

## Applications of a Rail-to-Rail Amplifier – Design Note 89

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The LT<sup>®</sup>1366 is Linear Technology's first bipolar dual operational amplifier to combine rail-to-rail input and output operation with precision  $V_{OS}$  specifications. The LT1366 maintains precision specifications over a wide range of operating conditions. The device will operate with supply voltages as low as 1.8V and is fully specified for 3V, 5V, and  $\pm 15V$  operation. Offset voltage is typically 200 $\mu V$  when operating from a single 5V supply. Open-loop gain,  $A_{VOL}$ , is 2 million driving a 2k $\Omega$  load. Supply current is typically 375 $\mu A$  per amplifier. The combination of precision specifications and rail-to-rail operation makes the LT1366 a versatile amplifier, suitable for signal processing tasks that demand the widest possible common-mode range.

### Precision Low Dropout Regulator

Microprocessors and complex digital circuits frequently specify tight control of power supply characteristics. The circuit shown in Figure 1 provides a precise 3.6V, 1A output from a minimum 3.8V input voltage. The circuit's nominal operating voltage is 4.75V  $\pm 5\%$ . The voltage reference and resistor ratios determine output voltage accuracy, while the LT1366's high gain enforces 0.2% line and 0.2% load regulation. Quiescent current is about 1mA and does not change appreciably with

supply or load. All components are available in surface mount packages.

The regulator's main loop consists of A1 and a logic level FET, Q1. The output is fed back to the op amp's positive input because of the phase inversion through Q1. The regulator's frequency response is limited by Q1's roll-off and the phase lead introduced by the output capacitor's effective series resistance (ESR). Two pole-zero networks compensate for these effects. The pole formed with R5 and C2 rolls off the gain set with the feedback network, while the pole formed with R7 and C3 rolls off A1's gain directly, which is the dominant influence on settling time. The zeros formed with R6 and C2, and R8 and C3 provide phase boost near the unity-gain crossover, which increases the regulator's phase margin. Although not directly part of the compensation, R9 decouples the op amp's output from the Q1's large gate capacitance.

A second loop provides a foldback current limit. A2 compares the sense voltage across R1 with 50mV referenced to the positive rail. When the sense voltage

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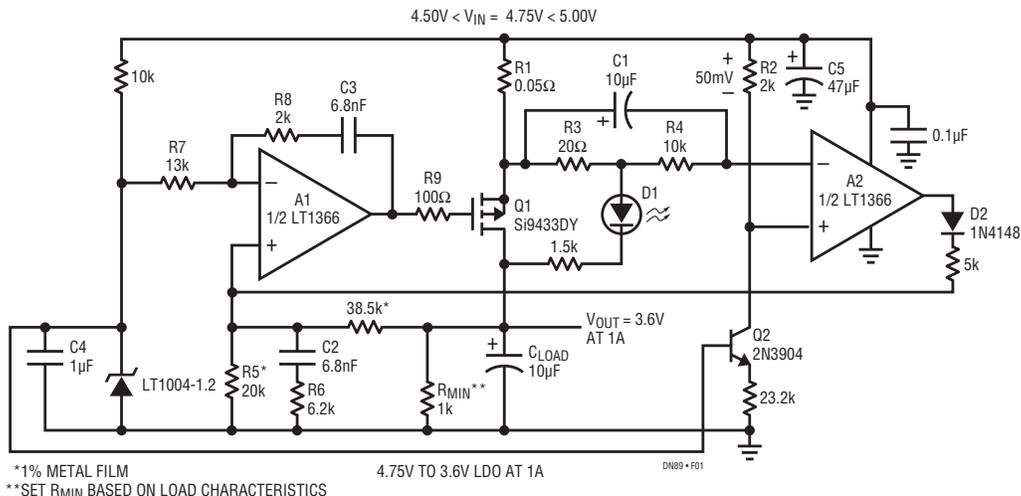


Figure 1. Precision 3.6V, 1A Low Dropout Regulator

exceeds the reference, A2's output drives Q2's gate positive via A1. In current limit, the output voltage collapses and the current limit LED (D1) turns on causing about 30mV to drop across R3. A2 regulates Q1's drain current so that the deficit between the 50mV reference and the voltage across R3 is made up across the sense resistor. The reduced sense voltage is 20mV, which sets the current limit to about 400mA. As the supply voltage increases, the voltage across R3 increases, and the current limit folds back to a lower level. The current limit loop deactivates when the load current drops below the regulated output current. When the supply turns on rapidly, C1 bypasses the fold back circuit allowing the regulator to start-up into a heavy load.

Q1 does not require a heat sink. When mounted on a type FR4 PC board, Q1 has a thermal resistance of 50°C/W. At 1.4W worst case dissipation, Q1 can operate up to 80°C.

### Single Supply, 1kHz, 4th Order Butterworth Filter

The LT1366 is also available as a quad op amp (LT1367), which is used in Figure 2 to form a 4th order Butterworth filter. The filter is a simplified state variable architecture consisting of two cascaded 2nd order sections. Each section uses the 360 degree phase shift around the 2 op amp loop to create a negative summing junction at A1's positive input.<sup>1</sup> The circuit has low sensitivities for center frequency and Q, which are set with the following equations:

$$\omega_0^2 = 1/(R1 \times C1 \times R2 \times C2)$$

where,

$$R1 = 1/(\omega_0 \times Q \times C1) \text{ and } R2 = Q/(\omega_0 \times C2).$$

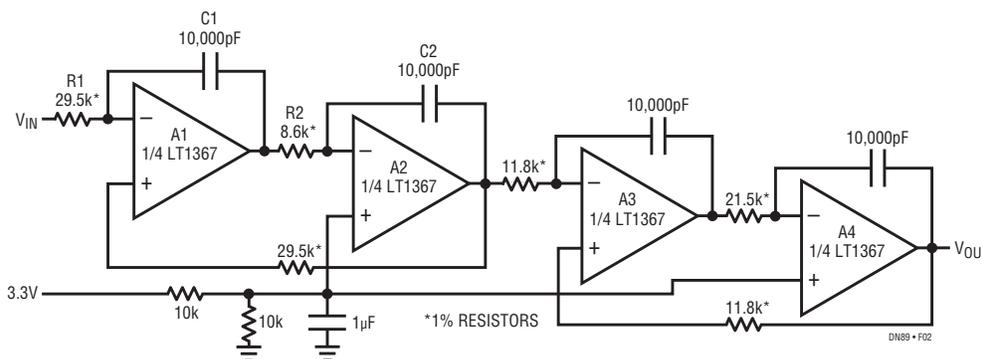


Figure 2. Single Supply Stage Variable Filter Using the LT1367

The DC bias applied to A2 and A4, half supply, is not needed when split supplies are available. The circuit swings rail-to-rail in the passband making it an excellent anti-aliasing filter for A/Ds. The amplitude response is flat to 1kHz then rolls off at 80dB/decade.

### Buffering A/D Converters

Figure 3 shows the LT1366 driving an LTC1288 two-channel micropower A/D. The LTC1288 can accommodate voltage references and input signals equal to the supply rails. The sampling nature of this A/D eliminates the need for an external sample-and-hold, but may call for a drive amplifier because of the A/D's 12µs settling requirement. The LT1366's rail-to-rail operation and low input offset voltage make it well suited for low power, low frequency A/D applications. In addition, the op amp's output settles to 1% in response to a 3mA load step through 100pF in less than 1.5µs.

<sup>1</sup>James Hahn, "State Variable Filter Trims Predecessor's Component Count", *Electronics*, April 21, 1982.

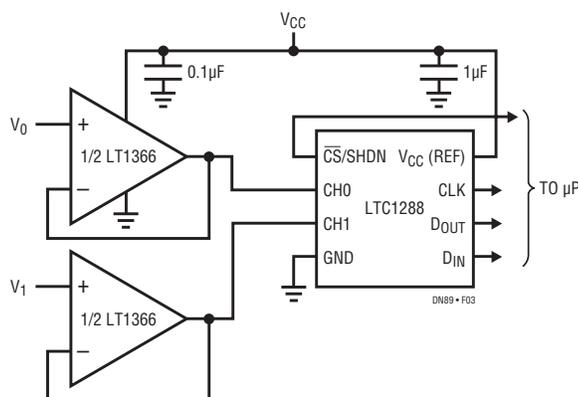


Figure 3. Two-Channel Low Power A/D

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