

Performance Verification of Low Noise, Low Dropout Regulators

by Jim Williams and Todd Owen

Introduction

In an increasing trend, telecommunications, networking, audio and instrumentation require low noise power supplies. In particular, there is interest in low noise, low dropout linear regulators (LDOs). These

components power noise-sensitive circuitry, circuitry that contains noise-sensitive elements or both. Additionally, to conserve power, particularly in battery-driven apparatus

such as cellular telephones, the regulators must operate with low input-to-output voltage differentials. Devices presently becoming available meet these requirements.

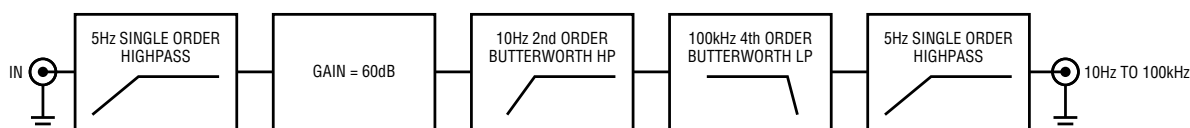


Figure 1. Filter structure for noise testing LDOs; Butterworth sections provide the appropriate response in the desired frequency range.

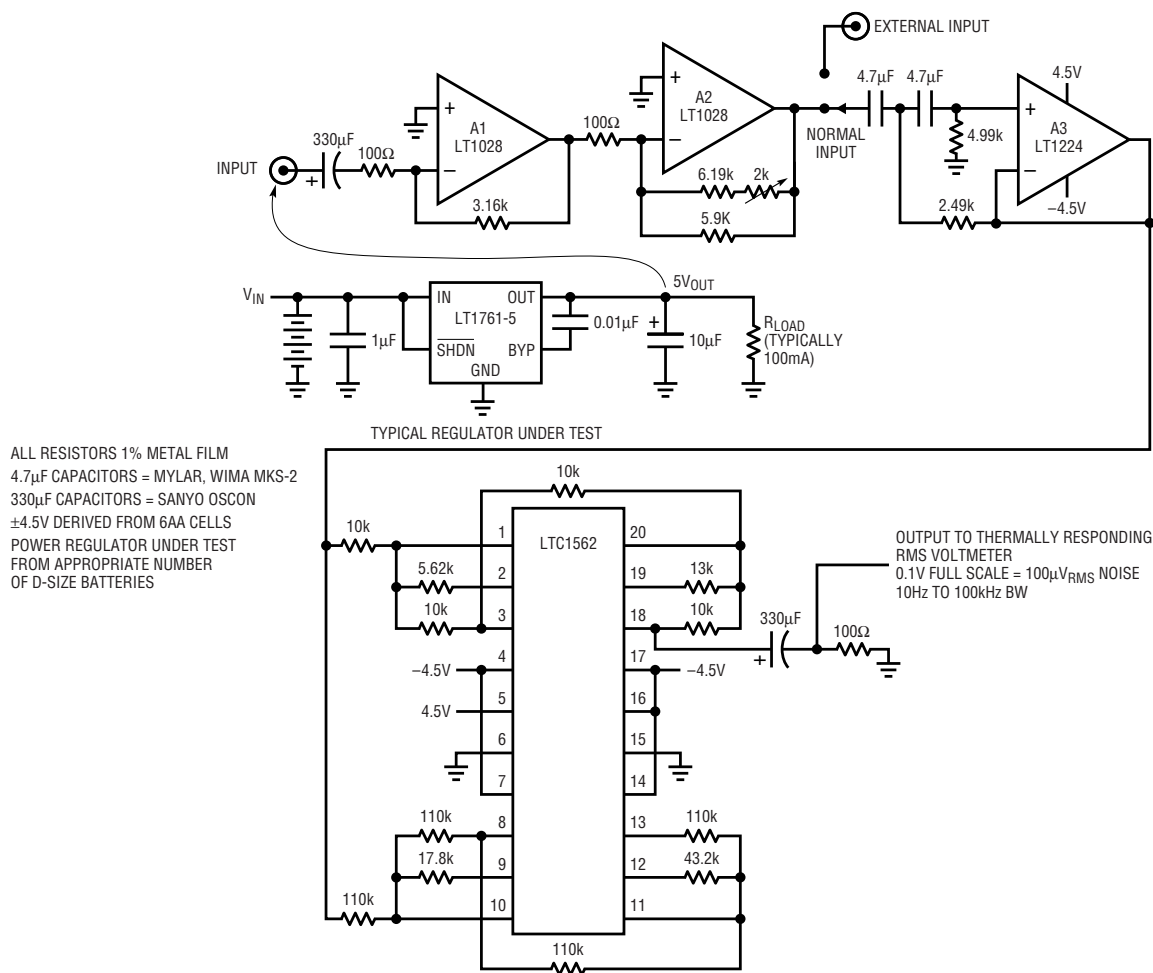


Figure 2. Implementation of Figure 1; low noise amplifiers provide gain and initial highpass shaping. The LTC1562 filter supplies a 4th order Butterworth lowpass characteristic.

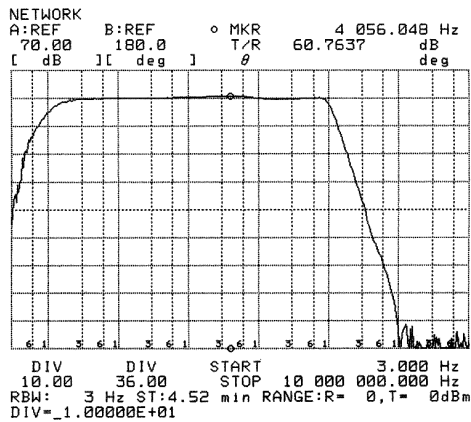


Figure 3. HP-4195A spectrum analyzer plot of filter characteristics; filter performance is nearly flat over the desired 10Hz to 100kHz range with a steep roll-off outside the bandpass region.

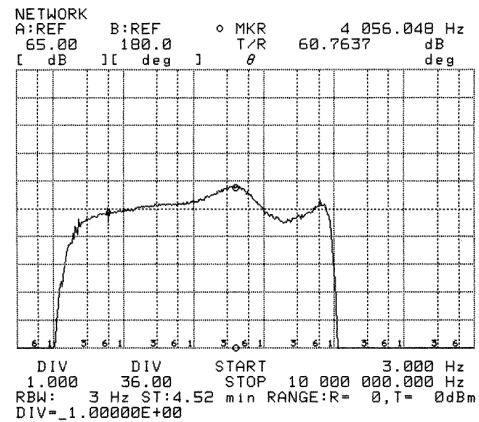


Figure 4. Expanded scale examination of the passband shows flatness within 1dB over almost the entire measurement range.

Noise and Noise Testing

Establishing and specifying LDO performance is relatively easy to do. Verifying that a regulator meets dropout specifications is similarly straightforward. Accomplishing the same missions for noise and noise testing is considerably more involved. The noise bandwidth of interest must be called out, along with operating conditions. Operating conditions can include regulator input and output voltage, load, assorted discrete components, and the like. Low noise performance is affected by numerous subtleties; changes in operating conditions can cause unwelcome surprises. Because of this, LDO noise must be quoted under specified operating and bandwidth conditions to be meaningful. Failure to observe this precaution will result in misleading data and erroneous conclusions.

Noise Testing Considerations

What noise bandwidth is of interest and why is it interesting? In most systems, the range of 10Hz to 100kHz is the information signal processing area of concern. Additionally, linear regulators produce little noise energy outside this region. These considerations suggest a measurement bandpass of 10Hz to 100kHz, with steep slopes at the band limits. Figure 1 shows a conceptual filter for LDO noise testing. The Butterworth sections are the key to steep slopes and flatness in the passband. The small input level requires 60dB of low noise gain to provide adequate signal for the Butterworth filters. Figure 2 details the filter scheme. The regulator under test is at the diagram's center. A1–A3 make up a 60dB gain highpass section. A1 and A2, extremely low noise devices ($<1\text{ nV}/\sqrt{\text{Hz}}$), comprise a

60dB gain stage with a 5Hz highpass input. A3 provides a 10Hz, 2nd order Butterworth highpass characteristic. The LTC1562 filter block is arranged as a 4th order Butterworth lowpass. Its output is delivered via the $330\mu\text{F}$ – 100Ω highpass network. The circuit's output drives a thermally responding RMS voltmeter. Note that all circuit power is furnished by batteries, precluding ground loops from corrupting the measurement.

Instrumentation

Performance Verification

Good measurement technique dictates verifying the noise test instrumentation's performance. Figure 3's spectral plot of the filter section shows essentially flat response in the 10Hz to 100kHz passband with abrupt slopes at the band extremes. Figure 4, expanding the vertical scale to 1dB/division, reveals some flatness deviation but well within 1dB throughout nearly the entire passband. Grounding the filter's input determines the tester's noise floor. Figure 5 shows less than $4\mu\text{V}_{\text{P-P}}$, corresponding to a $0.5\mu\text{V}_{\text{RMS}}$ voltmeter reading. This is only about 0.5% of full scale ($100\mu\text{V}_{\text{RMS}}$), contributing negligible error. These results ensure the confidence necessary to proceed with regulator noise measurement.

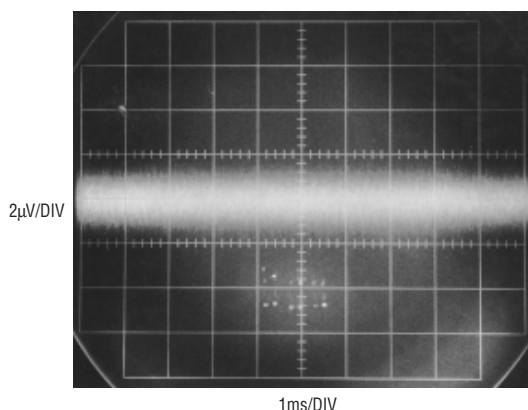


Figure 5. $<4\mu\text{V}_{\text{P-P}}$ test setup noise residue corresponds to about $0.5\mu\text{V}_{\text{RMS}}$ measurement noise floor



Figure 6a. LDO noise measurement bench setup: The shielded can contains the regulator. Noise filter circuitry occupies the box at photo lower center. The oscilloscope and RMS voltmeter are not simultaneously connected, precluding ground loops from corrupting measurement.



Figure 6b. Shielded can with cover removed; the LDO under test occupies the center. D-cells provide power, eliminating a potential ground loop. The BNC fitting (photo lower left) connects the output to the filter circuit test box, minimizing triboelectric based errors.

Regulator Noise Measurement

Regulator noise measurement begins with attention to test setup details. The extremely low signal levels require attention to shielding, cable management, layout and component choice. Figure 6a is the bench arrangement. The photo shows the completely shielded environment required to obtain faithful noise measurements. The metal can encloses the regulator under test and its internal battery power supply. A BNC fitting (photo lower center) connects the regulator output to the noise filter test circuit (black box). Note that the monitoring oscilloscope and voltmeter are not simultaneously connected to the output, precluding ground loops that would corrupt the measurement.

Figure 6b details the regulator enclosure with its cover removed. The battery supply is visible; the regulator occupies the can center. The BNC fitting connecting the noise filter box (lower left) eliminates triboelectric disturbances a cable might contribute.

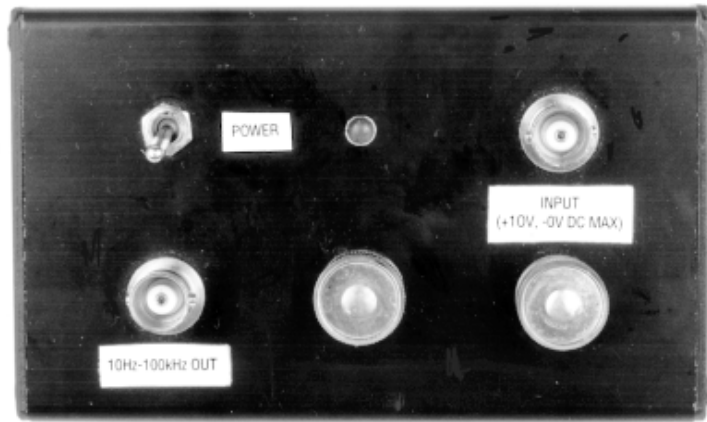


Figure 6c. The noise filter test box is fully shielded. Connections are as indicated. Capped BNC fittings (photo lower center and right) are unused entries.

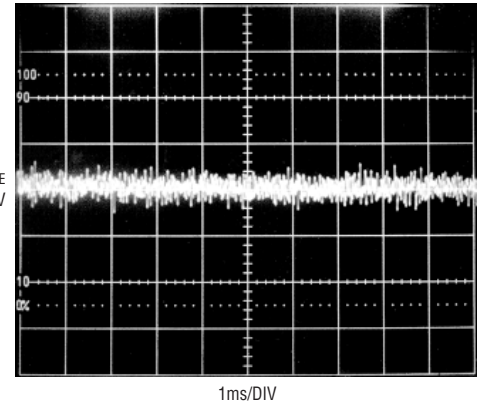


Figure 7. LT1761 Output voltage noise in a 10Hz to 100kHz bandwidth; RMS noise measures $20\mu\text{V}_{\text{RMS}}$.

Interpreting Comparative Results

Figure 6c is the noise test circuit box. Functions are as labeled in the photo. The two capped BNC connectors (box lower) are unused box entries.

Figure 7's oscilloscope photo shows an LT1761 regulator's noise measured at the filter output. Monitoring this point with the RMS voltmeter shows a $20\mu\text{V}_{\text{RMS}}$ reading. Figure 8's spectral plot of this noise indicates diminished power above 1kHz, in accordance with expected regulator noise density. Figure 9 shows more complete spectral noise density data for three regulator types. Noise power decays uniformly with increasing frequency, although the three regulators show some dispersion below 200Hz.

Bypass Capacitor (C_{BYP}) Influence

The regulator's internal voltage reference contributes most of the device's noise. The reference bypass capacitor filters reference noise, precluding it from appearing, in amplified form, at the output. Figure 10 (page 36) is a study of regulator noise vs various values of C_{BYP} . Figure 10a shows substantial noise for $C_{\text{BYP}} = 0\mu\text{F}$, while Figure 10d displays nearly 9x improvement with $C_{\text{BYP}} = 0.01\mu\text{F}$; intermediate values of C_{BYP} (Figures 10b and 10c) produce commensurate results.

Figure 11's photos (page 37) compare an LT1761-5's output noise (Figure 11d) with that of three other regulators (Figures 11a, 11b and 11c). These three devices are manufacturer specified for low noise performance, but the photos do not indicate this. The seeming contradiction is probably due to ambiguity in testing methods or specifications. For example, inappropriate choice of test equipment or measurement bandwidth can easily cause huge (5x) errors. This uncertainty mandates the noise testing described to ensure realistic conclusions.

See Linear Technology Application Note 83, from which this article was excerpted, for more details on LDO noise measurement. 

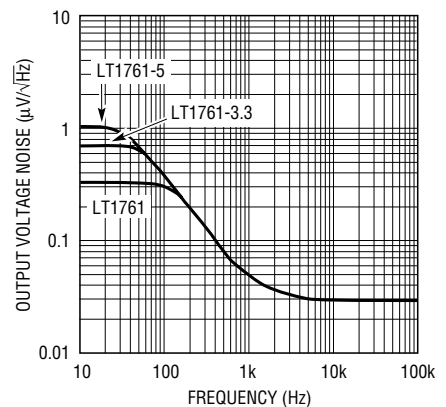


Figure 9. Output noise spectral density data curves for three regulators show dispersion below 200Hz.

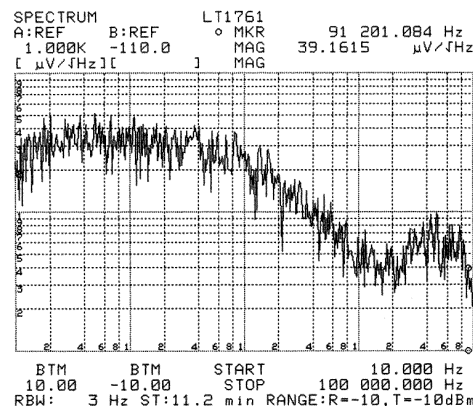


Figure 8. Noise spectrum plot shows diminishing power above 1kHz.

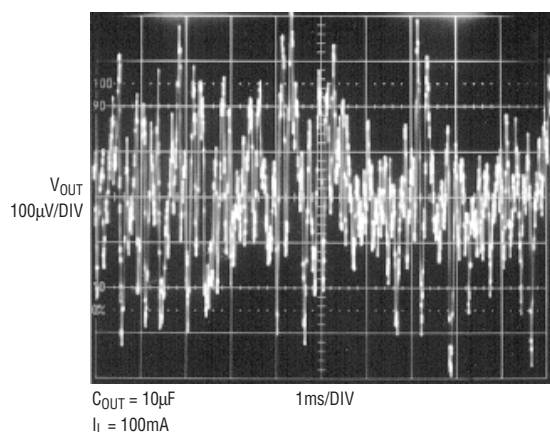


Figure 10a. LT1761-5
10Hz to 100kHz output noise
 $C_{BYP} = 0$

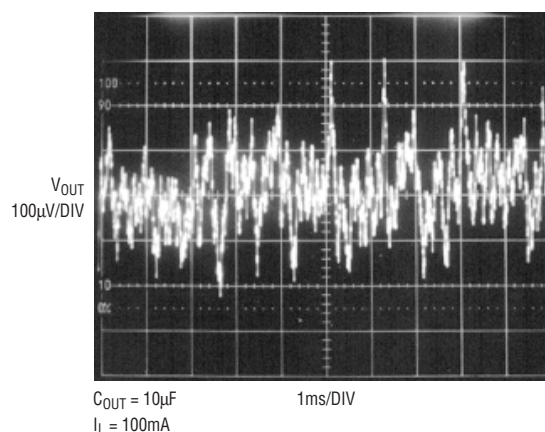


Figure 10b. LT1761-5
10Hz to 100kHz output noise
 $C_{BYP} = 100pF$

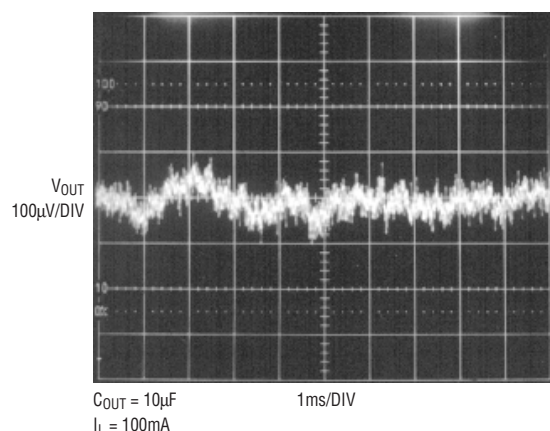


Figure 10c. LT1761-5
10Hz to 100kHz output noise
 $C_{BYP} = 1000pF$

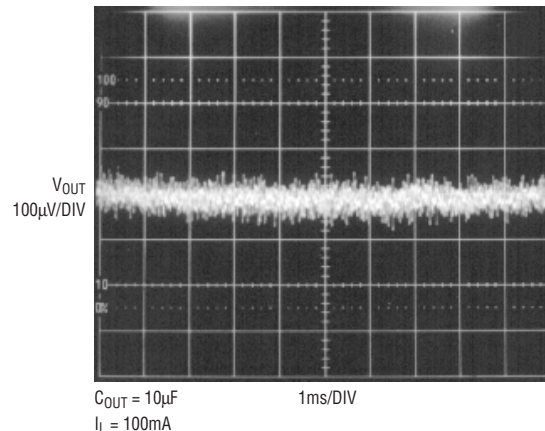


Figure 10d. LT1761-5
10Hz to 100kHz output noise
 $C_{BYP} = 0.01μF$

Figure 10. Regulator noise for various bypass capacitor (C_{BYP}) values; noise decreases with increasing C_{BYP} .

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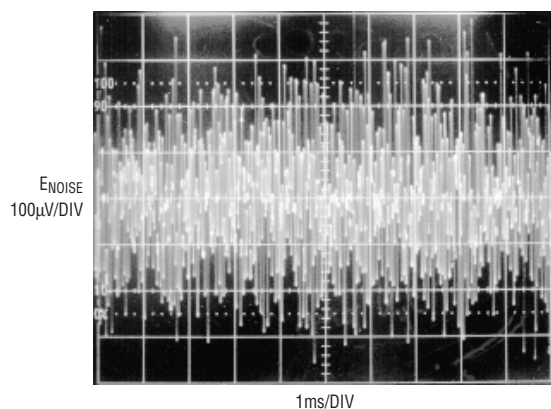


Figure 11a. Manufacturer "MI" output voltage noise (5V output)

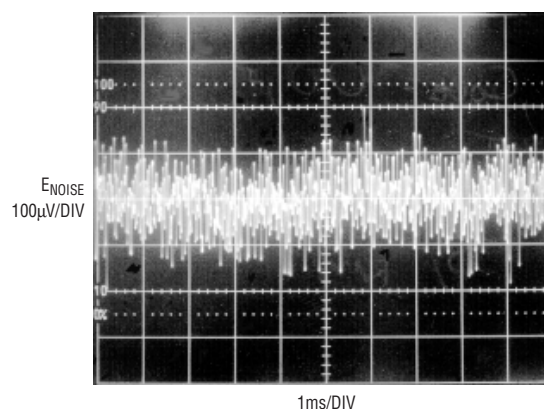


Figure 11b. Manufacturer "NS" output voltage noise (5V output)

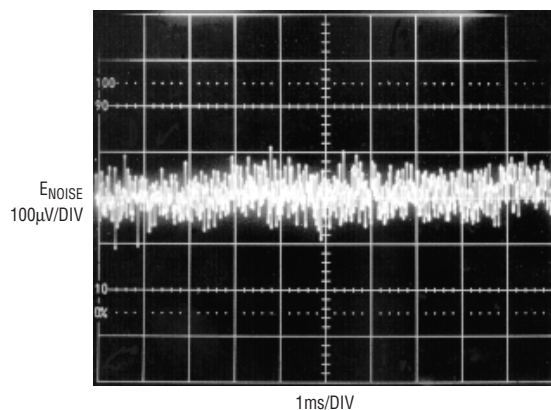


Figure 11c. Manufacturer "MA" output voltage noise (5V output)

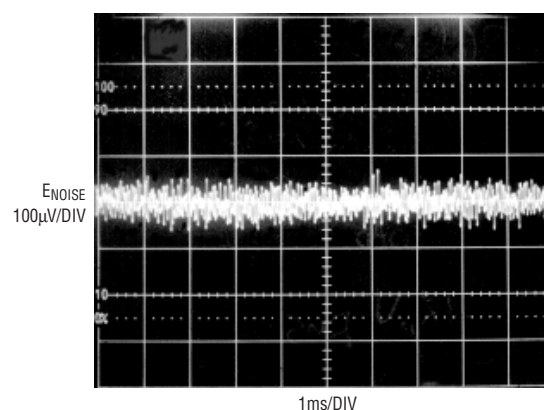


Figure 11d. LT1761-5 output voltage noise (5V output)

Figure 11. Noise for LT1761-5 vs three other devices; "C" is specified for RMS noise figure approaching the LT1761-5, but in a restricted noise measurement bandwidth. Caveat emptor!



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