message during a collision has a dominant bit earlier in the identifier. Therefore, if a transmitting node senses a dominant bit on the bus in place of the recessive bit it transmitted, it interprets this as another message with higher priority transmitting simultaneously. This node suspends transmission before the next bit and automatically retransmits when the bus is idle.

The evolution of automotive architectures and need for efficient power train and vehicle control mechanisms increased the demand for the number of nodes in vehicles (both passenger and commercial). Improvement in safety architectures increases demand for internal diagnosis and data sharing between multiple nodes with faster response times. The number of nodes to transmit and data loads push the limits of the CAN baud rates while staying within its advantages of reliable robust communication. CAN FD (flexible data rate) is one such flavor of CAN communications, which gained popularity for its flexibility of retaining the features of basic CAN (no change to physical layer) and supports high data rates with little rise in system cost.

Loop delays and round-trip delays are limiting factors in determining arbitration and data speeds (b/s) in classical CAN. In CAN FD, loop delay and network propagation delay are the major limiting factors during the arbitration phase. During the data phase, a secondary sampling point plays an important role for synchronizing data in transmitters. Transceiver delay compensation, which is nothing but a loop delay and offset, is used to check the previously transmitted data with secondary sample registers and check for bit errors.

图 1. Typical CAN in HEV/EV



In typical ICE vehicles, loop delay and round-trip delay are straight forward to configure the transceiver delay compensation.

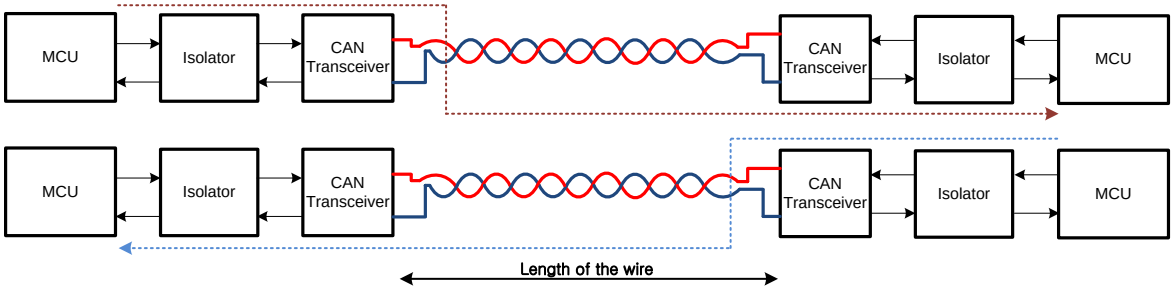
- Transceiver delay compensation = Loop delay + Offset

Factors to influence loop delay in a typical CAN (non-isolated):

- Impedance of controller to transceiver interface
- Transceiver TX-RX delay time (dominant or recessive)
- CAN bus impedance

HEV/EV or 48-V systems are isolated from chassis ground based on system architecture. Power and communication interfaces are isolated in high-voltage systems; ground loops are just insulated for 48-V applications. Based on the design of control units, CAN transceivers are isolated from micro controllers as 图 2 shows. In this case, transceiver delay compensation is increased based on the delay in the digital isolator

图 2. Propagation Delay in Isolated CAN



Factors to influence round-trip or propagation delay in isolated CAN:

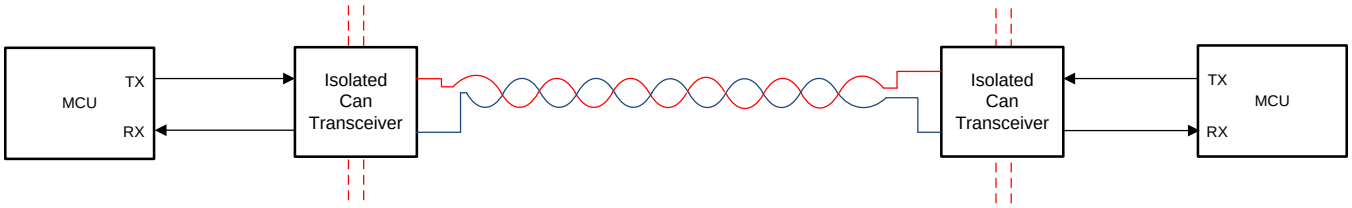
- Impedance of controller to digital isolator

- Propagation delay of digital isolator
- Impedance of digital isolator to CAN interface
- Transceiver TX-RX delay time (dominant or recessive)
- CAN bus impedance
- Length of the wire

Based on the CAN physical layer, the round-trip delay can be less significant. Neglecting the impedance delays and internal software delays, the approximate round-trip delay of two isolated CAN ECUs is calculated with the following equation:

Round-trip delay = 2 × (Propagation delay of digital isolator 1 + Propagation of CAN1 TX to bus + Propagation delay of wire + Propagation delay of CAN2 bus to RX + Propagation delay of digital isolator 2) (1)

图 **3. Expectations of Isolated CAN**



In isolated CAN communication, the digital isolator plays an important role for loop delay and round trip delay. It is expected that with an integrated isolated CAN transceiver, delays should be close to the normal CAN transceiver to have consistency in system parameters. This enables higher baud rates for isolated CAN while retaining the same system architecture of normal CAN.

1.1 Key System Specifications

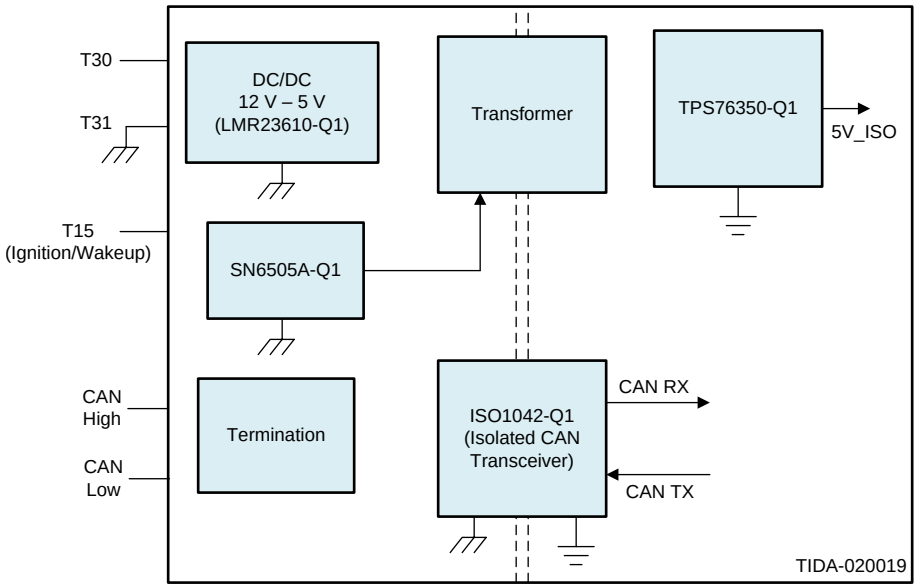
表 **1. Key System Specifications**

PARAMETER	CONDITIONS	TYP
TIDA-020019 round trip delay	R_L = 60 Ω, C_L = 4.7 ηF, twice ISO1042-Q1 device with 1.7-m twisted pair cable	300.8 ηs
TIDA-020019 loop delay (R-D)	R_L = 60 Ω, C_L = 4.7 ηF	138.3 ηs
TIDA-020019 loop delay (D-R)	R_L = 60 Ω, C_L = 4.7 ηF	139.2 ηs
Dominant TX to CAN bus	R_L = 60 Ω, C_L = 4.7 ηF	67.2 ηs
Recessive TX to CAN bus	1.7-m wire with R_L = 60 Ω, C_L = 4.7 ηF	66.27 ηs
Output of LMR23610-Q1	150-mA load current	5.062 V
Frequency of SN6505A-Q1	100-mA load	159.3 kHz

2 System Overview

2.1 Block Diagram

图 4. TIDA-020019 Block Diagram

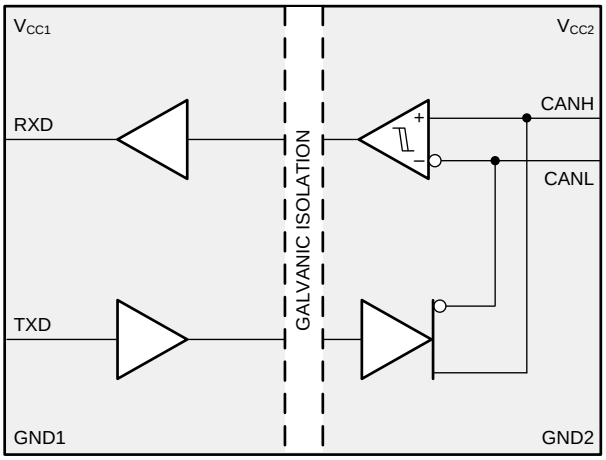


2.2 Highlighted Products

2.2.1 ISO1042-Q1

The ISO1042 -Q1 device is a galvanically-isolated controller area network (CAN) transceiver that meets the specifications of the ISO11898-2 (2016) standard. The ISO1042 -Q1 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 (SiO 2) 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 -Q1 device is available for both basic and reinforced isolation.

图 **5. ISO1042-Q1 Functional Block Diagram**



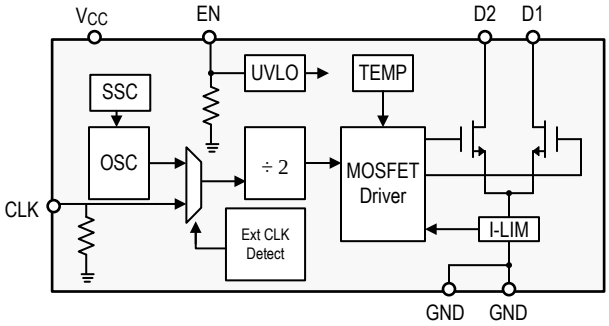
ISO1042 -Q1 features:

- Supports classic CAN up to 1 Mbps and FD (Flexible Data Rate) up to 5 Mbps
- Meets the ISO 11898-2:2016 and ISO 11898- 5:2007 physical layer standards
- Ideal passive, high impedance bus terminals when unpowered
- High CMTI: 100 kV/μs
- Robust Electromagnetic Compatibility (EMC)
- Grade 1: –40°C to 125°C ambient temperature

2.2.2 SN6505A-Q1

The SN6505A-Q1 device is a transformer driver designed for low-cost, small form-factor, isolated DC/DC converters utilizing the push-pull topology. The device includes an oscillator that feeds a gate-drive circuit. The gate-drive, comprising a frequency divider and a break-before-make (BBM) logic, provides two complementary output signals which alternately turn the two output transistors on and off. The output frequency of the oscillator is divided down by two. A subsequent break-before-make logic inserts a dead-time between the high-pulses of the two signals. Before either one of the gates can assume logic high, the BBM logic ensures a short time period during which both signals are low and both transistors are high-impedance. This short period, is required to avoid shorting out both ends of the primary. The resulting output signals, present the gate-drive signals for the output transistors

图 **6. SN6505A-Q1 Functional Block Diagram**



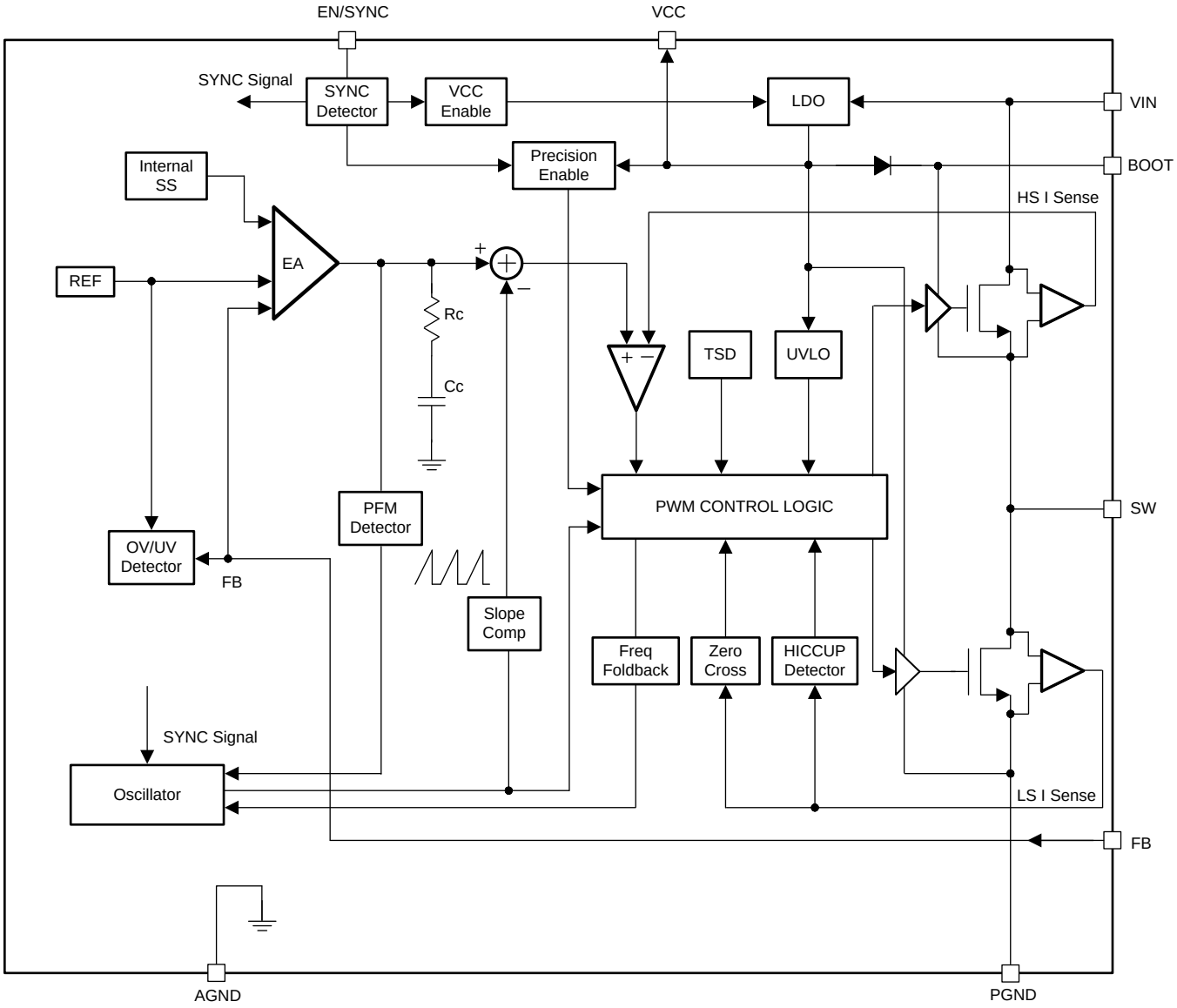
SN6505A-Q1 features:

- Push-pull driver for transformers
- Low R_{on} 0.25 Ω maximum at 4.5-V supply
- Spread-spectrum clocking
- Synchronization of multiple devices with external clock input
- 1.7-A current limit
- Wide temperature range: –55°C to 125°C
- Soft start to reduce In-rush current

2.2.3 LMR23610-Q1

The LMR23610-Q1 SIMPLE SWITCHER ® regulator is an easy to use synchronous step-down DC/DC converter operating from 4 V to 36 V supply voltage. It is capable of delivering up to 1 A DC load current with good thermal performance in a small solution size. An extended family is available in multiple current options from 1 A to 3 A in pin-to-pin compatible packages. The LMR23610-Q1 employs fixed frequency peak current mode control. The device enters PFM mode at light load to achieve high efficiency. The device is internally compensated, which reduces design time, and requires few external components. The LMR23610-Q1 is capable of synchronization to an external clock within the range of 200 kHz to 2.2 MHz. Additional features such as precision enable and internal soft start, provide a flexible and easy-to-use solution for a wide range of applications. Protection features include thermal shutdown, VIN and VCC undervoltage lockout, cycle-by-cycle current limit, and hiccup mode short-circuit protection. The family requires very few external components and has a pin-out designed for simple, optimum PCB layout.

图 **7. LMR23610-Q1 Functional Block Diagram**



LMR23610-Q1 features:

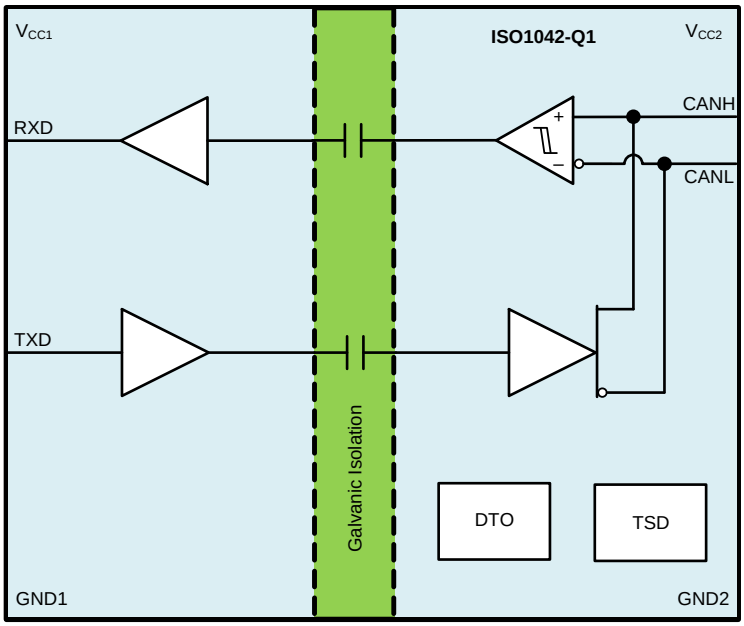
- Integrated synchronous rectification
- Internal compensation for ease-of-use
- Minimum switch-on time: 60 ns
- Frequency synchronization to external clock
- 75-μA quiescent current at no load
- Output short-circuit protection with Hiccup mode

2.3 System Design Theory

2.3.1 Isolated CAN Communication

The ISO1042-Q1 device is designed to support CAN communication with galvanic reinforced isolation. ISO1042-Q1 uses a silicon dioxide (SiO_2) insulation barrier with a withstand voltage of 5000 V_{RMS} and a working voltage of 1060 V_{RMS}.

图 **8. ISO1042-Q1 Block Diagram**



V_{CC1} on the controller side supports core voltages from 1.8 V to 5.5 V. V_{CC2} on the CAN communication section supports typical 5-V CAN (4.5 V to 5.5 V).

Dominant Time Out (DTO) and *Thermal Shutdown* (TSD) are the critical functions of CAN core used to ensure safety of CAN communication irrespective or internal failures of ISO1042-Q1 and internal supplies.

Due to the DTO feature, there is a limit on minimum baud rate to be used for ISO1042-Q1. If five successive bits are the same, it is considered a error frame. If the 11 successive bits are dominant, it is considered as *Dominant Time Out* error in the ISO1042-Q1 device. Based on the type of CAN impedance, the loading timeout of the ISO1042-Q1 device is 1.2 ms to 3.8 ms, the minimum baud rate is well in the range of 9.16 kbps to 2.89 kbps. Most of the standard CAN communications are set at 500 Kbps, ISO1042-Q1 can support CAN FD communication up to 5 Mbps data rate.

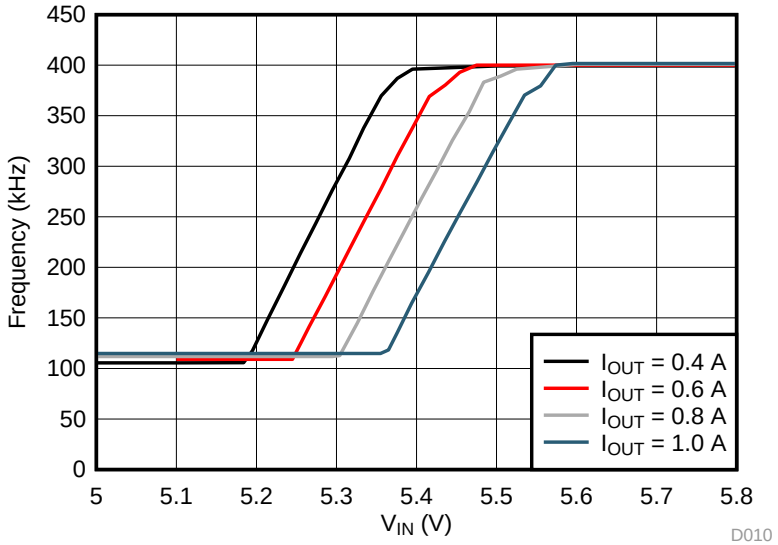
Reinforced galvanic isolation can support better during ground breaks. Failure of supply on VCC1 will not have an impact on communication of CAN.

2.3.2 Isolated Power

LMR23610-Q1 – An automotive-qualified simple switcher is used to work with 12-V automotive batteries. The LMR23610-Q1 device can withstand peaks of 42 V, but it recommended to operate until 36 V which supports for load-dump scenarios. If the enable pin of the LMR23610-Q1 device is turned off, it draws as low as 2 µA of current. If the LMR23610-Q1 device is enabled and there is no load to output , quiescent operating currents are typically 75 µA.

At light loads the LMR23610-Q1 device goes to PFM mode to achieve high efficiency, it works at fixed frequency of 400 kHz. The sync pin of the LMR23610-Q1 device can support external clocks from 200 kHz to 2 MHz. Based on the input voltage and output load currents, the LMR23610-Q1 device has a frequency fold back feature to maintain minimum off time at low input voltages.

图 **9. LMR23610-Q1 Frequency Fold Back V_{OUT} = 5 V**



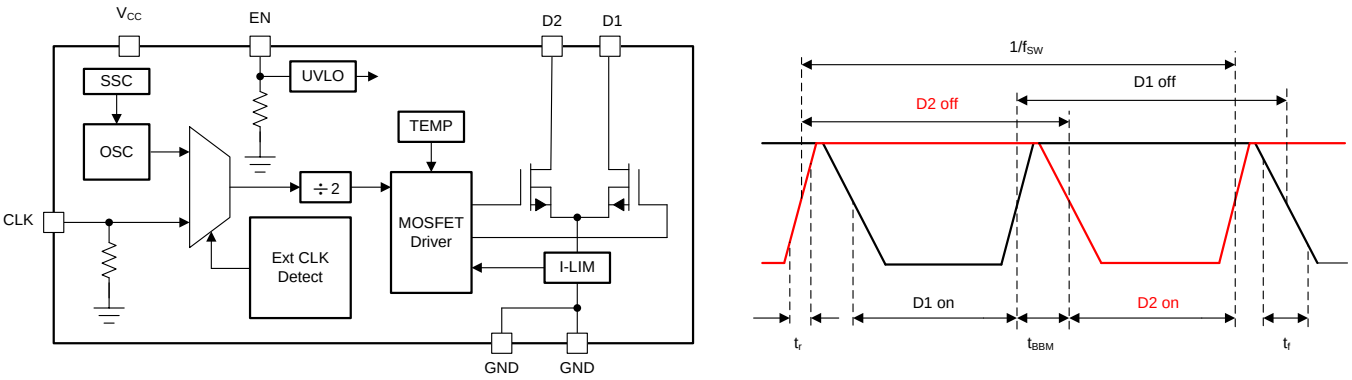
The LMR23610-Q1 device has adjustable output feature with FB pin. Internal compensation loop is designed such that the loop response is stable over the entire operating frequency and output voltage range. Depending on the output voltage, the compensation loop phase margin can be low with all ceramic capacitors. Based on the type of load scenario, the LMR23610-Q1 device can operate in *Continuous Conduction Mode* (CCM), *Discontinuous Conduction Mode* (DCM), and *Pulse Frequency Mode* (PFM).

The LMR23610-Q1 device 1 had overcurrent and short-circuit protection features with internal current sense and error amplifier. Overcurrent and short-circuit protection plays important role for the safety of the system. The thermal shutdown feature of the LMR23610-Q1 device shuts down the device when the junction temperature reaches 170°C, it starts the power-up sequence with soft start when the junction temperature falls to less than 155°C.

See *LMR23610-Q1 SIMPLE SWITCHER® 36 V, 1 A Synchronous Step-Down Converter* for information on selecting interface components to generate 5-V output.

SN6505A-Q1 is a push pull transformer driver with BBM logic to transfer power across isolation.

图 **10. SN6505A-Q1 Block Diagram and Timing**



The block diagram in 图 10 shows that the SN6505A-Q1 device has an internal oscillator which starts operating when VCC > 2.25 V. The SN6505A-Q1 device starts functioning normally when the VCC voltage is > 3 V (±10% of 3.3 V). The SN6505A-Q1 device has a feature to support external clocks from 100 kHz to 600 kHz. The output frequency of the oscillator is divided down by an asynchronous divider that provides two complementary output signals, with a 50% duty cycle. A subsequent break-before-make logic inserts a dead-time between the high-pulses of the two signals. The resulting output signals, present the gate drive signals for the output transistors. D2 and D1 signals are generated as 图 10 shows..

The spread spectrum of the SN6505A-Q1 device is an important feature to reduce the radiated emissions which is important in high current power supply systems. The SN6505A-Q1 device addresses this by modulating its internal clock in way the emitting energy is spread over multiple frequency bins . This Spread Spectrum clocking feature greatly improves the emissions performance of the entire power supply block and hence relieving the system designer of one major concern in isolated power supply design.

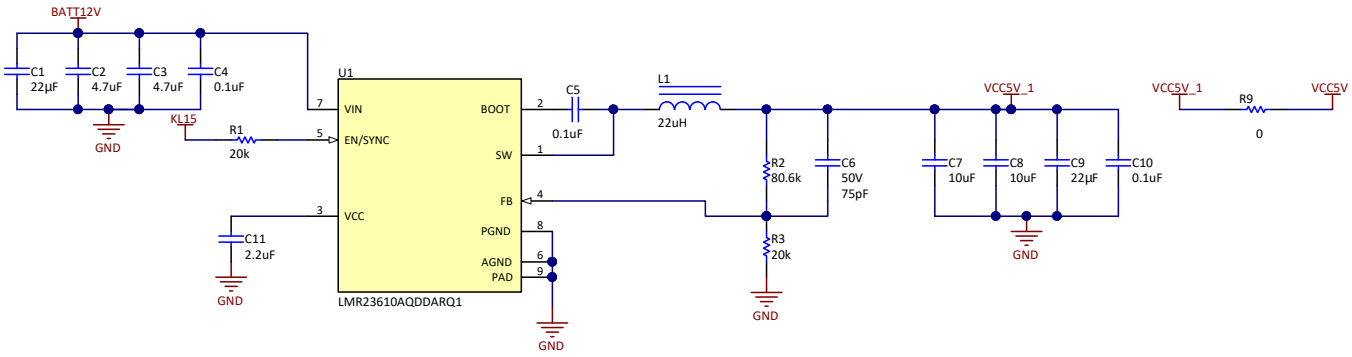
See *SN6505x-Q1 Low-Noise 1-A Transformer Drivers for Isolated Power Supplies* for information on selecting interface components to generate isolated 5-V output.

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware

3.1.1 Hardware

图 **11. LMR23610-Q1 Schematic**



BATT12V is the typical interface for any 12-V power supply. Input protection circuitry for 12-V systems is not in the scope of this TIDA. See TIDA-01167 and TIDA-00992 for different types of input protection systems for automotive 12-V batteries.

Place the input bypass capacitors (C1, C2 ,C3, and C4) very close to the LMR23610-Q1 VIN and PGND pins.

The KL15 input pin is directly connected to the EN pin with R1 20 kΩ. The KL15 pin supports the voltages up to VIN so it can support load dump of the battery.

The C5 boot strap capacitance of 0.1 µF should be close to the boot pin of the LMR23610-Q1 device.

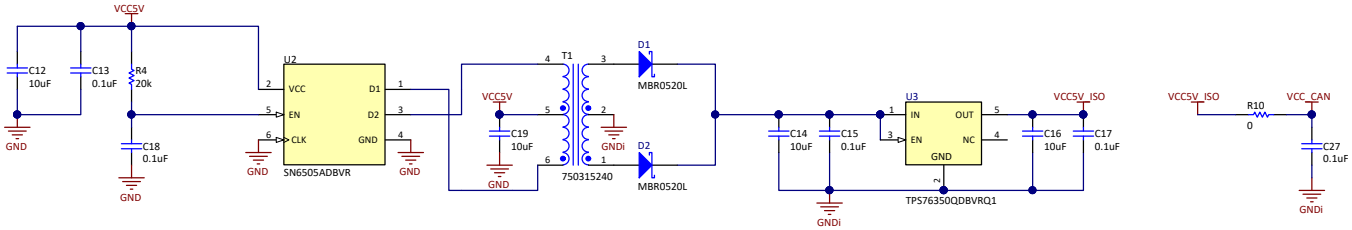
L1 with 22 µH is used for buck conversion of 5 V with a maximum load of 1 A. In TIDA-020019, the maximum load current is 200 mA, but same design can handle load currents up to 1 A.

R2, C5, and R3 support fixing the output voltage and support for cross-over frequency of the control loop to boost the phase margin.

C7, C8, C9 and C10 are output filter capacitors to support in handling voltage ripple for load currents.

The TIDA-020019 can work directly from an external 5-V supply. R9 is the junction resistor of non-isolated 5-V load. Depopulating the same enables the design to support external 5-V, connecting directly at the input.

图 12. SN6505A-Q1 Schematic



Place the input bypass capacitors (C12 and C13) very close to VCC pin of U2. R4 and C18 support enabling the SN6505A-Q1 device with a low-pass filter. SN6505A-Q1 enables transfer the power from primary side of T1 transformer by switching D1 and D2 pins.

Use D1 and D2 Schottky diodes to support rectifying the output voltage of transformer.

Isolated 5 V is generated by using LDO to power CAN transceiver ISO1042-Q1 on the control section.

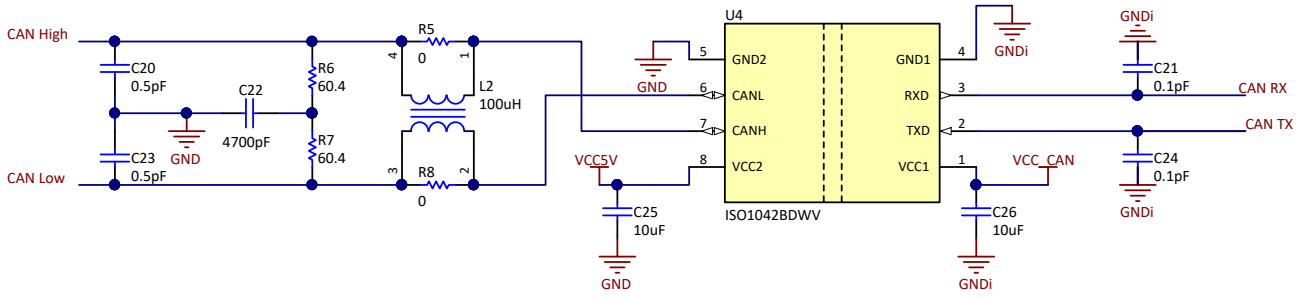
TPS65350-Q1 is used to regulate the output voltage to 5 V.

VCC5V_ISO on TIDA-020019 can be used to load other functions, for regulated high load currents it is recommended to use different LDO or bypass the onboard LDO TPS76350-Q1 as it can handle maximum load current of 150 mA.

C16 and C17 are used to filter the regulated output voltage with very low ripples for different load currents.

If the TIDA-020019 is directly connected to controllers with 3.3-V controllers, R10 can be depopulated and an external supply of 3.3 V can be connected directly to TIDA-020019.

图 13. ISO1042-Q1 Schematic



C25 and C26 are bypass capacitors for VCC2 and VCC1, respectively for ISO1042-Q1.

L2 common mode choke to filter the noises for CAN Communication. R5 and R8 are used to bypass the same if it is not required.

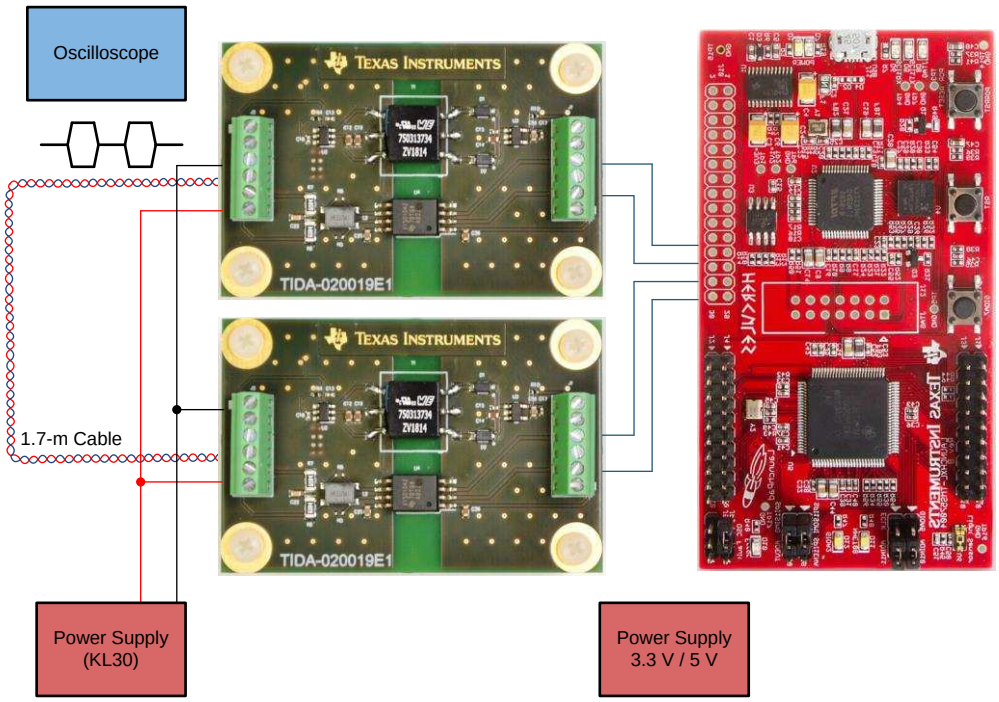
R6 ,R7, and C22 are the terminal components for ISO1042-Q1.The split-resistor capacitor method is one of the commonly used methods for CAN termination.

C20 and C23 are ESD capacitors which needs to be populated near the pins of CAN Communication.

3.2 Testing and Results

3.2.1 Test Setup

图 14. TIDA-020019 Test Setup



The TIDA-020019 is tested with the Hercules TMS570 LaunchPad™. Two TIDA-020019 boards are connected as 图 14 shows, to a LaunchPad for CAN communication:

- KL30 (12 V) is generated by using a laboratory power supply (0–60 V, 1.5 A)
- 1.7-m twisted pair cable is used for CAN Communication
- LaunchPad is interfaced to laptop with typical Micro USB cable
- *Code Composer Studio* is used to evaluate the performance of CAN and system
- Oscilloscope is used to check TIDA-020019 board performance

Basic CAN communication tests are performed using the LaunchPad, it is used to measure the loop delays and round trip delays of ISO1042-Q1 in TIDA-020019 when they interfaced with 1.7-m twisted pair cable.

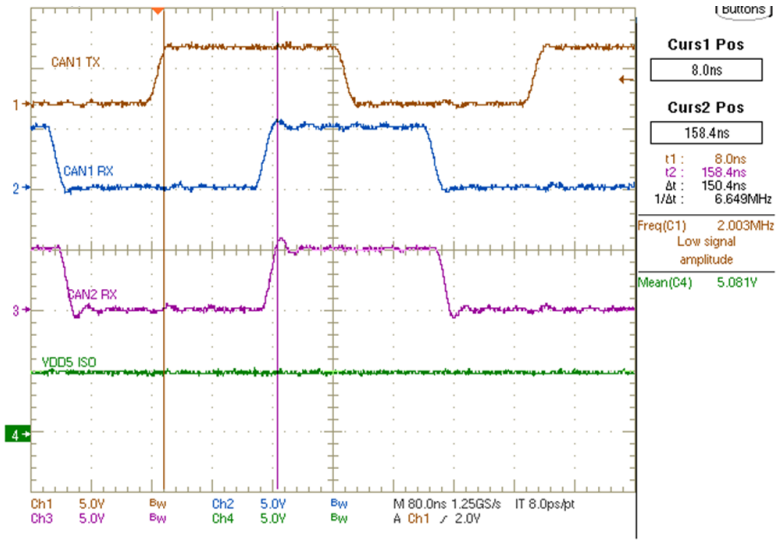
Performance of buck converter LMR23610-Q1 which is power front-end is measured. SN6505A-Q1 functional behavior is tested and plotted below.

System behavior of TIDA-020019 is optimal as per the expectations.

3.2.2 Test Results

图 15 through 图 22 illustrate the test results.

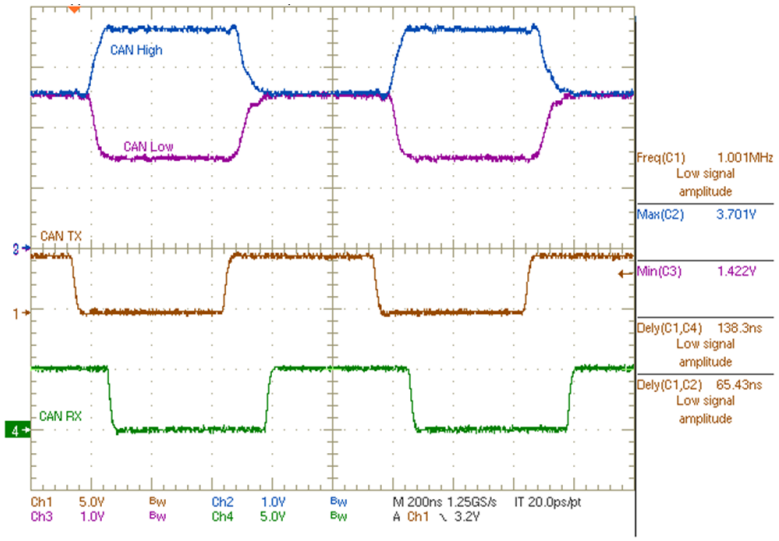
图 15. CAN Behavior of 1.7-m Cable



CH1: CAN1 TX
CH2 CAN1 RX
CH3: CAN2 RX
CH4: VDD5 ISO

Round trip delay with 1.7-m cable is 2 × 150.4 ηs = 300.8 ηs

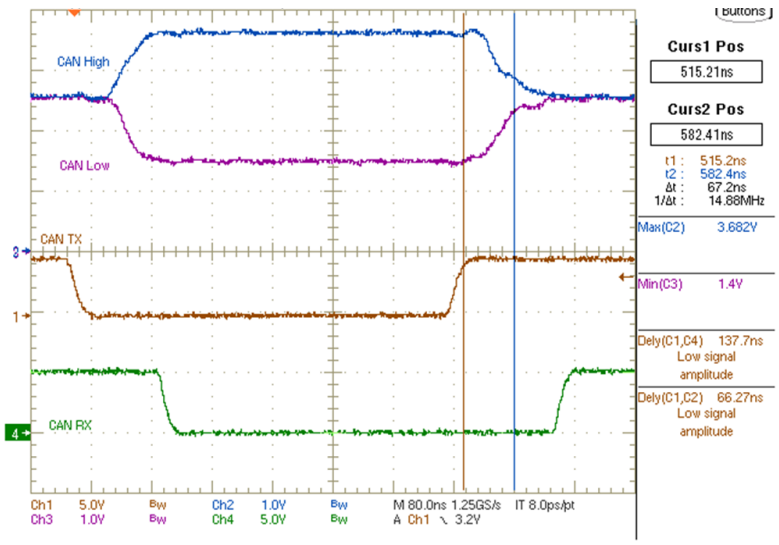
图 16. ISO1042-Q1 Loop Delay Behavior



CH1: CAN1 TX
CH2 CAN1 RX
CH3: CAN2 RX
CH4: VDD5 ISO

R-D loop delay: 138.3 ηs
Baud rate = 1 Mbps

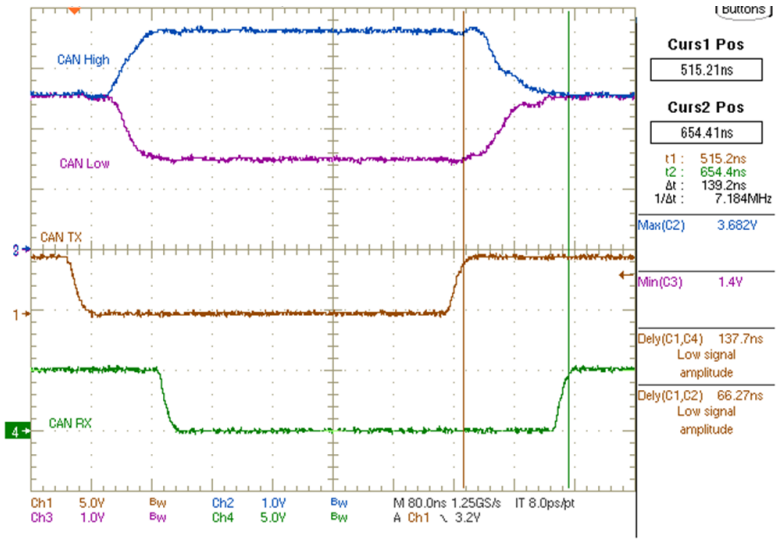
图 **17. ISO1042-Q1 Internal Delays - 1**



CH1: CAN1 TX
CH2 CAN1 RX
CH3: CAN2 RX
CH4: VDD5 ISO

R-D loop delay: 137.7 ηs
R-D delay: 66.27 ηs
D-R delay: 67.2 ηs

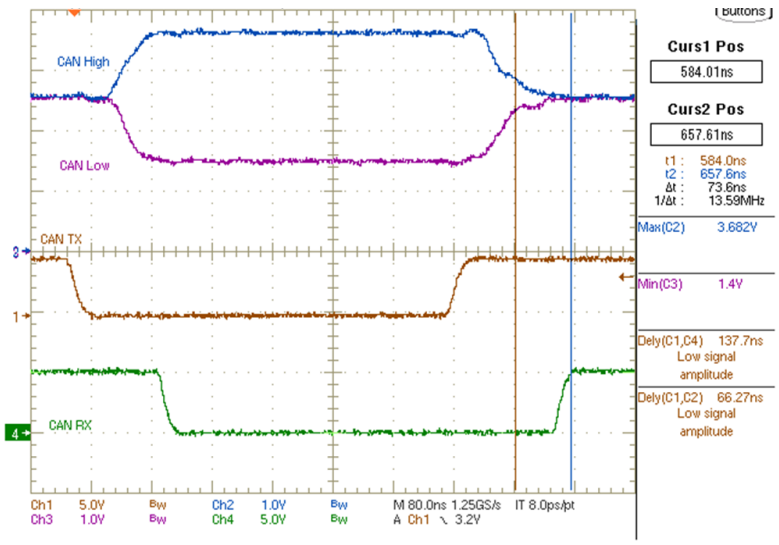
图 **18. ISO1042-Q1 Internal Delays - 2**



CH1: CAN TX
CH2 CAN High
CH3: CAN Low
CH4: CAN RX

R-D loop delay: 137.7 ηs
R-D delay: 66.27 ηs
D-R loop delay: 139.2 ηs

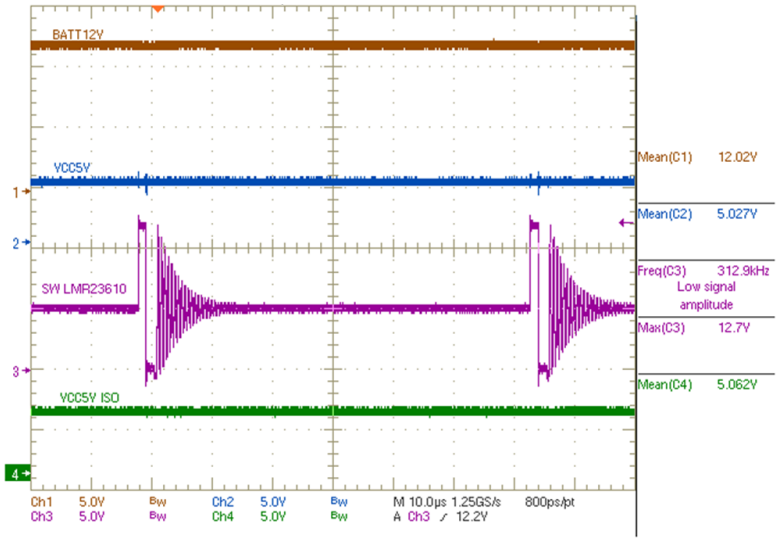
图 **19. ISO1042-Q1 Internal Delays - 3**



CH1: CAN TX
CH2 CAN High
CH3: CAN Low
CH4: CAN RX

Loop delay: 137.7 ηs
R-D delay: 66.27 ηs
D-R delay: 73.6 ηs

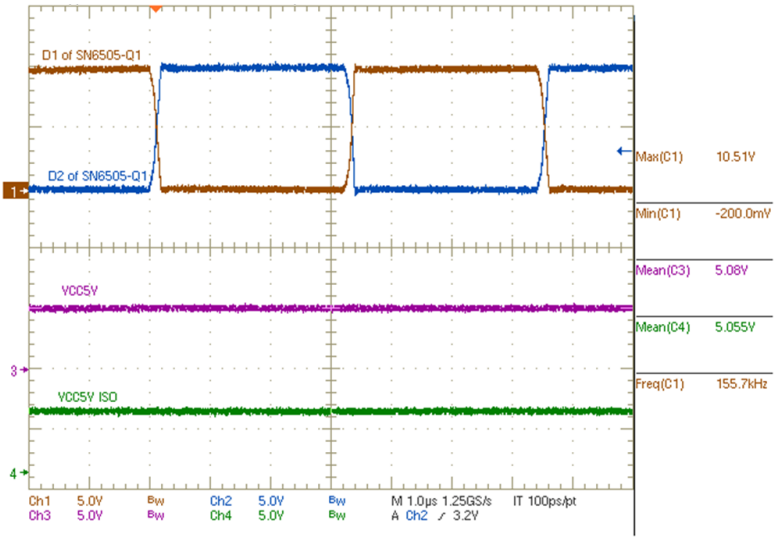
图 **20. LMR23610 Functional Behavior**



CH1: BATT12V
CH2: VCC5V
CH3: SW LMR23610
CH4: VDD5V ISO

Output voltage of LMR23610-Q1 is 5.062 V

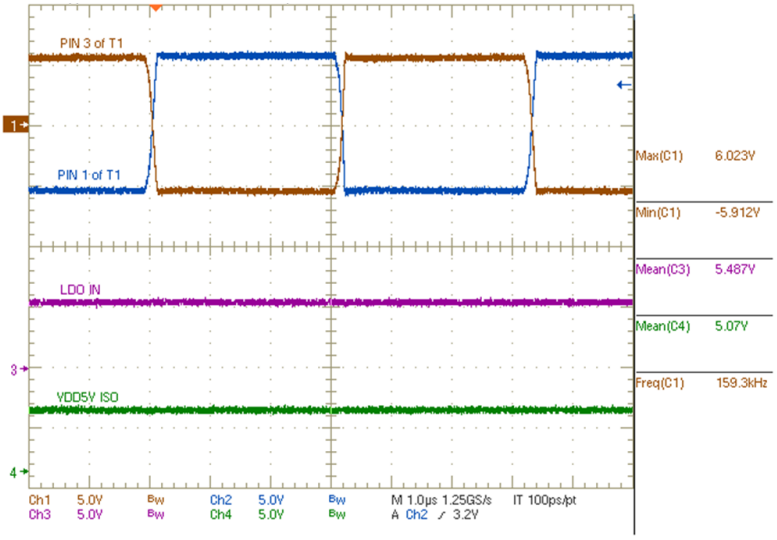
图 21. SN6505A-Q1 Functional Behavior



CH1: D1 of SN6505A-Q1
CH2: D2 of SN6505A-Q1
CH3: VCC5V
CH4: VCC5V ISO

Frequency of SN6505A-Q1 = 155.7 kHz
Min of D1 = –200 mV
Max of D1 = 10.51 V

图 22. SN6505-Q1 Transformer Behavior



CH1: Pin 3 of T1
CH2: Pin 1 of T1
CH3: LDO IN
CH4: VDD5V ISO

Frequency of SN6505A-Q1 = 159.3 kHz
Min of T1 = -5.91 V
Max of T1 = 6.023 V

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-020019.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-020019.

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-020019.

4.4 Altium Project

To download the Altium Designer® project files, see the design files at TIDA-020019.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-020019.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-020019.

5 Related Documentation

1. Texas Instruments, *Isolate your CAN systems without compromising on performance or space*
2. Texas Instruments, *How to Isolate Signal and Power in Isolated CAN Systems*
3. Texas Instruments, *The Essential Collection of DC/DC Buck Switching Regulator Technical Documentation*

5.1 商标

5.2 Third-Party Products Disclaimer

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