Application Note

Quick Reference Guide To TI Buck Switching DC/DC Application Notes

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ABSTRACT

This report aims to be a convenient guide to the many Texas Instruments application notes that discuss aspects of buck switching DC/DC converters, from topology basics to specific applications and designs. The application notes are categorized by topic and their content is briefly summarized to allow the reader to quickly find relevant information for any issue of interest. Each application note referenced in this document is identified by its title and unique TI literature number. A link to the each note's location on the www.ti.com website is provided, where the discussed document can be downloaded.

Table of Contents

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1 Introduction

This application report targets application designers and other users of TI products, looking for a handy overview of available technical information on TI buck switching DC/DC converters, from architecture fundamentals to concrete applications and designs. An extensive compilation of relevant TI application notes is presented below, together with a short summary of the discussed content. Each application note is arranged by topic and identified by its title and unique TI literature number. To access the documents online or download them for personal use, click on the document number tag (for example: SLVAXXX) which will direct you to the documents' location on www.ti.com. This application report is regularly maintained to ensure that the available information is up-to-date.

For assistance with DC/DC product selection, circuit design and simulation, refer to the DC/DC Switching Regulators Power Quick Search and the WEBENCH® Design Center tool available on www.ti.com.

For any question that those reports cannot answer, contact the TI E2E™ Community. (Note that this link requires a secure log-in.)

2 Summary Table

Fundamentals of Switchmode DC/DC Converters	
Understanding Buck Power Stages in Switchmode Power Supplies	SLVA057
Switching Regulator Fundamentals	SNVA559
Basic Calculation of a Buck Converter's Power Stage	SLVA477
Bang for your Buck – An Introduction to Buck Converter vs. Buck Power Module Comparison	SNVA988
Control-Mode Architecture	
Choosing the Right Variable-Frequency Buck-Regulator Control Strategy	SLUP319
Choosing the Right Fixed-Frequency Buck-Regulator Control Strategy	SLUP317
Internally Compensated Advanced Current Mode (ACM) Overview	SLYY118
High-efficiency, low-ripple DCS-Control™ offers seamless PWM/pwr-save transitions	SLYT531
Understanding frequency variation in the DCS-Control™ topology	SLYT646
Control-Mode Quick Reference Guide	SLYT710
Design, Layout and Manufacturing Support	
MSL Ratings and Reflow Profiles	SPRABY1
Long Term Storage Evaluation of Semiconductor Devices	SLPA019
Handling and Process Recommendations	SNOA550
QFN/SON PCB Attachment Application Report	SLUA271
Benefits and Trade-offs of Various Power-Module Package Options	SLYY120
HotRod™ QFN Package PCB Attachment	SLUA715
SMT Guidelines for Stacked Inductor (Inductor On Top) on Voltage Regulator IC	SLVA764
Five steps to a great PCB layout for a step-down converter	SLYT614
Design considerations for a resistive feedback divider in a DC/DC converter	SLYT469
Optimizing Resistor Dividers at a Comparator Input	SLVA450
Optimizing Transient Response of Internally Compensated DC-DC Converters with Feedforward Capacitor	SLVA289
Choosing an appropriate pull-up and pull-down resistor for Open Drain Outputs	SLVA485
Achieving a clean startup by using a DC/DC converter with a precise enable-pin threshold	SLYT730
Extending the Soft Start Time without a Soft Start Pin	SLVA307
Adjusting the soft-start time of an integrated power module	SLYT669
Sequencing and Tracking with the TPS621-Family and TPS821-Family	SLVA470
Understanding the Absolute Maximum Ratings of the SW Node	SLVA494
Minimizing Ringing at the Switch Node of a Boost Converter	SLVA255
I_Q: What it is, what it isn't, and how to use it	SLYT412
Understanding Eco-Mode™ Operation	SLVA388
Agency Requirements for Standby Power Consumption with Off-line and PoL Converters	SLYT665
The Forgotten Converter	SLPY005
Demystifying Input Supply Current in DC/DC Regulators: From Shutdown to Full Load	SLYY189
How the Switching Frequency Affects the Performance of a Buck Converter	SLVAED3
Methods to Solve Reverse Current-caused Damage in Synchronous Buck Converter	SLUA962
Understanding Flip Chip QFN (HotRod™) and Standard QFN Performance Differences	SLVAEE1
Understanding Power Module Operating Limits	SLUAAC9
The Stability of a D-CAP2™ Converter with Different Kinds of Capacitors	SLVAE93
Benefits Using a Buck Converter's External Vcc Bias Pin	SNVAA16
Multi-Function Pins for Easy Designing	SLVAF56
Stability Analysis and Design of D-CAP2 and D-CAP3 Converter – Part 1: How to Select Output Capacitor	SLVAF11
Stability Analysis and Design of D-CAP2 and D-CAP3 Converter – Part 2: How to Select Feedforward Capacitor	SLVAF45
Designing with small DC/DC converters: HotRod™ QFN vs. Enhanced HotRod™ QFN Packaging	SLYT816
Manufacturing and Rework Design Guide for MicroSiP™ Power Modules	SLIB006

Methods of output-voltage adjustment for DC/DC converters	SLYT777
Understanding OOA™ Operation	SLUA946
Intro to Multi-function Pins and their Applications in TI Step-down Converters	SLVAF64
Layout Guidelines for Switching Power Supplies	SNVA021
Reduced Size, Double-Sided Layout for High-Current DC/DC Converters	SLVA963
Reducing Ringing Through PCB Layout Techniques	SLPA005
Constructing Your Power Supply – Layout Considerations	SLUP230
Space Optimized, “Clam Shell” Layout for Step-Down DC/DC Converters	SLVA818
Breakthrough Power Delivery for Space-Constrained Applications	SSZY023
Thermal Considerations	
Semiconductor and IC Package Thermal Metrics	SPRA953
Techniques for Thermal Analysis of Switching Power Supply Designs	SNVA207
An Accurate Thermal-Evaluation Method for the TLV62065	SLVA658
Improving the thermal performance of a MicroSiP™ power module	SLYT724
TPS62366x thermal and device lifetime information	SLVA525
PCB Thermal Design Tips for Automotive DC/DC Converters	SNVA951
PowerPAD™ Thermally Enhanced Package	SLMA002
Practical Thermal Design With DC/DC Power Modules	SNVA848
Achieving High Thermal Performance in Compact Buck Power Modules	SLVAEI9
Thermal Performance Optimization of High Power Density Buck Converters	SLUAAD6
Thermal Design by Insight, not Hindsight	SNVA419
How to Evaluate Junction Temperature Properly with Thermal Metrics	SLUA844
Understanding the thermal-resistance specification of DC/DC converters with integrated power MOSFETs	SLYT739
Method of Graphing Safe Operating Area (SOA) Curves for DC-DC Converters	SLVA766
A Guide to Board Layout for Best Thermal Resistance for Exposed Packages	SNVA183
Thermal Comparison of a DC-DC Converter in SOT23 and the New SOT563	SLVAEB1
Understanding power module SOA curves to operate at high output currents and high temperatures	SLUAAJ1
Low Noise / Controlling EMI	
Not All Jitter is Created Equal	SLUA747
Controlling the Switch-node Ringing of Synchronous Buck Converters	SLYT465
Simplify Low-EMI Design with Power Modules	SLYY123
Snubber Circuits: Theory, Design and Application	SLUP100
Minimizing Output Ripple During Startup	SLVA866
Measuring Various Types of Low-frequency Noise from DC/DC Switching Converters	SLYY134
Using a 4MHz switching regulator w/o a Linear Regulator to Power a Data Converter	SLYT756
Extend Battery Life with < 100 nA IQ Buck Converter Achieving < 150 µV Voltage Ripple (with PI filter design)	SLVAEG1
Analysis and Design of Input Filters for DC-DC Circuits	SNVA801
Calculating Output Capacitance to Meet Transient and Ripple Requirements of an Integrated POL Converter Design Based on D-CAPx™ Modulators	SLVA874
Controlling Output Ripple and Achieving ESR Independence with Constant On-Time Regulators	SNVA166
EMI/RFI Board Design	SNLA016
Simple success with Conducted EMI from DC/DC Converters	SNVA489
Layout tips for EMI Reduction in DC/DC Converters	SNVA638
Output Noise Filtering for DC/DC Power Modules	SNVA871
Designing High-Performance, Low-EMI Automotive Power Supplies	SNVA780
Enhanced HotRod QFN Package: Achieving Low EMI Performance	SNVA935
Improve High-Current DC/DC Regulator EMI Performance for Free With Optimized Power Stage Layout	SNVA803
Device-Specific Technical Discussions	
Optimizing the TPS62130, TPS62140, TPS62150 and TPS62160 Output Filter	SLVA463

Optimizing the TPS62175 Output Filter	SLVA543
Optimizing the TPS62090 Output Filter	SLVA519
Feedforward Capacitor to Improve Stability and Bandwidth of TPS621 and TPS821-Family	SLVA466
Optimizing TPS6206x External Component Selection	SLVA441
TPS62130A Differences to TPS62130	SLVA644
TPS6208x and TLV6208x Device Comparison	SLVA803
Output Voltage Selection for the TPS62400 Family of Buck Converters	SLVA254
Designing an Isolated Buck (Flybuck) Converter using the LMR36520	SNVA790
Configuring LM62460 for Dual-Phase Operation	SNVAA21
How to Migrate Between LM614xx and LM624xx Product Families	SNVAA31
Powering Sensitive ADC Designs with the TPS62913 Low-Ripple and Low-Noise Buck Converter	SLVAEW7
Achieving Better than 1% Output Voltage Accuracy with TPS546D24A	SLUAA02
Enhance Stability of TPSM41625 Buck Module Designs with Minimized Ceramic Output Capacitors	SLVAEZ2
Powering the AFE7920 with the TPS62913 Low-Ripple and Low-Noise Buck Converter	SLVAF16
Comparison of TPS6290x vs. TPS621x0	SLVAF55
How Output Capacitor Reduction Affects Load Transient in TPS563231 with D-CAP3 Control	SLUA986
Minimize On-Time-Jitter and Ripple by Optimizing Compensation	SLUAA65
Demystifying and Mitigating Power Supply Ripple and Noise Implication on AFE8092	SLVAF52
Expand Buck Converter Minimum Input Voltage with External VCC Bias	SLVAE69
Large Duty Cycle Operation with the TPS568230	SBVA083
How to Understand LC Table and Select LC About TPS563202	SLUAAD3
Powering the TPS546D24A Device Family from a Single 3.3-V Input Power Supply	SLUAA03
How to Best Use TPS62903 for a Given Application Requirement	SLVAF76
Large Duty Cycle Operation On the TPS563211	SLUAAE4
Achieving Longer Hold-Up Time Using the TPS62130 in Enterprise SSD Applications	SLVAF70
TPSM8A29 Fast Load Transient with DCAP-3	SLVAFB5
Reducing Output Ripple and Noise with the TPS84259 Module	SLYT740
Calculation, Simulation and Measurement Techniques	
Calculating Efficiency	SLVA390
MOSFET Power Losses and How They Affect Power-Supply Efficiency	SLYT664
Output Ripple Voltage for Buck Switching Regulator	SLVA630
Accurately measuring efficiency of ultralow-IQ devices	SLYT558
Performing Accurate PFM Mode Efficiency Measurements	SLVA236
How to Measure the Loop Transfer Function of Power Supplies	SNVA364
Simplifying Stability Checks	SLVA381
How to Measure the Control Loop of DCS-Control™ Devices	SLVA465
Loop Gain Reconstruction of a Step-Down Converter from Output Impedance Measurement	SLUAAI0
How to Measure Impedance of a Power Distribution Network of a DC-DC Converter	SLUAAI3
HS Load/Line Transient Jigs and App Rpt for Testing POL Regulators	SNOA895
Measuring the Bode Plot of D-CAP™, D-CAP2™, and D-CAP3™ DC/DC Converters	SLUAAF4
DC/DC Converter Applications	
Step-Down LED Driver with Dimming, the TPS621-Family and TPS821-Family	SLVA451
Testing tips for applying external power to supply outputs without an input voltage	SLYT689
Efficient Super-Capacitor Charging with TPS62740	SLVA678
Low-Noise CMOS Camera Supply	SLVA672
Step-Down Converter with Input Overvoltage Protection	SLVA664
Step-Down Converter with Cable Voltage Drop Compensation	SLVA657
Using the TPS62150 in a Split Rail Topology	SLVA616
Using the TPS6215x in an Inverting Buck-Boost Topology	SLVA469

Using the TPS62175 in an Inverting Buck Boost Topology	SLVA542
Powering the MSP430 from a High Voltage Input using the TPS62122	SLVA335
Voltage Margining using the TPS62130	SLVA489
Working With Inverting Buck-Boost Converters	SNVA856
DC/DC Converter Solutions for Hardware Accelerators in Data Center Applications	SLVAEG2
Point-of-Load Solutions for Data Center Applications Implementing VR13.HC VCCIN Specification	SLVAE92
Non-Isolated Point-of-Load Solutions for Elkhart Lake in Industrial PC Applications	SLVAET0
Non-Isolated DC/DC Solutions for Alder Lake in Notebook Computing Applications	SLUAAA6
Non-Isolated Point-of-Load Solutions for Tiger Lake in PC Applications	SLUAA54
Point-of-Load Solutions in Data Center Applications for Intel® Xeon® Sapphire Rapids Scalable Processors	SLVAF22
Point-of-Load Solutions for Network Interface Cards (NIC)	SNVAA29
Synchronizing DC/DC Converters in a Power Tree	SLVAEG8
Benefiting from Step-Down Converters with an I2C Communication Interface	SLUAAE9
Dynamically Adjustable Output Using the TPS63000	SLVA251
Designing a Negative Boost Converter from a Standard Positive Buck Converter	SLYT516
Create a Split-Rail Power Supply with a Wide Input Voltage Buck Regulator	SLVA369
Designing an Isolated Buck (Fly-Buck™) Converter	SNVA674
Power-Supply Sequencing for FPGAs	SLYT598
Power Supply Design Considerations for Modern FPGAs (Power Designer 121)	SNOA864
Remote Sensing for Power Supplies	SLYT467
Effect of Resistor Tolerances on Power Supply Accuracy	SLVA423

3 Fundamentals of Switchmode DC/DC Converters

In this section, several application notes discussing the principles of switching regulators and their architecture are presented.

Understanding Buck Power Stages In Switchmode Power Supplies: SLVA057

This application report addresses the fundamentals of buck power stage but does not cover control circuits. Detailed steady-state and small-signal analysis of the buck power stage operating in continuous and discontinuous mode are presented. Variations in the standard buck power stage and a discussion of power stage component requirements are included.

Switching Regulator Fundamentals: SNVA559

This paper details the operating principles of commonly used switching converter types, which is the buck converter topology. It provides circuit examples that illustrate some of the applications of buck regulators.

Basic Calculation of a Buck Converter's Power Stage: SLVA477

This application report discusses the basic configuration of a buck converter and gives the formulas to calculate the power stage of a buck converter built with an integrated circuit having an integrated switch and operating in continuous conduction mode.

Bang for Your Buck – An Introduction to Buck Converter vs. Buck Power Module Comparison: SNVA988

This application report provides a high-level comparison between Texas Instruments' switching buck converter and buck power module. The value proposition of each device is highlighted along with a side-by-side comparison of each device's electrical performance, PCB solution size, and design considerations.

4 Control – Mode Architecture

This section provides insight into the different control mode architectures and how to select the right one.

Choosing the Right Variable-Frequency Buck-Regulator Control Strategy: SLUP319

This paper shifts focus to variable frequency control with a discussion of constant on-time control and its enhancements, along with various versions of the D-CAP architecture. The highlights and challenges for each technique are discussed.

Choosing the Right Fixed-Frequency Buck-Regulator Control Strategy: SLUP317

In this paper, the operation and basic design considerations of a buck converter are reviewed. The topic then examines the trade-offs between two fixed-frequency control strategies and some enhancements to extend their capabilities. Basic voltage mode control is adapted with input voltage feed-forward and current mode control is enhanced with emulated current mode control. The highlights and challenges for each technique are discussed and select design examples are presented.

Internally Compensated Advanced Current Mode (ACM) Overview: SLYY118

New low-noise DC/DC control mode benefits enterprise rack server and hardware accelerator applications that need fast transient response as well as active antenna systems (AAS) requiring fixed-frequency modulation and synchronization.

High-efficiency, Low-ripple DCS-Control™ Offers Seamless PWM/power-save Transitions: SLYT531

This article discusses how the DCS-Control™ topology works, demonstrating its low output-voltage ripple in power-save mode, its superb transient response, and its seamless mode transitions.

Understanding Frequency Variation in the DCS-Control™ Topology: SLYT646

This document explains the principles behind the DCS-control™ topology switching frequency variation. It shows that while the switching frequency does vary, this variation is understood, controlled, and usually sufficient for automotive and other frequency-sensitive applications.

Control-Mode Quick Reference Guide: SLYT710

TI is active in the development of leading-edge control circuits to help engineers address specific design challenges. Since no control mode is optimal for every application, various control modes for non-isolated step-down controllers and converters are referenced with their advantages and how to learn more about each mode. The TI portfolio contains 12 types of control architectures for non-isolated TPS- and LM-series switching DC/DC converters and controllers.

5 Design, Layout, and Manufacturing Support

This section summarizes notes to support the reader to make sensible design choices, selecting the appropriate components and passives, optimizing the PCB layout, ensuring manufacturability and fine-tuning the solution to meet the application's requirements.

MSL Ratings and Reflow Profiles: SPRABY1

This application reports explains the relationship of MSL rating to the customer production floor life and surface mount reflow temperatures for TI semiconductors.

Long Term Storage Evaluation of Semiconductor Devices: SLPA019

This paper details the ongoing results of studying the quality, reliability, and usability of semiconductor products after long-term storage in a controlled environment. To better understand long-term storage viability, additional data was collected to further comprehend the time that products can be stored before the reliability can be compromised.

Handling and Process Recommendations: SNOA550

This application report provides recommendations for handling, storing, and mounting Texas Instruments' surface mount IC packages. Please reference published IPC-J-STD-004, IPC-JEDEC J-STD-020, and IPC-JEDEC J-STD-033 documents for their latest versions.

QFN/SON PCB Attachment Application Report: SLUA271

Quad flat-pack no-leads (QFNs) and small-outline no leads (SONs) are leadless packages with electrical connections made via lands on the bottom side of the component to the surface of the connecting substrate (PCB, ceramic). This application report presents users with introductory information about attaching QFN/SON devices to printed circuit boards (PCBs).

Benefits and Trade-offs of Various Power-Module Package Options: SLYY120

This white paper discusses a few package options – embedded, leaded and quad flat no-lead (QFN) – and the benefits and trade-offs of each in terms of module size, component integration, thermal performance and electromagnetic interference (EMI) considerations.

HotRod™ QFN Package PCB Attachment: SLUA715

This application report presents users with information about attaching HotRod QFN devices to the printed circuit boards.

SMT Guidelines for Stacked Inductor (Inductor On Top) on Voltage Regulator IC: SLVA764

The following guideline is a step-by-step guide on assembling TI voltage regulator ICs and inductors on top of the IC in a high-volume manufacturing environment where SMT processes are used.

Five Steps to a Great PCB Layout for a Step-Down Converter: SLYT614

This article details a five-step procedure to design a good PCB layout for any TPS62xxx integrated-switch, step-down converter.

Design Considerations for a Resistive Feedback Divider in a DC/DC Converter: SLYT469

This article discusses the design considerations for the resistive divider in a feedback system and how the divider affects a converter's efficiency, output voltage accuracy, noise sensitivity, and stability.

Optimizing Resistor Dividers at a Comparator Input: SLVA450

This application report discusses several key factors involved with selecting optimally-sized resistors commonly used at the input to a comparator to set a threshold voltage on switching regulator devices, considering efficiency and voltage accuracy constraints.

Optimizing Transient Response of Internally Compensated DC-DC Converters with Feedforward Capacitor: SLVA289

This application report describes how to choose the feedforward capacitor value (Cff) of internally compensated dc-dc power supplies to achieve optimum transient response. The described procedure in this application report provides guidance in optimizing transient response by increasing converter bandwidth while retaining acceptable phase margin. This document is intended for all power-supply designers who want to Optimize the Transient Response of a working, Internally Compensated DC-DC Converter.

Choosing an Appropriate Pull-up and Pull-down Resistor for Open Drain Outputs: SLVA485

This application report discusses when to use a pull-up or pull-down resistor at open drain outputs commonly found on ICs, for example Power Good (PG), the factors that should be considered when selecting a pull-up or pull-down resistor, and how to calculate a valid range for the value of the resistor.

Achieving a Clean Startup by Using a DC/DC Converter With a Precise Enable-pin Threshold: SLYT730

Most DC/DC Converters contain an enable (EN) pin input that is used to control the startup behavior. This article explains some common EN-pin threshold specifications found in device data sheets and describes several application circuits that provide a clean startup, with or without using a converter with a precise EN-pin threshold.

Extending the Soft Start Time Without a Soft Start Pin: SLVA307

In battery-powered equipment, extending the soft-start time can be crucial to a glitch-free start-up. Especially toward the end of a battery's life, the voltage drop and increasing impedance of the battery from excessive inrush current into the power supply can be a problem. This application report demonstrates a simple circuit that extends the soft start time and reduces the inrush current, taking the examples of the TPS6107x family of boost converters.

Adjusting the Soft-start Time of an Integrated Power Module: SLYT669

This paper demonstrates three simple and low-cost solutions to adjust the soft-start time of an integrated power module and provide clean, acceptable start-up in applications with special soft-start requirements, particularly in FPGAs, which have lots of output capacitance or may draw large currents during the soft-start time.

Sequencing and Tracking With the TPS621-Family and TPS821-Family: SLVA470

This application note describes how to use the EN, PG, and SS/TR pins in tracking and sequencing applications.

Understanding the Absolute Maximum Ratings of the SW Node: SLVA494

This application note explains the operation of a synchronous buck converter, demonstrates why the SW node negative rating might be exceeded during switching operation, gives guidance for properly measuring the SW node voltage, and provides good layout practices for synchronous buck converters.

Minimizing Ringing at the Switch Node of a Boost Converter: SLVA255

This application report explains how to use proper board layout and/or a snubber to reduce high-frequency ringing at the switch node of any switching converter, using a boost converter as an example.

I_Q: What It Is, What It Isn't, and How to Use It: SLYT412

This article defines I_Q and how it is measured, explains what I_Q is not and how it should not be used, and gives design considerations on how to use I_Q while avoiding common measurement errors.

Understanding Eco-Mode™ Operation: SLVA388

To maximize efficiency, the output power must be maximized or the power dissipation must be minimized. When the load current is low, the output power will also be low, so the only way to increase efficiency at light loads is to reduce power dissipation in the converter. The losses in a dc/dc converter can generally be divided into three categories; conduction loss, switching loss and quiescent loss.

Agency Requirements for Standy Power Consumption with Off-line and PoL Converters: SLYT665

This article highlights new techniques used by new flyback and secondary-side controllers, and compares two complete POL architectures with and without the lightload efficiency feature. Also covered is the energy-saving advantage gained when selecting a POL solution with light-load efficiency features.

The Forgotten Converter (Charge Pumps): SLPY005

This white paper discusses the pros and cons of charge-pump converter topologies, provides industrial and personal electronics application examples, and covers component-selection guidelines.

Demystifying Input Supply Current in DC/DC Regulators: From Shutdown to Full Load: SLYY189

Quiescent current can be one of the most confusing specifications of a DC/DC converter, especially if you are not familiar with the detailed operation of a switching regulator. Because manufacturers use different terminology and definitions, you will often see *quiescent current*, *IQ* or *input supply current* used interchangeably. This paper explains the differences and clears up any confusion.

How the Switching Frequency Affects the Performance of a Buck Converter: SLVAD3

The buck converter uses an inherent switching action to regulate voltage. This switching frequency can affect the performance of a buck converter, and is thus very important. This application report analyzes the influence of switching frequency on buck converter performance in terms of efficiency, thermals, ripple, and transient response.

Methods to Solve Reverse Current-caused Damage in Synchronous Buck Converter: SLUA962

Reverse current is a common phenomenon that occurs in synchronous buck converters. If the reverse current is large enough, the low-side field-effect transistor (FET) is very likely to be damaged. Since this issue is relatively common in synchronous buck converters, it is worth investigating the mechanisms that lead to reverse current and the subsequent damage that it causes. At the same time, it is important to understand potential solutions to eliminate this condition altogether. In this application note, four such solutions are presented and evaluated.

Understanding Flip Chip QFN (HotRod™) and Standard QFN Performance Differences: SLAEE1

Many recently released DC/DC converters use Flip Chip Quad Flat No-lead (QFN) or HotRod™ (HR) QFN package technology to maximize their performance. However, HR QFN package technology typically lacks the large thermal pad present on the bottom of standard QFN packages. A common question for end equipment where thermal performance is a key concern due to high ambient temperatures is whether the HR QFN package can meet the thermal requirements. This application report compares the performance of the HR QFN and standard QFN packages using measurements taken with the TPS54824 and TPS54A24.

Understanding Power Module Operating Limits: SLUAAC9

This application report will discuss the driving factors behind a module's operating limits, to help engineers select and configure power modules most effectively in their designs. The TPSM5D1806 dual 6-A output buck power module is used as an example for the discussions in this application report.

The Stability of a D-CAP2™ Converter with Different Kinds of Capacitors: SLVAE93

This application report discusses the stability of D-CAP2 converters with different kinds of capacitors, especially electrolytic and polymer capacitors.

Benefits Using a Buck Converter's External Vcc Bias Pin: SNVAA16

his report compares the power losses of 16-V, 15-A TPS548A28 and TPS548A29 synchronous step-down converters when using internal and external bias voltages in a multi-rail point-of-load system. Both devices have the same integrated power stage but have a different internal LDO voltage.

Understanding OOA™ Operation: SLUA946

This application note presents a detailed introduction to this feature based on the TPS566235, including the audio noise generation mechanism, OOA operation behavior, and the performance characteristics.

Multi-Function Pins for Easy Designing: SLVAF56

A multi-function pinout is when two or more features are integrated into one pin. A table found in the device's data sheet is used to decipher what features are available with guidance of how to select the desired combination.

Stability Analysis and Design of D-CAP2 and D-CAP3 Converter – Part 1: How to Select Output Capacitor: SLVAF11

D-CAP series control schemes are widely used in TI buck controllers/converters due to the advantages of good dynamic performance and less external components. In D-CAP2 and D-CAP3 schemes, the limitation on the use of small ESR capacitor is broken through with the internal ripple injection circuit.

Stability Analysis and Design of D-CAP2 and D-CAP3 Converter – Part 2: How to Select Feedforward Capacitor: SLVAF45

In the previous application report SLVAF11 , the method to select output capacitor for D-CAP2/D-CAP3 converters without feedforward capacitor (Cff) is introduced. On the basis, the method to select Cff is further studied in this application report. First, the necessity to add a Cff for stability in D-CAP2/D-CAP3 converters with high output voltage is analyzed. Then the impacts of Cff on the converter loop are introduced. Combining the Cff impacts and D-CAP2/D-CAP3 loop characteristics, a method to select Cff for stability is proposed by ensuring -20dB/decade slope at converter loop gain crossover frequency.

Designing with small DC/DC converters: HotRod™ QFN vs. Enhanced HotRod™ QFN Packaging: SLYT816

In this article, we will take a look at two point-of-load DC/DC converters, providing up to 20 A with the same die, to directly compare a traditional flip-chip HotRod™ package and the new flip-chip Enhanced HotRod™ QFN package, demonstrating thermal, switch-node ringing, transient, efficiency and layout differences to help you decide if the Enhanced HotRod QFN package is more advantageous for your application, and if it can help improve power-supply density and performance enough to overcome any potential skepticism around adopting new technology.

Manufacturing and Rework Design Guide for MicroSiP™ Power Modules: SLIB006

With this technology, TI reaches the smallest solution size and highest levels of integration. This enables an easy-to-use power module for achieving the shortest time-to-market. As with any device package, attention must be given to the printed circuit board (PCB) layout, surface mount (SMT) assembly flow, and rework process. This white paper provides guidelines on each of these aspects, and these guidelines are achievable through normal manufacturing and rework flows.

Methods of output-voltage adjustment for DC/DC converters: SLYT777

Some systems benefit by adjusting the output voltage of one or more DC/DC converters while the converters are enabled and the system is operating. Solid-state drives, smartphones and optical modules adjust the core voltage (usually through I2C communication) to the main processor to fine-tune performance and power consumption. Other, simpler systems such as USB Type-C™ ports and lower-power microcontrollers (MCUs) use a single digital signal to adjust between two output voltages in order to adapt to power delivery demands or reduce power consumption in standby or sleep mode.

Intro to Multi-function Pins and their Applications in TI Step-down Converters: SLVAF64

This application report explains the Multi-function pin present in some of TI step-down converters (VSET/VID for TPS62864/6/8/9, VSET/MODE for TPS62865/7 and VSEL/MODE for TPS62800/1/2/6/7/8).

Layout Guidelines for Switching Power Supplies: SNVA021

Some of the main problems are loss of regulation at high output current and/or large input to output voltage differentials, excessive noise on the output and switch waveforms, and instability. Using the simple guidelines that follow will help minimize these problems.

Reduced Size, Double-Sided Layout for High-Current DC/DC Converters: SLVA963

The use of a double-sided topology for a space optimized, Clam Shell layout for step-down DC/DC converters has previously been evaluated.(1) The results showed that this technique was successful for small, SOT23 regulators delivering up to 2.5-A output current. Using both sides of the PCB gives a space efficient solution with no disadvantage in electrical or thermal performance.

Reducing Ringing Through PCB Layout Techniques: SLPA005

Designers must consider several topics when designing a printed-circuit board (PCB) layout for a dc-to-dc converter. In particular, the layout of the Power Stage components within a nonisolated synchronous buck converter requires special attention in order to optimize the overall performance of the switching function.

Constructing Your Power Supply – Layout Considerations: SLUP230

This topic addresses methods to keep circuit parasitic components from degrading the operation of your designs. Techniques to minimize the impact of parasitic inductance and capacitance of filter components and printed wire board (PWB) traces is discussed, together with a description of the impact that PWB trace resistance can have on power supply regulation and current capacity.

Space Optimized, “Clam Shell” Layout for Step-Down DC/DC Converters: SLVA818

The demand for smaller electronic products packed with more features means that the most space efficient layout is also desired. DC/DC converter ICs are available in tiny packages and it is generally the inductor which is the largest component. This paper examines the use of both sides of the PCB to achieve the most space efficient DC/DC converter layout while maintaining optimal performance.

Breakthrough Power Delivery for Space-Constrained Applications: SSZY023

For most end users, this does not mean much because they pay little attention to power supplies, even though power supplies typically consume up to half of the board space of an electronic system. Shrinking it to a fifth of its former size would mean that equipment could suddenly be much smaller and lighter-weight. Or the equipment could stay the same size and suddenly have much more space to include new high-performance functions. This is a game-changer for innovation in electronics.

6 Thermal Considerations

This section concentrates on giving a basic understanding of package thermal metrics and their real world application, along with specific package or device discussions.

Semiconductor and IC Package Thermal Metrics: SPRA953

Many thermal metrics exist for semiconductor and integrated circuit packages. Often, these thermal metrics are misapplied by those who try to use them to estimate junction temperatures in their systems. This very helpful document describes traditional and new thermal metrics and puts their application in perspective with respect to system-level junction temperature estimation.

Techniques for Thermal Analysis of Switching Power Supply Designs: SNVA207

This application note provides thermal power analysis techniques for analyzing the power IC. It includes analytical, simulation and hands-on approaches to estimating the IC temperature in a design.

An Accurate Thermal-Evaluation Method for the TLV62065: SLVA658

This application report is a basic overview of thermal evaluation and provides an accurate evaluation method of junction temperature in a real application. This method is proven to be easy to use and have good accuracy through measurements on the TLV62065.

Improving the Thermal Performance of a MicroSiP™ Power Module: SLYT724

Power module data sheets usually state their thermal-performance properties, but they are frequently based on a Joint Electron Devices Engineering Council (JEDEC) standard PCB, which generally does not match what is possible in the actual application. This article explains JEDEC's PCB design and compares it to various real-world PCB designs that demonstrate the impact of PCB design on the thermal performance of a MicroSiP™ power module.

TPS62366x Thermal and Device Lifetime Information: SLVA525

In this note, we investigate and quantify the potential reliability impact of temperature-dependent electromigration on wafer-level chip-scale (WCSP) packages, taking TI's TPS62366x (4-A peak output current) DC/DC Converter family as an example.

PCB Thermal Design Tips for Automotive DC/DC Converters: SNVA951

Thermal management is one of the most important aspects of designing power supplies. This is especially true in the automotive environment where converters must operate in high ambient temperatures and enclosed spaces. This paper provides guidance to the designer that will make the task of thermal management proceed more smoothly.

PowerPAD™ Thermally Enhanced Package: SLMA002

This document focuses on the specifics of integrating a PowerPAD™ package into the PCB design.

Practical Thermal Design With DC/DC Power Modules: SNVA848

This application note outlines a design procedure to quickly estimate the minimum required copper area on the PCB for a successful thermal design with DC/DC power modules.

Achieving High Thermal Performance in Compact Buck Power Modules: SLVAEI9

Modern communications equipment, personal electronics, and test and measurement equipment require highly-efficient, ultra-compact, and low-profile power solutions. Power modules with integrated passives provide customers with a smaller total solution size and ease the effort of power supply design.

Thermal Performance Optimization of High Power Density Buck Converters: SLUAAD6

This application report provides an insight into the thermal performance optimization of high-power density buck converters. The report shares several design implementations of the TPS62866, a high frequency synchronous step-down converter in a wafer chip-scale package (WCSP).

Thermal Design by Insight, not Hindsight: SNVA419

The listed reference material is home to additional data and many useful thermal calculators, covering material that is beyond the scope of this document. Our discussion of thermal design will begin with the definition of parameters used in data sheets such as θ_{JA} and θ_{JC}, and end with some rules of thumb for the thermal design of a DC-DC converter, including their derivation.

How to Evaluate Junction Temperature Properly with Thermal Metrics: SLUA844

The high junction temperature not only derate the device electrical characteristics, but increases the metal migration and other degeneration changes which cause accelerated aging and higher failure rate. According to the electronic design rules, every 10°C rise in temperature reduces the average life by 50%, so it is important to properly evaluate the thermal stress or junction temperature of the semiconductor devices.

Understanding the thermal-resistance specification of DC/DC converters with integrated power MOSFETs: SLYT739

This article presents assumptions that analog designers may make for thermal analysis. The analysis for each assumption is followed with insights to decipher the actual thermal information in the data sheet.

Method of Graphing Safe Operating Area (SOA) Curves for DC-DC Converters: SLVA766

This document describes how to graph the SOA curves with airflow in the DC-DC power supply converter. To reduce the overall cost of a system, the converter solution reduces the printed-circuit-board (PCB) area while maintaining the highest efficiency possible.

A Guide to Board Layout for Best Thermal Resistance for Exposed Packages: SNVA183

This thermal application report provides guidelines for the optimal board layout to achieve the best thermal resistance for exposed packages. The thermal resistance between junction-to-ambient (θ_{JA}) is highly dependent on the PCB (Printed Circuit Board) design factors.

Thermal Comparison of a DC-DC Converter in SOT23 and the New SOT563: SLVAEB1

This application note compares the thermal performance of flip-chip on lead (FCOL) SOT563 package with the conventional wire-bond SOT23 packages and FCOL SOT23 package. The document summarizes the packages thermal results and explains the advantages and disadvantages for electronic board design.

Understanding power module SOA curves to operate at high output currents and high temperatures: SLUAAJ1

This paper discusses the main thermal metrics $R_{\theta JA}$, Ψ_{JB}, and Ψ_{JT} and introduces SOA curves to understand the thermal performance and output current capability of power modules, in order to operate them within their recommended temperature limits.

7 Low Noise and Controlling EMI

In switching power supplies, electromagnetic interference (EMI) noise is unavoidable due to the switching actions of the semiconductor devices and resulting discontinuous currents. EMI control is one of the more difficult challenges in switching power supplies design. This section defines and discusses electromagnetic interference and describes ways to mitigate its effects.

Not All Jitter is Created Equal: SLUA747

This application report offers a tutorial discussion on jitter in switching DC-DC converters. Not all power supply designs are equally susceptible to jitter, nor are they equally affected by jitter. Modes of switching jitter are defined and explained for several popular control architectures, which are then analyzed for sources of jitter.

Controlling the Switch-node Ringing of Synchronous Buck Converters: SLYT465

This article focuses on three circuit designs that control switch-node ringing with either a boot resistor, a high-side gate resistor, or a snubber. Data is presented for each approach, and the benefits of each are also discussed.

Simplify Low-EMI Design with Power Modules: SLYY123

This paper explains the sources of EMI in a switching power supply and methods or technologies for mitigating EMI. I will also show you how power modules (controller, high side and low side FET and inductor in one package) help reduce EMI.

Snubber Circuits: Theory, Design and Application: SLUP100

This article describes some of the various types of snubbers, where they are used, how they function, how they are designed and what their limitations are.

Minimizing Output Ripple During Startup: SLVA866

This application note uses the TPS54620 as an example to provide recommendations to reduce the ripple caused by pulse-skipping during startup and shows some newer parts which use different circuits during startup to reduce the output voltage ripple.

Measuring Various Types of Low-frequency Noise from DC/DC Switching Converters: SLYY134

This white paper explains sources of low-frequency noise in bipolar junction transistors (BJTs), metal-oxide semiconductor field-effect transistors (MOSFETs) and resistors, and how this noise propagates to the output voltage of a DC/DC converter.

Using a 4MHz switching regulator w/o a Linear Regulator to Power a Data Converter: SLYT756

This article shows how a high-frequency DC/DC converter offers low ripple noise and good power-supply ripple rejection compared to a 400-kHz DC/DC converter followed by an LDO.

Extend Battery Life with < 100 nA IQ Buck Converter Achieving < 150 μV Voltage Ripple (with PI filter design): SLVAEG1

This document discusses different architectures for implementing buck converters for a battery-powered application, and the trade-offs for each.

Analysis and Design of Input Filters for DC-DC Circuits: SNVA801

This application report analyzes the influence of the input filter on the DC-DC control loop transfer function, and the influence of a closed loop on the input filter, explains why input filter causes unexpected problem, and suggests how to eliminate the side effect of the input filter.

Calculating Output Capacitance to Meet Transient and Ripple Requirements of an Integrated POL Converter Design Based on D-CAPx™ Modulators: SLVA874

This document provides guidance on how to calculate the amount of output capacitance needed to meet the transient and ripple requirements of a general buck converter design. D-CAPx modulators are used in the example.

Controlling Output Ripple and Achieving ESR Independence with Constant On-Time Regulators: SNVA166

Of all the voltage regulator control strategies ever devised, the hysteretic regulator is probably about the simplest. This control methodology simply turns a switch on when the output voltage is below a reference and turns the switch off when the output rises to a slightly higher reference. The output ripple is therefore a direct function of the difference between the upper and lower reference threshold, the hysteresis amplitude. It's hard to imagine something much simpler and, as usual, with simplicity comes performance shortcoming.

EMI/RFI Board Design: SNLA016

This generic application note defines electromagnetic interference and describes how it relates to the performance of a system. It looks at examples of inter-system noise and intra-system noise and presents techniques that can be used to ensure electromagnetic compatibility throughout a system and between systems.

Simple Success With Conducted EMI From DC/DC Converters: SNVA489

This paper details conducted EMI characteristics and mitigation techniques in switching power supplies.

Layout Tips for EMI Reduction in DC/DC Converters: SNVA638

This application note explores how the layout of your DC/DC power supply can significantly affect the amount of EMI that it produces. It will discuss several variations of a layout, analyze the results, and provide answers to some common EMI questions.

Output Noise Filtering for DC/DC Power Modules: SNVA871

This application report provides a comparative analysis between a LDO and a second stage LC filter to minimize the output of the LMZM33606 power module.

Designing High-Performance, Low-EMI Automotive Power Supplies:SNVA780

This application report discusses the unique challenges to designing automotive power supplies.

Enhanced HotRod QFN Package: Achieving Low EMI Performance in Industry's Smallest 4-A Converter: SNVA935

This application report highlights TI's fist DC/DC converter with Enhanced HotRod QFN package technology and provides insight on the EMI and thermal performance of the LM60440 device.

Improve High-Current DC/DC Regulator EMI Performance for Free With Optimized Power Stage Layout: SNVA803

This Tech Note explores EMI abatement in high-current DC/DC regulator circuits that employ a controller paired with discrete high-side and low-side silicon power MOSFETs. Using a single-sided PCB layout that specifically minimizes the parasitic inductance of the switching power loop, the switch-node voltage overshoot and ringing during MOSFET commutation are reduced, thus lowering regulator EMI signature.

8 Device-Specific Technical Discussions

This paragraph focuses on technical considerations regarding specific devices from our portfolio. The matters discussed in those notes may not be applicable to alternative part numbers unless noted otherwise.

Optimizing the TPS62130, TPS62140, TPS62150 and TPS62160 Output Filter: SLVA463

Optimizing the TPS62175 Output Filter: SLVA543

Optimizing the TPS62090 Output Filter: SLVA519

The DCS-Control™ topology used in the devices discussed in those notes allows for a wider range of inductor and output capacitor values than traditional voltage mode controlled buck converters. More lenience can therefore be tolerated in choosing inductor and output capacitor values to accomplish specific design goals, such as transient response, loop stability, maximum output current, or output voltage ripple, based on an application's needs.

Feedforward Capacitor to Improve Stability and Bandwidth of TPS621 and TPS821-Family: SLVA466

A common method to improve the stability and bandwidth of a power supply is to use a feedforward capacitor. This improvement can be measured in both the transient response and bode plot of the new circuit. This application report details two design strategies for optimizing the feedforward capacitor value to improve transient response and circuit stability.

Optimizing TPS6206x External Component Selection: SLVA441

This report describes how to select the proper feedforward capacitor value to match a wide range of LC output filter values and optimize the application for smaller solution size, faster load-step response, lower output voltage ripple, increased output current, and/or increased control loop stability.

TPS62130A Differences to TPS62130: SLVA644

This short report describes the difference in how the power good pin is controlled between the TPS62130A and TPS62130 devices.

TPS6208x and TLV6208x Devices Comparison: SLVA803

This application report presents an overview of the differences among the TPS6208x devices, which are part of a family of high frequency synchronous step-down converters available in a 2-mm × 2-mm QFN package.

Output Voltage Selection for the TPS62400 Family of Buck Converters: SLVA254

The TPS624xx family of dual output DC/DC Converters has adjustable output voltages, which can be programmed with an external resistor divider network to set the output voltage during power up. Then, after power up, the output voltage can be changed through software to several predefined values. This application report explains how to determine the output voltage of the TPS62400 after power up and the software adjustable range of voltages.

Designing an Isolated Buck (Flybuck) Converter using the LMR36520: SNVA790

This application report will describe the typical operation of a flybuck from a theoretical perspective, and then walk through the process of flybuck design from a set of given operating conditions using design equations derived in referenced reports. Physical measurements will be compared to expected results, and design limitations will also be discussed.

Configuring LM62460 for Dual-Phase Operation: SNVAA21

This application report details the design, implementation and preliminary lab results of two LM62460 buck regulators configured for a dual phase solution.

How to Migrate Between LM614xx and LM624xx Product Families: SNVAA31

This application report highlights the different feature options and pin-outs between the LM614xx and LM624xx and how to best design a single universal PCB layout.

Powering Sensitive ADC Designs with the TPS62913 Low-Ripple and Low-Noise Buck Converter: SLVAEW7

The power supply design demonstrates a simplified and efficient implementation of the TPS62913 low ripple and low noise buck converter to power an ADC12DJ5200RF, reducing power consumption by 1.5W (15% power savings).

Achieving Better than 1% Output Voltage Accuracy with TPS546D24A: SLUAA02

The TPS546D24A was developed to help designers achieve higher output voltage accuracy by actually specifying the output voltage accuracy, rather than the initial, reference, or VFB accuracy.

Enhance Stability of TPSM41625 Buck Module Designs with Minimized Ceramic Output Capacitors: SLVAEZ2

Reducing the value and quantity of output capacitors can help reduce overall solution size and cost. This application report shows how to improve the stability (phase and gain margins) of TPSM41625 when using a minimum number of all ceramic output capacitors.

Powering the AFE7920 with the TPS62913 Low-Ripple and Low-Noise Buck Converter: SLVAF16

The TPS62912 and TPS62913 devices are a family of high-efficiency, low-noise and low-ripple synchronous buck converters. The devices are ideal for noise sensitive applications that would normally use an LDO for post regulation such as AFEs, high-speed ADCs, Clock and Jitter Cleaner, Serializer, De-serializer, and Radar applications.

Comparison of TPS6290x vs. TPS621x0: SLVAF55

The TPS6290x family (TPS62903, TPS62902, TPS62901) is the next generation to the TPS621x0 (TPS62130, TPS62140, TPS62150) family. This application note goes through in detail the improvements that were made from the previous version to the new and how those changes benefit the designer.

How Output Capacitor Reduction Affects Load Transient in TPS563231 with D-CAP3 Control: SLUA986

Load-transient performance of the power supply is vital to the stable operation of digital systems like settop boxes, wireless routers, digital TVs, and so forth. TI's proprietary D-CAP3 control mode supports a fast transient response with low-ESR output capacitors. This application report introduces a method to evaluate how output capacitor reduction affects the load transient in a D-CAP3 buck converter.

Minimize On-Time-Jitter and Ripple by Optimizing Compensation: SLUAA65

Noise in the current loop can affect jitter and ripple, and when designers require low output ripple and minimal on-time jitter, optimizing the voltage and current loop gain improves performance.

Demystifying and Mitigating Power Supply Ripple and Noise Implication on AFE8092: SLVAF52

Demystifying and Mitigating Power Supply Ripple and Noise Implication on AFE8092 AFE RF performance application note describes the significance of power supply impact on key RF Performance and explains the high-efficiency power topology to meet the same. The application note covers the following key points.

Expand Buck Converter Minimum Input Voltage with External VCC Bias: SLVAE69

First, this report will describe the features of the TPS56C215 device before an example of a low input voltage application is introduced. Then, a detailed schematic with the external VCC bias configuration is presented, followed by the confirmation of this theory via bench testing and an efficiency comparison.

Large Duty Cycle Operation With the TPS568230: SBVA083

The TPS568230 is an 8-A DC/DC synchronous buck converter with integrated FETs. The IC is based on Texas Instruments proprietary D-CAP3™ control architecture and can support large duty cycle operation up to 97%.

How to Understand LC Table and Select LC About TPS563202: SLUAAD3

This application report introduces the theory of calculating inductor and output capacitance. Secondly it also introduces how LC affects the loop stability with several typical applications. Finally, it gives a rule to select LC.

Powering the TPS546D24A Device Family From a Single 3.3-V Input Power Supply: SLUAA03

This application note will explore several techniques using an available 3.3-V rail when the internal circuitry of the DC/DC converter does not support 3.3-V operation.

How to Best Use TPS62903 for a Given Application Requirement: SLVAF76

This application note is divided into two segments. The first segment walks through how best to configure the TPS62903 for applications with limited space. The second segment of the report provides a detailed analysis on how to configure TPS62903 for best efficiency.

Large Duty Cycle Operation on the TPS563211: SLUAAE4

This application report introduces how the TPS563211 device is designed to implement large duty cycle operation.

Achieving Longer Hold-Up Time Using the TPS62130 in Enterprise SSD Applications: SLVAF70

This application report introduces an application method for longer hold-up time using the TPS62130 device which is an easy-to-use synchronous step-down 3-A DC/DC converter.

TPSM8A29 Fast Load Transient with DCAP-3: SLVAFB5

This application note demonstration showcases the benefits of using a D-CAP3, constant-on-time-based buck switching regulator over a fixed frequency-based buck switching regulator.

Reducing Output Ripple and Noise with the TPS84259 Module: SLYT740

This article presents several solutions to reduce noise generated by DC/DC converters and includes test data that illustrates the trade-offs between noise reduction and efficiency performance.

9 Calculation, Simulation, and Measurement Techniques

This section presents an overview of techniques to perform accurate calculations, simulations and measurements of the performance of a low power DC/DC converter in an application.

Calculating Efficiency: SLVA390

This application report provides a step-by-step procedure for calculating buck converter efficiency and power dissipation at operating points not provided by the data sheet.

MOSFET Power Losses and How They Affect Power-Supply Efficiency: SLYT664

This article revisits some of the basic principles of power supplies and then addresses how MOSFETs—the power stage of any switching-voltage regulator—affect efficiency.

Output Ripple Voltage for Buck Switching Regulator: SLVA630

In this application report, the analytical model for the output voltage waveform and peak-to-peak ripple voltage for buck is derived. This model is validated against SPICE TINA-TI simulations.

Accurately Measuring Efficiency of Ultralow-I_Q Devices: SLYT558

This article reviews the basics of measuring efficiency, discusses common mistakes in measuring the light-load efficiency of ultralow-I_Q devices and demonstrates how to overcome them in order to get accurate efficiency measurements.

Performing Accurate PFM Mode Efficiency Measurements: SLVA236

This note describes guidelines that assist the user in acquiring accurate PFM mode efficiency measurements.

How to Measure the Loop Transfer Function of Power Supplies: SNVA364

This application report shows how to measure the critical points of a bode plot with only an audio generator (or simple signal generator) and an oscilloscope. The method is explained in an easy to follow step-by-step manner so that a power supply designer can start performing these measurements in a short amount of time.

Simplifying Stability Checks: SLVA381

This application report explains a method for verifying relative stability of a circuit by showing the relationship between phase margin in an AC loop response and ringing in a load-step analysis.

How to Measure the Control Loop of DCS-Control™ Devices: SLVA465

This application report reviews the basics of measuring control loops, and discusses the changes for the family of DCS-Control™ devices.

Loop Gain Reconstruction of a Step-Down Converter from Output Impedance Measurement: SLUAAI0

This application note explains how to achieve a stability analysis only by performing an output impedance measurement. This method is compared to the commonly used voltage injection method and then described step-by-step to enable power engineers to quickly start performing these measurements.

How to Measure Impedance of a Power Distribution Network of a DC-DC Converter: SLUAAI3

This application note explains how to measure the Power Distribution Network (PDN) impedance of a DC-DC converter with a 2-port shunt-through measurement, suitable for measuring down to milliohm impedances at very high frequency. The method can be reproduced in a short amount of time using common instruments available in most laboratories.

HS Load/Line Transient Jigs and App Rpt for Testing POL Regulators: SNOA895

This application note discusses good practice and fundamentals for transient analysis in the lab, and describes the construction of some improved transient test devices.

Measuring the Bode Plot of D-CAP™, D-CAP2™, and D-CAP3™ DC/DC Converters: SLUAAF4

The stability test is an important part of the evaluation of a DC/DC converter. If done properly, the Bode plot result can be a very quick and useful way to help you gauge the stability of the converter. In the absence of a theoretical analysis, use a network analyzer to measure the Bode plot and confirm the stability of the design.

10 DC/DC Converter Applications

This section gathers application notes concentrating on specific applications and design implementations of low power DC/DC converters. Example circuits are presented and their performance optimization is discussed.

Step-Down LED Driver With Dimming With the TPS621-Family and TPS821-Family: SLVA451

This application report demonstrates the TPS621x0 family as a small, simple, and easy way to implement a high-brightness LED driver.

Testing Tips for Applying External Power to Supply Outputs Without an Input Voltage: SLYT689

Powering a step-down (buck) converter with a voltage on the output and without a voltage on the input is an atypical application scenario that raises a flag for special considerations. This article explains the main concerns and their mitigation strategies.

Efficient Super-Capacitor Charging with TPS62740: SLVA678

The TI Design PMP9753 shows a concept to buffer energy in a super capacitor and therefore decouple load peaks from the battery. This application note helps designers to calculate and define the parameters like minimum and maximum voltage levels, storage capacitor size or maximum battery current.

Low-Noise CMOS Camera Supply: SLVA672

This application note describes how to design a highly efficient, low-noise CMOS Camera power supply solution based on switching regulators without the need of any additional filtering.

Step-Down Converter With Input Overvoltage Protection: SLVA664

This application report describes an input overvoltage protection circuit using a highly efficient and small step-down converter like TPS62130. It also details the design and selection of the key components and provides measurement results showing the performance of the circuit.

Step-Down Converter with Cable Voltage Drop Compensation: SLVA657

Output voltages of DC/DC converters typically are precisely regulated at the location the feedback divider is connected. In case of longer connections to the load, a voltage drop which depends on the load current must be expected. This application report describes a circuit where compensation is done by adjusting the output voltage of the converter to match the voltage drop along the cables.

Using the TPS62150 in a Split Rail Topology: SLVA616

This application report demonstrates a method of generating a split rail (bipolar +/- output voltages) supply with the TPS62150.

Using the TPS6215x in an Inverting Buck-Boost Topology: SLVA469

Using the TPS62175 in an Inverting Buck Boost Topology: SLVA542

These application reports are a how-to guide on using TI synchronous buck converters in an inverting buck-boost topology, where the output voltage is inverted or negative with respect to ground. The presented solutions are based on devices designed for many applications, such as standard 12-V rail supplies, embedded systems, and portable applications.

Powering the MSP430 From a High Voltage Input Using the TPS62122: SLVA335

This application example is presented to help designers and others who are using the MSP430 in a system with an input voltage range from 3.6 V to 15 V, and who are concerned with maintaining high efficiency and long battery life. Power requirements, illustrated schematic, operation waveforms and bill of materials are included.

Voltage Margining Using the TPS62130: SLVA489

This application report demonstrates a simple circuit that provides a ±5% margining function. This permits testing for high- and low-voltage margining for product evaluation.

Working with Inverting Buck-Boost Converters: SNVA856

Generating a negative output voltage rail from a positive input voltage rail can be done by reconfiguring an ordinary buck regulator. The result is an inverting buck-boost (IBB) topology implementation. This application report gives details regarding this conversion with examples.

DC/DC Converter Solutions for Hardware Accelerators in Data Center Applications: SLVAEG2

Hardware accelerators are custom-made hardware designs on a circuit board that perform specific functions better than software. Hardware accelerators use advanced processors, such as FPGAs, ASICs, SoC and GPUs. These processors are very suitable for performing specific, computation-intensive algorithms. Hardware acceleration helps enable artificial intelligence, including special functionalities such as machine learning, brain simulation, and neural engines. These functions use statistical techniques that allow computer systems to learn from data without being programmed, similar to our understanding of how the brain operates.

Point-of-Load Solutions for Data Center Applications Implementing VR13.HC VCCIN Specification: SLVAE92

Data centers are crucial for business continuity and reliable communications. TI provides performance power management solutions, enabling high availability and efficiency when powering processors for data centers and rack servers. Advanced processors and platforms, such as the Intel® Whitley and Cedar Island platforms, need point-of-load solutions for memory, low-power CPU rails, and 3.3-V and 5-V rail requirements from a 12-V nominal input bus.

Non-Isolated Point-of-Load Solutions for Elkhart Lake in Industrial PC Applications: SLVAET0

This document intends to highlight DC/DC converters from Texas Instruments that provide performance power management solutions to extend battery life while addressing Elkhart Lake platform power requirements.

Non-Isolated DC/DC Solutions for Alder Lake in Notebook Computing Applications: SLUAAA6

This document intends to highlight DC/DC converters and describe their features addressing general Alder Lake power requirements.

Non-Isolated Point-of-Load Solutions for Tiger Lake in PC Applications: SLUAA54

This document intends to highlight DC/DC converters and describe their features addressing general Tiger Lake power requirements. For specific information about Intel processors and their power requirements, log on to the Intel Resource and Design Center. Contact TI for information about multiphase controllers and power stages designed specifically for the Intel Mobile Voltage Positioning (IMVP) requirements.

Point-of-Load Solutions in Data Center Applications for Intel® Xeon® Sapphire Rapids Scalable Processors: SLVAF22

This document intends to highlight DC/DC converters and describe their features addressing performance processor power requirements.

Point-of-Load Solutions for Network Interface Cards (NIC): SNVAA29

Network Interface Cards (NIC) are crucial for business continuity and reliable communications by connecting physical layer circuitry with data link layer standards, such as wired Ethernet or wireless networking.

Synchronizing DC/DC Converters in a Power Tree: SLVAEG8

In this application note, five different configurations of a power tree example generating two output voltages are explained. All five circuits use the same inductors for the DC/DC converters and the same input and output capacitor configuration. In all examples, the converters are also configured to operate at the same nominal frequency of 2.25 MHz and use the same resistance value for the RCF resistors.

Benefiting from Step-Down Converters with an I2C Communication Interface: SLUAAE9

This application report shows the benefits of using a step-down converter with an I2C communication interface. Several applications benefit from controlling features and reading status information from a power management device.

Benefits of a Resistor-to-Digital Converter in Ultra-Low Power Supplies: SLYY180

This white paper explains the R2D circuit, describing its primary benefits as well as its main limitations.

Designing a Negative Boost Converter from a Standard Positive Buck Converter: SLYT516

This article describes a method using a standard positive buck converter to form a negative boost converter, which takes an existing negative voltage and creates an output voltage with a larger (more negative) amplitude. Using a boost regulator results in a smaller, more efficient, and more cost-effective design.

Create a Split-Rail Power Supply with a Wide Input Voltage Buck Regulator: SLVA369

This application report demonstrates a unique method of generating a positive and negative output power supply using a standard buck regulator – one that maintains good regulation, has excellent cross regulation, and can regulate the positive output from a lower input voltage.

Designing an Isolated Buck (Fly-Buck™) Converter: SNVA674

This article presents the basic operating principle of an isolated buck converter. The operating current and voltage waveforms are explained and design equations are derived. The design example shows a step-by-step procedure for designing a practical two-output 3 W isolated buck converter.

Power-Supply Sequencing for FPGAs: SLYT598

This article elaborates on sequencing solutions that can be implemented based on the level of sophistication needed by a system. Sequencing solutions addressed in this article are:

1. Cascading PGOOD pin into enable pin
2. Sequencing using a reset IC
3. Analog up/down sequencers
4. Digital system health monitors with PMBus interface

Power Supply Design Considerations for Modern FPGAs (Power Designer 121): SNOA864

Today's FPGAs tend to operate at lower voltages and higher currents than their predecessors. Consequently, power supply requirements may be more demanding, requiring special attention to features deemed less important in past generations. Failure to consider the output voltage, sequencing, power-on, and soft-start requirements can result in unreliable power-up or potential damage to FPGAs.

Remote Sensing for Power Supplies: SLYT467

This article discusses design considerations for remote sensing, including power-plane shortages, component placement, parasitic resistance, and potential oscillations. Also, a practical example demonstrates the effectiveness of a high-frequency bypass capacitor for mitigating oscillations associated with remote sensing.

Effect of Resistor Tolerances on Power Supply Accuracy: SLVA423

This document assists designers in determining the impact of resistor tolerances on a power supply's output accuracy. It explains how resistive dividers are used in power supply regulation, derives an equation for output accuracy in terms of the divider resistors' tolerances, and examines the impact of this equation on an example design.

11 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (June 2021) to Revision B (May 2022)	Page
• Updated to include content related to the entire TI buck switching DC/DC regulator portfolio throughout the publication	1

Changes from Revision * (April 2018) to Revision A (June 2021)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the publication	2