

Optimize output-voltage accuracy of adjustable low-dropout regulators

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Low-dropout regulators (LDOs) have become common in portable electronic equipment. Their small size, high noise rejection, and low cost make them an attractive solution to a range of system problems—from active power-supply decoupling to local

voltage regulation and control. Although LDO suppliers offer several fixed output-voltage settings, some applications require settings that you can't get in an off-the-shelf product.

Your solution to this problem is often a special order for a custom output-voltage LDO, but the disadvantages of longer leadtime, availability from only one vendor, and a possible increase in cost can make an adjustable-output LDO more attractive. Adjustable LDOs, however, lack the tight voltage accuracy of their fixed-output counterparts—a problem that is difficult to remedy in a cost-effective manner. However, you can improve the accuracy of adjustable LDOs to match the accuracy of their fixed-output counterparts by using a few circuit tricks.

The output-voltage accuracy of an adjustable LDO depends on the initial accuracy, stability, and temperature coefficient of its internal bandgap reference and the external feedback resistors. Rather than specifying V_{OUT} accuracy on adjustable regu-

An adjustable LDO is good choice when you need a nonstandard voltage, but getting the highest accuracy from one requires a few circuit tricks.

lators, the vendor specifies the initial accuracy and temperature coefficient of their internal reference; the vendor does not specify V_{OUT} accuracy because that accuracy depends on the external feedback resistors. In a typical adjustable-LDO feedback

circuit (Figure 1), resistors R_1 and R_2 set the output voltage, as determined by the following formula:

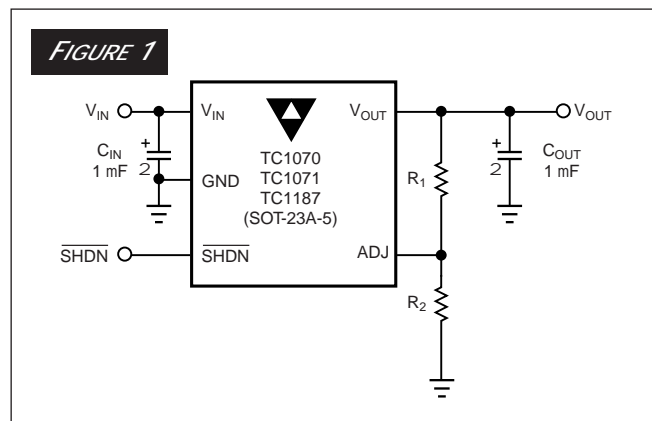
$$V_{OUT} = V_{REF} \left[\frac{R_1}{R_2} + 1 \right], \quad (1)$$

where $V_{REF} = 1.23V$.

The adjust pin (ADJ) is a high-impedance CMOS input. Consequently, resistor values can range from 300 kV to 1 MV to minimize the current through R_1 and R_2 . When V_{OUT} equals

V_{REF} (by making $R_1 = 0$), the tolerance of V_{OUT} is approximately that of V_{REF} . Also, when V_{OUT} is greater than V_{REF} (which occurs when $R_1/R_2 > 0$), the tolerance of V_{OUT} is a function of both the tolerance of V_{REF} and the tolerance of the R_1/R_2 ratio. In a worst-case analysis, the tolerances of R_1 and R_2 are additive; if both R_1 and R_2 are 1% resistors, the maximum tolerance of the R_1/R_2 ratio is 2%.

By re-examining the effect of tolerances on the equation, you can see that



In a typical adjustable LDO feedback circuit, resistors R_1 and R_2 set the output voltage.

ADJUSTABLE LDOs

the tolerance of V_{OUT} worsens proportionally as the V_{OUT} setting departs the value of V_{REF} . Stated another way,

$$\text{ERROR}_{V_{OUT}} \propto (V_{OUT} - V_{REF})$$

Table 1 shows the percentage of total output-voltage error contributed by the tolerances of V_{REF} and $R1/R2$ for various values of V_{OUT} . The output-voltage accuracy of the adjustable regulator improves with tighter tolerance resistors. However, accuracy is limited to $\pm 2\%$ due to the accuracy of the reference. Table 2 shows output-voltage accuracy for the adjustable LDO using resistors with 1, 0.5, and 0.1% tolerance.

The only way to improve the output accuracy to better than $\pm 2\%$ is to employ an external reference, such as Telcom Semiconductor's (www.telcom-semi.com) TCN4041, (Figure 2). By definition, the voltage at the adjust pin equals V_{REF} . Consequently, you can express V_{OUT} as:

$$V_{OUTLDO} = V_{REFLDO} + V_{OUTTCN4041}$$

With this configuration, the effect of the LDO's internal reference on output error is kept at 2% (24.6 mV) absolute, as opposed to being multiplied by the feedback resistance ratio. The external reference also improves output accuracy because, unlike the internal reference, it is not exposed to self-heating during high load conditions. You use resistors R_{1x} and R_{1y} to program the output voltage of the reference.

Don't neglect initial accuracy

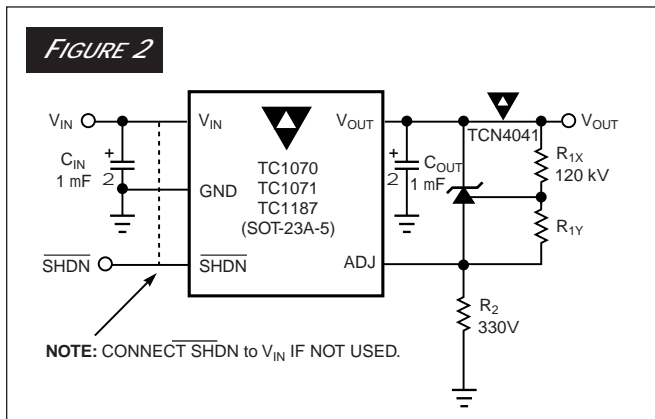
Initial accuracy, in addition to the tolerances of programming resistors R_{1x} and R_{1y} , also affects the voltage reference. The relationship between the V_{OUT} of the voltage reference and the programming resistors is given by:

$$V_{OUTTCN4041} = V_{REF4041} [1 + (R_{1y}/R_{1x})]$$

Note that $V_{REF4041}$ is the value of the TCN4041's internal-reference voltage, which depends on the output-voltage setting of the reference. You can express this reference voltage as

$$V_{REF4041} = V_{OUTTCN4041} (DV_{REF}/DV_{OUT}) + V_0_{REF4041}$$

The quantity (DV_{REF}/DV_{OUT}) is a reference-voltage error term.



You can use an adjustable reference for the LDO to improve V_{OUT} accuracy.

Table 1. Output Error Contributors

V_{OUT} (V)	Reference Tolerance (%)	Resistor Tolerance (%)	Resistor Error (%)	Total Output Error (%)
1.23	2	1	0	2
1.23	2	2	0	2
2.0	2	1	0.77	2.77
2.0	2	2	1.54	3.54
2.46	2	1	1.0	3.0
2.46	2	2	2.0	4.0
3.0	2	1	1.2	3.2
3.0	2	2	2.4	4.2
4.0	2	1	1.38	3.38
4.0	2	2	2.76	4.76
5.0	2	1	1.50	3.5
5.0	2	2	3.0	5.0

Table 2. Resistor Tolerance Effect on V_{OUT} Error

V_{OUT}	V_{OUT} ERROR		
	1% Resistor Tol.	0.5% Resistor Tol.	0.1% Resistor Tol.
5.0V	3.5%	2.75%	2.15%
4.0V	3.38%	2.69%	2.14%
3.0V	3.2%	2.6%	2.12%
2.46V	3.0%	2.5%	2.10%
2.0V	2.77%	2.39%	2.08%
1.23V	2.0%	2.0%	2.0%

Table 3. $V_{OUT4041}$ Output Error

V_{OUT}	TCN4041 Accuracy (%)	R_{1x} & R_{1y} Tol. (%)	Output Error (%)	TCN4041 Accuracy (%)	R_{1x} & R_{1y} Tol. (%)	$V_{OUT4041}$ Error (%)
2.46	0.5	1	1.5	1.0	1	2.0
2.46	0.5	0.5	1.0	1.0	0.5	1.5
2.46	0.5	0.1	0.6	1.0	0.1	1.1
3.0	0.5	1	1.68	1.0	1	2.18
3.0	0.5	0.5	0.80	1.0	0.5	1.59
3.0	0.5	0.1	0.62	1.0	0.1	1.12
4.0	0.5	1	1.89	1.0	1	2.39
4.0	0.5	0.5	0.85	1.0	0.5	1.69
4.0	0.5	0.1	0.64	1.0	0.1	1.14
5.0	0.5	1	2.01	1.0	1	2.51
5.0	0.5	0.5	0.88	1.0	0.5	1.75
5.0	0.5	0.1	0.65	1.0	0.1	1.15
6.0	0.5	1	2.09	1.0	1	2.59
6.0	0.5	0.5	0.90	1.0	0.5	1.80
6.0	0.5	0.1	0.67	1.0	0.1	1.16

ADJUSTABLE LDOS

In this case, internal reference voltage $V_{REF4041}^0$ is specified as 1.233V. Substituting this equation into the previous equation gives you the overall expression for the voltage reference's output voltage:

$$V_{REF4041} = [(V_{REF4041}^0)(DV_{REF}/DV_{OUT}) + V_{REF4041}^0]3[1 + (R_{1y}/R_{1x})].$$

This equation shows that the tolerances of the internal reference, the reference-voltage error term, and the tolerance of

the (R_{1y}/R_{1x}) ratio combine to determine the overall reference-output-voltage tolerance. Also, there is a small amount of bias current (<100 nA) that flows from the adjust input through R_{1y} to ground. You must add the resulting voltage built up across R_{1y} to $V_{OUT4041}$ as an error voltage. **Table 3** shows the effect of these tolerances on the TCN4041 output-voltage tolerance.

The voltage reference is not the only contributor to the LDO's output voltage. The LDO's internal reference also plays a major role in determining the LDO's output (see **Equation 1**). The LDO's internal reference has a $\pm 2\%$ accuracy, which adds 24.6 mV of absolute error. Consequently, the internal reference's effect on error decreases with increasing V_{OUT} (**Table 4**). R_2 has no effect on accuracy; it is used only to set the operating current of the voltage reference and to provide a current path for the (R_{1x}/R_{1y}) resistor divider.

The total error that $V_{REF4041}$ and V_{REFLDO} contribute to V_{OUT} is:

$$\%V_{OUT_{LDO}} \text{ ERR} =$$

$$\frac{\pm V_{REF_{LDO}}^0}{V_{OUT_{LDO}}} \pm V_{REF_{LDO}} \text{ ERR}\% + \frac{\pm (V_{OUT_{LDO}} - V_{REF_{LDO}})}{V_{OUT_{LDO}}} \pm V_{OUT_{4041}} \text{ ERR}\%;$$

$$\%V_{OUT_{LDO}} \text{ ERR} = \frac{\pm 26.4 \text{ mV}^0}{V_{OUT_{LDO}}} \pm \frac{\pm (V_{OUT} - V_{REF_{LDO}})}{V_{OUT_{LDO}}} \pm V_{OUT_{4041}} \text{ ERR}\%. \quad (2)$$

You can generate the total output error for the circuit in **Figure 2** by substituting output-error values from **Tables 3** and **4** into **Equation 2**. The findings are in **Table 5**, which uses a reference with 0.5% reference error for tabulation. Note the significant improvement in output error when you use 0.1% resistor tolerances. **Table 6** compares the total output error of the two LDO feedback circuits of **Figures 1** and **2** and shows that an external reference, such as the TCN4041, significantly improves accuracy, particularly as V_{OUT} and ohmic tolerances increase. ϵ

Author's biography

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Table 4. $V_{REF_{LDO}}$ Effect On V_{OUT} Error

V_{OUT} (V)	V_{OUT} Error Due To $V_{REF_{LDO}}$ (%)
2.46	1
3.0	0.88
4.0	0.66
5.0	0.53
6.0	0.44

Table 5. Total Output Error

V_{OUT} (V)	R_{1x} & R_{1y} Tol. (%)	$V_{OUT_{4041}}$ Error (%)	$V_{OUT_{4041}}$ Error Factor	$V_{OUT_{4041}}$ Error Cont (%)	$V_{REF_{LDO}}$ Error Cont (%)	Total Output Error (%)
2.46	1	1.5	0.5	0.75	1	1.75
2.46	0.5	1.0	0.5	0.5	1	1.5
2.46	0.1	0.6	0.5	0.3	1	1.3
3.0	1	1.68	0.59	0.99	0.88	1.87
3.0	0.5	0.80	0.59	0.47	0.88	1.35
3.0	0.1	0.62	0.59	0.47	0.88	1.25
4.0	1	1.89	0.693	1.31	0.66	1.96
4.0	0.5	0.85	0.693	0.59	0.66	1.25
4.0	0.1	0.64	0.693	0.44	0.66	1.1
5.0	1	2.01	0.754	1.52	0.53	1.25
5.0	0.5	0.88	0.754	0.66	0.53	1.18
5.0	0.1	0.65	0.754	0.49	0.53	1.02
6.0	1	2.09	0.795	1.66	0.44	2.10
6.0	0.5	0.90	0.795	0.72	0.44	1.16
6.0	0.1	0.67	0.795	0.53	0.44	0.97

Table 6. Circuit Accuracy Comparison

V_{OUT}	Resistor Tolerance	TCN4041 Tolerance	Circuit Error w/out TCN4041	Circuit Error with TCN4041	Accuracy Difference
2.46	1	0.5	3.0	1.75	1.25
2.46	0.1	0.5	2.1	1.3	0.8
3.0	1	0.5	3.2	1.87	1.33
3.0	0.1	0.5	2.12	1.25	0.87
4.0	1	0.5	3.38	1.25	2.13
4.0	0.1	0.5	2.14	1.02	1.12
5.0	1	0.5	3.5	2.10	2.4
5.0	0.1	0.5	2.15	0.97	1.18

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