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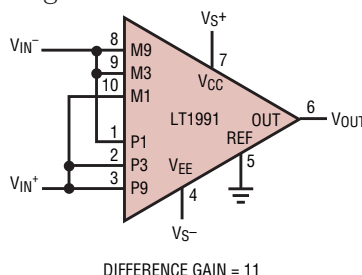
## Versatile Op Amps Need No Resistors

by Glen Brisebois and Jon Munson

### Introduction

The LT1990, LT1991 and LT1995 are ready-to-use op amps with their own resistors and internal compensation capacitors. Many difference or instrumentation amps offer precisely matched internal components, but such devices are usually designed to solve a specific application problem, and thus have limited versatility. Not the LT1990, LT1991, and LT1995. These are flexible parts that can be configured into inverting, non-inverting, difference amplifiers, and even buffered attenuators, just by strapping their pins (Figure 1).

The internal precisely matched resistors and capacitors make it possible to configure these op amps into hundreds of different application circuits without external components. Simply hook them up for type and gain and move on. By reducing the external components in your design, you simplify inventory, reduce pick and place costs, and make for easy probing.



**Figure 1. What could be easier? A precision difference amplifier; no resistors in sight. This is only one of hundreds of possible configurations. See Figure 3 for a few more.**

### What Do You Need: High Precision, High Input Voltage or High Speed?

Figure 2 shows simplified schematics of the three new amplifiers and in general, their comparative performance. The LT1990 is optimized for supporting high input common mode voltages of up to  $\pm 250V$ . The LT1991 is

**The LT1990, LT1991 and  
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op amps with their own  
resistors and internal  
compensation capacitors.  
Just wire them up.**

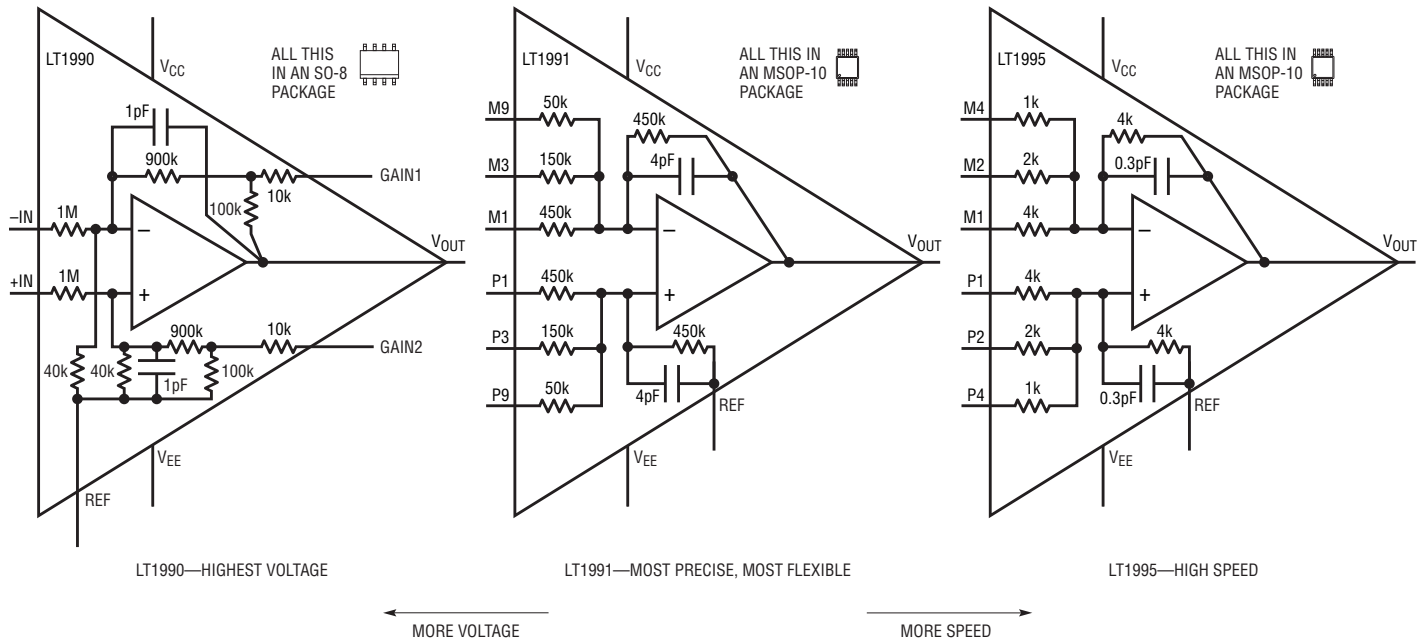
optimized for gain flexibility and overall precision, and supports common mode ranges up to  $\pm 60V$ . The LT1995 is designed for high speed applications up to 30MHz.

### The LT1991 for the Greatest Flexibility and Precision

The LT1991 is the most flexible and most precise of the three new devices. Its internal resistors guarantee 0.04% ratio-matching and 3ppm/ $^{\circ}C$  MAX matching temperature coefficient. The op amp offers 15 $\mu V$  typical input offset voltage and 50pA of input offset current. The LT1991 operates on supplies from 2.7V to 36V with rail to rail outputs, and remains stable while driving capacitive loads up to 500pF. Gain bandwidth product is

*continued on page 3*

LT1990, LT1991 and LT1995, continued from page 1



**Figure 2. The LT1990, LT1991, and LT1995 are ready-to-use op amps with their own resistors and internal compensation capacitors. Just wire them up.**

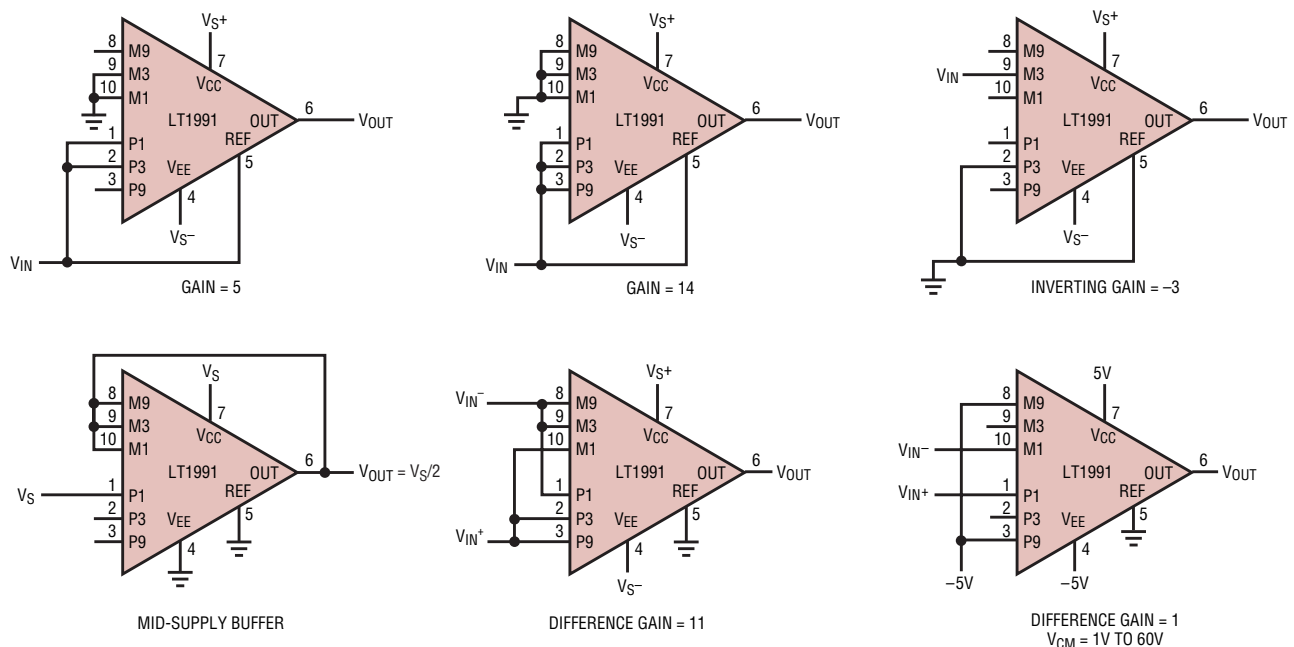
560kHz, while drawing only 100 $\mu$ A supply current.

The resistors are nominally 50k, 150k, and 450k. One end of each resistor is connected to an op amp input, and the other is brought out to a pin. The pins are named “M” or “P” depending on whether its resistor goes to the “minus” or “plus” input, and numbered “M1” M3” or “P9” etcetera

according to the relative admittance of the resistor. So the “P9” pin has 9 times the admittance (or force) of the “P1” pin. The 450k resistors connected to the M1 and P1 inputs are not diode clamped, and can be taken well outside the supply rails,  $\pm 60$ V maximum.

To use the LT1991, simply drive, ground or float the P, M, and REF inputs to set the configuration and gain.

There is a whole series of high input common mode voltage circuits that can be created simply by just strapping the pins. Figure 3 demonstrates the flexibility of the LT1991 with just a few examples of different configurations and gains. In fact, there are over 300 unique achievable gains in the non-inverting configuration alone. Gains



**Figure 3. Non-inverting, inverting, difference amplifiers, and buffered attenuators achieved simply by connecting pins. This illustration shows only a small sample of the op amp configuration circuits possible with the LT1991, all without requiring external resistors.**

of up to 14 and buffered attenuations down to 0.07 are possible.

## The LT1990 for High Input Voltages

The LT1990 has internal components with similar precision to the LT1991, but it is configured for high input voltages, up to  $\pm 250\text{V}$ . The high input voltage capability is achieved by the  $1\text{M}\Omega:40\text{k}\Omega$  attenuation at the inputs, and by careful internal layout and shielding. The LT1990 has two effective gain settings, 1 and 10. A gain of 1 is set by floating the Gain1 and Gain2 pins, and a gain of 10 is set by shorting the Gain1 and Gain2 pins. Bandwidth is  $100\text{kHz}$  in a gain of 1, and  $6.5\text{kHz}$  in a gain of 10. The op amp operates on supplies from  $2.7\text{V}$  to  $36\text{V}$  with rail to rail outputs, on  $105\mu\text{A}$  supply current. Like the LT1991, it remains stable while driving capacitive loads up to  $500\text{pF}$ .

## The LT1995 for High Speed

The LT1995 offers high speed with  $30\text{MHz}$  bandwidth,  $24\text{MHz}$  full power bandwidth and  $1000\text{V}/\mu\text{s}$  slew rate. It works on supplies from  $\pm 2.5\text{V}$  to  $\pm 15\text{V}$  drawing  $7\text{mA}$  supply current. Accuracy is unusually good for a high speed amplifier, with input offset typically  $600\mu\text{V}$  and guaranteed better than  $4\text{mV}$ . It is pinned out identically to the LT1991, but with different resistor ratios and values. The resistors are lower impedance ( $1\text{k}$ ,  $2\text{k}$ , and  $4\text{k}$ ) than those in the LT1991 and LT1990 to support this device's higher speed. They are as high a quality as you should ever need in a high speed application, guaranteeing  $0.25\%$  matching, worst case over temperature. As with the LT1991, the

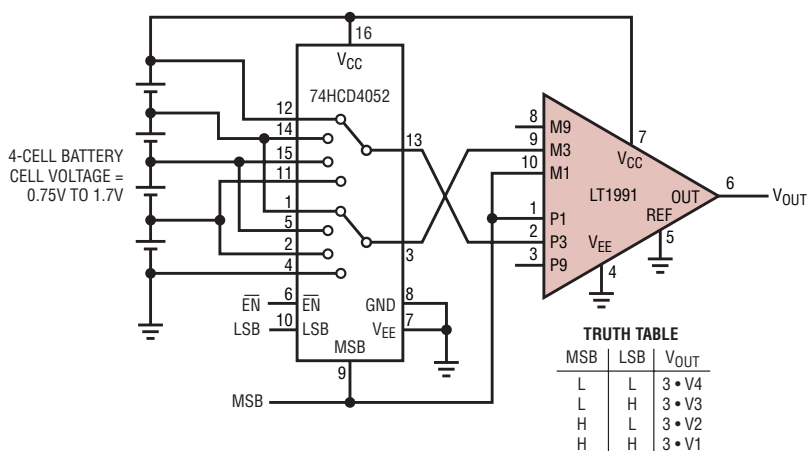


Figure 4. LT1991 applied as an individual battery cell monitor for a 4-cell battery

LT1995 takes its pin names from the relative admittances of their resistors and the amplifier input polarity: hence "M1", "M2", "P4", etcetera. For a difference gain of 6, short the M2 and M4 pins, and short the P2 and P4 pins ( $2 + 4 = 6$ ). In this example, the difference amplifier is formed by the minus input of the shorted M2 and M4 inputs, and the plus input of the shorted P2 and P4 inputs.

## Applications

### Battery Monitor

Many batteries are composed of individual cells with working voltages of about  $1.2\text{V}$  each, as for example NiMH and NiCd. Higher total voltages are achieved by placing these in series. The reliability of the entire battery pack is limited by the weakest cell, so battery designers often like to maintain data on individual cell charge characteristics and histories.

Figure 4 shows the LT1991 configured as a difference amplifier in a gain of 3, applied across the individual

cells of a battery through a dual 4:1 mux. Because of the high valued  $150\text{k}\Omega$  resistors on its M3 and P3 inputs, the error introduced by the multiplexer switch ON-resistance is negligible. As the mux is stepped through its addresses, the LT1991 takes each cell voltage, multiplies it by 3, and references it to ground for easiest measurement. Note that worst case combinations of very different cell voltages can cause the LT1991 output to clip. Connecting the MSB line to the M1 and P1 inputs helps reduce the effect of the wide input common mode fluctuations from cell to cell. The low supply current of the LT1991 makes it particularly suited to battery powered applications. Its  $110\mu\text{A}$  maximum supply current specification is about the same as that of the CMOS mux!

### Single-Supply Video Driver

Most op amps operating from a single supply voltage require several high-quality external resistors to generate a local bias voltage—to optimize the DC

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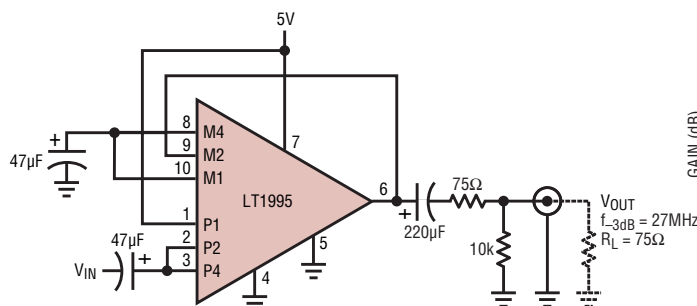
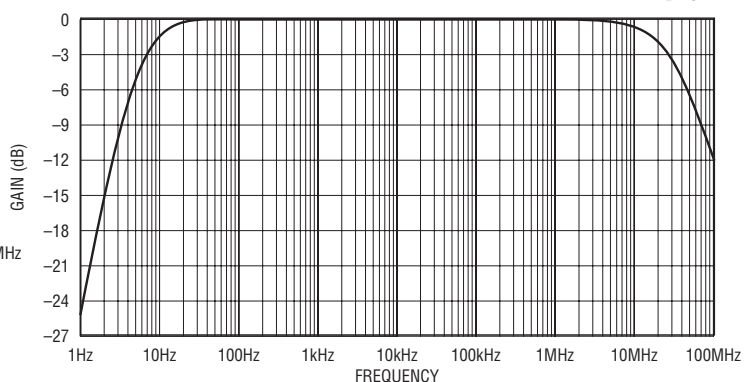


Figure 5. This single-supply composite video output-port driver requires no DC-biasing or gain-setting resistors



## Optimizing for Efficiency


While the LT3461A (boost) and LT3462A (inverting) are optimized for small size, the LT3461 (boost) and LT3462 (inverting) are intended for applications requiring higher efficiencies or high conversion ratios. The lower switching frequencies translate to higher efficiencies because of a reduction in switching losses.

The LT3461 (boost) is guaranteed to a maximum switch duty cycle of 92% in continuous conduction mode, and the LT3462 (inverting) is guaranteed to a maximum switch duty cycle of 90%, which enables high conversion ratios at relatively high output currents.

Although high conversion ratios can also be obtained using discontinuous conduction mode (DCM)—where current in the inductor is allowed to go to zero each cycle—the DCM technique requires higher switch currents and larger inductors/rectifiers than a system operating in continuous conduction mode at the same load current. Because the LT3461 can switch at 1.3MHz in continuous conduction mode with up to 92% switch duty cycle, and the LT3462 at 1.2MHz, 90% duty, they are the most compact solutions available for outputs 5 to 10 times the supply voltage. For example, the LCD bias circuit of Figure 7 provides

18mA at 25V from a 3.3V supply and occupies as little as 50mm<sup>2</sup> of board space. Figure 8 shows that the efficiency of the 25V converter is quite good, peaking at 79% for a 4.2V supply. Figure 9 shows a 3.3V to -25V, 14mA inverter with efficiency above 70% (Figure 10).

## Conclusion

The LT3461, LT3461A, LT3462 and LT3462A provide very compact boost and inverter solutions for a wide input voltage range of 2.5V to 16V, and outputs to  $\pm 38$ V, making these devices a good fit in a variety of applications. 

LTC2923, continued from page 15

rent produces an unacceptable output voltage error.

## Drivers for External, High Current Pass Devices

Table 3 summarizes the characteristics of the LT1575 and LT3150 low dropout regulators. These devices drive external N-channel MOSFET pass devices for high current/high power applications. The LTC3150

additionally includes a boost regulator that generates gate drive for the external FET.


The LTC2923 tracks the outputs of the LT1575 and LT3150 without any special modifications. Because these linear regulators only pull the FET's gate down to about 2.6V, low-threshold FETs may not allow the output to fall below a few hundred millivolts. This is acceptable for most applications. 

Table 3. Drivers for external, high current pass devices

Regulator	I <sub>OUT(MAX)</sub> (V)	V <sub>IN(MIN)</sub> (V)	V <sub>IN(MAX)</sub> (V)	V <sub>DROPOUT</sub> (V)
LT3150	10A*	1.4	10	0.13
LT1575	*	N/A	22	*

\*Depends on selection of external MOSFET

LT1990/91/95, continued from page 4

operating-point—and resistors to set gain. High quality resistors consume precious printed circuit board real estate, and test time. In contrast, the LT1995 provides on-chip resistors for voltage division and gain setting in a highly integrated video-speed op amp.

Figure 5 shows a simple way to drive AC-coupled composite video signals over 75 $\Omega$  coaxial cable using minimum component count. In this circuit, the input resistors form a supply splitter

for biasing and a net attenuation of 0.75. The feedback configuration provides an AC-coupled gain of 2.66, so that the overall gain of the stage is 2.0. The output is AC-coupled and series back-terminated with 75 $\Omega$  to provide a match into terminated video cable and an overall unity gain from signal input to the destination load. An output shunt resistor (10k $\Omega$  in this example) is always good practice in AC-coupled circuits to assure nominal biasing of the output coupling capacitor.

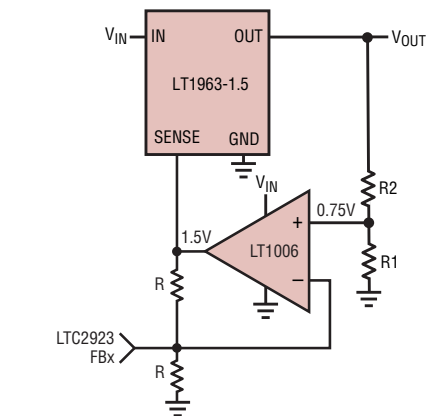


Figure 6. Using an op amp with the LT1963-1.5 allows lower output voltages and removes error due to the SENSE pin current.

Authors can be contacted  
at (408) 432-1900

## Full Bridge Load Current Monitor

Many new motor-drive circuits employ an H-bridge transistor configuration to provide bidirectional control from a single-voltage supply. The difficulty with this topology is that both motor leads “fly,” so current sensing becomes problematic. The LT1990 offers a simple solution to the problem by providing an integrated difference amp structure with an unusually high common-mode voltage rating, up to  $\pm 250$ VDC.