WIDE-INPUT-RANGE NONSYNCHRONOUS VOLTAGE-MODE CONTROLLER

Check for Samples: TPS40200-Q1

FEATURES

- **Qualified for Automotive Applications**
- **Input Voltage Range 4.5 V to 52 V**
- **Output Voltage (700 mV to 90% V_{IN})**
- **200-mA Internal P-FET Driver**
- **Voltage Feed-Forward Compensation**
- **Undervoltage Lockout (UVLO)**
- **Programmable Fixed-Frequency (35-kHz to 500-kHz) Operation**
- **Programmable Short-Circuit Protection**
- **Hiccup Overcurrent Fault Recovery**
- **Programmable Closed Loop Soft Start**
- **700-mV 1% Reference Voltage**
- **External Synchronization**
- **Small 8-Pin SOIC (D) Package**

APPLICATIONS

- **Automotive Controls**
- **Distributed Power Systems**
- **DSL/Cable Modems**
- **Scanners**
- **Telecom**

DESCRIPTION

The TPS40200 is a flexible nonsynchronous controller with a built-in 200-mA driver for P-channel FETs. The circuit operates with inputs up to 52 V, with a power-saving feature that turns off driver current once the external FET has been fully turned on. This feature extends the flexibility of the device, allowing it to operate with an input voltage up to 52 V without dissipating excessive power. The circuit operates with voltage-mode feedback and has feed-forward input-voltage compensation that responds instantly to input voltage change. The integral 700-mV reference is trimmed to 2%, providing the means to accurately control low voltages. The TPS40200 is available in an 8-pin SOIC and supports many of the features of more complex controllers. Clock frequency, soft start, and overcurrent limit are each easily programmed by a single, external component. The part has undervoltage lockout (UVLO) and can be easily synchronized to other controllers or a system clock to satisfy sequencing and/or noise-reduction requirements.

Major sections in this data sheet include:

- Specifications
- General Information
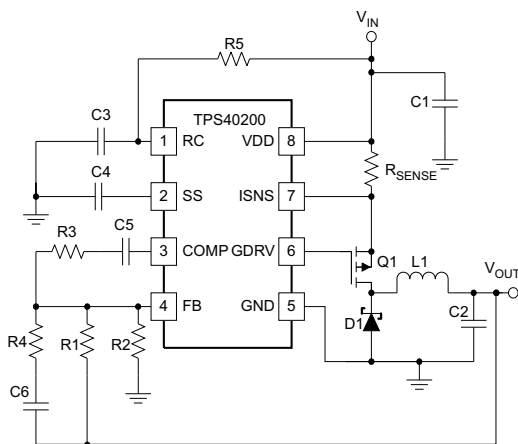- Example Applications
- Design References

TYPICAL APPLICATION

Figure 1. 12-V to 5-V Buck Converter With 94% Efficiency

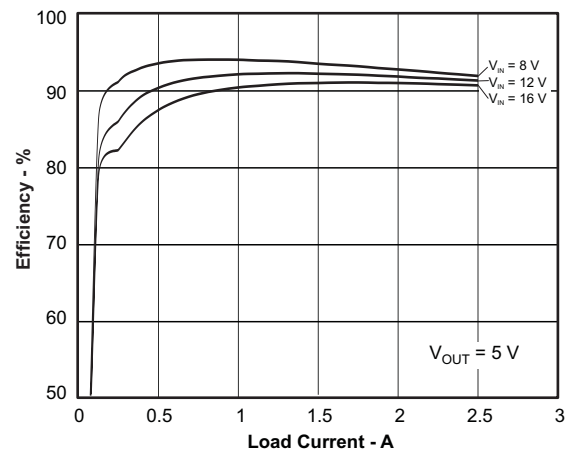**Figure 2. Typical Efficiency of Application Circuit 1 (Described in Application 1)**

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

Table 1. ORDERING INFORMATION[1]

T_A	OUTPUT VOLTAGE	PACKAGE[2]	PART NUMBER	MEDIUM	QUANTITY
–40°C to 125°C	Adjustable	Plastic small outline (D)	TPS40200QDRQ1	Tape and reel	2500/Reel

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.
(2) Package drawings, thermal data, and symbolization are available at www.ti.com/packaging.

Electrostatic Discharge (ESD) Protection

	MIN	MAX	UNIT
Human-Body Model (HBM)		1000	V
Charged-Device Model (CDM)		1500	V
Machine Model (MM)		100	V

Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)

			TPS40200	UNIT
Input voltage range		V_{DD}, ISNS	52	V
		RC, FB	–0.3 to 5.5	
		SS	–0.3 to 9.0	
Output voltage range		COMP	–0.3 to 9.0	V
		GDRV	$(V_{IN} - 10)$ to V_{IN}	
T_{stg}	Storage temperature range		–55 to 150	°C
	Lead temperature 1,6 mm (1/16 in) from case for 10 s		260	°C

Recommended Operating Conditions

		MIN	MAX	UNIT
V_{DD}	Input voltage	4.5	52	V
T_A	Operating temperature	–40	125	°C

Thermal Characteristics

over operating free-air temperature range (unless otherwise noted)

	PARAMETER	TYP	UNIT
θ_{JC}	Thermal resistance, junction to case[1]	49	°C/W

(1) TI uses test boards designed to JESD 51-3 and JESD 51-7 for thermal-impedance measurements. The parameters outlined in these standards are also used to set up thermal models. TI uses the thermal-model program ThermCAL, a finite-difference thermal-modeling tool. Using this test procedure, the junction-to-case thermal resistance of this part is 49°C/W.

Electrical Characteristics

$-40°C < T_A < 125°C$, $V_{DD} = 12$ V, $f_{OSC} = 100$ kHz (unless otherwise noted)

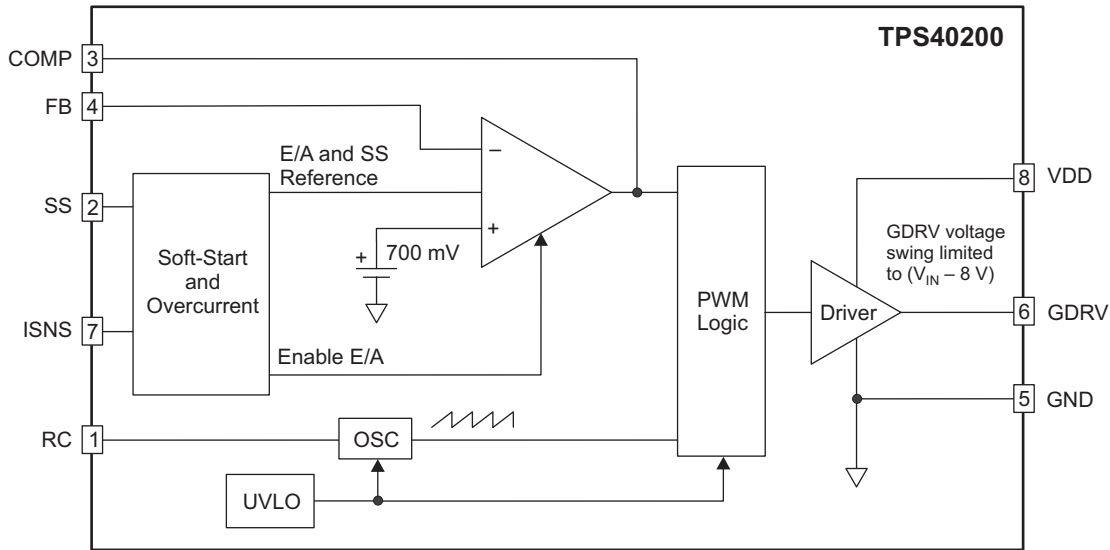| PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
Voltage Reference							
V_{FB}	Feedback voltage	COMP = FB, $T_A = 25°C$		689	696	702	mV
		4.5 V < V_{DD} < 52 V	$T_A = 25°C$	686	696	703	
			$-40°C < T_A < 125°C$	676	696	712	
Gate Driver							
I_{src}	Gate driver pullup current			125	300		mA
I_{snk}	Gate driver pulldown current			200	300		mA
V_{GATE}	Gate driver output voltage	$V_{GATE} = (V_{DD} - V_{GDRV})$, 12 V < V_{DD} < 52 V		5.6	8	10	V
Quiescent Current							
I_{qq}	Device quiescent current	$f_{OSC} = 300$ kHz, Driver not switching, 4.5 V < V_{DD} < 52 V			1.5	3.0	mA
Undervoltage Lockout (UVLO)							
$V_{UVLO(on)}$	Turn-on threshold	$-40°C < T_A < 125°C$		3.8	4.25	4.55	V
$V_{UVLO(off)}$	Turn-off threshold				4.05		V
$V_{UVLO(HYST)}$	Hysteresis			110	200	275	mV
Soft Start							
$R_{SS(chg)}$	Internal soft-start pullup resistance			65	105	170	kΩ
$R_{SS(dchg)}$	Internal soft-start pulldown resistance			190	305	485	kΩ
V_{SSRST}	Soft-start reset threshold			100	150	200	mV
Overcurrent Protection							
V_{ILIM}	Overcurrent threshold	4.5 V < V_{DD} < 52 V	$-40°C < T_A < 125°C$	50	100	140	mV
OC_{DF}	Overcurrent duty cycle	Note 1				2	%
$V_{ILIM(rst)}$	Overcurrent reset threshold			100	150	200	mV
Oscillator							
f_{OSC}	Oscillator frequency range	Note		35		500	kHz
	Oscillator frequency	$R_{RC} = 200$ kΩ, $C_{RC} = 470$ pF		85	100	118	
		$R_{RC} = 68.1$ kΩ, $C_{RC} = 470$ pF		210	300	345	
	Frequency line regulation	12 V < V_{DD} < 52 V		-9		0	%
		4.5 V < V_{DD} < 12 V		-21		0	
V_{RMP}	Ramp amplitude	4.5 V < V_{DD} < 52 V			VDD/10		V
Pulse-Width Modulator							
t_{MIN}	Minimum controllable pulse width	$V_{DD} = 12$ V			200	540	ns
		$V_{DD} = 30$ V			100	200	
D_{MAX}	Maximum duty cycle	$F_{osc} = 100$ kHz, $C_L = 470$ pF		93	95		%
		$F_{osc} = 300$ kHz, $C_L = 470$ pF		90	93		
K_{PWM}	Modulator and power-stage dc gain			8	10	12	V/V
Error Amplifier							
I_{IB}	Input bias current				100	250	nA
AOL	Open loop gain	Note		60	80		dB
GBWP	Unity gain bandwidth	Note		1.5	3		MHz
$I_{COMP(src)}$	Output source current	$V_{FB} = 0.6$ V, COMP = 1 V		100	250		µA
$I_{COMP(snk)}$	Output sink current	$V_{FB} = 1.2$ V, COMP = 1 V		1.0	2.5		mA

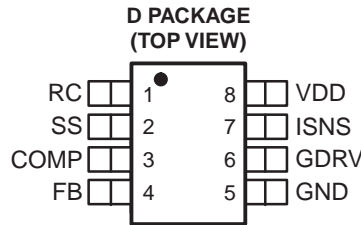## DEVICE INFORMATION

Figure 3. Functional Block Diagram

Figure 4. Device Pinout

TERMINAL FUNCTIONS

| TERMINAL		I/O	DESCRIPTION
NAME	NO.		
RC	1	I	Switching frequency setting RC network. Connect capacitor from RC pin to GND pin and resistor from V_{IN} pin to RC pin. The device may be synchronized to an external clock by connecting an open-drain output to this pin and pulling it to GND. The pulse width for synchronization should not be excessive (see General Information).
SS	2	I	Soft-start programming. Connect capacitor from SS to GND to program soft start time. Pulling this pin below 150 mV causes the output switching to stop, placing the device in a shutdown state. The pin also functions as a restart timer for overcurrent events.
COMP	3	O	Error amplifier output. Connect control loop compensation network from COMP to FB.
FB	4	I	Error amplifier inverting input. Connect feedback resistor network center tap to this pin.
GND	5		Device ground
GDRV	6	O	Driver output for external P-channel MOSFET
ISNS	7	I	Current-sense comparator input. Connect a current sense resistor between ISNS and V_{DD} in order to set desired overcurrent threshold.
VDD	8	I	System input voltage. Connect local bypass capacitor from V_{DD} to GND.

TYPICAL CHARACTERISTICS

QUIESCENT CURRENT
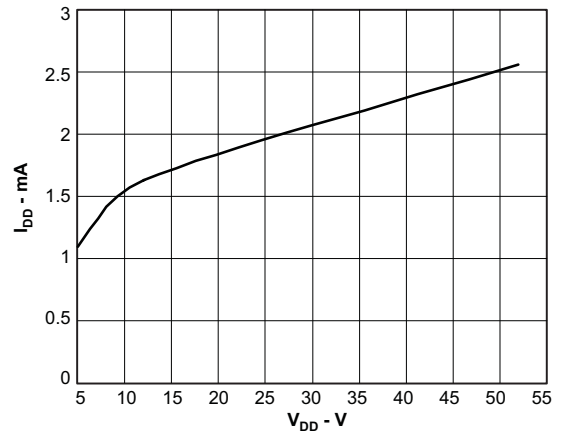**vs**
TEMPERATURE
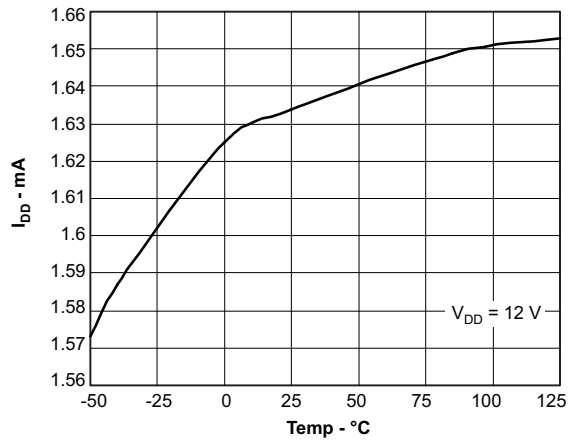
Figure 5.

QUIESCENT CURRENT
vs
V_{DD}

Figure 6.

SOFT-START THRESHOLD
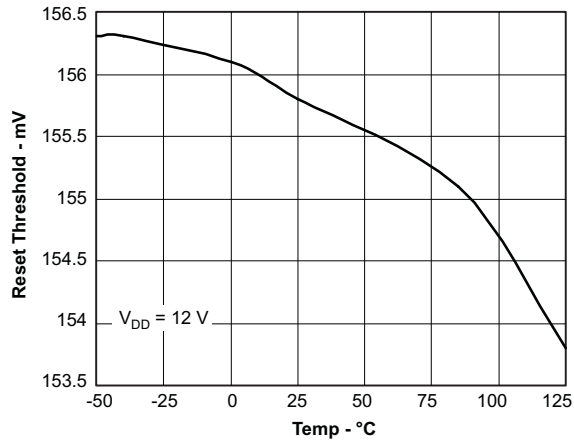**vs**
TEMPERATURE

Figure 7.

UVLO TURN ON AND TURN OFF
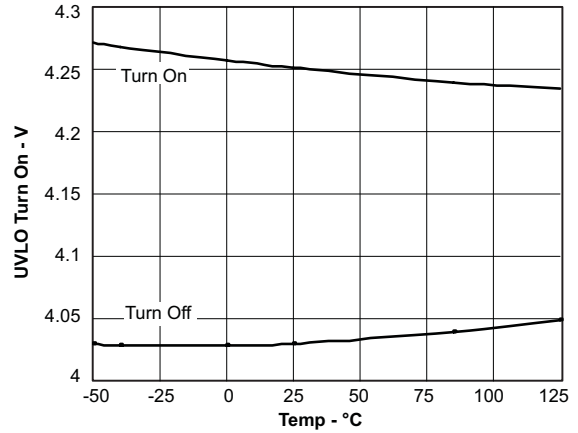**vs**
TEMPERATURE

Figure 8.

TYPICAL CHARACTERISTICS (continued)

OSCILLATOR FREQUENCY
vs
TEMPERATURE
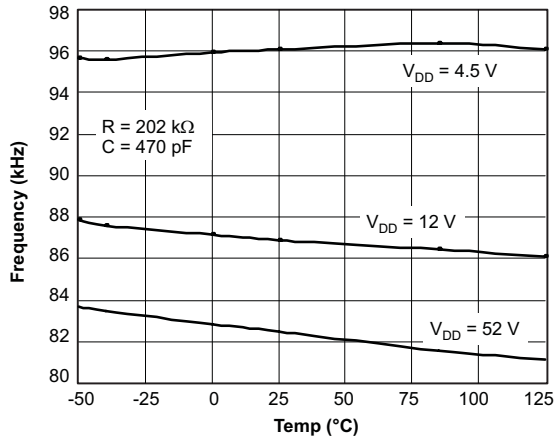
Figure 9.

CURRENT-LIMIT THRESHOLD
vs
TEMPERATURE
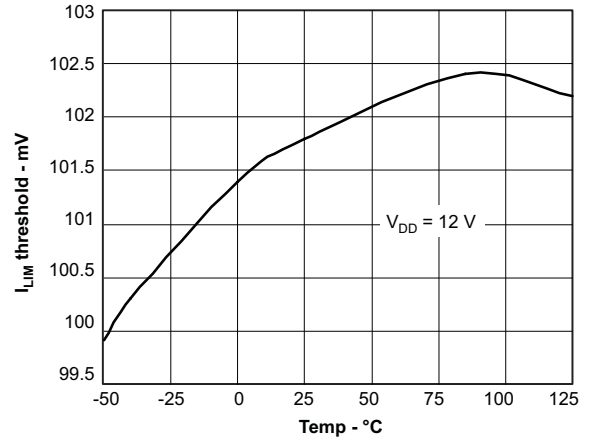
Figure 10.

OSCILLATOR FREQUENCY
vs
V_{DD}
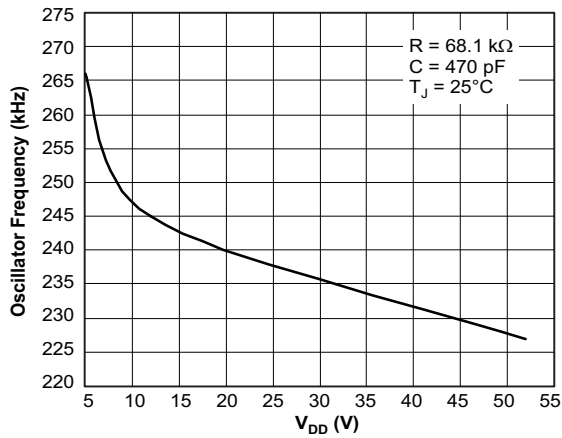
Figure 11.

POWER-STAGE GAIN
vs
V_{DD}
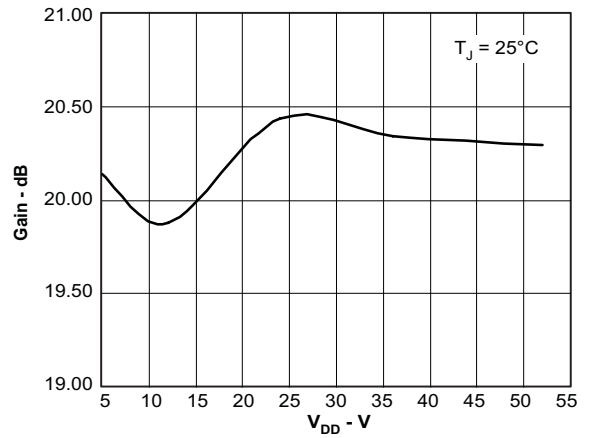
Figure 12.

TYPICAL CHARACTERISTICS (continued)

**POWER-STAGE GAIN
vs
TEMPERATURE**
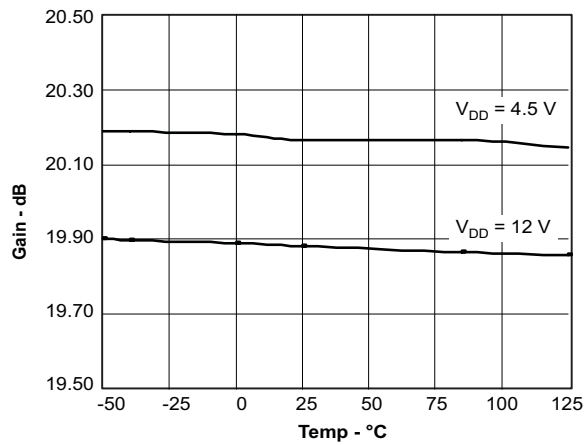
Figure 13.

**POWER-STAGE GAIN
vs
TEMPERATURE**
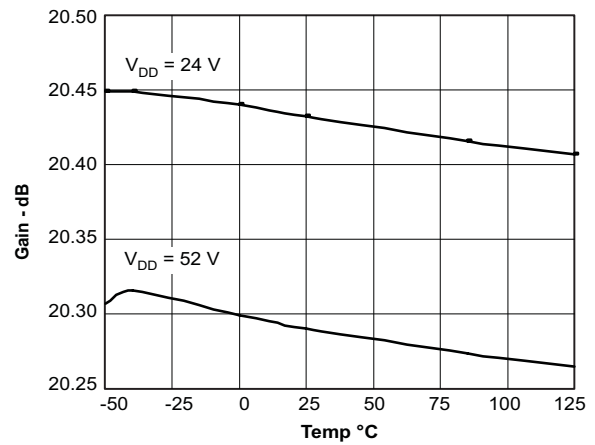
Figure 14.

**MODULATOR RAMP AMPLITUDE
vs
TEMPERATURE**
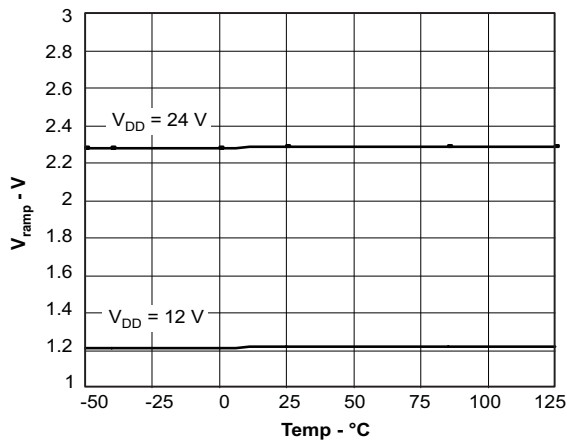
Figure 15.

**MODULATOR RAMP AMPLITUDE
vs
TEMPERATURE**
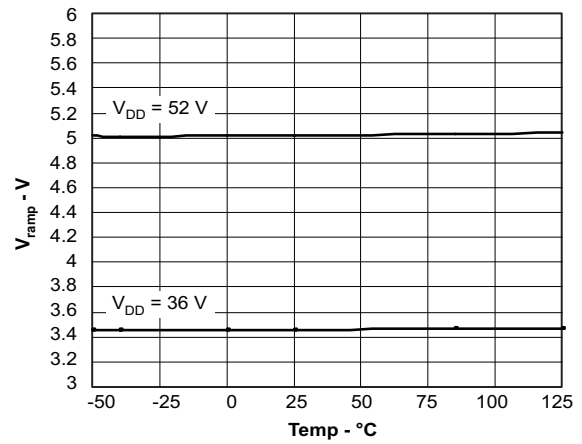
Figure 16.

TYPICAL CHARACTERISTICS (continued)

MODULATOR RAMP AMPLITUDE
vs
V_{DD}
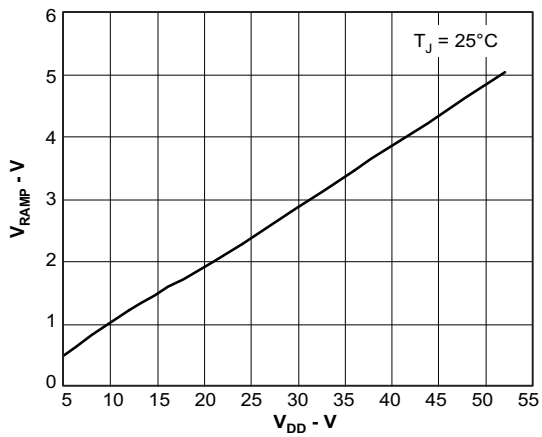
Figure 17.

FEEDBACK AMPLIFIER INPUT BIAS CURRENT
vs
TEMPERATURE
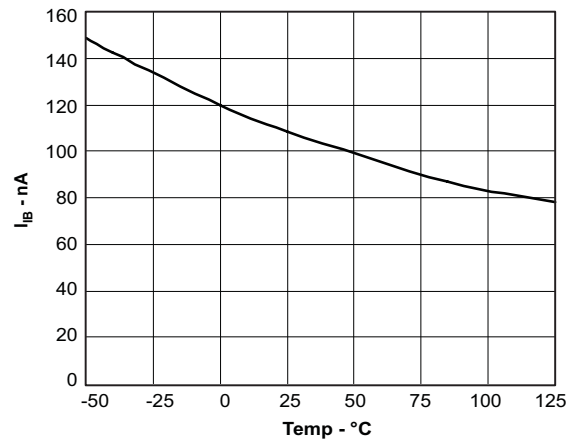
Figure 18.

COMP SOURCE CURRENT
vs
TEMPERATURE
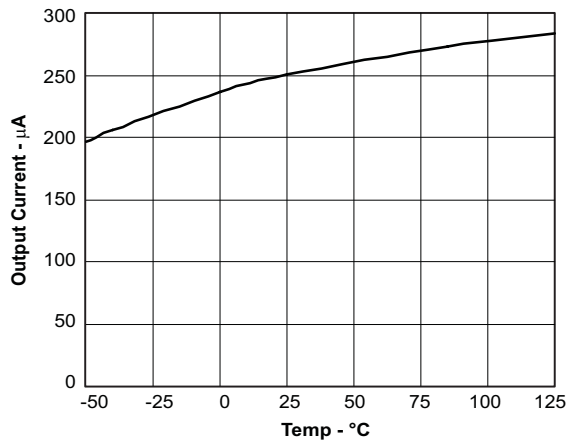
Figure 19.

COMP SINK CURRENT
vs
TEMPERATURE
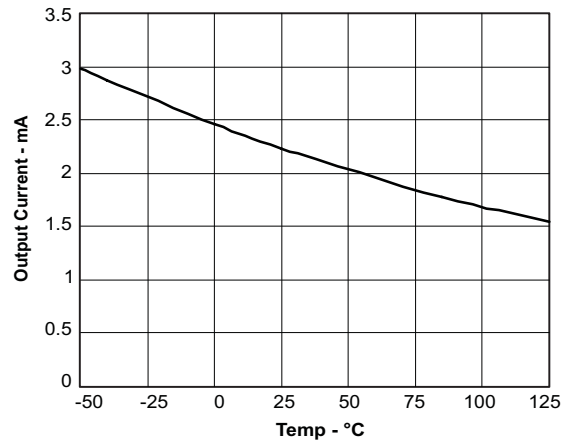
Figure 20.

TYPICAL CHARACTERISTICS (continued)

GATE DRIVE VOLTAGE
vs
TEMPERATURE
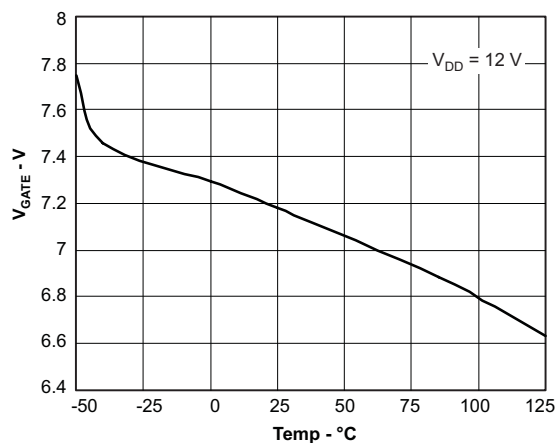
Figure 21.

GATE DRIVE VOLTAGE
vs
V_IN
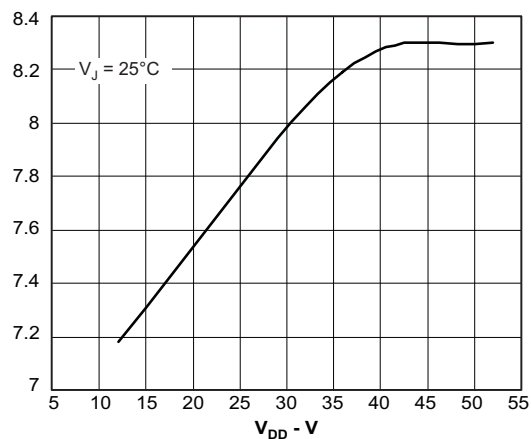
Figure 22.

REFERENCE VOLTAGE
vs
TEMPERATURE
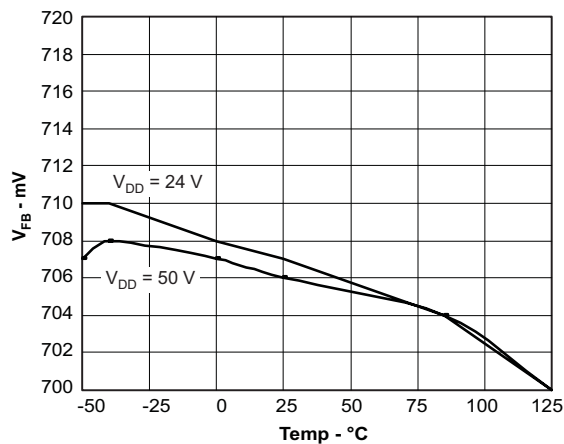
Figure 23.

REFERENCE VOLTAGE
vs
TEMPERATURE
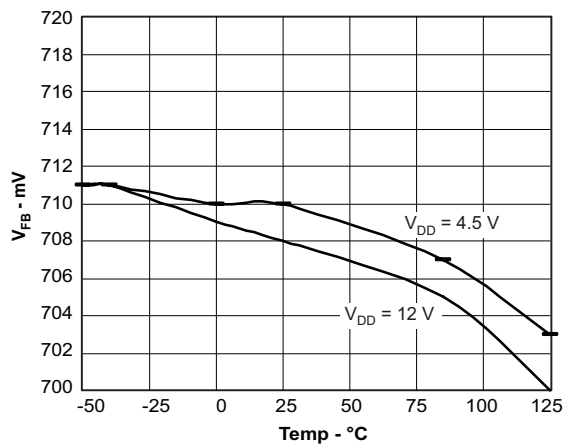
Figure 24.

TYPICAL CHARACTERISTICS (continued)

MINIMUM CONTROLLABLE PULSE WIDTH
vs
FREQUENCY
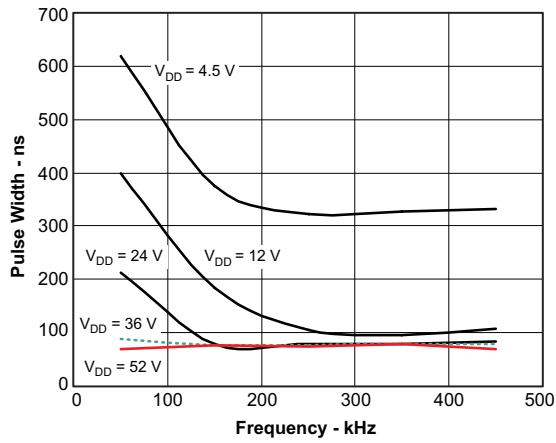
Figure 25.

MAXIMUM DUTY CYCLE
vs
INPUT VOLTAGE
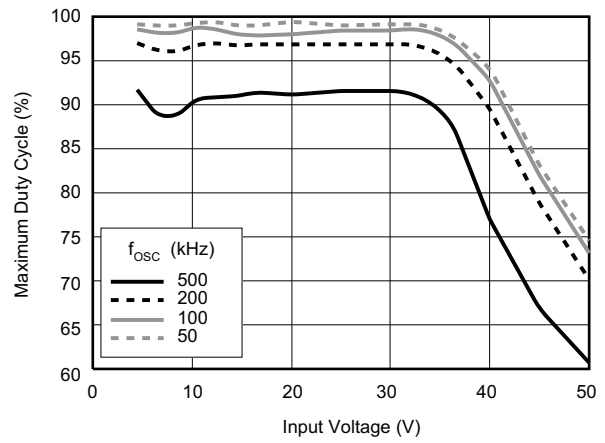
Figure 26.

GENERAL INFORMATION

Overview

The TPS40200 is a nonsynchronous controller with a built-in 200-mA driver designed to drive high-speed P-channel FETs up to 500 kHz. Its small size combined with complete functionality makes the part both versatile and easy to use.

The controller uses a low-value current-sensing resistor in series with the input voltage and the power FET's source connection to detect switching current. When the voltage drop across this resistor exceeds 100 mV, the part enters a hiccup fault mode at approximately 2% of the operating frequency.

The part uses voltage feedback to an error amplifier that is biased by a precision 700-mV reference. Feed-forward compensation from the input keeps the PWM gain constant over the full input voltage range, eliminating the need to change frequency compensation for different input voltages.

The part also incorporates a soft-start feature, during which the output follows a slowly rising soft-start voltage, preventing output-voltage overshoot.

Programming the Operating Frequency

The operating frequency of the controller is determined by an external resistor R_{RC} that is connected from the RC pin to VDD and a capacitor attached from the RC pin to ground. This connection and the two oscillator comparators inside the IC are shown in Figure 27. The oscillator frequency can be calculated from the following equation:

$$f_{SW} = \frac{1}{R_{RC} \times C_{RC} \times 0.105}$$

Where:
f_{SW} = clock frequency
R_{RC} = timing resistor value in Ω
C_{RC} = timing capacitor value in F

R_{RC} must be kept large enough that the current through it does not exceed 750 µA when the internal switch (shown in Figure 27) is discharging the timing capacitor. This condition may be expressed by Equation 1:

$$\frac{V_{IN}}{R_{RC}} \leq 750 \ \mu A$$

(1)

Synchronizing the Oscillator

Figure 27 shows the functional diagram of the TPS40200 oscillator. When synchronizing the oscillator to an external clock, the RC pin must be pulled below 150 mV for 20 ns or more. The external clock frequency must be higher than the free-running frequency of the converter as well. When synchronizing the controller, if the RC pin is held low for an excessive amount of time, erratic operation may occur. The maximum amount of time that the RC pin should be held low is 50% of a nominal output pulse, or 10% of the period of the synchronization frequency.

Under circumstances where the input voltage is high and the duty cycle is less than 50%, a Schottky diode connected from the RC pin to an external clock may be used to synchronize the oscillator. The cathode of the diode is connected to the RC pin. The trip point of the oscillator is set by an internal voltage divider to be 1/10 of the input voltage. The clock signal must have an amplitude higher than this trip point. When the clock goes low, it allows the reset current to restart the RC ramp, synchronizing the oscillator to the external clock. This provides a simple, single-component method for clock synchronization.
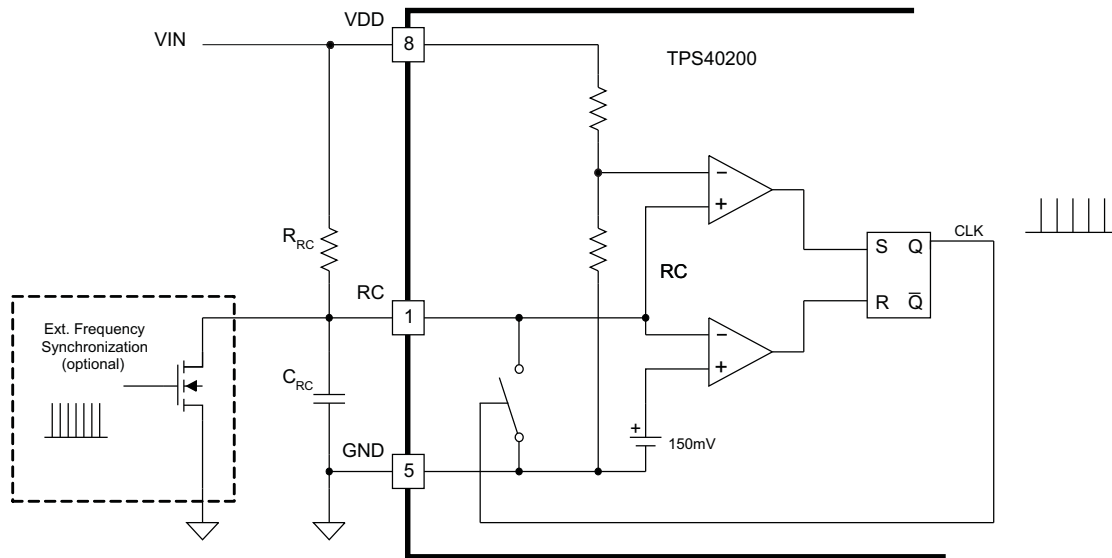
Figure 27. Oscillator Functional Diagram
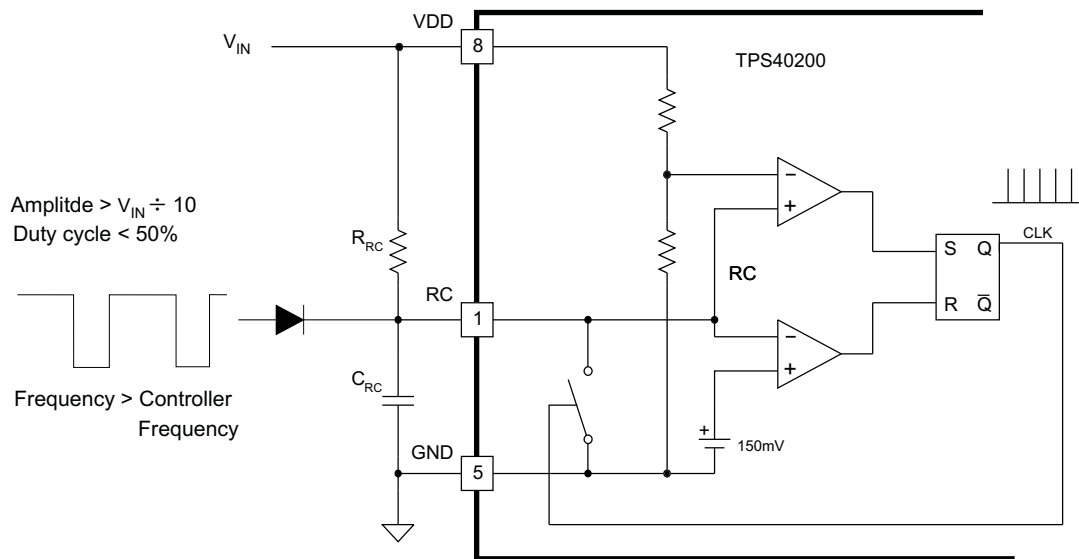
Figure 28. Diode Connected Synchronization

Current-Limit Resistor Selection

As shown in Figure 31, a resistor in series with the power MOSFET sets the overcurrent protection level. Use a low-inductance resistor to avoid problems with ringing signals and nuisance tripping. When the FET is on and the controller senses 100 mV or more drop from the VDD pin to the ISNS pin, an overcurrent condition is declared. When this happens, the FET is turned off and, as shown in Figure 30, the soft-start capacitor is discharged. When the soft-start capacitor reaches a level below 150 mV, the converter clears the overcurrent condition flag and attempts to restart. If the condition that caused the overcurrent event to occur is still present on the output of the converter (see Figure 29), another overcurrent condition is declared and the process repeats indefinitely. Figure 29 shows the soft-start capacitor voltage during an extended output fault condition. The overall duty cycle of current conduction during a persistent fault is approximately 2%.
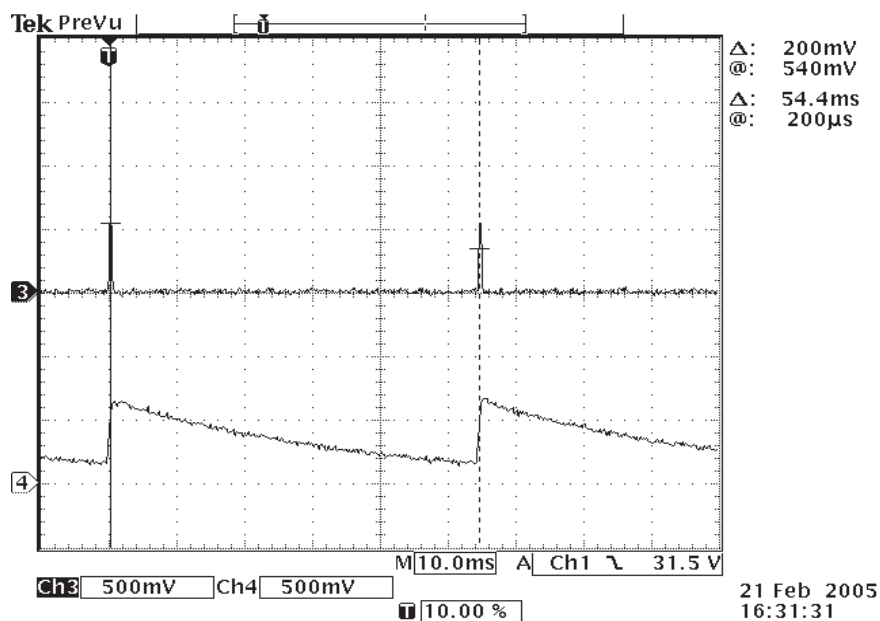
Figure 29. Typical Soft-Start Capacitor and V_{OUT} During Overcurrent
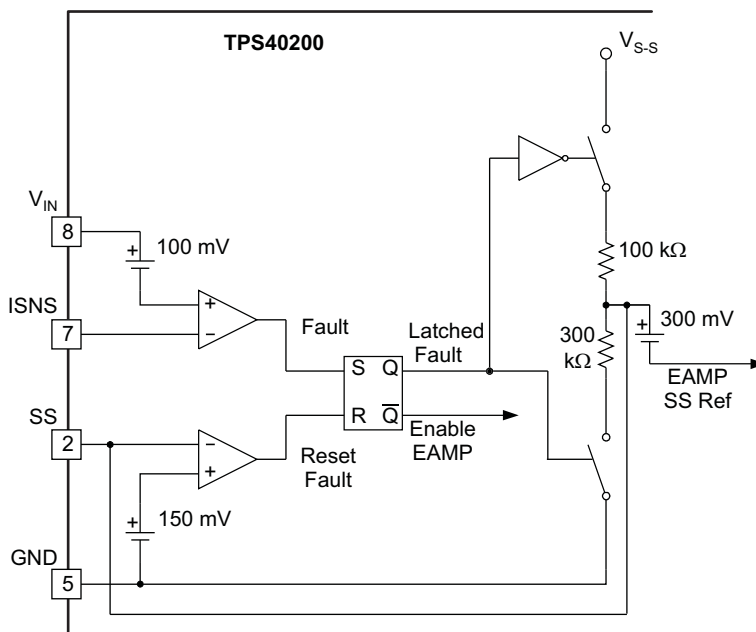
Figure 30. Current-Limit Reset

If necessary, a small R-C filter can be added to the current sensing network to reduce nuisance tripping due to noise pickup. This filter can also be used to trim the overcurrent trip point to a higher level with the addition of a single resistor (see Figure 31). The nominal overcurrent trip point using the circuit of Figure 31 is described as:

$$I_{OC} = \frac{V_{ILIM}}{R_{ILIM}} \times \frac{R_{F1} + R_{F2}}{R_{F2}}$$

Where:

I_{OC} = overcurrent trip point, peak current in the inductor

V_{ILIM} = overcurrent threshold voltage for the TPS40200, typically 100 mV

R_{ILIM} = value of the current sense resistor in Ω

R_{F1} and R_{F2} = values of the scaling resistors in Ω

The value of the capacitor is determined by the nominal pulse width of the converter and the values of the scaling resistors R_{F1} and R_{F2}. It is best not to have the time constant of the filter longer than the nominal pulse width of the converter, otherwise a substantial increase in the overcurrent trip point occurs. Using this constraint, the capacitor value may be bounded by the following:

$$C_f \le \frac{V_O}{V_{IN} \times f_{SW}} \div \frac{R_{f1} \times R_{f2}}{R_{f1} + R_{f2}}$$

Where:

C_f = value of the current limit filter capacitor in F

V_O = output voltage of the converter

V_{IN} = input voltage to the converter

f_{SW} = converter switching frequency

R_{f1} and R_{f2} = values of the scaling resistors in Ω
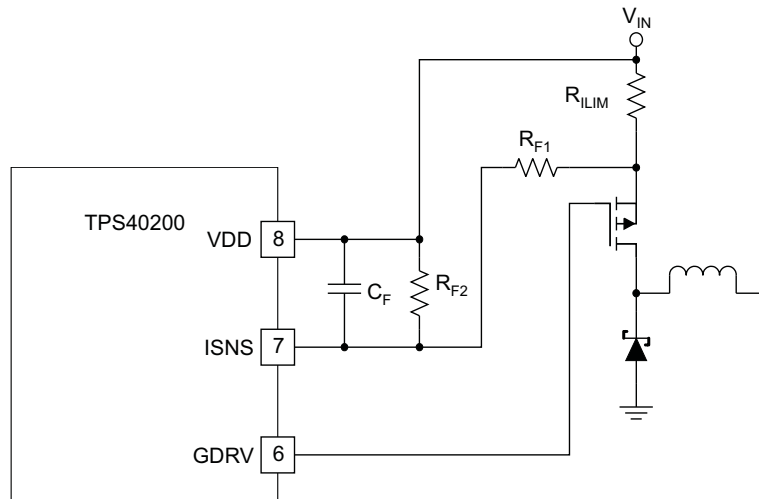
NOTE: The current-limit resistor and its associated circuitry can be eliminated, and pins 7 and 8 shorted. However, the result of this may result in damage to the part or PCB in the event of an overcurrent event.

Figure 31. Current-Limit Adjustment

MOSFET Gate Drive

The output driver sinking current is approximately 200 mA and is designed to drive P-channel power FETs. When the driver pulls the gate charge of the FET it is controlling to –8 V, the drive current folds back to a low level so that high power dissipation only occurs during the turn-on period of the FET. This feature is particularly valuable when turning on a FET at high input voltages, where leaving the gate drive current on would otherwise cause unacceptable power dissipation.

Undervoltage Lockout (UVLO) Protection

UVLO protection ensures proper start-up of the device only when the input voltage has exceeded minimum operating voltage. Undervoltage protection incorporates hysteresis that eliminates hiccup starting in cases where input supply impedance is high.
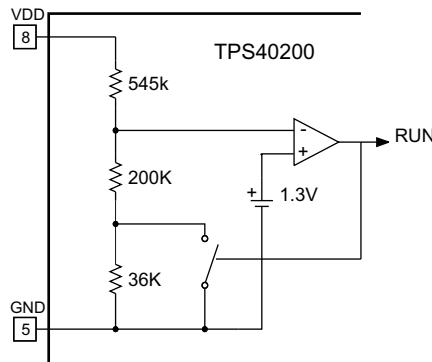
Figure 32. Undervoltage Lockout

Undervoltage protection ensures proper start-up of the device only when the input voltage has exceeded minimum operating voltage. The UVLO level is measured at the V_{DD} pin with respect to GND. Start-up voltage is typically 4.3 V with approximately 200 mV of hysteresis. The part shuts off at a nominal 4.1 V. As shown in Figure 32, when the input V_{DD} voltage rises to 4.3 V, the 1.3-V comparator threshold voltage is exceeded and a RUN signal occurs. Feedback from the output closes the switch and shunts the 200-kΩ resistor, so that an approximately 200-mV lower voltage, or 4.1 V, is required before the part shuts down.

Programming the Soft-Start Time

An external capacitor (C_{SS}) connected from the SS pin to ground controls the TPS40200 soft-start interval. An internal charging resistor connected to V_{DD} produces a rising reference voltage that is connected through a 700-mV offset to the reference input of the TPS40200 error amplifier. When the soft-start capacitor voltage (V_{CSS}) is below 150 mV, there is no switching activity. When V_{CSS} rises above the 700-mV offset, the error amplifier starts to follow V_{SST} – 700 mV and uses this rising voltage as a reference. When V_{CSS} reaches 1.4 V, the internal reference takes over, and further increases have no effect. An advantage of initiating a slow start in this fashion is that the controller cannot overshoot, because its output follows a scaled version of the controller's reference voltage. A conceptual drawing of the circuit that produces these results is shown in Figure 33. A consequence of the 700-mV offset is that the controller does not start switching until the V_{CSS} has charged up to 700 mV. The output remains at 0 V during the resulting delay. When V_{CCS} exceeds the 700-mV offset, the TPS40200 output follows the soft-start time constant. Once above 1.4 V, the 700-mV internal reference takes over, and normal operation begins.
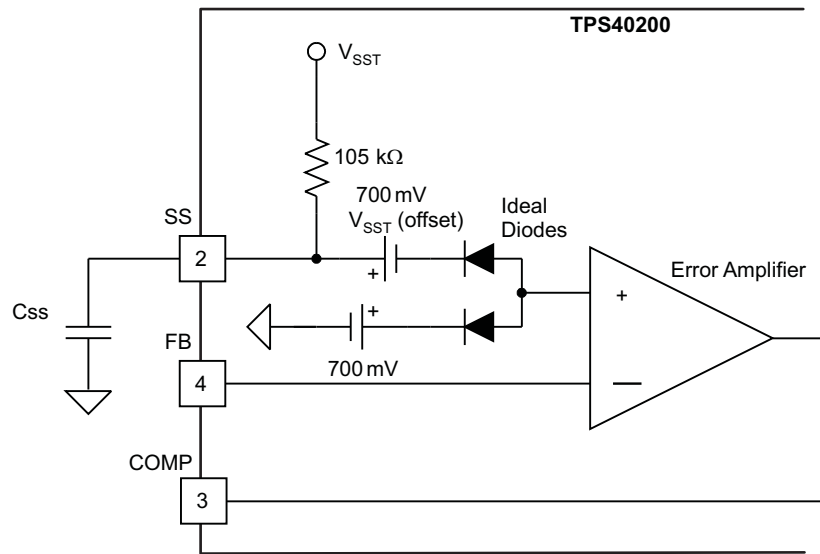
Figure 33. Soft-Start Circuit

The slow-start time should be longer (slower) than the time constant of the output LC filter. This time constraint may be expressed as:

$$t_S \geq 2\pi \times \sqrt{L_O \times C_O} \qquad (2)$$

The calculation of the soft-start interval is simply the time it takes the RC network to exponentially charge from 0 V to 1.4 V. An internal 105-kΩ charging resistor is connected from the SS pin to V_{SST}. For applications where the voltage is above 8 V, an internal regulator clamps the maximum charging voltage to 8 V.

The result of this is a formula for the start up time, as given by:

$$t_{SS} = R_c \times C_{SS} \times \ln\left(\frac{V_{SST}}{V_{SST} - 1.4} \right)$$

Where:

    t_{SS} = required soft-start time in seconds

    C_{SS} = soft-start capacitor value in F

    R_c = internal soft-start charging resistor (105 kΩ nominal)

    V_{SST} = input voltage up to a maximum of 8 V

Voltage Setting and Modulator Gain

Because the input current to the error amplifier is negligible, the feedback impedance can be selected over a wide range. Knowing that the reference voltage is 708 mV, pick a convenient value for R1 and then calculate the value of R2 from the following formula:

$$V_{OUT} = 0.708 \left(1 + \frac{R_2}{R_1} \right)$$

(3)
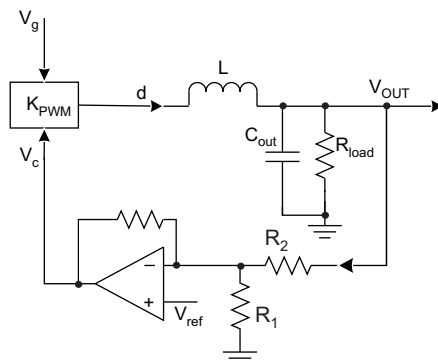
Figure 34. System Gain Elements

The error amplifier has a dc open-loop gain of at least 60 dB with a minimum of a 1.5-MHz gain bandwidth product, which gives the user flexibility with respect to the type of feedback compensation used for the particular application. The gain selected by the user at the crossover frequency is set to provide an overall unity gain for the system. The crossover frequency should be selected so that the error amplifier's open-loop gain is high with respect to the required closed-loop gain. This ensures that the amplifier's response is determined by the passive feedback elements.

EXAMPLE APPLICATIONS

Application 1: Buck Regulator, 8-V to 12-V Input, 3.3-V or 5-V Output at 2.5 A

Overview

The buck regulator design shown in Figure 35 shows the use of the TPS40200. It delivers 2.5 A at either 3.3 V or 5 V as selected by a single feedback resistor. It achieves approximately 90% efficiency at 3.3 V and 94% at 5 V. A discussion of design tradeoffs and methodology is included to serve as a guide to the successful design of forward converters using the TPS40200.

The bill of materials for this application is given in Table 3. The efficiency from boards built from this design is shown in Figure 36 and Figure 37. Gerber files and additional application information are available.
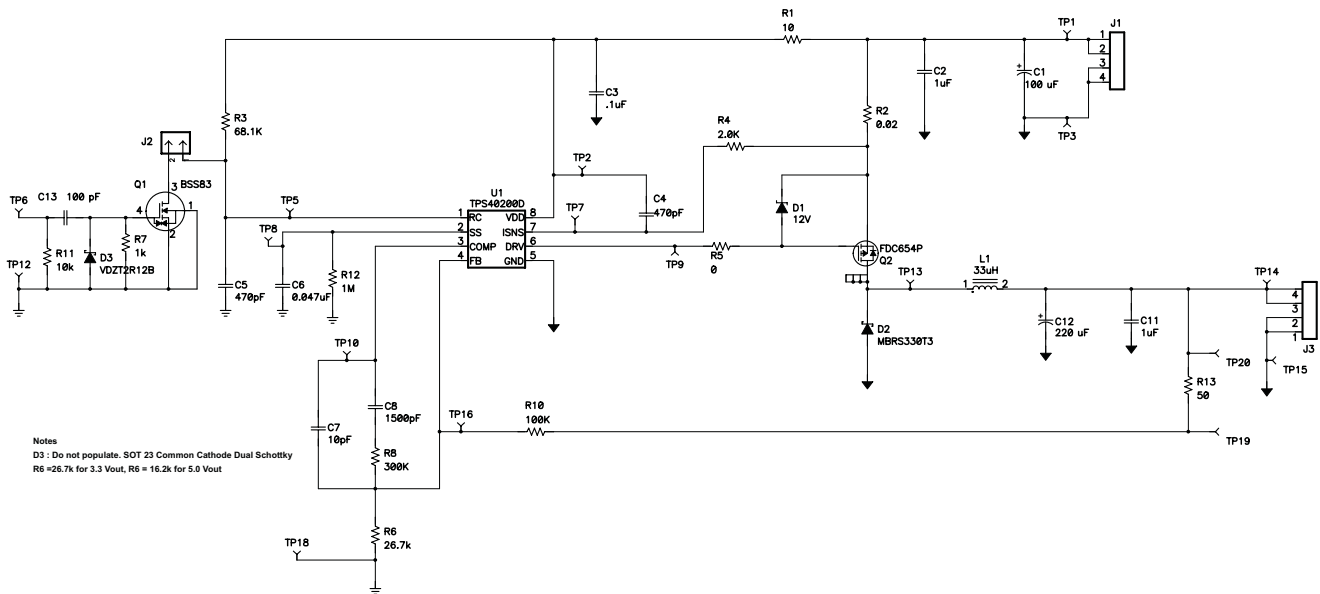
Figure 35. 8-V to 16-V V_{IN} Step-Down Buck Converter
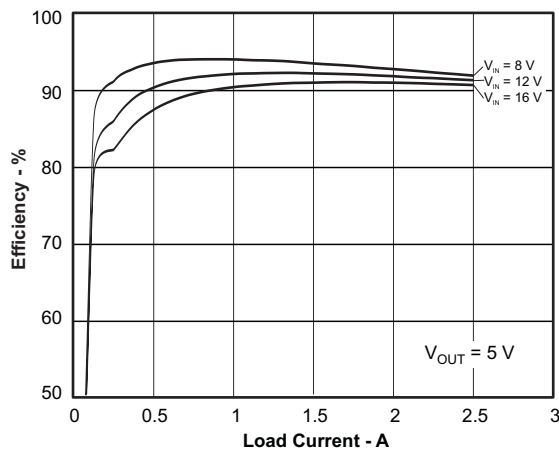
Figure 36. Full-Load Efficiency at 5-V V_{OUT}
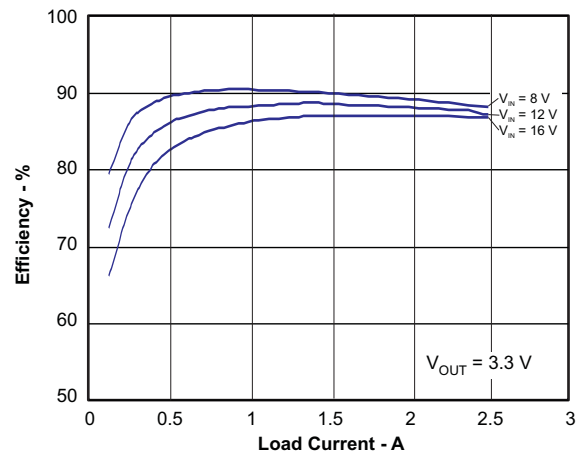
Figure 37. Full-Load Efficiency at 3.3-V V_{OUT}

Component Selection

Table 2. Design Parameters

SYMBOL	PARAMETER	TEST CONDITIONS	MIN	NOM	MAX	UNIT
V_{IN}	Input voltage		8.0	12	16.0	V
V_{OUT}	Output voltage	I_{OUT} at 2.5 A	3.200	3.3	3.400[1]	V
	Line regulation	~0.2 % V_{OUT}	3.293	3.3	3.307	V
	Load regulation	~0.2% V_{OUT}	3.293	3.3	3.307	V
V_{OUT}	Output voltage	I_{OUT} at 2.5 A	4.85	5.0	5.150[1]	V
	Line regulation	~0.2% V_{OUT}	4.990	5.0	5.010	V
	Load regulation	~0.2% V_{OUT}	4.990	5.0	5.010	V
V_{RIPPLE}	Output ripple voltage	At maximum output current		60		mV
V_{OVER}	Output overshoot	For 2.5-A load transient from 2.5 A to 0.25 A		100		mV
V_{UNDER}	Output undershoot	For 2.5-A load transient from 0.25 A to 2.5 A		60		mV
I_{OUT}	Output current		0.125		2.5	A
I_{SCP}	Short-circuit current trip point		3.75		5.00	A
	Efficiency	At nominal input voltage and maximum output current		90		%
F_S	Switching frequency			300		kHz

(1) Set-point accuracy is dependent on external resistor tolerance and the IC reference voltage. Line and load regulation values are referenced to the nominal design output voltage.

FET Selection Criteria

1. The maximum input voltage for this application is 16 V. Switching the inductor causes overshoot voltages that can equal the input voltage. Because the R_{DSON} of the FET rises with breakdown voltage, select a FET with the lowest breakdown voltage possible. In this case, a 30-V FET was selected.

2. The selection of a power FET's size requires knowing both the switching losses and dc losses in the application. AC losses are all frequency dependent and directly related to device capacitances and device size. On the other hand, dc losses are inversely related to device size. The result is an optimum where the two types of losses are equal. Because device size is proportional to R_{DSON}, a starting point is to select a device with an R_{DSON} that results in a small loss of power relative to package thermal capability and overall efficiency objectives.

3. In this application, the efficiency target is 90% and the output power 8.25 W. This gives a total power-loss budget of 0.916 W. Total FET losses must be small relative to this number.

The dc conduction loss in the FET is given by:

$$P_{DC} = I_{rms}^2 \times R_{DSON}$$

The RMS current is given by:

$$I_{rms} = \left[D \times \left(I_{OUT}^2 + \frac{\Delta I_{pp}^2}{12} \right) \right]^{\frac{1}{2}}$$

Where:
$\Delta I_{pp} = \Delta V \times D \times (t_s/L_I)$
$\Delta V = V_{IN} - V_{OUT} - (DCR + R_{DSON}) \times I_{OUT}$
R_{DSON} = FET on-state resistance
DCR = inductor dc resistance
D = duty cycle
t_S = reciprocal of the switching frequency

Using the values in this example, the dc power loss is 129 mW. The remaining FET losses are:
- P_{SW} – The power dissipated while switching the FET on and off
- P_{gate} – The power dissipated driving the FET's gate capacitance
- P_{COSS} – The power switching the FET's output capacitance

The total power dissipated by the FET is the sum of these contributions:

$$P_{FET} = P_{SW} + P_{gate} + P_{COSS} + P_{RDSON}$$

The P-channel FET used in this application is a FDC654P with the following characteristics:

$t_{rise} = 13 \times 10^{-9}$ $C_{OSS} = 83 \times 10^{-12}$

$t_{fall} = 6 \times 10^{-9}$ $Q_g = 9$ nC

$R_{DSON} = 0.1\ \Omega$ $V_{gate} = 1.9$ V

$Q_{gd} = 1.2 \times 10^{-9}$ $Q_{gs} = 1.0 \times 10^{-9}$

Using these device characteristics and the following formulas, P_{SW} is calculated as:

$$P_{SW} = \frac{f_S}{2} \times \left(V_{IN} \times I_{pk} \times t_{CHON} \right) + \frac{f_S}{2} \left(V_{IN} \times I_{pk} \times t_{CHOFF} \right) \quad = 10 \text{ mW}$$

(4)

Where $t_{CHON} = \dfrac{Q_{GD} \times R_G}{V_{IN} - V_{TH}}$ and $t_{CHOFF} = \dfrac{Q_{GD} \times R_G}{V_{IN}}$ are the switching times for the power FET.

$$P_{GATE} = Q_G \times V_{GATE} \times f_S = 22 \text{ mW}$$

(5)

$$P_{COSS} = \frac{C_{OSS} \times V_{IN\_MAX}^2 \times f_S}{2} = 2 \text{ mW}$$

(6)

$I_G = Q_G \times f_S = 2.7$ mA is the gate current.

The sum of the switching losses is 34 mW and is comparable to the 129-mW dc losses. At added expense, a slightly larger FET would be better, because the dc loss would drop and the ac losses would increase, with both moving toward the optimum point of equal losses.

Rectifier Selection Criteria

- Rectifier breakdown voltage

  The rectifier must withstand the maximum input voltage, which, in this case, is 16 V. To allow for switching transients that can approach the switching voltage, a 30-V rectifier was selected.

- Diode size

  The importance of power losses from the Schottky rectifier (D2) is determined by the duty cycle. For a low duty-cycle application, the rectifier is conducting most of the time, and the current that flows through it times its forward drop can be the largest component of loss in the entire controller. In this application, the duty cycle ranges from 20% to 40%, which, in the worst case, means that the diode is conducting 80% of the time. Where efficiency is of paramount importance, choose a diode with as low a forward drop as possible. In more cost-sensitive applications, size may be reduced to the point of the thermal limitations of the diode package.

  The device in this application is large relative to the current required by the application. In a more cost-sensitive application, a smaller diode in a less-expensive package could provide a less-efficient but appropriate solution.

  The device used has the following characteristics:

- V_f = 0.3 V at 3 A
- C_t = 300 pF (C_t = effective reverse voltage capacitance of the synchronous rectifier, D2)

The two components of the losses from the diode D2 are:

$$P_{COND} = V_f \times \left(I_{OUT} + \frac{I_{RIPPLE}}{4} \right) \times (1 - D) = 653 \text{ mW}$$

Where:

> D = the duty cycle
> I_{RIPPLE} = ripple current
> I_{OUT} = output current
> V_F = forward voltage
> P_{COND} = conduction power loss

The switching capacitance of this diode adds an ac loss, given by Equation 7:

$$P_{SW} = \frac{1}{2} \left[C \times (V_{IN} + V_f)^2 \times f \right] = 6.8 \text{ mW} \tag{7}$$

This additional loss raises the total loss to 660 mW.

At an output voltage of 3.3 V, the application runs at a nominal duty cycle of 27%, and the diode is conducting 72.5% of the time. As the output voltage is moved up to 5 V, the on time increases to 46%, and the diode is conducting only 54% of the time during each clock cycle. This change in duty cycle proportionately reduces the conduction power losses in the diode. This reduction may be expressed as 660(0.54/0.725) = 491 mW, for a savings in power of 660 – 491 = 169 mW.

To illustrate the relevance of this power savings, measure the full-load module efficiency for this application at 3.3 V and 5 V. The 5-V output efficiency is 92%, compared to 89% for the 3.3-V design. This difference in efficiency represents a 456-mW reduction in losses between the two conditions. This 169-mW power-loss reduction in the rectifier represents 37% of the difference.

Inductor Selection Criteria

The TPS40200 P-FET driver facilitates switching the power FET at a high frequency. This, in turn, enables the use of smaller less-expensive inductors as illustrated in this 300-kHz application. Ferrite, with its good high-frequency properties, is the material of choice. Several manufacturers provide catalogs with inductor saturation currents, inductance values, and LSRs (internal resistance) for their various-sized ferrites.

In this application, the part must deliver a maximum current of 2.5 A. This requires that the output inductor's saturation current be above 2.5 A plus one-half the ripple current caused during inductor switching. The value of the inductor determines this ripple current. A low value of inductance has a higher ripple current that contributes to ripple voltage across the resistance of the output capacitors. The advantages of a low inductance are a higher transient response, lower DCR, a higher saturation current, and a smaller less-expensive part. Too low an inductor, however, leads to higher peak currents, which ultimately are bounded by the overcurrent limit set to protect the output FET or by output ripple voltage. Fortunately, with low-ESR ceramic capacitors on the output, the resulting ripple voltage for relatively high ripple currents can be small.

For example, a single 1-µF 1206-sized 6.3-V ceramic capacitor has an internal resistance of 2 Ω at 1 MHz. For this 2.5-A application, a 10% ripple current of 0.25 A produces a 50-mV ripple voltage. This ripple voltage may be further reduced by additional parallel capacitors.

The other bound on inductance is the minimum current at which the controller enters discontinuous conduction. At this point, inductor current is zero. The minimum output current for this application is specified at 0.125 A. This average current is one-half the peak current that must develop during a minimum on time. The conditions for minimum on time are high line and low load.

L_{MAX} is calculated using:

$$L_{MAX} = \frac{V_{IN} - V_{OUT}}{I_{PEAK}} \times t_{ON} = 32 \ \mu H$$

Where:

V_{IN} = 16 V
V_{OUT} = 3.3 V
I_{PEAK} = 0.25 A
t_{ON} = 0.686 µs

t_{ON} is given by $\dfrac{1}{300 \ kHz} \times \dfrac{3.3 \ V}{16 \ V}$

The inductor used in the circuit is the closest standard value of 33 µH. This is the maximum inductance that can be used in the converter to deliver the minimum current while maintaining continuous conduction.

Output Capacitance

In order to satisfy the output voltage overshoot and undershoot specifications, there must be enough output capacitance to keep the output voltage within the specified voltage limits during load current steps.

In a situation where a full load of 2.5 A within the specified voltage limits is suddenly removed, the output capacitor must absorb energy stored in the output inductor. This condition may be described by realizing that the energy in the stored in the inductor must be suddenly absorbed by the output capacitance. This energy relationship is written as:

$$\frac{1}{2} \times L_O I_O{}^2 \le \frac{1}{2} \times \left[C_O \left(V_{OS}{}^2 - V_O{}^2 \right) \right]$$

Where:

V_{OS} = allowed over-shoot voltage above the output voltage
L_O = inductance
I_O = output current
C_O = output capacitance
V_O = output voltage

In this application, the worst-case load step is 2.25 A, and the allowed overshoot is 100 mV. With a 33-µH output inductor, this implies an output capacitance of 249 µF for a 3.3-V output and 165 µF for a 5-V output.

When the load increases from minimum to full load, the output capacitor must deliver current to the load. The worst case is for a minimum on time that occurs at 16 V in, 3.3 V out, and minimum load. This corresponds to an off time of (1 − 0.2) times the period 3.3 µs and is the worst-case time before the inductor can start supplying current. This situation may be represented by:

$$\Delta V_O < \Delta I_O \times \frac{t_{OFFMAX}}{C_O}$$

Where:

ΔV_O = undershoot specification of 60 mV

ΔI_O = load current step

t_{OFFMAX} = maximum off time

This condition produces a requirement of 100 µF for the output capacitance. The larger of these two requirements becomes the minimum value of output capacitance.

The ripple current develops a voltage across the ESR of the output capacitance, so another requirement on this component is that its ESR be small relative to the ripple voltage specification.

Switching Frequency

The TPS40200 has a built-in 8-V 200-mA P-channel FET-driver output that facilitates using P-channel switching FETs. A clock frequency of 300 kHz was chosen as a switching frequency that represents a compromise between a high frequency that allows the use of smaller capacitors and inductors, but one that is not so high as to cause excessive transistor switching losses. As previously discussed, an optimum frequency can be selected by picking a value where the dc and switching losses are equal.

The frequency is set by using the design formula given in the FET Selection Criteria section.

$$R_{RC} \times C_{RC} = \frac{1}{0.105 \times f_{SW}}$$

Where:

R_{RC} = timing resistor value in ohms or R_{RC} = 68.1 kΩ
C_{RC} = timing capacitor value in F or C5 = 470 pF
f_{SW} = desired switching frequency in Hz, which in this case calculates to 297 kHz

At a worst case of 16 V, the timing resistor draws about 250 µA, which is well below the 750-µA maximum that the circuit can pull down.

Programming the Overcurrent Threshold Level

The current limit in the TSP40200 is triggered by a comparator with a 100-mV offset whose inputs are connected across a current-sense resistor between V_{CC} and the source of the high-side switching FET. When current in this resistor develops more than 100 mV, the comparator trips and terminates the output gate drive.

In this application, the current-limit resistor is set by the peak output stage current, which consists of the maximum load current plus one-half the ripple current. In this case, 2.5 + 0.125 = 2.625 A. To accommodate tolerances, a 25% margin is added, giving a 3.25-A peak current. Using the equation in Figure 38 yields a value for R_{ILIM} of 0.30 Ω.

Current sensing in a switching environment requires attention to both circuit board traces and noise pickup. In the design shown, a small RC filter has been added to the circuit to prevent switching noise from tripping the current-sense comparator. The requirements of this filter are board dependent but, with the layout used in this application, no spurious overcurrent was observed.

$$ILIM = \frac{0.1}{R_{ILIM}}$$
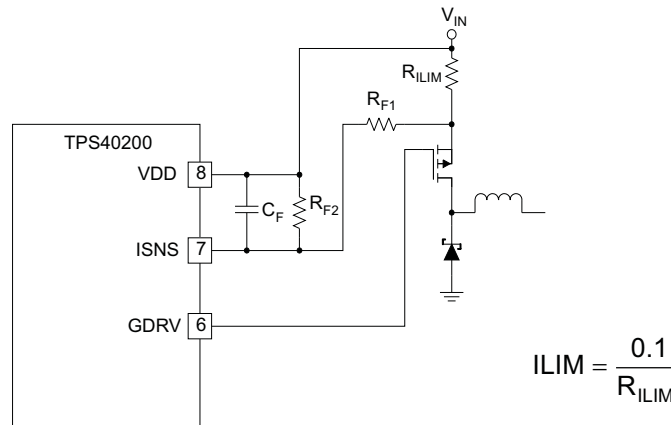
Figure 38. Overcurrent Trip Circuit for R_{F2} Open

Soft-Start Capacitor

The soft-start interval is given (in pF) by:

$$C_{SS} = \frac{t_{SS}}{R \times \ln\left(\dfrac{V_{SST}}{V_{SST} - 1.4}\right)} \times 10^3$$

Where:

R = internal 105-kΩ charging resistor

V_{CC} = input voltage up to 8 V, where the charging voltage is internally clamped to 8 V maximum

V_{OS} = 700 mV, and (because the input voltage is 12 V) V_{SST} = 8 V

The oscilloscope picture (see Figure 39) shows the expected delay at the output (middle trace) until the soft-start node (bottom trace) reaches 700 mV. At this point, the output rises following the exponential rise of the soft-start capacitor voltage until the soft-start capacitor reaches 1.4 V and the internal 700-mV reference takes over. This total time is approximately 1 ms, which agrees with the calculated value of 0.95 ms when the soft-start capacitance is 0.047 µF.
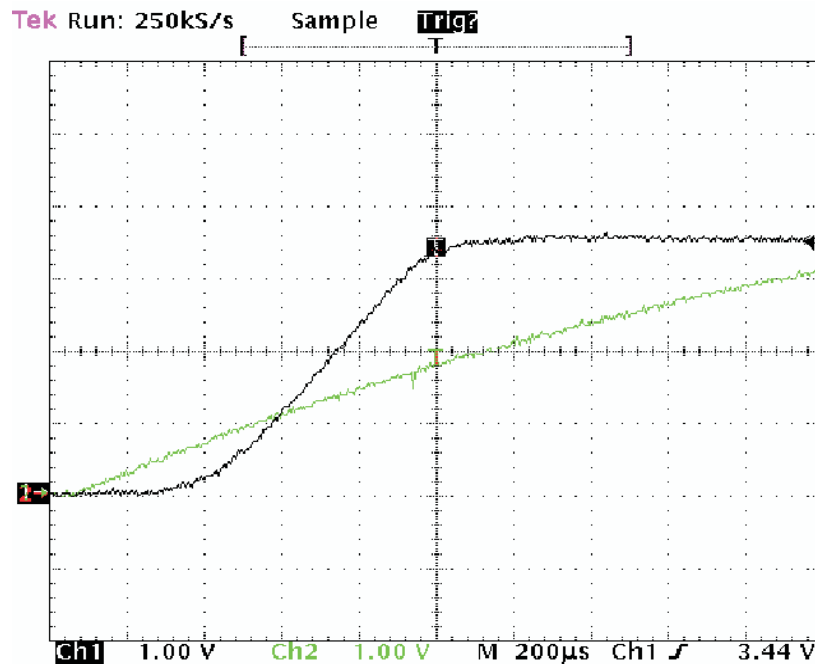
A. Channel 1 is the output voltage rising to 3.3 V.

B. Channel 2 is the soft-start pin.

Figure 39. Soft Start Showing Output Delay and Controlled Rise to Programmed Output Voltage

Frequency Compensation

The four elements that determine the system overall response are discussed in this section. The gain of the error amplifier (K_{EA}) is the first of these elements. Its output develops a control voltage that is the input to the PWM.

The TPS40200 has a unique modulator that scales the peak-to-peak amplitude of the PWM ramp to be 0.1 times the value of the input voltage. Because modulator gain is given by V_{IN} divided by V_{RAMP}, the modulator gain is 10 and is constant at 10 (20 dB) over the entire specified input-voltage range.

The last two elements that affect system gain are the transfer characteristic of the output LC filter and the feedback network from the output to the input to the error amplifier.

These four elements may be expressed by the following equation that represents the system transfer function as shown in Figure 40.

$$T_{V(S)} = K_{FB} \times K_{EA}(S) \times K_{PWM} \times X_{LC}(S)$$

Where:

K_{FB} = output voltage setting divider
K_{EA} = error amplifier feedback
K_{PWM} = modulator gain
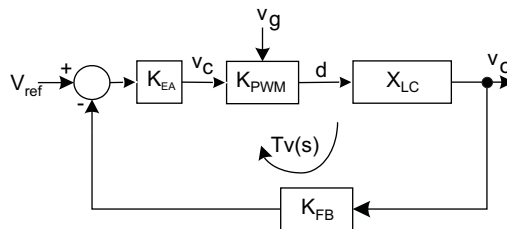X_{LC} = filter transfer function

Figure 40. Control Loop

Figure 41 shows the feedback network used in this application. This is a type-2 compensation network, which gives a combination of good transient response and phase boost for good stability. This type of compensation has a pole at the origin, causing a –20-dB/decade (–1) slope, followed by a zero that causes a region of flat gain, followed by a final pole that returns the gain slope to –1. The Bode plot in Figure 42 shows the effect of these poles and zeros.

The procedure for setting up the compensation network is:
1. Determine the break frequency of the output capacitor.
2. Select a zero frequency well below this break frequency.
3. From the gain bandwidth of the error amplifier, select a crossover frequency at which the amplifier gain is large relative to expected closed-loop gain.
4. Select a second zero well above the crossover frequency that returns the gain slope to a –1 slope.
5. Calculate the required gain for the amplifier at crossover.

Be prepared to iterate this procedure to optimize the pole and zero locations as needed.
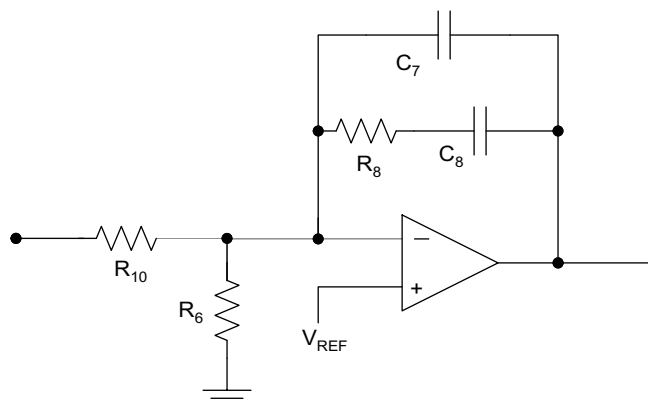
Figure 41. Error Amplifier Feedback Elements

The frequency response of this converter is largely determined by two poles that arise from the LC output filter and a higher-frequency zero caused by the ESR of the output capacitance. The poles from the output filter cause a 40-dB/decade rolloff with a phase shift approaching 180°, followed by the output capacitor zero that reduces the roll off to –20 dB and gives a phase boost back toward 90°. In other nomenclature, this is a –2 slope followed by a –1 slope. The two zeros in the compensation network act to cancel the double pole from the output filter. The compensation network's two poles produce a region in which the error amplifier is flat and can be set to a gain such that the overall gain of the system is 0 dB. This region is set so that it brackets the system crossover frequency.
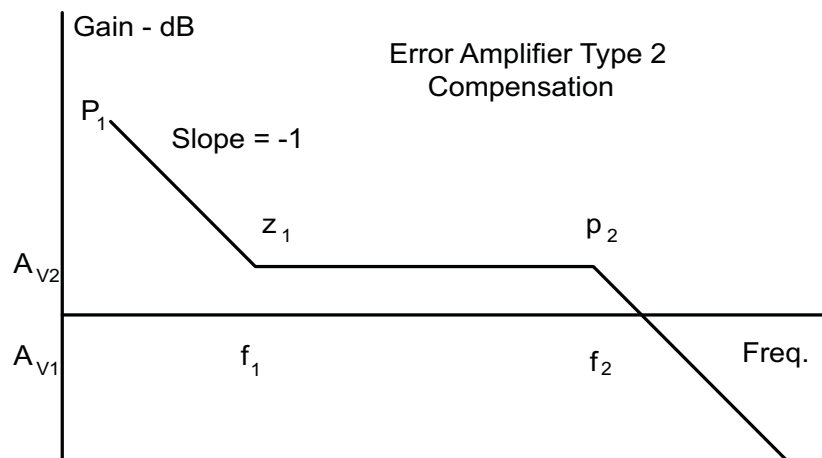
Figure 42. Error Amplifier Bode Plot

In order to properly compensate this system, it is necessary to know the frequencies of its poles and zeros.

Step 1

The break frequency of the output capacitor is given by:

$$F_{esr} = \frac{1}{2\pi R_{esr} C}$$

Where:

C = the output capacitor

R_{ESR} = the ESR of the capacitors

Because of the ESR of the output capacitor, this output filter has a single-pole response above the 1.8-kHz break frequency of the output capacitor and its ESR. This simplifies compensation since the system becomes essentially a single-pole system.

Step 2

The first zero is place well below the 1.8-kHz break frequency of the output capacitor and its ESR. Phase boost from this zero is shown in Figure 44.

$$f_{Z1} = \frac{1}{2\pi R_8 C_8}$$

Where:

R_8 = 300 kΩ

C_8 = 1500 pF

F_{Z1} = 354 Hz

Step 3

From a minimum gain bandwidth product of 1.5 MHz, and knowing it has a 20-dB/decade rolloff, the open-loop gain of the error amplifier is 33 dB at 35 kHz. This approximate frequency is chosen for a crossover frequency to keep the amplifier gain contribution to the overall system gain small, as well as following the convention of placng the crossover frequency between 1/6 to 1/10 the 300 kHz switching frequency.

Step 4

The second pole is placed well above the 35-kHz crossover frequency.

$$f_{P2} = \frac{1}{2\pi \times C_7 \times C_8 \times R_8} \times (C_7 + C_8)$$

Where:

R_8 = 300 kΩ

C_7 = 10 pF

C_8 = 1500 pF

f_{P3} = 53 kHz

Step 5

Calculate the gain elements in the system to determine the gain required by the error amplifier to make the overall gain 0 dB at 35 kHz:

$$T_{V(S)} = K_{FB} \times K_{EA}(S) \times K_{PWM} \times X_{LC}(S)$$

Where:
> K_{FB} is the output voltage setting divider
> K_{EA} is the error amplifier feedback
> K_{PWM} is the modulator gain
> X_{LC} is the filter transfer function

With reference to Figure 43, the output filter's transfer characteristic $X_{LC}(S)$ can be estimated by the following:
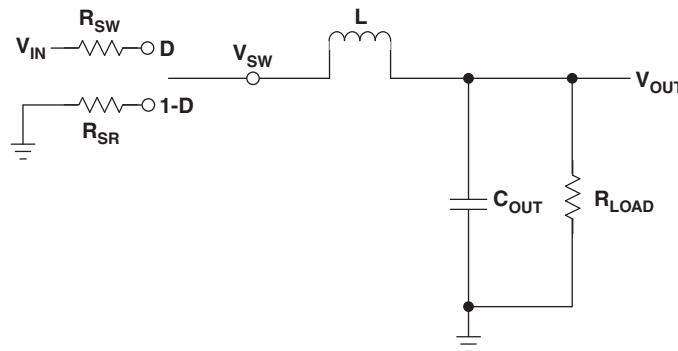
Figure 43. Output Filter Analysis

$$X_{LC}(S) = \frac{Z_{OUT}(S)}{Z_{OUT}(S) + Z_L(S) + R_{SW} \times D + R_{SR} \times (1-D)}$$

Where:
> Z_{OUT} is the parallel combination of output capacitor(s) and the load
> R_{SW} is the $R_{DS(on)}$ of the switching FET plus the current-sense resistor
> R_{SR} is the resistance of the synchronous rectifier
>   D is the duty cycle estimated as 3.3 / 12 = 0.27

To evaluate $X_{LC}(S)$ at 35 kHz use the following:
- $Z_{OUT}(S)$ at 35 kHz, which is dominated by the output capacitorr's ESR; estimated to be 400 mΩ
- $Z_L(S)$ at 35 KHz is 7.25 Ω
- R_{SW} = 0.95 mΩ, including the R_{LIM} resistance
- R_{SR} = 100 mΩ

Using these numbers, $X_{LC}(S)$ = 0.04 or -27.9 dB.

The feedback network has a gain to the error amplifier given by:

$$K_{fb} = \frac{R_{10}}{R_6}$$

Where for 3.3 V_{OUT}, R6 = 26.7 kΩ

Using the values in this application, K_{fb} = 11.4 dB.

The modulator has a gain of 10 that is flat to well beyond 35 kHz, so K_{PWM} = 20 dB.

To acheive 0 dB overall gain, the amplifier and feedback gain must be set to 7.9 dB (20 dB - 27.9 dB)

The amplifier gain, including the feedback gain, K_{fb}, can be approximated by this expression:

$$\frac{V_{OUT}}{V_{IN}}(S) = \frac{A_{VOL}}{1 + \dfrac{R_{10}}{R_8} + \dfrac{R_{10}}{Z_{FS}} \times (1 + A_{VOL})}$$

Where:

Z_{FS} is the parallel combination of C_7 in parallel with the sum of R_8 and the impedance of C_8

A_{VOL} is the open-loop gain of the error amplifier at 35 kHz, which is 44.6 or 33 dB

Figure 44 shows the result of the compensation. The crossover frequency is 35 kHz, and the phase margin is 45°. The response of the system is dominated by the ESR of the output capacitor and is exploited to produce an essentially single-pole system with simple compensation.
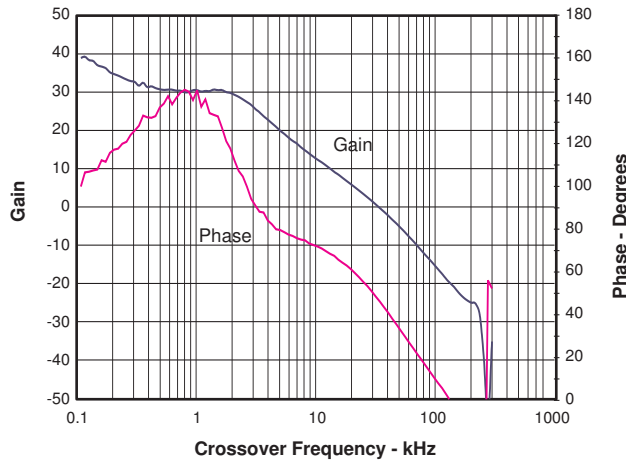

Figure 44. Overall System Gain and Phase Response

Figure 44 also shows the phase boost that gives the system a crossover phase margin of 47°.

The bill of materials for this application is shown in Table 3. Gerber PCB layout files and additional application information are available from the factory.

Table 3. Bill of Materials, Buck Regulator, 12 V to 3.3 V and 5 V

REF	VALUE	DESCRIPTION	SIZE	MFR	PART NUMBER
C1	100 µF	Capacitor, Aluminum, SM, 25 V, 0.3 Ω	8 mm × 10 mm	Sanyo	20SVP100M
C12	220 µF	Capacitor, Aluminum, SM, 6.3 V, 0.4 Ω	8 mm × 6.2 mm	Panasonic	EEVFC0J221P
C13	100 pF	Capacitor, Ceramic, 50 V, [COG], [20%]	603	muRata	Std.
C3	0.1 pF	Capacitor, Ceramic, 50 V, [X7R], [20%]	603	muRata	Std.
C2, C11	1 µF	Capacitor, Ceramic, 50 V, [X7R], [20%]	603	muRata	Std.
C4, C5	470 pF	Capacitor, Ceramic, 50 V, [X7R], [20%]	603	muRata	Std.
C6	0.047 µF	Capacitor, Ceramic, 50 V, [X7R], [20%]	603	muRata	Std.
C7	10 pF	Capacitor, Ceramic, 50 V, [COG], [20%]	603	muRata	Std.
C8	1500 pF	Capacitor, Ceramic, 50 V, [X7R], [20%]	603	muRata	Std.
D1	12 V	Diode, Zener, 12 V, 350 mW	SOT23	Diodes, Inc.	BZX84C12T
D2		Diode, Schottky, 30 A, 30 V	SMC	On Semi	MBRS330T3
D3	12 V	Diode Zener, 12 V, 5 mA	VMD2	Rohm	VDZT2R12B
J1,J3		Terminal Block, 4 Pin, 15 A, 5.1 mm	0.8 × 0.35	OST	ED2227
J2		Header, 2 pin, 100-mil spacing (36-pin strip)	0.100 × 2	Sullins	PTC36SAAN
L1	33 µH	Inductor, SMT, 3.2 A, 0.039 Ω	12.5 × 12.5 mm	TDK	SLF12575T330M3R2PF
PCB		2-Layer PCB 2-Ounce Cu	1.4 × 2.12 × 0.062		HPA164
Q1		Trans, N-Chan Enhancement Switching, 50 mA	SOT-143B	Phillips	BSS83
Q2		MOSFET, P-ch, 30 V, 3.6 A, 75 mΩ	SuperSOT-6	Fairchild	FDC654P
U1		IC, Low Cost Non-Sync Buck Controller	SO-8	TI	TPS40200D
R1	10 Ω	Resistor, Chip, 1/16 W, 1%	603	Std.	Std.
R10	100 kΩ	Resistor, Chip, , 1/16W, 1%	603	Std.	Std.
R11	10 kΩ	Resistor, Chip, 1/16 W, 1%	603	Std.	Std.
R12	1 MΩ	Resistor, Chip, 1/16 W, 1%	603	Std.	Std.
R13	49.9 Ω	Resistor, Chip, 1/16 W, 1%	603	Std.	Std.
R2	0.02 Ω	Resistor, Chip, 1/16 W, 5%	2010	Std.	Std.
R3	68.1 kΩ	Resistor, Chip, 1/16 W, 1%	603	Std.	Std.
R4	2.0 kΩ	Resistor, Chip, 1/16 W, 1%	603	Std.	Std.
R5	0 Ω	Resistor, Chip, 1/16 W, 1%	603	Std.	Std.
R6	26.7 kΩ	Resistor, Chip, 1/16 W, 1%	603	Std.	Std.
R7	1.0 kΩ	Resistor, Chip, 1/16 W, 1%	603	Std.	Std.
R8	300 kΩ	Resistor, Chip, 1/16 W, 1%	603	Std.	Std.

PCB Plots

Figure 45 through Figure 47 show the design of the TPS40200EVM-001 printed circuit board. The design uses 2-layer 2-oz copper and is 1.4 in × 2.3 in. All components are mounted on the top side to allow the user to easily view, probe, and evaluate the TPS40200 control IC in a practical application. Moving components to both sides of the PCB or using additional internal layers can offer additional size reduction for space-constrained applications.
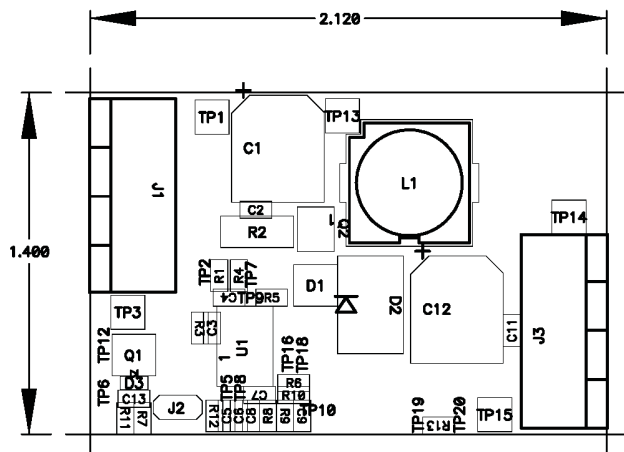
Figure 45. TPS40200EVM-001 Component Placement (Viewed From Top)
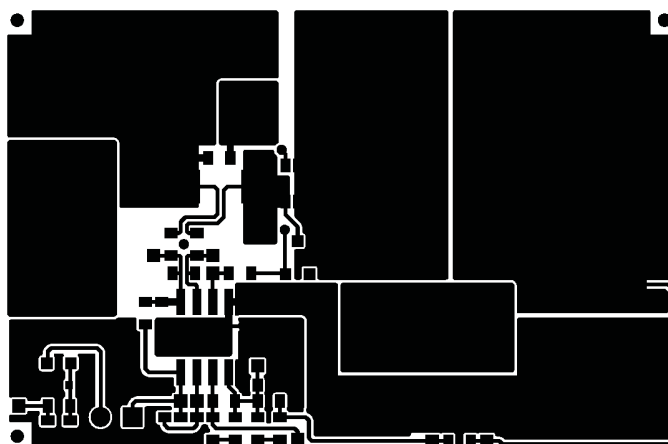
Figure 46. TPS40200EVM001 Top Copper (Viewed From Top)

Figure 47. TPS40200EVM-001 Bottom Copper (X-Ray View From Top)

Application 2: 18-V to 50-V Input, 16-V Output at 1 A

This is an example of using the TPS40200 in a higher voltage application. The output voltage is 16 V at 1 A with an 18-V to 50-V input. Module boards built to this schematic and a test report are available.

Test Results

The efficiency and load regulation from boards built from this design are shown in Figure 49 and Figure 50. Further information and support material is available.
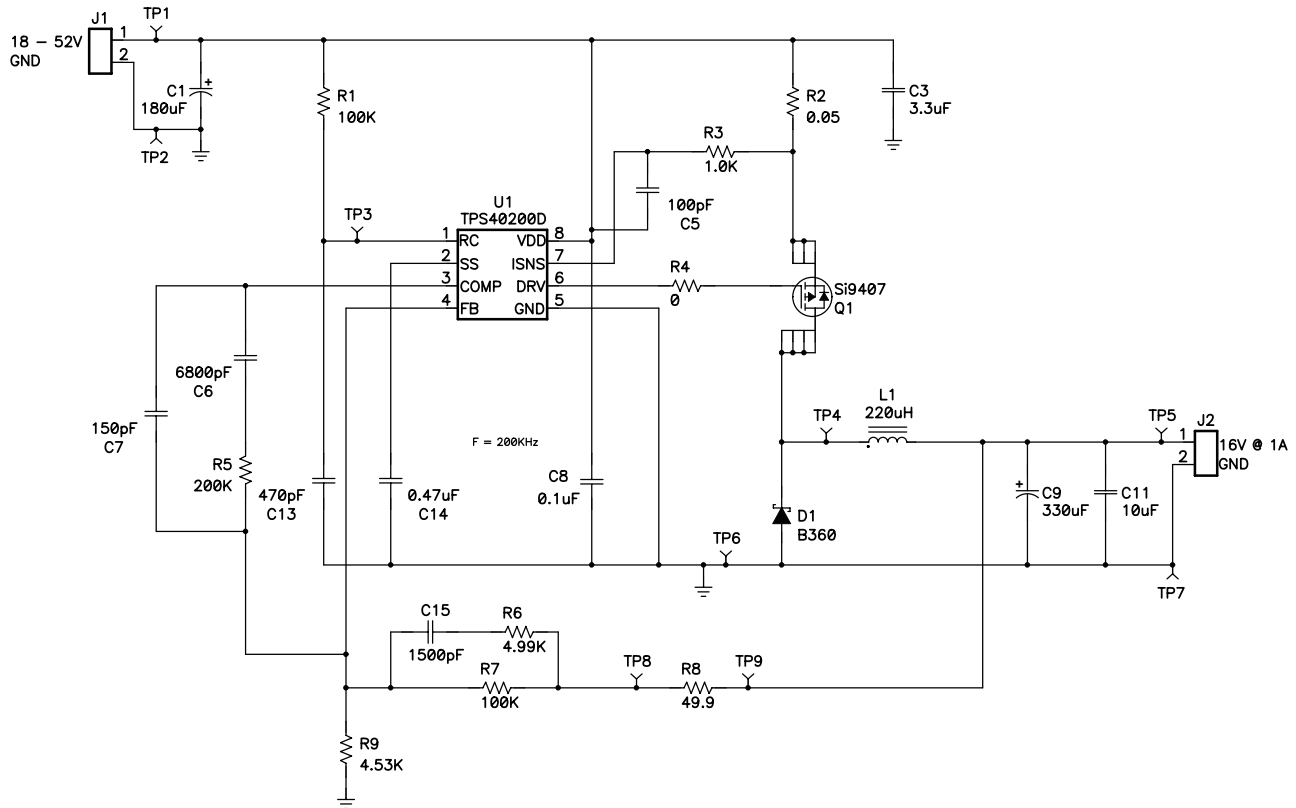
Figure 48. Buck Converter: V_{IN} = 18 V to 50 V, V_{OUT} = 16 V at 1 A
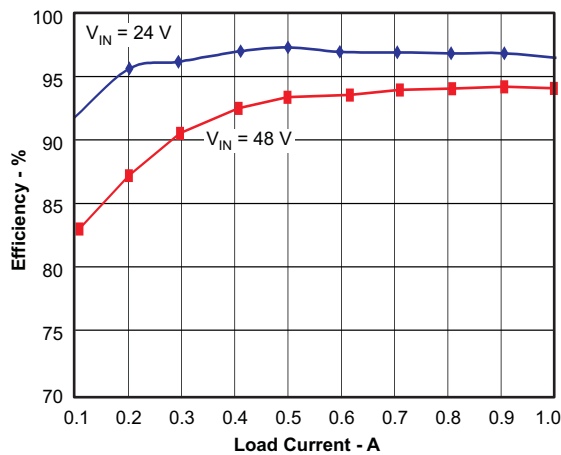
Figure 49. Efficiency vs Load
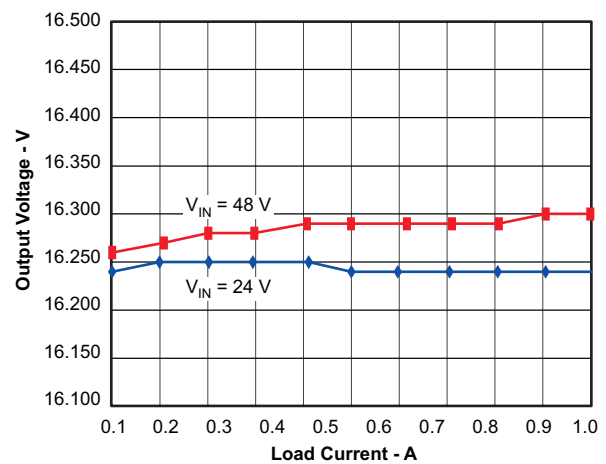
Figure 50. Load Regulation, Two Input Voltage Extremes

Application 3: Wide-Input-Voltage LED Constant-Current Driver

This application uses the TPS40200 as a buck controller that drives a string of LED diodes. The feedback point for this circuit is a sense resistor in series with this string. The low 0.7-V reference minimizes power wasted in this resistor and maintains the LED current at a value given by 0.7 V/R_{SENSE}. As the input voltage is varied, the duty cycle changes to maintain the LED current at a constant value, so that the light intensity does not change with large input-voltage variations.
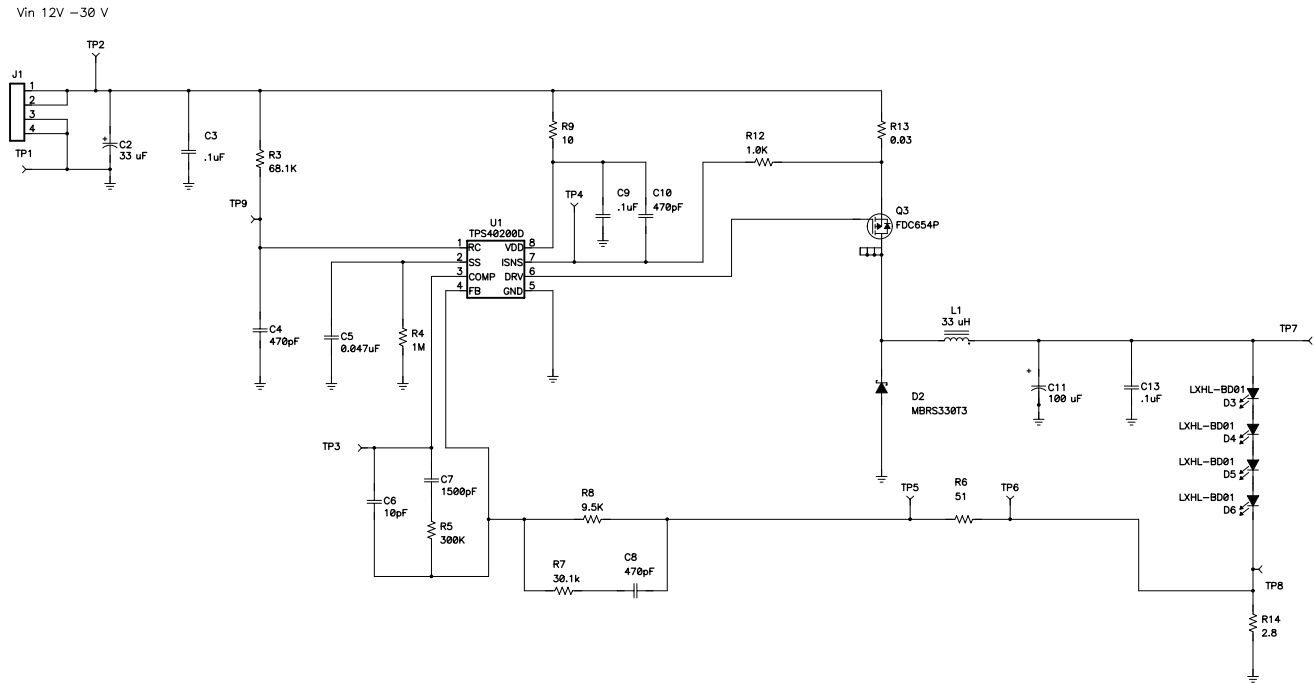
Figure 51. Wide-Input-Voltage Range LED Driver
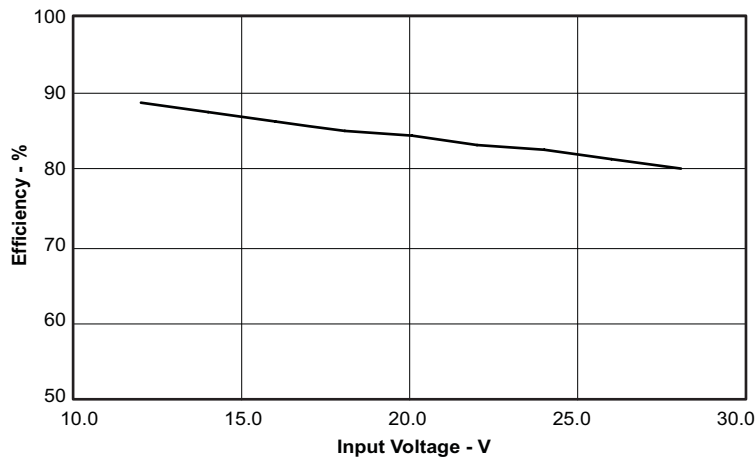
Figure 52. Efficiency vs Input Voltage

DESIGN REFERENCES

PCB Layout Recommendations
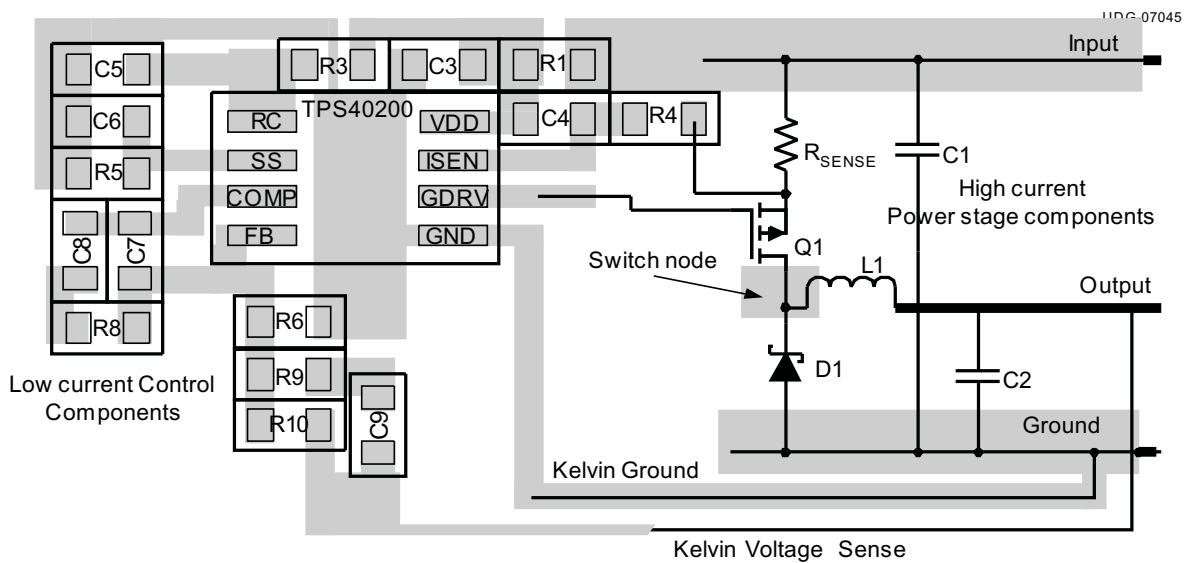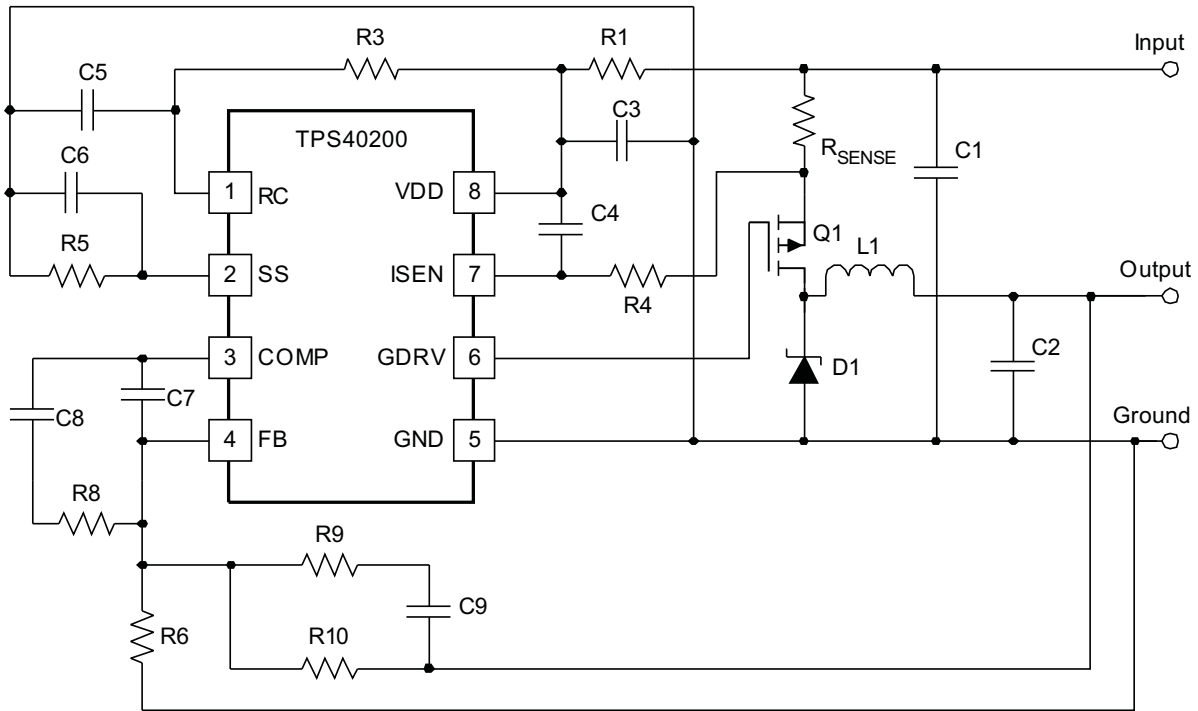
Figure 53. PCB Layout Recommendations

Layout Hints

*   AC current loops must be kept as short as possible. For the maximum effectiveness from C1, place it near the VDD pin of the controller and design the input ac loop consisting of C1-R$_{SENSE}$-Q1-D1 to be as short as possible. Excessive high-frequency noise on VDD during switching degrades overall regulation as the load increases.
*   The output loop A (D1-L1-C2) should also be kept as small as possible. Otherwise, the application's output noise performance will be degraded.
*   It is recommended that traces carrying large ac currents not be connected through a ground plane. Instead, use PCB traces on the top layer to conduct the ac current, and use the ground plane as a noise shield. Split the ground plane as necessary to keep noise away from the TPS40200 and noise-sensitive areas, such as feedback resistors R6 and R10.
*   Keep the SW node as physically small as possible to minimize parasitic capacitance and to minimize radiated emissions.
*   For good output-voltage regulation, Kelvin connections should be brought from the load to R6 and R10.
*   The trace from the R6-R10 junction to the TPS40200 should be short and kept away from any noise source, such as the SW node.
*   The gate drive trace should be as close to the power FET gate as possible.

The TPS40200 is encapsulated in a standard plastic SOIC-8 package. The typical PCB layout for this package is shown in Figure 54.
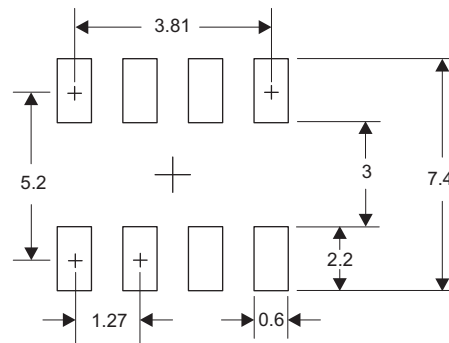
Dimensions are in millimeters

Figure 54. Suggested SOIC-8 PCB Footprint

Related Parts

*   TPS4007/9 Low-Input Synchronous Buck Controller
*   TL5001 Wide-Input-Range Controller

Reference Documents

*   *Under the Hood of Low-Voltage DC/DC Converters*, SEM1500 Topic 5, 2002 Seminar Series
*   *Understanding Buck Power Stages in Switch-Mode Power Supplies*, literature number SLVA057
*   *Design and Application Guide for High Speed MOSFET Gate Drive Circuits*, SEM 1400 – 2001 Seminar Series
*   *Designing Stable Control Loops*, SEM 1400, 2001 Seminar Series
*   http://power.ti.com
*   TPS40K - DC/DC Controller Products Designer Software. This simple design tool supports the TPS40xxx family of controllers. To order a CD from the Product Information Center, request literature number SLU015, TPS40K/SWIFT CD-ROM.

PACKAGING INFORMATION

Orderable Device	Status [1]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [2]	Lead/ Ball Finish	MSL Peak Temp [3]	Samples (Requires Login)
TPS40200QDRQ1	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Request Free Samples

[1] The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

[2] Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

[3] MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

OTHER QUALIFIED VERSIONS OF TPS40200-Q1 :

● Catalog: TPS40200

● Enhanced Product: TPS40200-EP

NOTE: Qualified Version Definitions:

● Catalog - TI's standard catalog product

● Enhanced Product - Supports Defense, Aerospace and Medical Applications

D (R−PDSO−G8)   PLASTIC SMALL OUTLINE

0.197 (5,00)
0.189 (4,80)
C

8   5

0.244 (6,20)
0.228 (5,80)

0.157 (4,00)
0.150 (3,80)
D

Pin 1
Index Area

1   4

0.050 (1,27)

0.020 (0,51)
0.012 (0,31)
⊕ 0.010 (0,25) M

0.069 (1,75) Max

0.010 (0,25)
0.004 (0,10)

0.010 (0,25)
0.005 (0,13)

Gauge Plane

0.004 (0,10)

Seating Plane

0.010 (0,25)

0°−8°

0.050 (1,27)
0.016 (0,40)

4040047−3/M   06/11

NOTES: A.   All linear dimensions are in inches (millimeters).
         B.   This drawing is subject to change without notice.
         C.   Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall
              not exceed 0.006 (0,15) each side.
         D.   Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
         E.   Reference JEDEC MS−012 variation AA.

TEXAS
INSTRUMENTS
www.ti.com

D (R−PDSO−G8)   PLASTIC SMALL OUTLINE

Example Board Layout
(Note C)

6x1,27

5,40

Stencil Openings
(Note D)

8x0,55

8x1,50

6x1,27

5,40

Example
Non Soldermask Defined Pad

0,60

1,55

0,07

All Around

Example
Pad Geometry
(See Note C)

Example
Solder Mask Opening
(See Note E)

4211283−2/E   08/12

NOTES: A.   All linear dimensions are in millimeters.
         B.   This drawing is subject to change without notice.
         C.   Publication IPC−7351 is recommended for alternate designs.
         D.   Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should
              contact their board assembly site for stencil design recommendations. Refer to IPC−7525 for other stencil recommendations.
         E.   Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

TEXAS
INSTRUMENTS
www.ti.com

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46C and to discontinue any product or service per JESD48B. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have *not* been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components which meet ISO/TS16949 requirements, mainly for automotive use. Components which have not been so designated are neither designed nor intended for automotive use; and TI will not be responsible for any failure of such components to meet such requirements.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Mobile Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2012, Texas Instruments Incorporated