# Effect of Resistor Tolerances on Power Supply Accuracy

*Maxwell Robertson* — *LP Linear Regulators*

**ABSTRACT**

This document assists designers in determining the impact of resistor tolerances on a power supply's output accuracy. It explains how resistive dividers are used in power supply regulation, derives an equation for output accuracy in terms of the divider resistors' tolerances, and examines the impact of this equation on an example design.

## 1 Introduction

In order for a power supply to properly regulate a voltage rail, it must have some way of sensing its output voltage. This is most commonly accomplished by using a resistive divider to scale the output voltage down so that it may be compared against an accurate reference. Figure 1, a simplified diagram of a linear regulator, illustrates this concept.

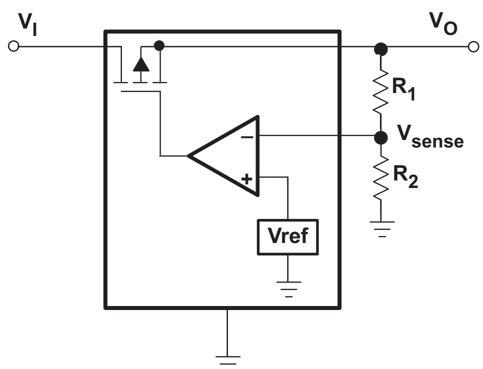


**Figure 1. Simplified Linear Regulator**

The accuracy of the resistors used in the divider, marked $R_1$ and $R_2$, has a direct impact on the accuracy of the power supply. For fixed-output supplies, this divider is internal, and thus its effects are already included in the rated accuracy of the device. For adjustable-output supplies, however, it is up to the designer to determine how resistor selection affects total power supply accuracy.

A common misconception is that using two resistors of a particular tolerance (notated ±T) in the divider corresponds to a maximum output error of ±2 × T. In fact, this is usually not the case. The maximum error is actually inversely proportional to the divider ratio and decreases linearly as the power supply's output voltage approaches its internal reference value. This report explains why this is so and discusses the impact that this fact has on total power supply accuracy.

## 2 Definitions

The following symbols and notation schemes are used in this report:

- $R_1$ and $R_2$ are the actual values of the resistors in the power supply's feedback loop. They are equal to the nominal resistances, notated as $\langle R_1 \rangle$ and $\langle R_2 \rangle$, plus an absolute error. The absolute errors are notated as $\Delta R_1$ and $\Delta R_2$ and are expressed in Ohms (Ω).

- The relative errors in $R_1$ and $R_2$ are represented by $\tau_1$ and $\tau_2$. These values are the ratio of the absolute error in each resistor to its nominal value and are bounded by each resistors' tolerance ($\pm T_1$ and $\pm T_2$). In this report, relative errors and resistor tolerances are both expressed as decimal ratios rather than percentages, e.g., ±0.01 rather than ±1%.
- The actual value of the power supply's output voltage is $V_O$. Like the aforementioned resistances, it is made up of a nominal value, $\langle V_o \rangle$, and an absolute error, $\Delta V_O$.
- The value of the power supply's reference voltage is $V_{ref}$.

## 3 Derivation

The output voltage of our power supply is given by Equation 1:

$$V_o = \left(1 + \frac{R_1}{R_2}\right) \times V_{ref} \tag{1}$$

Equation 1 is based on the assumption that the gain of the internal error amplifier is very high, and that current into the amplifier is significantly less than the current through the external voltage divider. This can be ensured in a design by choosing resistances such that the divider current is substantially higher than the leakage current into the feedback pin.

The output voltage and both resistances can be expressed in terms of their nominal values and absolute errors:

$$\langle V_o \rangle + \Delta V_o = \left(1 + \frac{\langle R_1 \rangle + \Delta R_1}{\langle R_2 \rangle + \Delta R_2}\right) \times V_{ref} \tag{2}$$

Equation 2 can be rewritten as:

$$\Delta V_o = \left(1 + \frac{\langle R_1 \rangle + \Delta R_1}{\langle R_2 \rangle + \Delta R_2}\right) \times V_{ref} - \langle V_o \rangle \tag{3}$$

The nominal output voltage, $\langle V_o \rangle$, can be defined in terms of the nominal resistances and $V_{ref}$. The resulting equation is:

$$\Delta V_o = \left(1 + \frac{\langle R_1 \rangle + \Delta R_1}{\langle R_2 \rangle + \Delta R_2}\right) \times V_{ref} - \left(1 + \frac{\langle R_1 \rangle}{\langle R_2 \rangle}\right) \times V_{ref} \tag{4}$$

Grouping both terms on the right side yields:

$$\Delta V_o = \left[\left(1 + \frac{\langle R_1 \rangle + \Delta R_1}{\langle R_2 \rangle + \Delta R_2}\right) - \left(1 + \frac{\langle R_1 \rangle}{\langle R_1 \rangle}\right)\right] \times V_{ref} \tag{5}$$

The absolute error terms $\Delta R_1$ and $\Delta R_2$ can be rewritten as the product of their relative errors and nominal values:

$$\Delta V_o = \left[\left(1 + \frac{\langle R_1 \rangle + \tau_1 \times \langle R_1 \rangle}{\langle R_2 \rangle + \tau_2 \times \langle R_2 \rangle}\right) - \left(1 + \frac{\langle R_1 \rangle}{\langle R_2 \rangle}\right)\right] \times V_{ref} \tag{6}$$

Algebraic manipulation of Equation 6 yields:

$$\Delta V_o = \left(\frac{1 + \tau_1}{1 + \tau_2} - 1\right) \times \frac{\langle R_1 \rangle}{\langle R_2 \rangle} \times V_{ref} \tag{7}$$

Note that Equation 7 is equivalent to:

$$\Delta V_o = \left(\frac{1+\tau_1}{1+\tau_2} - 1\right) \times \left(\langle V_o \rangle - V_{ref}\right) \tag{8}$$

It is often more useful to think of the output voltage error in relative rather than absolute terms. The relative output voltage error can be found by dividing both sides of Equation 8 by the nominal output voltage:

$$\frac{\Delta V_o}{\langle V_o \rangle} = \left(\frac{1+\tau_1}{1+\tau_2} - 1\right) \times \left(1 - \frac{V_{ref}}{\langle V_o \rangle}\right) \tag{9}$$

Equation 9 can be further simplified:

$$\frac{\Delta V_o}{\langle V_o \rangle} = \left(\frac{\tau_1 - \tau_2}{1+\tau_2}\right) \times \left(1 - \frac{V_{ref}}{\langle V_o \rangle}\right) \tag{10}$$

Note that this is a general equation for the relative output voltage error (output accuracy) in terms of the relative errors in the values of the external resistances. In designing a power supply, typically what is of interest is the maximum possible error. This occurs in two cases.

In the first case, $R_1$ is at the maximum of its range of tolerance and $R_2$ is at the minimum. To simplify, assume that both resistors have the same tolerance rating. Therefore,

$$\tau_1 = +T$$
$$\tau_2 = -T$$
$$\therefore \frac{\Delta V_o}{\langle V_o \rangle} = \left(\frac{2 \times T}{1 - T}\right) \times \left(1 - \frac{V_{ref}}{\langle V_o \rangle}\right) \tag{11}$$

In the second case, $R_1$ is at the minimum of its range of tolerance and $R_2$ is at the maximum. Therefore,

$$\tau_1 = -T$$
$$\tau_2 = +T$$
$$\therefore \frac{\Delta V_o}{\langle V_o \rangle} = \left(\frac{-2 \times T}{1 - T}\right) \times \left(1 - \frac{V_{ref}}{\langle V_o \rangle}\right) \tag{12}$$

For resistors tolerances of ±0.01 (i.e., 1%) or less, we can make the following assumption:

$$(1 + T) \cong (1 - T) \cong 1 \tag{13}$$

And the relative output voltage error can be expressed as merely:

$$\frac{\Delta V_o}{\langle V_o \rangle} = \pm(2 \times T) \times \left(1 - \frac{V_{ref}}{\langle V_o \rangle}\right) \tag{14}$$

Or, as a percentage:

$$\boxed{\frac{\Delta V_o}{\langle V_o \rangle}(\%) = \pm(2 \times T) \times \left(1 - \frac{V_{ref}}{\langle V_o \rangle}\right) \times 100\%} \tag{15}$$

In addition to resistor tolerance, device accuracy must also be taken into account when evaluating the total accuracy of a design. The total power supply accuracy is simply a sum of the rated accuracy of the device used and the relative output error due to the resistive divider.

## 4 Example

This section looks at the expected output accuracy of an example power supply design using the TPS79901 low-dropout regulator. The device has a typical reference voltage of 1.193 V. If the device is used to power a 3.30-V rail, then the necessary divider ratio is

$$\frac{V_{ref}}{\langle V_o \rangle} = \frac{1.193\ \text{V}}{3.30\ \text{V}} \cong 0.362 \tag{16}$$

Using divider resistors with tolerances of 0.01 (i.e., 1%), the maximum relative output error due to resistor tolerance is

$$\frac{\Delta V_o}{\langle V_o \rangle} = \pm 2 \times T \times \left(1 - \frac{V_{ref}}{\langle V_o \rangle}\right) \cong \pm 0.0128,\ \text{or}\ \pm 1.28\% \tag{17}$$

This value must be added to the rated accuracy of the device. The TPS79901 has a nominal accuracy of ±0.01 (i.e., ±1%). Therefore, the total accuracy of the power supply is now ±2.28%.

Recall that the power supply's total accuracy improves the closer its output voltage is to its reference voltage. For example, if the same device were used for a 1.80-V supply instead, then the divider ratio becomes

$$\frac{V_{ref}}{\langle V_o \rangle} = \frac{1.193\ \text{V}}{1.80\ \text{V}} \cong 0.663 \tag{18}$$

And the resulting error contribution from the divider is

$$\frac{\Delta V_o}{\langle V_o \rangle} = \pm 2 \times T \times \left(1 - \frac{V_{ref}}{\langle V_o \rangle}\right) \cong \pm 0.00674,\ \text{or}\ \pm 0.674\% \tag{19}$$

Adding this result to the nominal accuracy of the device results in a total output accuracy of ±1.674%, an improvement over the accuracy possible for a 3.30-V rail.

## 5 Other Factors

Although in this report the divider resistors' rated tolerances defined the worst-case deviation from nominal values, in practice this is not necessarily so. Many factors can further reduce the accuracy of resistors. For instance:

- Most resistors have some positive or negative temperature coefficient that defines how the resistance values vary with temperature.
- Exposure to various thermal conditions such as soldering or extended high- or low-temperature operation can cause resistances to drift over time.
- Other operating conditions such as humidity, pressure, and exposure to vibration or shock can increase the resistors' effective tolerances.

In many cases, it is safe to assume that these factors have a similar impact on both divider resistors, keeping the divide ratio constant. However, it is always a good idea to keep in mind that resistor accuracy is not always bounded by tolerance and to margin designs appropriately.

## 6 Conclusion

The tolerances of the resistors in a power supply's voltage divider do affect the supply's output accuracy, but the common assumption that the accuracy specification must be increased by twice the tolerance value is incorrect. In fact, this assumption is only true for the limiting case of the output voltage far exceeding the device's internal reference voltage. Realizing that the output accuracy improves as the divider ratio increases will allow designers to better estimate accuracy. It may also allow accuracy goals to be reached without resorting to costly precision components.

## 7 Further Reading

1. Mancini, Ron. *Worst-case circuit design includes component tolerances*, EDN Magazine, April 15, 2004, pp. 61-64.
2. Kollmann, Robert. *Your regulator's output-voltage accuracy may not be as bad as you think*, Power Management DesignLine, December 7, 2009. [Online]. Available: http://www.powermanagementdesignline.com. [Accessed April 16, 2010].

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