ABSTRACT

This application report explains how to use an external reference voltage to regulate the output voltage range of a linear regulator below its internal reference voltage.

Contents

1 Description of the Problem ................................................................. 1
2 Implementation of Solution .................................................................... 2

List of Figures

1 Block Diagram ................................................................................... 2
2 UC382-ADJ Providing 1.1-V Output .................................................... 3
3 TPS78601 Providing 1.1-V Output ........................................................ 4

1 Description of the Problem

All dc/dc switching converters and linear regulators regulate their output voltage relative to an internal reference voltage. Therefore, the lowest output voltage that these converters and regulators can provide is the internal reference voltage, which is frequently a 1.2 V bandgap derived reference. This application report explains how to use an external reference voltage to extend the output voltage range of a switching converter or linear regulator below its internal reference voltage. A ±1% accurate linear regulator (TPS736xx) with an enable pin is used as the external reference in order to prevent overshoot at start-up that can occur if the converter/regulator powers up before or powers down after the external reference.
2 Implementation of Solution

The block diagram in Figure 1 shows the general implementation.

![Block Diagram](image)

**Figure 1. Block Diagram**

The dc output voltage is computed by **Equation 1**:

\[
V_{\text{OUT}} = V_{\text{REF_int}} \times \left( 1 + \frac{R_{\text{TOP}}}{R_{\text{BOT}}} \right) - \left( \frac{R_{\text{TOP}}}{R_{\text{BOT}}} \times V_{\text{REF_ext}} \right)
\]

Equation 2 computes the maximum output voltage tolerance given the tolerances of each circuit component.

\[
\% \text{TOL}
V_{\text{OUT}} = \frac{\% \text{TOL}
V_{\text{REF_int}}}{V_{\text{OUT}}} - \frac{2 \times \% \text{TOL}
R}{V_{\text{OUT}} - V_{\text{REF_int}} + 1} + \frac{\% \text{TOL}
V_{\text{REF_ext}}}{R_{\text{BOT}} \times V_{\text{REF_ext}}}
\]

A more accurate output voltage can be achieved by using an external reference with higher accuracy and/or external resistors with higher accuracy. The output voltage accuracy worsens as the difference between \(V_{\text{REF_int}}\) and \(V_{\text{OUT}}\) increases and improves as the difference between \(V_{\text{REF_ext}}\) and \(V_{\text{REF_int}}\) increases.
2.1 Example 1

Figure 2 shows a circuit using the UC382-ADJ 3-A rated linear regulator and the TPS73133 to provide 1.1 V ±1.5%. The UC382-ADJ regulates $V_{FB}$ to $V_{REF\_INT} = 1.20 \text{ V} \pm 1\%$ and the TPS73133 provides $V_{REF\_ext} = 3.3 \text{ V} \pm 1\%$. Additionally, ±1% resistors were used.

![Figure 2. UC382-ADJ Providing 1.1-V Output](image)

By itself, the UC382 is a dual input regulator, requiring a bias voltage, $V_B \geq V_{OUT} + V_{B\_dropout}$, where $V_{B\_dropout}$ is the minimum allowed differential between $V_B$ and $V_{OUT}$ and a power input voltage, $V_{IN} \geq V_{OUT} + V_{IN\_dropout}$, where $V_{IN\_dropout}$ is the minimum allowed differential between $V_{IN}$ and $V_{OUT}$. In this application, the TPS73133 serves a dual purpose by providing 3.3 V for the external reference and the input bias voltage. When enabled and disabled using the EN pin of the TPS73133, the output voltage from the UC382 rises and falls smoothly with negligible overshoot. Recommended $V_{IN}$ is 1.6 V to 1.8 V for high efficiency and minimal power dissipation through the regulator. The maximum ambient temperature determines the package’s maximum power dissipation capability. The power dissipated in the regulator, computed as $P_d = (V_{IN} - 1.1) \times I_{OUT\_max}$, determines the maximum input voltage. A larger capacitor on $V_{IN}$ may be required depending on the regulator’s proximity to the $V_{IN}$ power supply. Using the larger 5-A output current rated UC385 device requires moving to the higher current TPS73233 regulator instead of the TPS73133 in order to provide the necessary bias current. For either the UC382 or UC385, there is a 1-mA minimum load for proper regulation and the output capacitor, C6, must be at least 100 µF with at least 50 mΩ of ESR for control loop stability.
2.2 Example 2

Figure 3 shows a circuit using the TPS78601 1.5-A rated linear regulator and the TPS73125 to provide 1.1 V ±2.8%. The TPS78601 regulates $V_{FB}$ to $V_{REF, INT} = 1.2246\ V \pm 2\%$ and the TPS73125 provides $V_{REF, ext} = 2.5\ V \pm 1\%$. Additionally, ±0.5% resistors are necessary for R2 and R3.

By itself, the TPS78601 has a minimum input voltage of 2.7 V. In this application, the TPS73125 serves a dual purpose by providing 2.5 V for the external reference and the enable signal for the TPS78601. Resistor R1 and capacitor C3 delay the start-up of the fast-starting TPS78601 until the TPS73125 provides the reference and diode D1 removes this delay and pulldown resistor R4 removes $V_{REF, ext}$ at power down. Therefore, when enabled and disabled using the EN pin of the TPS73125, the output voltage from the TPS78601 rises and falls smoothly with negligible overshoot. In order for the TPS73125 to maintain ±1% regulation, the minimum $V_{IN}$ is 3 V and R4 of 250 Ω is required to maintain 10-mA load. The maximum ambient temperature determines the package’s maximum power dissipation capability. The power dissipated in the regulator, computed as $P_d = (V_{IN} - 1.1) \times I_{OUT, max}$, determines the maximum input voltage. A larger capacitor on $V_{IN}$ may be required depending on the regulator’s proximity to the $V_{IN}$ power supply. Any of the TPS79x01 family of linear regulators can be substituted if lower output currents are needed. Although only a 2.2-µF ceramic output capacitor, C7, is required for regulator stability, a much larger output capacitance with low ESR is recommended for best PSRR and lowest noise performance.
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