Put BIFETs into your linear circuits.

These mixed-technology monolithic op amps perform so well they leave the standard bipolars far behind.

Complex linear circuits like instrumentation amplifiers, active filters, quadrature oscillators and even demanding high-fidelity amplifiers are only as good as their op amps. Use BIFETs instead of simple bipolar monolithics, and you will improve many of these linear circuits—for practically no additional cost.

BIFETs combine high speed and input impedance with low input offsets, drift, distortion and noise. And so, they bring monolithics much closer to the ever elusive ideal operational amplifier.

The first monolithic op amps fell far short: While they did have good uniformity, they were lacking in input impedance and gain, and were unstable to boot. These negative characteristics were upgraded in bipolar op amps like the 741, 1458 and 301A.

Bipolars had their day

These basic bipolars performed reasonably and for a reasonable price. But low input impedance and slew rate, narrow bandwidth and high input offsets sent designers scurrying to the more expensive hybrid circuits. But hybrids weren't always the answer. Though they usually provided good performance per dollar, often cost blocked high-volume use.

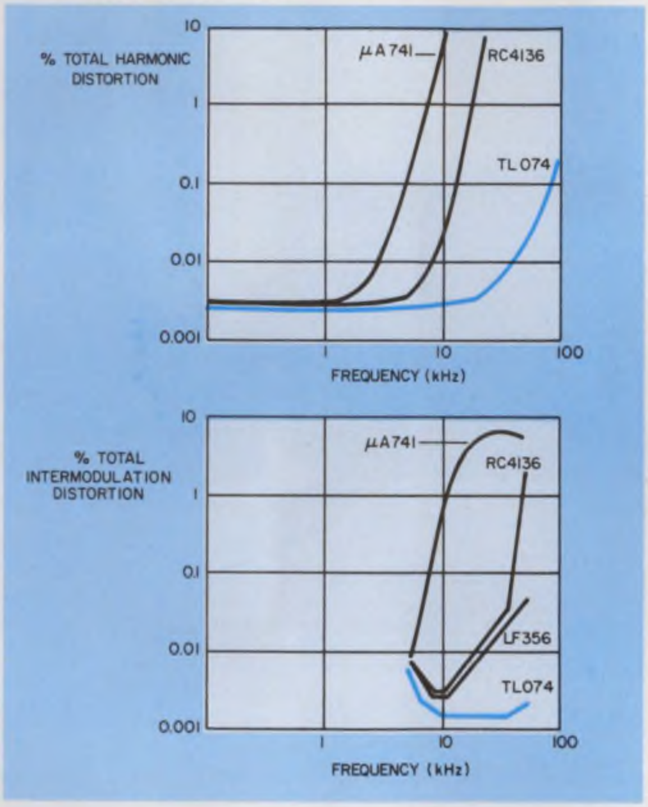
But now that ion implantation has overcome the stumbling block of high input-offset voltage, BIFET op amps outperform their monolithic bipolar counterparts. Important characteristics of some common bipolar and BIFET (and BiMOS) operational amplifiers are compared in Table 1.

General purpose BIFETs are available from National Semiconductor in Santa Clara, and Texas Instruments in Dallas. National currently produces the LF355 and LF356, single op amps which are internally compensated. National also offers the LF13741, which is basically a 741 but with a JFET input stage. A low-cost quad, the LF347, is imminent.

TI has five general-purpose BIFETs: the uncompensated single TL080 and compensated single TL081; the compensated dual TL082 and TL083, and the compensated quad TL084.

Besides general-purpose BIFETs, TI offers low-power units. The single TL061, dual TL062 and quad TL064 draw 250 μA max. And TI's TL066 consumes even less because of its power programming. This op amp can operate on mere microwatts, what's more its supply voltage can go as low as ±1.5 V.

In selecting a BIFET op amp, noise and distortion are usually major considerations. Low distortion and noise are crucial to data multiplexing, transducer preamps, instrumentation amplifiers, medical preamplifiers and high-fidelity amplifiers. Op amps with



1. **The BIFET TL074 boasts less distortion,** both harmonic and intermodulation, than common bipolar op amps.

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Table 1. Characteristics of common monolithic op amps

		Device	r_i (typ) Input impedance (Ω)	I_{ib} (max) Input-bias current (nA)	V_{io} (max) Input-offset voltage (mV)	I_{io} (max) Input-offset current (nA)	B_1 (typ) Unity-gain bandwidth (MHz)	S_r (typ) Slew rate (V/μs)	I_{cc} (max) Supply current (each amplifier) (mA)
Single	Uncompensated	TL080C	10^{12}	0.4	15	0.2	3	13	2.8
		TL080AC	10^{12}	0.2	6	0.1	3	13	2.8
		CA3130	1.5×10^{12}	0.05	15	0.03	4	10	15
		LM301A	2×10^6	250	7.5	50	1	0.5	3
		LM308	4×10^7	7	7.5	1	1	0.3	0.8
		μA748	2×10^6	500	6	200	1	0.5	2.8
	Compensated	TL081C	10^{12}	0.4	15	0.2	3	13	2.8
		TL081AC	10^{12}	0.2	6	0.1	3	13	2.8
		TL071C	10^{12}	0.2	10	0.05	3	13	2.5
		TL071AC	10^{12}	0.2	6	0.05	3	13	2.5
		TL061C	10^{12}	0.4	15	0.05	1	3.5	0.25
		TL061AC	10^{12}	0.2	6	0.05	1	3.5	0.25
		LF13741	5×10^{11}	0.2	15	0.05	1	0.5	4
		CA3140	1.5×10^{12}	0.05	15	0.03	4.5	9	5.5
		CA3160	1.5×10^{12}	0.05	15	0.03	4	10	15
		LF355	10^{12}	0.2	10	0.05	2.5	5	4
		LF356	10^{12}	0.2	10	0.05	5	12	10
		LF351	5×10^{11}	0.2	10	0.05	5	13	4
		μA741	2×10^6	500	6	200	1	0.5	2.8
		LM307	2×10^6	250	7.5	50	1	0.5	3
Dual-compensated		TL082C	10^{12}	0.4	15	0.2	3	13	2.8
		TL082AC	10^{12}	0.2	6	0.1	3	13	2.8
		TL072C	10^{12}	0.2	10	0.05	3	13	2.5
		TL072AC	10^{12}	0.2	6	0.05	3	13	2.5
		TL062C	10^{12}	0.4	15	0.05	1	3.5	0.25
		TL062AC	10^{12}	0.2	6	0.05	1	3.5	0.25
		MC1458	2×10^6	500	6	200	1	0.5	2.8
		RC4558	5×10^6	500	6	200	3	1	2.8
		μA747	2×10^6	500	6	200	1	0.5	2.8
Quad-compensated		TL084C	10^{12}	0.4	15	0.2	3	13	2.8
		TL084AC	10^{12}	0.2	6	0.1	3	13	2.8
		TL074C	10^{12}	0.2	10	0.05	3	13	2.5
		TL074AC	10^{12}	0.2	6	0.05	3	13	2.5
		TL064C	10^{12}	0.4	15	0.05	1	3.5	0.25
		TL074AC	10^{12}	0.2	6	0.05	1	3.5	0.25
		LF347	10^{12}	0.2	10	0.05	5	15	2.8
		MC3471	10^{12}	0.2	6	0.02	10	20	10
		MC4741C	2×10^6	500	6	200	0.8	0.5	1.75
		LM324	2×10^6	250	7	50	1	0.5	3
		RC4136	5×10^6	500	6	200	3	1	2.8

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a high slew rate can considerably reduce a system's harmonic and intermodulation distortion totals.[1] To this end, TI's TL081 general-purpose and TL071 low-noise series boast 13-V/μs slew rates. The result is a harmonic distortion of less than 0.01% at 10 kHz. As Fig. 1 illustrates, the high slew-rate TL074 has the lowest total harmonic and intermodulation distortion of the popular op amps.

BIFETs hold down the noise

Op amps must contend with three kinds of noise: burst, broadband and root-hertz. For each category, BIFET levels are lower than or comparable to those of the bipolar "jelly beans."

BIFETs reduce the burst or "popcorn" noise that can be a nightmare in audio, data-acquisition, instrumentation and preamp work. These rail-to-rail jolts are related to input-stage contamination. Though other factors may affect burst noise, generally the IC design isn't the culprit. Clean IC processing has reduced burst noise in many monolithic op amps. Passivation has also helped. But in BIFETs, burst noise is reduced even further because of the inherently clean ion-implantation process for the JFETs.

The JFET input stage would ordinarily spell caution to designers concerned with broadband, or reciprocal-frequency (l/f) noise. FETs are notoriously noisy in the broadband range. But BIFETs draw low input-bias current, which lowers the equivalent input noise in accordance with the following relation for the broadband-noise spectral density:

$$\xi_x(\omega) = kI^\alpha / \omega^\beta,$$

where I is the dc through the device, ω is the radian frequency and k, α and β are constants ($\alpha \approx 2$, $\beta \approx 1$).

Root-hertz noise is expressed in $nV/\sqrt{Hz}$ and is usually specified at spot frequencies from 10 Hz to 100 kHz. The level of this noise is typically 10 times higher at 10 Hz than it is at 1 kHz but it remains relatively flat from 1 to 100 kHz. For designs in which root-hertz noise must be minimal, the low-noise TL071 (single), TL072 (dual) and TL074 (quad) BIFETs boast, at 1 kHz, 18 $nV/\sqrt{Hz}$, as opposed to 47 for the noisier general-purpose TL081 BIFETs.

BIFETs measure up for instrumentation

Low noise and minimal distortion are important in instrumentation amplifiers, which amplify differential ac or dc signals precisely. Such amplifiers also require high common-mode rejection and high input impedance. Even with BIFET op amps, instrumentation amplifiers still aren't perfect. But as Table 2 shows, a TL081 BIFET op amp outshines the widely used bipolar 741s in this application.

Examine the 100-V common-mode instrumentation amplifier in Fig. 2. Here, the design depends on the BIFET op amp's low input-bias current. The TL080A accepts high-value input resistors. The input-bias currents are so low that the input resistors do not appreciably affect the offset voltage or circuit balance.

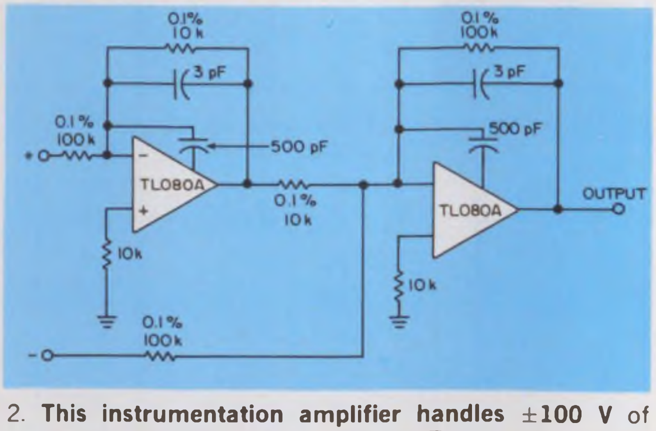
Another instrumentation amplifier, the circuit in Fig. 3, uses high-value input resistors to minimize source reflections. In this differential-input variable-gain circuit, as in the circuit in Fig. 2, low input-bias current produces low input-offset voltages, despite the high resistances in the input leads.

The TL071s at the input assure low noise. Offset controls connected to the TL081B, the output-buffer amplifier, provide the circuit adjustments. The TL080 is the heart of an active-feedback circuit that controls the amplifier's over-all gain and frequency response. The external components set the total bandwidth.

If the instrumentation amplifiers in Figs. 2 and 3 were to use bipolar op amps instead of BIFETs, the resulting circuits would have less capability. For example, the bipolar versions would have power bandwidths of only 60 kHz, compared to 1 MHz for the BIFET circuits. The input impedance with bipolars would be 4 MΩ, vs 10^{12} Ω with BIFETs. What's more,

Table 2. BIFET vs bipolar op amps

Characteristic	741	TL081
Input impedance	2×10^6 Ω	10^{12} Ω
Input-bias current	500 nA	0.4 nA
Input-offset current	200 nA	0.2 nA
Unity-gain bandwidth	1 MHz	3 MHz
Slew rate	0.5 V/μs	13 V/μs
Total harmonic distortion	0.01% to 2 kHz	0.01% to 35 kHz
Power bandwidth	10 kHz	100 kHz

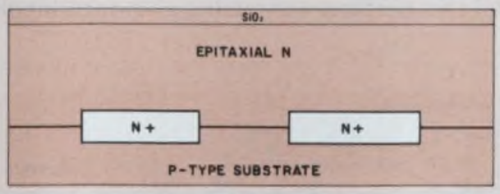


2. **This instrumentation amplifier handles ±100 V** of common-mode signal. Also, the BIFETs provide a power bandwidth of 1 MHz at a gain of 10, plus the BIFET specialty —an input impedance of 10^{12} Ω.

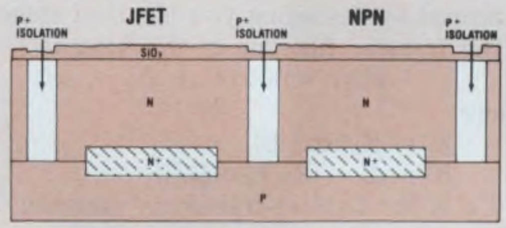
Ion implantation: The cornerstone of the BIFET process

Ion implantation is the great difference between BIFET and standard bipolar processing. In BIFETs, both p-type and n-type ions are implanted into the wafer. Because the ion implantation between the drain and source of the JFETs is so precise, the resulting FET pairs (input stage) are closely matched.

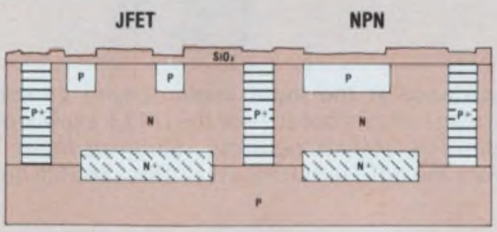
The ion-implanted FETs provide very high input impedance, controlled pinch-off voltage for maximum common-mode-input range, and matched input characteristics for low input-offset voltage. The JFETs also deliver adequate drive to the second stage for maximum pk-pk output and wide power bandwidth.



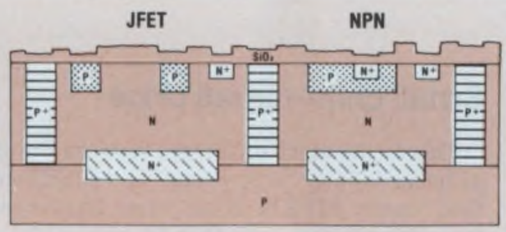
To start, n^+ is diffused into the substrate's n-type epitaxial layer:



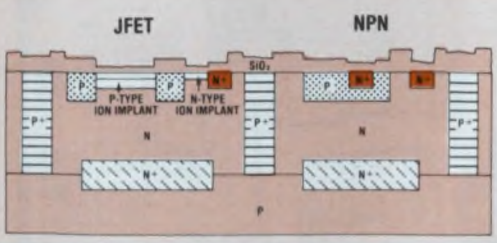
Then p^+ is diffused into the epitaxial layer. These p^+ areas separate the chip's JFET and bipolar sections:



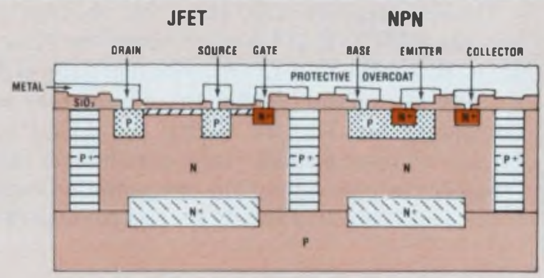
Next, p-type diffusion forms the JFET drains and sources as well as the bipolar bases:



The n^+-type diffusion forms the JFET gates plus the bipolar emitters and collectors:



Now comes the crucial step—both p-type and n-type ion implants form the JFET gates.



To end the process, the electrodes are metalized and a protective coating is applied over-all.

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with the same 10-times gain, bipolar input-bias currents would produce greater offset voltages.

BIFETs activate filter designs

Precise active filters—whether low-pass, high-pass, bandpass or notch—can make circuit designers cringe—especially filters for kHz center frequencies. With standard bipolar op amps, active filters often have problems with input impedance, bandwidth, crossover and harmonic distortions as well as speed. Fortunately, a BIFET op amp like the TL074 can often defuse active-filter design problems.

For example, consider the positive-feedback bandpass filter (Fig. 4a) whose Q and gain have been improved by cascading two identical stages.

The transfer function of the filter is

$$H(s) = Ks/(s^2 + Bs + \omega_0^2)$$

where

$$K = R_4/(R_1^2\ C),$$

$$B = (2 - R_4/R_3)/(R_1C)$$

and s is the Laplace-transform variable.

The center frequency is figured by

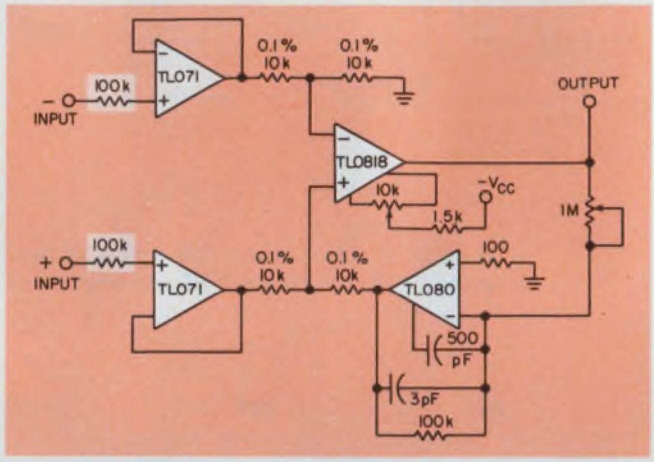
$$f_0 = \sqrt{1/R_1^2 + 1/(R_1R_2) + 1/(R_1R_3)}/2\pi C.$$

The Q of the filter can be increased, without appreciably changing f_0, either by cascading additional filter stages or by varying the value of R_4.

The output of a single filter stage, e_i, has a Q of 30 and a gain of 4 (Fig. 4b). The cascade output, e_0 (Fig. 4c), has a Q of 69 and a gain of 16. And all this performance is at a 100-kHz center frequency, thanks to a TL074 BIFET.

Often, a quadrature oscillator, a fixed-frequency circuit that provides both sine and cosine outputs, must combine low distortion with stable amplitude, phase and frequency. In addition, both outputs must often have equal amplitude.

To get all this performance using standard bipolar



3. **High resistance at the input leads** doesn't generate excessive voltage offsets because of the BIFET's low input-bias current. The 100-kΩ resistors minimize input reflections from the differential inputs of this variable amp.

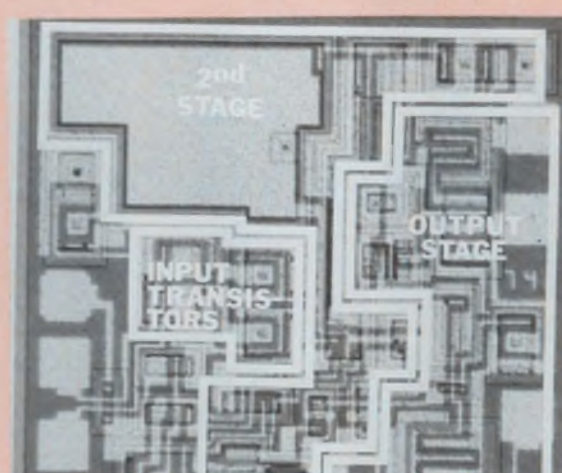
Small chip—small price

There's not much difference between the processing of linear bipolar "jelly beans" and BIFET devices. In fact, many BIFETs come from bipolar-production lines. What's more, the BIFET's relatively small chip suits high-volume production. Not surprisingly, then, BIFETs cost only slightly more to manufacture than the most economical of the bipolars.

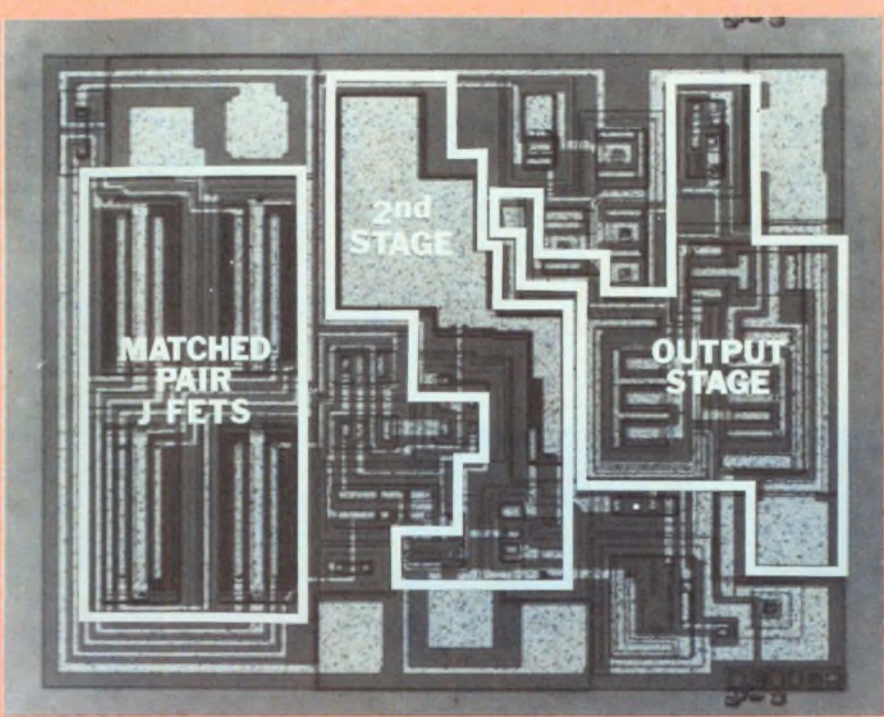
As a result, BIFET op amps are priced close to the most popular bipolar, the 741. These "jelly-bean" prices wouldn't be possible without high yields. A maxim from the early days of bipolar ICs still holds—the smaller a device, the more good chips from each slice. And this greater yield means lower cost.

The scale reproductions show that the bipolar 741 and the BIFET TL081 occupy about the same chip areas. By contrast the LF355, with four pairs of FETs, spreads over about double the silicon real estate. Comparing the 741, the TL081 and LF355 is fair because all three op amps have space-hungry internal frequency compensation. The compensation capacitor is the large metalized area in the second stage of each.

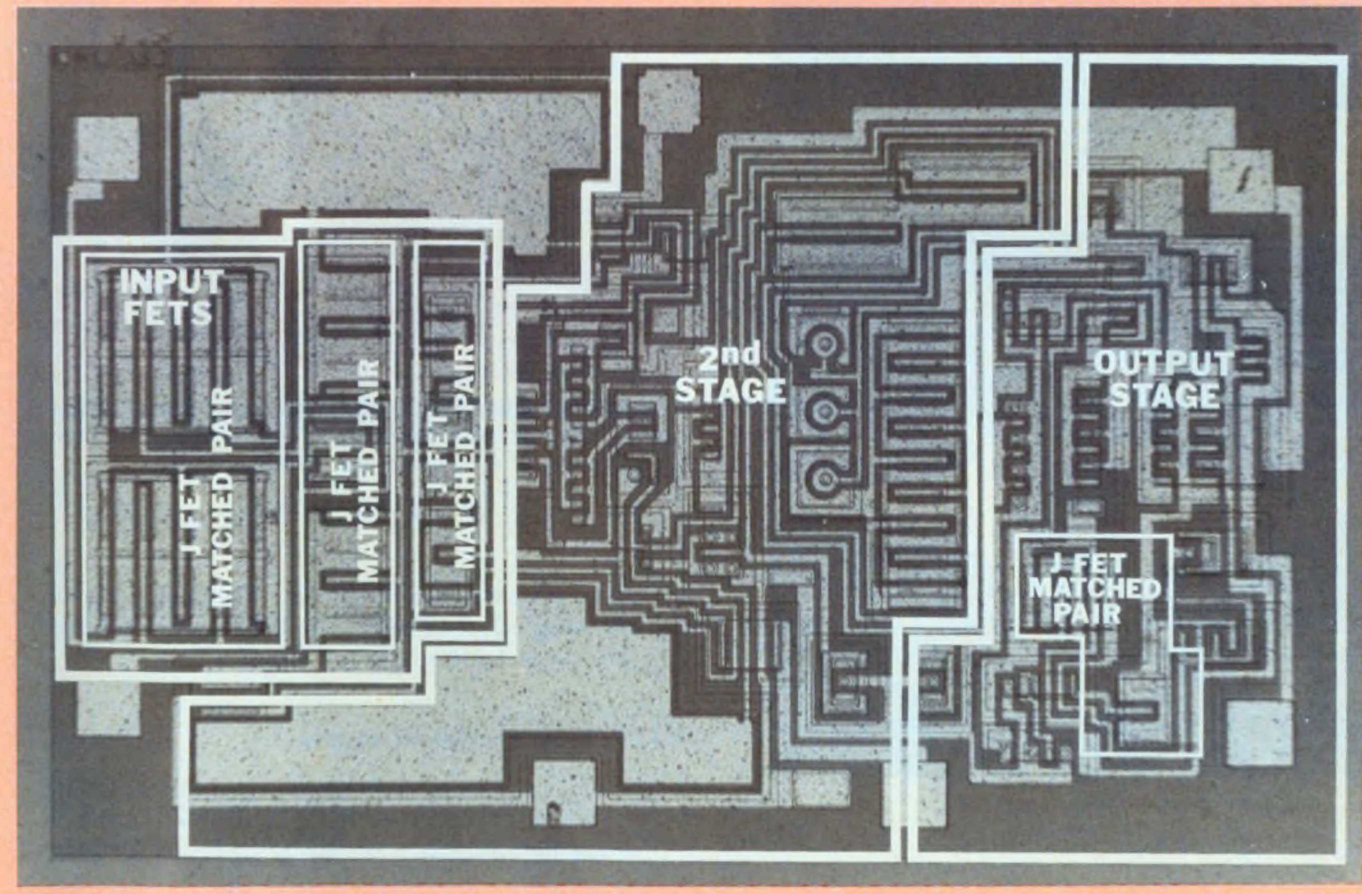
μA741



TL081


MATCHED PAIR J FETS
2nd STAGE
OUTPUT STAGE

LF355


INPUT FETS
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2nd STAGE
OUTPUT STAGE
J FET MATCHED PAIR

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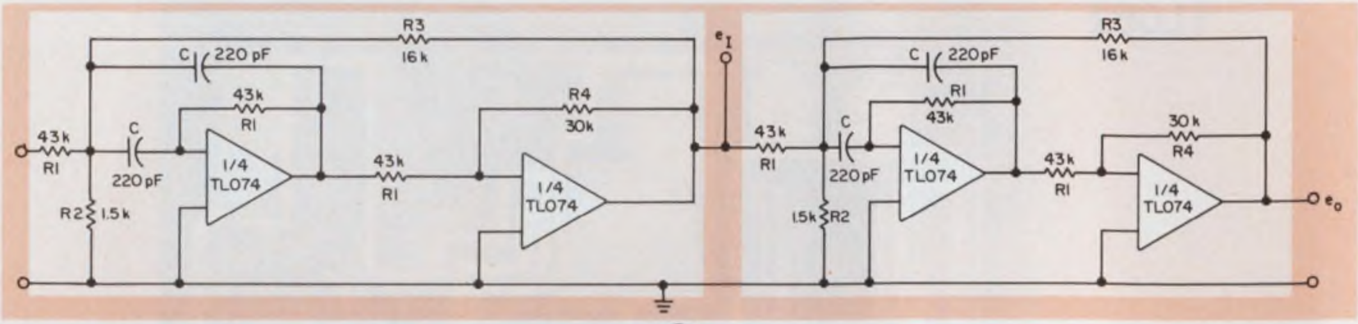
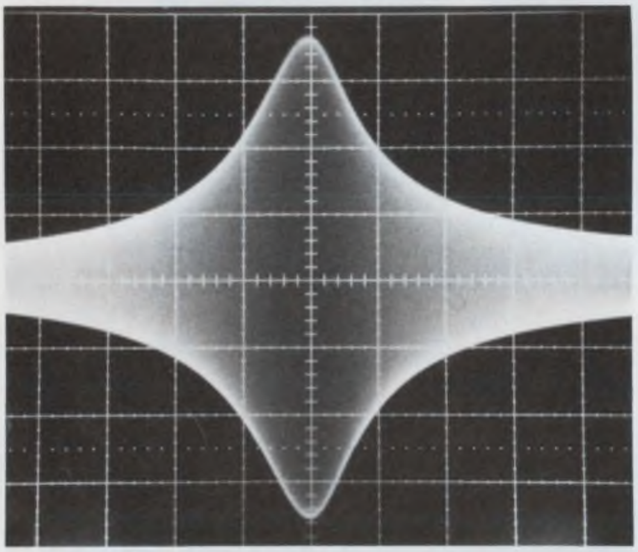
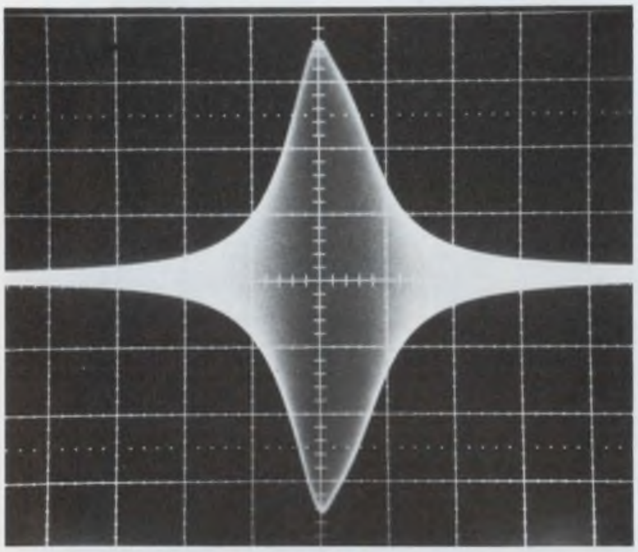


(a)

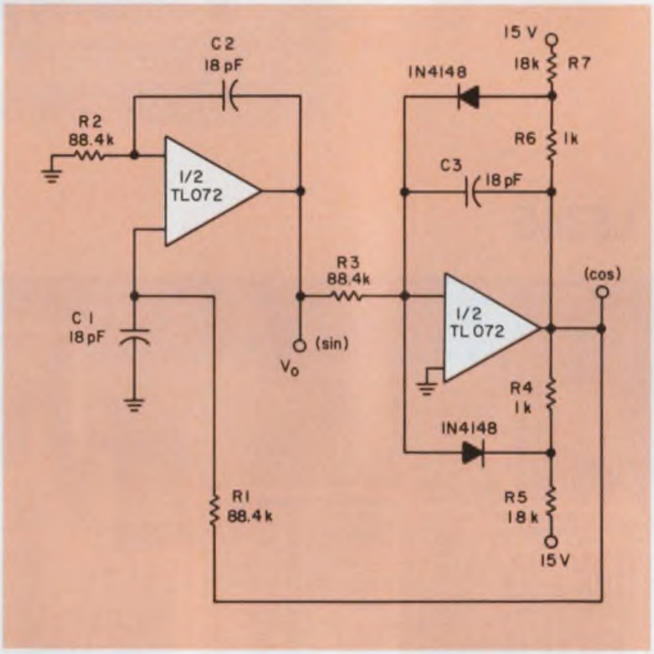


(b)



(c)

4. **BIFETs ensure stable operation at 100 kHz** for this cascade of two positive-feedback bandpass filter sections (a). The Q of 30 and the gain of 4 for each section (b) compound into a Q of 69 and a gain of 16 (c).



5. **Stable operation at 100 kHz** from this precision quadrature oscillator is due to the BIFETs. Only R_5 and R_7 must be trimmed for a symmetrical output.

op amps, a quadrature oscillator's frequency would have to stay below 10 kHz. But BIFETs extend this range to over 1 MHz, comfortably.

BIFETs keep oscillators steady

The wide bandwidth, high input impedance and slew rate, and low distortion of BIFETs enable the quadrature oscillator in Fig. 5 to operate stably at 100 kHz. A regenerative integrating loop is used to solve for v_o in the following differential equation:

$$\delta^2 \, v_o/(\delta t^2 + \omega_o^2 \, v_o) = 0.$$

The solution is

A typical BIFET circuit

On one chip, BIFET op amps combine high-impedance FET inputs with low-distortion bipolar-output circuitry. The result is performance previously available from hybrid devices only.

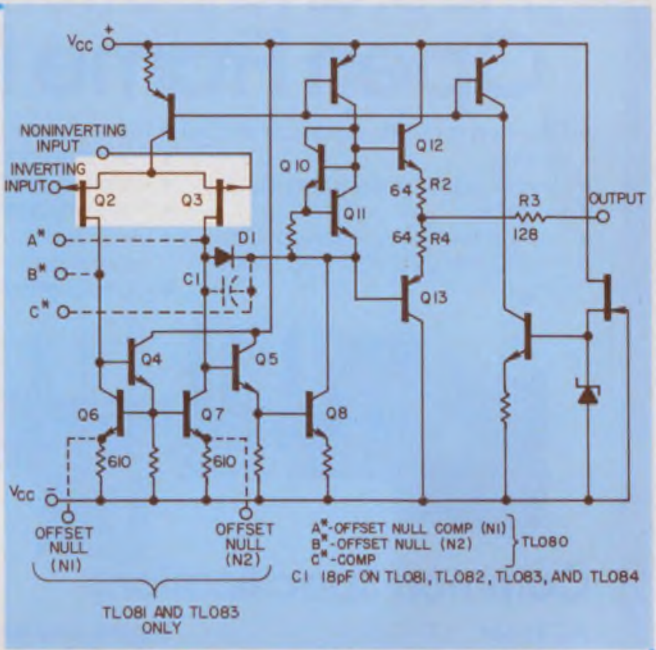
Consider TI's TL080 and TL081 (singles), TL082 and TL083 (duals) and TL084 (quad) BIFET op amps. As the family schematic shows, each op amp uses only two FETs—those at the very input. This stinginess minimizes chip size and FET matching. The result—high yields.

As the schematic also shows, the input stage consists of JFETs Q_2 and Q_3, which operate into the active load of Q_4, Q_5, Q_6 and Q_7. Current imbalance and input-offset voltage can be adjusted on the 081 and 082 via connections to the emitters of Q_6 and Q_7. Devices 081 through 084 contain compensation capacitors (C_1). The 080 can be compensated externally.

Each JFET provides 10^{12} Ω of typical input impedance and a high common-mode input-voltage range. Matching the two JFETs results in low input-offset voltage. Also, the JFETs drive the second stage hard enough to get a high pk-pk output voltage and a wide power bandwidth.

The collector of Q_7 drives the second stage. Here the clamp, D_1, across Q_5 and Q_8 prevents saturation of Q_8 and excessive current in Q_5. Bipolars Q_5 and Q_8 form the high-gain second stage. The collector Q_8 drives the output stage consisting of bias transistors Q_{10} and Q_{11} and output drivers Q_{12} and Q_{13}.

Output transistors Q_{12} and Q_{13} get their Class AB bias from Q_{10} and Q_{11}. The result is near-zero crossover distortion and low total-harmonic distortion at the output. The output is protected from short circuits by the R_2, R_3 and R_4 network.



$$v_o = A \sin(\omega_o t + \Theta),$$

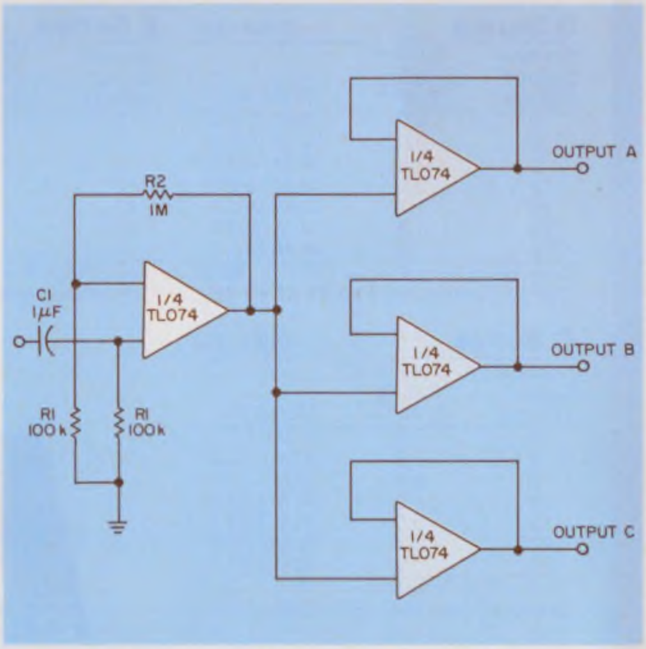
in which Θ is the phase angle.

For equal time constants

$$(\tau_1 \equiv R_1C_1 = \tau_2 \equiv R_2C_2 = \tau_3 \equiv R_3C_3),$$
$$f_o = 1/(2\pi RC).$$

A tradeoff must be made between amplitude limiting and distortion in this circuit. While the amplitude is limited by making τ_1 greater than τ_2, the difference should be only slight because the mismatch between these time constants also determines the degree of distortion in the output.

Still another circuit that can benefit from BIFETs is an audio-distribution amplifier. Using only one BIFET quad, the audio-distribution amplifier in Fig. 6 boasts a 100-kΩ input impedance, low distortion and flat frequency response over the entire audio range. The BIFET gives this audio circuit the versatility to buffer a microphone input, distribute audio signals throughout a studio or form the heart of an intercom system.■■



6. **Process audio signals** with 100-kΩ input impedance plus low distortion and noise over the full audio bandwidth, with only one BIFET quad.

Reference

1. Jung, Walter G.; Stephens, Mark L.; and Todd, Craig C., "Slewing Induced Distortion in Audio Amplifiers," *The Audio Amateur*, Peterborough, NH, 1977.