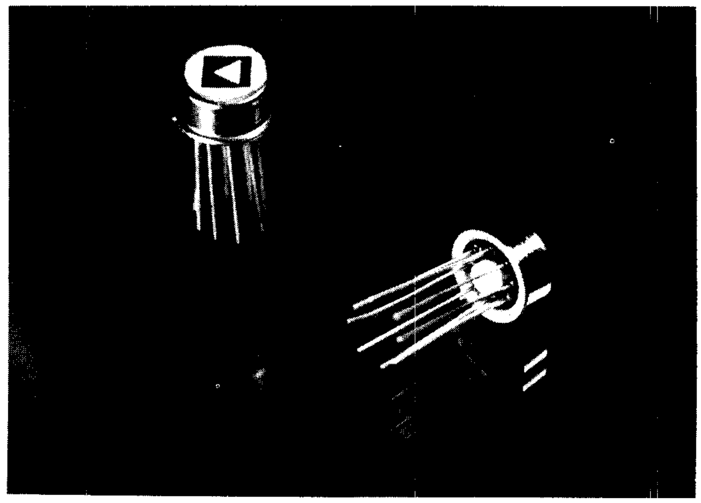
ANALOG DEVICES

High Accuracy IC Operational Amplifier

AD504

FEATURES
Low V_{OS}: 500μV max (AD504M)
High Gain: 10^6 min (AD504L, M, S)
Low Drift: 0.5μV/°C max (AD504M)
Free of Popcorn Noise



PRODUCT DESCRIPTION

The Analog Devices AD504J, K, L, M and S are the first IC operational amplifiers to provide ultra-low drift and extremely high gain comparable to that of modular amplifiers and the frequency response and slew rate of general purpose IC op amps. A new double integrator circuit concept combined with a precise thermally balanced layout achieves gain greater than 10^6, offset voltage drift of less than 1μV/°C, small signal unity gain bandwidth of 300kHz, and slew rate of 0.12V/μs. Because of monolithic construction, the cost of the AD504 is significantly below that of modules, and becomes even lower with larger quantity requirements. The amplifier is externally compensated for unity gain with a single 470pF capacitor; no compensation is required for gains above 500. The inputs are fully protected, which permits differential input voltages of up to $\pm V_S$ without voltage gain or bias current degradation due to reverse breakdown. The output is also protected from short circuits to ground and/or either supply voltage and is capable of driving 1000pF of load capacitance. The AD504J, K, L and M are supplied in the hermetically sealed TO-99 package and are specified for operation over the 0 to +70°C temperature range. The AD504S is specified over the -55°C to +125°C temperature range.

PRODUCT HIGHLIGHTS

1. Fully guaranteed and 100% tested 1μV/°C maximum voltage drift combined with voltage offset of 500μV (AD504L).
2. Fully protected input ($\pm V_S$) and output circuitry. The input protection circuit prevents offset voltage and bias current degradation due to reverse breakdown, and is of critical importance in this type of device whose overall performance is strongly dependent on front-end stability.
3. Single capacitor compensation eliminates elaborate stabilizing networks while providing flexibility not possible with an internally compensated op amp. This feature allows bandwidth to be optimized by the user for his particular application.
4. High gain is maintained independent of offset nulling, power supply voltage and load resistance.
5. Bootstrapping of the critical input transistor quad produces CMRR and PSRR compatible with the tight 1μV/°C drift. CMRR and PSRR are both in the vicinity of 120dB.
6. Noise performance is closely monitored at Outgoing QC to insure compatibility with the low error budgets afforded by the performance of all other parameters.
7. Every AD504 is stored for 48 hours at 200°C, temperature cycled 10 times from -65°C to +200°C and subjected to a high G shock test to assure reliability and long term stability.
8. The 100 piece price of the AD504 is 1/3 to 1/2 less than that of modular low drift operational amplifiers and is competitive with the price of less accurate IC op amps.

SPECIFICATIONS (typical @ +25°C and ±15V dc unless otherwise noted)

PARAMETER	AD504J	AD504K	AD504L
OPEN LOOP GAIN			
V_{OS} = ±10V, $R_L \geq 2k\Omega$	250,000 min (4 x 10^6 typ)	500,000 min (4 x 10^6 typ)	10^6 min (8 x 10^6 typ)
@ T_A = 0 to +70°C	125,000 min (10^6 typ)	250,000 min (10^6 typ)	500,000 min (10^6 typ)
OUTPUT CHARACTERISTICS			
Voltage at $R_L \geq 2k\Omega$, T_A = 0 to +70°C	±10V min (±13V typ)	*	*
Load Capacitance	1000pF	*	*
Output Current	10mA min	*	*
Short Circuit Current	25mA	*	*
FREQUENCY RESPONSE			
Unity Gain, Small Signal, C_c = 390pF	300kHz	*	*
Full Power Response, C_c = 390pF	1.5kHz	*	*
Slew Rate, Unity Gain, C_c = 390pF	0.12V/μs	*	*
INPUT OFFSET VOLTAGE			
Initial Offset, $R_S \leq 10k$	2.5mV max (0.5mV typ)	1.5mV max (0.5mV typ)	0.5mV max (0.2mV typ)
vs Temp, T_A = 0 to +70°C, V_{OS} nulled	5.0μV/°C max (0.5μV/°C typ)	3.0μV/°C max (0.5μV/°C typ)	1.0μV/°C max (0.3μV/°C typ)
T_A = 0 to +70°C, V_{OS} unnulled†	10μV/°C max (1.5μV/°C typ)	5.0μV/°C max (1.5μV/°C typ)	2.0μV/°C max (1.0μV/°C typ)
vs Supply	25μV/V max	15μV/V max	10μV/V max
@ T_A = 0 to +70°C	40μV/V	25μV/V max	15μV/V max
vs Time	20μV/mo	15μV/mo	10μV/mo
INPUT OFFSET CURRENT			
@ T_A = 25°C	40nA max	15nA max	10nA max
INPUT BIAS CURRENT			
Initial	200nA max	100nA max	80nA max
T_{min} to T_{max}	300nA max	150nA max	100nA max
vs Temp, T_{min} to T_{max}	300pA/°C	250pA/°C	200pA/°C
INPUT IMPEDANCE			
Differential	0.5MΩ	1.0MΩ	1.3MΩ
Common Mode	100MΩ‖4pF	*	*
INPUT NOISE			
Voltage, 0.01 to 10Hz	1.0μV (p-p)	*	*
100Hz	10nV/$\sqrt{Hz}$(rms)	*	*
1kHz	8nV/$\sqrt{Hz}$(rms)	*	*
Current, 0.01 to 10Hz	50pA(p-p)	*	*
100Hz	0.6pA/$\sqrt{Hz}$(rms)	*	*
1kHz	0.5pA/$\sqrt{Hz}$(rms)	*	*
INPUT VOLTAGE RANGE			
Differential or Common Mode, Max Safe	$\pm V_S$	*	*
Common Mode Rejection, V_{IN} = ±10V	94dB min (120dB typ)	100dB min (120dB typ)	110dB min (120dB typ)
POWER SUPPLY			
Rated Performance	±15V	*	*
Operating	±(5 to 18)V	*	*
Current, Quiescent	±4.0mA max (±1.5mA typ)	±3.0mA max (±1.5mA typ)	±3.0mA max (±1.5mA typ)
TEMPERATURE RANGE			
Operating, Rated Performance	0 to +70°C	*	*
Storage	-65°C to +150°C	*	*

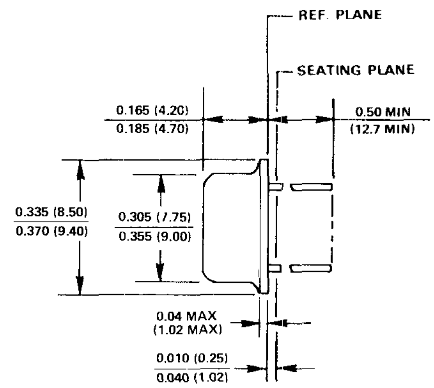
*Specifications same as for AD504J.
†This parameter is not 100% tested. Typically, 90% of the units meet this limit.
Specifications subject to change without notice.

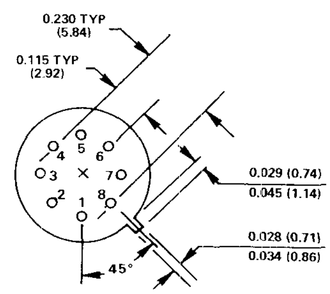
NOTE
Analog Devices 100% tests and guarantees all specified maximum and minimum limits. Certain parameters, because of the relative difficulty and cost of 100% testing, have been specified as "typical" numbers. At ADI, "typical" numbers are subjected to rigid statistical sampling and outgoing quality control procedures, resulting in "typicals" that are indicative of the performance that can be expected by the user.

AD504M	AD504S
10^6 min (8 x 10^6 typ)	10^6 min (8 x 10^6 typ)
500,000 min (10^6 typ)	250,000 min
*	*
*	*
*	*
*	*
*	*
*	*
*	*
0.5mV max (0.2mV typ)	0.5mV max
0.5μV/°C max (0.2μV/°C typ)	1.0μV/°C max (0.3μV/°C typ)
1.0μV/°C max (0.5μV/°C typ)	2.0μV/°C max (1.0μV/°C typ)
10μV/V max	10μV/V max
15μV/V max	20μV/V max
10μV/mo	10μV/mo
10nA max	10nA max
80nA max	80nA max
100nA max	200nA max
200pA/°C	200pA/°C
1.3MΩ	1.3MΩ
*	*
0.6μV (p-p) max	*
10nV/$\sqrt{Hz}$ max	*
9nV/$\sqrt{Hz}$ max	*
1.3pA/$\sqrt{Hz}$ max	*
0.6pA/$\sqrt{Hz}$ max	*
0.3pA/$\sqrt{Hz}$ max	*
*	*
110dB min (120dB typ)	110dB min (120dB typ)
*	*
*	*
±3.0mA max (±1.5mA typ)	±3mA max (±1.5mA typ)
*	-55°C to +125°C
*	-65°C to +150°C

OUTLINE DIMENSIONS

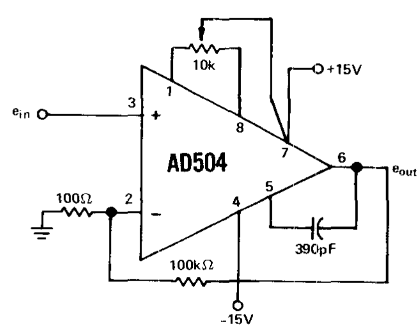
Dimensions shown in inches and (mm).





TO-99

PIN CONNECTIONS



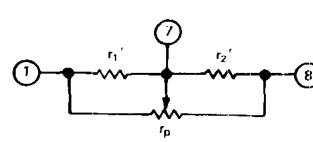


Figure 1. High Resolution, High Stability Nulling Circuit

DYNAMIC PERFORMANCE

The dynamic performance of the AD504, although comparable to most general purpose op amps, is superior to most low drift op amps. Figure 2 shows the small signal frequency response for both open and closed loop gains for a variety of compensating values. Note that the circuit is completely stable for C_C = 390pF with a -3dB bandwidth of 300kHz; with C_C = 0, the -3dB bandwidth is 50kHz, at a gain of 2000.

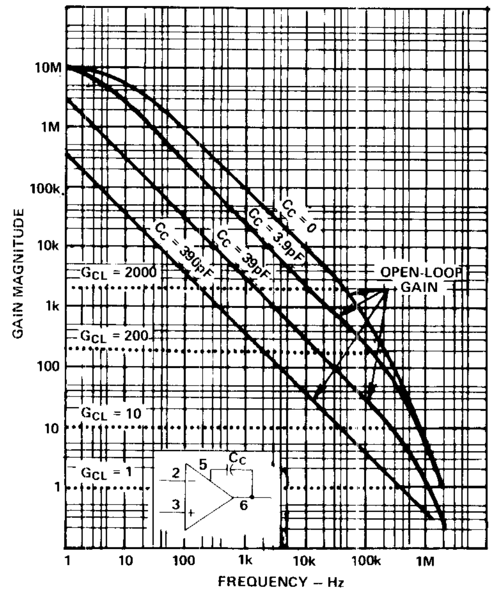


Figure 2. Small Signal Gain vs Frequency

NOISE CHARACTERISTICS

An op amp of the caliber of the AD504 must have correspondingly low noise levels if the user is to be assured he will be able to take advantage of its exceptional dc characteristics. Of primary importance in this type of amplifier is the absence of popcorn noise and minimum I/f or "flicker" noise in the 0.01Hz to 10Hz frequency band. Sample noise testing is done on every lot to guarantee that better than 90% of all devices will meet the noise specifications.

Separate voltage and current noise levels referred to the input are specified to enable the designer to calculate or optimize signal-to-noise ratio based on any desired source resistance. The spot noise figures are useful in determining total wideband noise over any desired bandwidth. (See Figure 3)

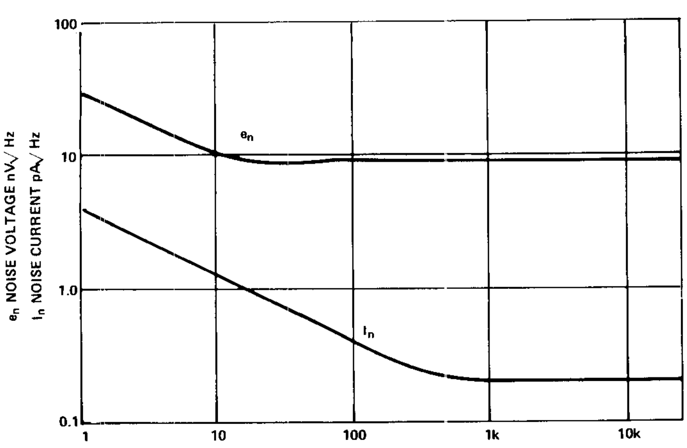


Figure 3. Spot Noise vs Frequency

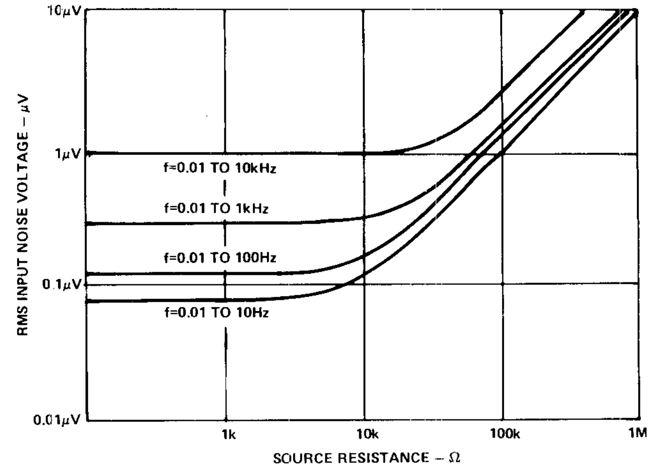


Figure 4. RMS Noise vs Source Resistance

NULLING THE AD504

Since calculations show that superior drift performance can be realized with the AD504, special care should be taken to null it in the most advantageous manner. Using the actual values of resistors in the AD504, it is possible to calculate, under worst case conditions, that the total adjustment range of the AD504 is approximately 8mV. Since the amplifier may often be trimmed to within 1μV, this represents an adjustment of 1 part in 8000. This type of accuracy would require a pot with 0.0125% resolution and stability. Because of the problems of obtaining a pot of this stability, a slightly more sophisticated nulling operation is recommended for applications where offset drift is critical (See Figure 1.)

NULLING PROCEDURE

1. Null the offset to zero using a commercially available pot (suggest r_p = 10kΩ).
2. Measure pot halves r_1 and r_2.
3. Calculate . . . .

$$r'_1 = \frac{r_1 \times 50k\Omega}{50k\Omega - r_1}, \quad r'_2 = \frac{r_2 \times 50k\Omega}{50k\Omega - r_2}$$

4. Insert r'_1 and r'_2 (closest 1% fixed metal film resistors).
5. Use an industrial quality 100kΩ pot (r_p) to fine tune the trim.

For applications in which stringent nulling is not required, the user may choose a simplified nulling scheme as shown in Figure 5. For best results the wiper of the potentiometer should be connected directly to pin 7 of the op amp. This is true for both nulling schemes.

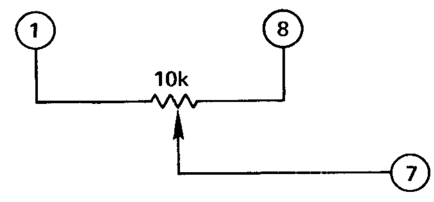


Figure 5. Simplified Nulling Circuit