Application Report

SLVA209–May 2005

Using the TPS61040 in High-Voltage Applications

Portable Power DC-DC Applications

ABSTRACT

The TPS61040 is a highly integrated, low-power, boost converter capable of delivering output voltages up to 28 V with input voltages up to 6 V. However, using an external transistor in a cascode configuration enables the TPS61040 to be used in applications where higher input or output voltages are required. Output voltages in the 100s of volts are achievable using this technique.

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1 Introduction

In the typical application circuit for the TPS61040, the maximum allowable voltage on the SW pin limits the output voltage to 28 V.

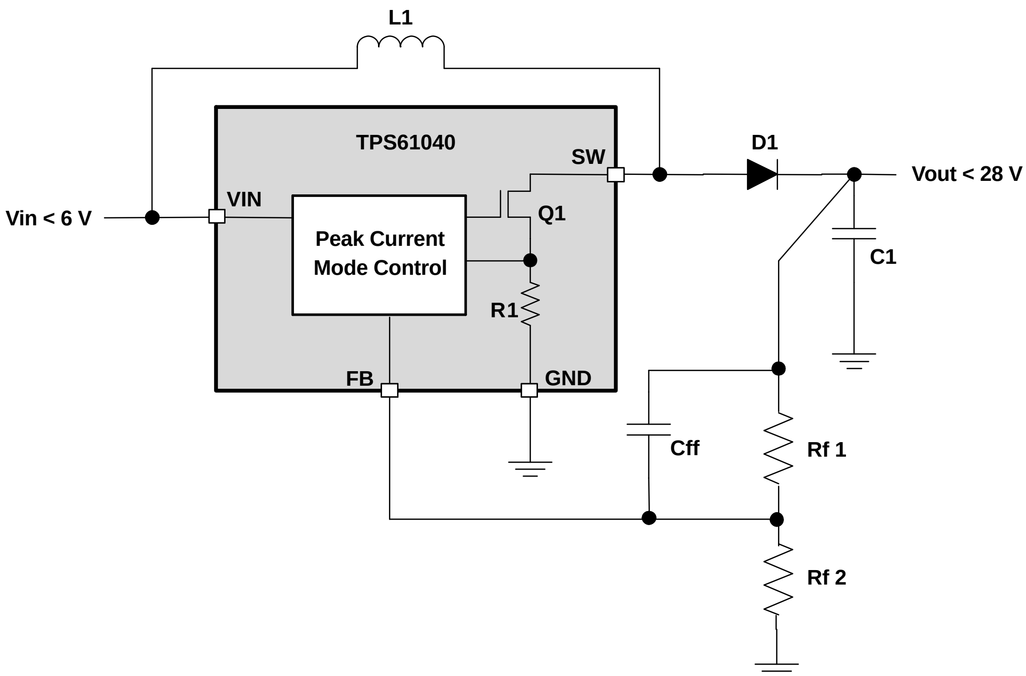

Figure 1. Block Diagram of a Boost Converter Based on the TPS61040

In the standard implementation, the input voltage, V_{in}, is applied to the VIN pin of the integrated circuit (IC) and to the inductor. The IC turns on its internal MOSFET, Q1, and current starts to flow from V_{in} through L1, the SW pin of the IC, Q1, and an internal sense resistor. The control portion of the IC monitors the current flowing through the internal sense resistor, R1, and when this current reaches 400 mA, the controller turns the internal MOSFET *off*. The voltage across the inductor then builds and forward-biases diode D1, thus delivering power at a higher voltage to the output capacitor C1. The *on* time of the internal MOSFET is determined by the input voltage, the value of the inductor, and the pre-determined peak current. The *off* time of the internal MOSFET is determined by sensing a voltage drop on the output via the feedback, FB, pin of the IC. The off time is a function of the output voltage, output capacitance, inductance, and the load. This control scheme requires that the inductor current flows through the IC's internal MOSFET so that the control circuitry can monitor the current in order to know when to turn the internal MOSFET *off*.

In order to increase the output voltage above the absolute maximum of the IC, an external transistor with a higher voltage rating than the internal transistor must be used. The SW pin cannot directly drive the gate of an external transistor because the inductor current would no longer flow through the SW pin. One solution is to use a MOSFET in a cascode, or common gate, configuration as shown in Figure 2.

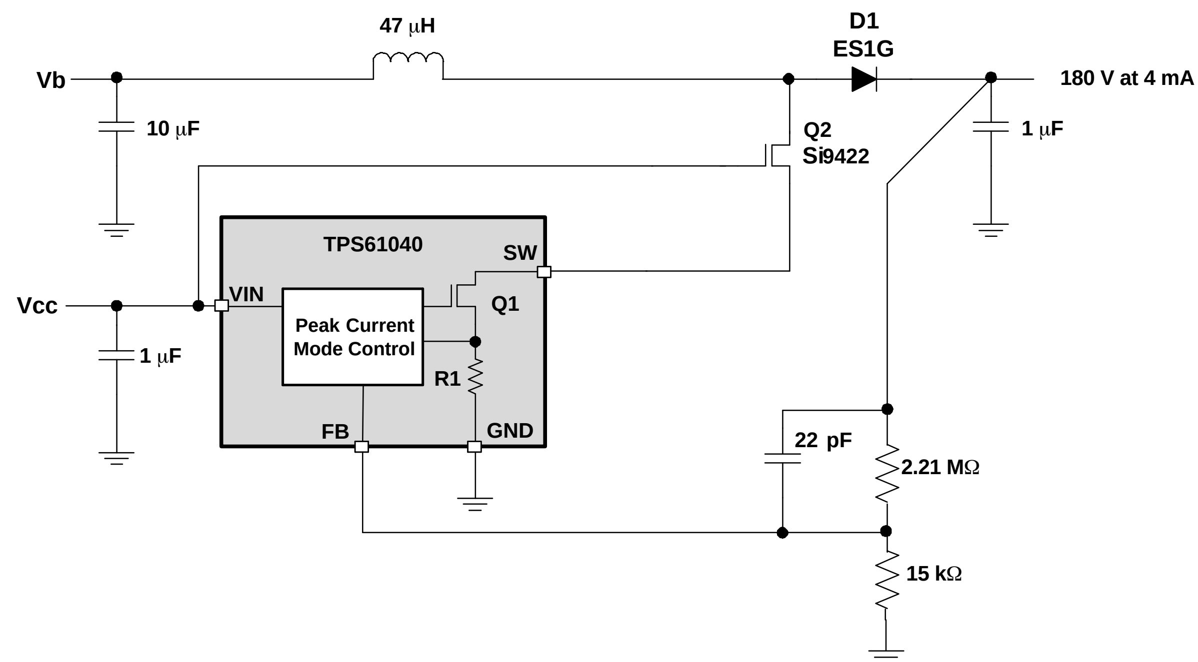

Figure 2. Boost Regulator With Cascode Transistor

In Figure 2, a low-resistance, low-gate-threshold, high-voltage, n-channel MOSFET, Q2, is added in series with the internal MOSFET Q1. The gate-threshold voltage of Q2 must be lower than V_{CC} in order for this circuit to operate properly. Now, when the control circuit turns *on* Q1, the source of Q2 is pulled close to ground level which makes the gate-to-source voltage of Q2 almost equal to V_{CC} and thus turns *on* Q2. The inductor current flows through Q2 and continues through Q1 and the sense resistor so that the control circuit is unaffected with Q2 installed. Once the inductor current reaches the pre-determined limit, Q1 turns *off*, leaving Q2 with no path for current to flow from its source. The voltage on the drain of Q2 rises rapidly to the output voltage plus the diode drop across D1. As the drain rises, the drain-to-source capacitance of Q2 attempts to pull the floating source of the MOSFET above V_{CC}. The gate to source capacitance and the capacitance of the SW pin act to limit the voltage rise on the source of Q2. By carefully selecting Q2 based on junction capacitance, the voltage on the SW pin remains under the absolute maximum voltage.

2 Transistor Selection

2.1 Junction Capacitance

The amount of voltage on the SW pin when the internal transistor turns off is proportional to the gate to source capacitance C_{gs} of Q2, drain-to-source capacitance C_{ds} of Q2, the capacitance of the SW pin to ground C_{sw}, the input voltage V_{CC} and the output voltage V_{out}. Equation 1 approximates the voltage on the SW pin:

$$V_{sw} \approx \frac{\left(V_{CC} \times C_{gs}\right) + \left(V_{out} \times C_{ds}\right)}{\left(C_{ds} + C_{sw} + C_{gs}\right)} \quad (1)$$

For the TPS61040, the capacitance of the switch pin is typically 170 pF. For the circuit in Figure 2, the peak voltage on the SW pin is 15 V when V_{CC} = 5 V and V_{out} = 180 V.

The capacitance of the MOSFET also directly impacts the output power available. The total energy available to the load is equal to the energy that can be stored in the inductor minus the energy needed to charge the stray capacitance each cycle. The net energy during each cycle is multiplied by the switching frequency to determine the total output power. To determine the maximum current capability of the design, first calculate the switching frequency. Equation 2 calculates the switching frequency of the converter:

$$F_{SW} = \frac{\left(1 - \frac{V_b - V_{dg2on}}{V_{out}}\right) \times \left(V_b - V_{dg2on}\right)}{L \times I_{on}} \tag{2}$$

Where V_{dq2on} is the voltage at the drain of Q2 when it is on. This voltage is related to the maximum current in the inductor, the inductor series resistance, the on resistance of the MOSFET, and the voltage drop across the SW pin when it is on. V_{dq2on} typically ranges from 0.2 V to 1 V depending on the selected inductor and MOSFET. Once the switching frequency is known, the maximum current output of the converter based on the transistor capacitance can be approximated as Equation 3 shows:

$$I_{omax} \approx F_{SW} \frac{\left[LI_{on}{}^{2} - C_{gd}\left(V_{out} - V_{CC}\right)^{2} - C_{ds}\left(V_{o} - V_{sw}\right)^{2}\right]}{2V_{out}} \tag{3}$$

Most MOSFET vendors do not directly specify the Cgs or Cds. Instead, the Crss, Coss, and Ciss are usually specified. The following relationships can be used to determine the MOSFETs Cgs, Cds, and Cgd values.

Cgs = Ciss – Crss

Cds = Coss – Crss

Cgd = Crss

The junction capacitance of a MOSFET correlates to other important specifications such as on-resistance, threshold voltage, and breakdown voltage. For some circuits, a suitable MOSFET with suitable junction capacitance may not be found. For these cases, a Schottky diode can be placed between the gate of Q2 to the SW pin of the TPS61040 to clamp the SW pin to the gate voltage during the off cycle. The cathode of the diode connects to the gate of Q2. This ensures that the SW pin never exceeds the value of V_{CC} plus one diode drop.

2.2 Threshold Voltage

It is also important to choose a MOSFET with a low enough threshold voltage to be able to turn on with the input voltages used. The maximum voltage available to turn the MOSFET on is V_{CC} minus the voltage drop across the SW pin of the IC during the on cycle, which can be close to 0.5 V. Therefore, if 5 V is used for V_{CC}, then the MOSFET needs to be fully turned on with a gate-to-source voltage of 4.5 V.

2.3 Rdson

The on resistance of the selected MOSFET directly impacts the overall efficiency of the converter. Select a MOSFET with the lowest possible Rdson.

2.4 Voltage and Current Rating

The absolute minimum voltage rating of the selected MOSFET needs to be at least equal to the desired output voltage plus the expected voltage drop across the output diode. It is recommended that the breakdown voltage of the MOSFET be at least 50% higher than the output voltage though to allow enough margin for changes due to temperature. The current rating of the MOSFET needs to be able to accommodate the peak current allowed by the TPS61040. A MOSFET with at least a 0.5-A current rating should be selected

3 Powering With a Single Input Voltage

Figure 2 shows a circuit with two separate voltages, V_{CC} and V_b. In this circuit, V_{CC} only supplies current to power the IC and to charge the gate-to-source capacitance of Q2 during switching. This is typically only a few milliamperes, depending on the switching frequency of the TPS61040 and the selected cascode MOSFET. If V_b is higher than V_{CC}, it is possible to simply generate V_{CC} with a resistor and Zener diode from V_b.

4 References

1. *TPS61040, TPS61041, Low Power DC/DC Boost Converter In SOT-23 Package* data sheet (SLVS 413)

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