

TI Designs: TIDA-010011

High Efficiency Power Supply Architecture Reference Design for Protection Relay Processor Module



Description

This reference design showcases various power architectures for generating multiple voltage rails for an application processor module, requiring >1-A load current and high efficiency. The required power supply is generated using 5-, 12- or 24-V DC input from the backplane. Power supplies are generated using DC-DC converters with an integrated FET and a power module with an integrated inductor for size. The design features a HotRod™ package type for applications requiring low EMI. It is also optimal for design time constrained applications. Additional features include DDR termination regulator, input supply OR-ing, voltage sequencing, eFuse for overload protection, and voltage and load current monitoring. This design can be used with a processor, digital signal processor and field-programmable gate array. It has been tested for radiated emission, per CISPR22 meeting class A and B requirements.

Resources

[TIDA-010011](#)

[LMZ34202](#), [LMZ20502](#), [LMZ20501](#), [LMZM33602](#)

[TPS82130](#), [TPS82084](#), [TPS82085](#), [LMZM23601](#)

[TPSM82480](#), [LMZ30604](#), [LMZ10501](#), [LM53635-Q1](#)

Design Folder

Product Folder

Product Folder

Product Folder

Features

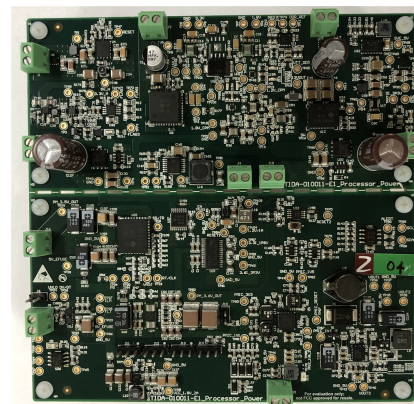
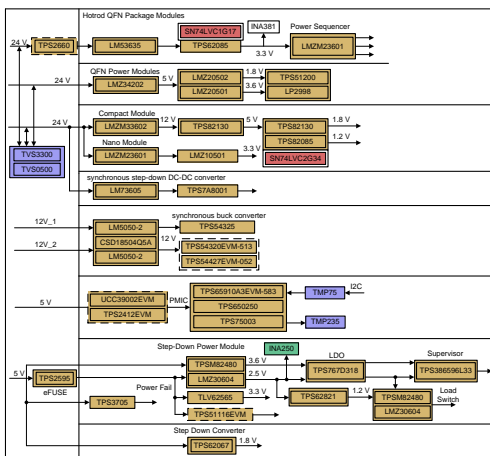
- Power supply generation with 24-V input using synchronous step down DC-DC converter with integrated FET, compact nano power module with excellent load transient performance and accurate output regulation
- Power modules in QFN package that offer optimal thermal performance
- DC-DC converters in HotRod™ package for low EMI
- Power supply generation with 12-V input using OR-ing controller for redundant operation interfaced to high efficiency DC-DC converter or external evaluation module
- Point of load (POL) supply generation with 5-V input using PMIC, DC-DC converter and linear regulators or DC-DC converter >3-A load with improved low load efficiency and load sharing
- Clean supply using 1A, dual-output, low dropout linear regulator with low-noise, high-bandwidth PSRR

Applications

- Protection Relay, Circuit Breakers, Grid Automation



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Resources (continued)

TPS62085, LM73605, TPS54325, TLV62565	Product Folder
TPS62821, TPS62067 , TPS75003, TPS650250	Product Folder
SN74LVC1G14, SN74LVC2G34, SN74LVC1G17, CSD17571Q2	Product Folder
LP2998, TPS51200, TPS7A80, TPS3808	Product Folder
TPS767D3, LM3881, TPS3705, TPS386596	Product Folder
TPS2595, TPS27081A, LM5050-2, CSD18504Q5A	Product Folder
INA381, INA250, TMP235, TMP75B	Product Folder
TVS3300, TVS1400	Product Folder

1 System Description

Failure of power systems is a common problem faced by power generation, transmission, and distribution companies. Power outages can result in a loss of revenue and a reduction of generation capacity. Power utilities are using secondary equipments for protection, control, monitoring, and measurement systems to improve the power systems efficiency and reliability. High-end secondary equipment used in this design includes protection relay and terminal units such as remote terminal units, distribution terminal units, and feeder terminal units. Utility companies are also implementing and improving multiple protection algorithms and diagnostic schemes to protect the assets and grid and to predict failures as early as possible. Signal and application processing includes digital filtering, implementation of protection algorithms, and user interface, including LCD display and the implementation of standard communication protocols based on IEC61850 standards.

For implementing applications that include user interface, standard communication protocols require a processor with multiple cores and higher execution speed, standard Arm® architecture, external DDR memory interface, and integrated peripherals. Processors with integrated peripherals require multiple power rails, power sequencing, voltage supervisors, and monitoring, along with DDR memory termination regulators for proper operation. The load current of the processors vary with execution speed, application, and transition between multiple operation modes, resulting in a wide variation in load current and required power supply with fast transient load response. Because multiple rails are required, the power supply becomes complex, increasing the solution size.

Designing power supply solutions with a small form factor, higher efficiency to minimize internal heat, and lower emission adds to other challenges during the design of an application processor module. Other challenges include protection of the DC inputs against output overload, providing capability for redundancy and load sharing, and processor diagnostics including voltage sequencing, voltage monitoring and load current monitoring.

This design addresses these challenges and provides a solution that can be used during the design of an application processor module resulting in reduced design efforts, faster time to market, and a high efficiency, small form factor board.

This design can be used in multiple applications including:

- **Protection Relay:** Protection relays detect defective lines, equipment, or other power system conditions that are abnormal or dangerous in nature. Digital protection relays detect and locate faults by measuring electrical quantities in the power system, which are different during normal and intolerable conditions. To measure and protect different end equipments protections relays interface to different IOs, including AC analog inputs for measuring current and voltages, DC analog input or output for control, digital input or output for monitoring and interlocking, interface including Ethernet, RS232, RS485 and USB for networking, and HMI including LCD display or LEDs, the processor module is interfaced to multiple IO modules for processing of algorithms and the implementation of standard protocols used for local and remote communication.
- **Substation Automation and Merging unit:** In substations, process-level primary equipments are monitored using RTU bay controllers. The inputs to these equipments include AC analog inputs for measuring current and voltages, DC analog input or output for control, and digital input or output for

monitoring and interlocking. Multiple communication options are also provided in these equipments for implementing automation protocols. Merging units are used to sample AC analog values on the process level in a substation and transmit the sampled values (SV) to protection devices, bay control units (BCU), or electric meters through fiber optic Ethernet interface based on the IEC61850-9-2 protocol. A processor with the capability to sample the analog inputs and process the samples is key to the design of the merging unit. Because these equipments are installed near the primary equipment, they are exposed to EMC and protection is required against transients or other EMC for proper operation.

1.1 Key System Specifications

The primary objective of this design is to create a reference design platform to showcase different approaches to the generation of power supply rails from 24-, 12-, or 5-V DC input using a DC/DC converter with integrated FET, by using power modules with an integrated inductor, or by using power management IC (PMIC) with multiple power rail outputs. This design also showcases monitoring of load current, power supply rails, and sequencing of the power supply rails. [Table 1](#) shows a summary of the key specifications.

Table 1. Specification for Processor Power Supply Module

PARAMETER	DESCRIPTION	SECTION
Supply generation using 24-V input	Cost effective solution: synchronous step-down DC/DC converter with integrated FET	Section 2.4.1
	Nano power module with integrated FET and inductor	Section 2.4.1
	Power modules in QFN package	Section 2.4.1
Supply generation using 5-V input	DC/DC converters in HotRod™ package with integrated FET	Section 2.4.1
	POL power module with greater than 3-A load in QFN or QFM package with low load efficiency	Section 2.4.3
Supply generation using 12-V input	PMIC with multiple DC/DC converters and LDOs to generate required supplies for processor and FPGA	Section 2.4.3
	Power supply OR-ing: power supply OR-ing for redundant operation of processor modules	Section 2.4.3
Clean supply with last stage LDO	1-A, dual-output, low dropout linear regulator with low-noise, high-bandwidth PSRR	Section 2.4.3
Memory termination	Multiple options for memory termination using LDOs with sink and source , Synchronous Buck Controller	Section 2.4.3
Supply rail monitoring	3-rail sequencing and quad voltage supervisor with manual reset	Section 2.4.3
Other protection features	Input overload protection using eFuse, load switch for power control	Section 2.4.1
Other diagnostics features	Load current monitoring, digital, analog temperature sensor for diagnostics and protection, input ok indication	Section 2.4.1

1.2 Device Mapping to Design Functionalities

Table 2 details the devices used and the functionalities implemented in this design.

Table 2. Details of Functions and Devices

FUNCTION	DEVICES	DESCRIPTION
HotRod™ package-based DC/DC power supply with power sequencer and indication and eFuse protection	LM53635, TPS62085, INA381A1, TVS3300, SN74LVC1G14, CSD17571Q2, LM3881, TPS2660	HotRod™ package reduces electromagnetic interference (EMI), low quiescent current (only 15 µA for the 3.3-V option) to ensure high efficiency and superior transient responses at all loads. HotRod™ QFN package with wettable flanks reduces parasitic inductance and resistance while increasing efficiency, minimizing switch node ringing, and dramatically lowering EMI.
QFN package-based DC/DC power supply with memory termination	LMZ34202, LMZ20502, LMZ20501, SN74LVC2G34, TPS51200, LP2998, TPS51116, TVS3300	DC/DC power module with integrated inductor, 40-V operation, and memory termination options. Easy-to-use integrated power supply that combines a 2-A DC/DC converter with a shielded inductor and passives into a low profile, QFN package. The QFN package has excellent power dissipation capability.
Compact power module, nano module DC/DC with supply status indication	LMZM33602, TPS82130, TPS82084, TPS82085, SN74LVC2G34, TVS3300, LMZ10501, LMZM23601V5	17-V input, 3-A step-down converter MicroSiP™ power module, showcases size advantage against competition. The device achieves excellent load transient performance and accurate output voltage regulation.
Synchronous step-down voltage converter with LDO	LM73605, TPS7A8001	DC/DC and LDO. Synchronous step-down DC/DC converters capable of driving up to 5 A of load current, 36 V. Provides exceptional efficiency and output accuracy in a very small solution size. Simple PCB layout with optimal EMI and thermal performance. Protection features include thermal shutdown, input undervoltage lockout, and hiccup short-circuit protection.
Redundant power supply interfaced to DC/DC converter	CSD18504Q5A, LM5050-2, TPS54325, TPS54320, TPS54427, TPSM84424	Paralleling of supply input. High-side OR-ing FET controller interfaced to DC/DC converter, 3-A output synchronous step-down switcher with integrated FET.
Point-of-load supply with LDO, eFuse for input protection, input voltage OK indication, supply supervisor	TPSM82480, TPS259531, TPS3705-33, LMZ30604, INA250A3, TPS3808G01, TPS27081A, TPS767D318, TPS386596L33, TPS62067, TPS62821, TLV62565	Synchronous step-down DC/DC converter module for low profile point-of-load power supplies. 5.5-V input, 6 A continuously provided by two phases of 3 A each, which run out-of-phase, reducing pulse current noise significantly. LDO and supervisor for supply monitoring and control. Synchronous step-down converters optimized for small solution size and high efficiency. The devices integrate switches capable of delivering an output current up to 1.5 A.
PMIC and temperature sensor	TPS75003, TMP75B, TPS650250, TMP235, SN74LVC1G17, TPS65910	Integrated and configurable Power Management IC (PMIC) with 2 buck controllers and 1 LDO. Power management IC for processor, FPGA, and temperature sensor with I ² C interface.

2 System Overview

Some of the key requirements for designing the power tree for the application processor modules include:

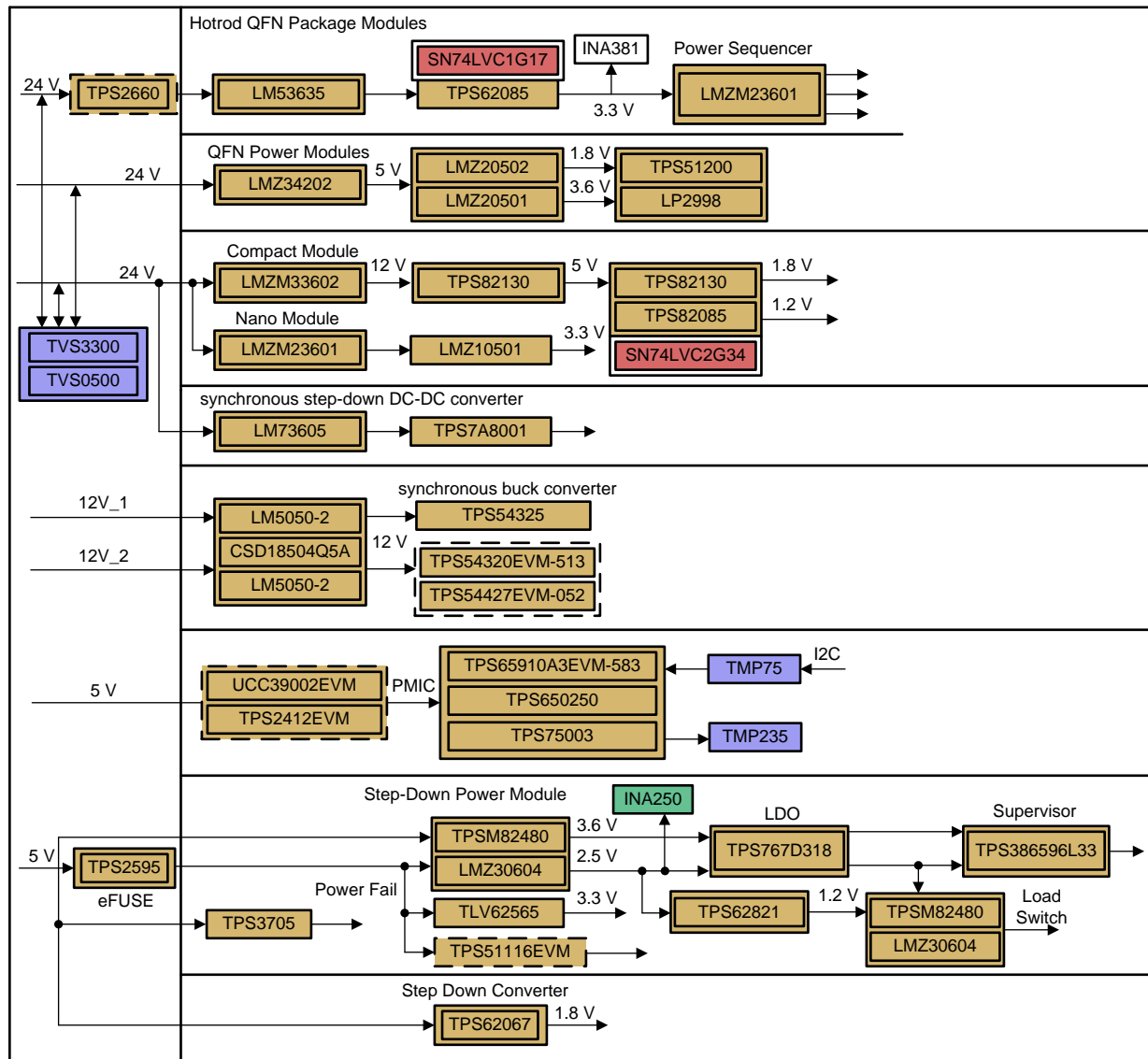
- Provision to generate the required power supply rails from 24 V, 12 V, or 5 V
- Generation of power supply rails with high efficiency and scalable load current
- Memory termination regulator with sink and source capabilities
- Monitoring of power supply rails and sequencing of the rails based on the processor
- Capability to monitor the load current for diagnostics
- Capability to operate from multiple power supply inputs by OR-ing the supplies
- Load sharing based on the current requirements
- Protection of the power supply input rails and isolating the rails during overload

This design provides solutions to these requirements and also solves the challenges associated with designing the power tree for the processor module.

2.1 Block Diagram

Figure 1 shows different approaches for the generation of power supplies used in the application processor module. This design is intended for use in processor modules. The following features are required to design the processing module using the processor or FPGA for multiple applications.

Figure 1. TIDA-010011 Processor Power Module Block Diagram



2.1.1 Generation of Power Supply Rails From 24-V Input

The following list showcases the functionality of the power supply rails generated from a 24-V input.

- Cost-effective solution: synchronous step-down DC/DC converter with integrated FET
- Compact solution: nano power module with excellent load transient performance and accurate output voltage regulation for size-constrained applications and lighter loads
- Excellent thermal performance: power modules in the QFN package offer excellent power dissipation capability and thermal performance
- Best emission performance: DC/DC converters in HotRod™ package with integrated FET

2.1.2 Generation of Power Supply Rails From 5-V Input

The following list showcases the functionality of the power supply rails generated from a 5-V input.

- POL power module with greater than 3-A load in the QFN or QFM package with low load efficiency
- PMIC with multiple DC/DC converters and LDOs to generate required supplies for the processor and FPGA

2.1.3 Generation of Clean Supply With Last Stage LDO

The following list showcases the functionality of clean supply generated with last stage LDO.

- 1-A, single or dual-output, low dropout linear regulator with low-noise, high-bandwidth PSRR
- Load current monitoring

2.1.4 Miscellaneous Power supply monitoring and diagnostics functionalities

The following list showcases additional power supply monitoring and diagnostics functionalities implemented in this design.

- Memory termination: multiple options for memory termination using LDOs with sink and source
- Power supply OR-ing: power supply OR-ing for redundant operation of processor modules
- Monitoring: 3-rail sequencing and quad voltage supervisor with manual reset
- Other hardware features: input overload protection using eFuse, load switch for power control, power supply status indication, digital and analog temperature sensor for diagnostics and protection, input ok indication

2.1.5 Interface to DC/DC converter device EVM

This design provides provisions to connect to external devices and to test the performance of some of the devices including the TPS51116, TPS54320 and TPS54427.

2.2 Design Considerations

Some of the key considerations for this design include:

- Using buck converter with integrated switch for generation of the required DC power supply rails providing cost optimized option
- Using buck converters with integrated inductor in QFN or μ SiL package with high efficiency, improving reliability in size constrained application
- Using buck converters with integrated switch in HotRod™ package for reduced EMI in applications requiring high performance
- Point-of-load power supply with high efficiency for generating low voltage and high current rails
- Generation of multiple power supplies with integrated solution using PMIC, focusing on family of processors
- Option to synchronize multiple DC/DC converter for improved performance
- Power supply diagnostics including power supply monitoring, power supply sequencing, and power supply switching using load switches
- OR-ing of supply inputs for multiple power supply rails on the backplane for redundancy
- Onboard temperature sensors for protection and diagnostics

This is a generic design focusing on the generation of power supply rails for processor modules and can be used across other end equipments in grid infrastructure and other adjacent sectors including motor drives, factory and building automation, T&M, and medical sectors.

2.2.1 Power Module Advantages

DC/DC buck modules integrate inductors, FETs, compensation, and other passive components into a single package to simplify the design process and speed customer time-to-market with a minimized power supply footprint. Power modules are gaining popularity with the guaranteed EMI and EMC as well as full characterized electrical and thermal performance and ease of prototyping. Step-down buck power modules offer superior performance against alternative solutions while also helping fasten the design and qualification process to help get to market faster. The following list describes the various advantages of power modules.

Advantages of the power module include:

- Simpler solution, small size, and high power density with minimum external components

- High efficiency and output accuracy, good load-transient response and low output ripple
- Single family of devices can support multiple power supply rails due to programmability
- Improved load and input regulation
- Quick, easy to design, use, and minimizes external components
- Reliable, low radiated EMI and cooler operating temperature

2.3 Highlighted Products

This section provides details of some of the products used in this design.

2.3.1 Buck Converter With Integrated Switch

This design uses the following buck converters with integrated switch. The following list includes the converters with different packages, including small-package SON and SOT and varying currents, that have been used in the design.

- LM53635-Q1, a 2.5/3.5-A, 36-V synchronous, 2.1-MHz, automotive step-down DC/DC converter
- TPS62085, a 3-A step-down converter with DCS-control and hiccup short circuit protection in 2x2 HotRod™ package
- TPS54320, a 4.5-V to 17-V input, 3-A synchronous step-down SWIFT™ converter
- LM73605, a 3.5-V to 36-V, 5-A synchronous step-down voltage converter
- TPS54325, a 4.5-V to 18-V input, 3-A synchronous step-down converter
- TPS54427, a 4.5-V to 18-V input, 4-A synchronous step-down converter
- TLV62565, a 1.5-A buck converter in SOT23 package
- TPS62067, a 3-MHz, 2-A step-down converter in 2x2 SON package
- TPS62821, a 1-A step-down converter with 1% accuracy in 1.5 x 2-mm QFN

See [DC/DC buck converters](#) for more details.

2.3.2 Buck Power Modules With Integrated Inductor

This design uses the following buck converters with integrated inductor. The following list includes the converters with different packages, including small-package SON and SOT and varying currents, the have been used in the design.

- TPSM82480, a 6-A, 5.5-V input step-down power module with MODE and VSEL options
- LMZ30604, a 2.95-V to 6-V, 4-A step-down power module in a 9-mm x 11-mm x 2.8-mm QFN package
- LMZM33602, a 4-V to 36-V, 2-A step-down DC/DC power module in a compact 7-mm x 9-mm x 4-mm QFN package
- TPS82130, a 3-A, 17-V step-down converter module with integrated inductor in a 3.0-mm x 2.8-mm x 1.5-mm MicroSiP™ package
- TPS82084, a 2-A, high-efficiency step-down converter module with integrated inductor in a 2.8-mm x 3.0-mm x 1.3-mm, 8-pin μSiL package
- TPS82085, a 3-A, high-efficiency step-down converter module with integrated inductor in a 2.8-mm x 3.0-mm x 1.3-mm, 8-pin μSiL package
- LMZM23601, a 36-V, 1-A step-down DC/DC power module in a 3.8-mm x 3-mm package
- LMZ34202, a 4.5-V to 42-V, 2-A step-down power module in a QFN package
- LMZ10501, a 5.5-V, 1-A step-down DC/DC power module in a 3-mm x 2.6-mm package
- LMZ20502, a 2.7-V to 5.5-V, 2-A high density nano module in a 3.5-mm x 3.5-mm x 1.75-mm package
- LMZ20501, a 2.7-V to 5.5-V, 1-A high density nano module in a 3.5-mm x 3.5-mm x 1.75-mm package

See [buck-modules-integrated-inductor](#), for more details.

2.3.3 DDR Power

This design uses the following devices for DDR memory termination:

- TPS51200, 3A Sink/Source DDR Termination Regulator w/ VTTREF Buffered Reference for DDR2, DDR3, DDR3L and DDR4
- TPS51206 2A Peak Sink/Source DDR Termination Regulator with VTTREF Buffered Reference for DDR2/3/3L/4
- LP2998, 1.5A DDR Termination Regulator with Shutdown Pin
- TPS51116 Memory Power Solution, Synchronous Buck Controller Evaluation Module

See [ddr-memory](#), for more details.

2.3.4 Low Dropout Voltage Regulator

This design uses the following devices to generate low-noise power supply for sensitive applications requiring clean power:

- TPS767D3, a 1-A, dual-output, low dropout voltage regulator
- TPS7A80, a low-noise, high-bandwidth PSRR, 1-A low-dropout (LDO) linear regulator

See [linear-regulator-ldo](#), for more details.

2.3.5 Integrated and Configurable Power Management IC PMIC

This design uses the following devices to generate power supply for processors using integrated PMIC, providing integrated power solutions:

- TPS650250, a configurable integrated power management (PMIC) with 3 DC/DC converters and 3 LDOs
- TPS75003, an integrated and configurable power management IC (PMIC) with 2 buck controllers and 1 LDO
- TPS65910, an integrated power management IC (PMIC) with 4 DC/DCs, 8 LDOs, and RTC in a 6-mm x 6-mm QFN family

See [multi-channel-ics-pmic](#), for more details.

2.3.6 Supervisor, Reset and Sequencers

This design uses the following devices for multiple voltage supervisors and the sequencing of multiple supply rails:

- TPS3705, a processor supervisory circuit with power-fail and integrated watchdog timer
- TPS3808, a low quiescent current supervisor with programmable delay
- TPS386596, a quad voltage supervisor with manual reset input
- LM3881, a 3-rail, simple power sequencer with adjustable time delay

See [supervisor-reset-ic](#), for more details on non-isolated modules.

2.3.7 Current Sense Amplifiers With Analog Output

This design uses the following instrument amplifiers for measuring the load current using an external or internal shunt resistor:

- INA250, a 36-V, low-/high-side, bi-directional, current sense amplifier with a precision-integrated shunt resistor
- INA381, a 26-V, low-/high-side, voltage output CSA with comparator

See [current-sense/analog-output](#), for more details.

2.3.8 Temperature Sensor for Diagnostics

This design uses the following temperature sensors for diagnostics:

- TMP75B, a 1.4-V capable temperature sensor with I²C/SMBus interface in LM75 form factor and pinout
- TMP235, a precision analog output temperature sensor

See [temperature-sensors](#), for more details.

2.3.9 Logic for Buffering Power Good Outputs

The following logics are used for buffering power good indication outputs from different DC/DC converters:

- SN74LVC1G17, a single Schmitt-trigger buffer
- SN74LVC1G14, a single Schmitt-trigger inverter
- SN74LVC2G34, a dual-buffer gate

See [logic-circuit](#), for more details

2.3.10 Transient Protection

The following flat-clamp TVS devices are used for protecting the DC/DC converter input against transients:

- TVS1400, a 14-V, flat-clamp surge protection device
- TVS3300, a 33-V, flat-clamp surge protection device

See digital logic [esd-protection-and-tvs-surge-diodes](#), for more details.

2.3.11 Enhancements

This section provides information on some of the design enhancements that can be considered during the design of the processor power modules and also provides a few commonly used devices.

2.3.11.1 Building Blocks

This design uses multiple building blocks that are commonly used in most of the power supply module designs and showcases the application of these building blocks for the generation of power supplies for processor modules and monitoring the supplies. [Table 3](#) details the device categories and applications.

Table 3. Building Block Device Category and Application

BUILDING BLOCK PRODUCTS	APPLICATIONS
Temperature and current sensing	Diagnostics and temperature drift compensation
Single or dual LDO with 1-A load current and low noise, DDR termination regulator	Used to provide power supply with low noise for DSP, processor, or memory
Voltage sequencer, voltage supervisor	Used for voltage sequencing of the processor and diagnostics
Integrated protection devices and power switches	Used for protection of the module against overload and short circuit
Buck DC/DC switching regulators, low power DC/DC	Used for generation of the required power supply using 12-, 24-, or 5-V input
Standard logic	Used of buffering of power good output

2.3.11.2 Protection of 24-V Input Using eFuse

The [Smart Holding Brake Controller Reference Design with Current Regulation for Servo Drives & Robotics reference design](#) provides protection against overvoltage, undervoltage, reverse polarity, and overcurrent for 24-V input using the TPS26600 and has been integrated with this design and tested with the current limit set to 2 A.

2.3.11.3 Current Sharing in Redundant Systems

In redundant systems, two or more power supplies are used in parallel to improve reliability. To maximize reliability, the load current should be shared equally among these modules. Current-sharing technology in combination with OR-ing FET control can help achieve precision sharing in redundant systems, which results in cooler, more efficient, and more reliable systems. The OR-ing FET can be used as a current-sensing element as well as an OR-ing device, which further improves system efficiency. The load share controller provides all of the necessary functions to parallel multiple independent power supplies or DC-to-DC modules. The controller is suitable for N+1 redundant system or high current applications where off-the-shelf power supplies must be paralleled. Current sharing has several features that improve overall system performance. For example, current sharing can equalize the load current and thermal stress among the different power supplies. Enforcing proper load sharing can also result in using power supplies with lower nominal ratings because of the reduced current in each. This technique, in turn, can translate into an overall lower system cost.

The UCC39002 is an advanced, high-performance load sharing controller that implements automatic master/slave architecture. The paralleling power modules and supplies that co-operate with the UCC39002 should be equipped with true remote sensing or access to the feedback divider of the module error amplifier. OR-ing FETs are used to emulate low forward voltage diodes and reduce power dissipation with low RDSON FETs. The combination of the current-sharing controller UCC39002 with the N+1 and OR-ing power rail controller TPS2412 achieves true current sharing with reverse current protection. See the [UCC39002 Evaluation Module](#) and the [TPS2412 Evaluation Module](#) for more details.

2.3.11.4 Completer DDR Power Solution Using Synchronous Buck Regulator With LDO

TI provides a complete power supply with DDR3L, LPDDR3 and DDR4 memory system solutions. It integrates a synchronous buck controller with a 3-A sink/source tracking linear regulator and buffered low noise reference. The device offers the lowest total solution cost in systems where space is at a premium. The 3-A sink/source LDO maintains fast transient response only requiring 20 μF ($2 \times 10 \mu\text{F}$) of ceramic output capacitance. In addition, the LDO supply input is available externally to significantly reduce the total power losses. Some of the key solutions include :

- TPS51116 DDR1, DDR2, DDR3 switcher and LDO
- TPS51716 complete DDR2/3/3L/4 memory power solution synchronous buck controller, 2-A LDO

In this design, the 5V_Efuse_Out was interfaced to the TPS51116EVM and tested for functionality. The TPS51116EVM can be configured to operate in DDR mode by setting the switching regulator output voltage (VVDDQ) to 2.5 V and the LDO termination voltage (VVTT) to 1.25 V. To program the EVM for DDR mode, place the JP4 jumper in the center vertical position

The TPS51116EVM comes pre-configured in DDR2 mode by setting the switching regulator output voltage (VVDDQ) to 1.8 V and the LDO termination voltage (VVTT) to 0.9 V. To program the EVM for DDR2 mode, place the JP4 jumper in the right horizontal position. The TPS51116EVM can be configured to operate in DDR3 or adjustable output mode, allowing the VVDDQ to be set between 1.5 V and 3.0 V by selecting the R10 and R11 voltage divider and using the internal 750-mV reference. The VVTT output voltage tracks this adjustable voltage. The default values for R10 and R11 provide DDR3 voltage levels. These set the switching regulator voltage (VVDDQ) to 1.5 V and the LDO termination voltage (VVTT) to 0.75 V.

2.3.11.5 Multiple Power Supply Rail Diagnostics Using ADCs

The power supply diagnostics can be implemented by using multi-channel SAR or Delta-Sigma ADC. The ADC resolution and the channels selection depends on the number of power rails used.

See [Precision ADCs](#) for more details.

2.3.11.6 Leveraging Other TI Designs

The following list of reference designs can be leveraged during the design of power supply rails for the processor module.

- [Integrated Power Supply Reference Design for Xilinx Zynq® UltraScale+™ ZU2CG–ZU5EV MPSoCs](#)
- [Integrated Power Supply Reference Design for Xilinx Artix®-7, Spartan®-7, and Zynq®-7000 FPGAs](#)
- [Space Optimized Wide Vin Triple-Output Power Module Reference Design](#)
- [Small, Efficient Power Supply Reference Design for Altera™ MAX® 10 FPGA for up to 125°C](#)
- [Multi-Rail Power Reference Design for Eliminating EMI Effects in High Performance DAQ Systems](#)
- [400-W Continuous, Scalable, \$\pm 2.5\$ - to \$\pm 150\$ -V, Programmable Ultrasound Power Supply Reference Design](#)
- [Low-Noise Fixed Drop-Out \$\pm 2.5\$ to \$\pm 12\$ -VOUT 3A Power Supply Reference Design for Ultrasound CW Pulser](#)
- [Low-Voltage, Low-Noise Power-Supply Reference Design for Ultrasound Front End](#)
- [Xilinx Kintex UltraScale XCKU040 FPGA Power Solution, 6W Reference Design](#)
- [High-Efficiency, Low-Output Ripple Power Supply Reference Design for Imaging Application](#)

2.3.11.7 Similar Family Devices

Multiple DC/DC converter functionalities have been showcased in this design. The devices selected are a family of devices with varying current or other functionalities. [Table 4](#) shows the devices used in this design and similar devices that can be considered based on the load current and other functionality requirements.

Table 4. Devices Used in This Design and Similar Family Devices

DEVICE USED IN THIS DESIGN	SIMILAR FAMILY DEVICES
LM53635-Q1	LM53625-Q1
TPS62085	TLV62084A, TPS62080, TPS62086, TPS62087
LM3881	LM3880
LMZ34202	LMZ36002
TPS51200	TPS51206
LP2998	LP2996A, LP2995, LP2997
LMZM33602	LMZM33603
TPS82130	TPS82140, TPS82150
TPSM84424	TPSM84624, TPSM84824
LMZM23601	LMZM23600
LMZ10501	LMZ10500
LM73605	LM73606
TPS7A8001	TPS7A8101
TPS54325	TPS54225, TPS54226, TPS54326, TPS54425, TPS54426
TPS54427	TPS54227
LMZ30604	LMZ30602, LMZ30606
TLV62565	TLV62568, TLV62569
TPS62067	TPS62065, TPS62060, TPS62061, TPS62063
TPS62821	TPS62822, TPS62823
TPS26600	TPS26601, TPS26602
TPS259531	TPS259533, TPS259535
TMP75B	TMP75, TMP75C
TMP235	LM235

The LM53635 synchronous buck regulator provides an output voltage of 5 V, 3.3 V, or an adjustable output. An input voltage range up to 36 V, with transient tolerance up to 42 V, eases input surge protection design. The automotive-qualified HotRod™ QFN package with wettable flanks reduces parasitic inductance and resistance while increasing efficiency, minimizing switch-node ringing, and dramatically lowering electromagnetic interference (EMI). An open-drain reset output, with built-in filtering and delay, provides a true indication of system status. This feature negates the requirement for an additional supervisory component, saving cost and board space. Seamless transition between PWM and PFM modes and low quiescent current (only 15 μ A for the 3.3-V option) ensure high efficiency and superior transient responses at all loads. Refer to section 9.2.1.2 of the product datasheet for Detailed Design Procedure to configure the output to the required voltage.

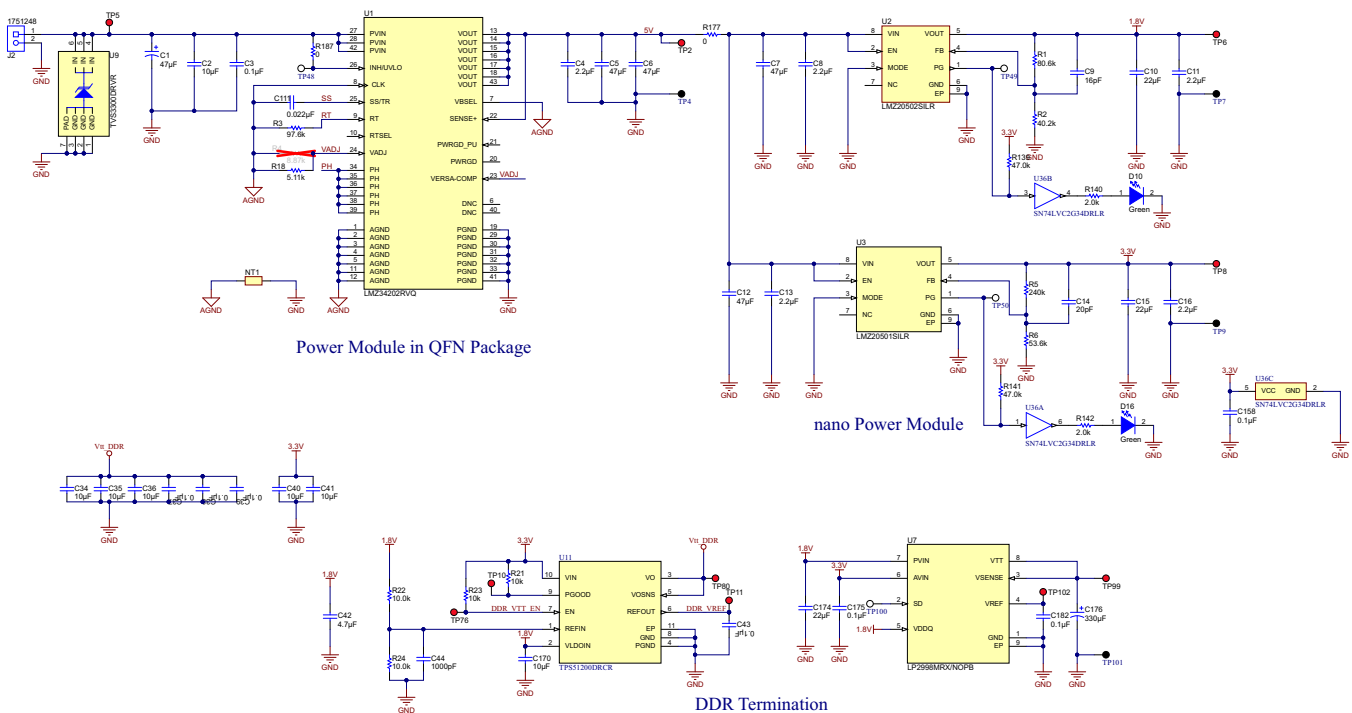
The TPS62085 is a high-frequency synchronous step-down converter optimized for small solution size and high efficiency. The devices focus on high-efficiency step-down conversion over a wide output current range. At medium to heavy loads, the converter operates in PWM mode and automatically enters Power Save Mode operation at light load to maintain high efficiency over the entire load current range. To address the requirements of system power rails, the internal compensation circuit allows a large selection of external output capacitor values ranging from 10 μ F to 150 μ F. Together with its DCS-Control architecture, excellent load transient performance and output voltage regulation accuracy are achieved. The devices are available in a 2-mm \times 2-mm VSON package.

2.4.1.2 Power Module in Nano Package and DDR Memory Termination

When better thermal performance in a size constrained application is required, power modules in the QFN package can be considered. In application processing modules using DDR memory, compared to standard linear and switching regulators, DDR termination LDOs and regulators have sink/source termination current capability and external reference inputs to track the VDDQ/2 input and generate the Vtt termination rail. DDR terminators with both linear regulator and switching regulator-based solutions are available to choose from. DDR, VDDQ, and VTT voltage regulator devices feature low internal voltage references to regulate low DDR core and termination output voltages. This section provides details of generation of the required power supply for processor module using power module in the QFN package and nano power module package as shown in Figure 3 for size optimized solution and showcases the following devices.

- LMZ34202 converts 24-V input to 5-V output.
- LMZ20502 converts 5-V input to 1.8-V output.
- LMZ20501 converts 5-V input to 3.3-V output.
- TPS51200 and LP2998 are DDR termination regulators
- SN74LVC2G34 is a dual buffer for indicating the power supply status using power good signals.
- TVS3300 is a 33-V flat-clamp surge protection device for input transient protection.

Figure 3. 24-V Input Power Module and DDR Termination



The LMZ34202 power module is an easy-to-use integrated power supply that combines a 2-A DC/DC converter with a shielded inductor and passives into a low profile, QFN package. This total power solution allows as few as three external components while maintaining an ability to adjust key parameters to meet specific design requirements. Refer to section 8 of the datasheet, Application and Implementation for configuring the DC/DC converter to the required output.

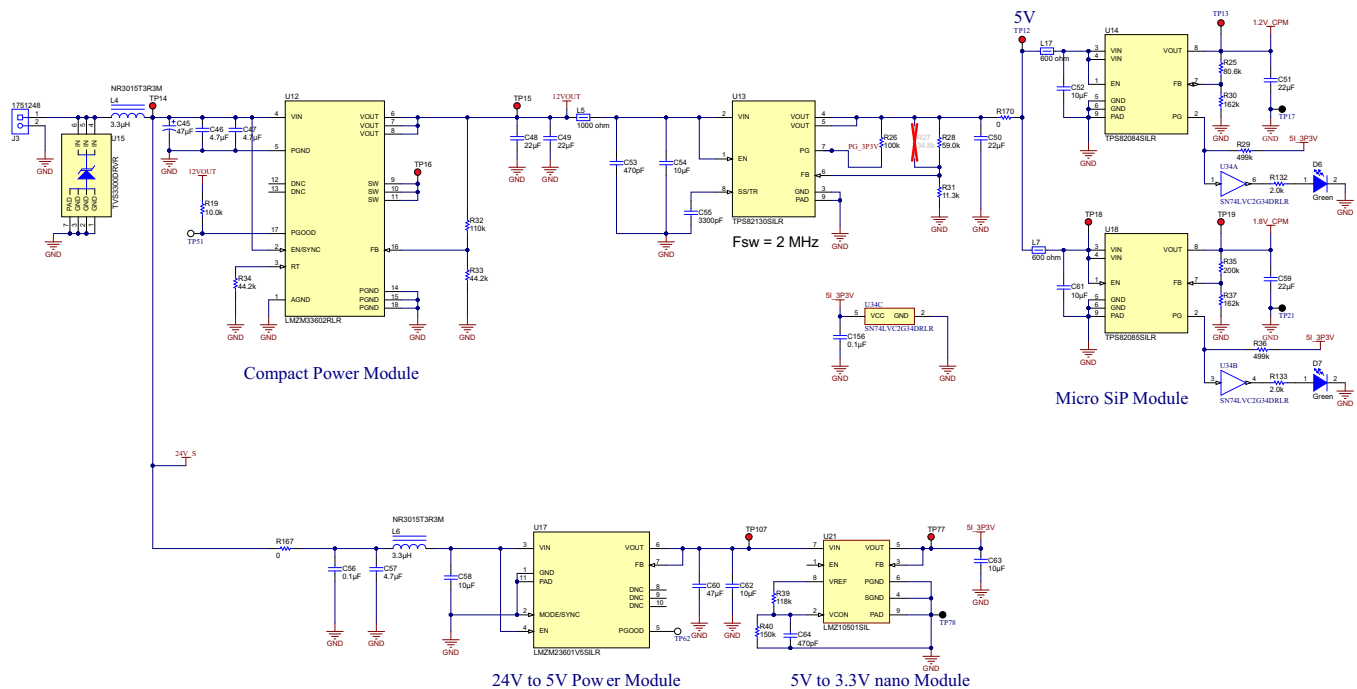
The LMZ20502 nano module regulator is an easy-to-use synchronous step-down DC/DC converter capable of driving up to 2 A of load from an input of up to 5.5 V, with exceptional efficiency and output accuracy in a very small solution size. The innovative package contains the regulator and inductor in a small 3.5-mm x 3.5-mm x-1.75 mm volume, thus saving board space and eliminating the time and expense of inductor selection. The LMZ20502 requires only five external components and has a pin-out designed for simple, optimum PCB layout.

2.4.1.3 Small Size QFN or MicroSiP™ Power Module With Integrated Inductor or Integrated FET, LDO

This section provides details of the generation of the required power supply for processor module using power module in the QFN package and the MicroSiP™ power module package as shown in Figure 4 for size-optimized solution and showcases the following devices.

- LMZM33602 converts 24-V input to 12-V output.
- TPS82130 converts 12-V input to 5-V output.
- TPS82084 converts 5-V input to 1.2-V output.
- TPS82084 converts 5-V input to 1.8-V output.
- LMZM23601 converts 24-V input to 5-V output.
- LMZ10501 converts 5-V input to 3.3-V output.
- SN74LVC2G34 is a dual buffer for indicating the power supply status using power good signals.
- TVS3300 is a 33-V flat-clamp surge protection device for input transient protection.

Figure 4. 24-V Input Compact Power Module with power good indication



The LMZM33602 power module is an easy-to-use integrated power solution that combines a 2-A, step-down, DC/DC converter with power MOSFETs, a shielded inductor, and passives into a low-profile package. This power solution requires as few as four external components and eliminates the loop compensation and magnetics part selection from the design process. Refer to 7.3.1 of the datasheet, Adjusting the Output Voltage to configure the DC/DC converter to common output voltage rails.

The TPS82130 is a 17-V input 3-A step-down converter MicroSiP™ power module optimized for small solution size and high efficiency. The module integrates a synchronous step-down converter and an inductor to simplify design, reduce external components and save PCB area. To maximize efficiency, the converter operates in PWM mode with a nominal switching frequency of 2 MHz and automatically enters Power Save Mode operation at light load currents. In Power Save Mode, the device operates with typically 20-µA quiescent current. Using the DCS-Control™ topology, the device achieves excellent load transient performance and accurate output voltage regulation. Refer to section 8 of data sheet Application and Implementation to configure the DC/DC converter for the required output voltage.

The TPS82084/5 are 2-A/3-A step-down converter MicroSiP™ modules optimized for small solution size and high efficiency. The power module integrates a synchronous step-down converter and an inductor to simplify design, reduce external components and save PCB area. To maximize efficiency, the converter operates in PWM mode with a nominal switching frequency of 2.4 MHz and automatically enters Power Save Mode operation at light load currents. Using the DCS-Control topology, the device achieves excellent load transient performance and accurate output voltage regulation. The EN and PG pins, which support sequencing configurations, bring a flexible system design. An integrated soft startup reduces the inrush current required from the input supply. Over temperature protection and hiccup short circuit protection deliver a robust and reliable solution.

2.4.2 Power Supply Generation From 12-V Input With OR-ing Controller and DC/DC Converter

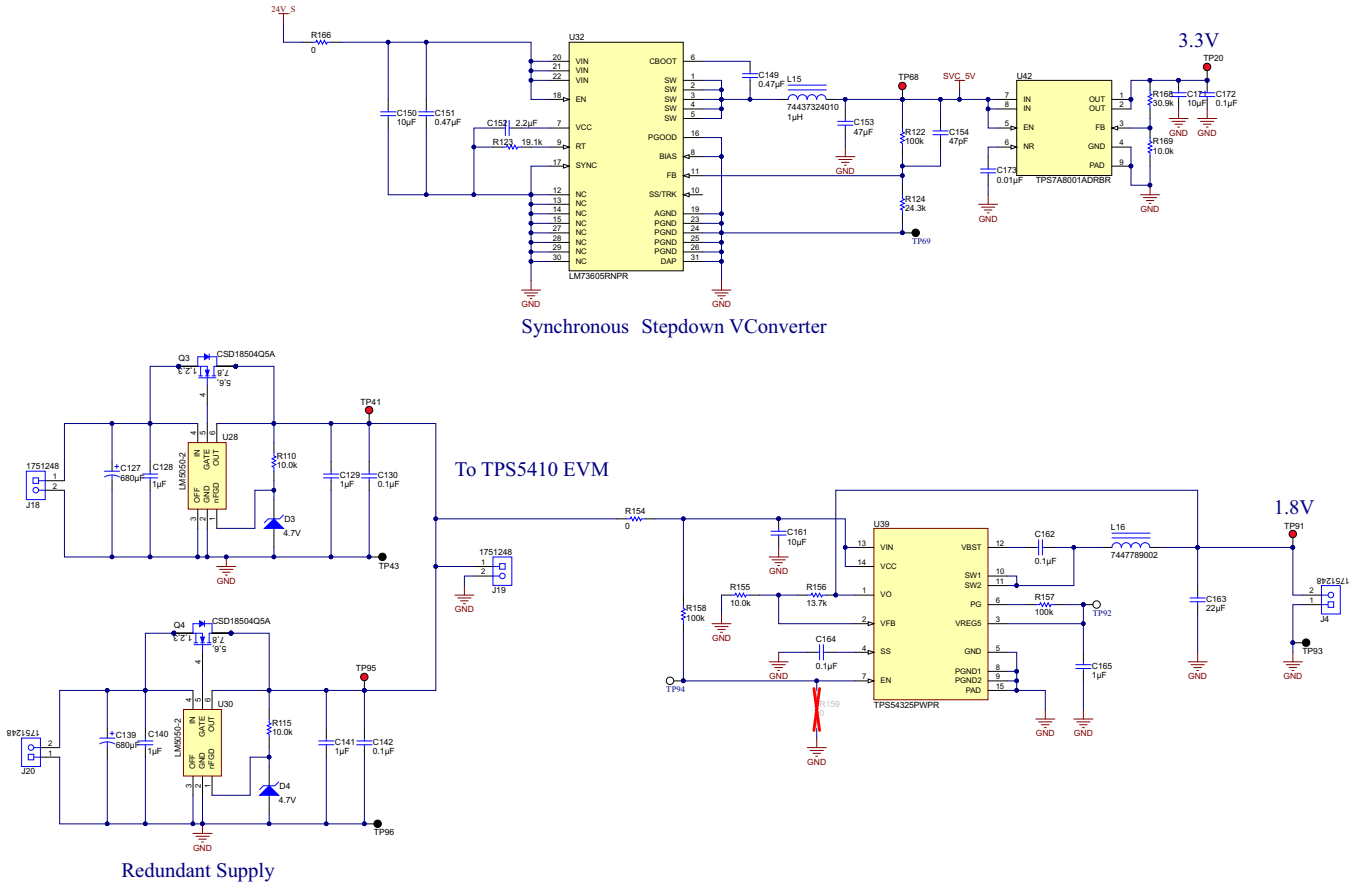
This section describes the design and implementation of the binary input module and digital output modules.

2.4.2.1 Isolated 24-V or 48-V AC or DC Binary Input Using Isolated Digital Input Receiver With Self-Power

OR-ing controllers offer space-saving and scalable solutions to protect your system against reverse voltage or reverse current. This section provides details of the generation of the required power supply for the processor module from redundant supply using OR-ing controller as shown in Figure 5 optimized for 12-V input and showcases the following devices.

- LM5050-2 is used for OR-ing two 12-V inputs, and the output is connected to an connector for external interface and onboard DC/DC converter.
- TPS54325 converts 12-V input to 1.8-V output.
- LM73605 converts 24-V input to 5-V output.
- TPS7A8001A is a LDO and regulated 5 V to 3.3 V.

Figure 5. 12-V Input OR-ing and EVM interface



J19 is provided to interface the OR-ing controller DC output to external EVM and is also connected to the TPS54325 to generate 1.8 V.

The TPS54325 device is an adaptive on-time D-CAP2™ mode synchronous buck converter. The TPS54325 device enables system designers to complete the suite of various end equipment's power bus regulators with a cost effective, low component count, low standby current solution. The device operates from 4.5-V to 18-V VCC input, and from 2.0-V to 18-V VIN input power supply voltage. The output voltage can be programmed between 0.76 V and 5.5 V. The device also features an adjustable slow start time and a power good function.

The LM5050-2 high side OR-ing FET controller operates in conjunction with an external MOSFET as an ideal diode rectifier when connected in series with a power source. This OR-ing controller allows MOSFETs to replace diode rectifiers in power distribution networks, thus reducing both power loss and voltage drops. The LM5050-2 controller provides charge pump gate drive for an external N-Channel MOSFET and a fast response comparator to turn off the FET when current flows in the reverse direction. The LM5050-2 can connect power supplies ranging from +6 V to +75 V and can withstand transients up to +100 V.

The LM73605 is an easy to-use, synchronous step-down DC/DC converter capable of driving up to 5 A of load current from a supply voltage ranging from 3.5 V to 36 V. The LM73605 provides exceptional efficiency and output accuracy in a very small solution size. Additional features such as adjustable switching frequency, synchronization to an external clock, FPWM option, power-good flag, precision enable, adjustable soft start, and tracking provide both flexible and easy-to-use solutions for a wide range of applications. Automatic frequency foldback at light load and optional external bias improve efficiency over the entire load range. Refer section 8 of data sheet, Application and Implementation for configuring the DC/DC converter to the required DC output.

2.4.3 Power Supply Generation From 5-V Input

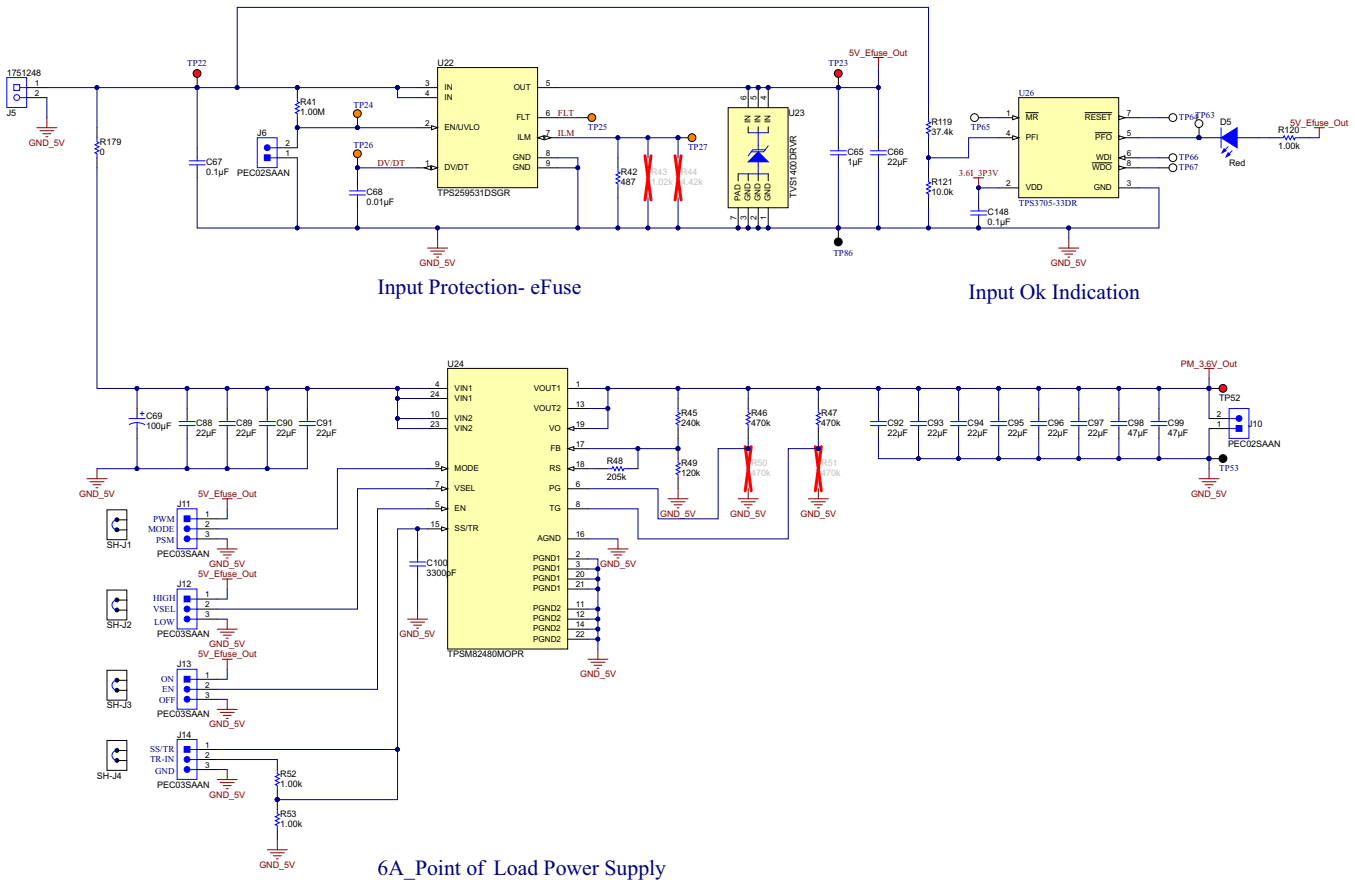
This section describes design and implementation of point of load power supplies with load currents >1A from 5V DC input

2.4.3.1 eFuse and DC/DC Converter With 6-A Load Capability

eFuse devices have extensive feature options including adjustable current limit, over and under voltage protection, and short circuit or reverse polarity protection. These power path protection devices are used to control load current with integrated or external FETs. This section provides details of the generation of the required power supply for processor module as shown in Figure 6 optimized for 5-V input and showcases the following devices.

- TPS259531 provides input protection against overload and short-circuit.
- TPS3705-33 provides input OK indication that can be looped back to the backplane for diagnostics.
- TPSM82480 converts 5-V input to 2.5 V or 1.8 V.
- TVS1400 is a 14-V flat-clamp surge protection device for eFuse output protection against reverse voltage.

Figure 6. 5-V Input with eFuse and 6-A POL power module



The TPSM82480 is a synchronous step-down DC/DC converter module for low profile point-of-load power supplies. The input voltage range of 2.4 to 5.5 V enables operation from typical 3.3-V or 5-V interface supplies as well as from backup circuits dropping down as low as 2.4 V. The output current is up to 6 A continuously provided by two phases of 3 A each, which run out-of-phase, reducing pulse current noise significantly. The TPSM82480 provides high efficiency down to very light loads. The device offers a Power Good signal and an adjustable soft start. Also, the device features a Thermal Good signal to indicate excessive internal temperature. The output voltage can be changed to a preselected value by VSEL pin. Refer to section 8.3 of the product datasheet for configuring the DC/DC converter to commonly used output voltage values.

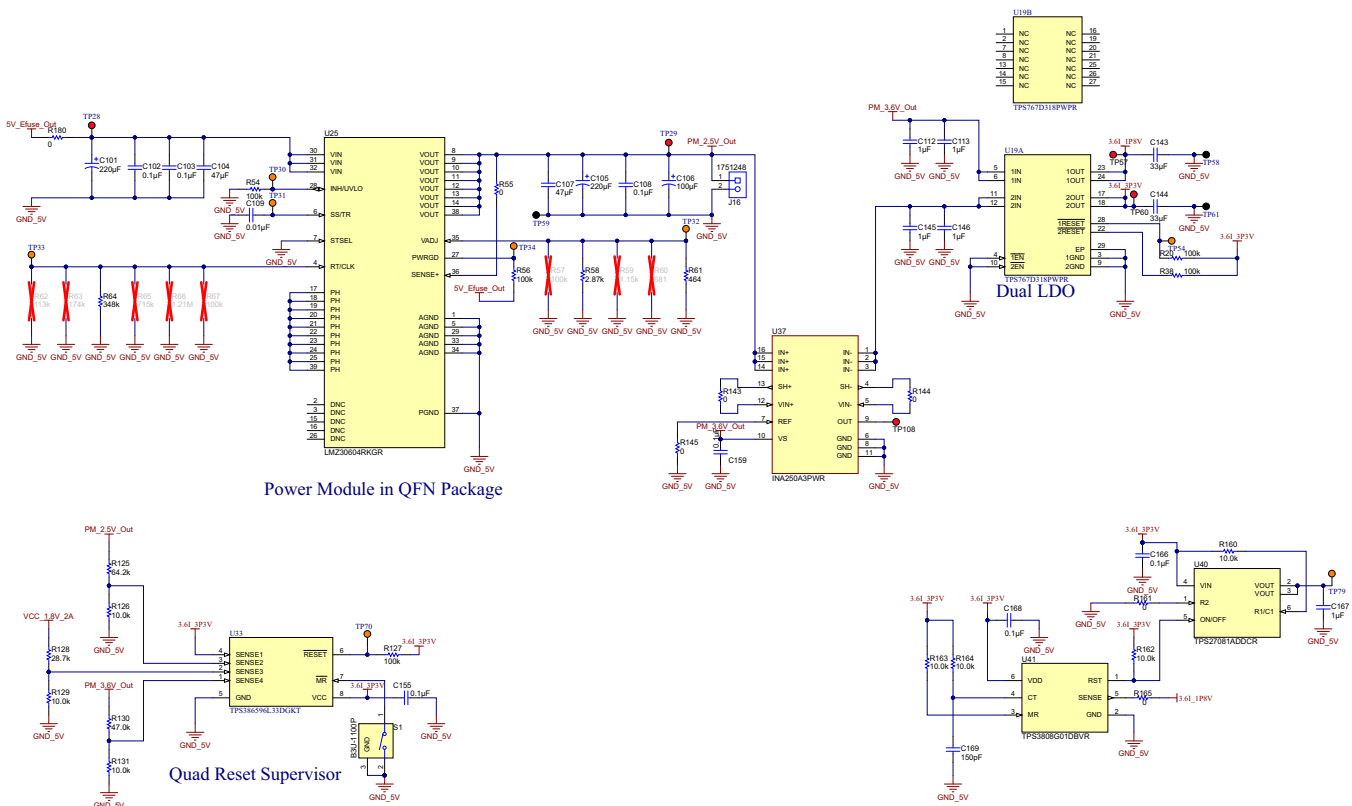
The TPSM82480 is a synchronous step-down DC/DC converter module for low profile point-of-load power supplies. The input voltage range of 2.4 to 5.5 V enables operation from typical 3.3-V or 5-V interface supplies as well as from backup circuits dropping down as low as 2.4 V. The output current is up to 6 A continuously provided by two phases of 3 A each, which run out-of-phase, reducing pulse current noise significantly. The TPSM82480 provides high efficiency down to very light loads. The device offers a Power Good signal and an adjustable soft start. Also, the device features a Thermal Good signal to indicate excessive internal temperature. The output voltage can be changed to a preselected value by VSEL pin. Refer to section 8.3 of the product datasheet for configuring the DC/DC converter to commonly used output voltage values.

2.4.3.2 Power Module With LDO, Load Current Monitor and Voltage Monitor

Supervisors and reset ICs, including watch dog timers, push-button ICs, voltage detectors, and fixed and programmable, delay time to supervisors to monitor system health. Low dropout regulators (LDOs) are a simple, inexpensive way to regulate an output voltage that is powered from a higher voltage input. They range across many different features such as low noise, wide Vin, small size, low Iq, and processor attach.

- LMZ30604 converts 5-V input to 3.6 V.
- INA250A3 monitors the load current across the LMZ30604.
- TPS386596L33 quad voltage supervisor monitors 4 voltage rails and pulls the reset low if any of the voltage is below threshold.
- TPS767D318 dual LDO generates 1.8-V and 3.3-V output.
- TPS3808G01 monitors 1.8 V and switches the load switch on the TPS27081.
- TPS27081 switches the 3.3 V based on the TPS3808G01 supervisor output.

Figure 7. 5-V Input QFN Power Module with Monitoring



The LMZ30604 power module is an easy-to-use integrated power solution that combines a 4-A DC/DC converter with power MOSFETs, a shielded inductor, and passives into a low profile, QFN package. This total power solution requires as few as 3 external components and eliminates the loop compensation and magnetics part selection process. LMZ30604 allows a compact point-of-load design with greater than 90% efficiency and excellent power dissipation with thermal impedance of 12°C/W junction to ambient. The device delivers the full 4-A rated output current at 85°C ambient temperature without airflow. Refer to section 8.1 of data sheet, adjusting the Output Voltage to configure the output between 0.8 to 3.6V.

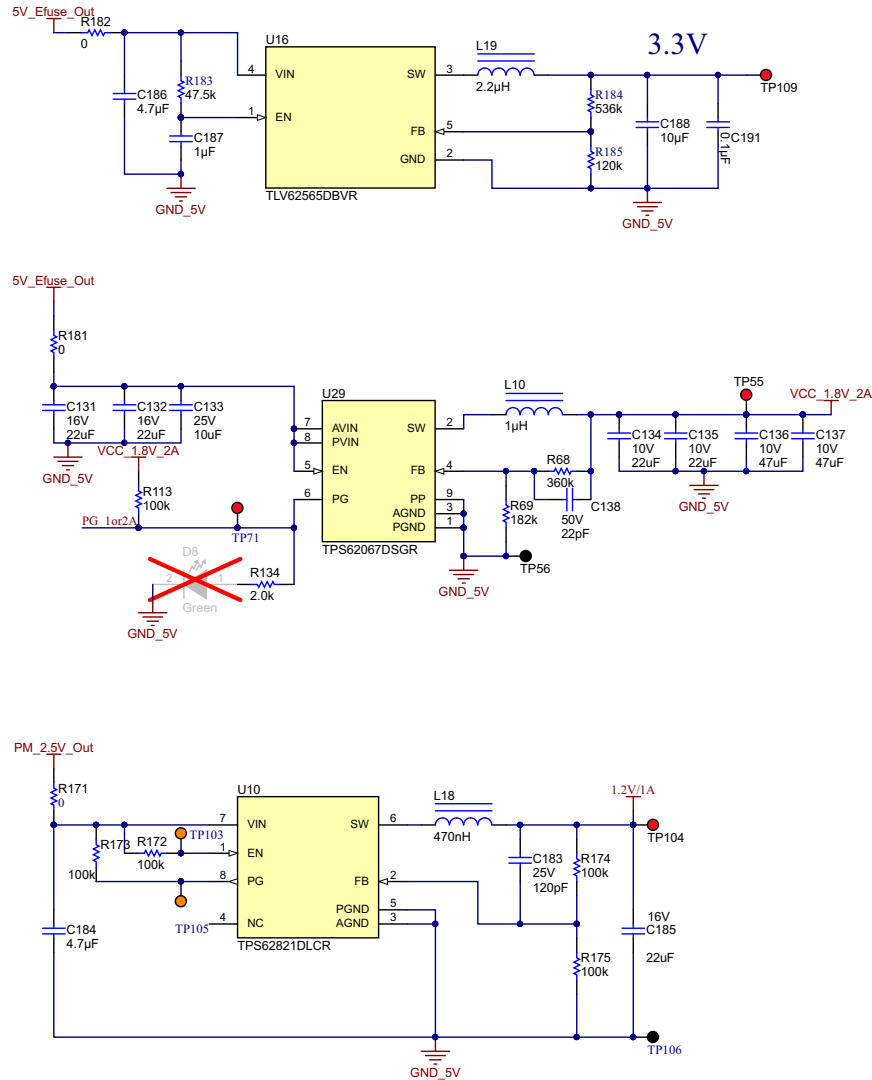
The TPS767D3xx family of dual voltage regulators offers fast transient response, low dropout voltages and dual outputs in a compact package and incorporating stability with 10µF low ESR output capacitors. The TPS767D3xx family of dual voltage regulators is designed primarily for DSP applications. These devices can be used in any mixed-output voltage application, with each regulator supporting up to 1A. Dual active-low reset signals allow resetting of core-logic and I/O separately. The RESET output of the TPS767D3xx initiates a reset in microcomputer and microprocessor systems in the event of an under voltage condition. An internal comparator in the TPS767D3xx monitors the output voltage of the regulator to detect an under voltage condition on the regulated output voltage.

2.4.3.3 5-V Switching Converter in SOT Package

This section provides details of the generation of the required power supply for processor module using synchronous step-down converters as shown in [Figure 8](#) optimized for small solution size and high efficiency.

- TLV62565 converts 5-V input to 3.3-V output.
- TPS62067 converts 5-V input to 1.8-V output.
- TPS62821 converts 5-V input to 1.2-V output.

Figure 8. 5-V Input DC/DC in SOT package with integrated switch



Switching Voltage Regulator

The TLV62565 devices are synchronous step-down converters optimized for small solution size and high efficiency. The devices integrate switches capable of delivering an output current up to 1.5 A. The TLV62565 provides an adjustable output voltage through an external resistor divider. The output voltage start-up ramp is controlled by an internal soft start, typically 250 μ s. Power sequencing is possible by configuring the Enable (TLV62565) and Power Good (TLV62566) pins.

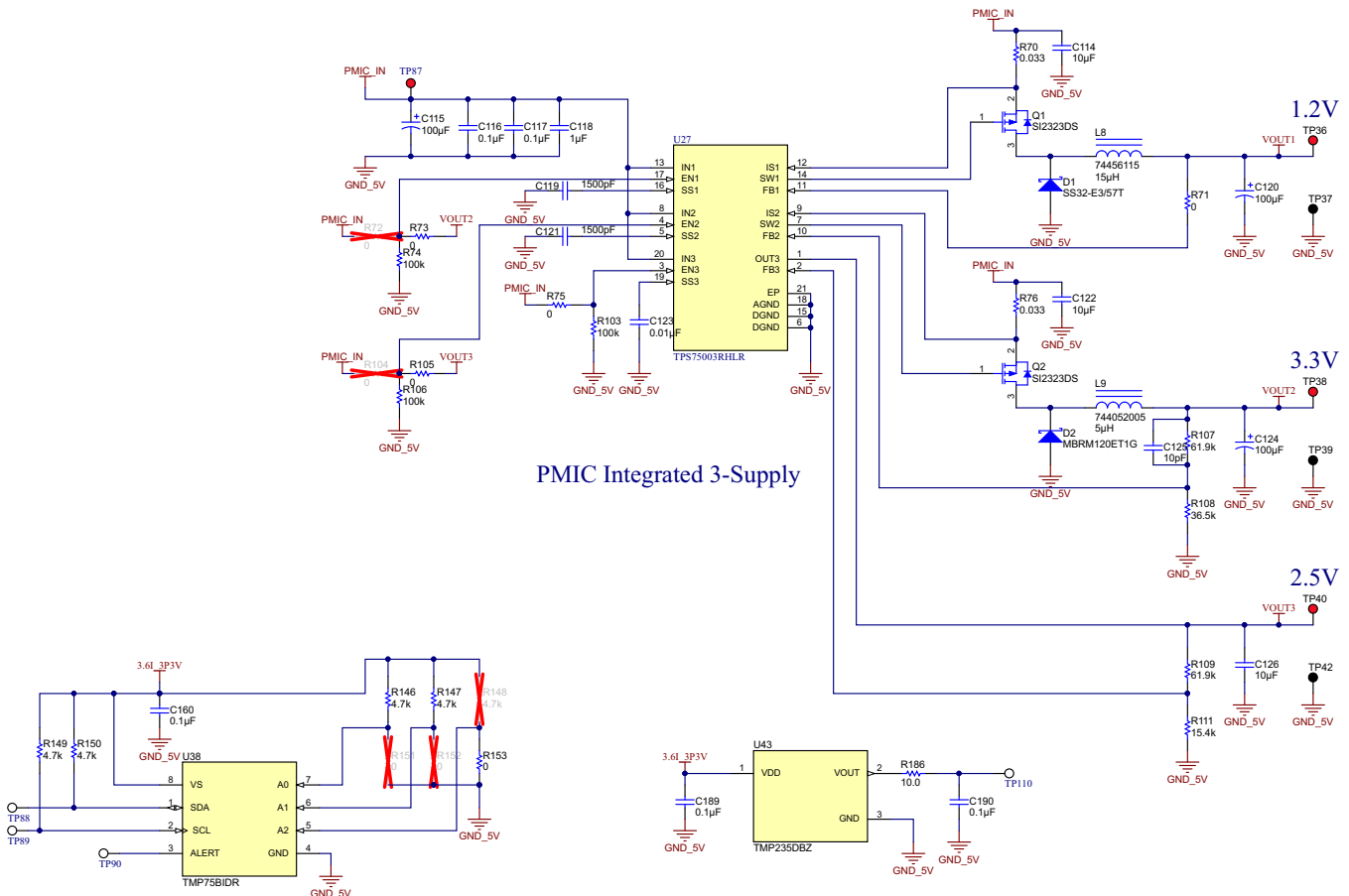
The TPS62821 is an all-purpose and easy-to-use synchronous step-down DC/DC converter with a very low quiescent current of only 4 μ A. The device supplies up to 1-A output current from a 2.4-V to 5.5-V input voltage. Based on the DCS-Control™ topology, it provides a fast transient response. The device features a Power Good signal and an internal soft start circuit. The device can operate in 100% mode. For fault protection, the device incorporates a Hiccup current limit as well as a thermal shutdown. The TPS6282x are packaged in a 2-mm x 1.5-mm QFN-8 package.

2.4.3.4 Power Supply Generation Using Power Management IC for FPGA

Fully-integrated PMICs reduce system complexity with fewer components. Built-in sequencing, monitoring, and voltage scaling help simplify the design versus a fully discrete solution. PMIC are available in factory programmed, hardware configurable, and software configurable options. This section provides details of the generation of the required power supply using hardware configured PMIC as shown in [Figure 9](#) optimized for Xilinx FPGA.

- TPS75003 is configured to generate 1.2 V and 3.3 V using DC/DC converters and 2.5 V using LDO.

Figure 9. Hardware Configurable PMIC for FPGA



The TPS75003 is a complete power management solution for FPGA, DSP, and other multi-supply applications. The device has been tested with and meets all of the Xilinx Spartan-3, Spartan-3E and Spartan-3L start-up profile requirements, including monotonic voltage ramp and minimum voltage rail rise time. Independent enables for each output allow sequencing to minimize demand on the power supply at start-up. Soft-start on each supply limits inrush current during start-up. Two integrated buck controllers allow efficient, cost-effective voltage conversion for both low and high current supplies such as core and I/O. A 300-mA LDO is integrated to provide an auxiliary rail such as VCCAUX on the Xilinx Spartan-3 FPGA. All three supply voltages are offered in user-programmable options for maximum flexibility.

2.4.3.5 Power Supply Generation Using Power Management IC for Processors

Fully-integrated PMICs reduce system complexity with fewer components. Built-in sequencing, monitoring, and voltage scaling help simplify the design versus a fully discrete solution. PMIC are available in factory programmed, hardware configurable and software configurable options. This section provides details of generation of the required power supply using hardware configured PMIC as shown in [Figure 10](#) optimized for AM335X processors.

- TPS650250 is configured to generate 1.1 V, 1.5 V and 3.3 V using DC/DC converters and 1.8 V using LDO1 and LDO2 and a keep alive output.

2.4.4 Board Layout

This section describes the board layout approach and guidelines implemented in this design.

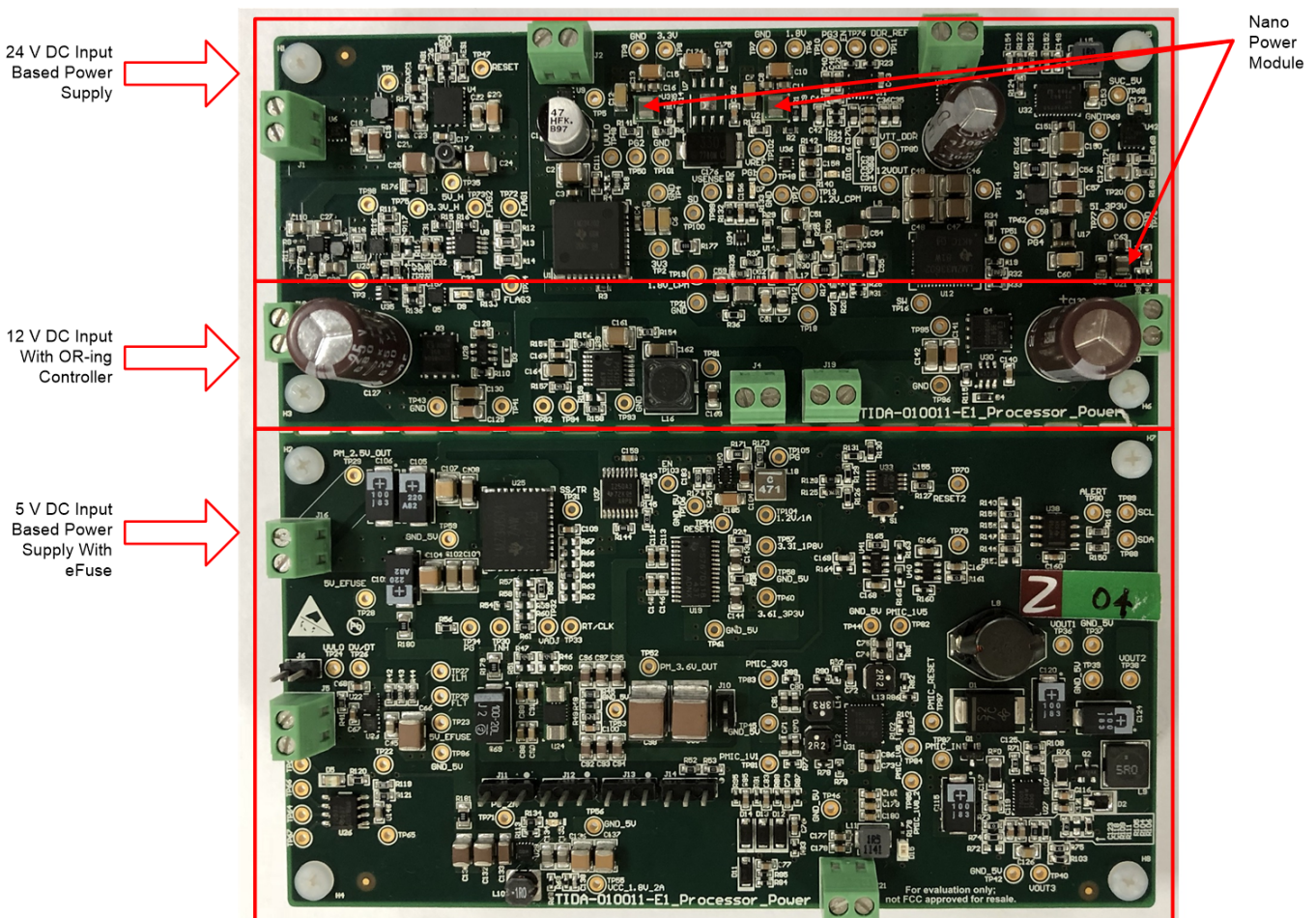
2.4.4.1 Board Segregation

The board layout has been planned and segregated into two parts:

- Generation of power supply from 24-V input and 12-V input with OR-ing capability, onboard DC/DC, and provision to interface to external EVM
- Generation of power supply from 5-V input using POL DC/DC converters or PMIC

The two sections are laid out on the same PCB with V-grooves between. Based on the backplane power available, the DC/DC converter and power supply option can be chosen. As shown in [Figure 11](#), using power modules reduces the overall space by more than 50% and also simplifies the power tree design.

Figure 11. TIDA-010011 Board Picture Labeled



2.4.4.2 PCB Layout for MicroSiP™ Module With Integrated Inductor

To achieve optimal electrical and thermal performance, an optimized PCB layout is required. Some considerations for an optimized layout are:

1. Place all components as close as possible to the IC.
2. The input capacitor placement, specifically, must be closest to the VIN and GND pins of the device.
3. Use wide and short traces for the main current paths to reduce the parasitic inductance and resistance.
4. Connect the exposed thermal pad to bottom or internal layer ground planes using vias to enhance heat dissipation of the device.

5. The output current of the module needs to be derated when the device operates in a high ambient temperature or delivers high output power. The amount of current derating is dependent upon the input voltage, output power, PCB layout design, and environmental thermal condition. Care should especially be taken in applications where the localized PCB temperature exceeds 65°C.

Generic layout guidelines have been covered in this section. Refer to the layout considerations section of specific device data sheet for more details.

2.4.4.3 PCB Layout for Power Module in QFN Package

To achieve optimal electrical and thermal performance, an optimized PCB layout is required. Some considerations for an optimized layout are:

1. Use large copper areas for power planes (VIN, VOUT, and PGND) to minimize conduction loss and thermal stress. Place ceramic input and output capacitors close to the module pins to minimize high frequency noise.
2. Locate additional output capacitors between the ceramic capacitor and the load.
3. Place a dedicated AGND copper area beneath the device.
4. Connect the AGND and PGND copper area at one point using multiple vias.
5. Place RSET, RRT, and CSS as close as possible to their respective pins.
6. Use multiple vias to connect the power planes to internal layers.

Generic layout guidelines have been covered in this section. Refer to the layout considerations section of specific device data sheet for more details.

3 Hardware, Software, Testing Requirements, and Test Results

This section provides details the setup and testing done on this design for validating the performance:

- Required hardware and software connection
- Functional testing
- Performance testing
- Summary of test results

3.1 Required Hardware and Connections

The following boards and equipments are required validating the functionality and performance:

- The TIDA-010011 board with basic functional tests completed and with jumpers mounted between pin1 and pin2 for J11, J12, J13
- Programmable DC voltage source capable of varying voltage between 5 V to 30 V
- Electronic load for testing the power supply output
- Digital multimeter for measuring the DC output voltage
- EVMs that are interfaced to this design for testing

3.1.1 TIDA-010011 Key Functional Blocks

The design has the following key functional blocks

- Power supply generation, monitoring and diagnostics from 24-V input
- OR-ing of two 12-V DC inputs, interface to external EVM and onboard supply generation
- Power supply generation, monitoring, and diagnostics from 5-V input using DC/DC
- Power supply generation, monitoring, and diagnostics from 5-V input using PMIC

3.2 Testing and Results

Testing of this design includes the following:

- Functional testing
- Performance testing
- EMI, thermal, and ripple performance

3.2.1 Test Setup

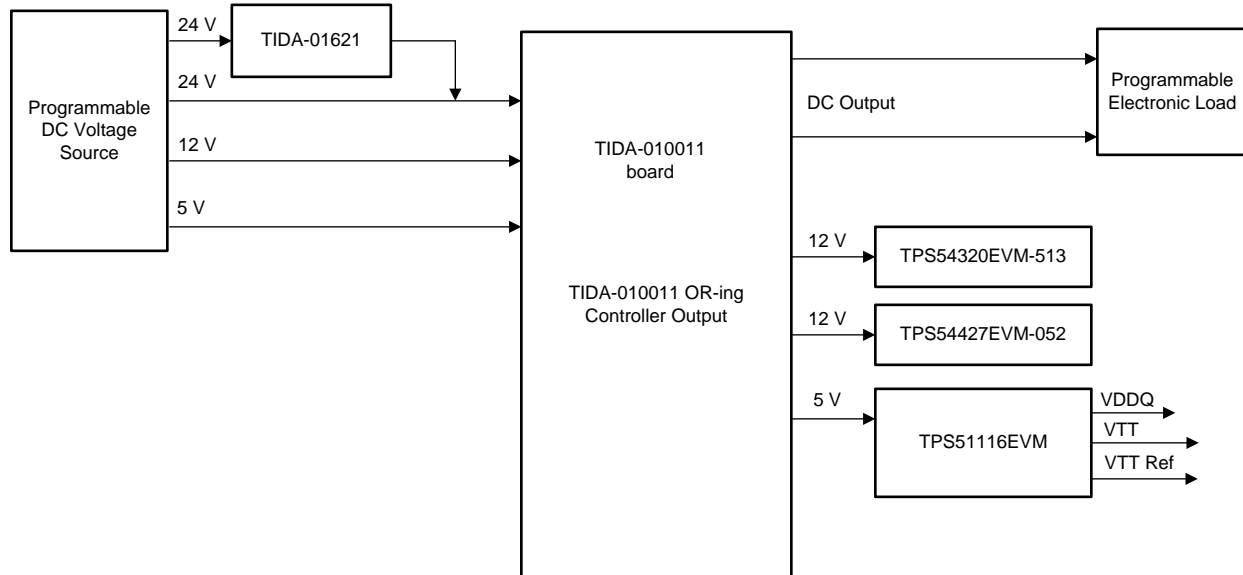
This design is broadly classified into the following function blocks:

- Interfacing between multiple boards including reference designs, EVMs, power supply and loads
- Generation of power supply rails using DC/DC or Power modules with diagnostics
- Generation of power supply rails from 12 V including redundant supply by OR-ing 2 inputs
- Generation of power supply rails from 5 V using DC/DC converters or Power Modules with diagnostics
- Generation of power supply rails from 5 V using PMIC

3.2.1.1 Interfacing Between Power Supply, Multiple Boards and Load

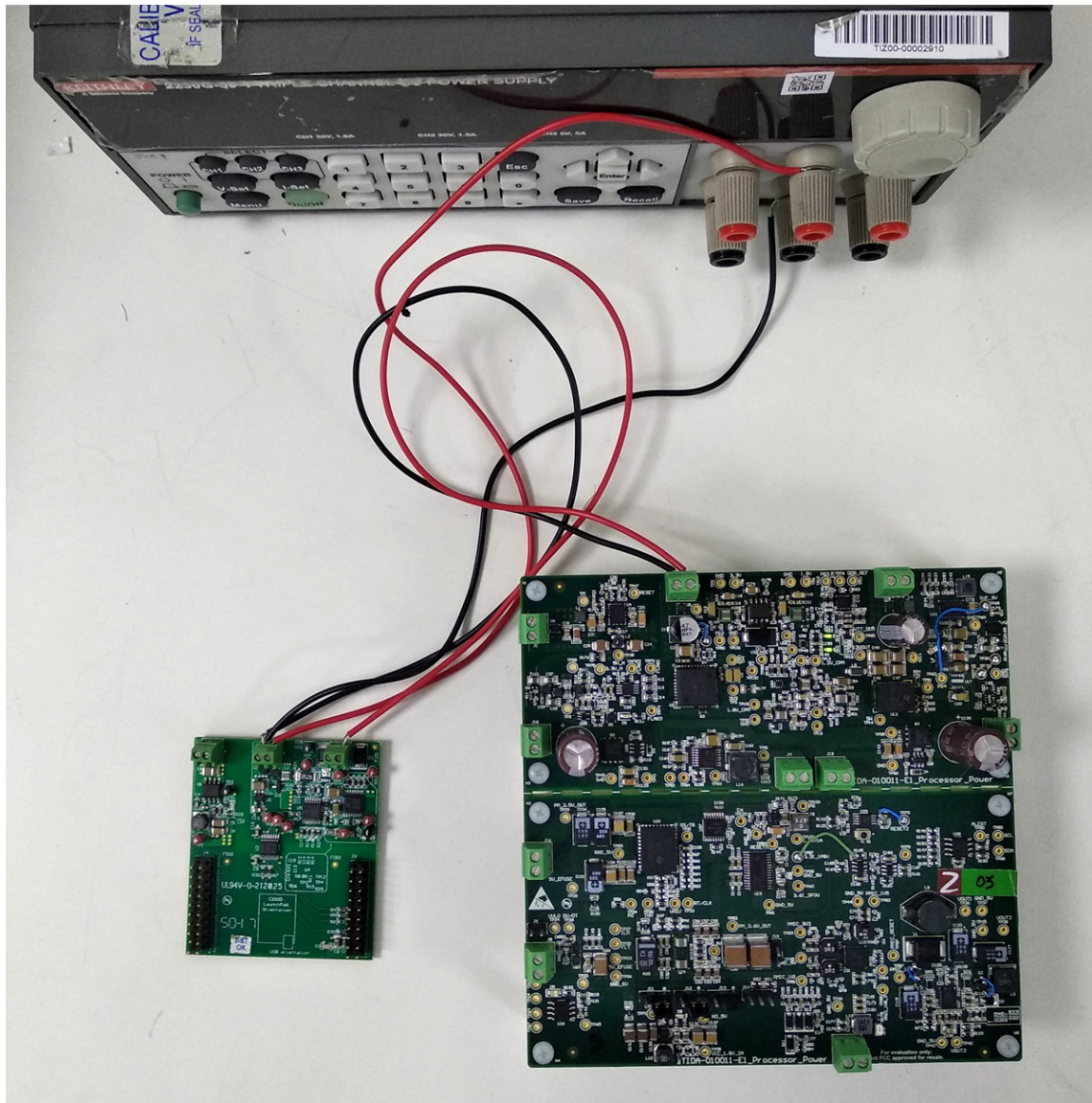
This section provides details of different boards that have been interfaced for testing this design's functionality. [Figure 12](#) shows the interconnections between multiple boards for testing functionality.

Figure 12. Test Setup for interfacing TIDA-010011 to EVMs



3.2.1.1.1 Interfacing TIDA-010011 With TIDA-01621

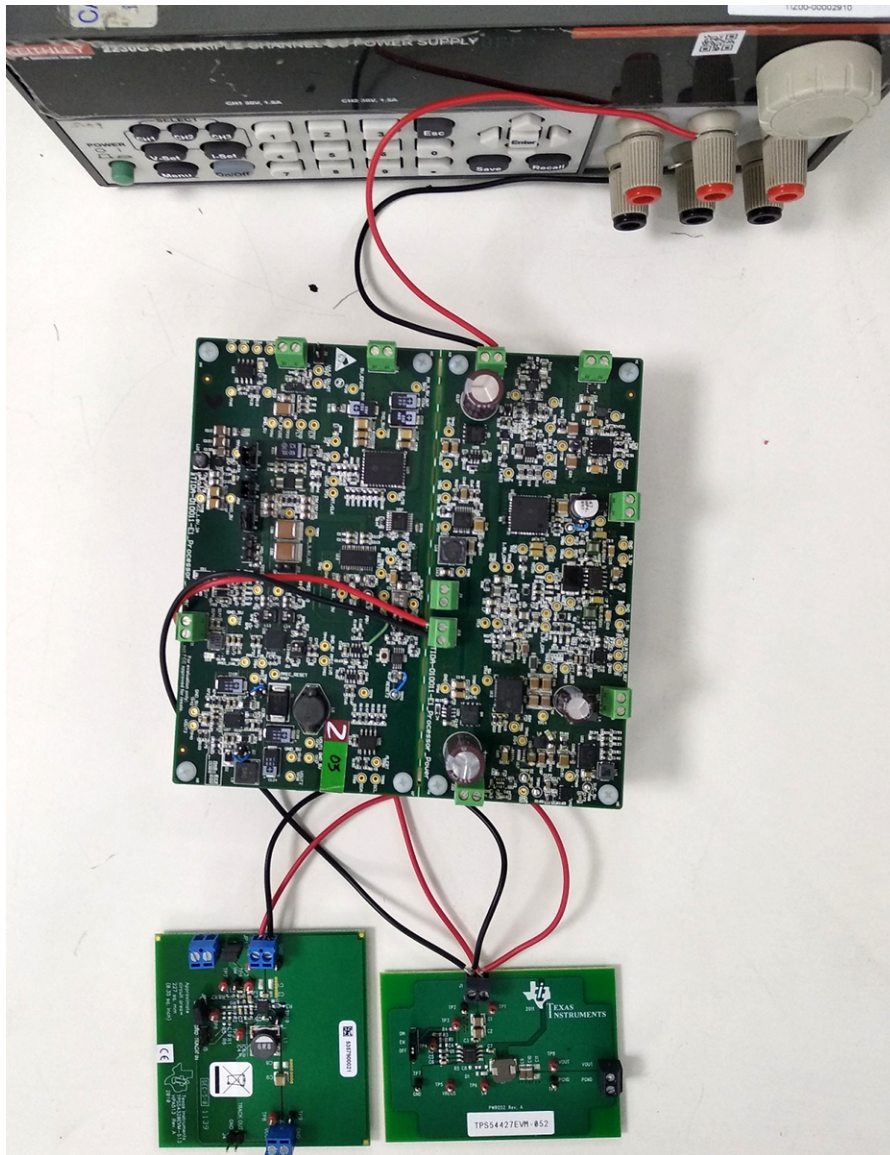
[Figure 13](#) shows the TIDA-01621 eFuse output connected to the TIDA-010011 for testing.

Figure 13. TIDA-01621 eFuse TIDA-010011


3.2.1.1.2 TIDA-010011 Connected to DC/DC Converter TPS54427EVM-052 and TPS54320EVM-513

Figure 14 shows the TIDA-010011 output across J18 connected to DC/DC converter TPS54427EVM-052 and TPS54320EVM-513 for functional and performance testing.

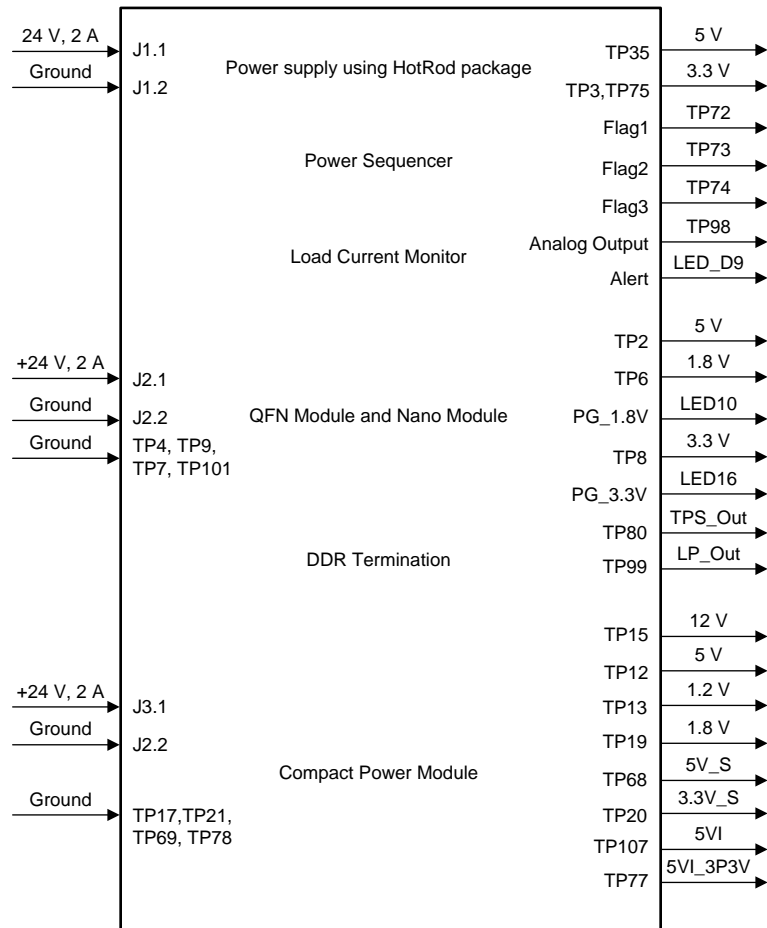
Figure 14. TIDA-010011 connected to DC/DC TPS54427EVM-052 and TPS54320EVM-513



3.2.1.2 Test Setup for Generation of Power Supply Rails From 24-V Input With Diagnostics

This section provides details of the connection and the test points for connecting the power supply input and measuring the power supply outputs with 24-V nominal inputs as shown in [Figure 15](#).

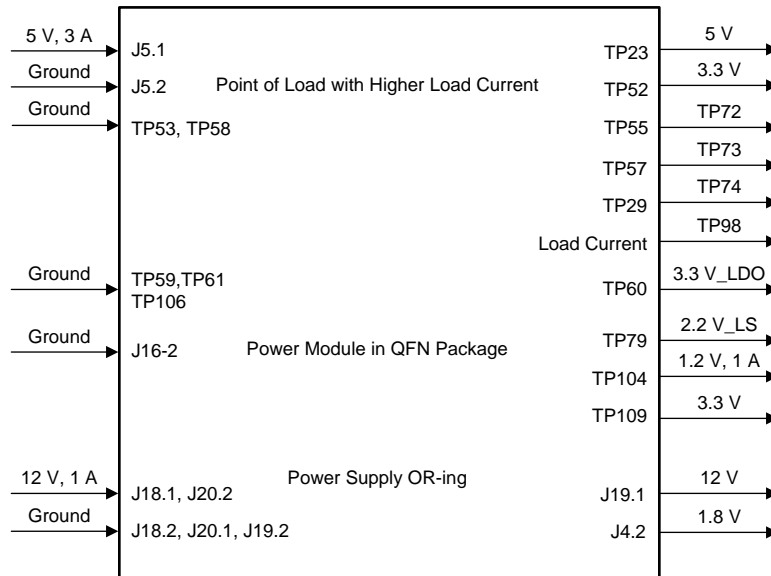
Figure 15. Supply Rails generated using 24-V Input



3.2.1.3 Test Setup for Generation of Power Supply Rails From 5-V or 12-V Input With Diagnostics

This section provides details of the connection and the test points for connecting the power supply input and measuring the power supply outputs with 5-V or 12-V nominal inputs as shown in [Figure 16](#).

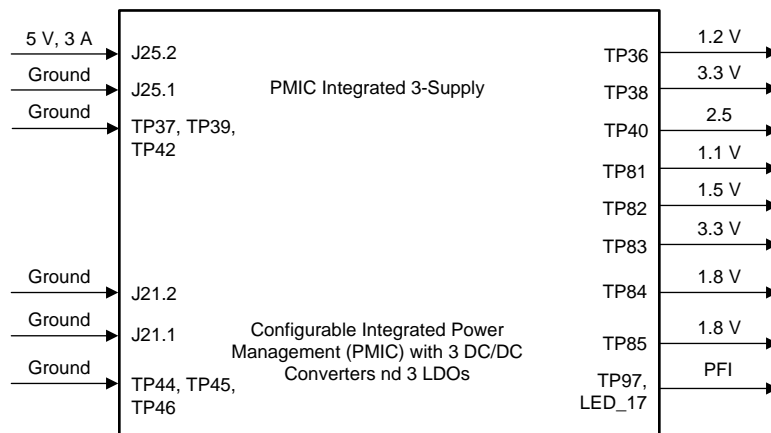
Figure 16. Supply Rails Generated using 5-V and 12-V Input



3.2.1.4 Test Setup Generation of Power Supply Rails From 5-V Input Using PMIC

This section provides details of the connection and the test points for connecting the power supply input and measuring the power supply outputs with 5-V or 12-V nominal inputs as shown in [Figure 17](#).

Figure 17. Supply Rails Generated from 5-V Input using PMIC



3.2.2 Functional Testing

This section provides details of the functional tests done with the TIDA-010011 and observations.

3.2.2.1 24-V DC Input

This section provides details of the tests done and the test observations for the power supply section of the design as shown in [Table 5](#).

Table 5. Supply Rails Generated using 24-V Input

SUPPLY INPUT	CONNECTOR AND FUNCTION	OUTPUT (V)	MEASURED (V)
Power supply with HotRod™ package	J1-1 : input, 24V	TP35 : 5V	5.44
		TP3, TP75 : 3.3V	3.20
	Power Sequencer	Flag1 : TP72	OK
		Flag2: TP73	OK
		Flag3: TP74	OK
	Load Current monitor	INA out : TP98	OK
		Alert : LED_D9	OK
	J1-2 : ground		
QFN module and Nano module	J2-1 : Input 24V	TP2: 5V	5.05
		TP6 : 1.8	1.806
		PG_1.8V : LED10	OK
		TP8 : 3.3	3.296
		PG_3.3V : LED16	OK
	DDR Termination regulator	TPS : TP80	0.907
		LP : TP99	0.912
	J2-2 : Ground	TP4, TP9, TP7, TP101 : Ground	
Compact Power Module	J3-1 : Input 24V	TP15: 12V	11.99
		TP12: 5V	5.023
		TP13 : 1.2V	1.203
		TP19 : 1.8V	1.798
		TP68 : SVC_5V	5.213
		TP20 : 3.3V_S	3.274
		TP107: 5VI	5.01
		TP77: 5VI_3P3V	3.296
	J3-2 : Ground	TP17, TP21, TP69, TP78	

3.2.2.2 Power Supply With 5-V and 12-V Input

This section provides details of the tests done and the test observations for the digital input and output section of the design as shown in [Table 6](#).

Table 6. Supply Rails Generated using 5-V,12-V Input

SUPPLY INPUT	CONNECTOR AND FUNCTION	OUTPUT	OBSERVATIONS
Point of Load with higher load current	J5-1 : 5V	TP23 : 5V_eFuse output	5.002
		TP52 : 2.5V_1.8V	2.51
		TP55: VCC_1.8V_2A	1.801
		TP57: 1.8V_LDO	1.799
	J5-2: Ground	TP53, TP58: Ground	
Power module in QFN package		TP29 : 3.6V	3.691
		Load current : U37_9, TP108	OK
		TP60: 3.3V_LDO	3.307
		TP79: 3.3V_LS	3.306
		TP104: 1.2V, 1A	1.209
		TP109: 3.3V	3.31
	J16-2 : Ground	TP59, TP61, TP106: Ground	
Power supply OR-ing	J18-1: 12V	J19-1: 12V	12
	J20-2 :12V	J4-2: 1.8V	1.813
	J18-2 – Ground		
	J20-1 : Ground	J19-2: Ground	
Diagnostics	Analog temp sensor	TP10	OK

3.2.2.3 Power Supply Rails Using PMIC

This section provides details of the tests done and the test observations for the analog input section of the design as shown in [Table 7](#).

Table 7. Supply Rails Generated using 5-V input and PMIC

SUPPLY INPUT	CONNECTOR	OUTPUT	OBSERVATIONS
PMIC Integrated 3-Supply	J25-2 : 5V	TP36 : 1.2V	1.23
		TP38 : 3.3V	3.312
		TP40 : 2.5V	2.553
	J25-1 : Gnd	TP37, TP39, TP42: Gnd	NA
Configurable Integrated Power Management (PMIC) with 3 DC/DC converters and 3 LDOs	J21-2 : 5V	TP81: 1.1V	1.09
		TP82: 1.5V	1.494
		TP83: 3.3V	3.328
		TP84: 1.8V	1.813
		TP85:1.8V	1.813
		TP111: VDD_Alive, 1V	0.998
		TP97, LED D17:PFI	OK
J25-1 : Gnd	TP44, TP45, TP46 : Gnd	NA	

3.2.2.4 Other Hardware Features

This design provides additional hardware features used for load current monitoring, power good indication for diagnostics, and DC voltage control. [Table 8](#) provides details of the test observations.

Table 8. Functional Tests and Observations

DEVICES	DESCRIPTION	OBSERVATION
INA250A3	36V Low-/High-Side, Bi-Directional, Current Sense Amp w/Precision Integrated Shunt Resistor	OK
TPS386596L33	Quad voltage Supervisor with manual reset	OK
TPS27081A	1.2v – 8V, 3A PFET High Side Load Switch w/ Level shift and Adj Slew Rate Control	OK
TPS3705-33	Processor Supervisory Circuit With Power-Fail and Integrated Watchdog Timer	OK
INA381A1	26V Low/High-Side, Voltage output CSA with Comparator	OK
SN74LVC1G17	Single Schmitt-Trigger buffer	OK
SN74LVC1G14	Single Schmitt-Trigger Inverter	OK
SN74LVC2G34	Dual Buffer Gate	OK

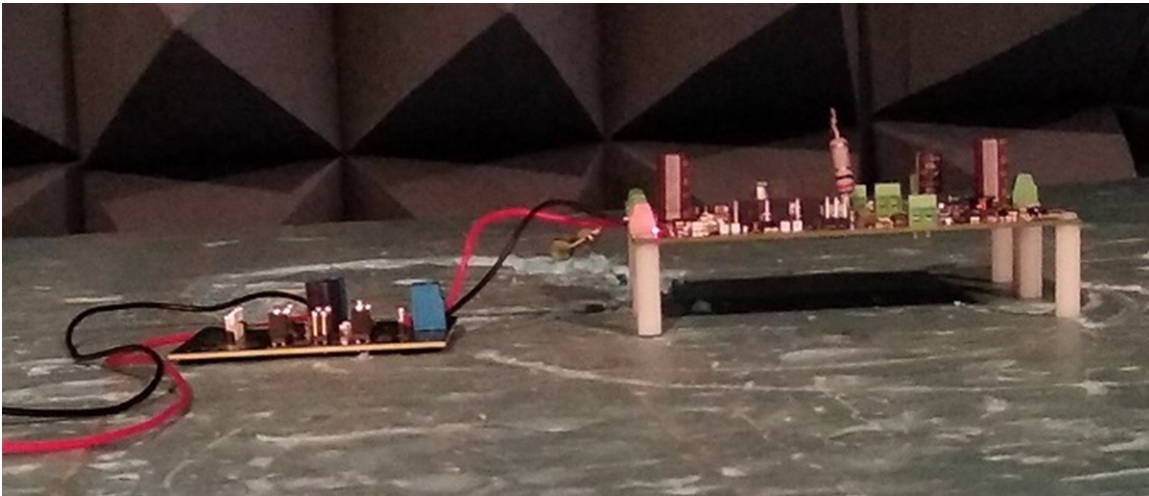
3.3 Performance Testing

This section provides details of the performance tests including EMI tests that have been performed using this design.

3.3.1 EMI Test Setup for Testing TIDA-010011

The radiated emission setup for this design with an antenna at a 3-M distance placed in a semi-anechoic chamber is shown in [Figure 18](#).

Figure 18. 3-Meter Radiated Emission setup including TIDA-01011 Board Placement



3.3.2 EMI Performance of Power Modules With 24-V Input Connected to J3

The radiated emission for supply rails using power modules with the below configuration was tested.

- LMZM33602 with 24-V input configured to generate 12-V output with load
- 12-V output connected to the TPS82130 to generate 5-V output with load
- 5-V output connected to the TPS82084 to generate 1.2-V output with load
- 5-V output connected to the TPS82085 to generate 1.8-V output with load
- The radiated emission plot is shown in [Figure 19](#).

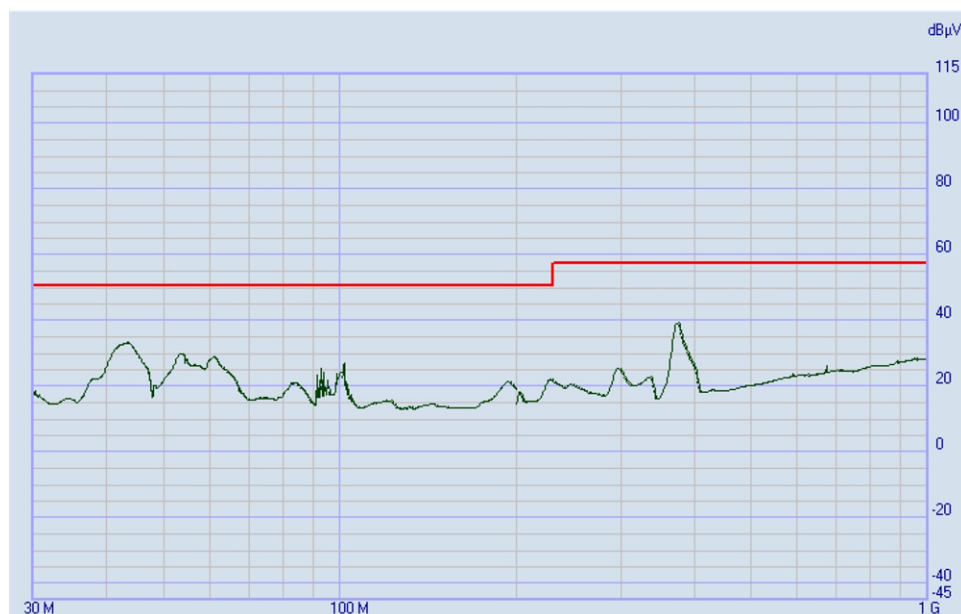
Figure 19. DC/DC Buck Power Module Radiated Emission J3


3.3.3 EMI Performance of Power Module With 24-V Input Connected to J2

The radiated emission for supply rails using power modules with the below configuration was tested.

- LMZ34202 with 24-V input configured to generate 5-V output with load
- 5-V output connected to the LMZ20502 to generate 1.8-V output with load
- 5-V output connected to the LMZ20501 to generate 3.3-V output with load

The radiated emission plot is shown in [Figure 20](#).

Figure 20. DC/DC Buck Power Module Radiated Emission J2


3.3.4 EMI Performance for Power Modules With 12-V and 5-V Input

The radiated emission for supply rails using power modules with the below configuration was tested.

- TPSM84424 (EVM) with 12-V input configured to generate 5-V output
 - TPSM84424 output connected to eFuse TPS259531
 - eFuse 5-V output connected to DC/DC buck modules TPSM82480 to generate 3.6 V with load
 - eFuse 5-V output connected to DC/DC buck modules LMZ30604 to generate 2.5 V with load
- The radiated emission plot is shown in [Figure 21](#).

Figure 21. DC/DC 12-V 5-V Buck Power Module Radiated Emission



3.3.5 EMI Performance for HotRod™ Package Power Modules With 24-V Input Connected to J1

The radiated emission for supply rails using HotRod™ package power modules with the below configuration was tested.

- LM53635 with 24-V input configured to generate 5.4-V output with load
- 5-V output connected to the TPS62085 to generate 3.3-V output with load

The radiated emission plot is shown in [Figure 22](#).

Figure 22. DC/DC 24-V Buck HotRod™ Package Radiated Emission J1



3.3.6 Power Modules Testing With Load

This section provides summary of the load tests done on different DC/DC buck converters used in this design and [Table 9](#) provides measurements for different devices.

Table 9. Power Modules Load Test Observations

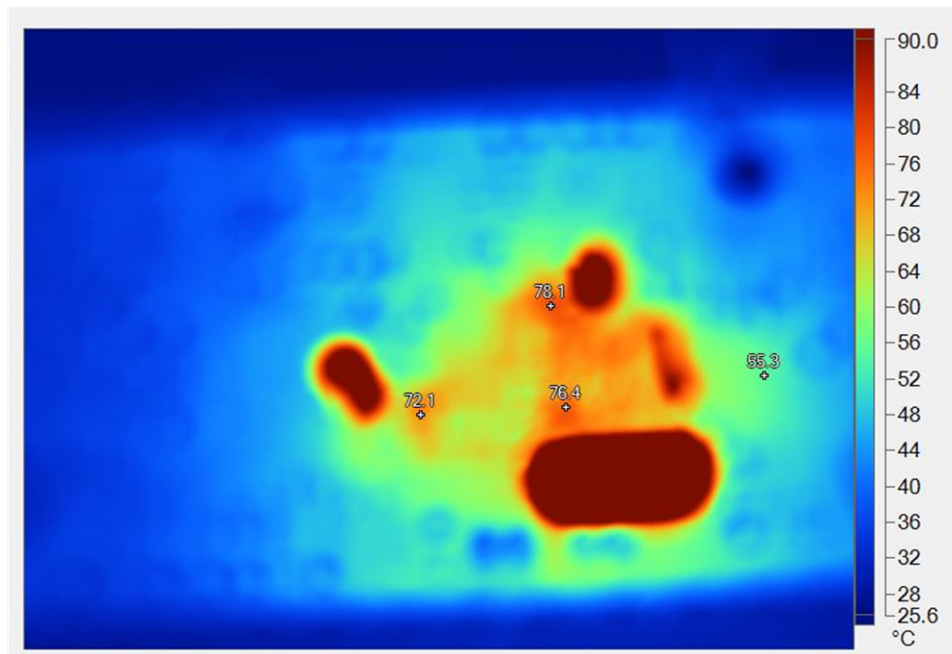
VOLTAGE OUTPUT	DEVICE	CURRENT (mA)	V (NO LOAD)	V (LOAD)
5.45	LM53635A	500	5.46	5.42
3.3	TPS62085	500	3.205	3.19
5	LMZ34202	500	5.05	4.999
1.8	LMZ20502	1000	1.806	1.801
3.3	LMZ20501	500	3.296	3.29
12	LMZM33602	1200	12.05	12.03
5	TPS82130	1200	5.023	5.013
1.2	TPS82084	1000	1.203	1.195
1.8	TPS82085	1500	1.798	1.790
3.3	LMZ10501	2000	3.296	3.294
2.5	TPSM82480	1500	2.51	2.506
3.6	LMZ30604	2000	3.691	3.686
1.8	TPS54325	1000	1.805	1.803
1.8	TPSM84424	2000	1.817	1.815
1.8	TPS62067	1000	1.807	1.79
1.2	TPS62821	800	1.209	1.23
5.2	LM73605	1500	5.213	5.15
1.2	TPS75003	1000	1.23	1.227
3.3	TPS75003	1000	3.312	3.297
2.5	TPS75003	250	2.553	2.54
1.1	TPS650250	1000	1.09	1.08
1.5	TPS650250	500	1.494	1.49
3.3	TPS650250	500	3.338	3.328

3.3.7 Thermal Performance of Power Module

The power modules were connected in the following configuration and were load with more than 70% of the rated load and the thermal performance was tested.

- LMZM33602 with 24-V input configured to generate 12-V output with load
- 12-V output connected to the TPS82130 to generate 5-V output with load
- 5-V output connected to the TPS82084 to generate 1.2-V output with load
- 5-V output connected to the TPS82085 to generate 1.8-V output with load

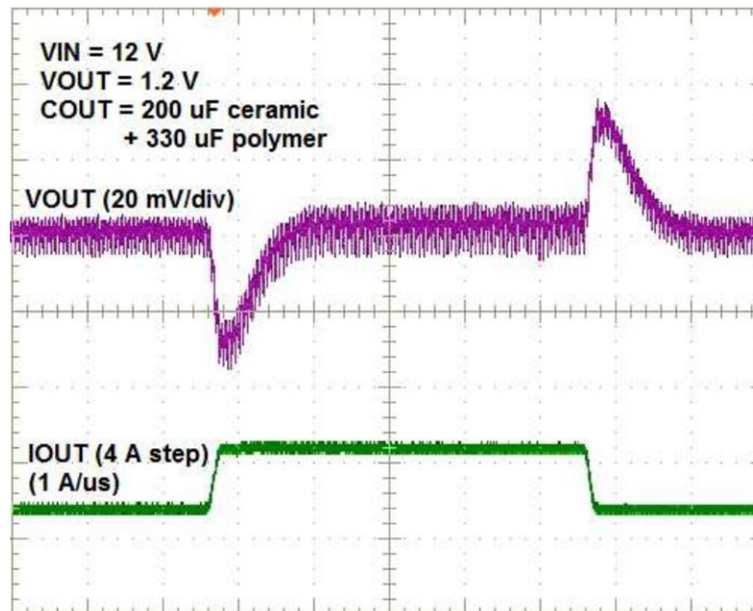
Figure 23. Thermal Performance QFN μ SiL MicroSiP™ Power Module



The power module temperature was measured between 72 to 78°C for different voltage rails using smaller package and the QFN module temperature was observed to be around 56°C. The QFN power module offers better thermal performance. Thermal performance can be improved by using thicker copper on the 2 internal layers, having bigger planes connecting to the IC, and using a thinner PCB.

3.3.8 Power Module Transient Load Performance Using TPSM84424EVM-013

The TPSM84424EVM-013 features the TPSM84424 synchronous buck power module configured for operation with a 4.5-V to 17-V input voltage range. The output voltage can be set to one of six common values by using a configuration jumper and was set to 1.2 V. Similarly, the switching frequency can be set to one of six values with a jumper and was set to 450 KHz. Additionally, the RTT resistor value, which selects the TurboTrans feature for improved transient response, is configured to 3K Ω . The output was loaded to 2 A and the output voltage measured was 1.205. [Figure 24](#) shows the load transient response.

Figure 24. TPSM84424 Output Transient Response


3.3.9 Power Module Ripple Performance

The power modules were connected in the following configuration and were loaded with more than 70% of the rated load.

- LMZ34202 with 24-V input configured to generate 5-V output with load
- 5-V output connected to the LMZ20502 to generate 1.8-V output with load
- 5-V output connected to the LMZ20501 to generate 3.3-V output with load

[Figure 25](#) shows the DC output of the power module.

Figure 25. LMZ34202 QFN Power Module DC Output

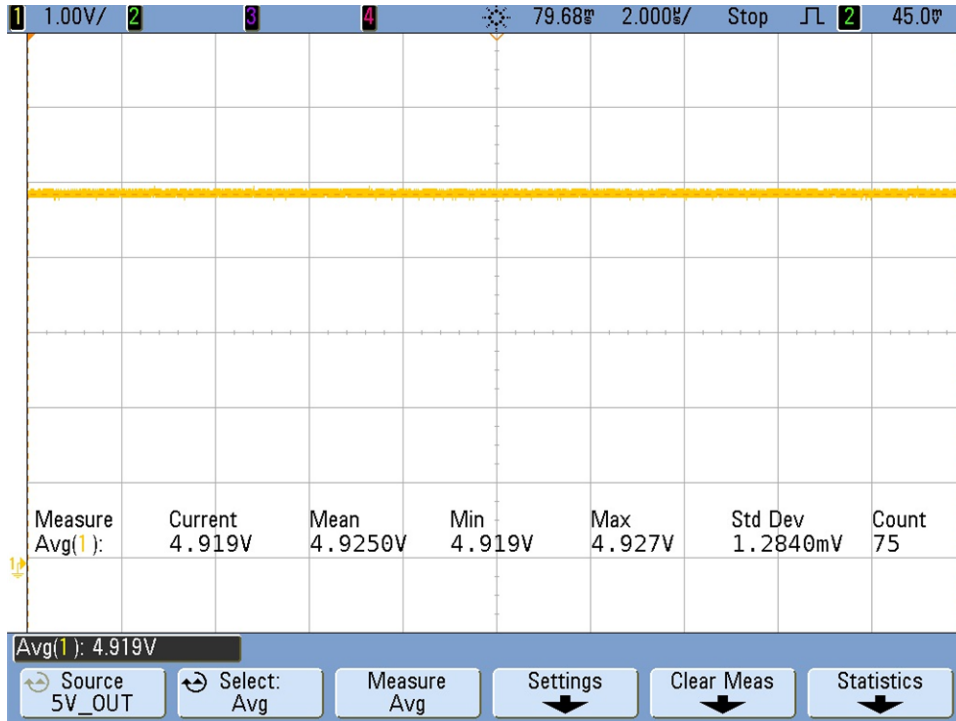
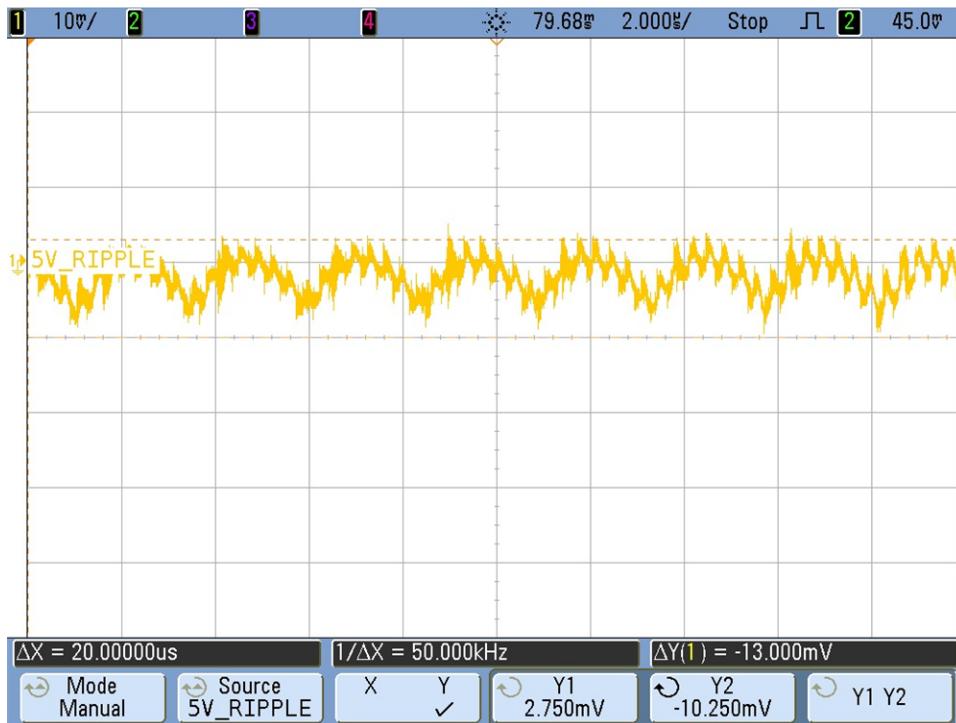


Figure 26 shows the expanded DC ripple measurement and is observed to be less than 10 mV.

Figure 26. LMZ34202_QFN Power Module Expanded Ripple



The DC ripple was measured with an X1 probe made using co-axial cable with a 10-μF electrolytic capacitor and 220-pF ceramic connected at the measurement end of the probe.

3.4 OR-ing Input and DC/DC Converter Performance

The OR-ing controller performance was tested by applying DC input to the two OR-ing controllers using J18 and J20. The 12-V output from the OR-ing controller at J19 was interfaced to the following EVM and tested for the following functionality.

3.4.1 TPS54320EVM-513, 4.5-V to 17-V Input, 3-A Synchronous Step-Down SWIFT™ Converter

The following tests were performed with a 12-V input connected to the EVM:

- Output voltage: 3.3 V and output current range: 0-2 A
- Input ripple: 450 mVPP, at a more than 2-A load and output ripple: 10-mV mVPP, at a more than 2-A load
- Load transient response: voltage change 90 mV for load current change from = 0.75 A to 1.5 A with less than 70-us recovery time
- Load transient response: voltage change 80 mV for load current change from = 1.5 A to 0.75 A with less than 70-us recovery time
- Maximum efficiency: VIN = 8 V, IO = 0.9 A, less than 94%

3.4.2 TPS54427EVM-052, Evaluation Module for TPS54427 Synchronous Step-Down Converter

The following tests were performed with a 12-V input connected to the EVM:

- Output voltage: 1.05 V and output current range: 0-4 A
- Output ripple: 15-mV mVPP at a greater than 3-A load
- Load transient response: voltage change of 40 mV for load current change from 1 A to 3 A with less than 70-us recovery time
- Load transient response: voltage change of 80 mV for load current change from = 1.5 A to 0.75 A with less than 20-us recovery time
- Maximum efficiency: VIN = 5 V, IO = 0.7 A, greater than 88%

3.5 Summary of Test Results

Table 10 summarizes the tests performed on this design and the resulting observations.

Table 10. Summary of the Tests Performed and Observations

SERIAL NUMBER	PARAMETERS	OBSERVATIONS
1	24-V DC input rail protection with eFuse	OK
2	5-V DC input rail protection with eFuse	OK
3	OR-ing control with 12-V input	OK
4	DC power rails generation from 24 V using HotRod™ package DC/DC converters	OK
5	DC power rails generation from 24 V using synchronous converters	OK
6	DC power rails generation from 24 V using power modules in QFN package and nano modules	OK
7	DC power rails generation from 5 V using DC/DC converters with integrated FET	OK
8	DC power rails generation from 5 V using power module with integrated inductor	OK
9	DC power rails generation from 5 V using PMIC	OK
10	Load current monitoring	OK
11	On board analog and digital temperature monitoring	OK
12	DDR termination regulator output	OK
13	Power good indication using buffer and LED	OK
14	Voltage supervisor and sequencer output DC output voltage control using load switch	OK
15	DC output voltage control using load switch	OK
16	Testing OR-ing controller output with the TPS54320EVM, TPS51116EVM, TPS54427EVM and TPSM84424EVM-013M	OK

4 Design Files

4.1 Schematics

To download the schematics for each board, see the design files at [TIDA-0010011](#).

4.2 Bill of Materials

To download the bill of materials (BOM) for each board, see the design files at [TIDA-010011](#).

4.3 PCB Layout Recommendations

To download the layout prints for each board, see the design files at [TIDA-010011](#).

4.4 Altium Project

To download the Altium Designer® project files for each board, see the design files at [TIDA-010011](#).

4.5 Gerber Files

To download the Gerber files for each board, see the design files at [TIDA-010011](#).

4.6 Assembly Drawings

To download the assembly drawings for each board, see the design files at [TIDA-010011](#).

5 Related Documentation

- Texas Instruments, [Power Management Guide 2018](#)
- Texas Instruments, [A Topical Index of TI LDO Application Notes](#)
- Texas Instruments, [Innovative DC/DC Power Modules Selection Guide](#)
- Texas Instruments, [TI Power Solutions. DC/DC Converter Modules for Space-Constrained Applications](#)
- Texas Instruments, [Current Sharing in Redundant Systems Application Report](#)
- Texas Instruments, [EMI Mitigation Techniques Using the LMZM23601 Application Report](#)
- Texas Instruments, [Benefits and trade-offs of various power-module package options](#)
- Texas Instruments, [Enhancing DAQ performance for grid protection, control and monitoring equipment, using DC/DC power modules](#)

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6 Terminology

PMIC — Power Management Multi-Channel IC

EMI — Electro Magnetic Interference

POL — Point of Load

7 About the Authors

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