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OP07 Is Still Evolving

by Reza Moghimi

INTRODUCTION

The OP07 has been tinkered with over the years, and versions of it are still available in plastic packages.

This application note highlights some of the major features that the OP7x7 brings into new designs. A number of applications using these features are presented.

SINGLE-SUPPLY OPERATION

One of the biggest problems with the part in today's environment is that the OP07 requires dual supplies. This family of amplifiers from Analog Devices, Inc., addresses this problem while still giving a close replica of the original specifications. The OP777 single, OP727 dual, and OP747 quad operational amplifiers allow supplies from ±15 V down to ±1.35 V with split rails and from +30 V down to +2.7 V with single rail operation. The OP777/OP727/OP747 data sheet characterizes the parts with rails of +5 V and ±15 V. The OP7x7 family's true single-supply capability enables designers to operate down to the negative supply or ground in both single- and dual-supply applications.

Figure 1 shows that the gain of the instrumentation amplifier (made up of U3 and U4) is set for 100. The AD589 establishes 1.235 V, while the U1 amplifier servos the bridge and maintains the voltage across the parallel combination of 2.55 MΩ and 6.19 kΩ to generate a 200 μA current source. This current splits evenly, flows into both halves of the bridge, eventually through RTD, and establishes an output voltage based upon its value.

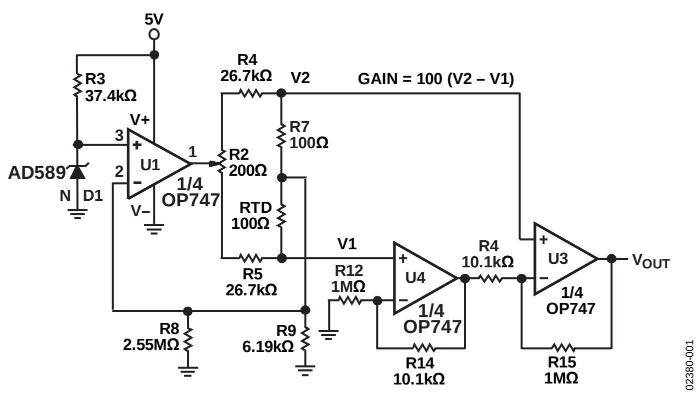

Figure 1. Low Power Single-Supply RTD Amplifier

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3/10—Rev. A to Rev. B

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6/03—Rev. 0 to Rev. A

11/02—Revision 0: Initial Version

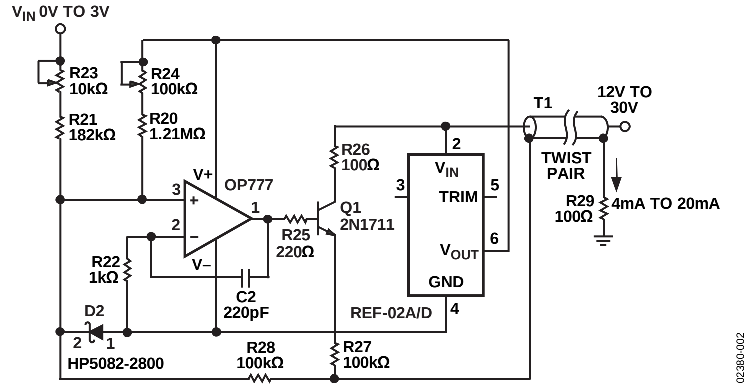

Figure 2. Self-Powered 4 mA to 20 mA Current Loop Transmitter

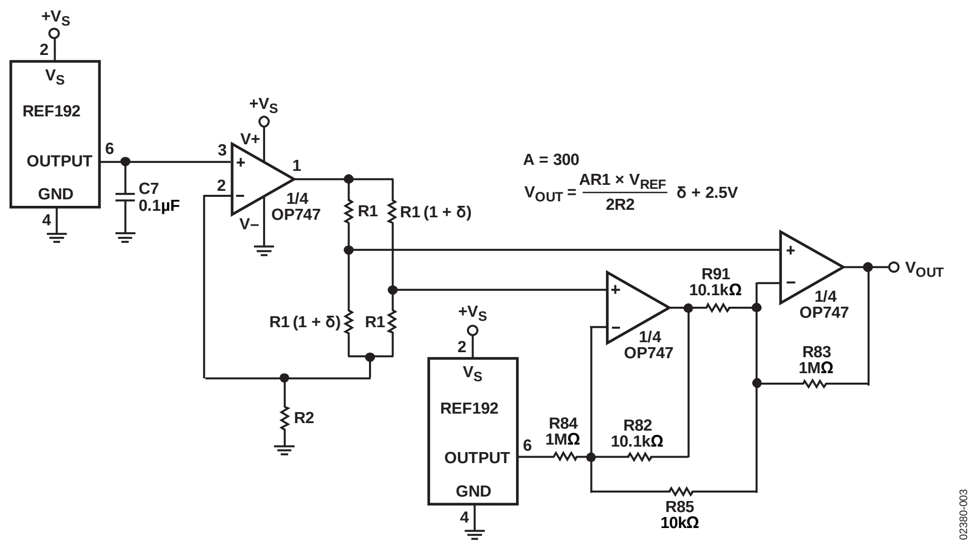

Figure 3. Single-Supply Linear Response Bridge

As shown in Figure 2, the circuit floats up from the single-supply (12 V to 30 V) return. It consumes only 1.5 mA, leaving 2.5 mA available to the user for powering other signal conditioning circuitry.

The OP7x7 is very useful in many bridge applications. Figure 3 shows a single-supply bridge circuit whose output is linearly proportional to the fractional deviation (δ) of the bridge.

Note that $\delta = \frac{\Delta R}{R}$

To process ac signals in single-supply systems, it is often best to use a false-ground biasing scheme. In Figure 4, this is done by Amplifier A3. The user should replace the 2.67 kΩ Twin-T section with a 3.16 kΩ resistor to reject 50 Hz. Sensitivity is due to the relative matching of the capacitors and resistors in the Twin-T section. Use Mylar (5%) and 1% resistors for satisfactory results.

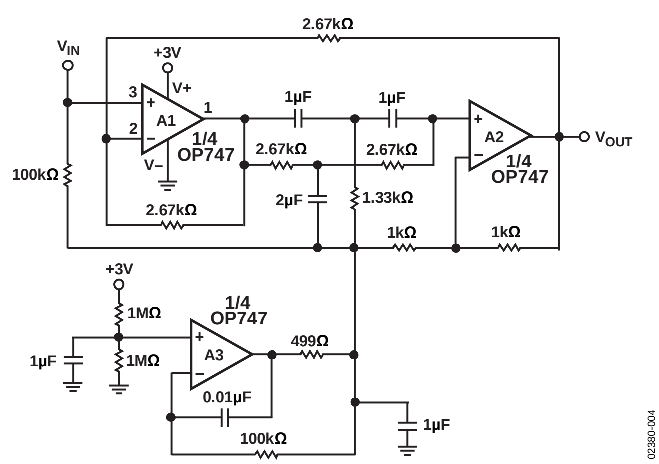

Figure 4. 3 V Single-Supply 50 Hz/60 Hz Active Notch Filter with False Ground

MUCH LOWER SUPPLY CURRENTS

The OP07 has a quiescent current that is higher than desired in today's portable applications. The quiescent current of the OP777 in-amp is less than 350 µA, while the OP07 requires 4 mA for ±15 V operation. In terms of power consumption, the OP777 allows the part to be designed into many portable applications.

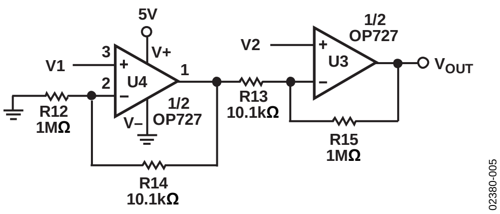

Figure 5. Single-Supply Micropower In-Amp

The OP727 can be used to build an in-amp with two op amps. A single-supply in-amp using one OP727 amplifier is shown in Figure 5. For true difference, R14/R12 = R15/R13. The formula for the CMRR of the circuit at dc is

$$CMRR = 20 \times \log(100/(1 - (R15 \times R14)/(R13 \times R12))$$

It is common to specify the accuracy of the resistor network in terms of resistor-to-resistor percentage mismatch. The CMRR equation can be rewritten to reflect this.

$$CMRR = 20 \times \log(10000/\%\ mismatch)$$

The key to high CMRR is a network of resistors that is well matched from the perspective of both resistive ratio and relative drift. The absolute value of the resistors and their absolute drift are of no consequence; matching is the key. CMRR is 100 dB with a 0.1% mismatched resistor network. To maximize CMRR, one of the resistors, such as R12, should be trimmed. Tighter matching of two op amps in one package (OP727) offers a significant boost in performance over the triple op amp configuration.

For this circuit, $V_O = 100(V2 - V1)$ for 0.02 mV ≤ (V1 − V2) ≤ 290 mV, 2 mV ≤ V_{OUT} ≤ 29 V.

Due to its great dc accuracy and specification, the OP747 can be used to create a multiple output tracking voltage reference from a single source, as shown in Figure 6.

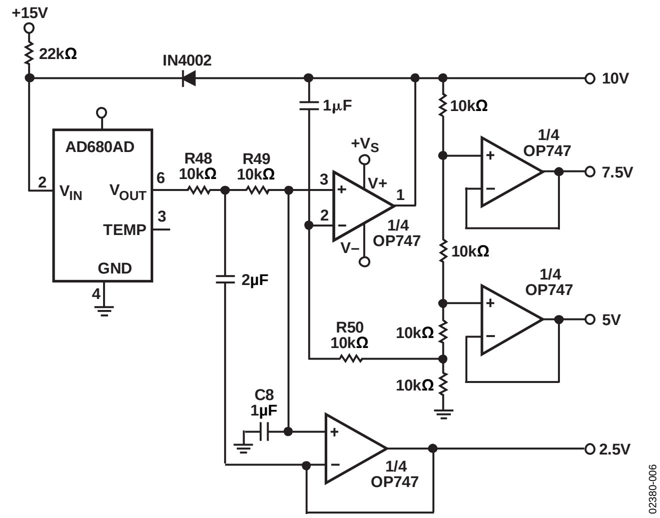

Figure 6. Multiple Output Tracking Voltage Reference

Figure 7 shows an example of a 5 V single-supply current monitor that can be incorporated into the design of a voltage regulator with foldback current limiting or a high current power supply with crowbar protection. The design capitalizes on the common-mode range of the OP777 that extends to ground. Current is monitored in the power supply return where a 0.1 Ω shunt resistor, R_{SENSE}, creates a very small voltage drop. The voltage at the inverting terminal becomes equal to the voltage at the noninverting terminal through the feedback of Q1, which is a 2N2222A or equivalent NPN transistor. This makes the voltage drop across R3 equal to the voltage drop across R_{SENSE}. Therefore, the current through Q1 becomes directly proportional to the current through R_{SENSE}, and the output voltage is given by

$$V_{OUT} = 5\text{ V} - (R2/R3) \times R_{SENSE} \times I_L)$$

The voltage drop across R2 increases when I_L increases; therefore, V_{OUT} decreases when a higher supply current is sensed. For the element values shown, V_{OUT} is 2.5 V for a return current of 1 A.

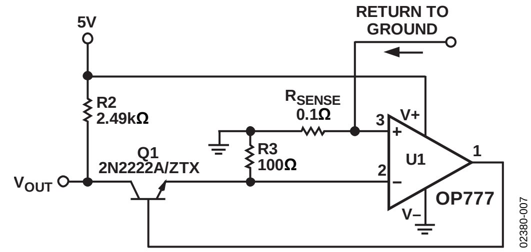

Figure 7. Low-Side Current Sensing Circuit

Figure 8 shows the OP777 configured as a simple summing amplifier. The output is the sum of V1 and V2.

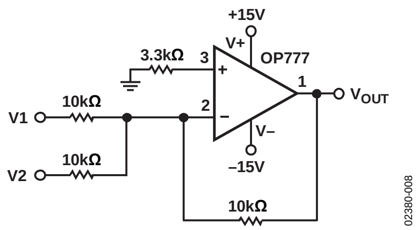

Figure 8. Summing Amplifier

ABSENCE OF CLAMPING DIODES AT THE INPUTS

The large differential voltage capability allows for operation of the parts in both rectifier circuits and precision comparator applications. The need for external clamping diodes (on-board in the OP07) is eliminated; such diodes are often needed on precision op amps and are the bane of many comparator designs.

The simple oscillator shown in Figure 9 creates a square wave output of $\pm V_S$ at 1 kHz for the values shown. Other oscillation frequencies can be derived by using

$$f = 1/(2R3 \times C10 \times \ln((R61 + R60)/R61))$$

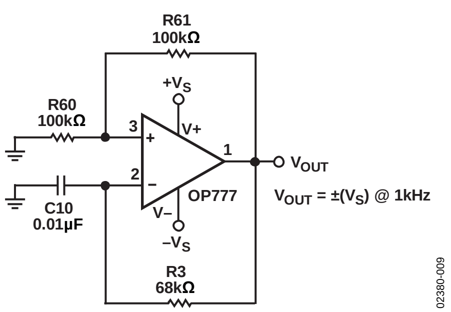

Figure 9. Free-Running Square Wave Amplifier

The programmable window comparator is capable of 12-bit accuracy. DAC8222 is used in the voltage for setting the upper and lower thresholds.

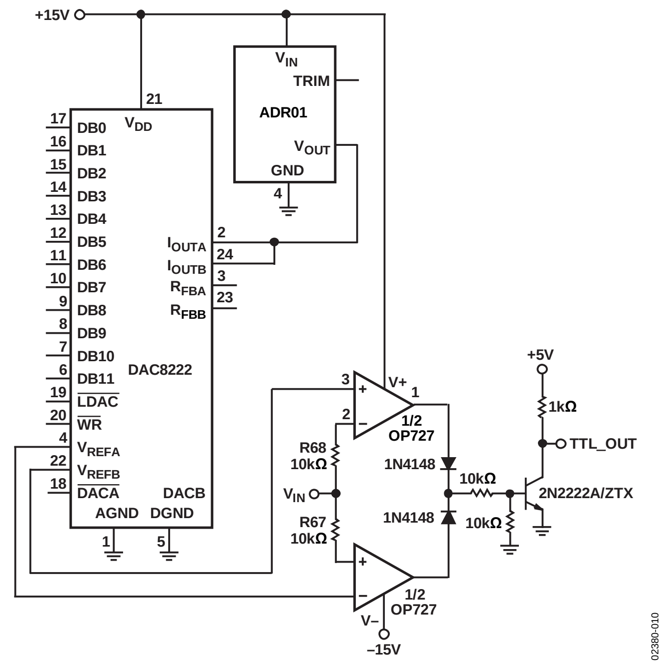

Figure 10. Programmable High Resolution Window Comparator

An OP777 is used to build a precision threshold detector. In this circuit, when $V_{IN} < V_{TH}$, the amplifier swings negative, reverse biasing the diode. If R_L = infinite, $V_{OUT} = V_{TH}$. When $V_{IN} \geq V_{TH}$, the feedback occurs and $V_{OUT} = V_{TH} + (V_{IN} - V_{TH})(1 + R_F/R_S)$. C is selected to make the loop respond in a smoother fashion.

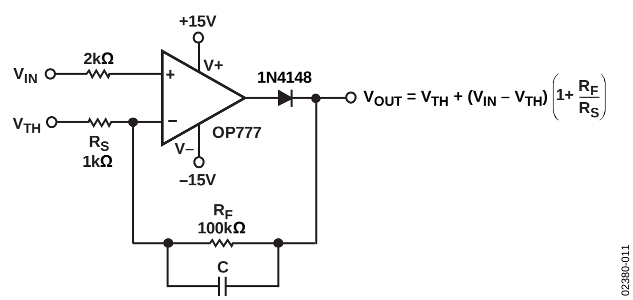

Figure 11. Precision Threshold Detector/Amplifier

For $V_{IN} > 0$ V and <2 kHz, there is no current flow through the feedback resistors, and the output voltage tracks the input. For $V_{IN} < 0$ V, the output of the first amplifier goes to 0 V (that is, $-V_S$), which configures the second amplifier in inverting follower mode. The output is then a full-wave rectified version of the input signal. As can be seen from the schematic shown in Figure 12, a half-wave rectified version of the signal is also available at the output of the first amplifier.

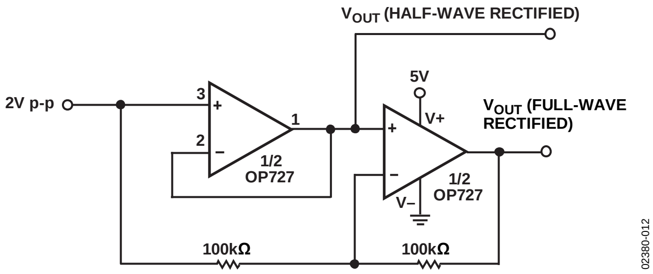

Figure 12. Single-Supply Half-Wave and Full-Wave Rectifier

RAIL-TO-RAIL OUTPUT

With light loads, the output can swing to within 1 mV of both supply rails, and the parts are stable in a voltage follower configuration. Short-circuit protection on the output protects the devices up to 30 mA with split ±15 V supplies (10 mA with a single 5 V supply).

NEGATIVE RAIL INPUT

The amplifiers respond to signals as low as 1 mV above ground in a single-supply arrangement. The true single-supply capability of the OP7x7 family enables designers to operate down to the negative supply or ground in both single- and dual-supply applications.

The high gain and low TCV_{OS} of the OP727 ensure accurate operation with microvolt input signals (see Figure 13). In this circuit, the input always appears as a common-mode signal to the op amps. The CMRR of the OP727 exceeds 120 dB, yielding an error of less than 2 ppm.

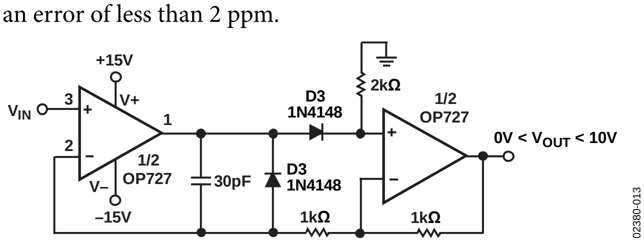

Figure 13. Precision Absolute Value Amplifier

A single-supply current source is shown in Figure 14. Large resistors are used to maintain micropower operation. Output current can be adjusted by changing the R10 resistor. Compliance voltage is

$$|V_L| \leq |V_{SAT}| - |V_S|;\ I_{OUT} = R2/(R8 \times R10) \times V_S;$$
$$I_{OUT} = 1\text{ mA to }11\text{ mA};\ R2 = R10 + R7$$

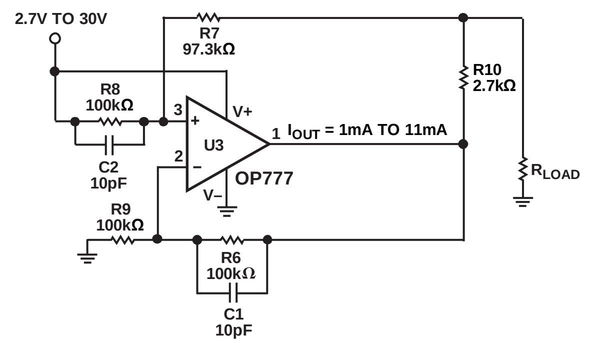

Figure 14. Single-Supply Current Source

When in single-supply applications, driving motors or actuators in two directions is often accomplished using an H-bridge (see Figure 15). This driver is capable of driving loads from 0 V to 5 V in both directions. To drive inductive loads in both directions, be sure to add diode clamps to protect the bridge from inductive kickback.

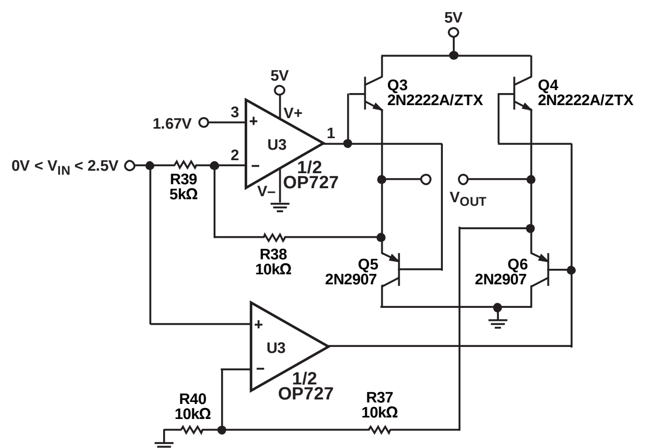

Figure 15. H Bridge

The current source shown in Figure 16 supplies both positive and negative current into grounded load. Note that

$$Z_{OUT} = R2B \times ((R2A/R1) + 1)/((R2B + R2A)/R1) - R2/R5$$

and, for Z_{OUT} to be infinite, $(R2A + R2B)/R1 = R2/R5$.

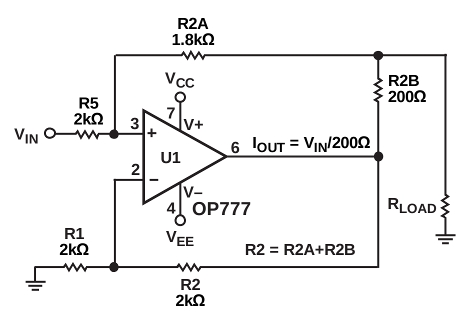

Figure 16. Bilateral Current Source

3 V OVER THE INPUT

The PNP input stages are protected with 500 Ω current-limiting resistors, allowing input voltages up to 3 V higher than either rail without causing damage or phase reversals. The phase reversal protection operates for conditions where either one or both inputs are forced beyond their input common-mode voltage range.

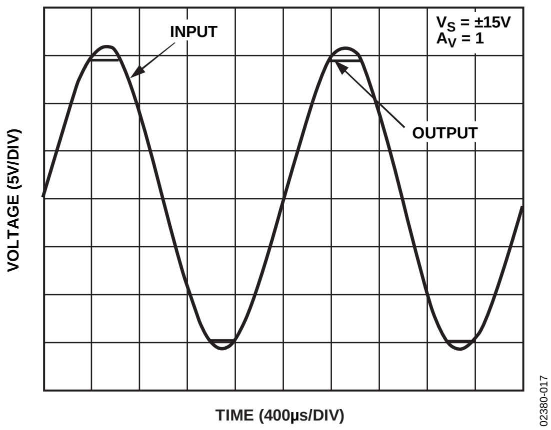

Figure 17. No Phase Inversion

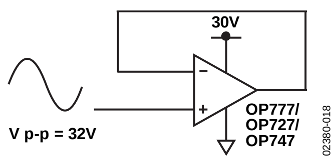

Figure 18. Unity-Gain Follower

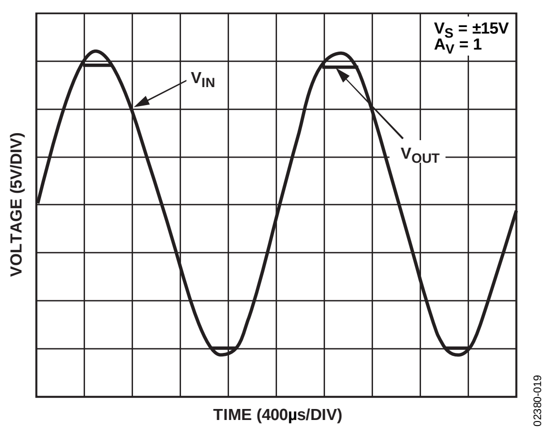

Figure 19. Input Voltage Can Exceed the Supply Voltage Without Damage

The dynamic performance and noise characteristics of the devices are similar whether they are being used with single or dual supplies. The slew rate with a 2 kΩ load is 200 mV/µs, and the gain bandwidth product is 700 kHz. Peak-to-peak voltage noise from 0.1 Hz to 10 Hz is 0.4 µV, and the voltage noise density at 1 kHz is 15 nV√Hz.

The gain characteristics, of course, are rather different at differing rails. The inputs have a maximum, single temperature offset of 100 µV with an input offset current of 2 nA and input bias current of only 10 nA maximum. With a single 5 V rail, the CMRR is typically 110 dB, and the large signal voltage gain is typically 500 V/mV with a 10 kΩ load. With ±15 V rails, the CMRR increases, not surprisingly, by 10 dB to 120 dB, and the large signal voltage gain increases to 2500 V/mV.

For designs operating at ±15 V, the OP777 is a low noise precision amplifier available in a tiny, 8-lead MSOP package. The OP777 is also available in an 8-lead SOIC surface-mount package.

This family is extremely useful in instrumentation, for remote sensor acquisition, and in precision filters. The high voltage range allows the use of the parts for single-supply current sourcing and large range instrumentation amplifiers. Both single-supply and dual-supply linear response bridges can also be built. The parts are ideal for use in low-side current monitors in power supply control circuits because the common-mode range extends to ground in the single-supply configuration.

DESIGN REMINDERS FOR ACHIEVING HIGH PERFORMANCES

As with any application, a good ground plane is essential to achieve optimum performance. This can significantly reduce the undesirable effects of ground loops and I × R losses by providing a low impedance reference point. Best results are obtained with a multilayer board design with one layer assigned to the ground plane.

To minimize high frequency interference and prevent low frequency ground loops, shield grounding techniques are required when sensors are used. The cable shielding system should include the cable end connectors.

Switching power supplies with high output noise is normally used in many systems. This noise generally extends over a broad band of frequencies and occurs as both conducted and radiated noise, and unwanted electric and magnetic fields. The voltage output noise of switching supplies is short-duration voltage transients or spikes that contain frequency components easily extending to 100 MHz or more. Although specifying switching supplies in terms of rms noise is a common vendor practice, users should also specify the peak (or peak-to-peak) amplitudes of the switching spikes with the output loading of the individual system. Capacitors, inductors, ferrite beads, and resistors are used in filters for noise reduction. Linear post regulation can also be done and separates the power supply circuit from sensitive analog circuits. Analog Devices manufactures many anyCAP® low dropout linear regulators. Examples of these devices are the ADP3300 to ADP3310 and ADP3335 to ADP3339 for supply voltages less than 12 V.

Capacitors are probably the single most important filter component for switchers. There are generally three classes of capacitors useful in filters in the 10 kHz to 100 MHz frequency range suitable for switchers. Capacitors are broadly distinguished by their generic dielectric types: electrolytic, film, and ceramic. Background and tutorial information on capacitors can be found in the Walter G. Jung, Richard Marsh, *Picking Capacitors*, Part 1 and Part 2, AUDIO (February, March 1980) article and many vendor catalogs.

Chip capacitors should be used for supply bypassing, with one end of the capacitor connected to the ground plane and the other end connected within ⅛ inch of each power pin. An additional large tantalum electrolytic capacitor (4.7 μF to 10 μF) should be connected in parallel. This capacitor does not need to be placed as close to the supply pins because it provides current for fast large signal changes at the output of the device.

Use short and wide PCB tracks to decrease voltage drops and minimize inductance. Make track widths at least 200 mils for every inch of track length for lowest DCR and use 1 ounce or 2 ounce copper PCB traces to further reduce IR drops and inductance.

Be careful not to exceed the maximum junction temperature or the maximum power dissipation rating of an amplifier. When a capacitive load connects to the output of the amplifier, include the power dissipation caused by the rms ac current delivered to the load in the calculation.

Use short leads or leadless components to minimize lead inductance. This minimizes the tendency to add excessive ESL and/or ESR. Surface-mount packages are preferred. Use a large area ground plane for minimum impedance. Note how components behave over frequency, current, and temperature variations.

Make use of vendor component models for the simulation of prototype designs, and make sure that lab measurements correspond reasonably with the simulation. SPICE modeling is a powerful tool for predicting the performance of analog circuits. Analog Devices provides macro models for most of its ICs. SPICE models can be downloaded on the OP777 product page.

Because models omit many real-life effects and no model can simulate all of the parasitic effects of discrete components and PCB traces, build/prove prototypes before they go into production. To ensure successful prototyping, always use a ground plane for precision or high frequency circuits. Minimize parasitic resistance, capacitance, and inductance. If sockets are required, use pin sockets (cage jacks). Pay equal attention to signal routing, component placement, grounding, and decoupling in both the prototype and the final design. Popular prototyping techniques include Freehand dead-bug using point-to-point wiring and solder-mount, milled PCB from CAD layout, multilayer boards that are double-sided with additional point-to-point wiring.

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