ELECTRONIC DESIGN EXCLUSIVE

# 200-MHz pnp transistors spawn fast analog chips

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Imagine for a moment that the industry-standard CMOS process could produce p-channel transistors operating at no more than 1/200 the speed of their n-channel counterparts. Such a constraint would limit designers to n-channel circuits in any signal path where speed was crucial—even though they could combine n-channel and p-channel transistors elsewhere. Designers of digital systems would still have their wide range of logic functions, but CMOS could never have realized its present potential.

***Three op amps, two buffers, and a unit playing both roles eliminate trade-offs in speed and power. The secret is a fast pnp device.***

That scenario corresponds loosely to a problem that has frustrated analog designers for years: While there have been plenty of inexpensive, speedy bipolar digital chips, analog designers have had to wait for something better. They have settled for trade-offs between speed and common-mode and output voltage range. Bipolar vertical npn transistors sport an $f_T$ of 400 MHz and a beta (current gain) of more than 200, yet lateral pnp transistors have no gain above 2 MHz and a beta of only 20 at a collector current of 1 mA. So although the basic industry-standard bipolar process has produced scores of successful analog products, they are not usually noted for their speed.

Enter the vertically integrated pnp (VIP) process, which builds pnp transistors with an $f_T$ of 200 MHz. In almost every respect—beta, breakdown voltage, and speed—the new transistor is the true complement to the npn. The extra steps that add the pnp devices are no more complex than those for building a biFET (see "Vertical Elegance," p. 112). The transistor's $f_T$, however, is still half that of the npn for the same reason that p-channel MOS devices are slower than n-channel devices—the electrons move two to three times faster than holes.

The first results of the new process do not merely provide circuit designers with some elegant solutions to wideband circuit problems; they also challenge designers to find new uses for their circuits. Three op amps are already at hand, the LM6261, LM6264, and LM6265; they will soon be joined by a pair of buffers, the LM6121 and LM6125, and subsequently by an op amp–buffer, the LM6113. Fast and inexpensive, all these devices use little power, run off a 5-V to ±15 V supply, are easy to use, and come in a variety of packages. The buffers, in addition, are fault-protected.

## SPEED REIGNS

A designer chooses a high-speed op amp over a general-purpose unit for just one reason: speed. Unity-gain stable op amps, by far the most popular today, free the user from worrying about frequency compensation, but are not the fastest way to go. There are uncompensated or decompensated devices that deliver more speed than internally com-

pensated units, although application difficulties hold back their use: The designer has to determine the resistance and capacitance values for proper external compensation. Moreover, if a gain of 1 or 2 is required, he must draw from one family, a gain of 5 or more from a second, and higher gain from a third family. In addition, members of the three families usually bear no physical resemblance to one another. Invariably, they sport different pinouts and package size.

### ALL IN THE FAMILY

In contrast, each of the three pin-compatible VIP op amps handles a different range of closed-loop gain. The LM6261 is stable down to a noise gain of 1 and has a unity-gain bandwidth of 50 MHz. The other two are decompensated internally: The LM6264 has a gain bandwidth of 180 MHz and a closed-loop gain of 5, and the LM6265 has a gain bandwidth of 700 MHz and a gain of 25. All three models have a conservative phase margin of 45° when running at a worst-case, or minimum, gain. All, moreover, have a slew rate of no less than 250 V/$\mu$s and they typically deliver 300 V/$\mu$s.

Unlike other decompensated amplifiers, in which capacitive reduction is used to raise only ac gain, the three VIP op amps use the transconductance boost technique to increase both dc and ac open-loop gains (Fig. 1). In a conventional decompensated op amp, the flat, dc portion of the response curve remains at the same level as that of the unity-gain version of the device, while the sloped ac portion extends farther to the right. But with the VIP op amps, the specified dc gain increases with the specified bandwidth and by the same relative amount.

Why is the relationship between dc gain and bandwidth so important? The loop gain of a finished circuit is defined as the ratio of the op amp's open-loop gain ($A_{OL}$) to the entire circuit's closed-loop gain ($A_{CL}$) at the frequencies of interest. (In decibels, loop gain equals $A_{OL} - A_{CL}$.) Simply put, the greater the loop gain, the more accurate the closed-loop gain—wherein lies the secret of negative feedback.

### EQUAL TO THE TASK

For example, the LM6261 would be equal to the task if a 1-MHz application calls for a closed-loop gain of 5. At 1 MHz, the device has an ac open-loop gain of 50 and an unloaded dc open-loop gain of 5000. The ac and dc loop gains are thus 10 and 1000, respectively (50 and 5000 divided by 5). The LM6264 might be a better choice, how-

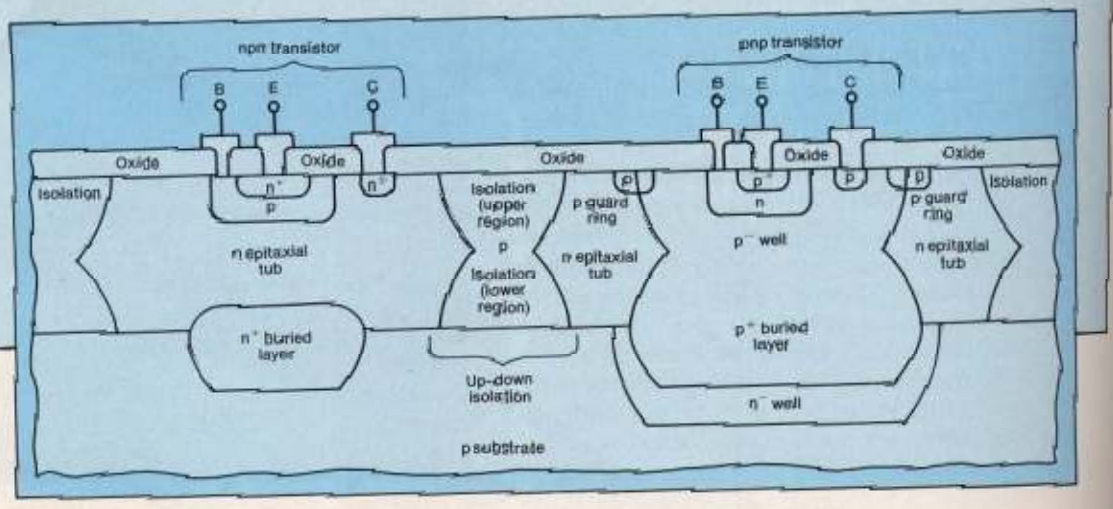
## Vertical elegance

The vertically integrated pnp (VIP) process has a standard p substrate and the usual $n^+$ buried-layer diffusion of the npn transistor. In addition, an $n^-$ well is diffused into the substrate to hold the pnp transistor and isolate it from the substrate. A standard but relatively uncommon $p^+$ isolation-up diffusion forms both the lower portion of the isolation region and the pnp transistor's $p^+$ buried layer. A conventional epitaxial layer is then added.

Next come a conventional p isolation-down diffusion, forming the upper portion of the isolation region, and the $p^-$ well, which becomes the pnp transistor's collector. The $p^+$ buried layer rapidly diffuses up and merges with the $p^-$ well, which is diffusing down. The pnp transistor's material is now completely isolated by the epitaxial tubs from the substrate and from the npn transistor.

The p material's doping levels are controlled to set the pnp transistor's breakdown voltage. The p-type guard rings permit devices to handle 40 V.

Finally, the process steps for the npn and the pnp transistors are interleaved. The base of the pnp transistor is formed first, followed by that of the npn transistor, with the emitter steps following a similar sequence. The guard rings are formed during either of the p diffusions. The process results in complementary profiles and almost complementary electrical characteristics.



ever, because of its ac loop gain of 36, which shoots up to 3600 for dc—a threefold across-the-board improvement just from choosing the right amplifier from a simple chart (Fig. 2). Noise can be the deciding factor in that choice. Regardless of circuit configuration, noise is computed from the same equation:

$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_{in}}$$

In addition, thanks again to transconductance boost, the common-mode and power-supply rejection ratios increase with the op amp's gain bandwidth. At the same time, noise, offset voltage, and offset drift all show a decrease—a welcome effect that prevents offset and noise errors from representing an ever-greater part of the ever-smaller signals feeding the higher-gain circuits.

### ESSENTIAL DESIGN

Besides their pnp transistors, the op amps depend on the good design essential for high-gain, high-speed analog circuits. In the first place, the circuit has only one inverting stage: a differential amplifier that sets the transconductance boost with a pair of resistors. The resistors are placed in series with the two differential-stage input emitters. The transconductance of the differential stage, divided by the compensation capacitance, gives the amplifier's gain bandwidth: The smaller the two resistors, the greater the gain bandwidth.

The differential amplifier, in turn, drives a folded-cascode circuit formed by a pair of VIP transistors, which is the op amp's only stage with voltage gain. Another VIP transistor leads to a high-speed complementary output. The stray capacitance acts as the internal compensation and can be considered as a lumped capacitor, sitting at the junction of the pair of diodes that bias the output stage and the negative supply.

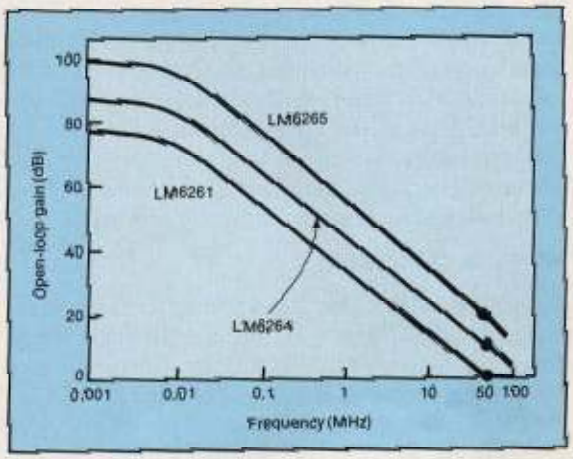
Circuit design and the VIP process combine in other ways to help make these op amps easy to use. Other amplifiers need very low impedances on their supply rails to remain stable, and frequent encounters with those parts could turn a designer into a specialist in lead dressing and power-supply bypassing. But because the internal circuits of the VIP op amps are free of the quirks that plague other kinds, supply bypassing is no more complicated here than for the ubiquitous 741: Simply put a 0.01- to 0.1-$\mu$F capacitor reasonably near each supply pin.

### HANDLING CAPACITIVE LOADS

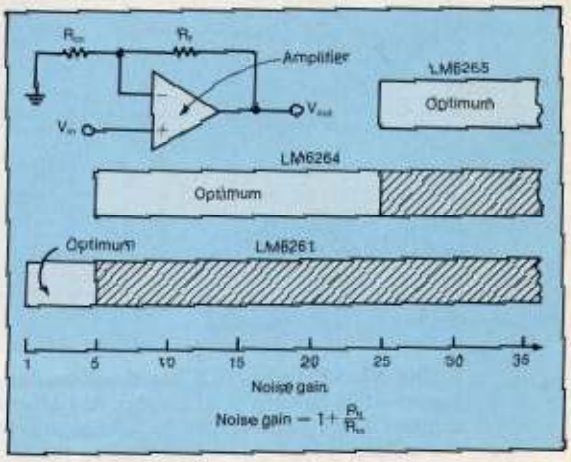
Best of all, driving a capacitive load presents no problems. Whereas other op amps show little tolerance for the output capacitance that leads to oscillation, the new models will not oscillate, just slow down, even with an infinitely large capacitance on the output—for example 10 $\mu$F. Furthermore, this tolerance means that applications with widely varying capacitance do not need extra stability built in.

But what about power consumption? While many fast op amps run too hot to touch, even on a breadboard, the VIP models draw 5 mA from a $\pm$15-V supply, even when slewing at 300 V/$\mu$s and offering gain bandwidths to 700 MHz—a speed-power product no other op amp can touch. The low power and small size mean that they can be put in small-outline packages, whose correspondingly small-scale wiring also improves speed by cutting down parasitic currents. In addition, because of the low power drain, a simple charge-pump circuit can provide a $-$5-V rail from a single $+$5-V supply.

Given their need for power and speed, buffer amplifiers




**1. Op amps built with the new VIP process increase in both ac and dc open-loop gains as their useful bandwidth increases with decompensation. Bode plots of those with the greater gain bandwidths fall both to the right and above those with lower gain. Selecting the right op amp for the job helps keep loop gain constant with frequency, regardless of the required closed-loop circuit gain.**




**2. The most suitable op amp for a particular application can be found by calculating the noise gain of the circuit and choosing the op amp whose optimum area lies above that noise gain.**

benefit even more from the VIP process than do the straight op amps. In most systems, dealing with fast signals on a pc board is one thing. Sooner or later the signals have to come off the board, and that takes cable drivers, also known as buffers. Because cables are handled frequently—and frequently mishandled—they often develop shorts or opens, calling for some form of protection for the cable driver. Devices offering even minimum protection are few and far between; indeed, the industry-standard LH0002 buffer offers none at all.

Buffers now available can present other problems. There are, for example, no guaranteed specifications for driving a 50-Ω load, a frequently encountered situation. Many buffers perform poorly when running from a +5-V rail. A shutdown mode would be useful for battery operation, but no current buffer has that feature. To top it off, standard buffers cost three to ten times more than the VIP kind. All in all, the VIP process might have been devised with buffers particularly in mind, since they require a blazingly fast, class AB output stage—something not easily built without fast complementary transistors.

### MOREOVER, OLD STANDBY

The LM6121 is a general-purpose buffer meant to replace the LH0002 in form and function. But unlike the industry standard, the LM6121 has both current-limiting and thermal-shutdown circuitry. The other new buffer, the LM6125, has similar specifications, but adds external shutdown and an error flag. Both new buffers can drive ±10 V into a 50-Ω load while slewing at 400 V/μs, enough current to ease the driving of capacitive loads.

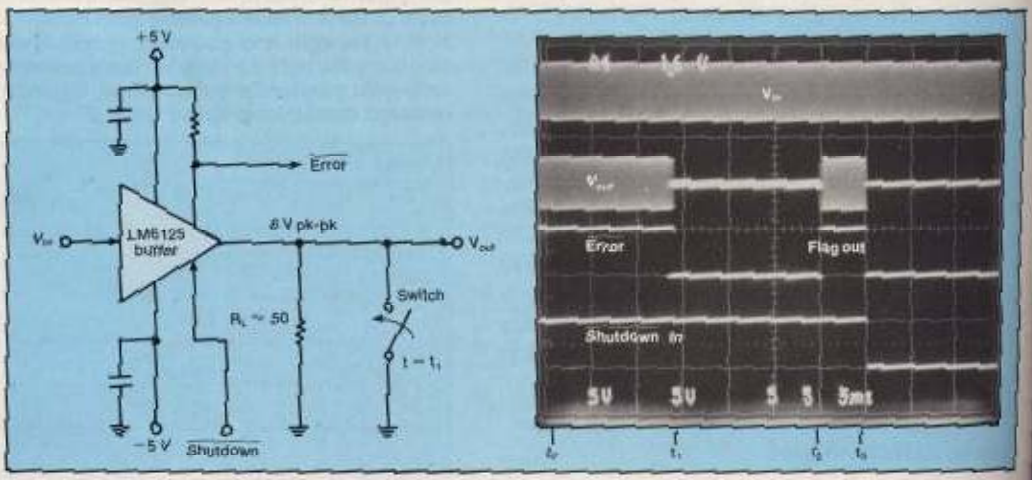
**Price and availability**

Among models currently or soon to be available are commercial-grade versions of the op amps, all costing $1.95 each in quantities of 100. A commercial-grade version of the LM6221 buffer goes for $2.95 and of the LM6125 buffer for $3.95 each, also in lots of 100. Samples of the LM6113 op amp–buffer will also arrive shortly, with production quantities due in early 1987. CIRCLE 501

Running from ±5-V rails, the buffers easily drive a 6-V pk-pk, 10-MHz video signal into 50 Ω, with only 1% total harmonic distortion. Moreover, their protection features ensure that the buffers can take almost any amount of mishandling without damage.

Both buffers have a maximum output current of 300 mA and can operate at up to 160°C. Current limiting takes place on the first cycle and relies on peak clipping rather than foldback to drive reactive loads. The internal thermal limit has 15°C of hysteresis, ensuring that the chip will cool to 150°C before the signal path is restored. The LM6121 protects itself without any outward indications, but the LM6125 reports any "transgressions" by means of an open-collector output, or flag. Host circuitry can thus detect a fault and shut the chip down (Fig. 3).

In taking this warning action, the LM6125 buffer undergoes the following sequence: It drives the 6-V pk-pk signal into a 50-Ω load at time $t_0$, when $\overline{\text{Shutdown}}$ is high. At time $t_1$, the switch closes, shorting the output to ground; the output goes into current limiting and the Error flag goes low. At time $t_2$, the short is removed and the




**3. The LM6125 buffer has good self-protection features. Here, at time $t_0$, it handles a 6 V pk-pk signal while driving a 50-Ω load. At $t_1$, its output is shorted by a switch (second trace); the output current is limited, and the Error flag goes low (third trace). The short is removed at $t_2$, and at $t_3$ the output is shut down by bringing the Shutdown pin low (fourth trace).**

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# ELECTRONIC DESIGN

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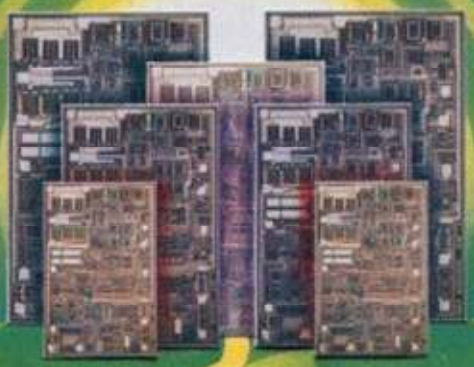

## Vertical pnp transistors pave the way for fast analog ICs