Application Note 16

Improving Adjustable Regulator Accuracy

by Bob Wolbert

Introduction

Micrel LDO Regulators are high accuracy devices with output voltages factory-trimmed to much better than 1% accuracy. Across the operating temperature, input voltage, and load current ranges, their worst-case accuracies are still better than ±2%. For adjustable regulators, the output also depends upon the accuracy of two programming resistors. Common systems, such as high performance, low-voltage microprocessors, require supply voltage accuracies better than ±2.5%—including noise and transients. While noise is generally not a major contributor to output inaccuracy, load transients caused by high-speed microprocessors are significant, even when using fast transient-response LDO regulators and high-quality filter capacitors.

This note will demonstrate that the most cost-effective way to achieve better than ±2.5% accuracy is by employing a precision reference in the feedback loop. While the MIC29512 is the "featured" regulator, the same techniques are directly applicable for the MIC29152/3, MIC29302/3, MIC29312, MIC29502/3, MIC29712, and MIC29752. Other Micrel adjustable regulators achieve similar performance enhancement.

"Adjustable Regulator Sensitivity" describes the accuracy of the standard adjustable regulator with the usual resistor feedback configuration. "Improving Accuracy" describes how the output performance may be improved using the Micrel LM4041-ADJ voltage reference.

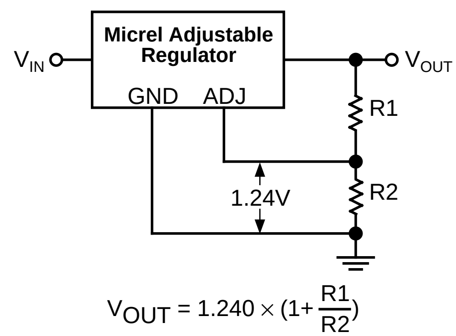

Figure 1. Basic Adjustable Regulator Circuit.

Adjustable Regulator Sensitivity

Achieving a worst-case error of ±2.5%, including all D/C and A/C error terms, is possible by increasing the basic accuracy of the regulator itself, but this is expensive since high current regulators have significant self-heating. Its internal reference must maintain accuracy across a wide temperature range. Testing for this level of performance is time consuming and raises the cost of the regulator, which is unacceptable for extremely price-sensitive marketplaces.

Resistor Tolerance Effects on Adjustable Regulator Accuracy

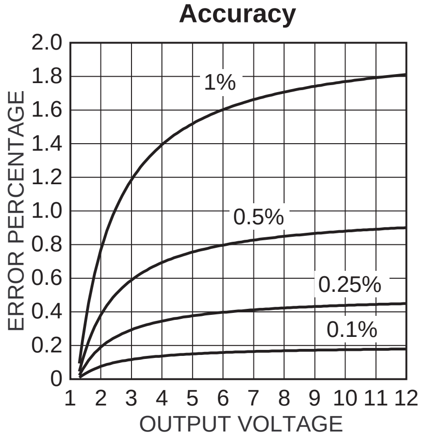

Figure 2.

Adjustable regulators use the ratio of two resistors to multiply the reference voltage as required to produce the desired output voltage (see Figure 1). The formula for output voltage from two resistors is presented as Equation 1.

$$(1) \qquad V_{OUT} = V_{REF}\left(1+\frac{R1}{R2}\right)$$

The basic MIC29512 has a production-trimmed reference (V_{REF}) with better than ±1% accuracy at a fixed temperature of 25°C. It is guaranteed better than ±2% over the full operating temperature range, input voltage variations, and load current changes. Since practical circuits experience large temperature swings we should use the ±2% specification as our theoretical worst-case. This value assumes no error contribution from the programming resistors.

Referring to Figure 1 and Equation 1, we see that resistor tolerance (tol) must be added to the reference tolerance to determine the total regulator inaccuracy. A sensitivity analysis of this equation shows that the error contribution of the adjust resistors is:

$$(2) \qquad \text{Error Contribution}\ \% = \left(\frac{2\times \text{tol}\%}{1-\left(\frac{\text{tol}\%}{100}\right)}\right)\times\left(1-\frac{V_{REF}}{V_{OUT}}\right)$$

Since the output voltage is proportional to the product of the reference voltage and the ratio of the programming resistors, at high output voltage, the error contribution of the programming resistors is the sum of each resistor's tolerance. Two standard ±1% resistors contribute as much as 2% to output voltage error. At lower voltages, the error is less significant. Figure 2 shows the effects of resistor tolerance on regulator accuracy from the minimum output voltage (V_{REF}) to 12V. At the minimum V_{OUT}, theoretical resistor tolerance has no effect on output accuracy. Resistor error increases proportionally with output voltage: at an output of 2.5V, the sensitivity factor is 0.5; at 5V it is about 0.75; and at 12V it is over 0.9. This means that with 5V of output, the error contribution of 1% resistors is 0.75 times the sum of the tolerances, or $0.75 \times 2\%$ = 1.5%. As expected, more precise resistors offer more accurate performance.

The output voltage error of the entire regulator system is the sum of reference tolerance and the resistor error contribution. Figure 3 shows this worst-case tolerance for the MIC29512 as the output voltage varies from minimum to 12V using ±1%, ±0.5%, ±0.25%, and ±0.1% resistors. The more expensive, tighter accuracy resistors provide improved tolerance, but it is still limited by the adjustable regulator's ±2% internal reference.

A better method is possible: increase the overall accuracy of the regulator by employing a precision reference in the feedback loop.

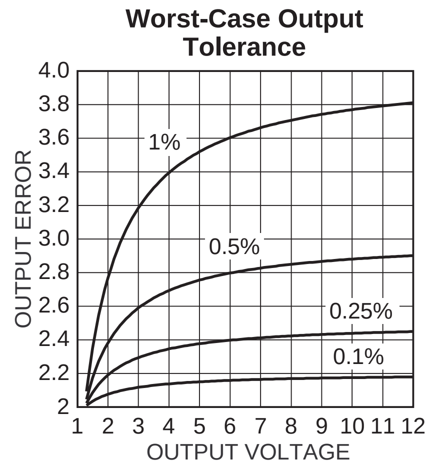

Figure 3.

Improving Accuracy

Some systems require better than ±2% accuracy. This high degree of accuracy is possible using Micrel's LM4041 voltage reference instead of one of the programming resistors (refer to Figure 4). The regulator output voltage is the sum of the internal reference and the LM4041's programmed voltage (Equation 3).

(3) $V_{OUT} = V_{REF\ Regulator} + V_{LM404} = 1.240 + V_{LM4041}$

The benefit of this circuit is the increased accuracy possible by eliminating the multiplicative effect of the MIC29512's internal reference. In normal configurations, the reference

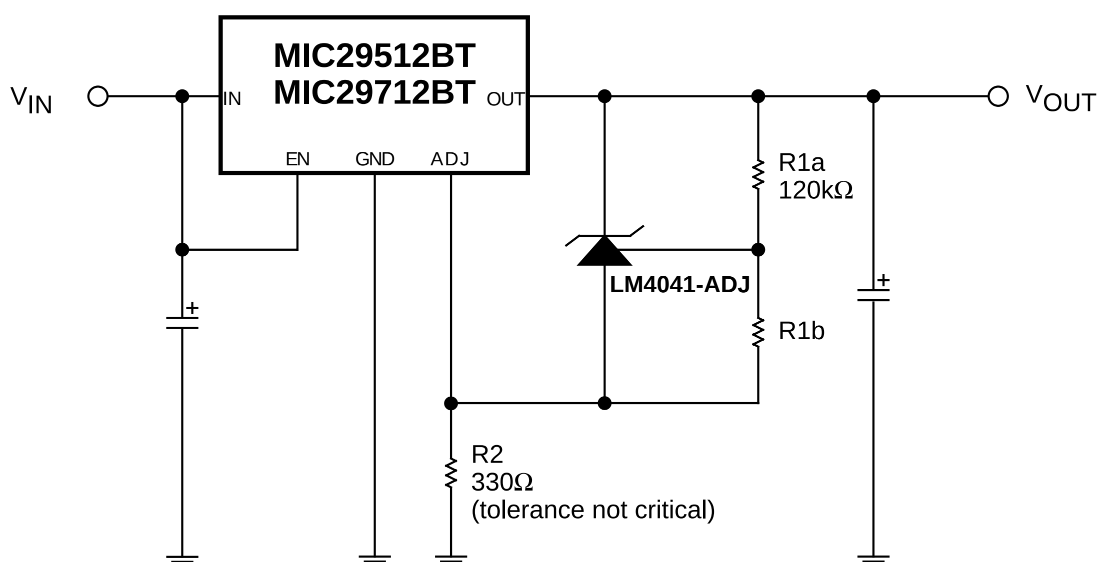

Figure 4. Improved Accuracy Composite Regulator Circuit

error is multiplied up by the resistor ratio, keeping the error percentage constant. With this circuit, the error voltage is within 25mV, absolute. Another benefit of this arrangement is that the LM4041 is not a dissipative device: there is only a small internal temperature rise to degrade accuracy. Additionally, both references are operating in their low-sensitivity range so we get less error contribution from the resistors. A drawback of this configuration is that the minimum output voltage is now the sum of both references, or about 2.5V. The adjustable LM4041 is available in accuracies of ±0.5% and ±1%, which allows better overall system output voltage accuracy.

Equation 4 presents the formula for the LM4041-ADJ output voltage. Note the output voltage has a slight effect on the reference. Refer to the LM4040 data sheet for full details regarding this second-order coefficient.

(4) $$V_{LM4041} = \left[V_{OUT} \times \frac{\Delta V_{REF}}{\Delta V_{OUT}} + 1.233 \right] \times \left[\frac{R1b}{R1a} + 1 \right]$$

Actually, the voltage drop across R1b is slightly higher than that calculated from Equation 4. Approximately 60nA of current flows out of the LM4041 FB terminal. With large values of R1b, this current creates millivolts of higher output voltage; for best accuracy, compensate R1b by reducing its size accordingly. This error is +1mV with R1b = 16.5kΩ.

Equation 5 shows the nominal output voltage for the composite regulator of Figure 4.

(5) $$V_{OUT} = \frac{1.233\left(\frac{R1b}{R1a} + 1\right)}{1.0013 + \left(\frac{0.0013 R1b}{R1a}\right)} + (60nA \times R1b) + 1.240$$

Note that the tolerance of R2 has no effect on output voltage accuracy. It sets the diode reverse (operating) current and also allows the divider current from R1a and R1b to pass. With R2 = 1.2kΩ, 1mA of bias flows. If R2 is too small (less than about 105Ω, the maximum reverse current of the LM4041-ADJ is exceeded. If it is too large with respect to R1a and R1b then the circuit will not regulate. The recommended range for R2 is from 121Ω to $^{R1a}/_{10}$.

With this circuit we achieve much improved accuracies. Our error terms are:

25mV	(constant) from the MIC29512
0.5%	from the LM4041C
+ 0 to 2%	from R1a and R1b
0.5% + 25mV to 2.5% + 25mV	Total Error budget

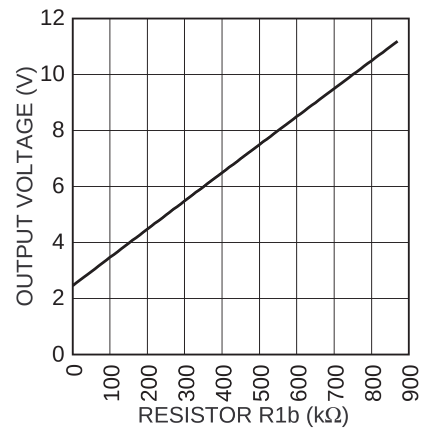

Figure 5.

Figure 6 shows the resistor error contribution to the LM4041C reference output voltage tolerance. Figure 7 shows the worst-case output voltage error of the composite regulator circuit using various resistor tolerances and a 0.5% LM4041C reference is employed. The top four traces reflect use of 1%, 0.5%, 0.25%, and 0.1% resistors. Table 1 lists the production accuracy obtained with the low-cost LM4041C and standard 1% resistors as well as the improvement possible with 0.1% resistors.

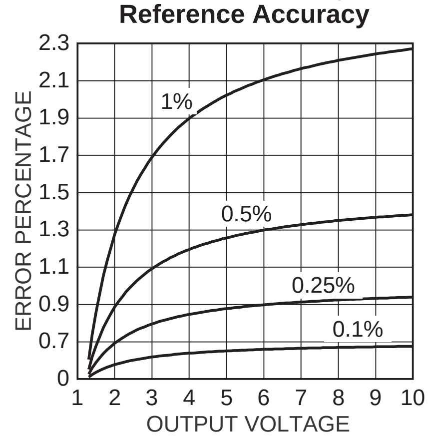

Figure 6.

What does the extra complexity of the composite regulator circuit of Figure 4 buy us in terms of extra accuracy? With precision components, we may achieve tolerances better than ±1% with the composite regulator, as compared to a theoretical best case of worse than 2% with the standard regulator and resistor configuration. Figure 8 and Table 2 show the accuracy difference between the circuits as the output voltage changes. The accuracy difference is the

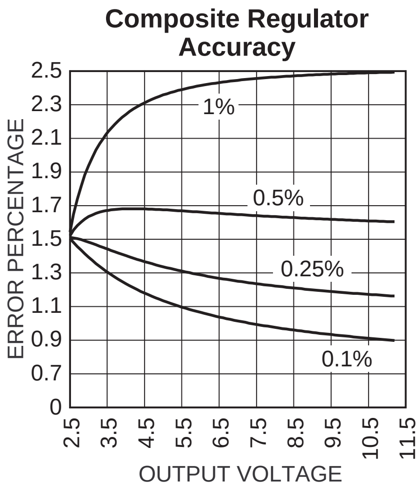

Figure 7.

tolerance of the two-resistor circuit minus the tolerance of the composite circuit. Both tolerances are the calculated worst-case value, using 1% resistors. This figure shows the composite circuit is always at least 1% better than the standard configuration. Both the figure and the table assume standard ±1% resistors and the LM4041C-ADJ (0.5%) reference.

Conclusion

Adjustable regulator applications requiring high-accuracy output voltages may be satisfied by replacing the normal resistive divider circuit with a precision reference. The resulting high accuracy is achieved by a combination of reduced reference tolerances and lower sensitivity to resistor tolerances. The accuracy improvement afforded by the reference circuit is greater than 1% and absolute accuracy of less than ±1% is attainable.

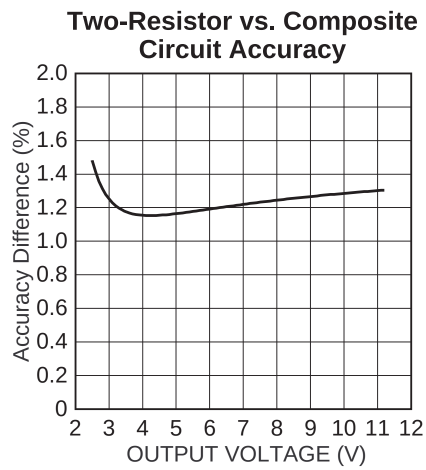

Figure 8.

V_{OUT}	1% Resistors	0.1% Resistors
2.50V	±1.54%	±1.50%
2.90V	±1.88%	±1.41%
3.00V	±1.94%	±1.39%
3.30V	±2.07%	±1.34%
3.45V	±2.12%	±1.31%
3.525V	±2.14%	±1.30%
3.60V	±2.16%	±1.29%
5.00V	±2.36%	±1.13%
6.00V	±2.41%	±1.07%
8.00V	±2.46%	±0.98%
10.00V	±2.49%	±0.92%
11.00V	±2.49%	±0.90%

Table 1. Worst-case output voltage error for typical operating voltages

V_{OUT}	Composite Circuit	Standard Circuit
2.50V	±1.6%	±3.0%
3.00V	±1.9%	±3.2%
3.30V	±2.1%	±3.3%
3.50V	±2.1%	±3.2%
5.00V	±2.4%	±3.5%
6.00V	±2.4%	±3.6%
8.00V	±2.5%	±3.7%
10.00V	±2.5%	±3.8%
11.00V	±2.5%	±3.8%

Table 2. Comparing the worst-case output voltage error for the two topologies with typical output voltages.