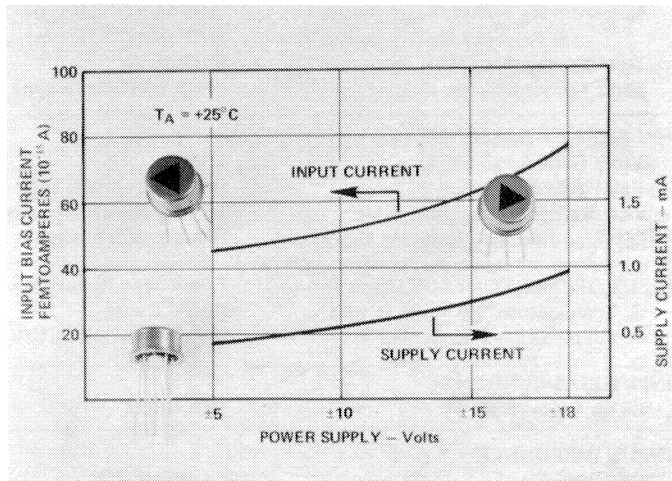
ANALOG DEVICES

Precision, Low-Power FET-Input Electrometer Op Amp

AD515

FEATURES

Ultra Low Bias Current: 0.075pA max (AD515L)
0.150pA max (AD515K)
0.300pA max (AD515J)
Low Power: 1.5mA max Quiescent Current (0.8mA typ)
Low Offset Voltage: 1.0mV max (AD515 K & L)
Low Drift: 15μV/°C max (AD515K)
Low Noise: 4μV p-p, 0.1 to 10Hz
Low Cost: $10.40 (J – 100+)



PRODUCT DESCRIPTION

The AD515 series of FET-input operational amplifiers are second generation electrometer designs offering the lowest input bias currents available in any standard operational amplifier. The AD515 also delivers laser-trimmed offset voltage, low drift, low noise and low power, a combination of features not previously available in ultra-low bias current circuits. All devices are internally compensated, free of latch-up, and short circuit protected.

The AD515 delivers a new level of versatility and precision to a wide variety of electrometer and very high impedance buffer measurement situations, including photo-current detection, vacuum ion-gauge measurement, long term precision integration, and low drift sample/hold applications. The device is also an excellent choice for all forms of biomedical instrumentation such as pH/pIon sensitive electrodes, very low current oxygen sensors, and high impedance biological microprobes. In addition, the low cost and pin compatibility of the AD515 with standard FET op amps will allow designers to upgrade the performance of present systems at little or no additional cost. The 10^{15} ohm common mode input impedance, resulting from a solid bootstrap input stage, insures that the input bias current is essentially independent of common mode voltage.

As with previous electrometer amplifier designs from Analog Devices, the case is brought out to its own connection (pin 8) so that the case can be independently connected to a point at the same potential as the input, thus minimizing stray leakage to the case. This feature will also shield the input circuitry from external noise and supply transients, as well as reducing common mode input capacitance from 0.8pF to 0.2pF.

The AD515 is available in three versions of bias current and offset voltage, the "J", "K", and "L"; all are specified for rated performance from 0 to +70°C and supplied in a hermetically sealed TO-99 package.

PRODUCT HIGHLIGHTS

1. The AD515 provides the lowest bias currents available in an integrated circuit amplifier.
   - The ultra low input bias currents are specified as the maximum measured at either input with the device fully warmed up on ±15 volt supplies at +25°C ambient with no heat sink. This parameter is 100% tested.
   - By using ±5 volt supplies, input bias current can typically be brought below 50fA.
2. The input offset voltage on all grades is laser trimmed to a level typically less than 500μV.
   - The offset voltage drift is the lowest available in an FET electrometer amplifier.
   - If additional nulling is desired, the amount required will have a minimal effect on offset drift (approximately 3μV/°C per millivolt).
3. The low quiescent current drain of 0.8mA typical and 1.5mA maximum, which is among the lowest available in operational amplifier designs of any type, keeps self-heating effects to a minimum and renders the AD515 suitable for a wide range of remote probe situations.
4. The combination of low input noise voltage and very low input noise current is such that for source impedances from much over one Megohm up to 10^{11} ohm, the Johnson noise of the source will easily dominate the noise characteristic.
5. Every AD515 receives a 24 hour stabilization bake at +150°C, to ensure reliability and long term stability.

Route 1 Industrial Park; P.O. Box 280; Norwood, Mass. 02062
Tel: 617/329-4700 TWX: 710/394-6577
West Coast 714/842-1717
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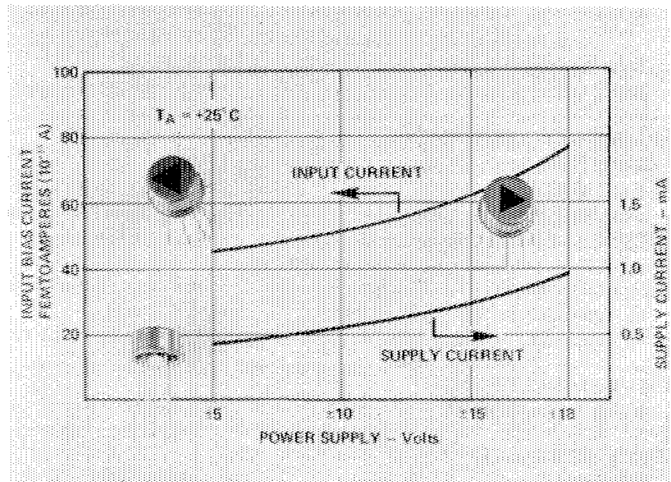

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SPECIFICATIONS (typical @ +25°C with V_S = ±15V dc, unless otherwise specified)

MODEL	AD515J	AD515K	AD515L
OPEN LOOP GAIN (Note 1)			
V_{out} = ± 10V, $R_L \geq 2k\Omega$	20,000V/V min	40,000V/V min	25,000V/V min
$R_L \geq 10k\Omega$	40,000V/V min	100,000V/V min	50,000V/V min
T_A = min to max $R_L \geq 2k\Omega$	15,000V/V min	40,000V/V min	25,000V/V min
OUTPUT CHARACTERISTICS			
Voltage @ $R_L = 2k\Omega$, T_A = min to max	±10V min (±12V typ)	*	*
@ $R_L = 10k\Omega$, T_A = min to max	±12V min (±13V typ)	*	*
Load Capacitance (Note 2)	1000pF	*	*
Short Circuit Current	10mA min (25mA typ)	*	*
FREQUENCY RESPONSE			
Unity Gain, Small Signal	350kHz	*	*
Full Power Response	5kHz min (16kHz typ)	*	*
Slew Rate Inverting Unity Gain	0.3V/μs min (1.0V/μs typ)	*	*
Overload Recovery Inverting Unity Gain	100μs max (16μs typ)	*	*
INPUT OFFSET VOLTAGE (Note 3)	3.0mV max (0.4mV typ)	1.0mV max (0.4mV typ)	1.0mV max (0.4mV typ)
vs. Temperature, T_A = min to max	50μV/°C max	15μV/°C max	25μV/°C max
vs. Supply, T_A = min to max	400μV/V max (50μV/V typ)	100μV/V max	200μV/V max
INPUT BIAS CURRENT			
Either Input (Note 4)	300fA max	150fA max	75fA max
INPUT IMPEDANCE			
Differential	$1.6pF \| 10^{13}\Omega$	*	*
Common Mode	$0.8pF \| 10^{15}\Omega$	*	*
INPUT NOISE			
Voltage, 0.1Hz to 10Hz	4.0μV (p-p)	*	*
f = 10Hz	$75nV/\sqrt{Hz}$	*	*
f = 100Hz	$55nV/\sqrt{Hz}$	*	*
f = 1kHz	$50nV/\sqrt{Hz}$	*	*
Current, 0.1 to 10Hz	0.003pA (p-p)	*	*
10Hz to 10kHz	0.01pA rms	*	*
INPUT VOLTAGE RANGE			
Differential	±20V min	*	*
Common Mode, T_A = min to max	±10V min (±12V typ)	*	*
Common Mode Rejection, V_{IN} = ±10V	66dB min (94dB typ)	80dB min	70dB min
Maximum Safe Input Voltage (Note 5)	$\pm V_S$	*	*
POWER SUPPLY			
Rated Performance	±15V typ	*	*
Operating	±5V min (±18V max)	*	*
Quiescent Current	1.5mA max (0.8mA typ)	*	*
TEMPERATURE			
Operating, Rated Performance	0 to +70°C	*	*
Storage	–65°C to +150°C	*	*
PRICE			
(1–24)	$18.30	$24.00	$31.50
(25–99)	$14.30	$19.30	$25.20
(100+)	$10.40	$14.70	$19.30

*Specifications same as AD515J.

NOTES:
1. Open Loop Gain is specified with or without nulling of V_{OS}.
2. A conservative design would not exceed 750pF of load capacitance.
3. Input Offset Voltage specifications are guaranteed after 5 minutes of operation at T_A = +25°C.
4. Bias Current specifications are guaranteed after 5 minutes of operation at T_A = +25°C. For higher temperatures, the current doubles every +10°C.
5. If it is possible for the input voltage to exceed the supply voltage, a series protection resistor should be added to limit input current to 0.5mA. The input devices can handle overload currents of 0.5mA indefinitely without damage. See next page.

Specifications and prices subject to change without notice.

LAYOUT AND CONNECTION CONSIDERATIONS

The design of very high impedance measurement systems introduces a new level of problems associated with the reduction of leakage paths and noise pickup.

1. A primary consideration in high impedance system designs is to attempt to place the measuring device as near to the signal source as possible. This will minimize current leakage paths, noise pickup and capacitive loading. The AD515, with its combination of low offset voltage (normally eliminating the need for trimming), low quiescent current (minimal source heating, possible battery operation), internal compensation and small physical size lends itself very nicely to installation at the signal source or inside a probe. Also, as a result of the high load capacitance rating, the AD515 can comfortably drive a long signal cable.
2. The use of guarding techniques is essential to realizing the capability of the ultra-low input currents of the AD515. Guarding is achieved by applying a low impedance bootstrap potential to the outside of the insulation material surrounding the high impedance signal line. This bootstrap potential is held at the same level as that of the high impedance line; therefore, there is no voltage drop across the insulation, and hence, no leakage. The guard will also act as a shield to reduce noise pickup and serves an additional function of reducing the effective capacitance to the input line. The case of the AD515 is brought out separately to pin 8 so that the case can also be connected to the guard potential. This technique virtually eliminates potential leakage paths across the package insulation, provides a noise shield for the sensitive circuitry, and reduces common-mode input capacitance to about 0.2pF. Figure 1 shows a proper printed circuit board layout for input guarding and connecting the case guard. Figures 2 and 3 show guarding connections for typical inverting and non-inverting applications. If pin 8 is not used for guarding, it should be connected to ground or a power supply to reduce noise.

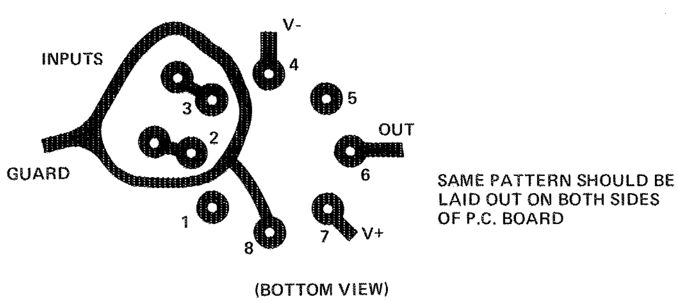


Figure 1. Board Layout for Guarding Inputs with Guarded TO-99 Package

3. Printed circuit board layout and construction is critical for achieving the ultimate in low leakage performance that the AD515 can deliver. The best performance will be realized by using a teflon IC socket for the AD515; but at least a teflon stand-off should be used for the high-impedance lead. If this is not feasible, the input guarding scheme shown in Figure 1 will minimize leakage as much as possible; the guard ring should be applied to both sides of the board. The guard ring is connected to a low impedance potential at the same level as the inputs. High impedance signal lines should not be extended for any unnecessary length on a printed circuit; to minimize noise and leakage, they must be carried in rigid, shielded cables.
4. Another important concern for achieving and maintaining low leakage currents is complete cleanliness of circuit boards and components. Completed assemblies should be washed thoroughly in a low residue solvent such as TMC Freon or high-purity methanol followed by a rinse with deionized water and nitrogen drying. If service is anticipated in a high contaminant or high humidity environment, a high dielectric conformal coating is recommended. All insulation materials except Kel-F or teflon will show rapid degradation of surface leakage at high humidities.

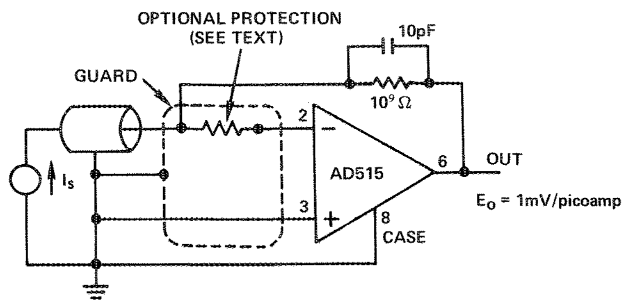


Figure 2. Picoampere Current-to-Voltage Converter Inverting Configuration

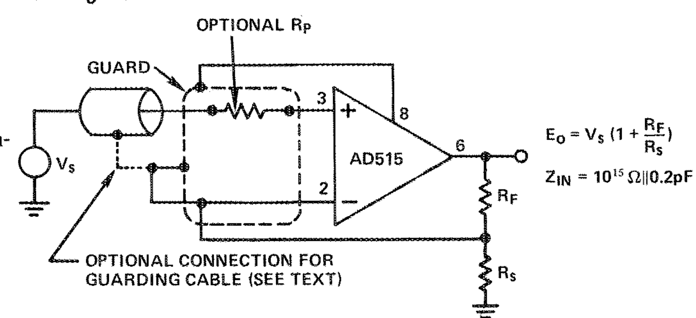


Figure 3. Very High Impedance Non-Inverting Amplifier

INPUT PROTECTION

The AD515 is guaranteed for a maximum safe input potential equal to the power supply potential. The unique bootstrapped input stage design also allows differential input voltages of up to ±20 volts (or within 10 volts of the sum of the supplies) while maintaining the full differential input resistance of $10^{13}\Omega$, as shown in Figure 10. This makes the AD515 suitable for low speed comparator situations employing a direct connection to a high impedance source.

Many instrumentation situations, such as flame detectors in gas chromatographs, involve measurement of low level currents from high-voltage sources. In such applications, a sensor fault condition may apply a very high potential to the input of the current-to-voltage converting amplifier. This possibility necessitates some form of input protection. Many electrometer type devices, especially CMOS designs, can require elaborate zener protection schemes which often compromise overall performance. The AD515 requires input protection only if the source is not current-limited, and as such is similar to many JFET-input designs. The failure mode would be overheating from excess current rather than voltage breakdown. If the source is not current-limited, all that is required is a resistor in series with the affected input terminal so that the maximum overload current is 0.5mA (for example, 200kΩ for a 100 volt overload). This simple scheme will cause no significant reduction in performance and give complete overload protection. Figures 2 and 3 show proper connections.

COAXIAL CABLE AND CAPACITANCE EFFECTS

If it is not possible to attach the AD515 virtually on top of the signal source, considerable care should be exercised in designing the connecting lines carrying the high impedance signal. Shielded coaxial cable must be used for noise reduction, but use of coaxial cables for high impedance work can add problems from cable leakage, noise, and capacitance. Only the best polyethylene or virgin teflon (not reconstituted) should be used to obtain the highest possible insulation resistance.

Cable systems should be made as rigid and vibration-free as possible since cable movement can cause noise signals of three types, all significant in high impedance systems. Frictional movement of the shield over the insulation material generates a charge which is sensed by the signal line as a noise voltage. Low noise cable with graphite lubricant such as Amphenol 21-537 will reduce the noise, but short rigid lines are better. Cable movements will also make small changes in the internal cable capacitance and capacitance to other objects. Since the total charge on these capacitances cannot be changed instantly, a noise voltage results as predicted from: $\Delta V = Q/\Delta C$. Noise voltage is also generated by the motion of a conductor in a magnetic field.

The conductor-to-shield capacitance of coaxial cable is normally about 30pF/foot. Charging this capacitance can cause considerable stretching of high impedance signal rise-time, thus cancelling the low input capacitance feature of the AD515. There are two ways to circumvent this problem. For inverting signals or low-level current measurements, the signal is carried on the line connected to the inverting input and shielded (guarded) by the ground line as shown in Figure 2. Since the signal is always at virtual ground, no voltage change is required and no capacitances are charged. In many circumstances, this will de-stabilize the circuit; if so, capacitance from output to inverting input will stabilize the circuit.

Non-inverting and buffer situations are more critical since the signal line voltage and therefore charge will change, causing signal delay. This effect can be reduced considerably by connecting the cable shield to guard potential instead of ground, an option shown in Figure 3. Since such a connection results in positive feedback to the input, the circuit may destabilize and oscillate. If so, capacitance from positive input to ground must be added to make the net capacitance at pin 3 positive. This technique can consiaerabıy reduce the effective capacitance which must be charged.

Typical Performance Curves

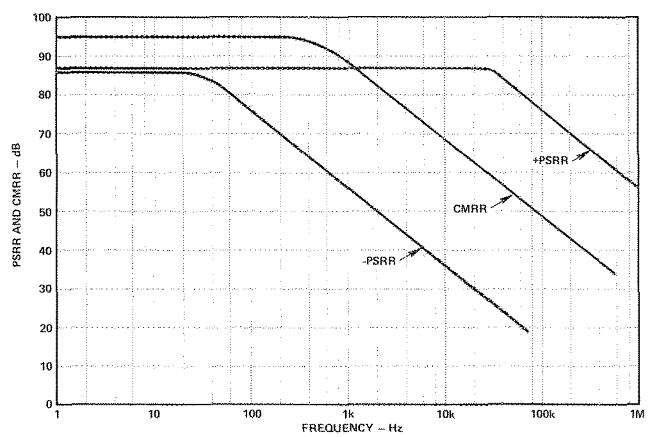


Figure 4. PSRR and CMRR Versus Frequency

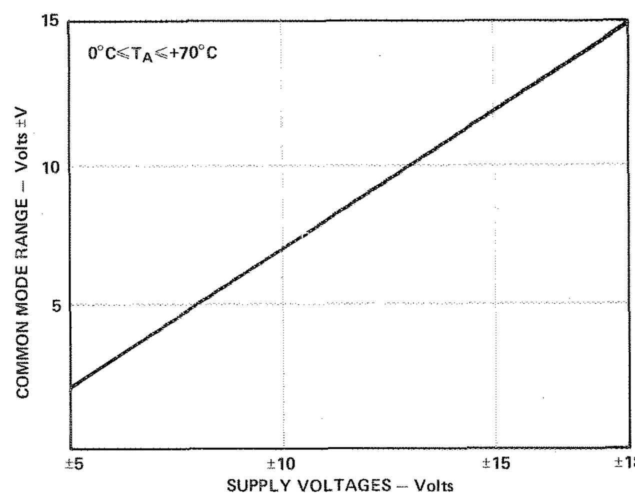


Figure 6. Input Common Mode Range Versus Supply Voltage

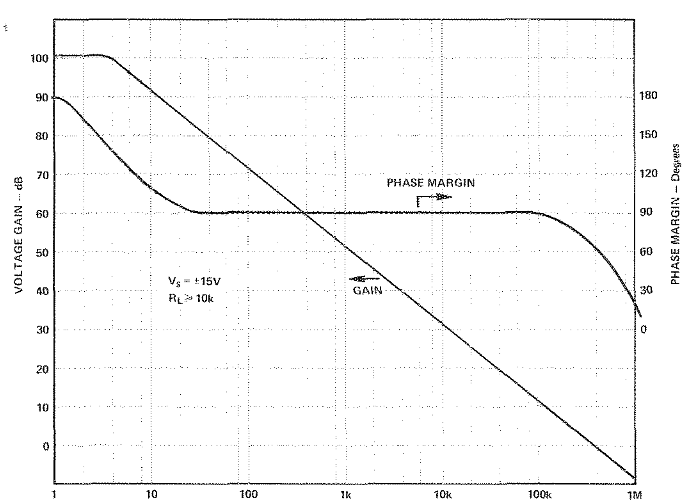


Figure 5. Open Loop Frequency Response

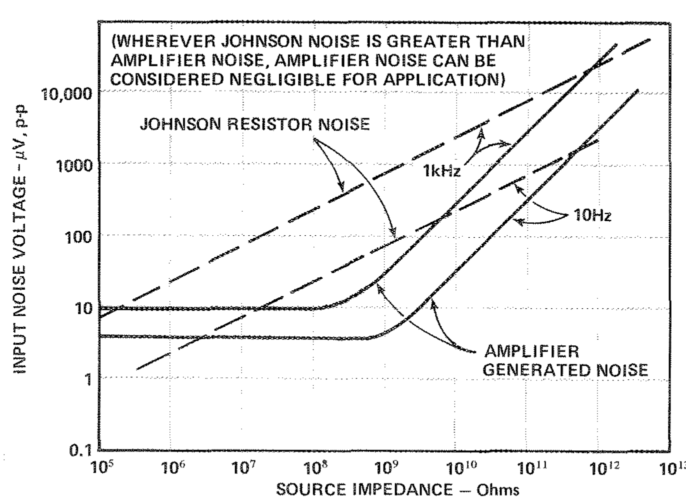


Figure 7. Peak-to-Peak Input Noise Voltage Versus Source Impedance and Bandwidth

ELECTROMETER APPLICATION NOTES

The AD515 offers the lowest input bias currents available in an integrated circuit package. This design will open up many new application opportunities for measurements from very high impedance and very low current sources. Performing accurate measurements of this sort requires careful attention to detail; the notes given here will aid the user in realizing the full measurement potential of the AD515 and perhaps extending its performance limits.

1. As with all junction FET input devices, the temperature of the FET's themselves is all-important in determining the input bias currents. Over the operating temperature range, the input bias currents closely follow a characteristic of doubling every 10°C; therefore, every effort should be made to minimize device operating temperature.
2. The heat dissipation can be reduced initially by careful investigation of the application. First, if it is possible to reduce the required power supplies, this should be done since internal power consumption contributes the largest component of self-heating. To minimize this effect, the quiescent current of the AD515 has been reduced to a level much lower than that of any other electrometer-grade device, but additional performance improvement can be gained by lowering the supply voltages, to ±5 volts if possible. The effects of this are shown in Figure 8, which shows typical input bias current and quiescent current versus supply voltage.
3. Output loading effects, which are normally ignored, can cause a significant increase in chip temperature and therefore bias current. For example, a 2kΩ load driven at 10 volts at the output will cause at least an additional 25 milliwatts dissipation in the output stage (and some in other stages) over the typical 24 milliwatts, thereby at least doubling the effects of self-heating. The results of this form of additional power dissipation are demonstrated in Figure 9, which shows normalized input bias current versus additional power dissipated. Therefore, although many dc performance parameters are specified driving a 2kΩ load, to reduce this additional dissipation, we recommend restricting the load impedance to be at least 10kΩ.

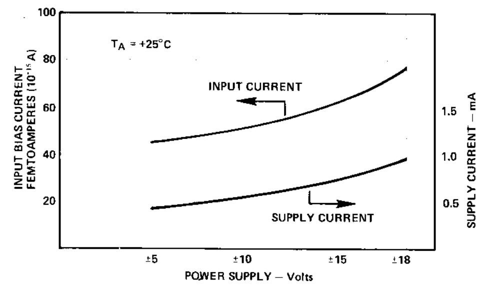


Figure 8. Input Bias Current and Supply Current Versus Supply Voltage

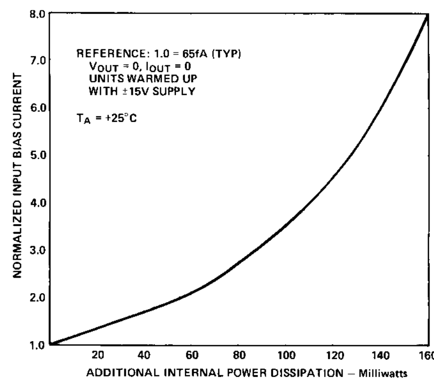


Figure 9. Input Bias Current Versus Additional Power Dissipation

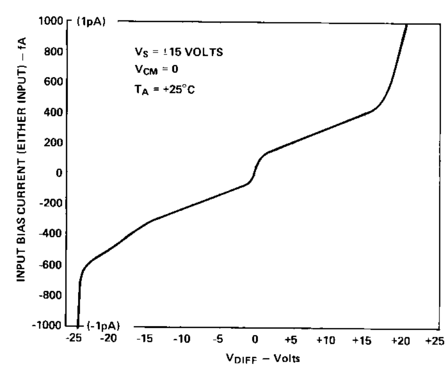
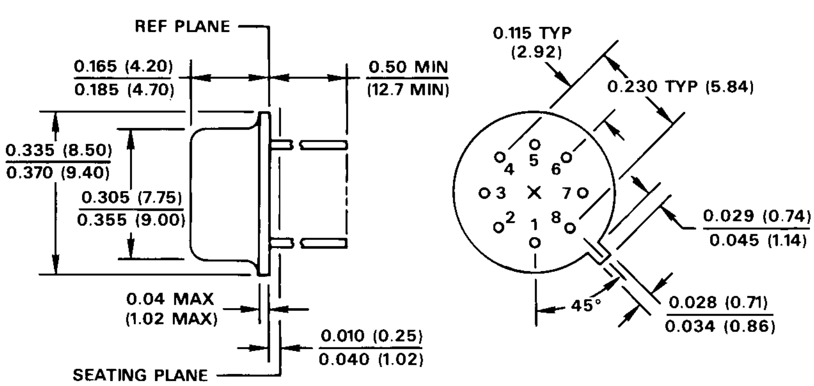


Figure 10. Input Bias Current Versus Differential Input Voltage

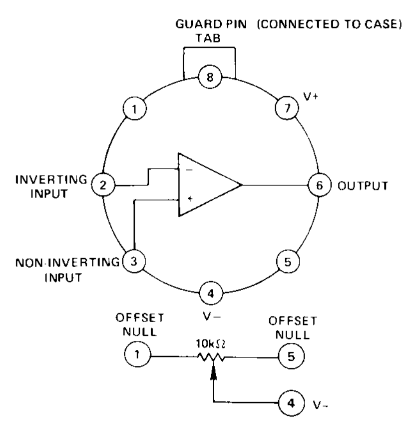
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



TO-99

PIN CONFIGURATION



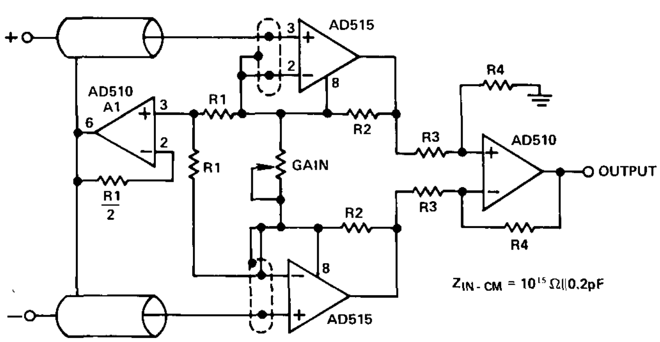
TOP VIEW

AD515 CIRCUIT APPLICATION NOTES

The AD515 is quite simple to apply to a wide variety of applications because of the pre-trimmed offset voltage and internal compensation, which minimize required external components and eliminate the need for adjustments to the device itself. The major considerations in applying this device are the external problems of layout and heat control which have already been discussed. In circuit situations employing the use of very high value resistors, such as low level current to voltage converters, electrometer operational amplifiers can be destabilized by a pole created by the small capacitance at the negative input. If this occurs, a capacitor of 2 to 5pF in parallel with the resistor will stabilize the loop. A much larger capacitor may be used if desired to limit bandwidth and thereby reduce wideband noise.

Selection of passive components employed in high impedance situations is critical. High-megohm resistors should be of the carbon film or deposited ceramic oxide to obtain the best in low noise and high stability performance. The best packaging for high-megohm resistors is a glass body sprayed with silicone varnish to minimize humidity effects. These resistors must be handled very carefully to prevent surface contamination. Capacitors for any high impedance or long term integration situation should be of a polystyrene formulation for optimum performance. Most other types have too low an insulation resistance, or high dielectric absorption.

Unlike situations involving standard operational amplifiers with much higher bias currents, balancing the impedances seen at the input terminals of the AD515 is usually unnecessary and probably undesirable. At the large source impedances where these effects matter, obtaining quality, matched resistors will be difficult. More important, instead of a cancelling effect, as with bias current, the noise voltage of the additional resistor will add by root-sum-of-squares to that of the other resistor thus increasing the total noise by about 40%. Noise currents driving the resistors also add, but in the AD515 are significant only above $10^{11}\Omega$.



(ALL RESISTORS OF SAME NUMBER SHOULD BE MATCHED ±0.1%)
(BUFFER A1 BOOSTS COMMON MODE Z_{IN} BY DRIVING CABLE SHIELDS AT COMMON MODE VOLTAGE AND NEUTRALIZING CM CAPACITANCE)

Figure 11. Very High Impedance Instrumentation Amplifier

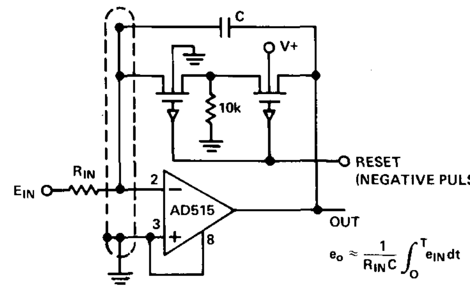


Figure 12. Low Drift Integrator and Low-Leakage Guarded Reset

LOW-LEVEL CURRENT TO VOLTAGE CONVERTERS

Figure 2 shows a standard low-level current-to-voltage converter. To obtain higher sensitivity, it is obvious to simply use a higher value feedback resistor. However, high value resistors above $10^9\Omega$ tend to be expensive, large, noisy and unstable. To avoid this, it may be desirable to use a circuit configuration with output gain, as in Figure 13. The drawback is that input errors of offset voltage drift and noise are multiplied by the same gain, but the precision performance of the AD515 makes the tradeoff easier.

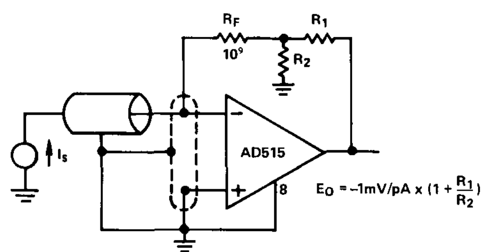


Figure 13. Picoampere to Voltage Converter with Gain

One of the problems with low-level leakage current testing or low-level current transducers (such as Clark oxygen sensors) is finding a way to apply voltage bias to the device while still grounding the device and the bias source. Figure 14 shows a technique in which the desired bias is applied at the non-inverting terminal thus forcing that voltage at the inverting terminal. The current is sensed by R_F, and the AD521 instrumentation amplifier converts the floating differential signal to a single-ended output.

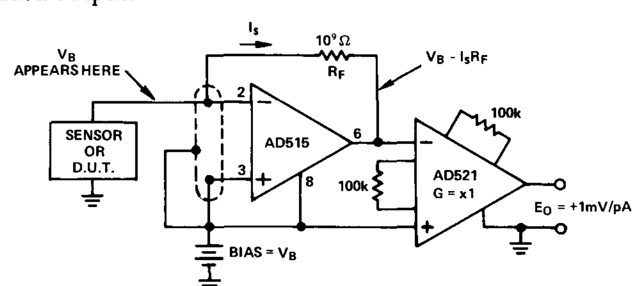


Figure 14. Current-to-Voltage Converters with Grounded Bias and Sensor

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