Application Note

Bidirectional TEC Driver Design for 40-W TEC

Matthew Chen, Holly Hong, Stefan Schauer

ABSTRACT

Thermoelectric cooler (TEC) is a heating and cooling device based on the Peltier effect. Due to the advantages of no noise, no vibration, no refrigerant, small size, and light weight, TEC is widely used as the precise temperature control system in industrial areas such as optical communication and medical equipment. In medical in-vitro diagnosis (IVD) equipment such blood gas analyzer, Polymerase Chain Reaction (PCR), and Immuno-analyzer, TEC can keep a stable reaction temperature or accomplish rapid temperature changes. In these applications, bidirectional current control is required to support both heating and cooling and more efficient temperature control. This application note introduces a flexible TEC driver strategy for voltage and current control. To realize the bidirectional current, the TEC is connected between the output (Vout) and input (Vin) of a DC/DC controller (such as the LM5176). The Vout changes from (Vin -10 V) to (Vin +10 V) while Vin is fixed and the maximum current can reach up to ±4 A; therefore, the direction of the current can change to support heating or cooling. Since the current is also effected by the temperature difference of the TEC, a current sense amplifier is implemented for precise temperature control.

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1 Introduction

1.1 Principle of the TEC

The principle of TEC is the Peltier effect. When the current passes through a circuit composed of different conductors, there are endothermic and exothermic phenomenon at the joint of each conductor.

Figure 1-1 is a diagram of a TEC. When voltage is applied at the two sides, the electrons travel through Copper to P-type semiconductor, N-type semiconductor, then back to Copper. Due to the energy level transition of electrons, there is heating or cooling at the joint. When the direction of current changes, the heating and cooling sides exchange. The heat absorbed and released is proportional to the current intensity, and is related to the properties of the two conductors and the temperature of the hot end.

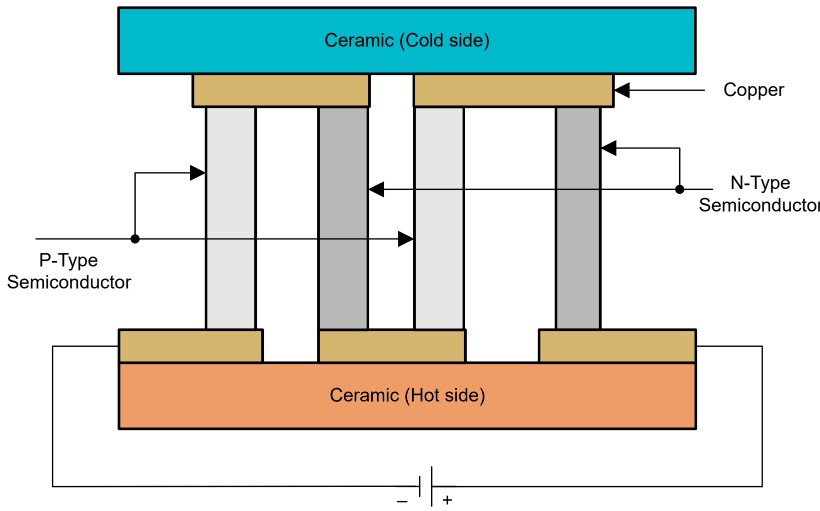

Figure 1-1. Structure of TEC Element

1.2 Design Specification and Key Challenge

In the medical in-vitro diagnostics product, the samples and reagent must stay at a stable temperature for precise detection. In the Polymerase chain reaction (PCR) instrument, a rapid temperature change (for example, from 50℃ to 90℃ in a few seconds) is necessary for the DNA amplification. In the traditional TEC control design, a step-down regulator with gate driver and H-bridge is often used. This note introduces a single chip design using a buck-boost controller to drive the TEC. Due to the requirement of heating and cooling, the key design challenges are as follows:

- Driver for TEC needs to be able to control the current in both directions
- Adjustable voltage control between TEC for a flexible and fast temperature change

Based on the application requirements explained previously, the design specification of the bidirectional current control for TEC are shown in Table 1-1.

Table 1-1. Design Specifications

Characteristic	Specification
Input voltage	15 V
Maximum voltage for TEC	±10 V
Maximum current for TEC	±4 A
Adjustable voltage for TEC	Yes
Constant voltage drive	Yes

2 Tec Driver Design Using Buck-Boost Controller

2.1 System Description

Due to the direction change in this application, the power supply needs to have the capacity to sink and source current. The buck-boost regulator is a good choice in this application. Most buck-boost modules and converters are limited in sink current; therefore, the buck-boost controller is selected in this note. LM5176 is a wide-input voltage four-switch buck-boost controller device with integrated drivers for N-channel MOSFETs. LM5176 can automatically transfer between the buck and boost mode. When Vin equals Vout, the device also provides a low ripple output voltage.

In this design, the LM5176 is supplied by a regulated voltage rail of 15 V. The TEC is connected between the Vin and Vout pin of the LM5176. The output voltage can be varied from 5 V to 25 V by adjusting the V_{ctrl} in the microcontroller. Since Vin is fixed, the voltage applied on the TEC can be changed from -10 V to 10 V, which can regulate the current of TEC.

2.2 Block Diagram of TEC Design With LM5176

As shown in Figure 2-1, the TEC is connected between the Vin and Vout of the four-switch-buck-boost controller LM5176. The output voltage is set by the FB pin, which is controlled by the microcontroller and the feedback voltage from the output. For the temperature control, a temperature sensor is required to sense the temperature for feedback control. Due to the characteristics of the TEC, the resistance of the TEC can change as the temperature goes higher so a current sense amplifier is optional for current monitoring. The MSPM0G3507 performs the proportional-integral-derivative control of the whole design to keep or change voltage for heating and cooling.

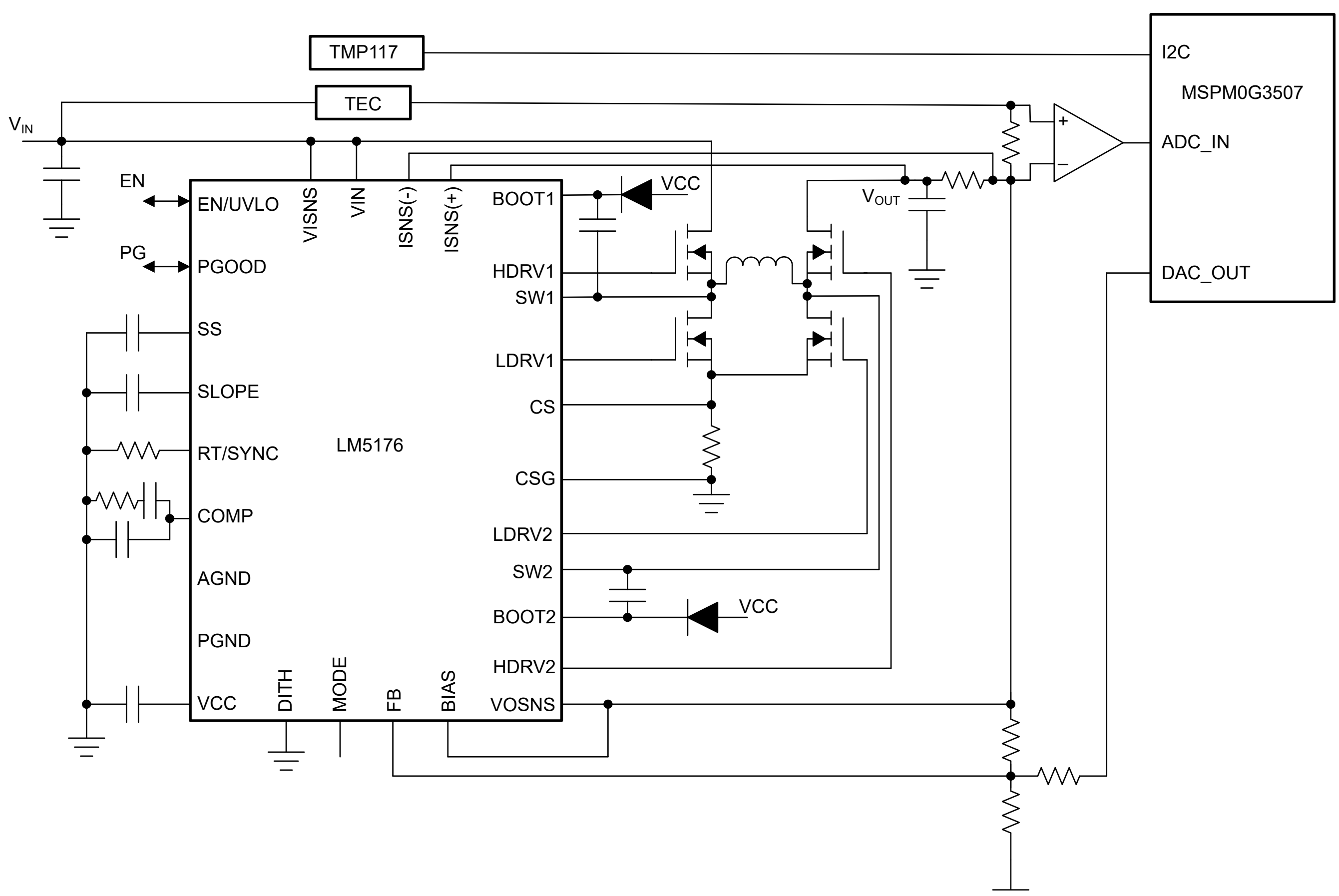

Figure 2-1. Block Diagram of TEC Design Using LM5176

2.3 Output Voltage Control of LM5176

Figure 2-2 shows the topology of the output voltage control using a microcontroller. Vout is regulated by using a resistor divider (R1 and R2) to the FB pin. The internal reference voltage of the LM5176 is 0.8 V. To control Vout through the DAC, the Resistor R3 is connected with the feedback divider and allows current to feed into the feedback node. For a detailed explanation, please refer to *PMP9796 5 V Low-Power TEC Driver Reference Design*.

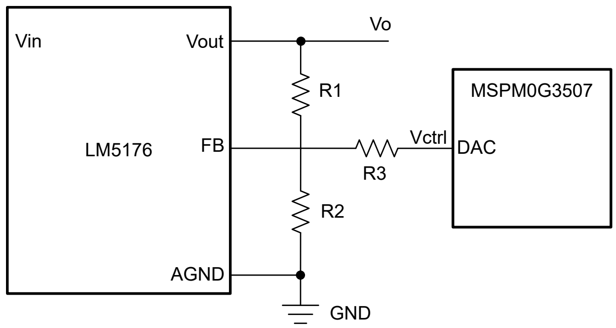

Figure 2-2. Control of Vout Using MCU

According to the data sheet, the bottom resistor R2 in the resistor divider is in the 1 kΩ to 100 kΩ range. Once the value of R1 has been chosen, R2 and R3 can be calculated by using the following equations:

$$R_3 = \frac{V_{ctrl\_max} - V_{ctrl\_min}}{V_{o\_max} - V_{o\_min}} \times R_1 \quad (1)$$

$$R_2 = \frac{V_{FB} \times R_1 \times R_3}{V_{o\_max} \times R_3 - V_{FB} \times (R_1 + R_3) + V_{ctrl\_min} \times R_1} \quad (2)$$

where

- R_3 is the resistor between control voltage and FB pin
- V_{ctrl_max} is the maximum value of control voltage
- V_{ctrl_min} is the minimum value of control voltage
- V_{o_max} is the minimum value of output voltage
- V_{o_min} is the minimum value of output voltage

For example, if R1 is selected as 280 kΩ, and Vout is from 5 V to 25 V, Vctrl needs to be varied from 0.5 V to 2 V. According to the previous equations, R2 and R3 are selected to be 11 kΩ and 21 kΩ respectively.

3 Test Result

In this application note, the test is performed using the LM5176EVM-HP and MSPM0G3507 Launchpad. Due to the requirement of an adjustable output voltage, R22 is replaced by an 11 kΩ resistor. C13 and C14 are replaced by 330 uF 100 V capacitors on the LM5176EVM-HP; the other components remain the same. The TEC element used in the test is MCTE1-19913L-S (Vmax: 24.1 V, Imax: 13 A).

3.1 TEC Current Versus Output Voltage

Figure 3-1, Figure 3-2, and Figure 3-3 show the waveform of Vout, SW1, SW2, and ITEC when Vout < Vin. The maximum voltage applied to the TEC element is about +10 V and ITEC is tested up to 4.34 A. Figure 3-4, Figure 3-5, and Figure 3-6 show the waveforms of LM5176 when Vout > Vin. In contrast to above, the maximum voltage is approximately -10 V and ITEC is up to -4.42 A.

CH1: SW1, CH2: SW2, CH3: V_{OUT}, CH4: I_{TEC}

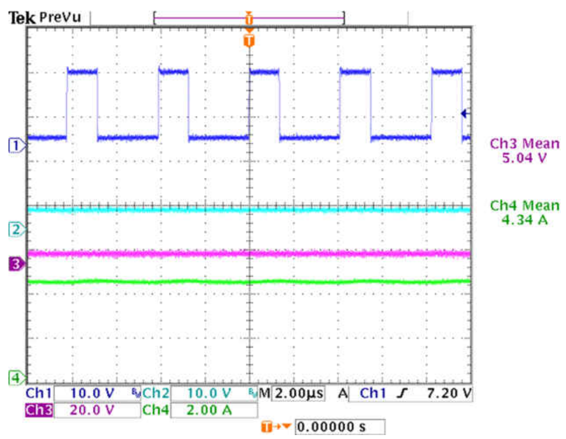

Figure 3-1. 15-V Input, 5-V Output

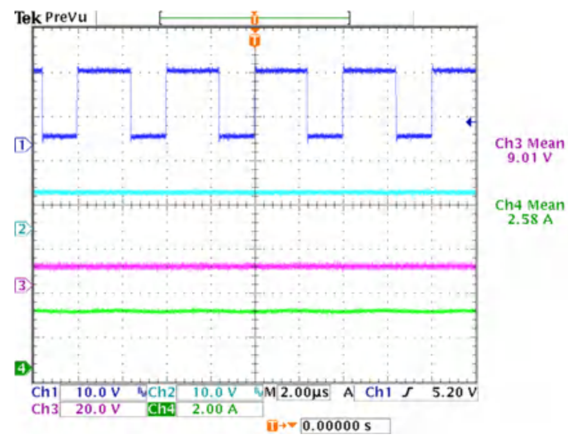

Figure 3-2. 15-V Input, 9-V Output

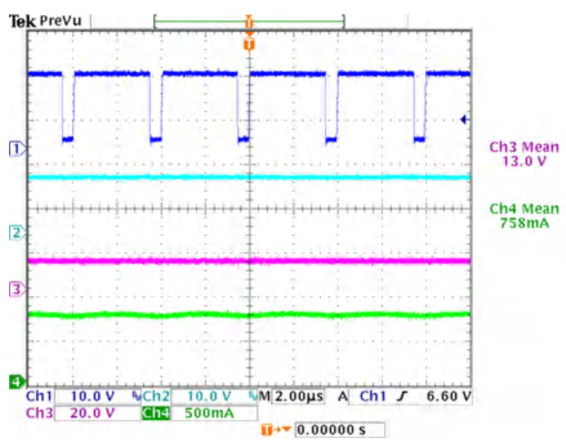

Figure 3-3. 15-V Input, 13-V Output

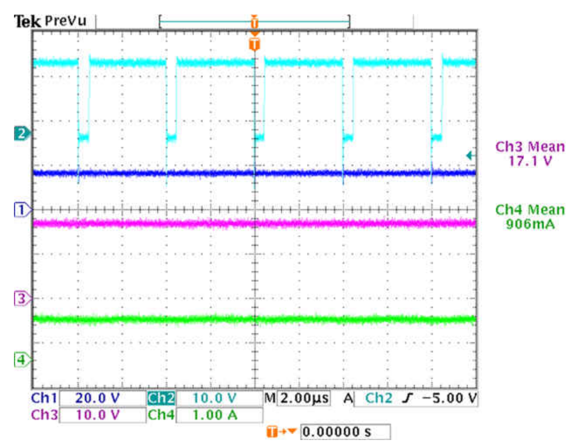

Figure 3-4. 15-V Input, 17-V Output

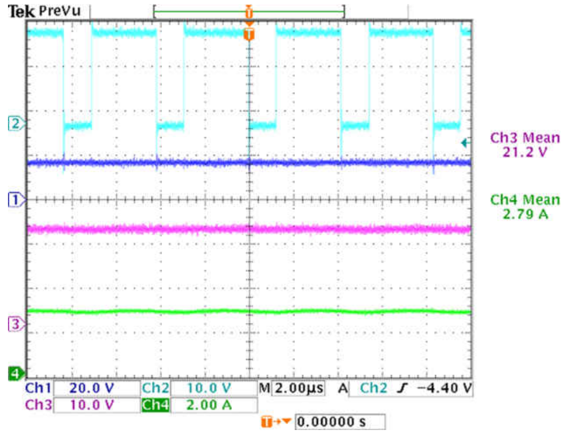

Figure 3-5. 15-V Input, 21-V Output

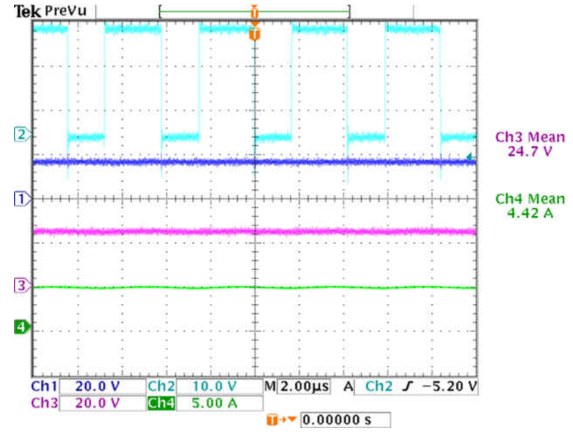

Figure 3-6. 15-V Input, 25-V Output

3.2 Current Ripple Measurement Through TEC Element

The maximum temperature differential across the element decreases if the ripple current increases. Thus, the maximum ripple current is recommended to be less than 10% for peak performance. Figure 3-7, Figure 3-8, Figure 3-9, and Figure 3-10 show the ripple current under different output voltages. All the tests meet the ripple requirement.

CH1: SW1, CH2: SW2, CH3: V_{OUT}, CH4: I_{Ripple}

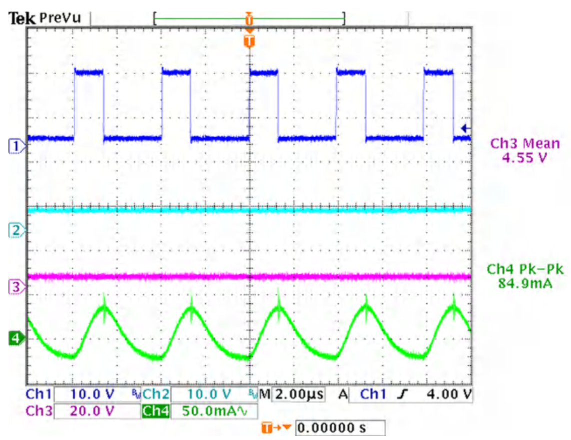

Figure 3-7. 15-V Input, 5-V Output

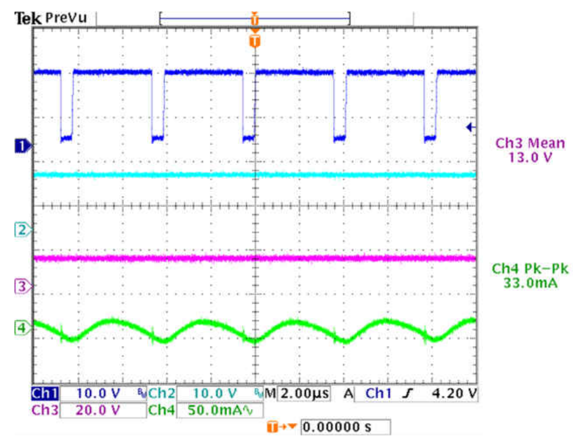

Figure 3-8. 15-V Input, 13-V Output

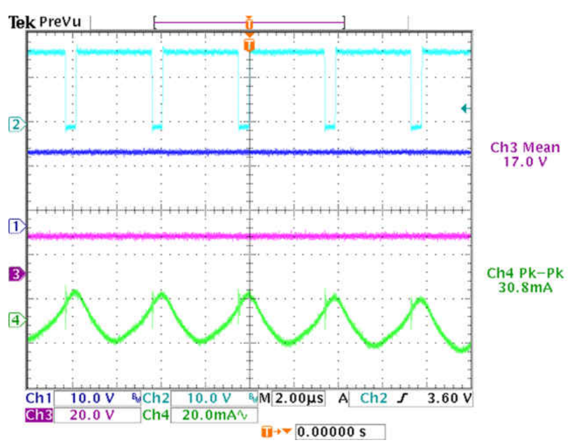

Figure 3-9. 15-V Input, 17-V Output

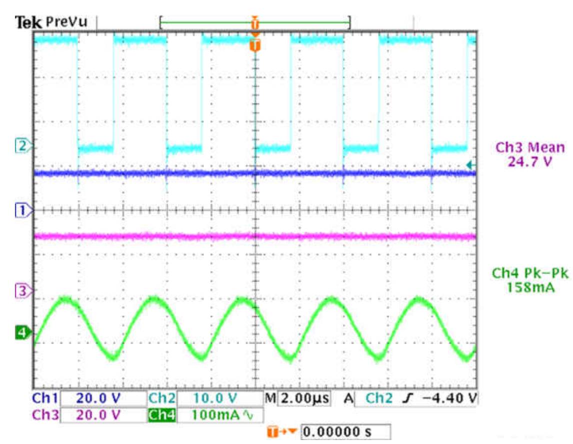

Figure 3-10. 15-V Input, 25-V Output

3.3 Start-Up

Figure 3-11 and Figure 3-12 show the start-up of LM5176 at different output voltages. In this application note, the design starts up well under the voltage difference across the TEC element within 10 V. As the TEC element is connected between the Vin and Vout of the LM5176, the TEC element biases the Vout. Thus, TI recommends setting the initial Vout close to Vin for a more stable start-up and then regulate the Vout to required voltage.

CH1: SW1, CH2: SW2, CH3: V_{OUT}, CH4: I_{TEC}

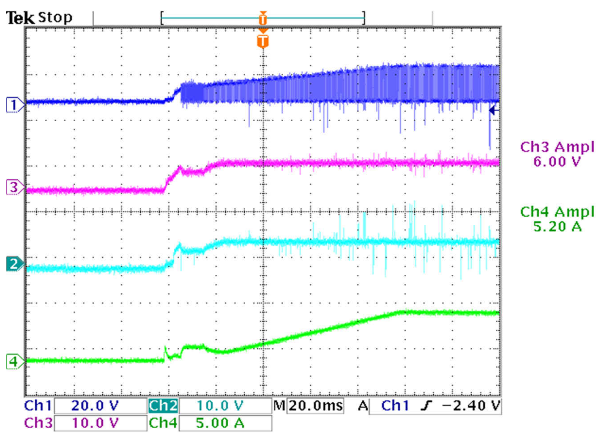

Figure 3-11. 15-V Input, 5-V Output

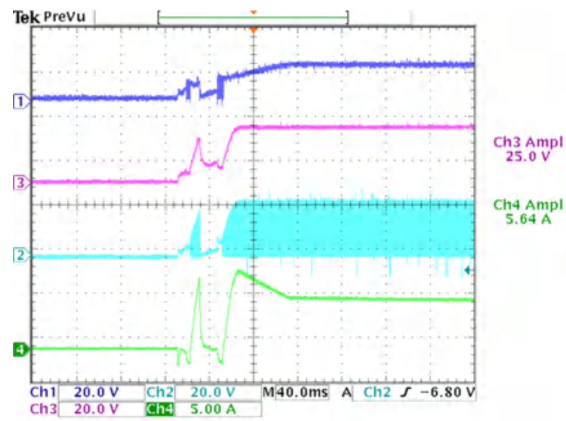

Figure 3-12. 15-V Input, 25-V Output

3.4 Efficiency

Figure 3-13 and Figure 3-14 show the efficiency of the design when Vin > Vout and Vin < Vout. The efficiency rises as the voltage increases. Maximum efficiency reaches 99.13% during the test.

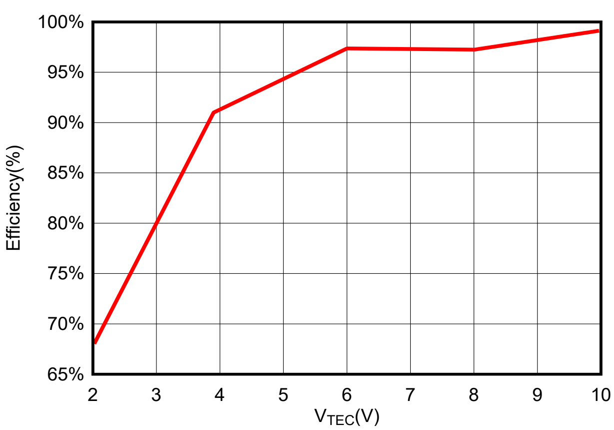

Figure 3-13. Efficiency (Vin > Vout)

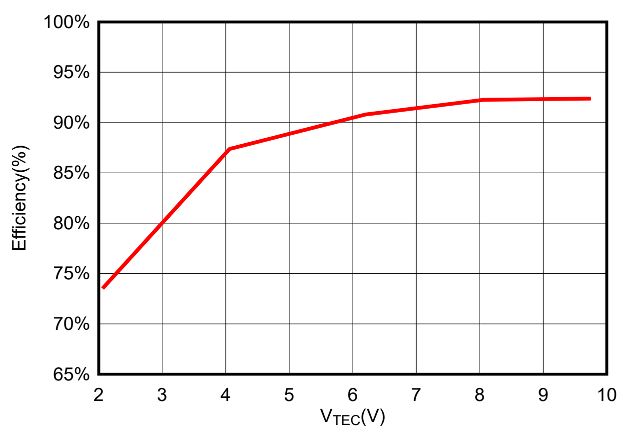

Figure 3-14. Efficiency (Vin < Vout)

4 Summary

TEC element is often used for applications that require heating and cooling. With the combination of LM5176 and MCU, customers can control the current direction through TEC element and adjust the voltage to meets the requirement of TEC element. Since the TEC current is limited by the external inductor and MOSFETs, it can be scaled to high current TEC element.

5 References

1. Texas Instruments, *PMP9796 - 5V Low-Power TEC Driver Reference Design*.
2. Texas Instruments, *TEC Driver Reference Design for 3.3-V Inputs*.
3. Texas Instruments, *LM5176 Wide-VIN Buck-Boost Controller EVM* user's guide