Minimum Load Current Operation—Zero-Load Operation

By Luca Vassalli

As an applications engineer, I am frequently asked about operating regulators with no load. Most modern LDOs and switching regulators are stable with no load, so why do people repeatedly ask? Some older power devices require a minimum load to guarantee stability, as one of the poles that must be compensated is affected by the effective load resistance, as discussed in "Low-Dropout Regulators (Ask the Applications Engineer—37)." For example, Figure A shows that the LM1117 requires a 1.7-mA minimum load current (up to 5 mA).

LM1117-N ELECTRICAL CHARACTERISTICS (continued)

Typicals and limits appearing in normal type apply for T_J = 25°C. Limits appearing in **Boldface** type apply over the entire junction temperature range for operation, 0°C to 125°C.

Symbol	Parameter	Conditions	Min [1]	Typ [2]	Max [1]	Units
I_{LIMIT}	Current Limit	$V_{IN} - V_{OUT}$ = 5V, T_J = 25°C	800	1200	1500	mA
	Minimum Load Current [5]	LM1117-N-ADJ V_{IN} = 15V		1.7	**5**	mA

Figure A. *LM1117 minimum load current specifications.*

Most newer devices are designed to operate with no load, and exceptions to this rule are very limited. The same design techniques that allow LDOs to be stable with any output capacitor, especially low ESR caps, are used to guarantee stability at no load. For those few modern devices that require a load, the limitation is usually a result of leakage current through the pass element, not the stability. So, how can you tell? Read the data sheet. If the device requires a minimum load, the data sheet would surely say something.

The ADP1740 and other low-voltage, high-current LDOs fall into this category. The worst-case leakage current from the integrated power switch is about 100 µA at 85°C and 500 µA at 125°C. Without a load, the leakage current would charge the output capacitor until the switch VDS was low enough to reduce the leakage current to a negligible level, raising the no-load output voltage. The data sheet says that a 500 µA minimum load is required, so a dummy load is advisable if the device will operate at high temperature. This load is small compared to the device's 2-A rating. Figure B shows the minimum load current specification from the ADP1740 data sheet.

ADP1740/ADP1741 Data Sheet

Parameter	Symbol	Test Conditions/Comments	Min	Typ	Max	Unit
SENSE INPUT BIAS CURRENT (ADP1740)	SNS_{I-BIAS}	1.6 V ≤ V_{IN} ≤ 3.6 V		10		µA
OUTPUT NOISE	OUT_{NOISE}	10 Hz to 100 kHz, V_{OUT} = 0.75 V		23		µV rms
		10 Hz to 100 kHz, V_{OUT} = 2.5 V		65		µV rms
POWER SUPPLY REJECTION RATIO	PSRR	V_{IN} = V_{OUT} + 1 V, I_{OUT} = 10 mA				
		1 kHz, V_{OUT} = 0.75 V		65		dB
		1 kHz, V_{OUT} = 2.5 V		56		dB
		10 kHz, V_{OUT} = 0.75 V		65		dB
		10 kHz, V_{OUT} = 2.5 V		56		dB
		100 kHz, V_{OUT} = 0.75 V		54		dB
		100 kHz, V_{OUT} = 2.5 V		51		dB

1 Minimum output load current is 500 µA.
2 Accuracy when V_{OUT} is connected directly to ADJ. When V_{OUT} voltage is set by external feedback resistors, absolute accuracy in adjust mode depends on the tolerances of the resistors used.
3 Based on an endpoint calculation using 10-mA and 2-A loads. See Figure 6 for typical load regulation performance.
4 Dropout voltage is defined as the input to output voltage differential when the input voltage is set to the nominal output voltage. This applies only to output voltages above 1.6 V.
5 Start-up time is defined as the time between the rising edge of EN to V_{OUT} being at 95% of its nominal value.
6 Current-limit threshold is defined as the current at which the output voltage drops to 90% of the specified typical value. For example, the current limit for a 1.0-V output voltage is defined as the current that causes the output voltage to drop to 90% of 1.0 V, or 0.9 V.

Figure B. *ADP1740 minimum load current specification.*

What if the data sheet doesn't explicitly specify a minimum load? In most cases, a minimum load is not required. It may not sound very convincing, but if a minimum load was required, the data sheet would certainly say so. The confusion often comes into play because data sheets will often include graphs showing the specifications over some operating range. Most of these graphs are logarithmic, allowing them to show multiple decades of load ranges, but a log scale cannot go to zero. Figure C shows the ADM7160 output voltage and ground current vs. load current over the 10-µA to 200-mA range. Other graphs, such as ground current vs. input voltage, show measurements at multiple load currents, but don't show data at zero current. In addition, parameters such as PSRR, line regulation, load regulation, and noise specify a certain load current range that does not include zero, as shown in Figure D. None of this means that a minimum load is required, though.

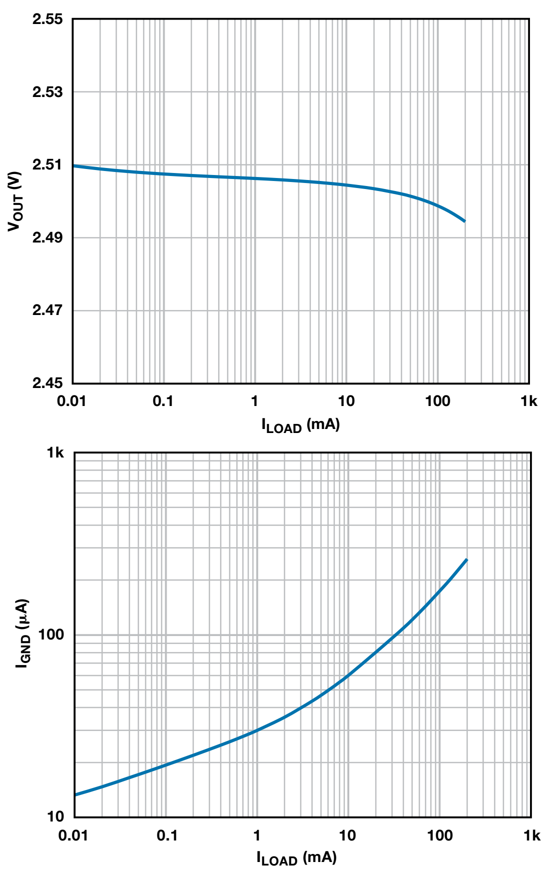

Figure C. *ADM7160 output voltage and ground current vs. load current.*

LOAD REGULATION	$\Delta V_{OUT}/\Delta I_{LOAD}$				
V_{OUT} < 1.8 V		I_{LOAD} = 100 µA to 200 mA	0.006		%/mA
		I_{LOAD} = 100 µA to 200 mA, T_J = −40°C to +125°C		0.012	%/mA
V_{OUT} ≥ 1.8 V		I_{LOAD} = 100 µA to 200 mA	0.003		%/mA
		I_{LOAD} = 100 µA to 200 mA, T_J = −40°C to +125°C		0.008	%/mA

Figure D. *ADM7160 load regulation.*

Users of switching regulators with power-saving mode (PSM) are often worried about operation at light loads because PSM reduces the operating frequency, skips pulses, provides a burst of pulses, or some combination of these. PSM reduces power consumption and increases efficiency at light loads. Its disadvantage is a noticeable increase in output ripple, but the device remains stable and can easily operate with no load.

As shown in Figure E, the ADP2370 high-voltage, low-quiescent-current buck regulator produces increased ripple due to PSM operation when the load switches between 800 mA and 1 mA. The fact that the test was done at 1 mA does not indicate that 1 mA is the minimum load.

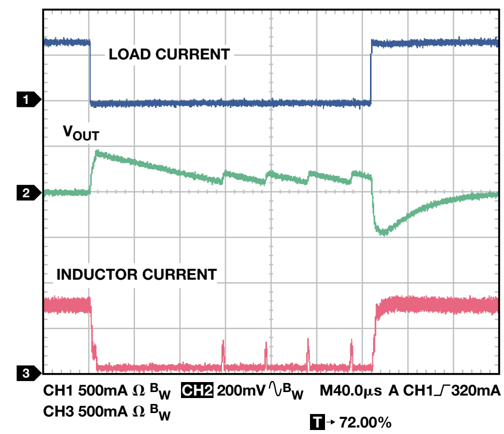

Figure E. *ADP2370 load transient in power-saving mode.*

Figure F shows the ripple voltage changing with load current. In this case the graph goes all the way to zero, indicating both that the load can be zero and that the noise at no load may not be any worse than the noise at 1 mA or 10 mA.

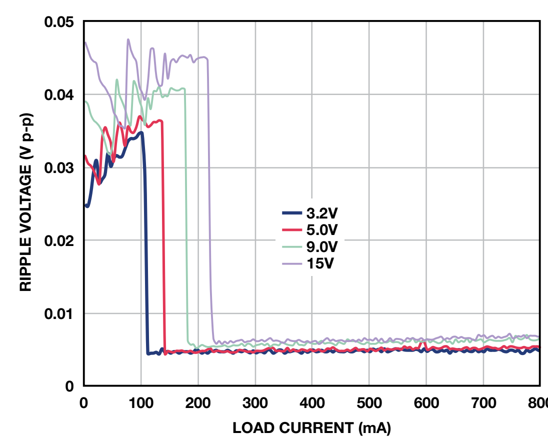

Figure F. *ADP2370 output ripple vs. load current.*

Conclusion

Most modern regulators are stable with zero load current, but when in doubt, consult the data sheet. Be careful, though. Logarithmic graphs don't go to zero, and tests aren't always done with zero load current, so you shouldn't infer that the regulator won't work with no load even though no-load data isn't shown. With switching regulators, ripple in power-saving mode is normal, not a sign of instability.

References

Caveat Emptor

Linear Regulators

Switching Regulators

Patoux, Jerome. "Low-Dropout Regulators (Ask the Applications Engineer—37)," *Analog Dialogue*, Volume 41, Number 2, 2007.

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Luca Vassalli [luca.vassalli.luca@analog.com] has been with Analog Devices for over 12 years in a variety of roles. He has been involved with the support and design of many analog systems, including optical communication, wireless systems, medical diagnostics equipment, and test equipment. Luca is currently part of the ADIsimPower™ development team and engages with customers in design, simulation, prototyping, and testing of power supplies for high-performance systems. Luca has an MSEE in Power Electronics from NC State and a BSEE from HEIG-VD (Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud) in Switzerland.