ANALOG DEVICES

AN-573 APPLICATION NOTE

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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 OP17x7 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. A new family of amplifiers from Analog Devices 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 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.

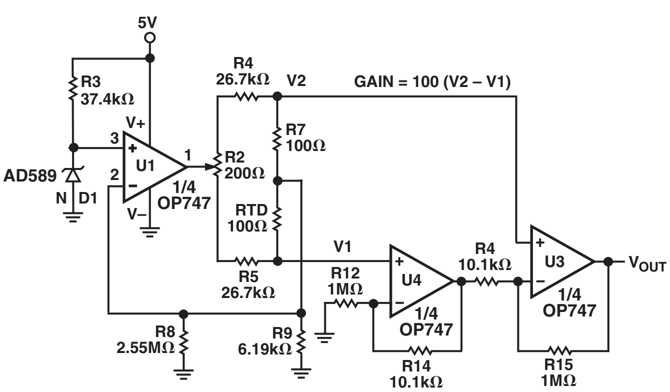

Figure 1. Low Power Single-Supply RTD Amplifier

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 while maintaining 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 and flows into both halves of the bridge, eventually through RTD, and establishes an output voltage based upon its value.

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.

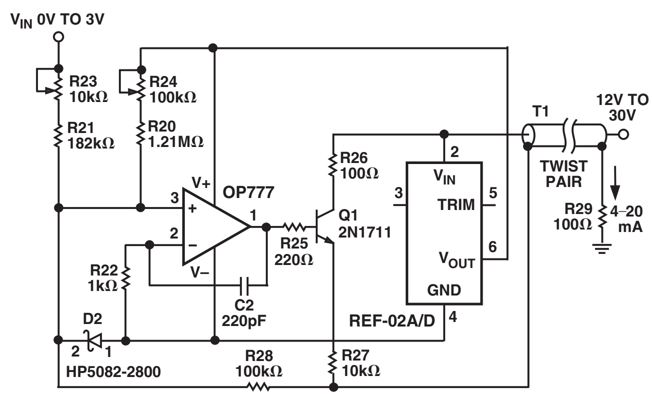

Figure 2. Self-Powered 4–20 mA Current Loop Transmitter

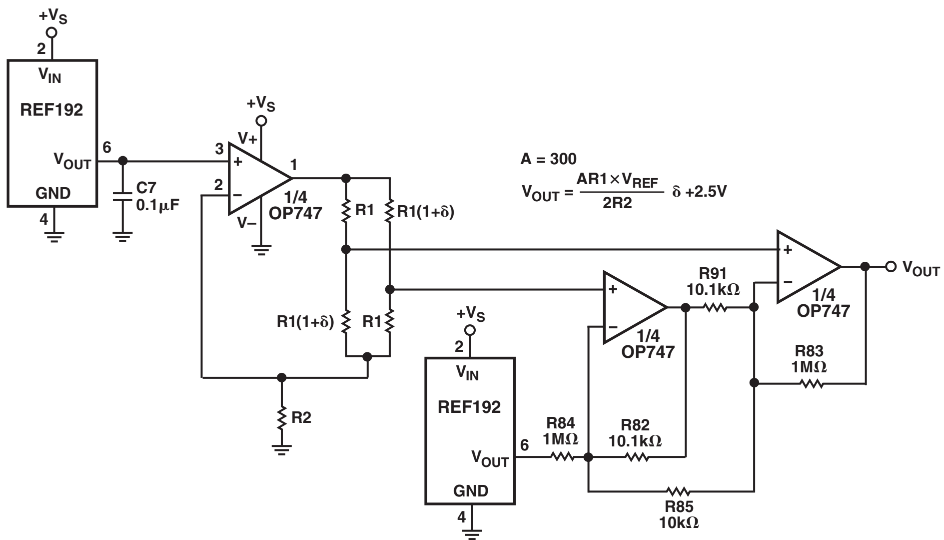

Figure 3. Single-Supply Linear Response Bridge

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. This is shown in Figure 4, 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.

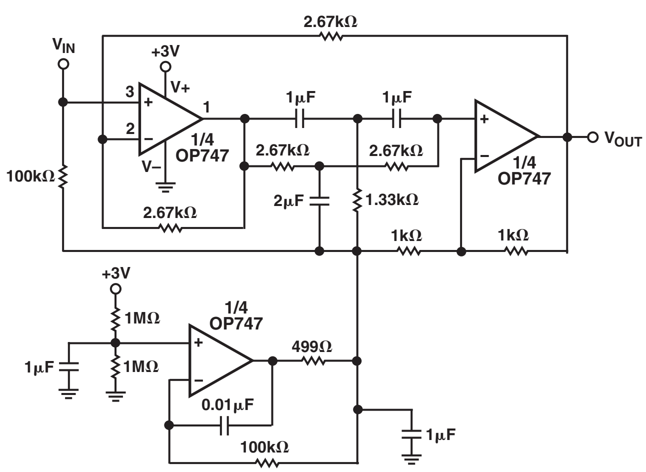

Figure 4. 3 V Single-Supply 50 Hz/60 Hz Active Notch Filter with False Ground

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-amplifier is less than 350 µA, while the old OP07 required 4 mA for ±15 V operation. In terms of power consumption, the new part wins hands down. This allows the part to be designed into many portable applications.

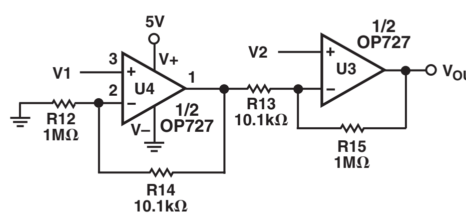

Figure 5. Single-Supply Micropower In-Amp

OP727 can be used to build an instrumentation amplifier (IA) with two op amps. A single-supply instrumentation amplifier 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 × log (100/(1 – (R15 × R14)/(R13 × 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 × 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. It should be noted that 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 $0.02\ mV \leq (V1 - V2) \leq 290\ mV$, $2\ mV \leq V_{OUT} \leq 29\ V$.

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.

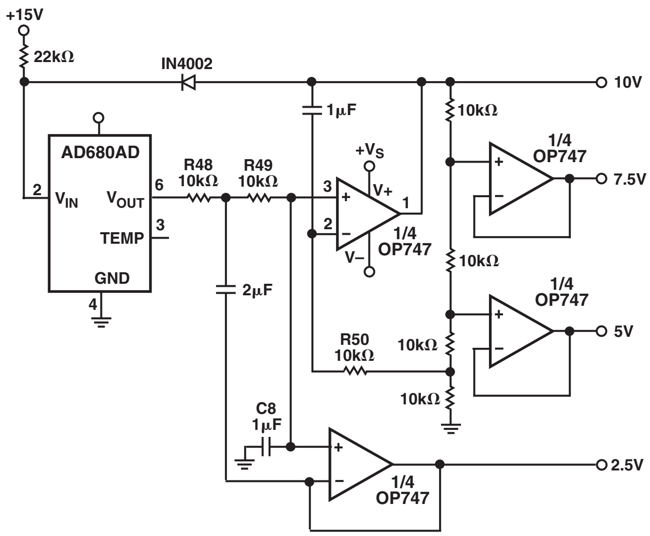

Figure 6. Multiple Output Tracking Voltage Reference

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 OP777's common-mode range 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 2N2222 or equivalent NPN transistor. This makes the voltage drop across R1 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: $V_{OUT} = 5\ V - (R2/R3) \times R_{SENSE} \times I_L)$. The voltage drop across R2 increases with I_L increasing, so V_{OUT} decreases with higher supply current being sensed. For the element values shown, the V_{OUT} is 2.5 V for a return current of 1 A.

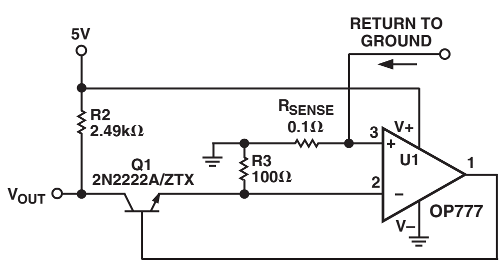

Figure 7. Low-Side Current Sensing Circuit

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

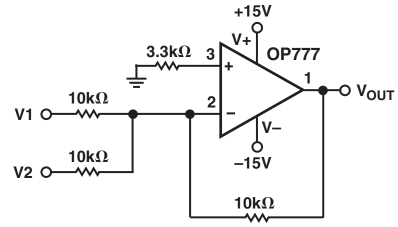

Figure 8. Summing Amplifier

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

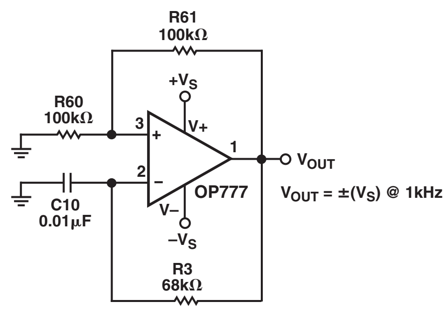

Figure 9. Free-Running Square Wave Amplifier

The programmable window comparator is capable of 12-bit accuracy. DAC8212 is used in the voltage for setting the upper and lower thresholds.

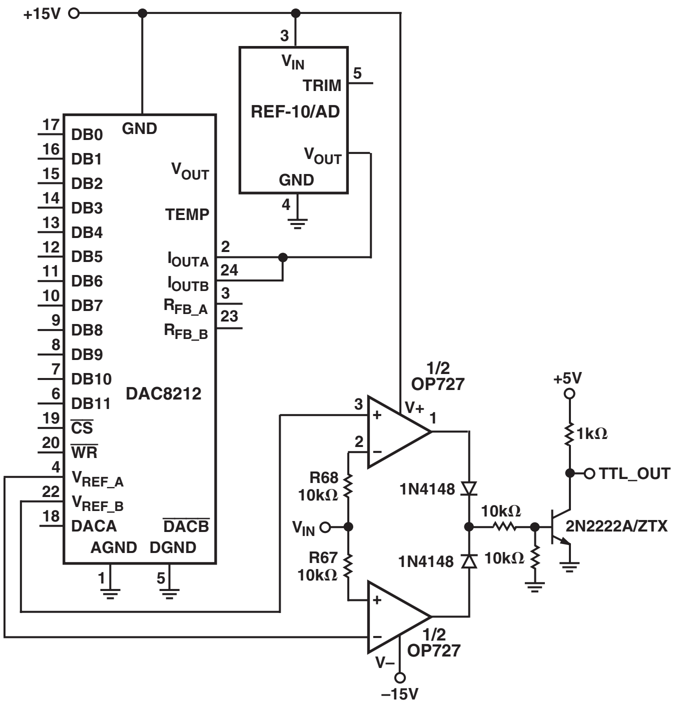

Figure 10. Programmable High Resolution Window Comparator

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. $V_{OUT} = V_{TH}$ if R_L = infinite. When $V_{IN} >= V_{TH}$, 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.

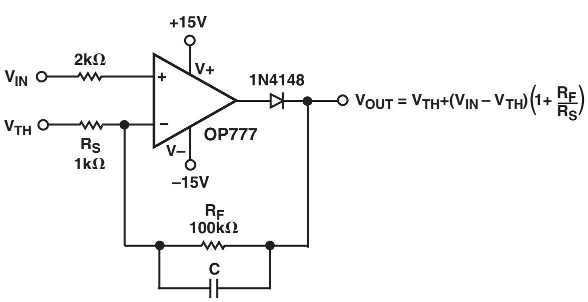

Figure 11. Precision Threshold Detector/Amplifier

For V_{IN} > 0 V and less than 2 kHz, there will not be any 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 (i.e., $-V_S$), 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, a half-wave rectified version of the signal is also available at the output of the first amplifier.

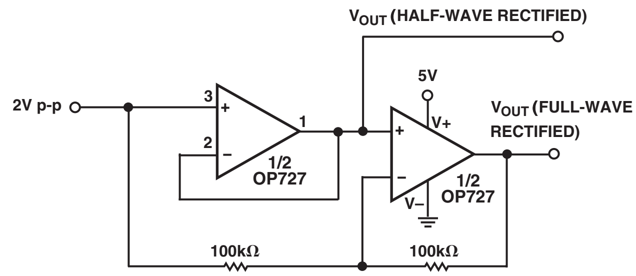

Figure 12. Single-Supply Half-Wave and Full-Wave Rectifier

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 will respond to signals as low as 1 mV above ground in a single-supply arrangement. 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.

The high gain and low TCV_{OS} of OP727 ensures 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.

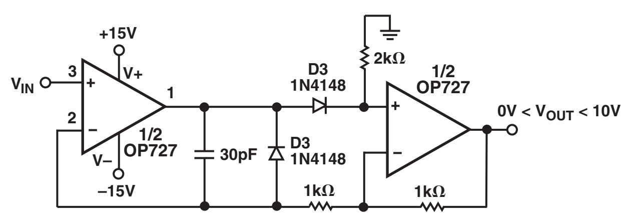

Figure 13. Precision Absolute Value Amplifier

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

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

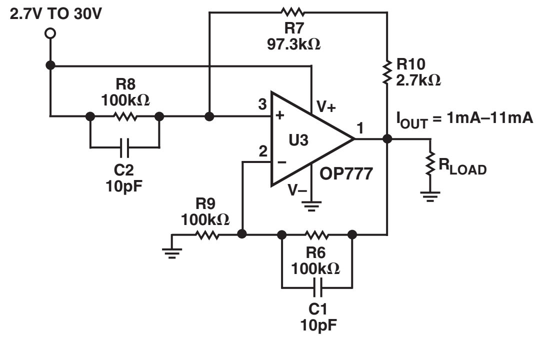

Figure 14. Single-Supply Current Source

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. If this is used to drive inductive loads, be sure to add diode clamps to protect the bridge from inductive kickback.

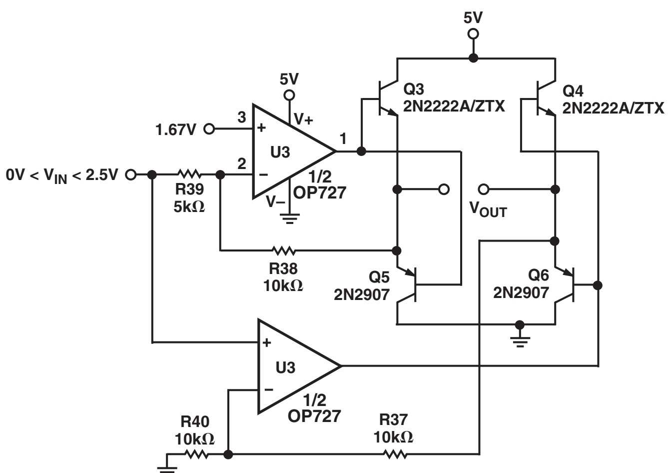

Figure 15. H Bridge

The current source shown in Figure 16 supplies both positive and negative current into grounded load. It should be noted that $Z_{OUT} = R2B \times ((R2A/R1) + 1)/((R2B + R2A)/R1) - R2/R5$ and that for Z_{OUT} to be infinite, there should be $(R2A + R2B)/R1 = R2/R5$.

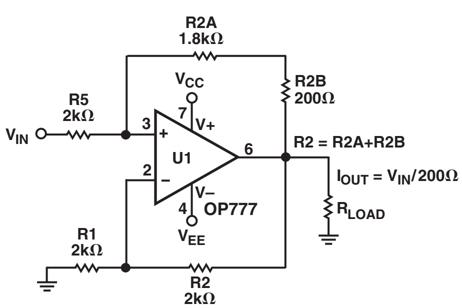

Figure 16. Bilateral Current Source

3V 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 voltage range.

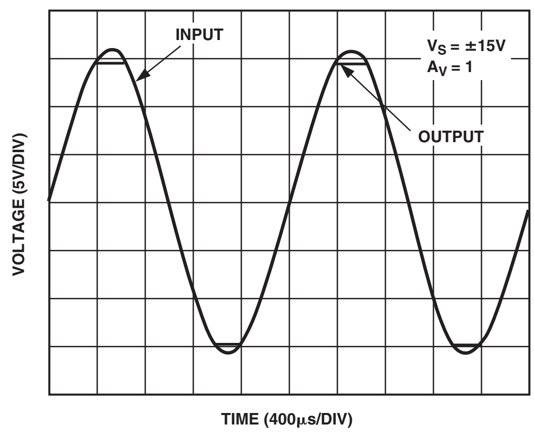

Figure 17. No Phase Inversion

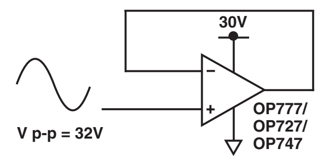

Figure 18a. Unity Gain Follower

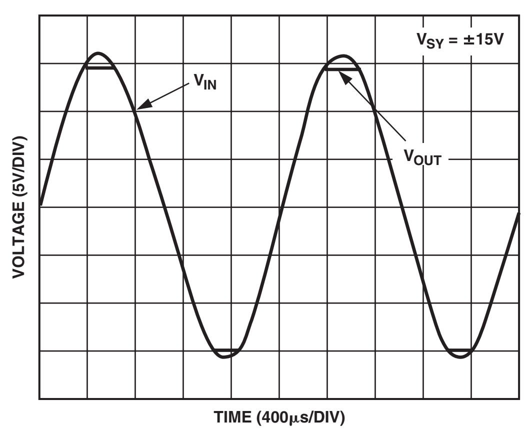

Figure 18b. Input Voltage Can Exceed the Supply Voltage without Damage

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, while the gain-bandwidth product is 700 kHz. Peak-to-peak voltage noise from 0.1 Hz to 10 Hz is 0.4 µV, while the voltage noise density at 1 kHz is 15 nV$\sqrt{Hz}$.

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 (I_B) of only 10 nA maximum. With a single 5 V rail, the common-mode rejection ratio (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 the first low noise precision amplifier available in the tiny MSOP 8-lead package. The OP777 is also available in the SOIC 8-lead surface-mount package.

This family will be extremely useful in instrumentation, for remote sensor acquisition, and in precision filters. The high voltage range will allow 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 since the common-mode range extends to ground in the single-supply configuration.

DESIGN REMINDERS FOR ACHIEVING HIGH PERFORMANCE

As with any application, a good ground plane is essential to achieve the 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.

In order 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 are 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, a user should also specify the peak (or p-p) 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. One can also do linear post regulation and separate 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 article "Picking Capacitors"* 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 1/8 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 as it provides current for fast large signal changes at the device's output.

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. If a capacitive load is to be connected to the output of the amplifier, be sure to include in the calculation the power dissipation caused by the rms ac current delivered to the load.

*Walt Jung, Dick Marsh. "Picking Capacitors," Parts 1 and 2. *Audio* (February, March 1980).

Use short leads or leadless components to minimize lead inductance. This will minimize the tendency to add excessive ESL and/or ESR. Surface-mount packages are preferred. Use a large area ground plane for minimum impedance. Know 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 from the ADI website (http://products.analog.com/products/info.asp?product=OP777).

Since models omit many real-life effects and no model can simulate all of the parasitic effects of discrete components and PCB traces, prototypes should be built and proven before production. In order 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 PC board from CAD layout, multilayer boards that are double-sided with additional point-to-point wiring.

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