National Semiconductor

LM121/LM221/LM321, LM121A/LM221A/LM321A Precision Preamplifiers

General Description

The LM121 series are precision preamplifiers designed to operate with general purpose operational amplifiers to drastically decrease dc errors. Drift, bias current, common mode and supply rejection are more than a factor of 50 better than standard op amps alone. Further, the added dc gain of the LM121 decreases the closed loop gain error.

The LM121 series operates with supply voltages from ±3V to ±20V and has sufficient supply rejection to operate from unregulated supplies. The operating current is programmable from 5μA to 200μA so bias current, offset current, gain and noise can be optimized for the particular application while still realizing very low drift. Super-gain transistors are used for the input stage so input error currents are lower than conventional amplifiers at the same operating current. Further, the initial offset voltage is easily nulled to zero.

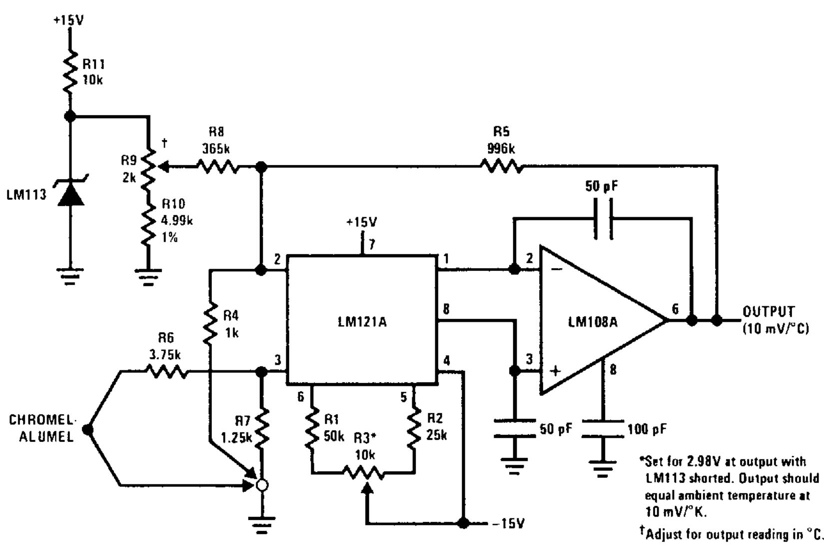
Features

- Guaranteed drift of LM121A series — 0.2μV/°C
- Guaranteed drift of LM121 series — 1μV/°C
- Offset voltage less than 0.4 mV
- Bias current less than 10 nA at 10μA operating current
- CMRR 126 dB minimum
- 120 dB supply rejection
- Easily nulled offset voltage

The extremely low drift of the LM121 will improve accuracy on almost any precision dc circuit. For example, instrumentation amplifier, strain gauge amplifiers and thermocouple amplifiers now using chopper amplifiers can be made with the LM121. The full differential input and high common-mode rejection are another advantage over choppers. For applications where low bias current is more important than drift, the operating current can be reduced to low values. High operating currents can be used for low voltage noise with low source resistance. The programmable operating current of the LM121 allows tailoring the input characteristics to match those of specialized op amps.

The LM121 is specified over a −55°C to +125°C temperature range, the LM221 over a −25°C to +85°C range and the LM321 over a 0°C to +70°C temperature range.

Typical Applications



Thermocouple Amplifier with Cold Junction Compensation

Absolute Maximum Ratings

Supply Voltage	±20V
Power Dissipation (Note 1)	500 mW
Differential Input Voltage (Notes 2 and 3)	±15V
Input Voltage (Note 3)	±15V
Operating Temperature Range	
LM121	−55°C to +125°C
LM221	−25°C to +85°C
LM321	0°C to +70°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	300°C

Electrical Characteristics (Note 4) LM121, LM221, LM321

PARAMETER	CONDITIONS	LM121, LM221 MIN	LM121, LM221 TYP	LM121, LM221 MAX	LM321 MIN	LM321 TYP	LM321 MAX	UNITS
Input Offset Voltage	$T_A = 25°C$, $6.4k \le R_{SET} \le 70k$			0.7			1.5	mV
Input Offset Current	$T_A = 25°C$,							
	$R_{SET} = 70k$			1			2	nA
	$R_{SET} = 6.4k$			10			20	nA
Input Bias Current	$T_A = 25°C$,							
	$R_{SET} = 70k$			10			18	nA
	$R_{SET} = 6.4k$			100			180	nA
Input Resistance	$T_A = 25°C$,							
	$R_{SET} = 70k$	4			2			MΩ
	$R_{SET} = 6.4k$	0.4			0.2			MΩ
Supply Current	$T_A = 25°C$, $R_{SET} = 70k$			1.5			2.2	mA
Input Offset Voltage	$6.4k \le R_{SET} \le 70k$			1.0			2.5	mV
Input Bias Current	$R_{SET} = 70k$			30			28	nA
	$R_{SET} = 6.4k$			300			280	nA
Input Offset Current	$R_{SET} = 70k$			3			4	nA
	$R_{SET} = 6.4k$			30			40	nA
Input Offset Current Drift	$R_{SET} = 70k$		3			3		pA/°C
Average Temperature Coefficient of Input Offset Voltage	$R_S \le 200\Omega$, $6.4k \le R_{SET} \le 70k$ Offset Voltage Nulled			1			1	μV/°C
Long Term Stability			5			5		μV/yr
Supply Current				2.5			3.5	mA
Input Voltage Range	$V_S = \pm 15V$, (Note 5)							
	$R_{SET} = 70k$	±13			±13			V
	$R_{SET} = 6.4k$	+7, −13			+7, −13			V
Common-Mode Rejection Ratio	$R_{SET} = 70k$	120			114			dB
	$R_{SET} = 6.4k$	114			114			dB
Supply Voltage Rejection Ratio	$R_{SET} = 70k$	120			114			dB
	$R_{SET} = 6.4k$	114			114			dB
Voltage Gain	$T_A = 25°C$, $R_{SET} = 70k$, $R_L > 3\ M\Omega$	16			12			V/V
Noise	$R_{SET} = 70k$, $R_{SOURCE} = 0$		8			8		$nV/\sqrt{Hz}$

Note 1: The maximum junction temperature of the LM121 is 150°C, while that of the LM221 is 100°C. The maximum junction temperature of the LM321 is 85°C. For operating at elevated temperature, devices in the TO-5 package must be derated based on a thermal resistance of 150°C/W, junction to ambient, or 45°C/W, junction to case. For the flat package, the derating is based on a thermal resistance of 185°C/W when mounted on a 1/6 inch thick epoxy glass board with ten, 0.03 inch wide, 2 ounce copper conductors. The thermal resistance of the dual-in-line package is 100°C/W junction to ambient.

Note 2: The inputs are shunted with back-to-back diodes in series with a 500Ω resistor for overvoltage protection. Therefore, excessive current will flow if a differential input voltage in excess of 1V is applied between the inputs.

Note 3: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

Note 4: These specifications apply for $\pm 5 \le V_S \le \pm 20V$ and $-55°C \le T_A \le +125°C$, unless otherwise specified. With the LM221, however, all temperature specifications are limited to $-25°C \le T_A \le +85°C$, and for the LM321 the specifications apply over a 0°C to +70°C temperature range.

Note 5: External precision resistor – 0.1% – can be placed from pins 1 and 8 to 7 to increase positive common-mode range.

Absolute Maximum Ratings

Supply Voltage	±20V
Power Dissipation (Note 1)	500 mW
Differential Input Voltage (Notes 2 and 3)	±15V
Input Voltage (Note 3)	±15V
Operating Temperature Range	
LM121A	−55°C to +125°C
LM221A	−25°C to +85°C
LM321A	0°C to +70°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	300°C

Electrical Characteristics (Note 4) LM121A, LM221A, LM321A

PARAMETER	CONDITIONS	LM121A, LM221A			LM321A			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
Input Offset Voltage	$T_A = 25°C$, $6.4k \leq R_{SET} \leq 70k$		0.2	0.4		0.2	0.4	mV
Input Offset Current	$T_A = 25°C$, $R_{SET} = 70k$		0.3	0.5		0.3	0.5	nA
	$R_{SET} = 6.4k$			5			5	nA
Input Bias Current	$T_A = 25°C$, $R_{SET} = 70k$		5	10		5	15	nA
	$R_{SET} = 6.4k$		50	100		50	150	nA
Input Resistance	$T_A = 25°C$, $R_{SET} = 70k$	4	8		2	8		MΩ
	$R_{SET} = 6.4k$	0.4			0.2			MΩ
Supply Current	$T_A = 25°C$, $R_{SET} = 70k$		0.8	1.5		0.8	2.2	mA
Input Offset Voltage	$6.4k \leq R_{SET} \leq 70k$		0.5	0.65		0.5	0.65	mV
Input Bias Current	$R_{SET} = 70k$		15	30		15	25	nA
	$R_{SET} = 6.4k$		150	300		150	250	nA
Input Offset Current	$R_{SET} = 70k$		0.5	1		0.5	1	nA
	$R_{SET} = 6.4k$		5	10		5	10	nA
Input Offset Current Drift	$R_{SET} = 70k$		3			3		pA/°C
Average Temperature Coefficient of Input Offset Voltage	$R_S \leq 200\Omega$, $6.4k \leq R_{SET} \leq 70k$ Offset Voltage Nulled		0.07	0.2		0.07	0.2	μV/°C
Long Term Stability			3			3		μV/yr
Supply Current			1	2.5		1	3.5	mA
Input Voltage Range	$V_S = \pm15V$, (Note 5) $R_{SET} = 70k$	±13			±13			V
	$R_{SET} = 6.4k$	+7, −13			+7, −13			V
Common-Mode Rejection Ratio	$R_{SET} = 70k$	126	140		126	140		dB
	$R_{SET} = 6.4k$	120	130		120	130		dB
Supply Voltage Rejection Ratio	$R_{SET} = 70k$	120	126		118	126		dB
	$R_{SET} = 6.4k$	114	120		114	120		dB
Voltage Gain	$T_A = 25°C$, $R_{SET} = 70k$, $R_L > 3\ M\Omega$	16	20		12	20		V/V
Noise	$R_{SET} = 70k$, $R_{SOURCE} = 0$		8			8		$nV/\sqrt{Hz}$

Note 1: The maximum junction temperature of the LM121A is 150°C, while that of the LM221A is 100°C. The maximum junction temperature of the LM321A is 85°C. For operating at elevated temperature, devices in the TO-5 package must be derated based on a thermal resistance of 150°C/W, junction to ambient, or 45°C/W junction to case. For the flat package, the derating is based on a thermal resistance of 185°C/W when mounted on a 1/6 inch thick epoxy glass board with ten, 0.03 inch wide, 2 ounce copper conductors. The thermal resistance of the dual-in-line package is 100°C/W junction to ambient.

Note 2: The inputs are shunted with back-to-back diodes in series with a 500Ω resistor for overvoltage protection. Therefore, excessive current will flow if a differential input voltage in excess of 1V is applied between the inputs.

Note 3: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

Note 4: These specifications apply for $\pm5 \leq V_S \leq \pm20V$ and $-55°C \leq T_A \leq +125°C$, unless otherwise specified. With the LM221A, however, all temperature specifications are limited to $-25°C \leq T_A \leq +85°C$, and for the LM321A the specifications apply over a 0°C to +70°C temperature range.

Note 5: External precision resistor — 0.1% — can be placed from pins 1 and 8 to 7 to increase positive common-mode range.

Frequency Compensation

UNIVERSAL COMPENSATION

The additional gain of the LM121 preamplifier when used with an operational amplifier usually necessitates additional frequency compensation. When the closed loop gain of the op amp with the LM121 is less than the gain of the LM121 alone, more compensation is needed. The worst case situation is when there is 100% feedback—such as a voltage follower or integrator—and the gain of the LM121 is high. When high closed loop gains are used—for example A_V = 1000—and only an addition gain of 200 is inserted by the LM121, the frequency compensation of the op amp will usually suffice.

The frequency compensation shown here is designed to operate with any unity-gain stable op amp. *Figure 1* shows the basic configuration of frequency stabilizing network. In operation the output of the LM121 is rendered single ended by a 0.01μF bypass capacitor to ground. Overall frequency compensation then is achieved by an integrating capacitor around the op amp.

$$\text{Bandwidth at unity-gain} \cong \frac{12}{2\pi R_{SET} C}$$

$$\text{for 0.5 MHz bandwidth } C = \frac{4}{10^6 R_{SET}}$$

For use with higher frequency op amps such as the LM118 the bandwidth may be increased to about 2 MHz.

If the closed loop gain is greater than unity, "C" may be decreased to:

$$C = \frac{4}{10^6 A_{CL} R_{SET}}$$

ALTERNATE COMPENSATION

The two compensation capacitors can be made equal for improved power supply rejection. In this case the formula for the compensation capacitor is:

$$C = \frac{8}{10^6 A_{CL} R_{SET}}$$

Table I shows typical values for the two compensating capacitors for various gains and operating currents.

TABLE I

CLOSED LOOP GAIN	CURRENT SET RESISTOR				
	120 kΩ	60 kΩ	30 kΩ	12 kΩ	6 kΩ
A_V = 1	68	130	270	680	1300
A_V = 5	15	27	56	130	270
A_V = 10	10	15	27	68	130
A_V = 50	1	3	5	15	27
A_V = 100	–	1	3	5	10
A_V = 500	–	–	1	1	3
A_V = 1000	–	–	–	–	–

This table applies for the LM108, LM101A, LM741, LM118. Capacitance is in pF.

DESIGN EQUATIONS FOR THE LM121 SERIES

$$\text{Gain } A_V \approx \frac{1.2 \times 10^6}{R_{SET}}$$

Null Pot Value should be 10% of R_{SET}

$$\text{Operating Current} \approx \frac{2 \times 0.65V}{R_{SET}}$$

$$\text{Positive Common-Mode Limit} \approx V^+ - \left[0.6 - \frac{0.65V \times 50k}{R_{SET}}\right]$$

Typical Applications

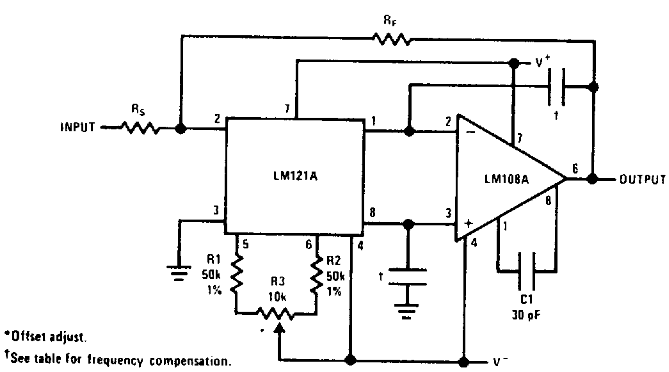
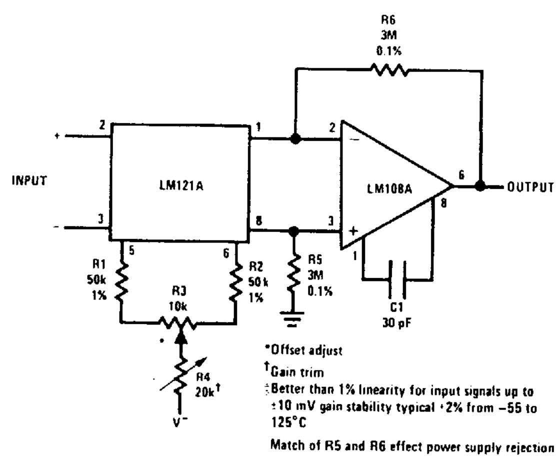
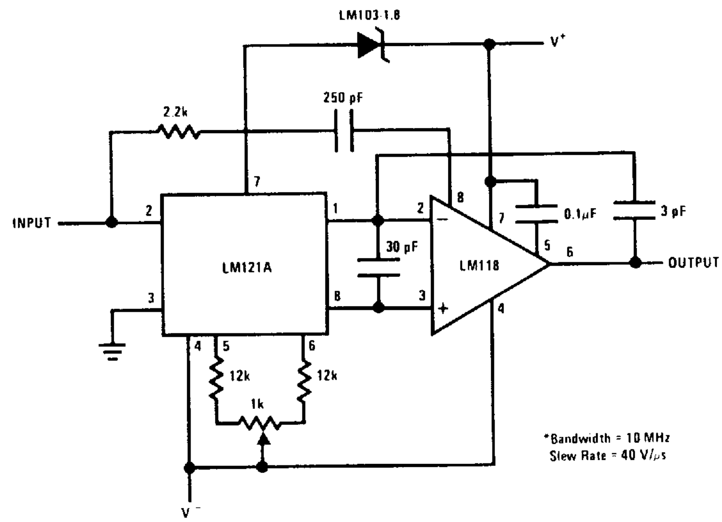


FIGURE 1. Low Drift Op Amp Using the LM121A as a Preamp

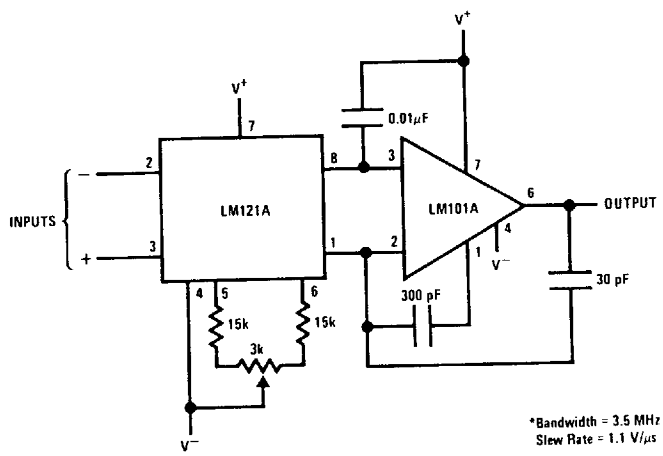


Gain of 1000 Instrumentation Amplifier‡

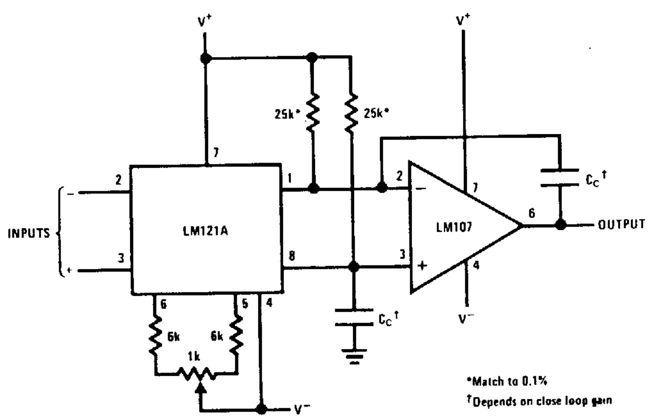
Typical Applications (Continued)



High Speed* Inverting Amplifier with Low Drift



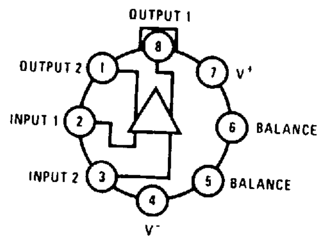
Medium Speed* General Purpose Amplifier



Increased Common-Mode Range at High Operating Currents

Connection Diagrams

Metal Can Package



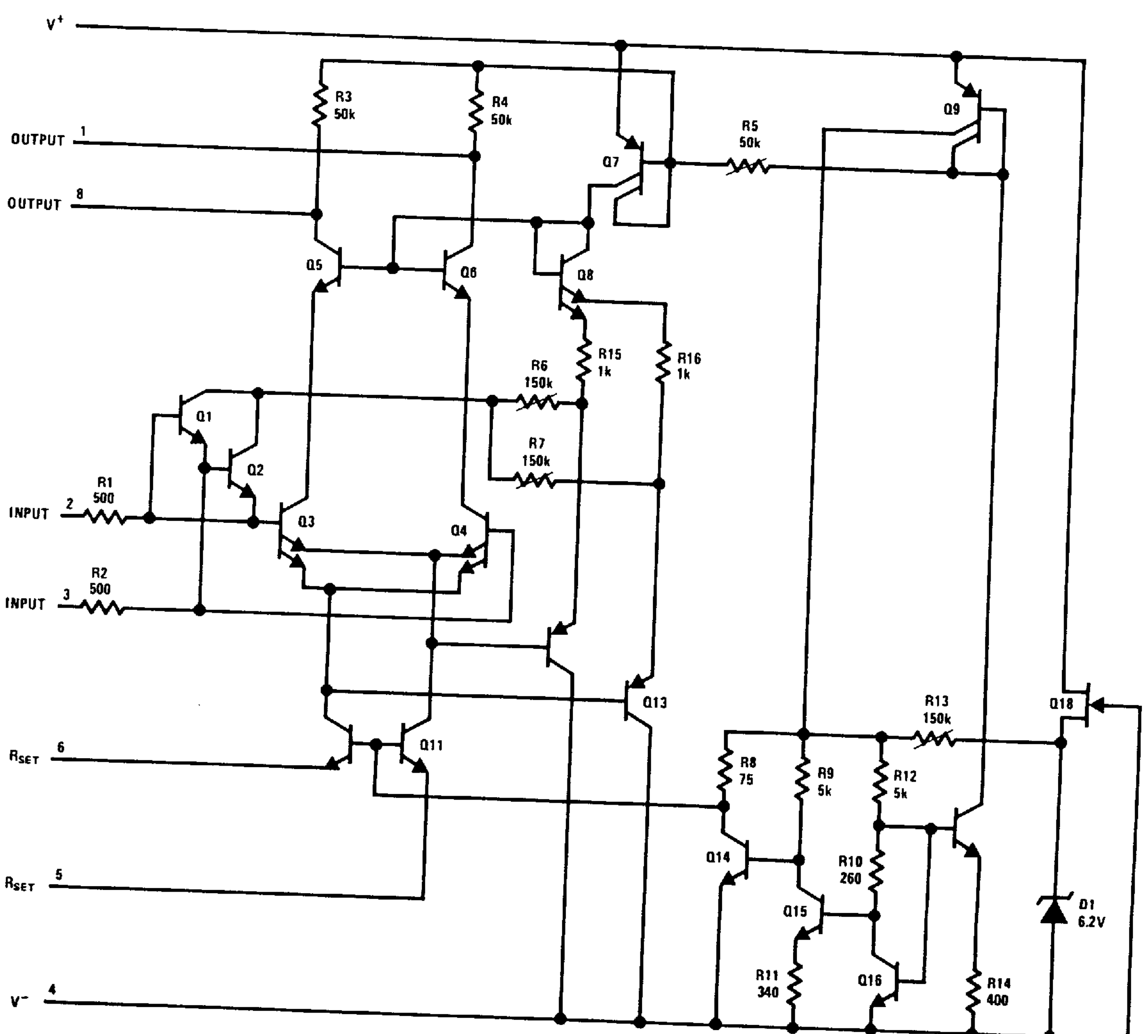
Note: Pin 4 connected to case.

TOP VIEW

Order Number LM121H, LM221H, LM321H, LM121AH, LM221AH or LM321AH
See NS Package H08C

Note: Outputs are inverting from the input of the same number.

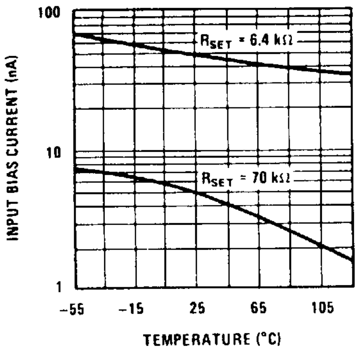
Schematic Diagram*



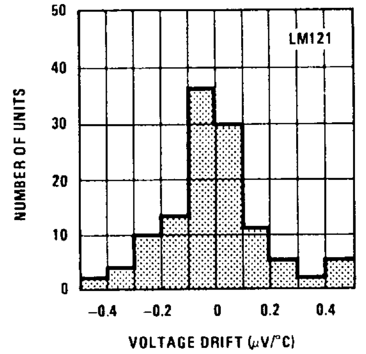
*Pin connections shown on schematic diagram and typical applications are for TO-5 package.

Typical Performance Characteristics

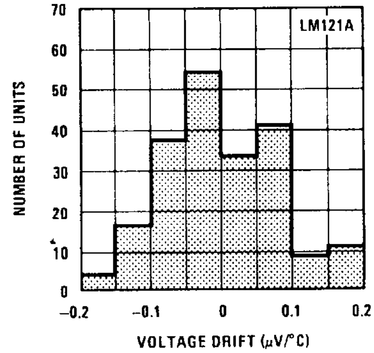
Input Bias Current



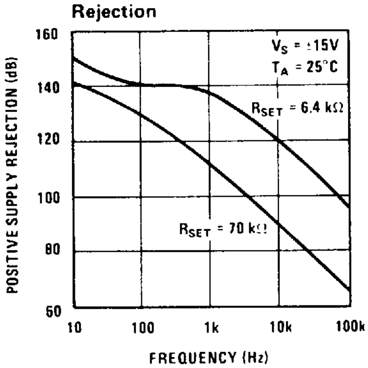
Distribution of Offset Voltage Drift (Nulled)



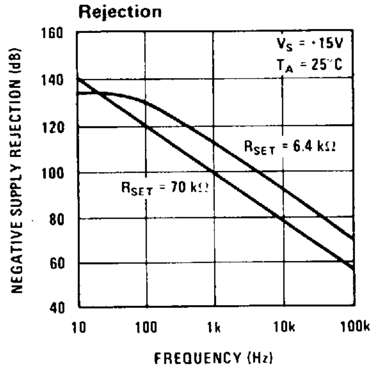
Distribution of Offset Voltage Drift (Nulled)



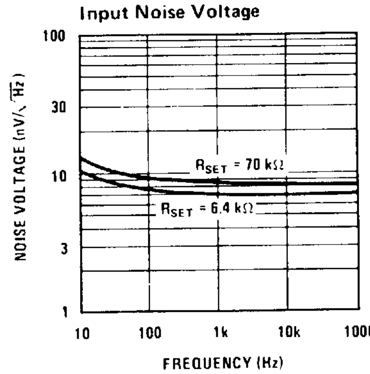
Positive Power Supply Rejection



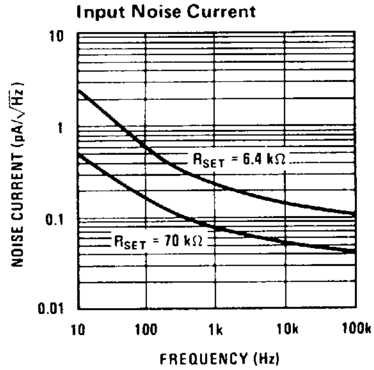
Negative Power Supply Rejection



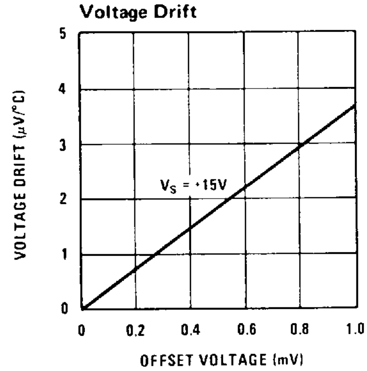
Input Noise Voltage



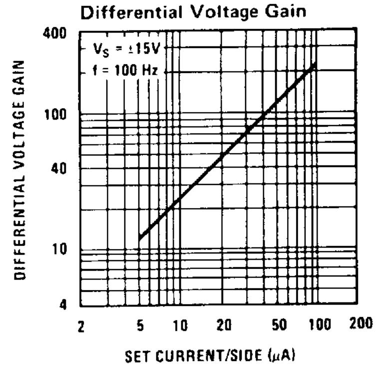
Input Noise Current



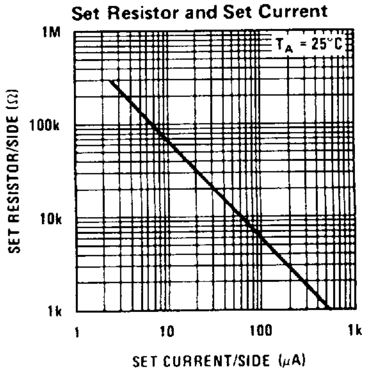
Voltage Drift



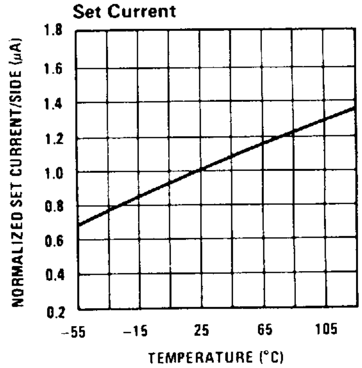
Differential Voltage Gain



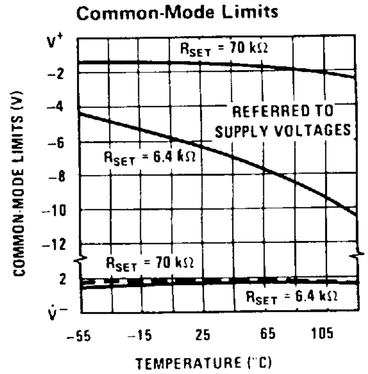
Set Resistor and Set Current



Set Current

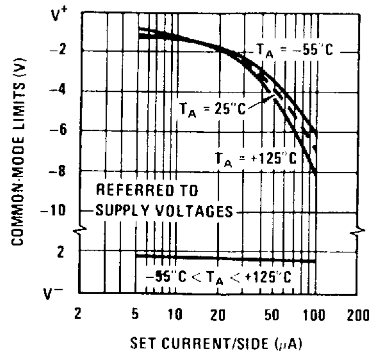


Common-Mode Limits

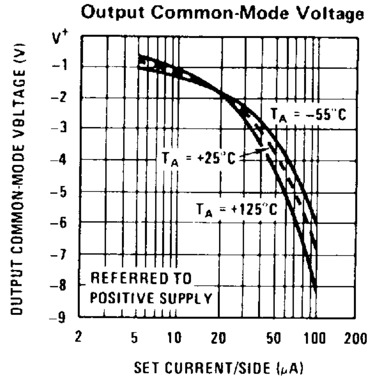


Typical Performance Characteristics (Continued)

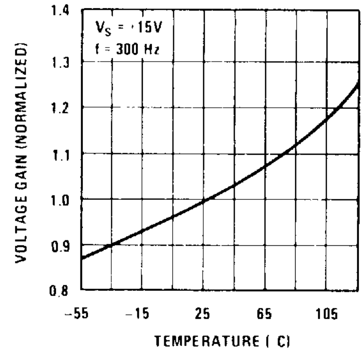
Common-Mode Limits



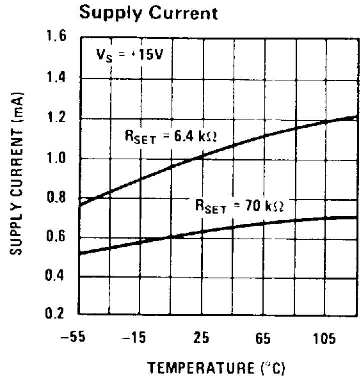
Output Common-Mode Voltage



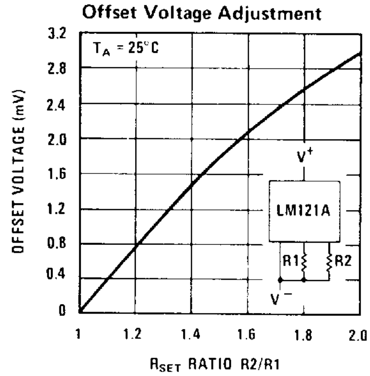
Differential Voltage Gain



Supply Current



Offset Voltage Adjustment



Common-Mode Rejection Ratio