ELECTRONIC DESIGN EXCLUSIVE

High-power hybrid op amp dissipates up to 500 W and guards against burnout

Withstanding four times the heat of all previous hybrid circuits, a power op amp competes with bridge and parallel IC networks, power transistors, amplifiers, and other high-current schemes.

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Convenience, versatility, reliability, and accuracy attract designers to IC power op amps. But some tasks, particularly in motion control and robotics, demand higher current than today's monolithic or even hybrid op amps can deliver. Consider that right now, hybrid ICs can dissipate up to 125 W and drive loads of 250 W; monolithics can handle only a tenth that. To meet higher peak power requirements, op amps must be connected in parallel or bridge networks, or use external booster transistors or a power amplifier must be added. But those choices can increase a design's complexity, cost, size, and weight while cutting into reliability and linearity.

A new hybrid IC lifts the power limits. Owing in part to a specially developed package, the PA03 dissipates up to 500 W, four times that of the largest op amp now available. That rating means that the hybrid can drive 500-W linear motors, 1000-W passive resistive loads, and 2000-W loads in the switching mode. Furthermore, the op amp drives up to 30 A and operates from supplies of ± 75 V (ELECTRONIC DESIGN, Dec. 12, 1985, p. 164).

Besides having a high continuous power rating, the hybrid's thermal protection circuits enable it to operate anywhere within a 2400-W, 1-ms safe operating area. If an overload occurs, the circuits shut down the amplifier. Thus, the single amplifier is not only more economical than four separate ones in parallel, but it is also safer under abnormal conditions. In addition, by including its own current-limiting resistors, the circuit eliminates the bulky and expensive external current-limiting devices normally required for competitive power op amps.

The output stage, a common-collector complementary configuration (Fig. 1), can swing to within 4 V of the supply rail at 12 A and to within 6 V at 30 A. Furthermore, with a shutdown control, designers can protect sensitive loads or conserve power during battery operation. By dismissing external power transistors, the amplifier also casts off any emitter-follower oscillations. What's more, in class AB operation, it achieves low crossover distortion—a benefit of the thermal tracking of a one-package device.

The laser-trimmed FET input stage exhibits 10-μV/°C drift, 0.5-mV offset, and low thermal tail (the effect of heat flow on input offset voltage). Since an external balance control further improves those parameters, the hybrid can connect directly to devices such as a photodiode. It also can work in programmable power supplies with 12-bit resolution, as well as in integrators with long time periods.

PACKAGED FOR POWER

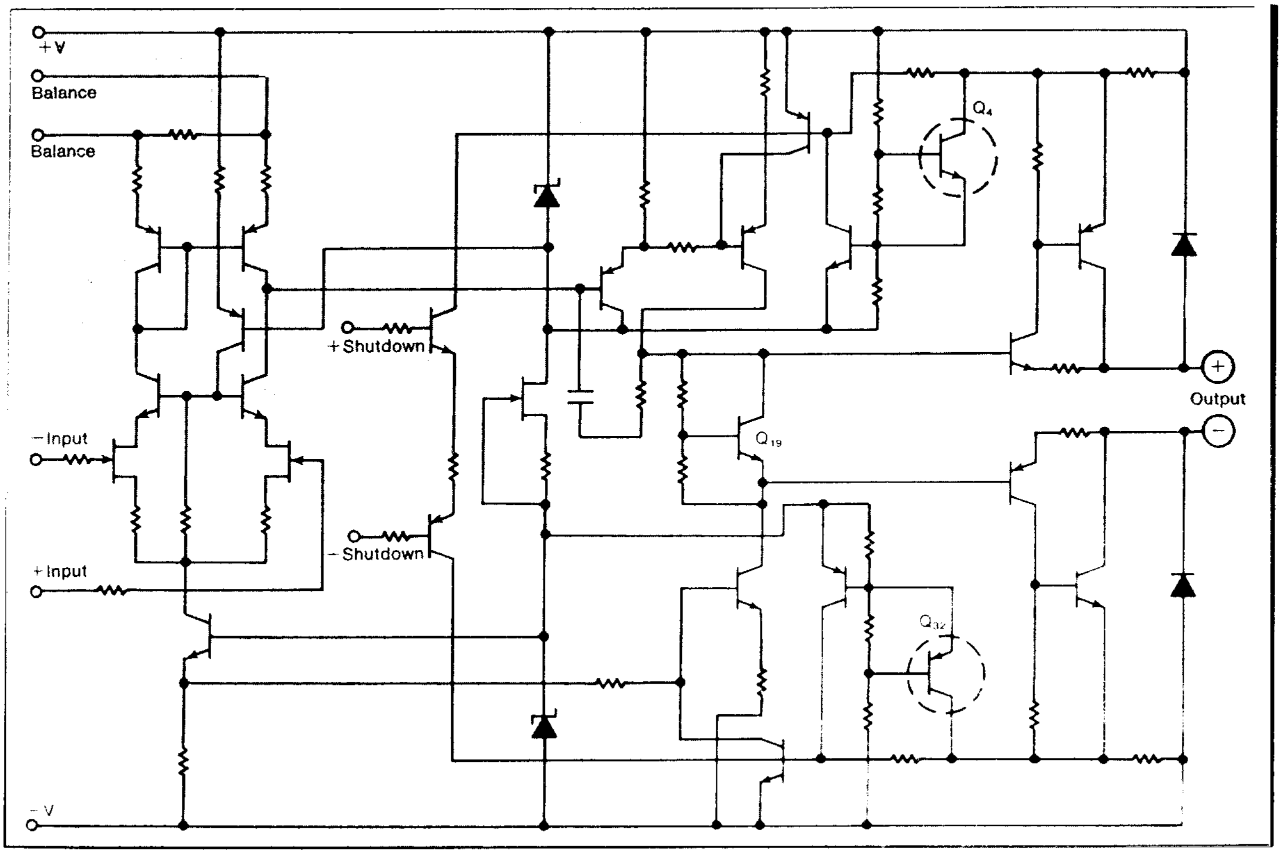
To help it accommodate high currents, the hybrid is housed in a copper DIP. Pins are 0.060 in. wide and spaced 0.200 in. apart to simplify layout on a standard 0.100-in. grid. Conventionally, power op amps occupy a TO-3 container with 0.040-in. pins on 0.170-in. centers.

In general, the op amp will find its way into single-ended circuits that must deliver as much as 1000 W to a resistive load and 2000 W peak to a bridge-motor servo system. Specifically, the hybrid will operate in linear and magnetic deflection circuits, and programmable power supplies.

The amplifier's high power dissipation suits it to linear control, especially in robots, lasers, and other high-speed jobs. The op amp is also desirable in motor controls that stop or reverse dynamically. High efficiency, switching motor controls can take advantage of the amplifier's high slew rate to modulate pulse width at frequencies up to 50 kHz.

The hybrid's slew rate and voltage rating equip it for high-power deflection circuits with fast write and retrace speeds. In power supplies, the amplifier's overload features improve its chances of surviving a short circuit. In addition, phased-array transmitters and high-powered transducers, akin to those in sonar, can exploit the amplifier's accurate phase response and its linearity in class AB operation.

The PA03 functions most efficiently at the minimum power-supply voltage needed to produce the required output. For example, a ±45-V, 12-A output requires



1. The PA03 power op amp's common-collector output stage dissipates up to 500 W of power while remaining within 6 V of the power supply at 30 A. Moreover, low crossover distortion marks the hybrid because it operates in class AB. The op amp also features shutdown control and a laser-trimmed FET input stage with drift, for the A version, of only 10-μV/°C and 0.5-mV offset.

the power supply to reach ± 50 V, which accounts for a 5-V supply-to-output differential. The power op amp works wtih symmetrical dual supplies of up to ± 75 V or single voltage supplies of 150 V or less rail to rail. The supply voltage must exceed input voltages by at least 10 V.

SHOWING HEAT THE DOOR

Because the op amp must dissipate high levels of power, its thermal path plays an especially critical role. A heat sink rated at 1 °C/W may effectively remove up to 50 W, but of course cannot handle 500 W. As a result, the higher power dictates a heat sink rated at 0.1 °C/W —a large heat-radiating surface cooled by forced air or even water. (Fortunately, insufficient cooling causes the hybrid to shut down rather than destroy itself.)

In a dc circuit, the internal power dissipation, P, is:

$$P = (V_S - V_O)\,I_O + (|V_S| + |-V_S|)\,I_Q$$

where I_O and I_Q are the output and quiescent currents and V_Q and V_S are the output and supply voltages, respectively. In calculating internal dissipation, V_S must represent the value at the supply that is the source or sink of the corresponding current. In addition, the designer must determine whether the worst-case condition is a short circuit to ground or to the power supply.

When the op amp drives a reactive load, power dissipation becomes a function of the phase difference between the output voltage and current. For the same values of voltage and current, the actual dissipation may be several times higher than for a resistive load. In this case, $P = P_I - P_O$, where P_I is the power drawn from the supply and P_O is the power delivered to the load. Thus, in purely reactive loads, all the power drawn from a supply is dissipated in the op amp.

CALCULATING THE OPERATING LIMITS

As determined through standard methods, the op amp's absolute maximum power-dissipation rating is 500 W, assuming a case temperature, T_C, of 25 °C and a maximum junction temperature, T_J, of 150°C. Given the power dissipation and the maximum ambient temperature, T_A, the op amp's case and output transistor-junction temperature, T_J, can be found. Specifically, $T_C = T_A + P\Theta_{HS}$, and $T_J = T_C + P\Theta_{JC}$, where Θ_{HS} is the thermal resistance between the heat sink and the ambient air, and Θ_{JC} is the internal thermal resistance between the junction and the case.

To find the required thermal resistance of the heat sink, first calculate internal power dissipation P. Then, given the maximum recommended junction temperature, determine the junction's increase above the ambient temperature, denoted as $T_J - T_A$. The heat sink should have a thermal resistance of no greater than $\theta_{HS} = [(T_J - T_A)/P] - \theta_{JC}$.

Price and availability

The PA03 power op amp is available now and sells for $190 each in quantities of 100. For applications requiring up to 10 pA of input bias current, the PA03A sells for $247, also in quantities of 100. CIRCLE 502

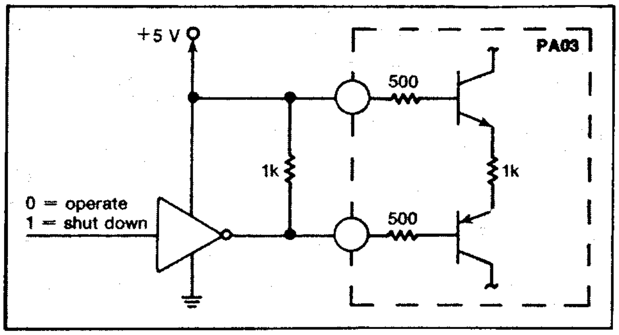
For example, a circuit that dissipates 300 W at a 30 °C ambient temperature requires a heat sink whose thermal resistance is no more than $\theta_{HS} = [(150-30)/300] - 0.3 = 0.1$ °C/W.

SIMPLE TO SHUT DOWN

When the op amp's output needs to be turned off, at least 3.5 V is applied between its shutdown pins. When TTL circuits activate the pins, the plus shutdown pin should connect to the +5 V of the logic supply voltage and the minus shutdown pin driven by the TTL logic gate (Fig. 2). In addition, a resistor pulls up the TTL gate to at least 3.5 V to ensure normal operation when the op amp's output stage is active.

CMOS logic can activate the shutdown mechanism as well, since only 100 µA is needed. Either pin can be switched, but a high logic level exceeding 5 V requires a resistive ladder to limit the voltage differential to 5 V between the pins.

To nullify the input voltage offset with the op amp's balance control, a 100- to 200-Ω potentiometer fits be-



2. Either TTL or CMOS logic circuits operate the op amp's shutdown mechanism. For TTL, the plus pin connects to the 5-V logic supply, and a gate activates the minus pin. A pull-up resistor (highlighted) also is recommended. On the other hand, a CMOS gate can drive either shutdown input pin, since 100 µA is sufficient and no pull-up resistor is needed.

tween the IC's balance pins. The potentiometer's wiper arm, which connects to the positive supply voltage, should be separate from the main current-carrying path to prevent any ripple from coupling into the balance circuit. If balance control is not needed, both pins link to the positive supply, again by a separate connection.

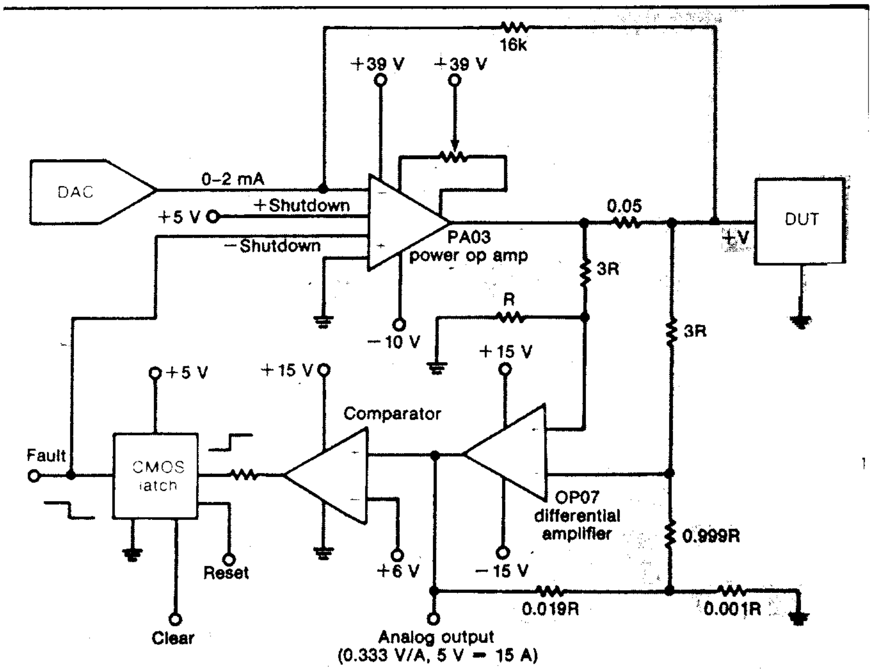
All high-current op amps can succumb to unwanted current feedback from electromagnetic radiation and voltage drops in wiring. The high current and speed ratings of the PA03 emphasize those effects. To prevent feedback, all supply and output leads must be fabricated from 12-gauge or thicker conductors. (The op amp's current capacity exceeds that of most residential wiring branch circuits.) In addition, external bypass capacitors prevent feedback through the power supplies. One capacitor, a 0.47-μF ceramic or low-impedance foil type, should parallel a low-frequency bypass capacitor of 10 μF for every ampere of peak output current—up to 300 μF. Both should be mounted no more than 1.5 in. from the amplifier's supply pins.

The op amp can go to work in a simple programmable power supply (Fig. 3). The supply tests dc-dc power modules, which draw up to 15 A at 28 V. For 0.5 seconds each, a low-voltage of 18.5 V and high-voltage of 32 V are applied; the normal 28-V test is performed as well. The module outputs must achieve accuracy to within 0.5% and be able to survive momentary short circuits to ground.

The programmable supply requires little calibration, because the power op amp changes the output current of a highly accurate d-a converter into a voltage. A circuit built around a differential amplifier (OP07) and four terminal shunt resistors senses the current drawn by the dc-dc module, the device under test (DUT). The circuit drives a comparator with a voltage equaling 0.333 V/A. If the DUT current exceeds 18 A, a CMOS latch shuts down the power op amp, and a pulse to the latch resets the circuit when the malfunction clears.

STRONG SENSOR

When the d-a converter's output is set to 2 mA, a 16-Ω feedback resistor yields the 32-V full-scale output to drive the DUT. At the same time, a 0.05-Ω current-sensing resistor develops 0.75 V when the supply's output current reaches 15 A. The relatively low 0.75-V full-scale voltage keeps the sensing resistor from dissipating excessively high power. Nevertheless, the resistor must be mounted on a heat sink: At 15 A it produces 11.25 W, and at the supply's current limit of 42 A, it throws off 88 W.



3. A high-power op amp goes to work in a test system as a simple programmable power supply. In this case, the supply tests dc-dc modules by applying 18.5, 28, and 32 V at 15 A across them and the test system checks their output voltage for accuracy. Under normal conditions, the op amp must dissipate up to 306 W peak. A short circuit in the test fixture pushes the power in the op amp to over 1.5 kW.

The programmable supply requires positive and negative power sources. For the positive source to generate the correct output voltage, the sense resistor's 0.75-V drop must be included in the power op amp's supply-to-output differential. Since the op amp's specifications indicate a 7-V drop at 30 A and a 5-V drop at 12 A, a maximum drop of 6 V can be assumed at 15 A. Choosing an output of 39 V leaves a 5.25-V margin. The overall approach, though conservative, is justified given the IR drop at high current and the lack of remote sensing circuits. The 10-V negative supply satisfies the power op amp's common-mode voltage specification.

A HANDLE ON POWER DISSIPATION

Determining the op amp's maximum power dissipation depends on an examination of four different power levels. Three of the levels apply the different output voltages to the DUT when it draws its 15-A maximum normal operating current. The fourth case covers abnormal situations that may arise from faulty timing or defective test units.

Calculating the power levels for the three normal voltage ranges shows the 18.5-V output to be the worst case. An output of 18.5 V added to 0.75 V across the sense resistor leaves 19.75 V across the power op amp's output stage. At 15 A, the internal power dissipation is 306 W, including a quiescent 9.8 W. Therefore, the junction-to-case temperature rises 92°C. In the other two normal testing levels, the power at 28 V is 163.6 W, and at the 32-V output level, the op amp dissipates the least power: 103.6 W.

The actual heat sink values must take into account the general test plan or test sequence timing (Fig. 4). Since the three high-power tests last only 0.5 seconds apiece, examining thermal time constants and average power can reduce the heat sink requirements. During the 4.5 seconds of the test, the current is 1 A and the power is 20.8 W. In addition, removing and inserting the DUT takes at least 4 seconds, when only 9.8 W of quiescent power is dissipated. Thus, the average power dissipated is 41.93 W.

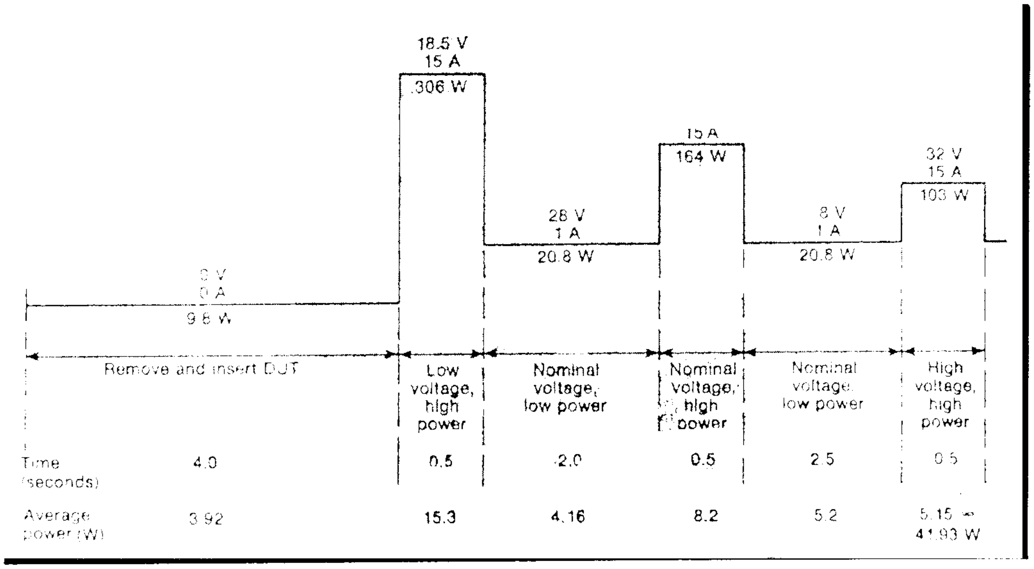
Assuming a heat sink time constant of 10 seconds, the highest power peak of 306 W for 0.5 seconds amounts to 5% of the time constant. That power, in turn, increases the temperature only 4.9% compared with dissipating 306 W continuously. The result equates to a 15-W spike. Thus, the peak short-term equivalent power is 57.2 W.

For a peak junction temperature of 150°C and a maximum of 38°C for ambient air, the heat sink can rise 18°C. Then, to dissipate the peak short-term equivalent power of 57.2 W, the heat sink rating must be 0.35°C/W. An HS06 heat sink with a 0.6°C/W rating in free air does the job if air is forced past it at 500 ft/min.

The final power calculation covers faulty test timing or a defective DUT. Prolonged operation at the 306-W level, however, will not destroy the power op amp because its thermal shutoff limits the temperature rise. The worst case actually occurs from a short circuit in the test socket. When that happens, the power op amp limits the current to 42 A, the sense-resistor voltage rises to 2.1 V, and 36.9 V develops across the amplifier. The resulting voltage and current levels, although producing 1.55 kW, are well within the amplifier's 2.4-kW, 1-ms secondary breakdown line on its safe operating-area curve. Therefore, the thermal shutoff circuit's fast response protects the amplifier.

Granger Scofield, vice president of marketing for Apex, previously worked as a senior application engineer assisting customers and giving seminars on power op amps. He has also designed products for Apex, as well as for Burr-Brown's test equipment and product development groups.

How valuable?	**Circle**
Highly	544
Moderately	545
Slightly	546



4. The test cycle sets the op amp's average power, which in turn determines the thermal resistance of the op amp's heat sink. Of the three supply-voltage tests, the low voltage demands the most dissipation from the op amp, a total of 306 W. Because each of the voltage tests lasts only 0.5 seconds, however, the power averages about 41.93 W.