Application Report
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Adjusting the Output Voltage of Internally Compensated Low Input Voltage SWIFT™ DC/DC Converters

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ABSTRACT

This application report outlines a procedure for adjusting output voltages with internally compensated TPS54x11 through TPS54x16 SWIFT™ dc/dc converters. The converter can be programmed to an output voltage between 0.9 V–3.3 V with an output current up to 6 A, and requiring only eight external components. The report provides a straightforward design procedure for setting the output voltage and calculating the external component values. Two design examples are provided to demonstrate the procedure.

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Introduction

The TPS5431x and TPS5461x families of regulators integrate all active components for a synchronous dc/dc converter. The TPS5431x family is rated at 3 A of output current, while the TPS5461x converters are rated at 6 A of output current. Table 1 summarizes the standard product family. Design of a complete dc/dc solution can be achieved by using the step-by-step instructions given by the Texas Instruments application reports SLVA104 (external compensation) or SLVA105 (internal compensation). Alternatively, the SWIFT Designer software tool can also be used to design a complete power supply solution. With the SWIFT Designer, design time is greatly reduced with only a few clicks of a mouse. The software is available for download at http://power.ti.com/swift.

Table 1. TPS5431x and TPS5461x Product Families

3 A Part Number	6 A Part Number	Output Voltage	Compensation
TPS54310	TPS54610	Adjustable	External
TPS54311	TPS54611	0.9 V	Internal
TPS54312	TPS54612	1.2 V	Internal
TPS54313	TPS54613	1.5 V	Internal
TPS54314	TPS54614	1.8 V	Internal
TPS54315	TPS54615	2.5 V	Internal
TPS54316	TPS54616	3.3 V	Internal

The TPS54310 and TPS54610 are both externally compensated dc/dc converters with adjustable output voltages. However, these converters require a higher part count than the internally compensated versions and may also require more board area. The internally compensated versions, on the other hand, are only available in the standard output voltages listed in Table 1. It may be desirable to have a solution that gives the benefits of the internally compensated converters, but at a non-standard output voltage. This application note gives design procedures for adjusting the output voltage of an internally compensated TPS54x11 through TPS54x16 dc/dc converter.

Adjusting V_{out} From 0.9 V–3.3 V

To adjust the output voltage of the dc/dc converter it is essential to have a basic understanding of the feedback circuitry. For the available internally compensated converters, the error amplifier input differs for the versions with an output voltage of 1.5 V and below, versus those with an output voltage of 1.8 V and above. Figure 1 shows that all versions with an output voltage of 1.5 V and below have a voltage reference equal to the output voltage. As Figure 2 shows, for the versions of 1.8 V and above, there is a resistor divider after the VSENSE pin, consisting of two 2-kΩ resistors that divides the sense voltage in half before it is fed into the inverting node of the error amplifier. So the 1.8-V version has a 0.9-V reference, the 2.5-V version a 1.25-V reference, and the 3.3-V version a 1.65-V reference.

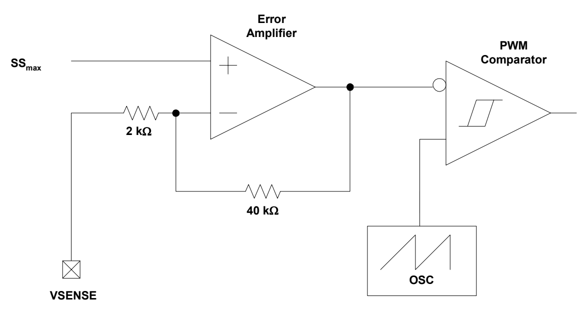

Figure 1. Feedback Section of the TPS54x11, TPS54x12 and TPS54x13

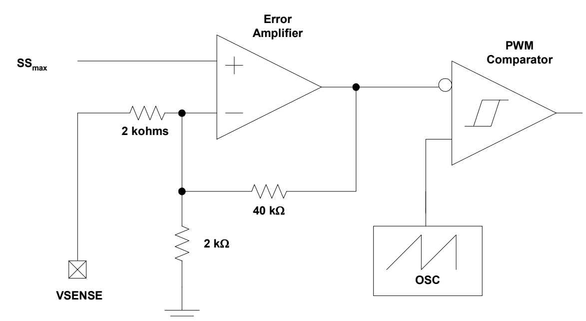

Figure 2. Feedback Section of the TPS54x14, TPS54x15, and TPS54x16

Design Procedure

The internally compensated SWIFT™ converters need a simple resistor divider connected to the VSENSE pin to adjust the output voltage to the desired value. The external resistor divider must draw a higher current than the internal resistor divider to ensure that the current flow into the VSENSE pin has a negligible effect on the voltage setting.

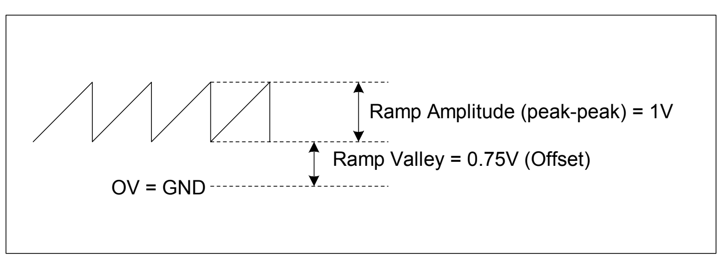

Figure 3. Ramp Waveform

Step One: Determine Maximum Current into VSENSE

Figure 3 shows the ramp waveform that is generated by the oscillator and fed into the non-inverting input of the PWM comparator. The peak-to-peak amplitude of the ramp is 1 V with an offset of 0.75 V. Given the ramp characteristics, equation 1 can be used to find the maximum current drawn by VSENSE.

Equation 1

$$I_{VSENSE-MAX} = \frac{V_{OUT} - V_{RAMP-MIN}}{R_{DIVIDER}}$$

where: V_{OUT} is the preset output voltage of the internally compensated converter.

$V_{RAMP\text{-}MIN}$ is the minimum ramp voltage. This value equals 0.75 V for all versions.

$R_{DIVIDER}$ is the internal resistance on VSENSE. This value equals 42 kΩ for the TPS54x11, TPS54x12, and TPS54x13 (Figure 1). The value is 4 kΩ for the TPS54x14, TPS54x15, and TPS54x16 (Figure 2).

Table 2 provides a summary of $I_{VSENSE\text{-}MAX}$ for each version of internally compensated SWIFT™ converter.

Step Two: Calculate External Resistor Values

The external resistor divider is connected as follows (Figure 4): R_1 is connected between VSENSE and the output voltage rail. R_2 is connected between VSENSE and ground. Place the resistor divider as close as possible to VSENSE to avoid noise coupling on this node.

To ensure proper programming of the output voltage, the current flowing through the external resistor divider must be much greater than the current flowing into VSENSE. To guarantee this condition, set R_2 to be 360 Ω and then solve for R_1 with equation 2. Note that to maintain high regulation accuracy, the resistors must have a 1% tolerance or better.

Equation 2

$$R_1 = \left(R_2 \cdot \frac{V_{FB}}{V_{OUT}} \right) - R_2$$

where: V_{FB} is the desired output voltage.

R_2 is the resistor connected between VSENSE and ground with a value of 360 Ω.

V_{OUT} is the preset output voltage of the internally compensated converter.

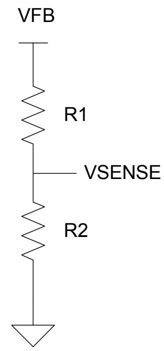

Figure 4. External Resistor Divider Connection

Step Three (Optional): Calculate the Offset Caused by the External Resistor Divider

The addition of the external resistor divider to VSENSE introduces a small amount of voltage offset to the feedback loop. This offset is typically very small and should have an unnoticeable effect on the regulation of the converter. Equation 3 gives a calculation for this offset.

Equation 3

$$V_{OFFSET} = \frac{R_1 \cdot R_2}{R_1 + R_2} \cdot I_{VSENSE-MAX}$$

where: R_1 is the resistor connected between VSENSE and the output voltage rail.

R_2 is the resistor connected between VSENSE and ground.

$I_{VSENSE\text{-}MAX}$ is the maximum current drawn by VSENSE. This value is determined in equation 1.

In addition to the voltage offset created by the resistor divider, the voltage tolerance of the output is affected by the tolerance values of the resistors. To minimize this effect, use 1% tolerance resistors, or better. Equation 4 shows the calculation for the new tolerance.

Equation 4

$$TolV_{OUT} = TolV_{REF} + \frac{2 \cdot R_1}{R_1 + R_2} \cdot TolR$$

where: R_1 is the resistor connected between VSENSE and the output voltage rail.

R_2 is the resistor connected between VSENSE and ground.

$TolV_{REF}$ is the tolerance of the internal reference which is 1%.

TolR is the tolerance values of resistors R_1 and R_2.

Design Note

The procedure outlined in this application note works with any member of the internally compensated SWIFT™ family. However, the most flexible and highest performing version to choose is the TPS54311 for 3-A applications and the TPS54611 for 6-A applications. There are two reasons for these choices.

First, refer to Table 2 for the internally set reference voltage for the SWIFT™ product family. The minimum output voltage that can be achieved using the design procedure outlined above is the internal reference voltage of the selected converter. As a consequence, choosing the TPS54x11 or the TPS54x14 gives the largest output voltage range, from 0.9 V to 5.0 V.

Second, minimizing the value of $I_{VSENSE-MAX}$ reduces the voltage offset created by the insertion of the external resistor divider, thereby improving overall system performance (see Equation 3). From Table 2, choosing the TPS54x11 gives the lowest $I_{VSENSE-MAX}$.

Table 2. TPS5431x and TPS5461x Feedback Circuit Summary

3 A Part Number	6 A Part Number	Output Voltage	Reference Voltage	$I_{VSENSE-MAX}$
TPS54311	TPS54611	0.9 V	0.9 V	3.6 μA
TPS54312	TPS54612	1.2 V	1.2 V	11 μA
TPS54313	TPS54613	1.5 V	1.5 V	18 μA
TPS54314	TPS54614	1.8 V	0.9 V	263 μA
TPS54315	TPS54615	2.5 V	1.25 V	438 μA
TPS54316	TPS54616	3.3 V	1.65 V	638 μA

Design Example 1. TPS54614 Adjusted to VOUT = 2.9 V

For this example, the design parameters are as follows: VIN = 5.0 V, VOUT = 2.9 V, IOUT = 6 A. The TPS54614 has been chosen as the internally compensated part whose output is adjusted. Using the *SWIFT Designer*, a temporary design has been created for VIN = 5.0 V, IOUT = 6 A, and VOUT = 1.8 V, so that the TPS54614 can be chosen. The schematic output of the software tool is found in Figure 5, showing the base circuit to be modified.

Following the design procedure:

Step 1. Look up the value for $I_{VSENSE-MAX}$ in Table 2. The value is 263 μA.

Step 2. Solve for R_1 with equation 2 given that R2 is 360 Ω.

$$R_1 = \left(360\Omega \cdot \frac{2.9V}{1.8V}\right) - 360\Omega = 220\Omega$$

Step 3. Using equation 3, the voltage offset caused by the calculated resistor divider is:

$$V_{OFFSET} = \frac{220\Omega \cdot 360\Omega}{220\Omega + 360\Omega} \cdot 263uA = 35.9mV$$

Finally, the change in output voltage tolerance due to the resistor divider is calculated using equation 4. This design uses 1% tolerance resistors.

$$TolV_{OUT} = 1\% + \frac{2 \cdot 220\Omega}{220\Omega + 360\Omega} \cdot 1\% = 1.76\%$$

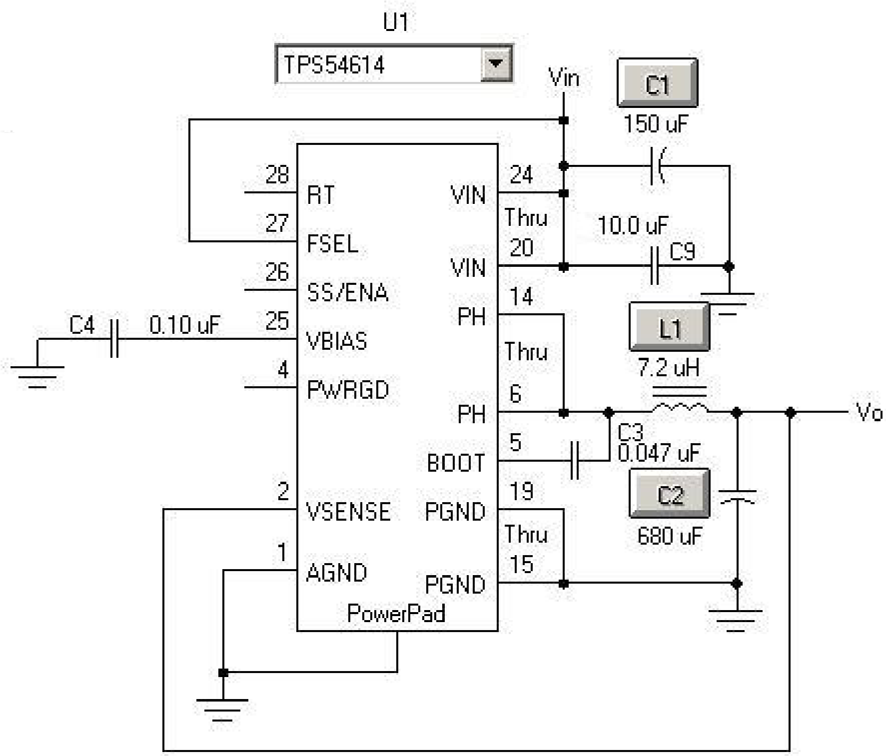

Figure 5. TPS54614 Schematic From SWIFT Designer

Figure 6 shows the schematic for the adjusted 2.9-V solution. This solution only requires eight external components.

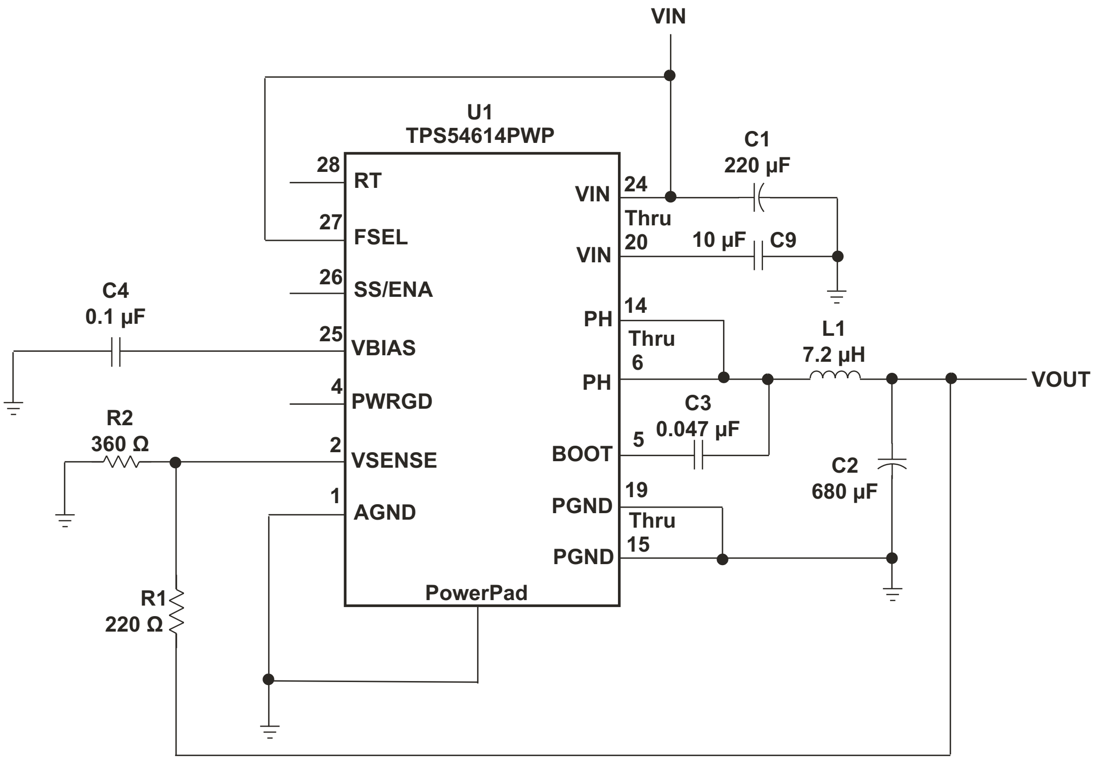

Figure 6. TPS54614 Schematic Adjusted for VOUT = 2.9 V

Design Example 2. TPS54311 Adjusted to VOUT = 1.3 V

For this example, the design parameters are as follows: VIN = 3.3 V, VOUT = 1.3 V, IOUT = 3 A. The TPS54311 has been chosen as the internally compensated part whose output is adjusted. Using the *SWIFT Designer*, a temporary design has been created for VIN = 3.3 V, IOUT = 3 A, and VOUT = 0.9 V, so that the TPS54311 can be chosen. The schematic output of the software tool is found in Figure 7, showing the base circuit to be modified.

Following the design procedure:

Step 1. Look up the value for $I_{VSENSE\text{-}MAX}$ in Table 2. The value is 3.6 µA.

Step 2. Solve for R_1 with equation 3 given that R2 is 360 Ω.

$$R_1 = \left(360\Omega \cdot \frac{1.3V}{0.9V}\right) - 360\Omega = 160\Omega$$

Step 3. Using equation 3, the voltage offset caused by the calculated resistor divider is:

$$V_{OFFSET} = \frac{160\Omega \cdot 360\Omega}{160\Omega + 360\Omega} \cdot 3.6uA = 0.4mV$$

Finally, the change in output voltage tolerance due to the resistor divider is calculated using equation 4. This design uses 1% tolerance resistors.

$$TolV_{OUT} = 1\% + \frac{2 \cdot 160\Omega}{160\Omega + 360\Omega} \cdot 1\% = 1.62\%$$

Figure 8 shows the schematic for the adjusted 1.3-V solution. This solution only requires seven external components. Note that the voltage offset for the TPS54311 solution is significantly smaller than for the TPS54614. As stated before, using the TPS54311 for 3-A applications and the TPS54611 for 6-A applications gives the highest performance and most flexibility for this application.

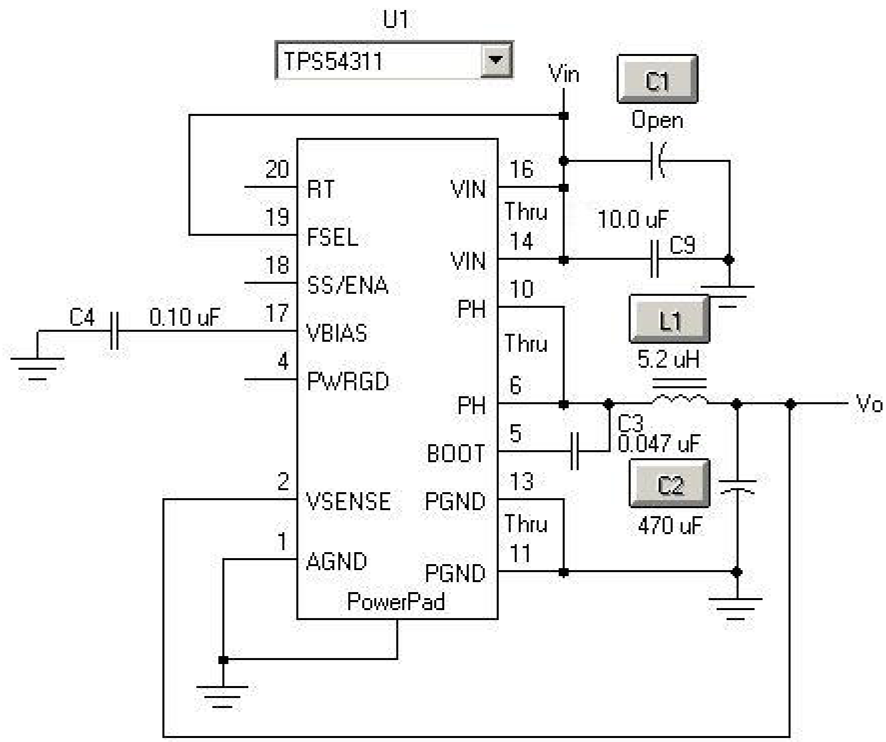

Figure 7. TPS54311 Schematic From SWIFT Designer

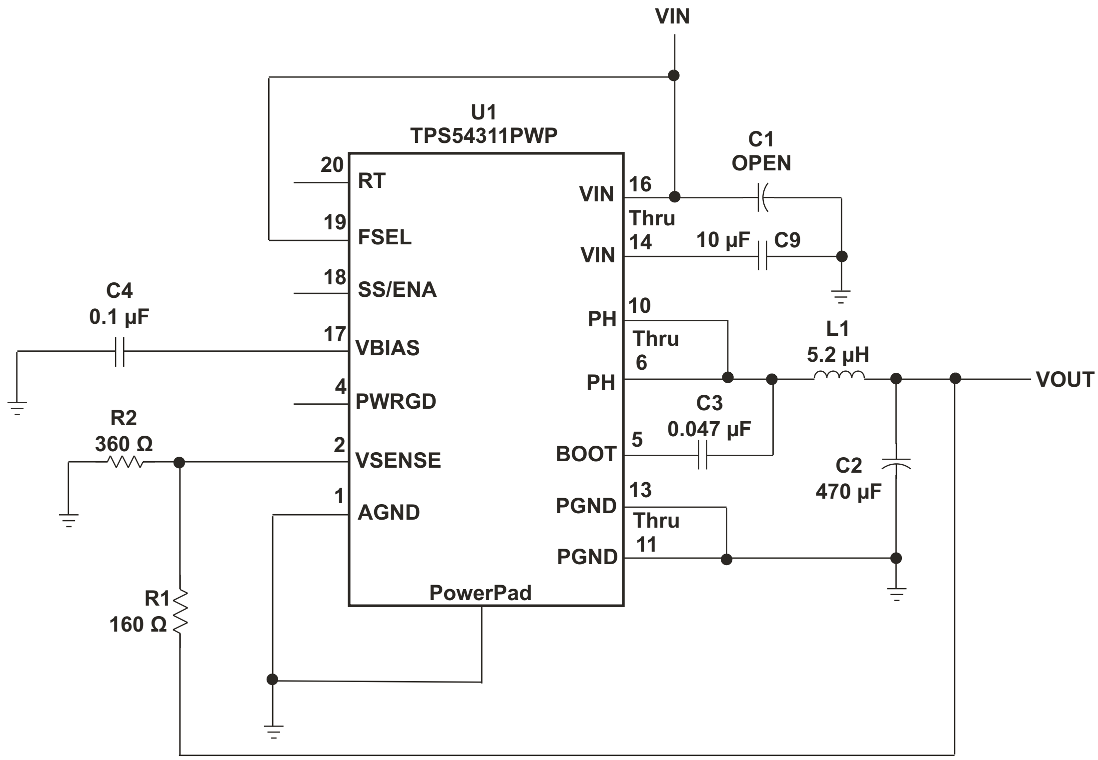

Figure 8. TPS54311 Schematic Adjusted for VOUT = 1.3 V

Conclusion

When a designer needs a dc/dc converter solution that provides an output voltage other than 0.9 V, 1.2 V, 1.5 V, 1.8 V, 2.5 V, or 3.3 V, they typically use an externally compensated TPS54310 or TPS54610 to realize a solution. However, it may be beneficial to take advantage of the reduced component count and potential board area savings with an internally compensated SWIFT™ regulator. With the design procedure in this application note, a designer can take an internally compensated design and adjust the output voltage to the desired value in very little time.

References

1. *TPS54611, TPS54612, TPS54613, TPS54614, TPS54615, TPS54616, 3-V to 6-V Input, 6-A Output Synchronous Buck PWM Switcher With Integrated FETs (SWIFT™)* (SLVS400)

2. B. King, *Designing With the TPS54611 Through TPS54616 Synchronous Buck Regulators* (SLVA105)

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