Design Guide: TIDA-011004

Space Grade 3U VPX Power Supply Module Reference Design

TEXAS INSTRUMENTS

Description

This reference design is a space-grade power supply module compliant with the VITA-62 standard for space-rated 3U VPX architectures. The Space VPX standard enables standardization and interoperability by defining a framework for modular and scalable systems that can be used in a variety of different mission profiles. This reference design is implemented with a compact form factor while maintaining a high overall performance.

Resources

TIDA-011004	Design Folder
TPS7H5020-SEP	Product Folder
TPS7H6015-SEP	Product Folder
TPS7H6025-SEP	Product Folder
TPS7H5005-SEP	Product Folder
TPS7H4011-SEP	Product Folder
TPS7H4013-SEP	Product Folder
TPS7H1121-SEP	Product Folder
OPA4H199-SEP	Product Folder
TMP9R01-SEP	Product Folder
THVD9491-SEP	Product Folder
MSP430FR5969-SP	Product Folder
TL1431-SP	Product Folder

Features

- 300W Power supply module with nominal 28V input voltage
- Output voltage rails: 12V at 18A, 5V at 12A, and 3.3V at 3A
- Overcurrent protection on each output rail, temperature sensing, and microcontroller on board
- Follows mechanical requirements of VITA62 standard and includes VPX power connector on board
- Dimensions: 3U space VPX form factor (100mm × 160mm)

Applications

- Satellite electrical power system (EPS)
- Power control & distribution unit (PCDU)
- Space-grade isolated DC/DC module
- Space-grade point-of-load (PoL) DC/DC module

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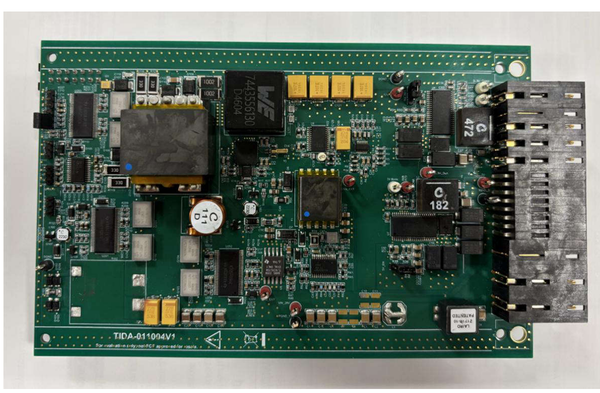
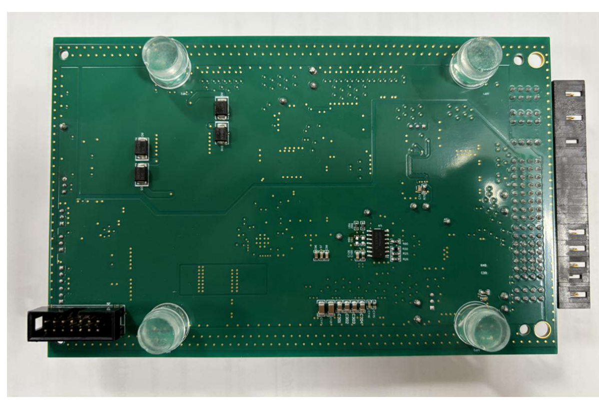




1 System Description

TIDA-011004 is composed of multiple subsystems including:

- EMI Filter
- Primary-side regulated flyback topology for housekeeping
- Full-Bridge ZVS DC-DC Converter (28V → 12V)
- Point of load buck regulators (12V to 5V and 12V to 3.3V)
- Power Distribution for Telemetry
- Telemetry and Protection

Primary-side regulated flyback topology for housekeeping

This reference design uses TPS7H5020-SEP PWM controller for driving GaN FETs for a primary-side regulated flyback converter. This stage converts the nominal 28V input into two isolated 12V outputs:

- Primary 12V bias (referenced to primary ground) – Powers the full-bridge gate drivers
- Secondary 12V bias (referenced to secondary ground) – Powers secondary-side gate drivers, control circuitry, and telemetry systems

Full-Bridge ZVS DC-DC Converter (28V → 12V)

The main power conversion stage uses a full-bridge topology featuring:

- TPS7H5005-SEP PWM controller (secondary-side referenced)
- Three TPS7H6005-SEP half-bridge gate drivers:
  - Two primary-side drivers operate in PWM mode to achieve zero-voltage switching (ZVS) under higher load conditions
  - One secondary-side driver controls secondary rectifiers to further improve conversion efficiency
- GaN FETs throughout for improved switching performance

Point-of-Load Buck Regulators

Two buck converters generate the 3.3V and 5V voltages from the 12V full-bridge output:

- TPS7H4011-SEP: 12V → 5V buck regulator
- TPS7H4013-SEP: 12V → 3.3V buck regulator
- Both operate at 500kHz switching frequency and are located on the secondary side of the isolation barrier

Power Distribution for telemetry

- LDO regulator: Generates a 3.3V rail from the secondary 12V bias
- 3.3V LDO rail: Powers microcontroller, RS-485 transceiver, and temperature sensor
- Secondary 12V bias: Powers quad op-amp for current monitoring

Telemetry and Protection

- Temperature sensor with remote diode positioned near secondary rectifiers for thermal monitoring via I²C interface
- Quad op-amp (three channels active) monitors output current on all three rails (12V, 5V, 3.3V)
- Microcontroller:
  - Three ADC inputs connected to op-amp outputs for current measurement
  - Three GPIO outputs tied to enable pins of power stages for overcurrent protection
  - I²C interface for temperature monitoring
- RS-485 communication interface (demonstrates 3U VPX form factor integration capability)

1.1 Terminology

EPS	Electrical Power System
PCDU	Power Control and Distribution Unit
PoL	Point of Load
ZVS	Zero Voltage Switching
PWM	Pulse Width Modulation
EMI	Electromagnetic Interference
GaN	Gallium Nitride
FET	Field Effect Transistor
LDO	Low Dropout Regulator
ADC	Analog to Digital Converter
GPIO	General Purpose Input/Output

2 System Overview

Table 2-1. Voltage and Current Requirements

PARAMETER	SPECIFICATIONS
Input Voltage	22V to 36V, 28V nominal
Output Voltage and Current	12V at 18A max, 5V at 12A max, and 3.3V at 3A max
Switching Frequency	500kHz

2.1 Block Diagram

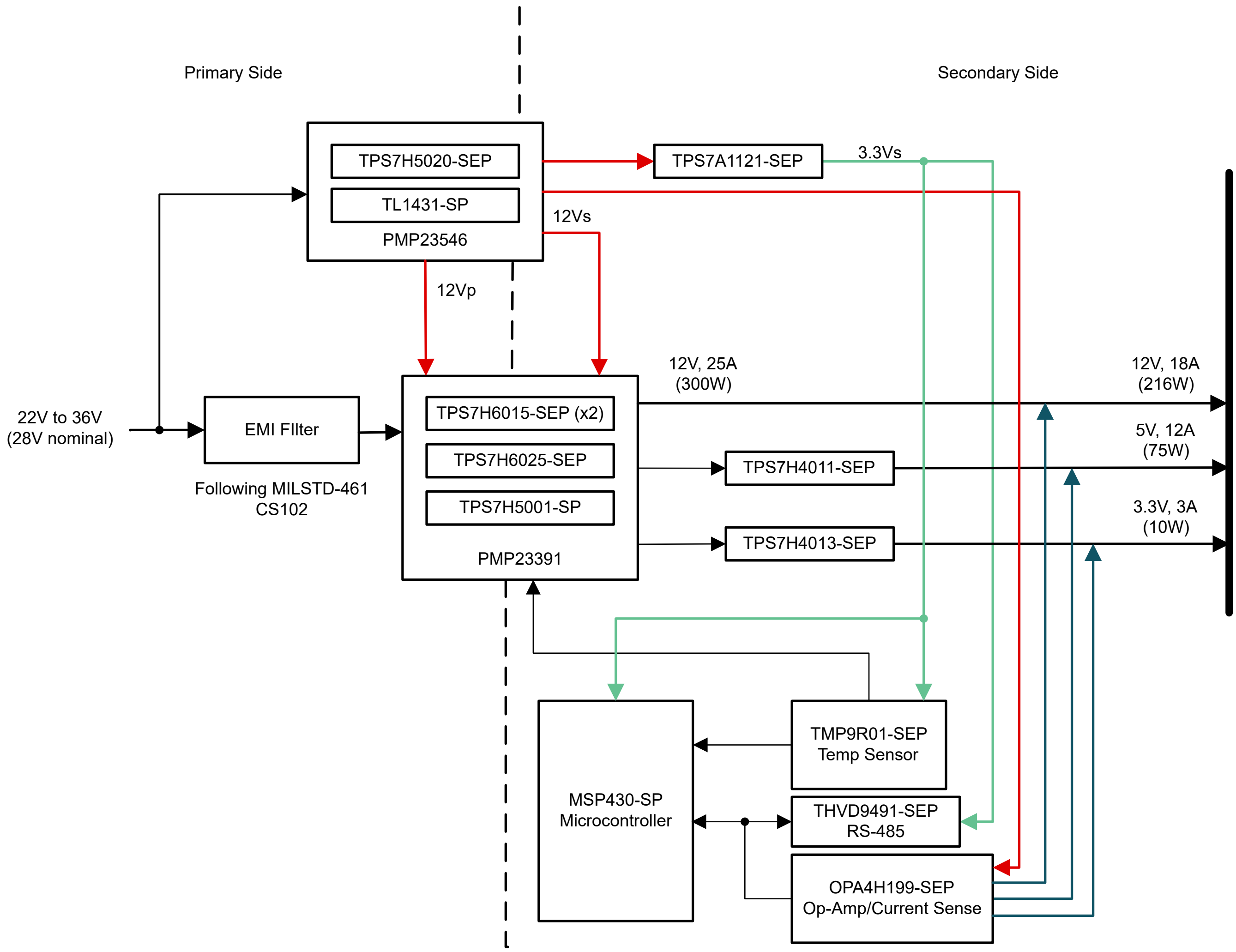


Figure 2-1. TIDA-011004 Block Diagram

2.2 Design Considerations

The following sections describe fundamental design considerations used for subsystems of this reference design based on end-use applications.

2.2.1 Part Selection

A key consideration in component selection was scalability across mission radiation profiles. All the chosen power management devices have pin-to-pin compatible QMLP equivalents, which enables seamless scaling from lower radiation environments to higher radiation environments without required board redesign or layout modifications. This strategy can help reduce development costs since a single PCB design can support multiple mission profiles. By maintaining electrical compatibility across the radiation tolerance range, this design can be rapidly adapted to meet different mission requirements while preserving the base architecture for reference.

Additionally, this design prioritizes size, efficiency, and cost in that order. The VPX 3U form factor imposes a difficult size constraint, making board area the primary consideration. Efficiency was the second priority to maximize the deliverable output power. The design uses all the available input power rather than wasting input power on conversion losses. Cost was only considered after size and efficiency requirements were met. The results is maximum power delivery capability in a small form factor.

2.2.2 EMI Filter

This design followed CS102 EMI requirements from MIL-STD-461. No EMI filter testing was performed on this reference design. A simulation was developed to guide part selection for the filter. Figure 2-2 shows the output of the EMI filter simulation made in SIMPLIS™. Figure 2-3 shows how the EMI filter fits the requirements of the standard.

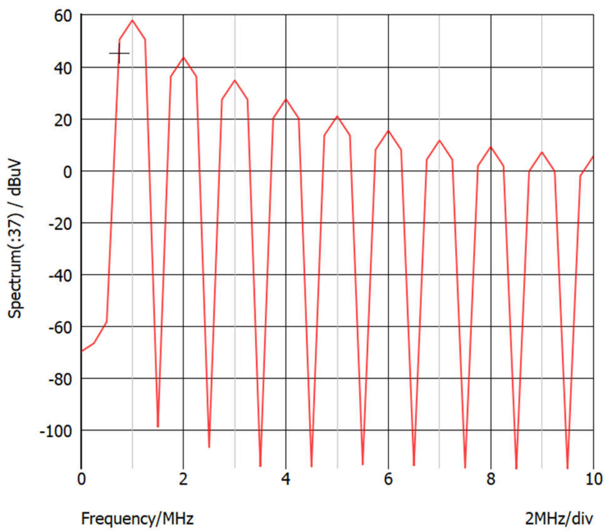


Figure 2-2. EMI Filter Output from SIMPLIS Model

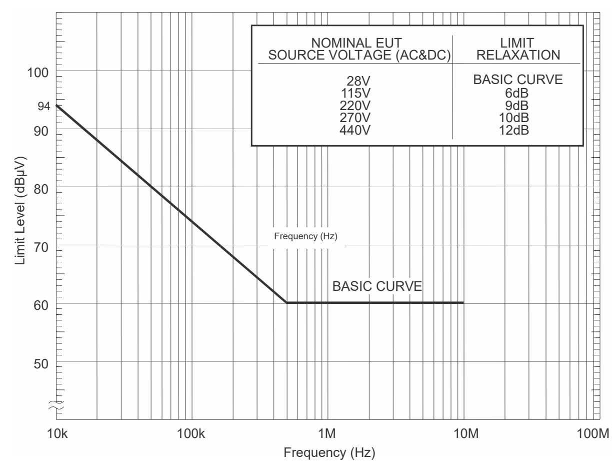


Figure 2-3. Requirements of EMI Filter from MIL-STD-461 CS102

2.2.3 Secondary Side Control for Full Bridge

For the ZVS full bridge portion of this design, secondary side control was chosen due to the advantage of fast transient response which enables fast response to dynamic loads. Additionally, second side control allows for direct over current protection making, which is designed for increasing the robustness of the overall system.

This design can be altered for primary side control. ISOS510-SEP can transmit feedback signals back to the controller from the secondary side in this configuration.

2.3 Highlighted Products

The following sections describe the highlighted products used in the reference design for the housekeeping supply, full bridge topology, switching regulator outputs, and telemetry.

2.3.1 TPS7H5020-SEP/TPS7H5020-SP

The TPS7H5020-SEP and TPS7H5020-SP are a radiation-hardened, current mode, single-ended PWM controller with integrated gate drivers. The TPS7H502x can be used in both silicon and gallium nitride (GaN) power semiconductor-based converter designs. The controllers integrate several key functions, such as soft-start, enable, and adjustable slope compensation while maintaining a small package size. The controllers also feature a 0.6V ±1% voltage reference tolerance to support highly accurate power converter designs.

2.3.2 TPS7H6015/25-SEP/TPS7H6015/25-SP

The TPS7H60x5 series of radiation-hardness-assured (RHA) gallium nitride (GaN) field effect transistor (FET) gate drivers is designed for high frequency, high efficiency, and high current applications. The series consists of the TPS7H6005 (200V rating), the TPS7H6015 (60V rating), and the TPS7H6025 (22V rating). Each of these devices has a 56-pin HTSSOP plastic package and availability in both the QMLP and Space Enhanced Plastic

(SEP) grades. The drivers feature adjustable dead time capability, small 30ns propagation delay, and 5.5ns high-side and low-side matching. These parts also include internal high-side and low-side LDOs, which produces a drive voltage of 5V regardless of supply voltage. The TPS7H60x5 drivers all have split-gate outputs, providing flexibility to adjust the turn-on and turn-off strength of the outputs independently.

2.3.3 TPS7H5005-SEP/TPS7H5001-SP

The TPS7H500x-SEP series (which includes TPS7H5005-SEP, TPS7H5006-SEP, TPS7H5007- SEP, and TPS7H5008-SEP) is a family of high-speed, radiation-tolerant, PWM controllers in space enhanced plastic. The controllers provide many features that are beneficial for the design of DC-DC converter topologies intended for space applications. The controllers have a 0.613V +0.7%/– 1% accurate internal reference and configurable switching frequency up to 2MHz. Each device offers programmable slope compensation and soft-start.

2.3.4 TPS7H4011-SEP/TPS7H4011-SP

The TPS7H4011 is a 14V, 12A synchronous buck converter optimized for use in a space environment. The peak current mode converter obtains high efficiency with good transient performance and reduced component count. The wide voltage range of the TPS7H4011 enables the device to be used as a point of load regulator to convert directly from a 12V or 5V rail. The output voltage start-up ramp is controlled by the SS_TR pin. Power sequencing is possible with the EN and PWRGD pins. The device can be configured with up-to-four devices in parallel without an external clock for increased current capabilities. Additionally, various features are included such as differential remote sensing, selectable current limit, a flexible fault input pin, and configurable compensation.

2.3.5 TPS7H4013-SEP/TPS7H4013-SP

The TPS7H401x devices are 14V synchronous buck converters optimized for use in a space environment. The TPS7H4012 is a 6A device and the TPS7H4013 is a 3A device. The peak current mode converter obtains high efficiency with good transient performance and reduced component count. The wide voltage range of the TPS7H401x enables the device to be used as a point of load regulator to convert directly from a 12V or 5V rail. The output voltage start-up ramp is controlled by the SS_TR pin. Power sequencing is possible with the EN and PWRGD pins. Additionally, various features are included such as an optimized current limit for each device, a flexible switching frequency, and configurable compensation.

2.3.6 TPS7H1121-SEP/TPS7H1121-SP

The TPS7H1121 is a radiation-hardened, low dropout linear regulator (LDO) which operates over a wide input voltage range and is optimized for powering devices in a space environment. The device can source up to 2A over a 2.25V to 14V input. The device offers excellent stability and features a programmable current limit with a wide adjustment range. To support the complex power requirements of FPGAs, DSPs, and microcontrollers, the TPS7H1121 provides enable on and off functionality, programmable soft start, and a power good open-drain output.

2.3.7 OPA4H199-SEP/OPA4H199-SP

The OPA4H199-SEP is a high voltage (40V) general purpose operational amplifiers for space application. The device offers exceptional DC precision and AC performance, including rail-to-rail input/output, low offset (typically ±125μV), low offset drift (typically ±0.3μV/°C), low noise (10.8nV/√Hz and 1.8μVPP), and 4.5MHz bandwidth. Unique features such as differential and common-mode input-voltage range to the supply rail, high output current (±75mA), high slew rate (21V/μs), and high capacitive load drive (1nF) make the OPA4H199-SEP a robust, high-performance operational amplifier for high-voltage space applications.

2.3.8 TMP9R01-SEP

The TMP9R01-SEP device is a radiation-tolerant, high-accuracy, low-power remote and local temperature sensor that integrates a 12-bit ADC, bias currents, and on-chip calibration circuitry for temperature sensing. This device is available in a 10-pin VSSOP plastic-encapsulated package. By forcing a bias current through an external BJT transistor, or the diode and junction integrated in an FPGA, ADC, or ASIC, the device digitizes the resulting ΔVBE and directly reports with a 0.0625°C temperature resolution. The second on-chip sensor measures local temperature, enabling on-board temperature sensing.

The TMP9R01-SEP device incorporates multiple calibration and protection features, including series resistance cancellation, programmable non-ideality factor (η-Factor), offset correction, and programmable digital filter. The user can set high and low temperature limits that drive the ALERT output for over- and under-temperature thermal protection. The I2C and SMBus serial interface accepts up to nine different pin-programmable addresses on the same I2C bus. The TMP9R01-SEP device is also available in a QMLV (TMP461-SP) and QMLP (TMP9R01-SP, prerelease) versions, with higher radiation specs.

2.3.9 THVD9491-SEP

THVD9491-SEP is a space enhanced, ±40V fault-protected full-duplex RS-422/RS-485 transceiver using a 1.65V to 5.5V logic supply for data and enable logic signals, and a 3V to 5.5V bus side supply. The device has a slew rate select feature that enables the use at two maximum speeds based on the SLR pin setting. The device features integrated IEC ESD protection, eliminating the need for external system-level protection components. The ±12V input common-mode range makes reliable data communication over longer cable run lengths or in the presence of large ground loop voltages. Enhanced 250mV receiver hysteresis provides high noise rejection. In addition, the receiver fail-safe feature makes sure of a logic high when the inputs are open or shorted together

2.3.10 MSP430FR5969-SP

The MSP430™ ultra-low-power (ULP) FRAM platform combines uniquely embedded FRAM and a holistic ultra-low-power system architecture, allowing innovators to increase performance at lowered energy budgets. FRAM technology combines the speed, flexibility, and endurance of SRAM with the stability and reliability of flash at much lower power. The ultra low-power architecture of the MSP430FR5969-SP showcases seven low-power modes, optimized to achieve power efficient distributed telemetry and housekeeping systems. The integrated mixed-signal features make MSP430FR5969-SP suited for distributed telemetry applications in next-generation spacecraft. The strong immunity to single-event latchup and total ionizing dose enables the device to be used in a variety of space and radiation environments.

2.3.11 TL1431-SP

The TL1431 is a precision programmable reference with specified thermal stability over automotive, commercial, and military temperature ranges. The output voltage can be set to any value between $VI_{(ref)}$ (approximately 2.5V) and 36V with two external resistors. This device has a typical output impedance of 0.2Ω. Active output circuitry provides a very sharp turn on characteristic, making the device an excellent replacement for Zener diodes and other types of references in applications such as onboard regulation, adjustable power supplies, and switching power supplies.

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Hardware Requirements

- Power Supply: rated to handle 30V and 15A
- Three electronic loads
- Digital Multimeters
- Oscilloscope
- Fan

3.2 Software

- CCStudio™ Software
- MSP-FET

3.3 Test Setup

This design was tested using a backplane connector that fits into the VPX connector on the reference design. Any backplane that contains 2309390-1 works with the connector on board and make testing this reference design simpler. Follow the specific backplane routing to set up the board correctly.

To test this reference design, TI purchased the Pixus Technologies PIBV62 interface board. This board plugs into the connector that is on the reference design. This reference design has alignment key 1 (input voltage) keyed to 0° which correlates to a nominal input voltage range between 18VDC to 36VDC. The output is intended for final power out and alignment key 2 (output voltage) is keyed to 0° which correlates to PO1 = 12VDC, PO2 = 3.3VDC, and PO3 = 5VDC. Figure 3-1 shows a schematic provided by Pixus. In that schematic, the following configurations were made:

- PE1 = 28V supply
- PE2 = 28V supply ground
- PE4 = 12V e-load
- PE5 = 3.3V e-load
- PE6 = 5V e-load
- PE7 = Secondary ground

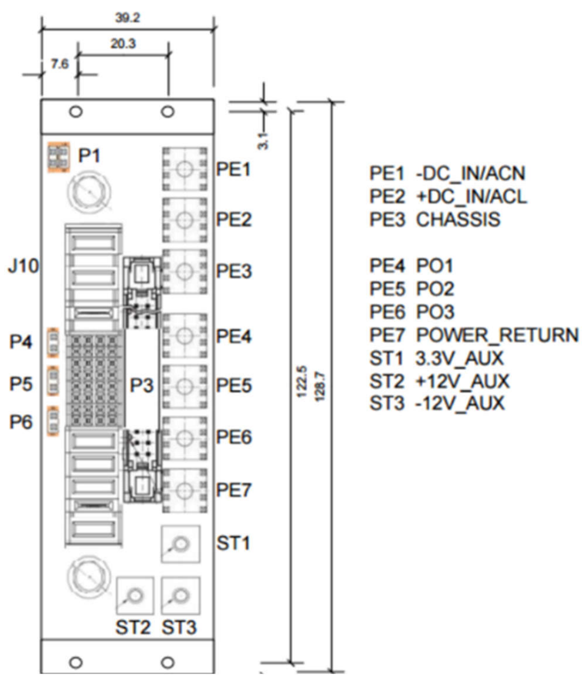


Figure 3-1. Pixus Technologies Schematic of backplane connector for testing

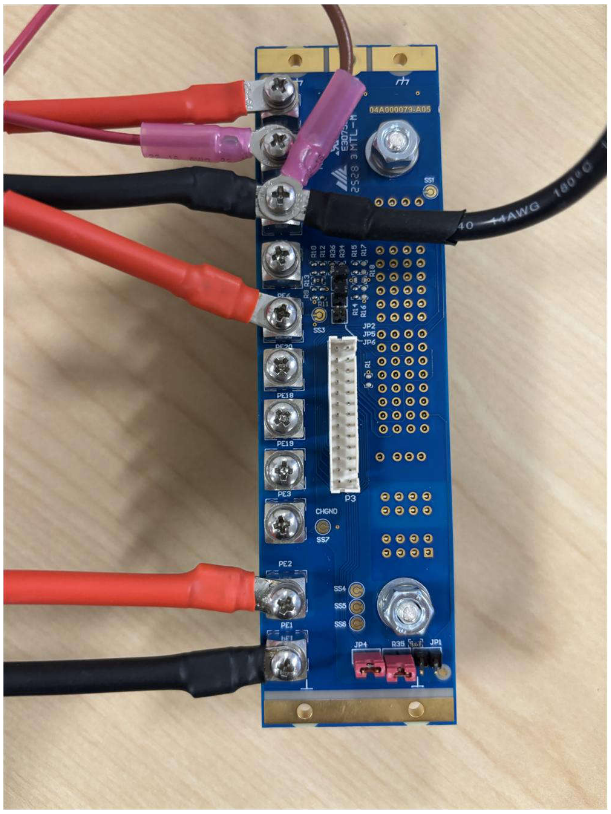


Figure 3-2. Backside of backplane

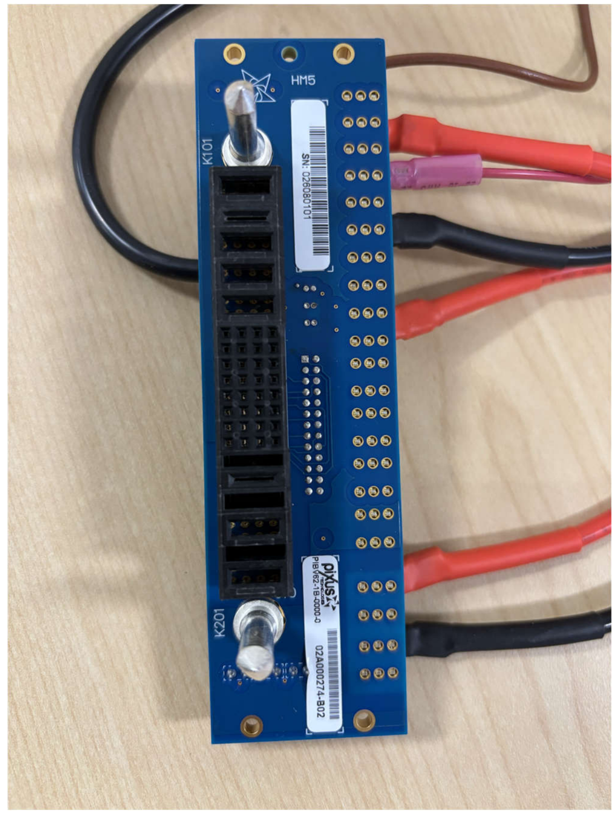


Figure 3-3. Front side of backplane

When testing the full-load conditions of this reference design, air flow is recommended.

3.4 Test Results

The following is a summary of test results from TIDA-011004. Measurements were taken at full load of the rail unless mentioned otherwise. The input voltage was measured after the EMI filter. Additionally, a fan provided air flow.

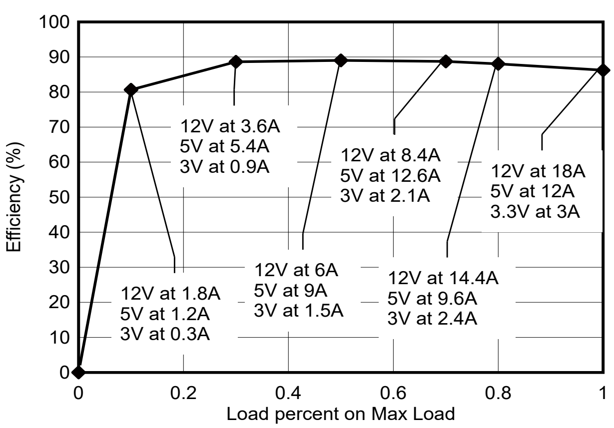


Figure 3-4. Efficiency of Full PSU at 28V Nominal Input

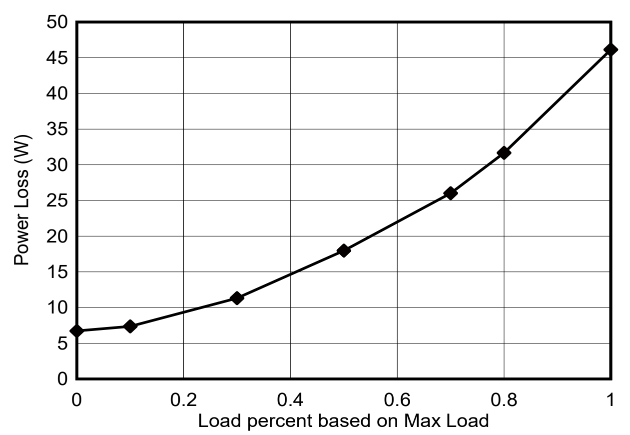


Figure 3-5. Power Loss of Full PSU at 28V Nominal Input

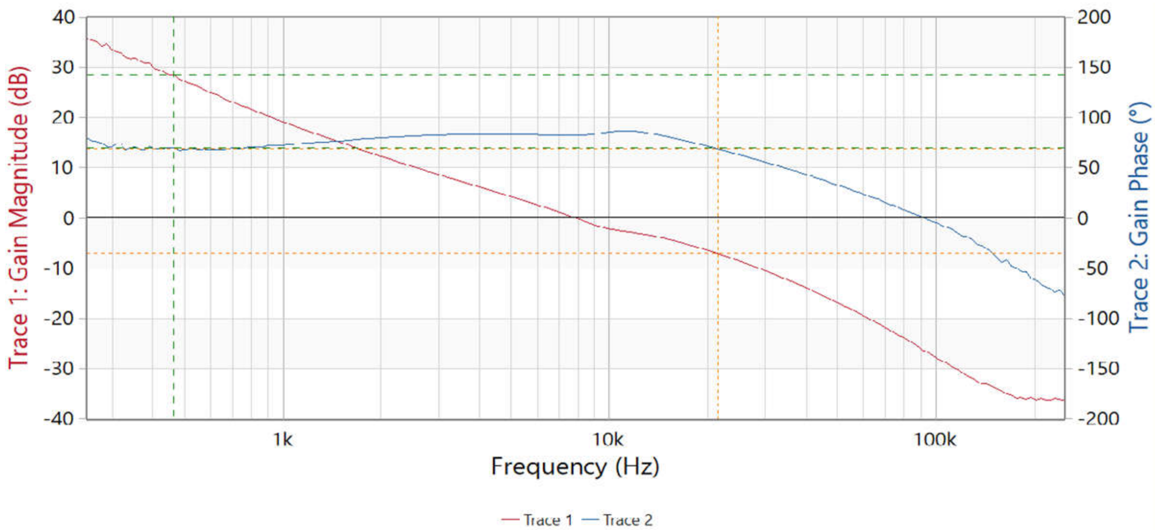
Table 3-1. Efficiency and Power Loss Data with 28V Input

Input		Output						Total		
Voltage (V)	Current (A)	5V Rail Voltage (V)	3.3V Rail Voltage (V)	12V Rail Voltage (V)	5V Rail Current (A)	3.3V Rail Current (A)	12V Rail Current (A)	Load Percent based on Max Load	Efficiency (%)	Power Loss (W)
27.99	0.240	5.013	3.322	12.09	0	0	0	0%	0	6.718
27.97	1.359	5.012	3.322	12.09	1.600	0.299	1.790	10%	80.643	7.358
27.92	3.562	5.011	3.323	12.08	4.000	0.898	5.390	30%	88.626	11.312
27.87	5.871	5.012	3.323	12.08	6.400	1.498	8.990	50%	89.017	17.971
27.82	8.286	5.013	3.324	12.08	8.800	2.099	12.700	70%	88.717	26.009
27.80	9.5253	5.015	3.324	12.07	10.000	2.398	14.500	80%	88.041	31.667
27.74	12.054	5.018	3.325	12.07	12.400	2.998	17.999	100%	86.203	46.133

3.4.1 12V Output Rail Test Results (Full Bridge)

The following results are for the phase shifted full bridge portion of this reference design.

The Bode plot is measured at full load with nominal input voltage (28V).



28V input, 12V output Bandwidth = 100Hz Phase Margin = 75.6℃

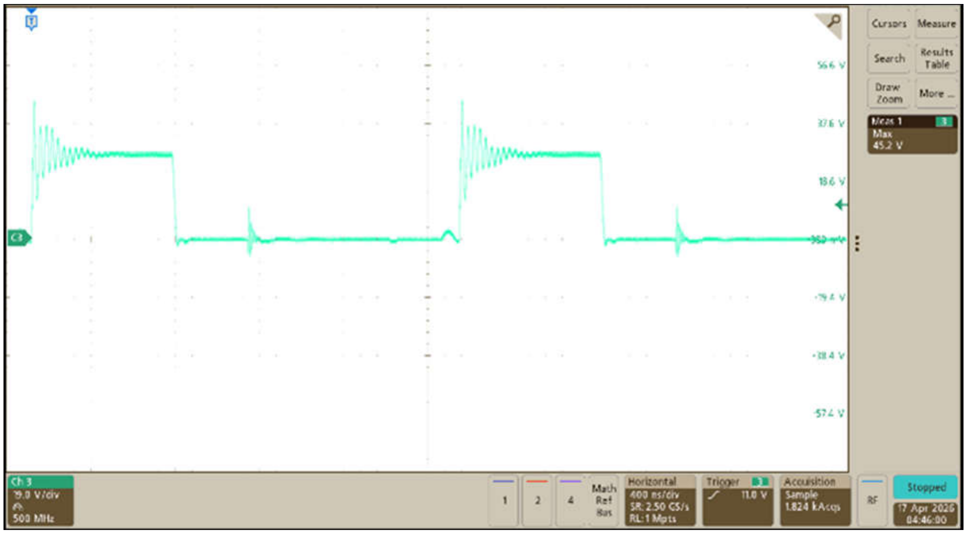


Figure 3-6. Primary Switch Node, 28V Input

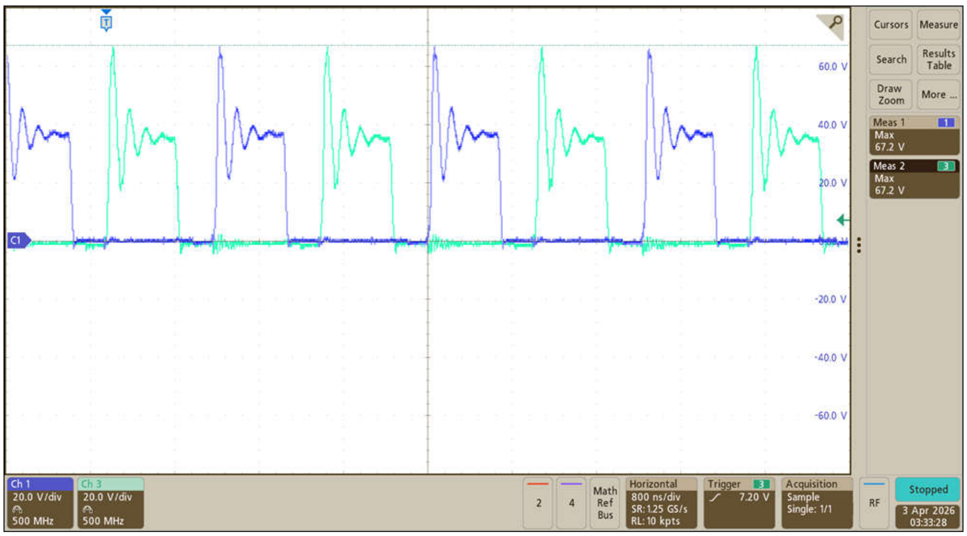


Figure 3-7. Secondary Switch Nodes

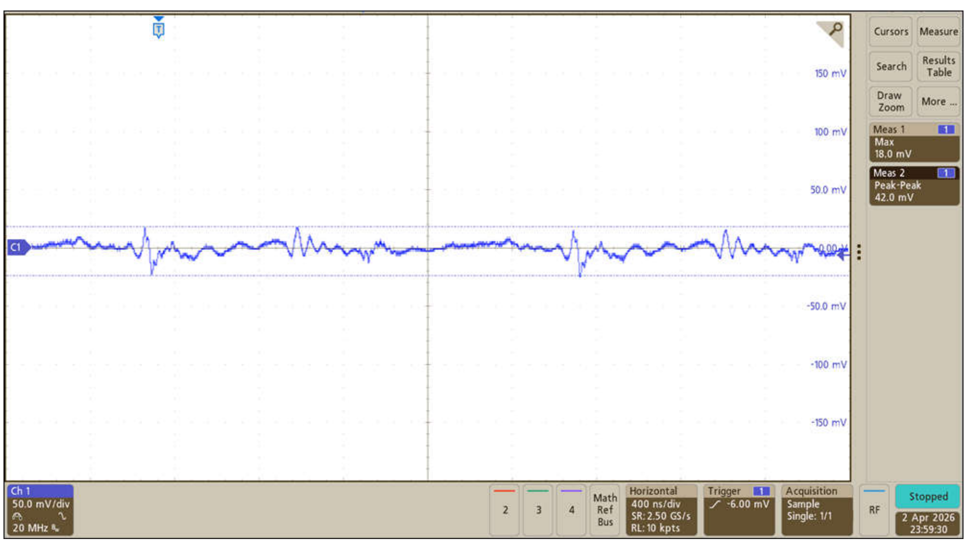


Figure 3-8. Output Voltage Ripple; 42.0mV Peak to Peak

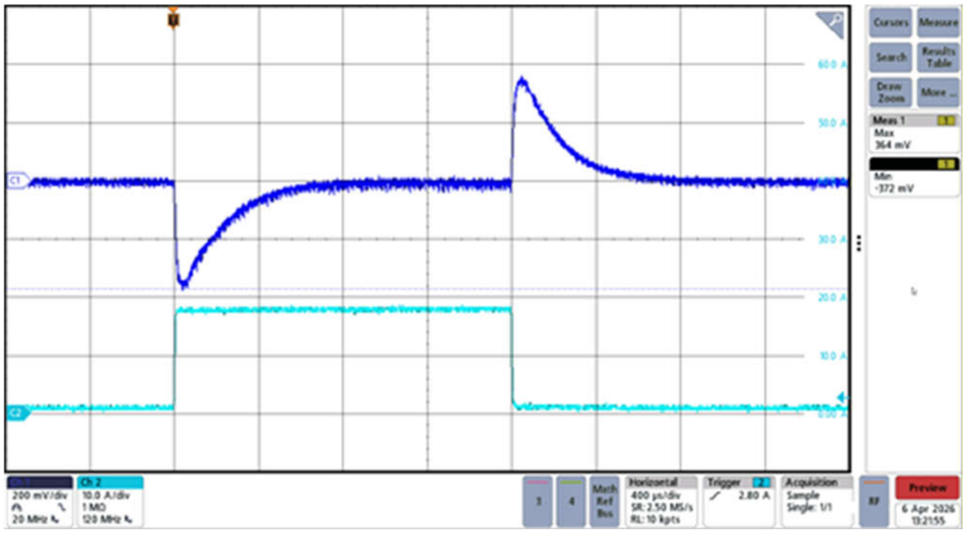


Figure 3-9. Load Transient Response is Shown for a 1A to 18A Step

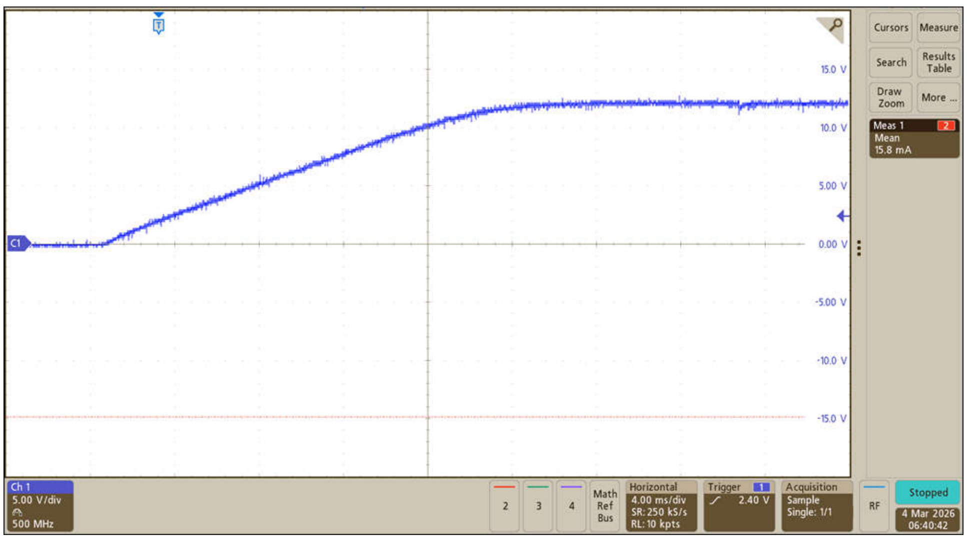


Figure 3-10. Start-up Timing

28V input 12V output at 18A

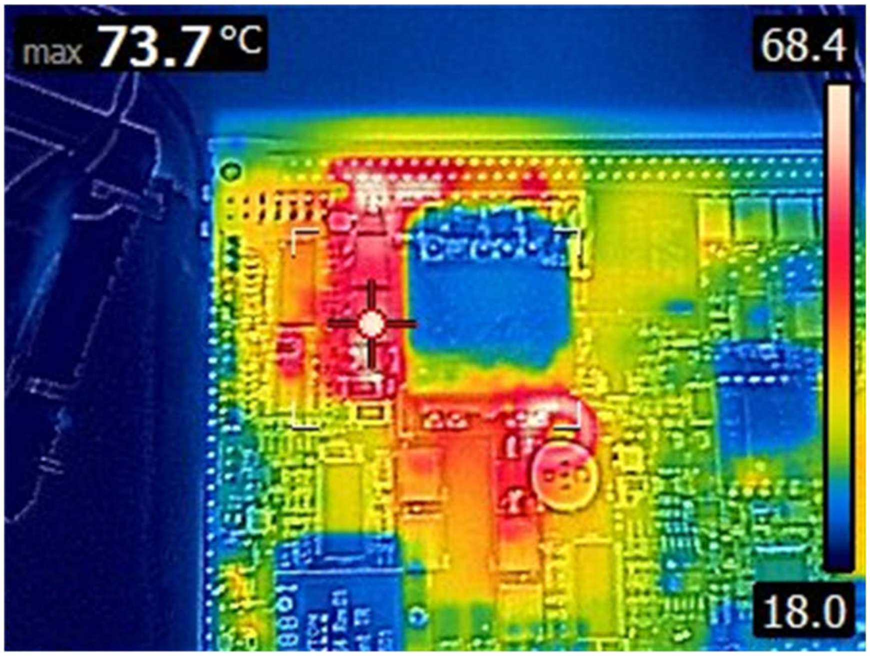
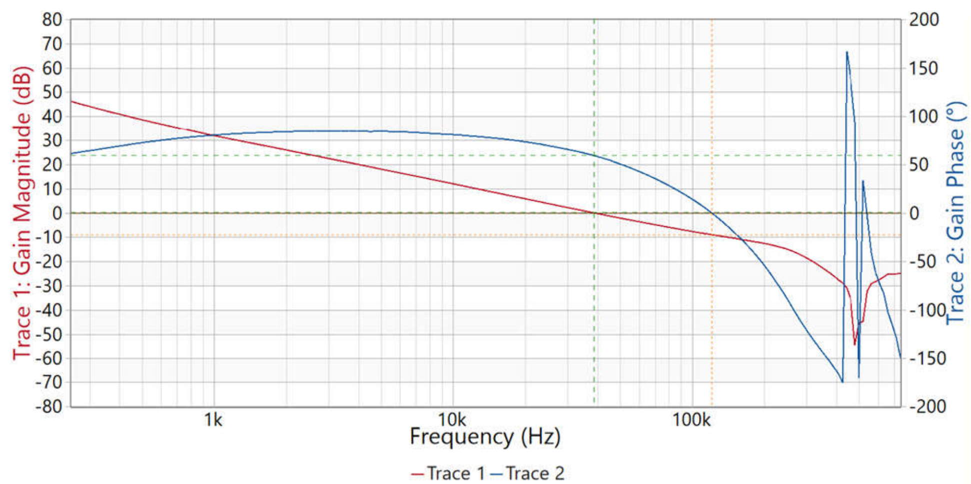


Figure 3-11. Top View of Secondary Side of Full Bridge

3.4.2 5V Output Rail Test Results (TPS7H4011-SP)

The following results are for the 12V to 5V buck regulator.



28V input, 12V output	Bandwidth = 100Hz	Phase Margin = 59.1°C at 38.7kHz	Gain Margin = –9.011dB at 121.5kHz

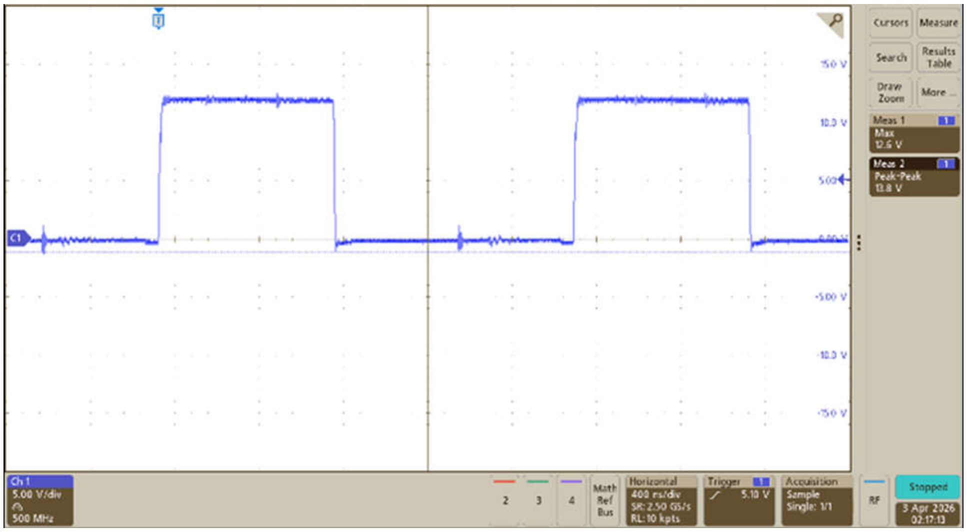


Figure 3-12. Switch Node, 12V Input

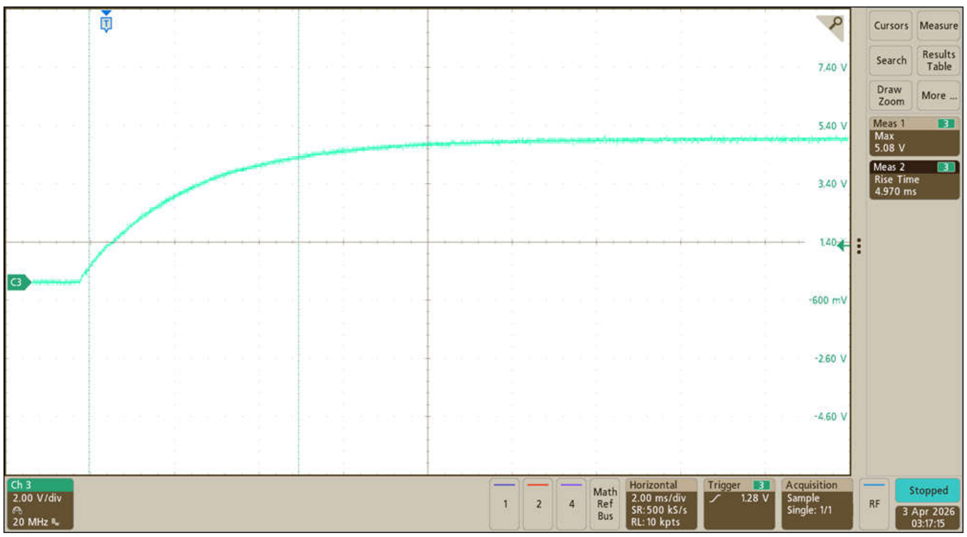


Figure 3-13. Start-up Timing

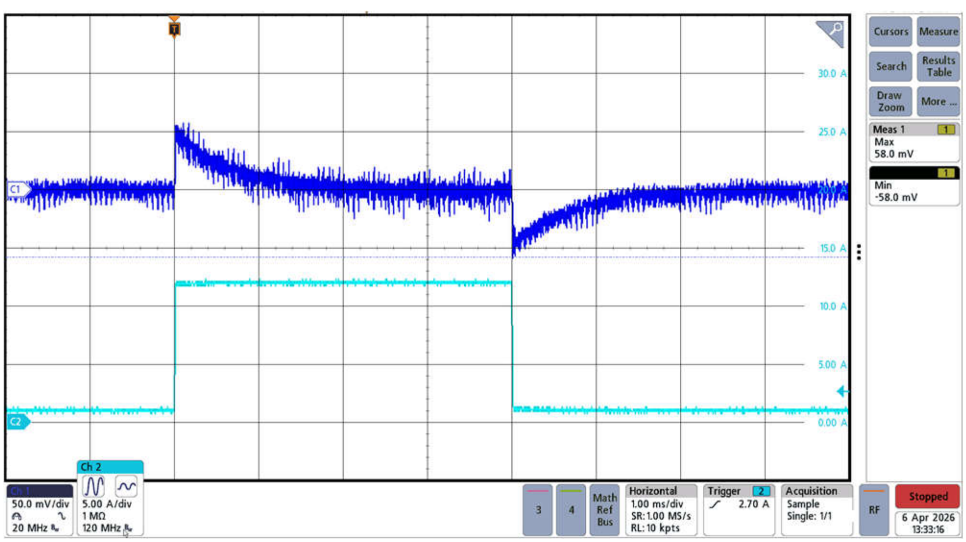


Figure 3-14. Load Transient Response is Shown for a 1A to 12A Step

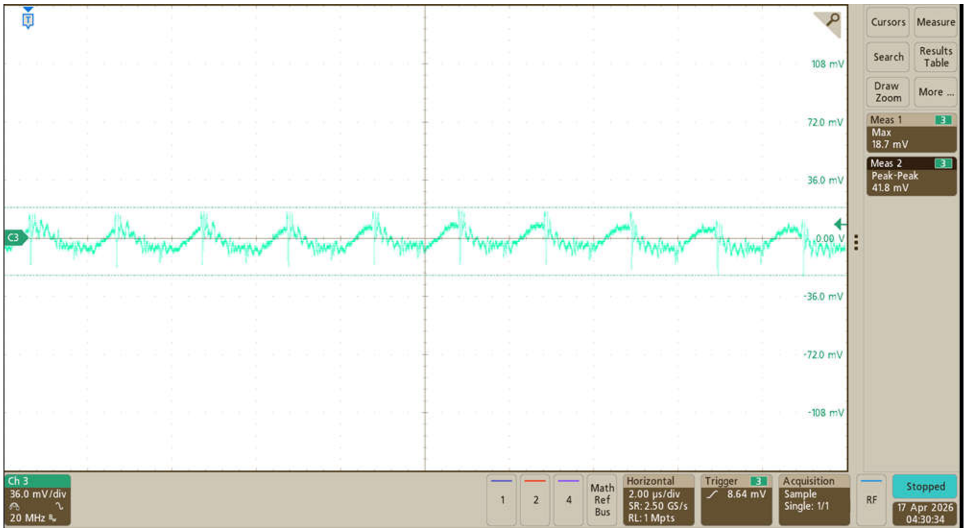


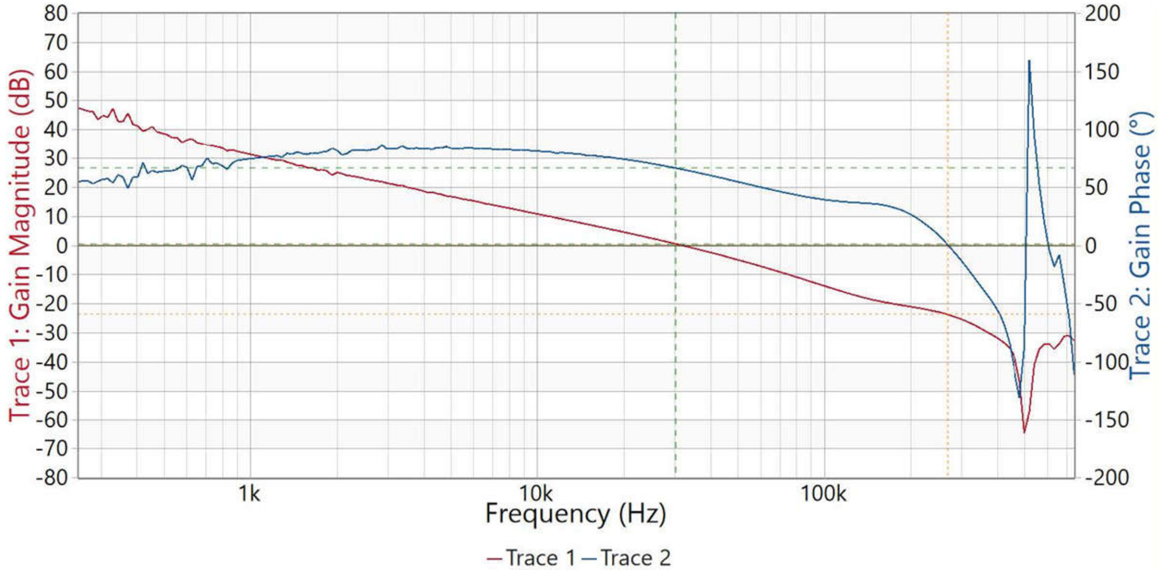
Figure 3-15. Output Voltage Ripple

12V input　　5V output at 12A

Figure 3-16. Top View of 12V to 5V buck regulator; 12V input, 5V output at 12A

3.4.3 3.3V Output Rail Test Results (TPS7H4013-SP)

The following results are for the 12V to 3.3V buck regulator.



12V input, 5V output	Bandwidth = 100Hz	Phase Margin = 66.3℃ at 30.4kHz	Gain Margin = –23.8dB at 269.7kHz

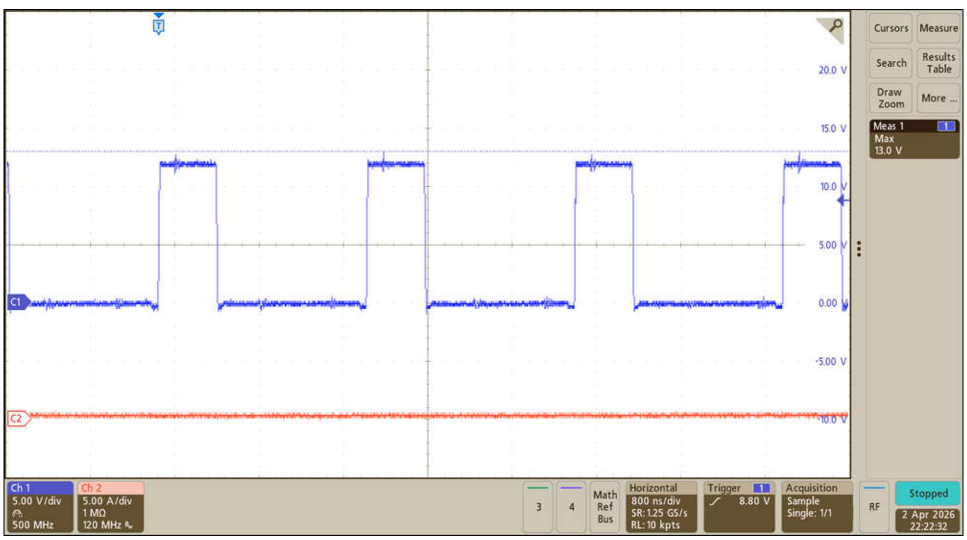


Figure 3-17. Switch Node, 12V input

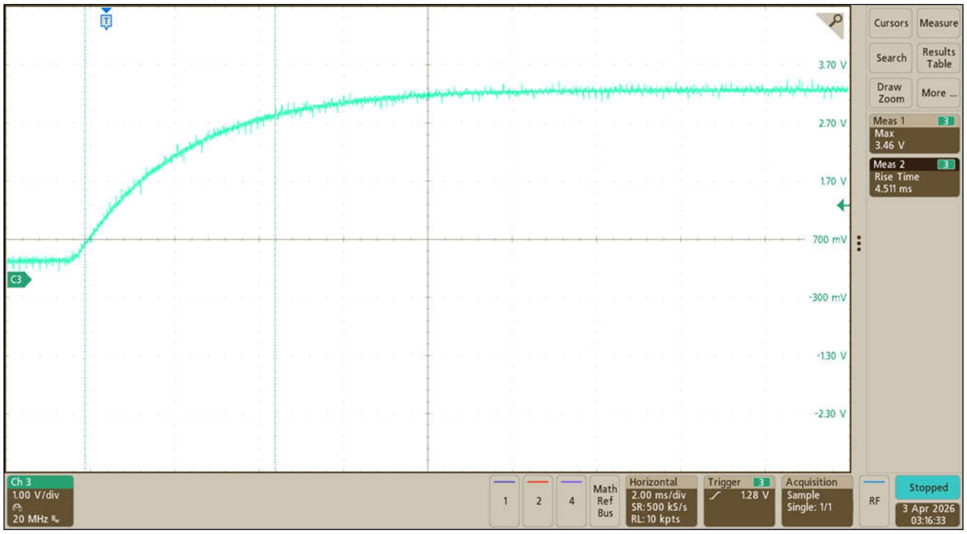


Figure 3-18. Start-up Timing

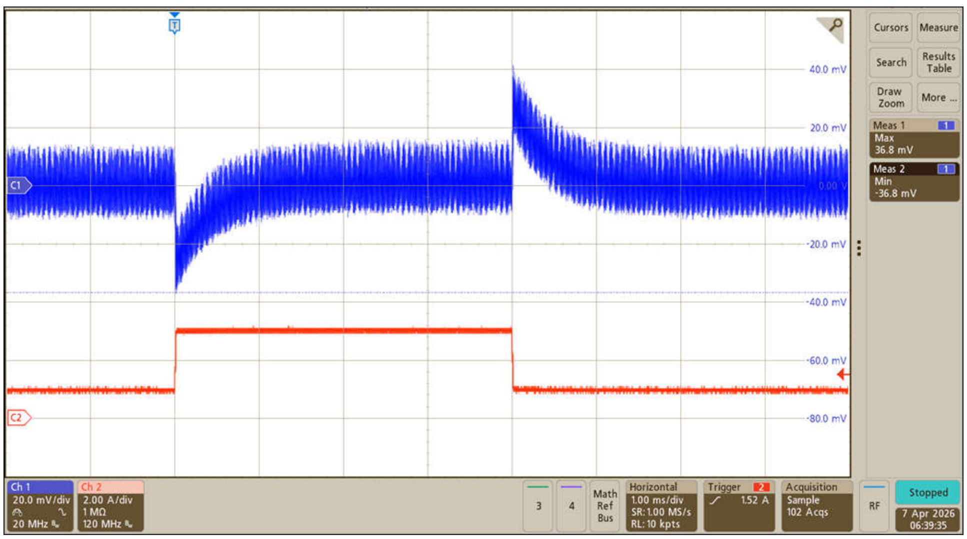


Figure 3-19. Load Transient Response is Shown for A 1A to 3A Step

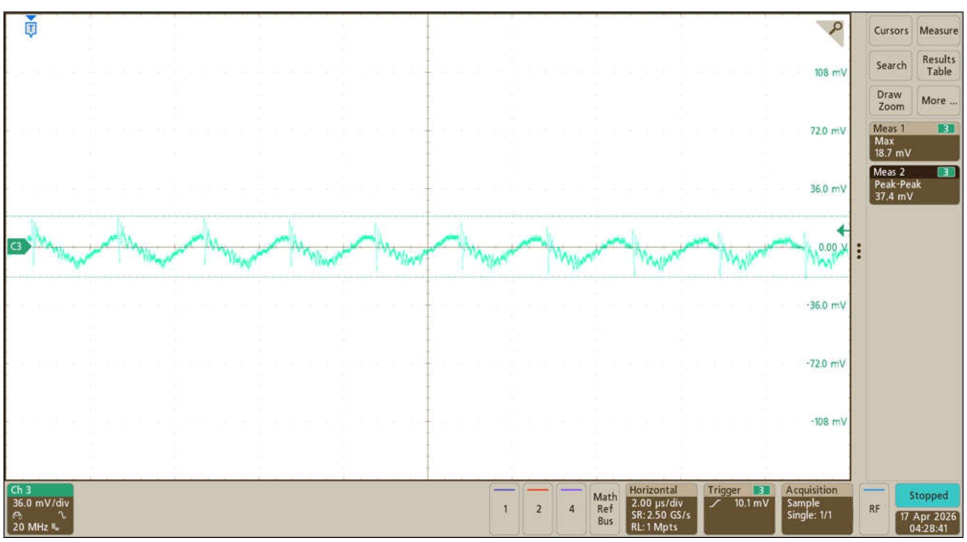


Figure 3-20. Output Voltage Ripple

12V input 3.3V output at 3A

Figure 3-21. Top View of 12V to 3.3V Buck Regulator

4 Design and Documentation Support

The following information contains supporting documentation and files that relate to TIDA-011004

4.1 Design Files

4.1.1 Schematics

To download the schematics, see the design files at TIDA-011004

4.1.2 4.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-011004.

4.2 Tools and Software

4.2.1 Tools

POWERSTAGE-DESIGNER Power Stage Designer™: software tool of most used switch-mode power supplies.

MSP430 Debugger: Debugger for firmware programming

TPS7H4011-CALC — TPS7H4011 component calculator

4.2.2 Software

CCSTUDIO IDE, configuration, compiler or debugger | TI.com

4.3 Documentation Support

1. Texas Instruments, *TPS7H500x-SEP Radiation-Tolerant 2MHz Current Mode PWM Controllers in Space Enhanced Plastic datasheet*
2. Texas Instruments, *TPS7H60x5-SP and TPS7H60x5-SEP Radiation-Hardness-Assured Half Bridge GaN FET Gate Drivers datasheet*
3. Texas Instruments, *TPS7H502x-SP/SEP and TPS7H503x-SP/SEP Radiation-Hardened Current Mode PWM Controllers With Integrated Gate Driver datasheet*
4. Texas Instruments, *TPS7H4011-SP and TPS7H4011-SEP 4.5V to 14V Input 12A Radiation Hardened Synchronous Buck Converter datasheet*
5. Texas Instruments, *TPS7H401x-SP and TPS7H401x-SEP 4.5V to 14V Input, 3A and 6A, Radiation Hardened Synchronous Buck Converter datasheet*
6. Texas Instruments, *TPS7H1121-SP and TPS7H1121-SEP 2.25V to 14V Input, 2A, Radiation Hardened Low Dropout (LDO) Linear Regulator datasheet*
7. Texas Instruments, *OPA4H199-SEP 40-V, Radiation Hardened, Rail-to-Rail Input/Output, Low Offset Voltage, Low Noise Op Amp in Space Enhanced Plastic datasheet*
8. Texas Instruments, *TMP9R01-SEP Radiation Tolerant, I2 C Digital Temperature Sensor with Remote and Local (On-Chip) Temperature Sensing datasheet*
9. Texas Instruments, *THVD9491-SEP Radiation Tolerant 3V to 5.5V RS-485 Transceiver with Flexible I/O Supply and IEC ESD Protection datasheet*
10. Texas Instruments, *MSP430FR5969-SP Radiation Hardened Mixed-Signal Microcontroller datasheet*
11. Texas Instruments, *TL1431-SP Class V, Precision Programmable Reference datasheet*

4.4 Support Resources

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

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5 About the Author

BHAVIKA KAGATHI is a systems engineer for Aerospace and Defense at Texas Instruments where she is responsible for developing reference designs for space applications. She earned her Bachelor of Science and Master of Engineering in Bioengineering from the University of Illinois Urbana-Champaign. Bhavika thanks John Dorosa for assistance on this design.