Application Report

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Design of the Adjustable V_{OUT} Boost Circuit

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ABSTRACT

This application note introduces a method to design an adjustable or programmable output voltage for a boost converter. The circuit implementation and design procedure are discussed in detail.

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1 Introduction

In some DC/DC boost power supply designs, an adjustable output voltage boost stage can be required by the system. For example, in a compatible DC source power supply, the voltage needs to be programmable step-up from 5 V to 9 V/12 V/15 V, and so forth, to adapt to different equipment port supply requirements. In some low-power systems, the port voltage needs to provide a changeable low-voltage option to optimize the light-load consumption or efficiency performance.

Most Boost controllers or converters set the programmable output with a voltage feedback divider resistors network. The output voltage is sampled and scaled down to comparatively to a certain reference voltage. Changing the scaling down ratio would directly decide the output voltage.

An intuitive idea is to program the feedback resistor value to control the output voltage, but it would affect the following [1]:

- System efficiency
- Output voltage accuracy
- Noise sensitivity
- Stability

A practical method is leveraging the internal error amplifier and implementing it as a summing circuit, to rebuild the voltage feedback with an addition voltage term. This article discusses how to design this kind of the circuit and evaluate the power supply performance.

2 Transfer Character Calculation

Figure 1 shows the circuit configuration.

Create the FB point Kirchhoff law equation as:

$$\frac{V_{out} - V_{FB}}{R_F} + \frac{V_{con} - V_{FB}}{R_c} = \frac{V_{FB}}{R_g} \tag{1}$$

Re-structure the equation as the expression from V_{con} to V_{out}:

$$V_{out} = \left(1 + \frac{R_F}{R_g}\right) \cdot V_{FB} + \frac{R_F}{R_c} \cdot (V_{FB} - V_{con}) \tag{2}$$

Based on the operation amplifier principal, as the boost circuit working in close loop, $V_{FB} = V_{REF}$. Re-write the equation as:

$$V_{out} = \left(1 + \frac{R_F}{R_g}\right) \cdot V_{REF} + \frac{R_F}{R_c} \cdot (V_{REF} - V_{con}) \tag{3}$$

$$V_{out} = -a \cdot V_c + b \cdot V_{REF}$$

where

- $a = \frac{R_F}{R_c}$
- $b = \left(1 + \frac{R_F}{R_g} + \frac{R_F}{R_c}\right)$ (4)

The additional Vcon voltage introduces a new inverting term, which is multiplied by R_f / R_c, so that V_{out} has a linear relationship with V_{con}. This explains how an external analog signal can easily control the boost output voltage.

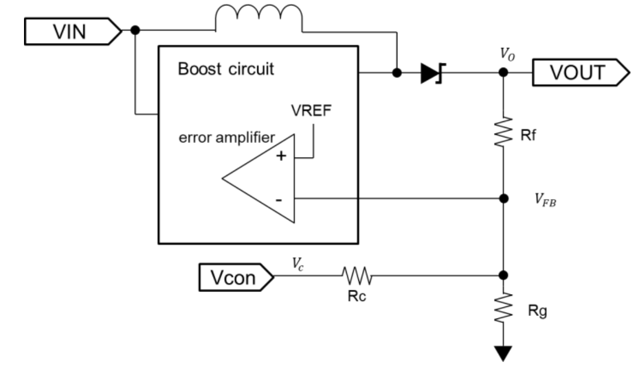

Figure 1. Adjustable Output Voltage Boost Circuit Configuration

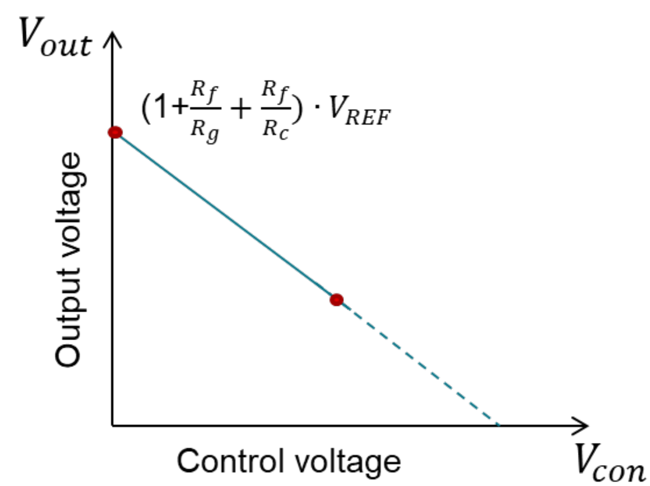

Figure 2. V_{out} versus V_{con}

3 Detailed Design Procedure

3.1 Design Requirements

For this example, use the design parameters listed in Table 1.

Table 1. Adjustable Output Boost Design Requirement

DESIGN PARAMETERS	EXAMPLE VALUES
V_{in}	5 V
V_{out} range	[9 V, 15 V]
Control voltage range	[0 V, 5 V]
Output power	15 V at 0.5 A

3.2 Design Procedure

Based on the input voltage range, output voltage range, and the output power requirements, the TPS61085 is selected as the boost converter. The TPS61085 is a high frequency, high efficiency boost converter with an integrated 2-A, 0.13-Ω power switch capable of providing an output voltage up to 18.5 V. The input voltage range is from 2.3 V to 6 V.

3.2.1 Setting the Output Voltage

Use the V_{con} range [0 V, 5 V] and output range [9 V, 15 V] correspondingly as the variable in Equation 3 to calculate the R_f, R_c, and R_g.

$$V_{o(Max)} = \left(1+\frac{R_F}{R_g}\right)\cdot V_{REF} + \frac{R_F}{R_c}\cdot\left(V_{REF} - V_{c(Min)}|0V\right) = 15V$$

$$V_{o(Min)} = \left(1+\frac{R_F}{R_g}\right)\cdot V_{REF} + \frac{R_F}{R_c}\cdot\left(V_{REF} - V_{c(Max)}|5V\right) = 9V \quad (5)$$

where

- V_{REF} = 1.238 V (6)

Then use the following equations to get:

$$R_F = 1.2 * R_c \quad (7)$$

$$R_F = 9.92 * R_g \quad (8)$$

Generally, the R_g value needs to meet a certain feedback loop requirement. For the TPS61085, a minimum current of 50 μA flowing through the feedback divider gives good accuracy and noise covering. A standard low-side resistor of 18 kΩ is typically selected. Then, select R_f as 180 kΩ and R_c as 150 kΩ.

3.2.2 Duty Cycle, Output Current, and Inductor

3.2.2.1 Duty Cycle, D

$$D = 1 - \frac{V_{IN} \cdot \eta}{V_{OUT}} \quad (9)$$

According to the efficiency curve, assume efficiency is 85% in the condition of V_{in} = 5 V and V_{out} = 15 V. Use the input voltage (V_{in} = 5 V) and output voltage (V_{out} = [9 V, 15 V]) to calculate D = 0.7 ~ 0.5. The maximum duty cycle, D_{max}, is 0.7 when setting 5 V for V_{in} and 15 V for V_{out}.

3.2.2.2 Output Current, I_o Maximum

$$I_o \max \leq \left(I_{CL} \min - \frac{IL_{ripple}}{2}\right) \times (1 - D_{max}) \quad (10)$$

For the TPS61085, the I_{cl} minimum is 2 A, assuming $I_{Lripple}$ is 25% of the minimum current limit. When you use the TPS61085 as the converter to boost from 5 V to maximum output voltage, 15 V, the supposed I_{out} ≤ 0.525 A.

3.2.2.3 Inductor

Calculate the inductor value based on $I_{Lripple}$ within 25% of average inductor current.

$$IL_{avg} = \frac{I_{OUT}}{1 - D} \quad (11)$$

$$IL_{ripple} = \frac{V_{IN} \cdot D}{f_s \cdot L} \quad (12)$$

$$L \geq \frac{V_{IN} \cdot (1 - D) \cdot D}{f_s \cdot I_{OUT} \cdot 25\%} \quad (13)$$

$$\geq \left(\frac{V_{IN}}{V_{OUT}}\right)^2 \cdot \left(\frac{V_{OUT} - V_{IN}}{I_{OUT} \cdot f_S}\right) \cdot \left(\frac{\eta}{0.25}\right) \quad (14)$$

The worst case is under the 50% duty cycle and 9 V V_{out}, which is calculated to be L = 7.0 µH at 1.5 MHz and L = 12.9 µH at 650 kHz.

The inductor current must be more than I_{Lavg} + $I_{Lripple}$ and some additional margin. The worst case is under 70% duty cycle, and it can be calculated that I_{Lsat} must be at least more than 1.875 A, but more than 2 A is highly recommended.

4 Test Result

Figure 3 shows the performance of V_{out} programmed by signal V_{con}. V_{out} matches to the calculation result with a good linearity. The error is less than 1.5%.

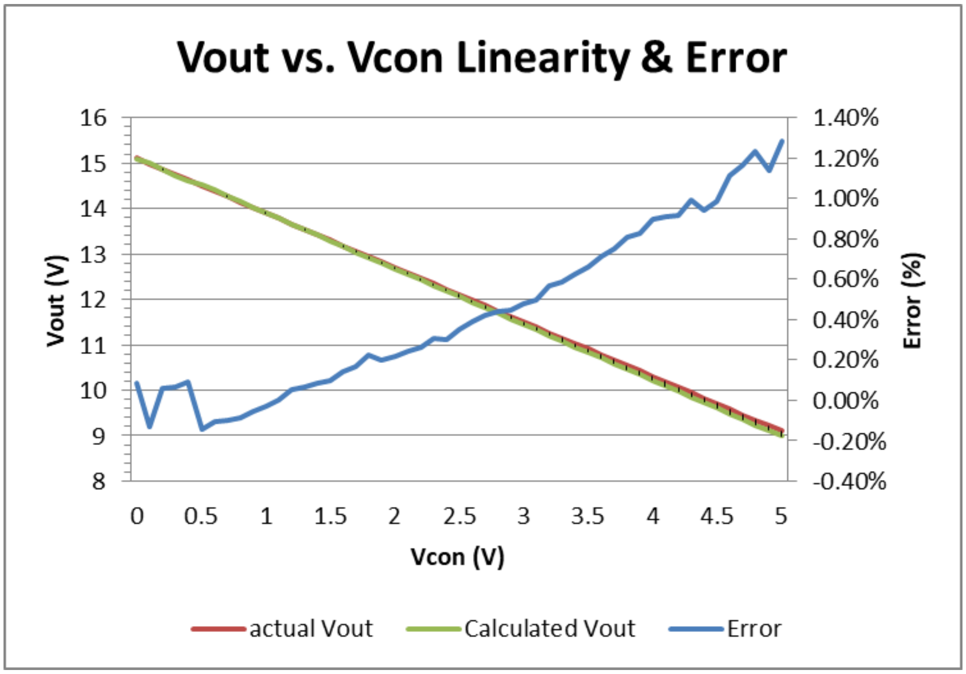

Figure 3. Vout versus Vcon Linearity and Error

5 Variant Circuit Design

5.1 Multi-level Voltage Output Switchover

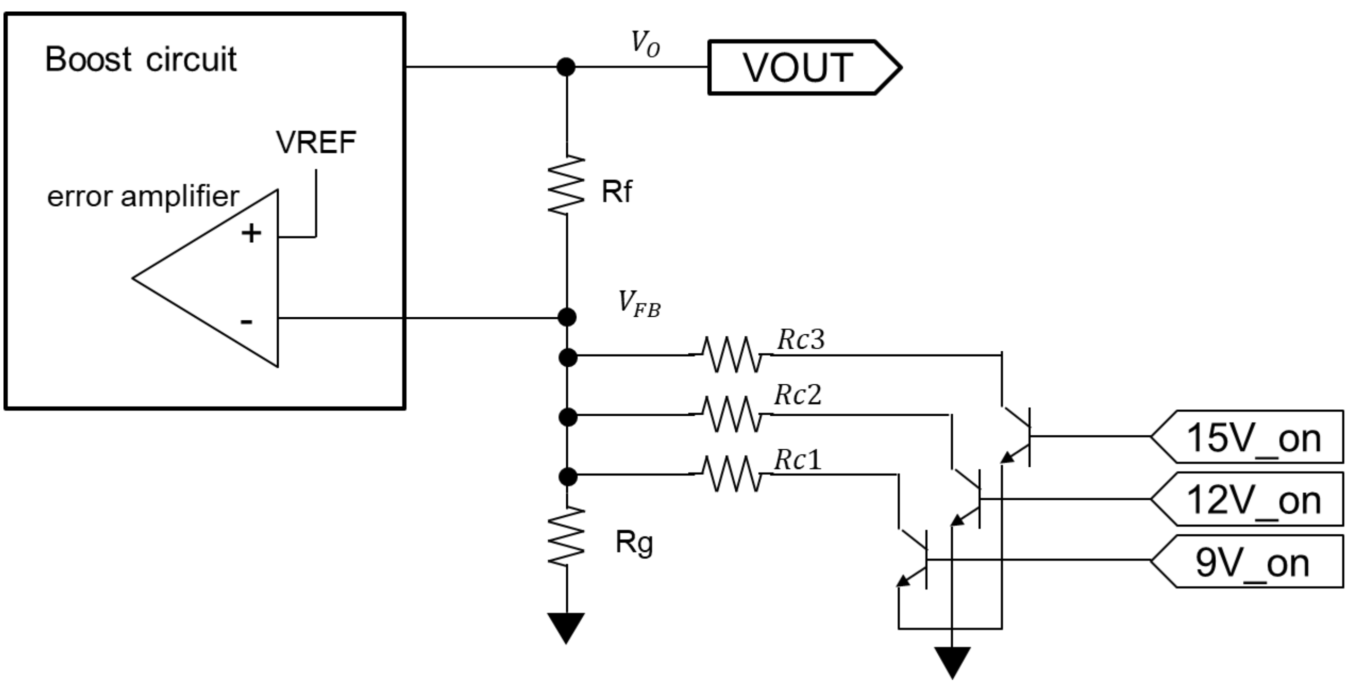

Figure 4. Variant Circuit for Multi-level Voltage Output

5.2 Program-controlled Vout Power Supply

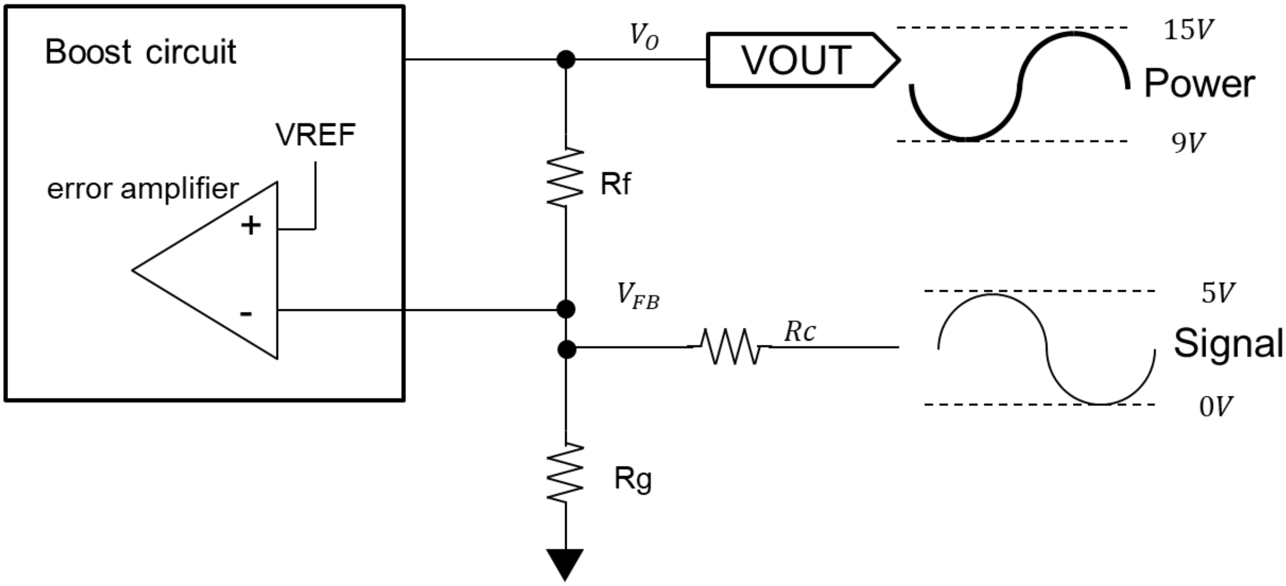

Figure 5. Variant Circuit for Program-controlled Power Supply

6 References

1. Texas Instruments, *Design Considerations for a Resistive Feedback Divider in a DC/DC Converter Technical Brief*
2. Texas Instruments, *Methods of Output-voltage Adjustment for DC/DC Converters Technical Brief*

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