

TPS54310EVM

**3-Amp Externally Compensated SWIFT™
Regulator Evaluation Module**

User's Guide

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EVM WARNINGS AND RESTRICTIONS

This EVM is designed to operate over an input voltage range of 4.0 V to 6.0 V, and over a load range of 0 A to 3 A.

It is important to operate this EVM within the specified input and output ranges described in the EVM User's Guide.

Exceeding the specified input range may cause unexpected operation and/or irreversible damage to the EVM. If there are questions concerning the input range, please contact a TI field representative prior to connecting the input power.

Applying loads outside of the specified output range may result in unintended operation and/or possible permanent damage to the EVM. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative.

During normal operation, some circuit components may have case temperatures greater than 60°C. The EVM is designed to operate properly with certain components above 60°C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during operation, please be aware that these devices may be very warm to the touch.

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Contents

1	Introduction	1-1
1.1	Background	1-2
1.2	Performance Specification Summary	1-2
1.3	Modifications	1-3
1.3.1	General	1-3
1.3.2	Switching Frequency	1-3
1.3.3	Output Voltage	1-4
1.3.4	Slow Start	1-4
1.3.5	Improving Transient Response	1-4
2	Test Setup and Results	2-1
2.1	Input/Output Connections	2-2
2.2	Loop Characterization Setup	2-3
2.3	Efficiency	2-3
2.4	Thermal Performance	2-4
2.5	Output Voltage Regulation	2-5
2.6	Load Transients	2-6
2.7	Loop Characteristics	2-7
2.8	Output Voltage Ripple	2-8
2.9	Input Ripple Voltage	2-9
2.10	Start-Up	2-10
3	Board Layout	3-1
3.1	Layout	3-2
4	Schematic and Bill of Materials	4-1
4.1	Schematic	4-2
4.2	Bill of Materials	4-3

Figures

1-1	Frequency Trimming Resistor Selection Graph	1-3
2-1	Connection Diagram	2-2
2-2	Measured Efficiency	2-3
2-3	Measured Board Losses	2-4
2-4	Measured Junction Temperature at 25°C Ambient	2-4
2-5	Measured Load Regulation	2-5
2-6	Measured Load Transient Response	2-6
2-7	Improved Load Transient Response	2-6
2-8	Improved Loop Gain and Phase	2-7
2-9	Measured Loop Gain and Phase for Alternate Compensation	2-7
2-10	Measured Output Voltage Ripple	2-8
2-11	Measured Input Voltage Ripple	2-9
2-12	Measured Start-Up Waveforms	2-10
3-1	Top Side Assembly	3-2
3-2	Bottom Side Assembly	3-3
3-3	Top Side Layout	3-4
3-4	Bottom Side Layout	3-5
4-1	TPS54310 EVM Schematic	4-2

Tables

1-1	Performance Specification Summary	1-2
1-2	Output Voltage Programming	1-4
1-3	Alternate Compensation for Improved Transient Response	1-5
4-1	TPS54310 EVM Bill of Materials	4-3

Introduction

This chapter contains background information for the TPS54310 and support documentation for the TPS54310 evaluation module. The EVM performance specifications are also given.

Topic	Page
1.1 Background	1-2
1.2 Performance Specification Summary	1-2
1.3 Modifications	1-3

1.1 Background

The TPS54310 evaluation module (EVM) uses the TPS54310 synchronous buck regulator to provide a 3.3-V output over an input range of 4.0 V to 6.0 V, and over a load range of 0 A to 3 A. Less than 0.55 square inches of board space is occupied by the electrical components of the TPS54310 circuit. Additional pads support multiple input and output capacitors. A jumper allows the switching frequency to be easily changed from 350 kHz to 550 kHz.

The MOSFETs of the TPS54310 are incorporated inside the TPS54310 package. This eliminates the need for external MOSFETs and their associated drivers. The low drain-to-source on resistance of the MOSFETs gives the TPS54310 high efficiency and helps to keep the junction temperature low at high output currents. The compensation components, external to the IC, allow for an adjustable output voltage and a customizable loop response.

1.2 Performance Specification Summary

Table 1–1 provides a summary of the TPS54310 EVM performance specifications. All specifications are given for an ambient temperature of 25°C, unless otherwise noted.

Table 1–1. Performance Specification Summary

Specification	Test Conditions	Min	Typ	Max	Units
Input voltage range		4.0	5.0	6.0	V
Output voltage set point			3.3		V
Output current range	$V_{IN} = 5\text{ V}$	0		3	A
Load regulation	$V_{IN} = 5\text{ V}$	-7		7	mV
Load transient response	$I_O = 0\text{ A to }3\text{ A}$		-95		mV _{PK}
			30†		μs
	$I_O = 3\text{ A to }0\text{ A}$		75		mV _{PK}
			25†		μs
Loop bandwidth	$V_{IN} = 5\text{ V}, I_O = 3\text{ A}$		30		kHz
Phase margin	$V_{IN} = 5\text{ V}, I_O = 3\text{ A}$		95		°
Input ripple voltage			120	200	mV _{PP}
Output ripple voltage			30	50	mV _{PP}
Output rise time		2.6	3.6	4.1	ms
Operating frequency		640	700	760	kHz
Efficiency	$V_{IN} = 5\text{ V}, I_O = 1\text{ A}$		93%		-

† Transient response time is defined as the time elapsed from the onset of the transient to the time that the output returns within ±2% of its steady state value.

1.3 Modifications

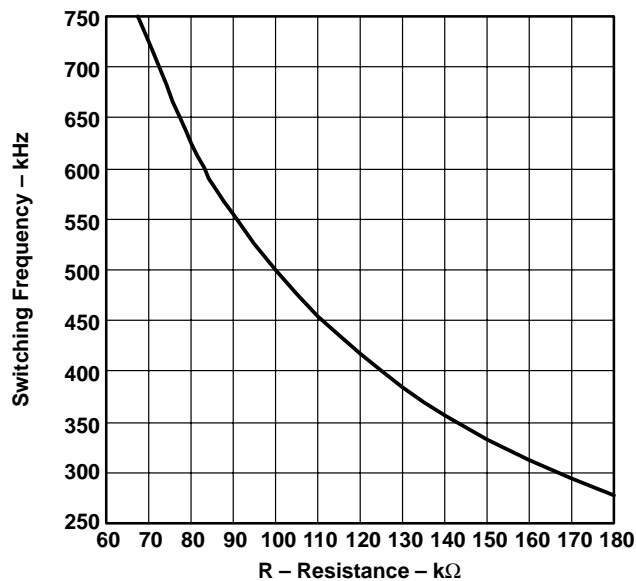
1.3.1 General

The TPS54310 EVM is designed to demonstrate the small amount of board space taken up by the TPS54310 electrical components. In addition, the EVM can be used to evaluate different output filters by substituting an alternate inductor for L1, or by using the optional pads for capacitors C2 and C11 (see Figure 3–1). When changing the output filter, the compensation values must also be changed to ensure that stability is maintained. The SWIFT Designer software tool or Texas Instruments application note SLVA109 can be used to assist in the calculation of compensation components. Both SWIFT Designer and SLVA109 are available for download at the Texas Instruments web site.

1.3.2 Switching Frequency

The TPS54310 is configured to switch at a frequency of 700 kHz. Alternatively, the EVM can be easily configured to switch at either 350 kHz or 550 kHz by removing the frequency trimming resistor R3, and placing the shunt on jumper JP1 in the proper location. Also, by changing the value of RT (R3), the switching frequency can be trimmed to any value between 280 kHz and 700 kHz. A plot of the value of RT versus the switching frequency is given in Figure 1–1.

Figure 1–1. Frequency Trimming Resistor Selection Graph



1.3.3 Output Voltage

The output voltage of the TPS54310 EVM can be adjusted to any value down to 0.9 V by changing only one component value (R4). The value of R4 for a specific output voltage can be calculated by using equation 1–1. Table 1–2 lists the value of R4 for some common bus voltages.

$$R_4 = 10 \text{ k}\Omega \times \frac{0.891 \text{ V}}{V_O - 0.891 \text{ V}} \quad (1-1)$$

Table 1–2. Output Voltage Programming

Output Voltage (V)	R4 (k Ω)
0.9	1000
1.2	28.7
1.5	14.7
1.8	9.76
2.5	5.49
3.3	3.74

1.3.4 Slow Start

The slow start time of the EVM can be modified by changing the value of C1. Use equation 1–2 to calculate the value of C1 for a specific slow start time. With C1 open, the slow start time is typically 3.6 ms. The slow start time can not be made faster than 3.6 ms.

$$C_1 = \frac{T_{SS} \times 5 \mu\text{A}}{0.891 \text{ V}} \quad (1-2)$$

1.3.5 Improving Transient Response

The feedback compensation components are R2, R4, R5, R6, C4, C5, and C6 (see Figure 4–1), and were selected based on the output of the SWIFT Designer software tool. This results in a unity gain bandwidth of 30 kHz, and a phase margin of 95° (see Figure 2–8). The TPS54310 EVM responds to a 3-A load transient within 30 μs using the compensation shown in the schematic. While this response time is more than sufficient for most applications, the response time can be made faster by changing the values of the feedback compensation components. Using the values given by Table 1–3, the unity gain bandwidth is increased to 75 kHz, and the phase margin is 72° (see Figure 2–9). With this alternate compensation, the output voltage remains within a $\pm 2\%$ regulation band during a 3-A load transient (see Figure 2–7).

Table 1–3. Alternate Compensation for Improved Transient Response

Reference Designator	Component Value
R2	15 k Ω
R4	3.74 k Ω
R5	10 k Ω
R6	1.78 k Ω
C4	33 pF
C5	1000 pF
C6	1500 pF



Test Setup and Results

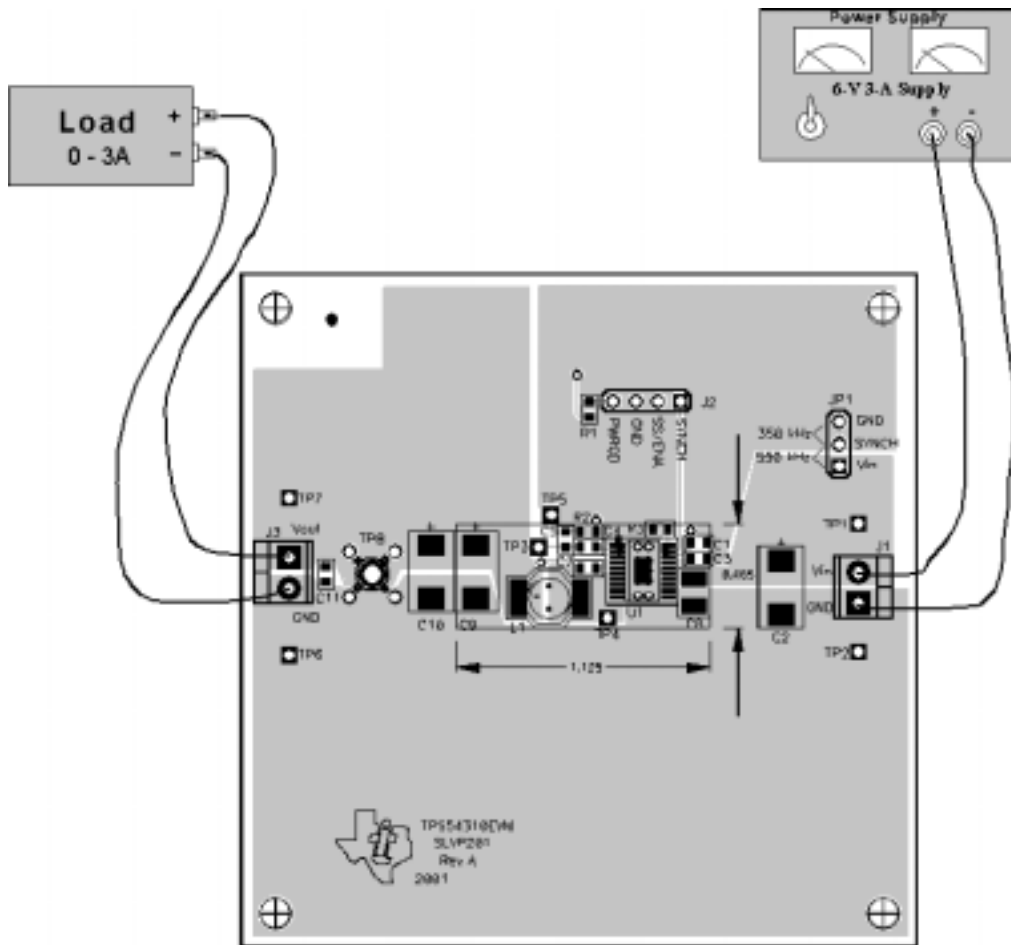
This chapter describes how to properly connect, setup, and use the TPS54310 EVM. It also presents the test results and covers efficiency, output voltage regulation, load transients, loop response, output ripple, input ripple, and start-up.

Topic	Page
2.1 Input/Output Connections	2-2
2.2 Loop Characterization Setup	2-3
2.3 Efficiency	2-3
2.4 Thermal Performance	2-4
2.5 Output Voltage Regulation	2-5
2.6 Load Transients	2-6
2.7 Loop Characteristics	2-7
2.8 Output Voltage Ripple	2-8
2.9 Input Ripple Voltage	2-9
2.10 Start-Up	2-10

2.1 Input/Output Connections

The TPS54310 EVM has the following four input/output connections: J1 (V_{in} and GND) and J3 (V_{out} and GND). A diagram showing the connection points is shown in Figure 2–1. Connect a power supply capable of supplying 3 A to J1 through a pair of 20 AWG wires. Connect the load to J3 through a pair of 20 AWG wires. Minimize wire lengths to reduce losses in the wires. Test point TP8 provides easy connection for an oscilloscope voltage probe to monitor the output voltage.

Figure 2–1. Connection Diagram



2.2 Loop Characterization Setup

The TPS54310 EVM contains a 49.9 Ω resistor (R7) in the feedback path for use in measuring the loop response. Test points on either side of R7 (TP5 and TP7) provide connection points for network analyzer signals. By injecting a small ac signal across R7, the loop gain and phase can be measured from one side of R7 to the other. Because the value of R7 is small in relation to the value of R5, it does not significantly affect the output voltage set point of the regulator.

2.3 Efficiency

The TPS54310 EVM efficiency peaks at around 1 A of load current. At full load this drops to around 90.5%. Figure 2–2 shows the typical efficiency for a 5-V input and an ambient temperature of 25°C. The efficiency is lower at higher ambient temperatures due to temperature variation in the drain-to-source resistance of the MOSFETs. The efficiency is also slightly higher at lower switching frequencies due to the gate and switching losses in the MOSFETs. The total board losses are shown in Figure 2–3.

Figure 2–2. Measured Efficiency

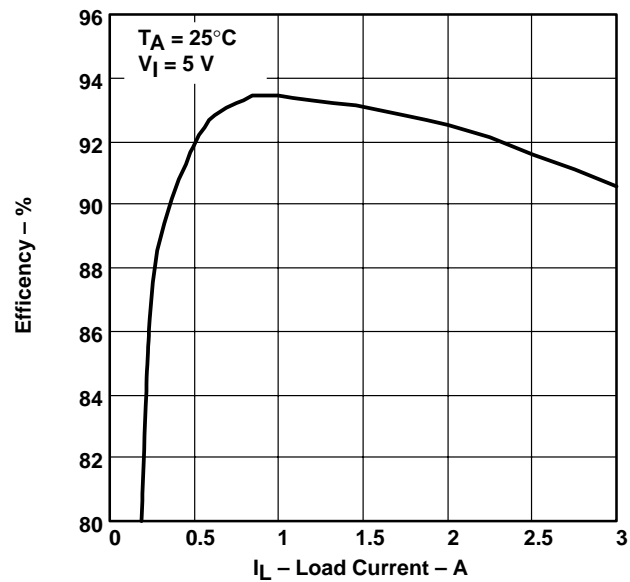
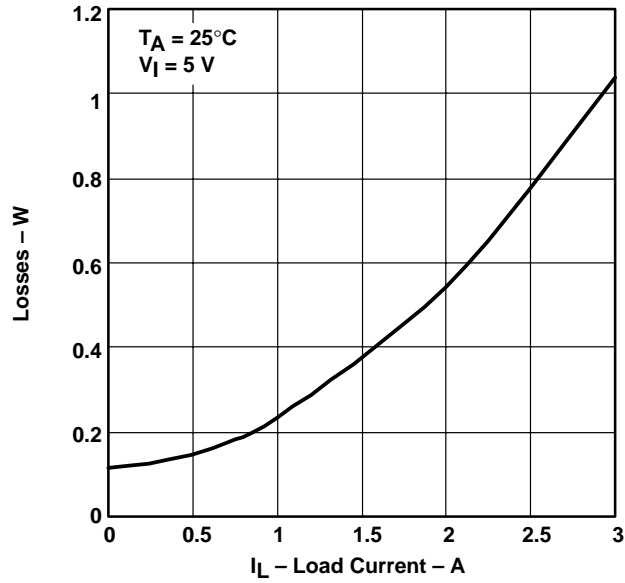


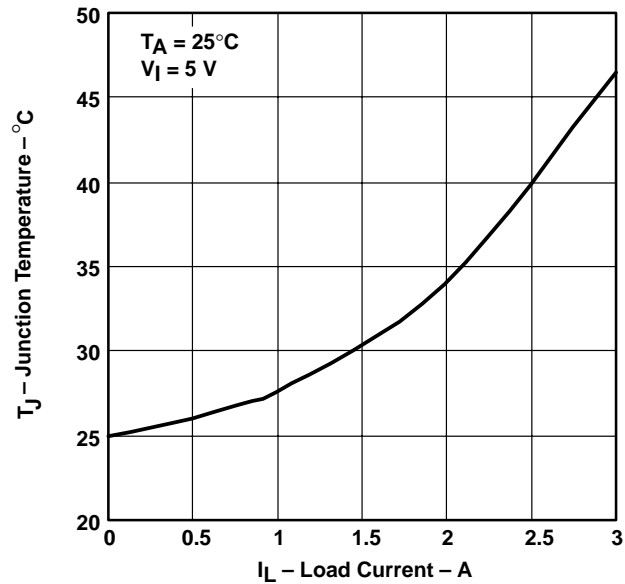
Figure 2–3. Measured Board Losses



2.4 Thermal Performance

The junction temperature is plotted versus the load current with a 5-V input voltage and a 25°C ambient temperature in Figure 2–4. The low junction-to-case thermal resistance of the PWP package, along with a good board layout, helps to keep the junction temperature low at high output currents. With a 5-V input source and a 3-A load, the junction temperature is approximately 47°C.

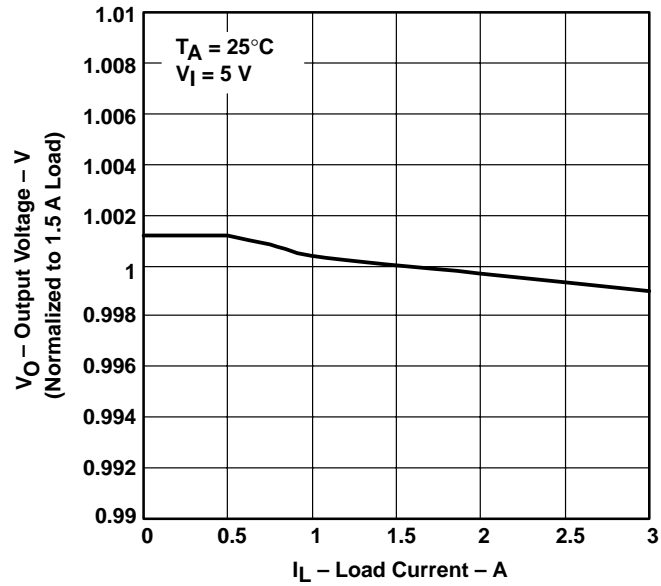
Figure 2–4. Measured Junction Temperature at 25°C Ambient



2.5 Output Voltage Regulation

The output voltage load regulation, with a 5-V input and a 25°C ambient temperature, is shown in Figure 2–5. Over the load range of 0 A to 3 A, the output voltage varies less than 0.2%.

Figure 2–5. Measured Load Regulation



2.6 Load Transients

The TPS54310 EVM response to load transients is shown in Figure 2–6. The load transient in Figure 2–6 transitions between 0 A and 3 A. The output voltage deviates approximately -95 mV (-2.9%) and 75 mV (2.3%) from its average value as a result of these transients. In Figure 2–6, the output voltage returns to a $\pm 2\%$ regulation band within $30\text{ }\mu\text{s}$. Using the alternate feedback compensation described in Section 1.3.5 *Improving Transient Response*, the output voltage deviation can be reduced to -55 mV (-1.7%) and 45 mV (1.4%), as shown in Figure 2–7. With the alternate compensation, the output voltage remains within a $\pm 2\%$ regulation band through the duration of the load transient.

Figure 2–6. Measured Load Transient Response

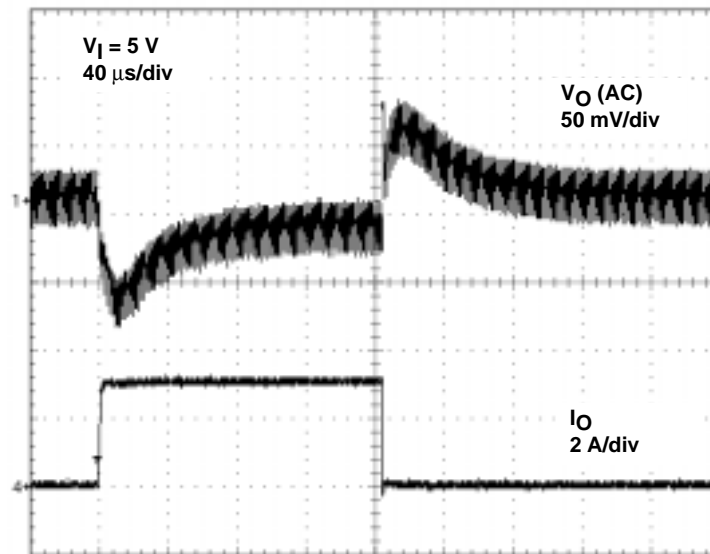
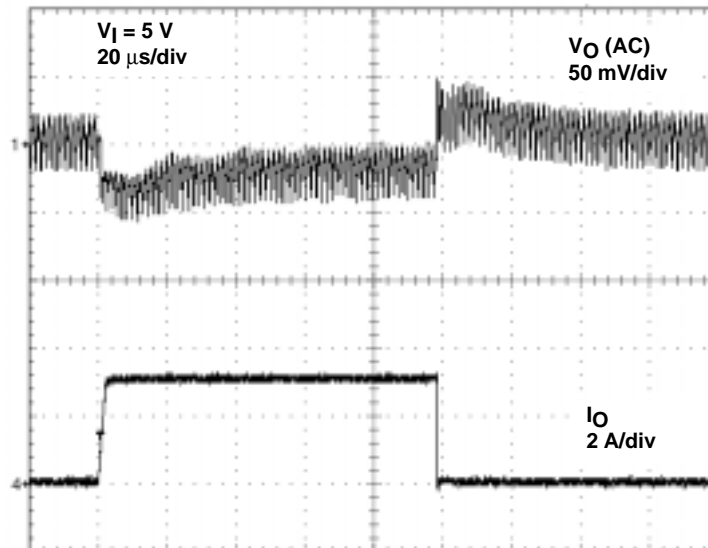


Figure 2–7. Improved Load Transient Response



2.7 Loop Characteristics

The loop gain and phase for a 5.0-V input and a 3.0-A load is shown in Figure 2–8. The loop crossover frequency is approximately 30 kHz, and the phase margin is approximately 75°. Figure 2–9 shows the loop response using the alternate compensation described in Section 1.3.5 *Improving Transient Response*. With the alternate feedback compensation, the loop crossover frequency is approximately 75 kHz, and the phase margin is approximately 72°.

Figure 2–8. Improved Loop Gain and Phase

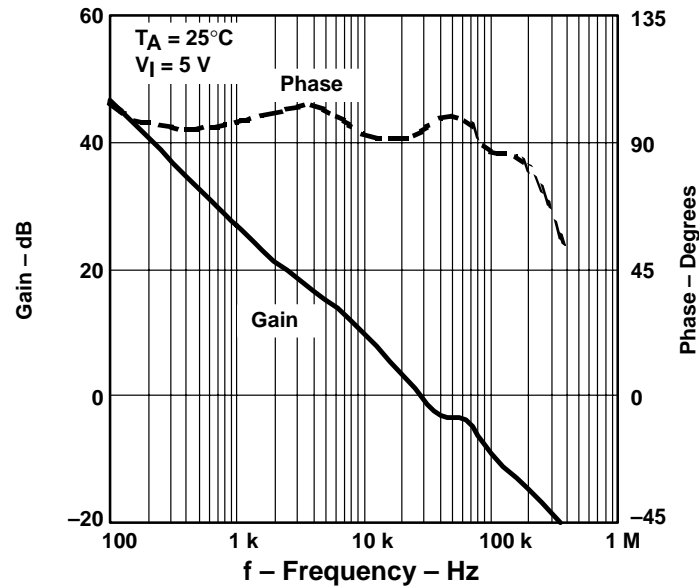
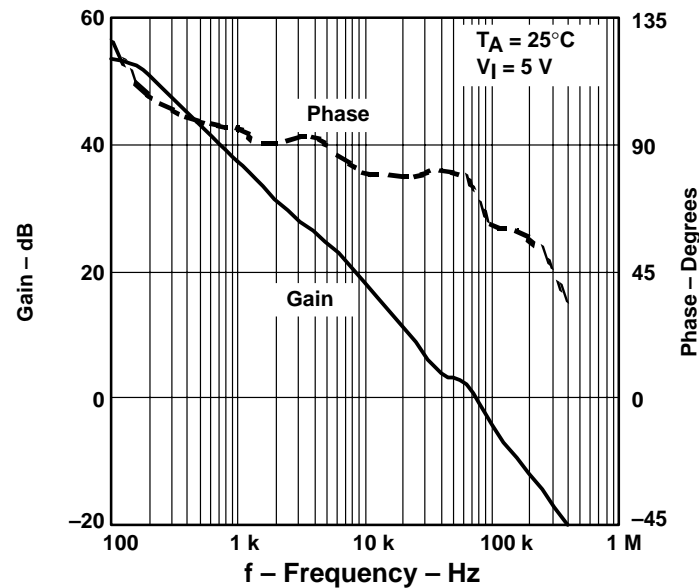


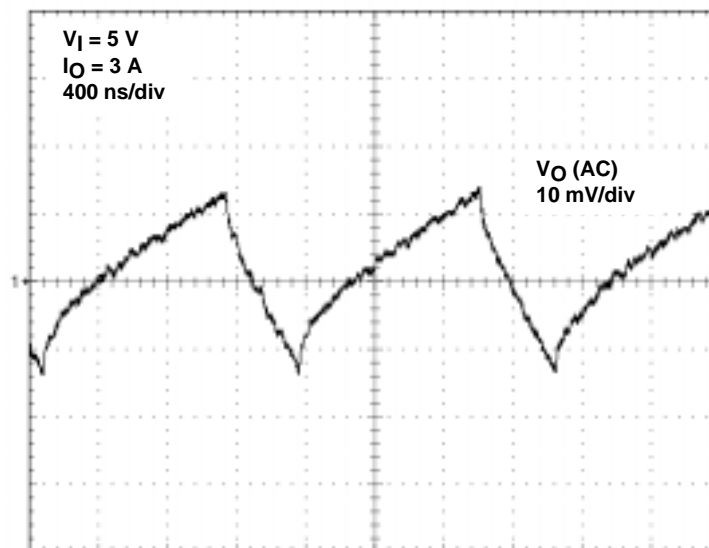
Figure 2–9. Measured Loop Gain and Phase for Alternate Compensation



2.8 Output Voltage Ripple

The output ripple voltage is plotted in Figure 2–10 with an input voltage of 5.0 V and a load current of 3 A. The TPS54310 EVM has a typical output voltage ripple of less than 33 mV_{pp}. If the switching frequency is reduced, the output ripple voltage is higher. The output ripple voltage can be decreased by using a larger inductor, or by reducing the equivalent series resistance of the output capacitor. Changing either of these components requires the feedback compensation to be redesigned.

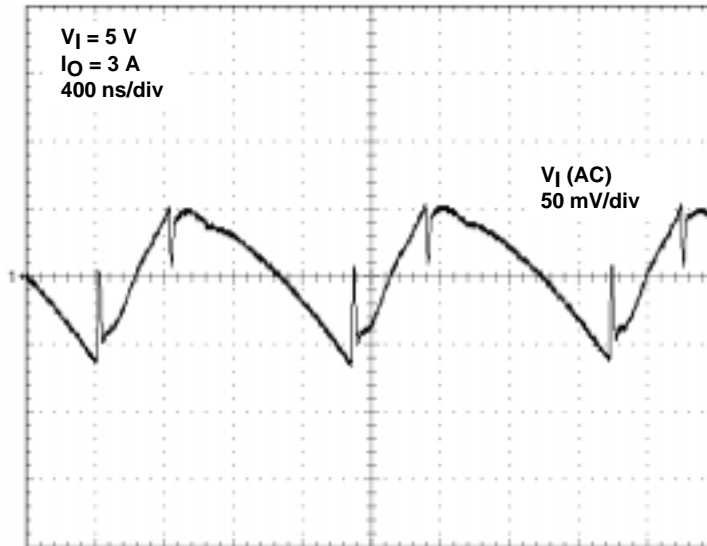
Figure 2–10. Measured Output Voltage Ripple



2.9 Input Ripple Voltage

The input ripple voltage for a 3-A load is shown in Figure 2–11. With an input voltage of 5.0 V, the input ripple is approximately 120 mV_{pp}. The input ripple voltage can be made lower by adding capacitance to the input.

Figure 2–11. Measured Input Voltage Ripple

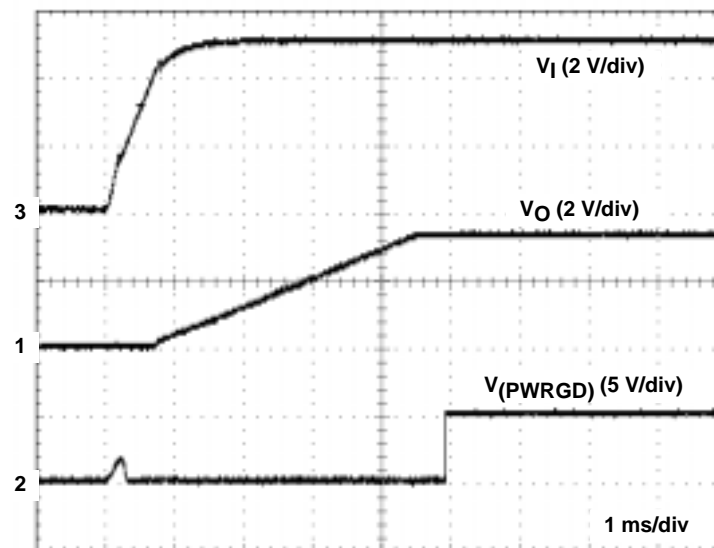


2.10 Start-Up

Figure 2–12 shows the start-up voltage waveform of the TPS54310 EVM with C1 left open. The input voltage is displayed on channel 3, the output voltage on channel 1, and the power good signal on channel 2. Once the input voltage rises above the 2.9-V start-up threshold, the output voltage begins to rise linearly to 3.3 V in 3.6 ms. When the output voltage has reached its final value, the open-drain power good signal rises to a high state. The start-up time can be extended by using an external slow-start capacitor, C1. To program a specific slow start time, see Section 1.3.4 *Slow Start*.

The shorting jumper on J2 should not be used to enable the EVM, as this may cause excessive voltage transients on the SS/ENA pin. Use an external enable signal instead of the J2 jumper.

Figure 2–12. Measured Start-Up Waveforms



Board Layout

This chapter provides a description of the TPS54310 EVM board layout and layer illustrations.

Topic	Page
3.1 Layout	3-2

3.1 Layout

The top-side layer for the TPS54310 EVM is shown in Figure 3–1. The input capacitors (C8 and C9), bias decoupling capacitor (C3), and bootstrap capacitor (C7), are all located as close to the IC as possible. In addition, the feedback compensation components are also kept close to the IC. The compensation circuit ties to the output voltage at the point of regulation (TP7).

The TPS54310 EVM PWB consists of two layers of 1.5 oz. copper. The bottom half of the top layer is used as a power ground plane, while the bottom layer is used as a *quiet* (analog) ground plane. The two ground planes tie together at U1 to reduce the noise injected between the two IC ground connections. A total of 10 vias are used to tie the thermal land area under the TPS54310 device to the thermal plane on the backside of the board.

Figure 3–1. Top Side Assembly

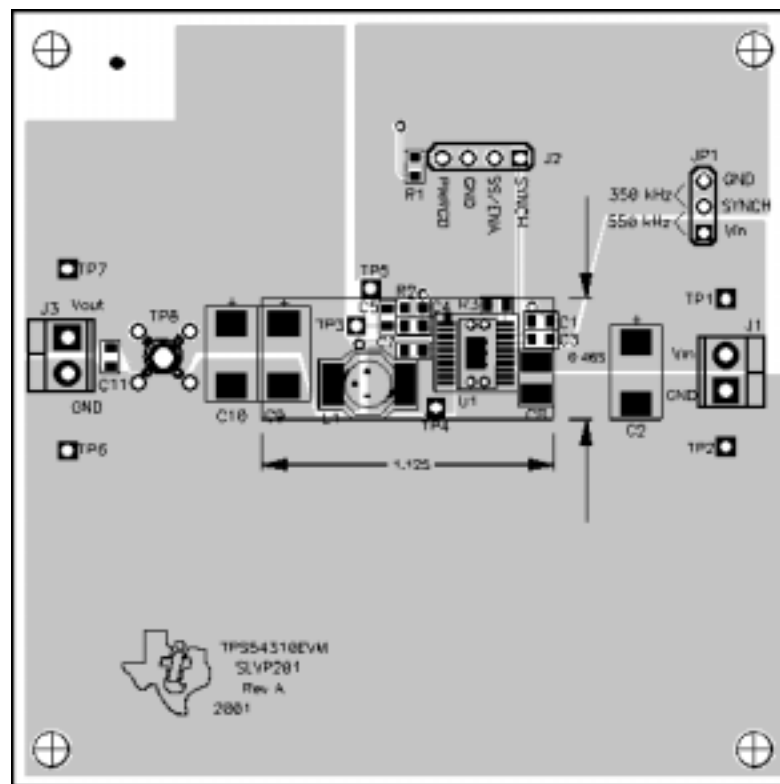


Figure 3-2. Bottom Side Assembly

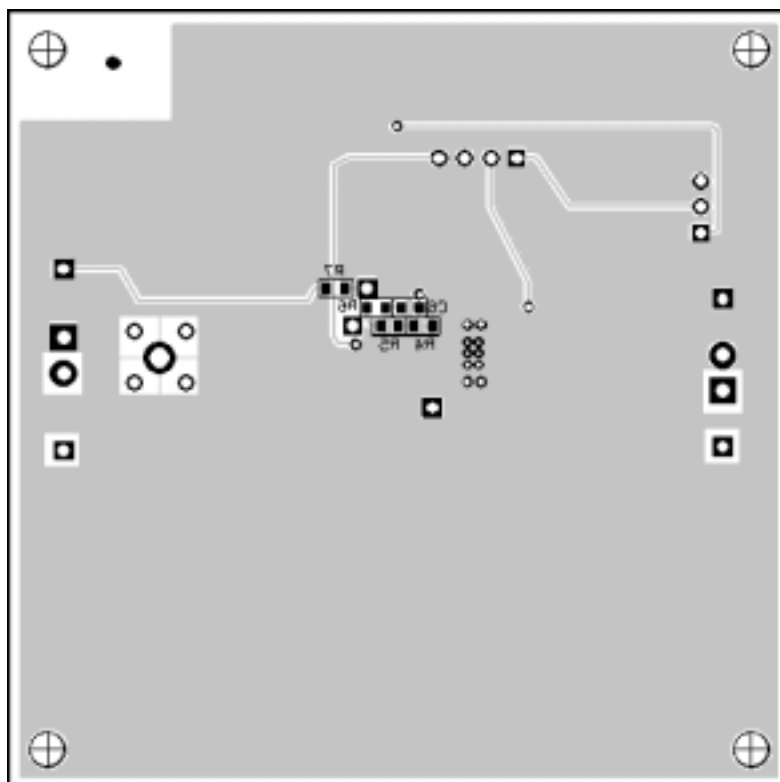


Figure 3–3. Top Side Layout

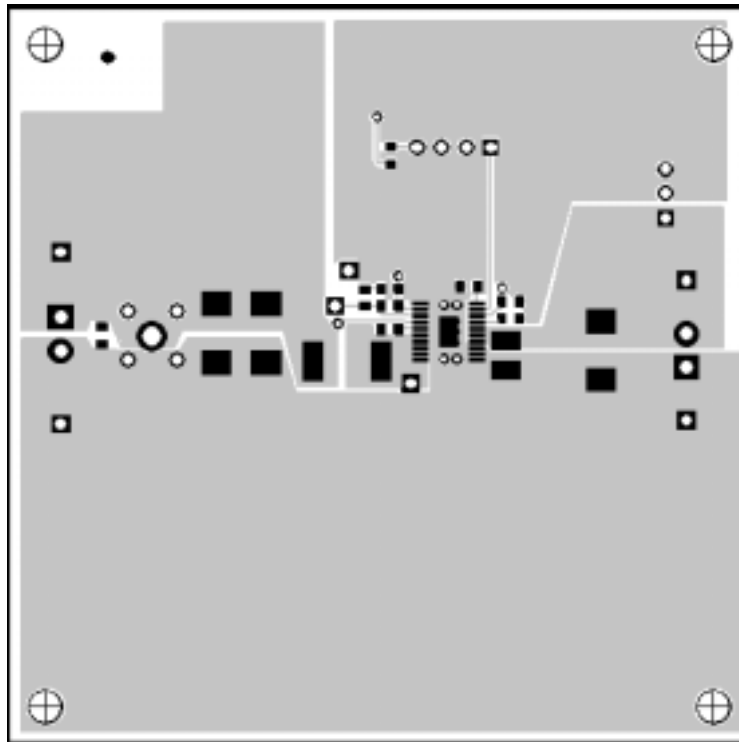
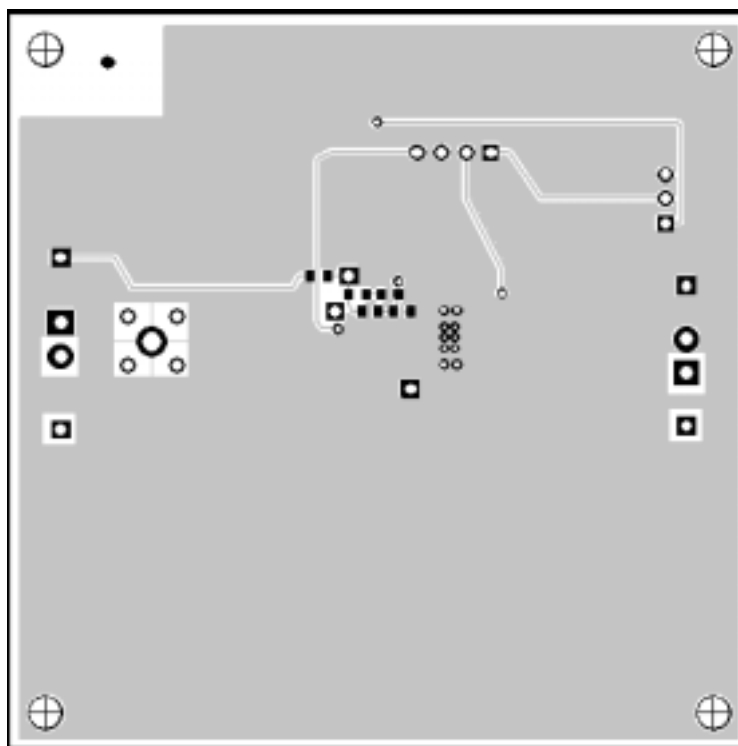


Figure 3–4. Bottom Side Layout





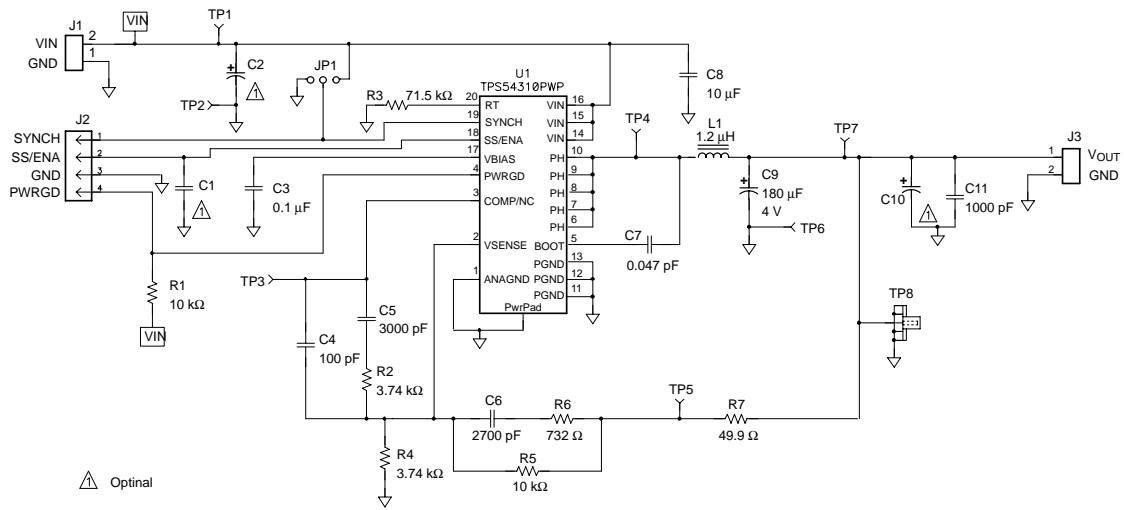
Schematic and Bill of Materials

The EVM schematic and bill of materials are presented in this chapter.

Topic	Page
4.1 Schematic	4-2
4.2 Bill of Materials	4-3

4.1 Schematic

Figure 4–1. TPS54310 EVM Schematic



4.2 Bill of Materials

Table 4–1. TPS54310 EVM Bill of Materials

Count	Ref Des	Description	Size	MFR	Part Number
1	C1	Open	603		
1	C11	Capacitor, ceramic, 1000 pF, 25 V, X7R, 10%	603	Vishay	VJ0603Y102KXXAT
2	C2, C10	Open	7343 (D)		
1	C3	Capacitor, ceramic, 0.1 μ F, 25 V, X7R, 10%	603	Vishay	VJ0603Y104KXXMT
1	C4	Capacitor, ceramic, 100 pF, 50 V, C0G, 5%	603	Vishay	VJ0603A101KXAAC
1	C5	Capacitor, ceramic, 3900 pF, 50 V, X7R, 10%	603	Vishay	VJ0603Y392KXAAB00
1	C6	Capacitor, Ceramic, 2700 pF, 50 V, X7R, 10%	603	Vishay	VJ0603Y272KXAAB00
1	C7	Capacitor, ceramic, 0.047 μ F, 25 V, X7R, 10%	603	Vishay	VJ0603Y473KXXAB00
1	C8	Capacitor, ceramic, 10 μ F, 10 V, X5R, 20%	1210	Panasonic	ECJ–4YB1A106K
1	C9	Capacitor, spec polymer, 180 μ F, 4 V, 20%	7343	Panasonic	EEF–UEG181R
2	J1, J3	Terminal block, 2 pin, 6 A, 3,5 mm	0.27 x 0.25	OST	ED1514
1	J2	Header, 4 pin, 100 mil spacing, (36-pin strip)	0.100 x 4	Sullins	PTC36SAAN
1	JP1	Header, 3 pin, 100 mil spacing, (36-pin strip)	0.100 x 3	Sullins	PTC36SAAN
1	L1	Inductor, SMT, 1.2 μ H, 4.4 A, 17–m Ω		Coilcraft	DO1813P–122HC
1	R1	Resistor, chip, 10 k Ω , 1/16 W, 1%	603	Vishay	CRCW060310K0FKSF
1	R2	Resistor, chip, 3.74 k Ω , 1/16 W, 1%	603	Vishay	CRCW06033K74FKTA
1	R3	Resistor, chip, 71.5 k Ω , 1/16 W, 1%	603	Vishay	CRCW060371K5FKTA
1	R4	Resistor, chip, 3.74 k Ω , 1/16 W, 0.1%	603	Vishay	TNPW06033741BT9RT
1	R5	Resistor, chip, 10 k Ω , 1/16 W, 0.1%	603	Vishay	TNPW060310K0BETAR2
1	R6	Resistor, chip, 732 Ω , 1/16 W, 1%	603	Vishay	CRCW0603732RFKTA
1	R7	Resistor, chip, 49.9 Ω , 1/16 W, 1%	603	Vishay	CRCW060349R9FKSF
5	TP1, TP3–TP5, TP7	Test point, red, 1 mm	0.038"	Farnell	240–345
2	TP2, TP6	Test point, black, 1 mm	0.038"	Farnell	240–333
1	TP8	Adaptor, 3,5 mm probe clip (or 131–5031–00)	0.200"	Tektronix	131–4244–00
1	U1	IC, SWIFT™ power controller, Adj V, 3 A	PWP20	TI	TPS54310PWP
1	—	PCB, 3 In x 3 In x 0.062 In		Any	SLVP201
2	—	Shunt, 100 mil, black	0.100	3M	929950–00

