Design Guide: TIDA-020079

Zone Reference Design

Description

This reference design demonstrates key functions of next-generation zone control modules including power distribution, load actuation, and in-vehicle networking. The design highlights functional safety compliant PMIC and microcontroller (MCU) design, redundant power supply management with ideal diode controllers, and smart eFuses for safe power distribution. The design also features various options for load actuation expected in zone control modules, such as high-side drivers, motor drivers, configurable drivers, and a Class-D audio amplifier. The zone reference design showcases a variety of communication protocols, such as Ethernet, CAN, and LIN and enables emerging trends in vehicle networking technology such as Ethernet AVB, 10BASE-T1S, and CAN FD Light.

Resources

TIDA-020079	Design Folder
AM263P4-Q1, DP83TG721S-Q1	Product Folder
TPS653860-Q1, TPS2HCS10-Q1	Product Folder
DRV8245S-Q1, TIC12400-Q1	Product Folder

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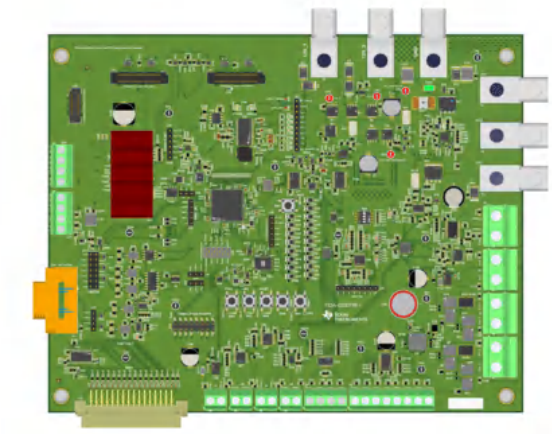
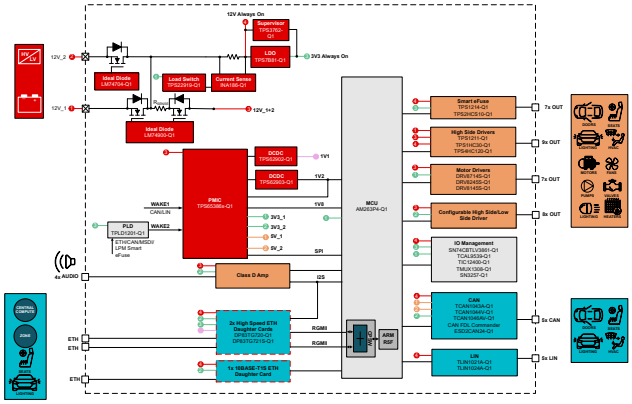
Features

- MCU with integrated Ethernet switch to optimize Ethernet ring topologies by implementing the following hardware protocols:
  - 802.1Qav, 802.1Qbv, 802.1cb (partial), 1588 TE, and 802.1Q ALE
- AVB Ethernet audio support with Ethernet PHY hardware time stamping and integrated media clock adjustment
- ASIL D-rated MCU and PMIC with system Limp Home Mode (LHM) capability
- Low-power mode with wake from Ethernet, CAN, LIN, smart eFuses, and MSDI off-board switch inputs
- Optimized microcontroller GPIO:
  - SPI daisy chain of smart eFuses and motor drivers
  - SPI and I2C IO expanders

Applications

- Zone control module





1 System Description

Automotive OEMs are moving towards a zone-based architecture where control modules are based on the location within the vehicle and software is centralized. This allows for over-the-air updates, easier collection of vehicle data, design and manufacturing cost savings, and new potential revenue streams. For more information, see *Software-Defined Vehicles Shift the Future of Automotive Electronics Into Gear* and *How a Zone Architecture Paves the Way to a Fully Software-Defined Vehicle* application briefs. This reference design showcases various subsystems within a zone control module, such as input power protection and distribution, load drivers, communication, and IO management.

This design features redundant 12V inputs that are ORed together with ideal diode controllers to create a 12V always-on rail and a second 12V rail for load disconnect. The 12V always-on rail is used to supply power to the PMIC, MCU, smart eFuse, CAN, LIN, ETH, and always-on 3.3V LDO. The 12V load disconnect rail supplies power to load drivers that do not require always-on operation such as high-side switches, motor drivers, and class D audio amplifiers. Additionally, this design showcases smart eFuses which feature configurable overcurrent protection and programmable fuse profiles to optimize the wire harness for any load profile with full protection.

This zone reference design showcases multiple types of load drivers that can be seen in typical zone control modules, including high-side drivers, motor drivers, and a configurable high-side or low-side driver to drive various actuators, such as motors, fans, pumps, valves, lighting, and heating elements. This design showcases high-side switches and controllers with high-accuracy current sensing and output diagnostics, such as overload and short-circuit protection, undervoltage lockout (UVLO) protection, thermal shutdown recovery, ground loss protection, and reverse battery protection. TI's motor drivers offer voltage monitoring and load diagnostics as well as protection against overcurrent and overtemperature. Additionally, this design features a Class-D audio amplifier to demonstrate zonal audio.

Various types of networking protocols can be used in zonal architecture, and this design provides versatility by offering 1000BASE-T1, 100BASE-T1, 10BASE-T1S, CAN FD, CAN FD Light, and LIN. The board has two connectors with RGMII and additional IO needed for high-speed Ethernet to enable Ethernet ring and Ethernet AVB support. The connectors allow daughter cards to be attached to enable testing of various PHYs. There is an additional daughter card connector for a 10BASE-T1S card. This design has three CAN FD transceivers supplying four ports with the option of 2 × UART over CAN. This design also features a CAN FD Light commander for a 5Mbps data rate. Lastly, this design features two LIN transceivers with a total of 5 ports.

Shifting to zone architecture increases the amount of load drivers on a single board, resulting in a need for more GPIO. This design uses I2C and SPI IO expanders and multiplexers to offer additional IO. The board also offers a 24-pin multiple switch detection interface (MSDI) for autonomous input and output monitoring when the MCU is powered down. Lastly, this board utilizes programmable logic devices to reduce the overall logic footprint by integrating logic functions into one package.

2 System Overview

For extensive details on the reference design, including Schematics, BOM, Altium Files, Test Data, and more, request access to the *Secure resources* folder.

2.1 Block Diagram

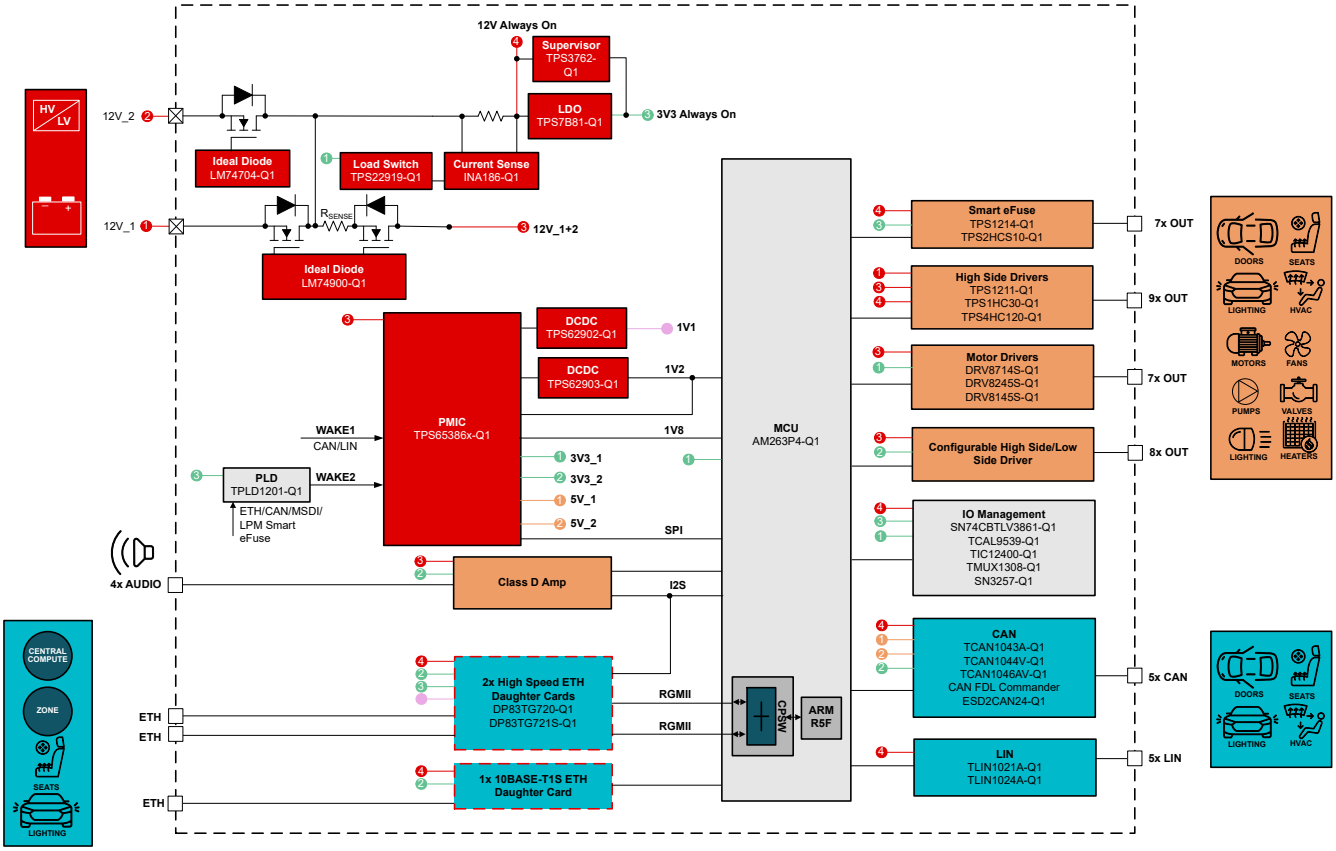


Figure 2-1. TIDA-020079 Block Diagram

2.2 Design Considerations

2.2.1 Redundant Input Supplies

This design features two ideal diodes for the redundant 12V inputs, the LM74704-Q1 and LM74900-Q1. The LM74704-Q1 drives an external N-channel MOSFET to regulate forward voltage drop and turns off the MOSFET when a reverse current event is detected. The LM74900-Q1 behaves similarly, but drives back-to-back N-channel MOSFETs to emulate an ideal diode rectifier and has integrated current sense. The first MOSFET provides reverse input protection and output voltage holdup, and the second MOSFET allows load disconnect in case of an overcurrent or overvoltage event. In our system, the drain of the N-channel MOSFET driven by LM74704-Q1 is connected to the drain of the first N-channel MOSFET driven by LM74900-Q1 to create a 12V always-on rail. The second MOSFET of LM74900-Q1 is providing power to load drivers to allow for load disconnect in the case of overcurrent or overvoltage and to disconnect the supply during a low-power state to reduce quiescent current.

2.2.2 Ethernet Ring

The AM263P4-Q1 has an integrated 3-port gigabit Ethernet switch (common platform switch, CPSW) supporting 2 external ports to implement an Ethernet ring topology. The CPSW supports multiple features and protocols in hardware to off-load computing resources for redundant packet replication, ring termination, and packet forwarding.

2.2.3 Audio Video Bridging (AVB)

In addition to Ethernet ring topologies, the zone reference design supports Ethernet audio video bridging (AVB) protocol to play local audio through a combination of the AM263P4-Q1, DP83TG721S-Q1, and the local class-D amplifier. The AM263P4-Q1 supports Ethernet AVB protocol through a combination of hardware (integrated in the CPSW switch and the programmable real-time unit) and software to play local digital audio. The DP83TG721S-Q1 PHY implements IEEE1588v2, 802.1AS time synchronization and IEEE1722 media clock generation to adjust the local media clocks and output all necessary audio clocks including the serial clock (SCLK) and frame sync (FSYNC) clock to the AM263P4-Q1 and the Class-D amplifier.

The AM263P4-Q1 integrated CPSW Ethernet switch supports AVB protocols such as 802.1Qav, 802.1Qbv, and IEEE1588 time stamping. In addition, the programmable real-time unit is capable of supporting Inter-Integrated Circuit Sound (I2S) to transmit local digital audio data. The Ethernet AVB hardware bill of materials is simplified by implementing the DP83TG721S-Q1 Ethernet PHY to remove the need for an additional clock generator or phased-lock loop.

2.2.4 Low-Power Mode and Wake

Low-power mode reduces energy consumption by limiting or turning off non-essential functions to extend the range of a vehicle. This design demonstrates low-power mode by turning off nonessential load drivers connected to the output of LM74900-Q1 and only devices connected to the 12V and 3.3V always-on rails (that is, PMIC, smart eFuse, MSDI, CAN, LIN, ETH) receive power. The design allows for wake activation from Ethernet, CAN, LIN, smart eFuse, and MSDI. For the system to wake up, packets must be detected on the communication bus for Ethernet, CAN, and LIN, and the load current increases on the smart eFuses, or MSDI detects an off-board switch input. The TPS65386x-Q1 PMIC has two wake pins rated for up to 40V. Figure 2-2 shows the CAN and LIN INH pins tied together for a 12V wake signal going to WAKE1 and the TPLD1201-Q1 being used to aggregate the 3.3V wake signals going to WAKE2.

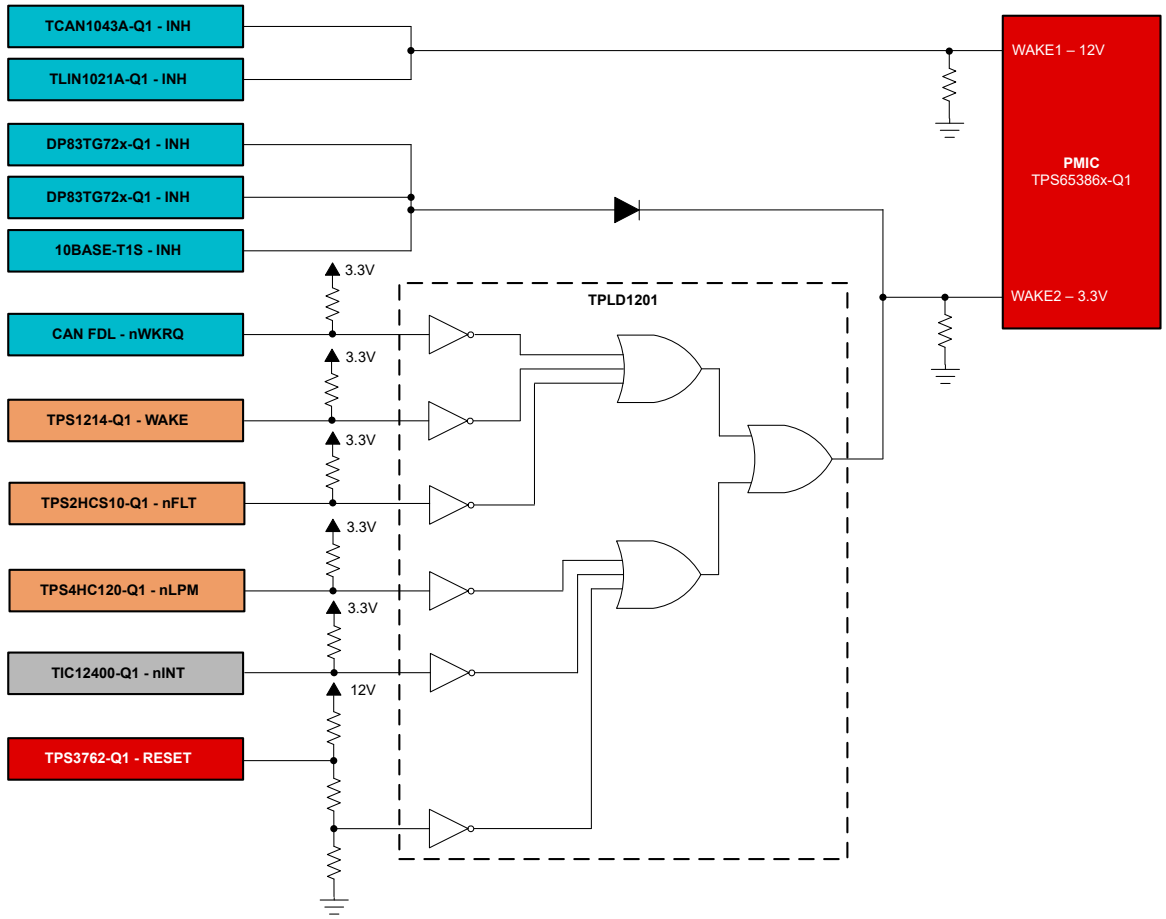


Figure 2-2. Wake Diagram

2.2.5 Limp Home Mode

Limp home mode (LHM) is a safety feature in vehicles used to maintain essential functions when a critical fault is detected. This design uses the PMIC to detect a safety issue and place the system into LHM where the outputs are in the desired safe state. The PMIC has two SAFE_OUT outputs that can be configured for the desired safing condition. These outputs can connect to the LHI pin of the smart eFuse to tell the smart eFuse to enter LHM and enter the desired safe state (can be configured ON or OFF). Additionally, the smart eFuses can detect an SPI watchdog timeout error (that is, an SPI communication error) and if V_{DD} is lost, the device signals a fault as SPI is not supported without V_{DD}.

2.2.6 SPI Daisy Chain

This design demonstrates separate smart eFuse and motor drive SPI daisy chaining by using a single SPI port for multiple smart eFuses or motor drivers. These devices can be configured to allow for a single chip select pin to be shared across all devices in a chain, enabling control and diagnostic feedback using only 5 pins (4 SPI, 1 FAULT). SPI daisy-chaining creates system-level savings of GPIO and ADC pins. For more information, including test results, see the *Reducing System Bill of Materials and MCU Pin Requirements With SPI eFuse Switches* application brief.

2.3 Highlighted Products

2.3.1 AM263P4-Q1

The AM263P4-Q1 device is a quad-core Arm Cortex-R5F MCU for up to 400MHz with real-time control and expandable memory. The integrated Ethernet switch makes this MCU an excellent choice for Ethernet ring networking using MII, RMII, or RGMII. The AM263P4 is designed for the future of motor control with advanced analog sensing and digital actuation modules. This device also has a Hardware Security Manager (HSM) allowing for implementation of stringent security frameworks.

2.3.2 DP83TG721S-Q1

The DP83TG721S-Q1 is an automotive 1000BASE-T1 Ethernet PHY with TC-10, 802.1AS, advanced TSN, and AVB features. This device provides all physical layer functions needed to transmit and receive data with the flexibility to support RGMII and SGMII MAC interfaces. The DP83TG721S-Q1 supports OA TC10 low-power sleep with wake forwarding to reduce system power consumption when communication is not needed. This PHY integrates IEEE 1722 CRF decode to generate Media Clock, FSYNC, and SCLK for I2S and TDM8, making the device an excellent choice for AVB applications.

2.3.3 TPS653860-Q1

The TPS653860-Q1 is an automotive power management IC (PMIC) for safety-relevant applications for microcontrollers, sensors, transceivers, and peripherals. This device was developed with functional safety in mind, offering systematic capability and hardware integrity up to ASIL D. This PMIC is rated for 2.3V to 36V and 2.8A and has a synchronous buck-boost preregulator, four LDOs, and two additional protected LDOs for sensor or peripheral supplies.

2.3.4 TPS2HCS10-Q1

The TPS2HCS10-Q1 is an automotive, dual channel, 10mΩ smart high-side switch with I^2T wire protection, low I_Q mode, and SPI. This device supports an SPI-configurable capacitive charging mode for ECU loads in power distribution switch applications. This smart eFuse integrates a programmable fuse profile that turns off the switch under persistent overload conditions to reduce the overhead on the MCU.

2.3.5 DRV8245S-Q1

The DRV8245S-Q1 is a SPI-controlled, fully integrated H-bridge driver for automotive applications. This device can be configured as a single full-bridge or two independent half-bridge drivers. The DRV8245S-Q1 integrates an N-channel H-bridge, chard pump regulator, high-side current sensing with regulation, current proportional output, and protection circuitry. The device has voltage monitoring, load diagnostics, and overcurrent and overtemperature protection.

2.3.6 TIC12400-Q1

The TIC12400-Q1 is an advanced Multiple Switch Detection Interface (MSDI) designed to detect external switch status in an automotive system. This device has an integrated 10-bit ADC to monitor multi-position analog switches and a comparator to monitor 24 digital switches independently of the MCU. The TIC12400-Q1 supports wake-up operation on all switch inputs to allow the MCU to shut down and can enter polling mode to periodically sample the input status for low-power-mode applications.

3 Design and Documentation Support

3.1 Design Files

For extensive details on the reference design, including Schematics, full BOM, and Altium Files, request access to the *Secure resources* folder.

3.1.1 Schematics

For extensive details on the reference design, including Schematics, full BOM, and Altium Files, request access to the *Secure resources* folder.

3.1.2 BOM

For extensive details on the reference design, including Schematics, full BOM, and Altium Files, request access to the *Secure resources* folder.

3.2 Tools and Software

Tools

SYSCONFIG	System Configuration Tool

Software

AM263P4-Q1 SDK	AM263Px software development kit (SDK) for Sitara™ microcontrollers

3.3 Documentation Support

1. Texas Instruments, *Software-Defined Vehicles Shift the Future of Automotive Electronics Into Gear Marketing White Paper*
2. Texas Instruments, *How a Zone Architecture Paves the Way to a Fully Software-Defined Vehicle Marketing White Paper*
3. Texas Instruments, *Zone architecture, Ethernet drive vehicle of the future Technical Article*
4. Texas Instruments, *DP83TC812-Q1 TC10 System Timing Measurements Application Note*
5. Texas Instruments, *Zonal Architecture and MCU I/O Expansion Application Brief*
6. Texas Instruments, *Priority Power MUX Using Ideal Diodes in Automotive Zonal Modules Application Brief*
7. Texas Instruments, *Reducing System Bill of Materials and MCU Pin Requirements With SPI eFuse Switches Application Brief*
8. Texas Instruments, *AM263Px Sitara™ Microcontrollers with Optional Flash-in-Package Data Sheet*
9. Texas Instruments, *DP83TG721x-Q1 1000BASE-T1 Automotive Ethernet PHY with Advanced TSN and AVB Data Sheet*
10. Texas Instruments, *TPS653860/61-Q1 Power Management IC For Safety-Relevant Applications Data Sheet*
11. Texas Instruments, *TPS1214-Q1 Low I_Q Automotive High Side Switch Controller With Low Power Mode, Load Wakeup, I^2t, and Diagnostics Data Sheet*
12. Texas Instruments, *TPS2HCS10-Q1 11-mΩ, Automotive Dual-Channel, SPI Controlled High-Side Switch With Low Quiescent Current ON Mode and Integrated I^2t Wire Protection Data Sheet*
13. Texas Instruments, *DRV8245-Q1 Automotive H-Bridge Driver with Integrated Current Sense and Diagnostics Data Sheet*
14. Texas Instruments, *TIC12400-Q1 24-Input Multiple Switch Detection Interface (MSDI) With Integrated ADC and Adjustable Wetting Current for Automotive Systems Data Sheet*

3.4 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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