ANALOG DEVICES

Dual Micropower Operational Amplifier

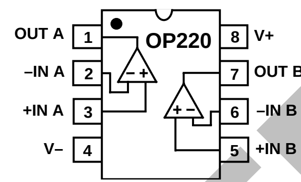
OP220

FEATURES

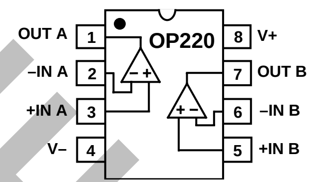
- **Excellent TCV_{OS} Match: 2 μV/°C Max**
- **Low Input Offset Voltage: 150 μV Max**
- **Low Supply Current: 100 μA**
- **Single-Supply Operation: 5 V to 30 V**
- **Low Input Offset Voltage Drift: 0.75 μV/°C Max**
- **High Open-Loop Gain: 2,000 V/mV**
- **High PSRR: 3 μV/V**
- **Low Input Bias Current: 12 nA**
- **Wide Common-Mode Voltage Range: V– to Within 1.5 V of V+**
- **Pin Compatible with 1458, LM158, and LM2904**
- **Available in Die Form**

PIN CONFIGURATIONS

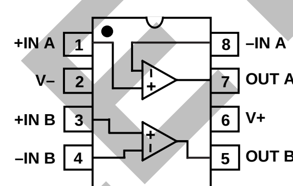
8-Lead Hermatic Dip (Z-Suffix)



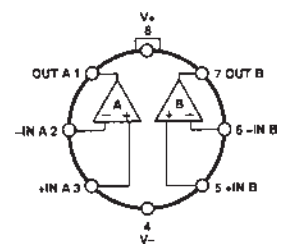
8-Lead Plastic Dip (P-Suffix)



8-Lead SOIC (S-Suffix)



8-Lead TO-99 (J-Suffix)

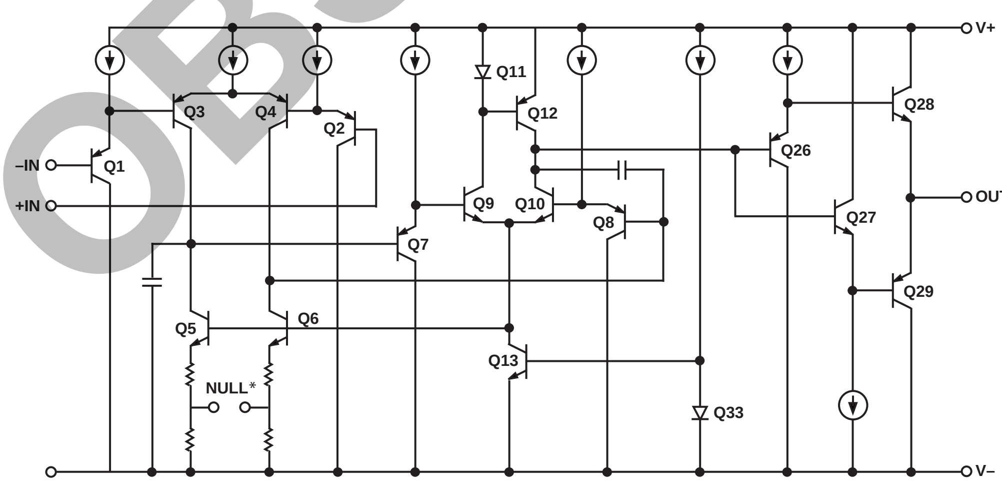


GENERAL DESCRIPTION

The OP220 is a monolithic dual operational amplifier that can be used either in single or dual supply operation. The low offset voltage and input offset voltage tracking as low as 1.0 μV/°C, make this the first micropower precision dual operational amplifier.

The excellent specifications of the individual amplifiers combined with the tight matching and temperature tracking between channels provides high performance in instrumentation amplifier designs. The individual amplifiers feature extremely low input offset voltage, low offset voltage drift, low noise voltage, and low bias current. They are fully compensated and protected.

Matching between channels is provided on all critical parameters including input offset voltage, tracking of offset voltage versus temperature, noninverting bias currents, and common-mode rejection ratios.



*ACESSIBLE IN CHIP FORM ONLY

Figure 1. Simplified Schematic

REV. A

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Fax: 781/326-8703

OP220–SPECIFICATIONS

ELECTRICAL CHARACTERISTICS (@ V_S = ±2.5 V to ±15 V, T_A = 25°C, unless otherwise noted.)

Parameter	Symbol	Conditions	OP220A/E Min	OP220A/E Typ	OP220A/E Max	OP220F Min	OP220F Typ	OP220F Max	OP220C/G Min	OP220C/G Typ	OP220C/G Max	Unit
Input Offset Voltage	V_{OS}	V_S = ±2.5 V to ±15 V		120	150		250	300		500	750	µV
Input Offset Current	I_{OS}	V_{CM} = 0		0.15	1.5		0.2	2		0.2	3.5	nA
Input Bias Current	I_B	V_{CM} = 0		12	20		13	25		14	30	nA
Input Voltage Range	IVR	V+ = 5 V, V– = 0 V V_S = ±15 V	0/3.5 –15/+13.5			0/3.5 –15/+13.5			0/3.5 –15/+13.5			V V
Common-Mode Rejection Ratio	CMRR	V+ = 5 V, V– = 0 V 0 V ≤ V_{CM} ≤ 3.5 V V_S = ±15 V –15 V ≤ V_{CM} ≤ +13.5 V	90 95	100 100		85 90	90 95		75 80	85 90		dB dB
Power Supply Rejection Ratio	PSRR	V_S = ±2.5 V to ±15 V, V– = 0 V, V+ = 5 V to 30 V		3 6	10 18		10 18	32 57		32 57	100 180	µV/V µV/V
Large-Signal Voltage Gain	A_{VO}	V+ = 5 V, V– = 0 V, R_L = 100 kΩ, 1 V ≤ V_O ≤ 3.5 V V_S = ±15 V, R_L = 25 kΩ V_O = ±10 V	500 1,000	1,000 2,000		500 1,000	800 2,000		300 800	500 1,600		V/mV V/mV
Output Voltage Swing	V_O	V+ = 5 V, V– = 0 V R_L = 10 kΩ V_S = ±15 V, R_L = 25 kΩ	0.7/4 ±14			0.7/4 ±14			0.8/4 ±14			V V
Slew Rate*	SR	R_L =25 kΩ		0.05			0.05			0.05		V/µs
Bandwidth	BW	A_{VCL} = 1, R_L =25 kΩ		200			200			200		kHz
Supply Current (Both Amplifiers)	I_{SY}	V_S = ±2.5 V, No Load V_S = ±15 V, No Load		100 140	115 170		115 150	125 190		125 205	135 220	µA µA

*Sample tested.

ELECTRICAL CHARACTERISTICS (V_S = ±2.5 V to ±15 V, –55°C ≤ T_A ≤ +125°C for OP220A/C, –25°C ≤ T_A ≤ +85°C for OP220E/F, –40°C ≤ T_A ≤ +85°C for OP220G unless otherwise noted.)

Parameter	Symbol	Conditions	OP220A/E Min	OP220A/E Typ	OP220A/E Max	OP220F Min	OP220F Typ	OP220F Max	OP220C/G Min	OP220C/G Typ	OP220C/G Max	Unit
Input Offset Voltage Drift*	TCV_{OS}	V_S = ±15 V		0.75	1.5		1.2	2		2	3	µV/°C
Input Offset Voltage	V_{OS}			200	300		400	500		1,000	1,300	µV
Input Offset Current	I_{OS}	V_{CM} = 0		0.5	2		0.6	2.5		0.6	5	nA
Input Bias Current	I_B	V_{CM} = 0		12	25		13	30		14	40	nA
Input Voltage Range	IVR	V+ = 5 V, V– = 0 V V_S = ±15 V	0/3.2 –15/+13.2			0/3.2 –15/+13.2			0/3.2 –15/+13.2			V V
Common-Mode Rejection Ratio	CMRR	V+ = 5 V, V– = 0 V 0 V ≤ V_{CM} ≤ 3.2 V V_S = ±15 V –15 V ≤ V_{CM} ≤ +13.2 V	86 90	90 95		80 85	85 90		70 75	80 85		dB dB
Power Supply Rejection Ratio	PSRR	V_S = ±2.5 V to ±15 V, V– = 0 V, V+ = 5 V to 30 V		6 10	18 32		18 32	57 100		57 100	180 320	µV/V µV/V
Large-Signal Voltage Gain	A_{VO}	V_S = ±15 V, R_L = 50 kΩ V_O = ±10 V	500	1,000		500	800		400	500		V/mV
Output Voltage Swing	V_O	V+ = 5 V, V– = 0 V R_L = 20 kΩ V_S = ±15 V, R_L = 50 kΩ	0.9/3.8 ±13.6			0.9/3.8 ±13.6			1.0/3.8 ±13.6			V V
Supply Current (Both Amplifiers)	I_{SY}	V_S = ±2.5 V, No Load V_S = ±15 V, No Load		135 190	170 250		155 200	185 280		170 275	210 330	µA µA

*Sample tested.

MATCHING CHARACTERISTICS (@ V_S = ±15 V, T_A = 25°C, unless otherwise noted.)

Parameter	Symbol	Conditions	OP220A/E Min	OP220A/E Typ	OP220A/E Max	OP220F Min	OP220F Typ	OP220F Max	OP220C/G Min	OP220C/G Typ	OP220C/G Max	Unit
Input Offset Voltage Match	ΔV_{OS}			150	300		250	500		300	800	µV
Average Noninverting Bias Current	I_B+	V_{CM} = 0		10	20		15	25		20	30	nA
Noninverting Offset Current	I_{OS}+	V_{CM} = 0		0.7	1.5		1	2		1.4	2.5	nA
Common-Mode Rejection Ratio Match[1]	ΔCMRR	V_{CM} = –15 V to +13.5 V	92	100		87	95		72	85		dB
Power Supply Rejection Ratio Match[2]	ΔPSRR	V_S = ±2.5 V to ±15 V,		6	14		18	44		57	140	µV/V

NOTES
[1]ΔCMRR is 20 $\log_{10} V_{CM}/\Delta CME$, where V_{CM} is the voltage applied to both noninverting inputs and ΔCME is the difference in common-mode input-referred error.
[2]ΔPSRR is $\frac{\text{Input Referred Differential Error}}{\Delta V_S}$.
[3]Sample tested.

MATCHING CHARACTERISTICS (V_S = ±15 V, –55°C ≤ T_A ≤ +125°C for OP220A/C, –25°C ≤ T_A ≤ +85°C for OP220E/F, –40°C ≤ T_A ≤ +85°C for OP220G unless otherwise noted. Grades E, F are sample tested.)

Parameter	Symbol	Conditions	OP220A/E Min	OP220A/E Typ	OP220A/E Max	OP220F Min	OP220F Typ	OP220F Max	OP220C/G Min	OP220C/G Typ	OP220C/G Max	Unit
Input Offset Voltage Match	ΔV_{OS}			250	500		400	800		800	1,800	µV
Input Offset Voltage Tracking[1]	$TC\Delta V_{OS}$			1	2		1.5	3		1.5	5	µV/°C
Average Noninverting Bias Current	I_B+	V_{CM} = 0		10	25		15	30		22	40	nA
Average Drift of Noninverting Bias Current[1]	TCI_B+	V_{CM} = 0		15	25		15	30		30	50	pA/°C
Noninverting Offset Current	I_{OS}+	V_{CM} = 0		0.7	2		1	2.5		2.5	5	nA
Average Drift of Noninverting Offset Current[1]	TCI_{OS}+	V_{CM} = 0		7	15		12	22.5		15	30	pA/°C
Common-Mode Rejection Ratio Match[2]	ΔCMRR	V_{CM} = –15 V to +13 V	87	96		82	96		72	80		dB
Power Supply Rejection Ratio Match[3]	ΔPSRR	V_S = ±2.5 V to ±15 V,		10	26		30	78		57	250	µV/V

NOTES
[1]Sample tested.
[2]ΔCMRR is 20 $\log_{10} V_{CM}/\Delta CME$, where V_{CM} is the voltage applied to both noninverting inputs and ΔCME is the difference in common-mode input-referred error.
[3]ΔPSRR is $\frac{\text{Input Referred Differential Error}}{\Delta V_S}$.

TYPICAL ELECTRICAL CHARACTERISTICS (@ V_S = ±15 V, T_A = 25°C, unless otherwise noted.)

Parameter	Symbol	Conditions	OP220N Typical	Unit
Average Input Offset Voltage Drift	TCV_{OS}		1.5	µV/°C
Large-Signal Voltage Gain	A_{VO}	R_L = 25 kΩ	2000	V/mV

OP220–SPECIFICATIONS

ABSOLUTE MAXIMUM RATINGS*

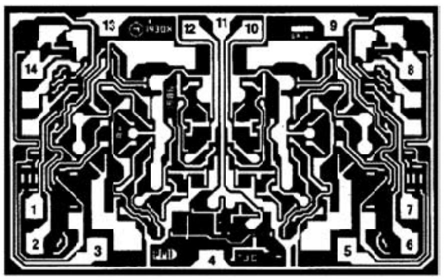
Supply Voltage . . . . ±18 V
Differential Input Voltage . . . . 30 V or Supply Voltage
Input Voltage . . . . Supply Voltage
Output Short-Circuit Duration Indefinite
Storage Temperature Range . . . . –65°C to +150°C
Junction Temperature (T_j) . . . . –65°C to +150°C
Operating Temperature Range
  OP220A/OP220C . . . . –55°C to +125°C
  OP220E/OP220F . . . . –25°C to +85°C
  OP220G . . . . –40°C to +85°C
Lead Temperature Range (Soldering, 60 sec) . . . . 300°C

NOTES
*Absolute Maximum Ratings apply to packaged parts, unless otherwise noted.

Package Type	θ_{JA}*	θ_{JC}	Unit
8-Lead Hermetic DIP (Q)	148	16	°C/W
8-Lead Plastic DIP (N)	103	43	°C/W
8-Lead SOL (RN)	158	43	°C/W
TO-99 (H)	150	18	°C/W

*θ_{JA} is specified for worst-case mounting conditions, i.e., θ_{JA} is specified for device in socket for CERDIP and PDIP packages; θ_{JA} is specified for device soldered to printed circuit board for SO packages.

DIE CHARACTERISTICS



1. INVERTING INPUT (A)
2. NONINVERTING INPUT (A)
3. BALANCE (A)
4. V–
5. BALANCE (B)
6. NONINVERTING INPUT (B)
7. INVERTING INPUT (B)
8. BALANCE (B)
9. V+
10. OUT (B)
11. V+
12. OUT (A)
13. V+
14. BALANCE (A)

DIE SIZE 0.097 INCH × 0.063 INCH, 6111 SQ. MILS
(2.464 mm × 1.600 mm, 3.94 SQ. mm)

NOTE : ALL V+ PADS ARE INTERNALL CONNECTED

ORDERING GUIDE

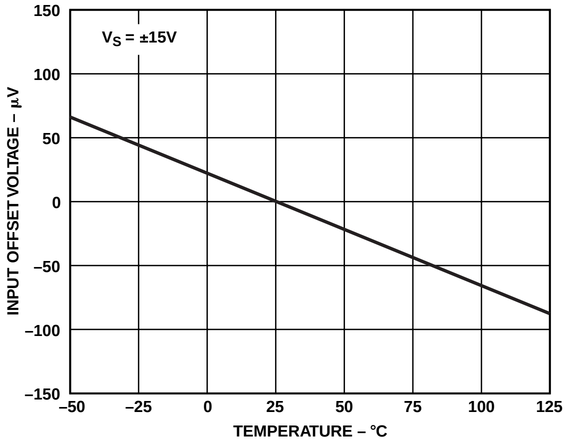
T_A = 25°C V_{OS} MAX (mV)	Package Options CERDIP	Plastic	TO-99	Operating Temperature Range
150	OP220AZ*			MIL
150	OP220EZ*			IND
300	OP220FZ*			IND
750		OP220CJ*	MIL	
750	OP220GZ*	OP220GP*		XIND
750		OP220GS		XIND

For military processed devices, please refer to the Mil Standard Data Sheet
OP220AJ/883*.
*Not for new design. Obsolete April 2002.

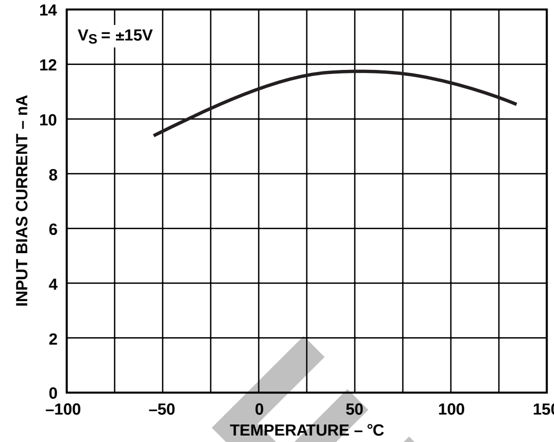
WAFER TEST LIMITS (@ V_S = ±2.5 V, to ±15 V, T_A = 25°C, unless otherwise noted.)

Parameter	Symbol	Conditions	OP220N Limit	Unit
Input Offset Voltage	V_{OS}		200	µV Max
Input Offset Voltage Match	ΔV_{OS}		300	µV Max
Input Offset Current	I_{OS}	V_{CM} = 0	2	nA Max
Input Bias Current	I_B	V_{CM} = 0	25	nA Max
Input Voltage Range	IVR	V_S = ±15 V	–15/13.5	V Min
Common-Mode Rejection Ratio	CMRR	V– = 0 V, V+ = 5 V, 0 V ≤ V_{CM} ≤ 3.5 V –15 V ≤ V_{CM} ≤ 13.5 V, V_S = ±15 V	88 93	dB Min
Power Supply Rejection Ratio	PSRR	V_S = ±2.5 V to ±15 V V– = 0 V, V+ = 5 V to 30 V	12.5 22.5	µV/V Max
Large-Signal Voltage Gain	A_{VO}	R_L = 25 kΩ, V_S = ±15 V V_O = ±10 V	1000	V/mV Min
Output Voltage Swing	V_O	V+ = 5 V, V– = 0 V, R_L = 10 kΩ V_S = ±15 V, R_L = 25 kΩ	0.7/4 ±14	V Min
Supply Current (Both Amplifiers)	I_{SY}	V_S = ±2.5 V, No Load V_S = ±15 V, No Load	125 190	µA Max

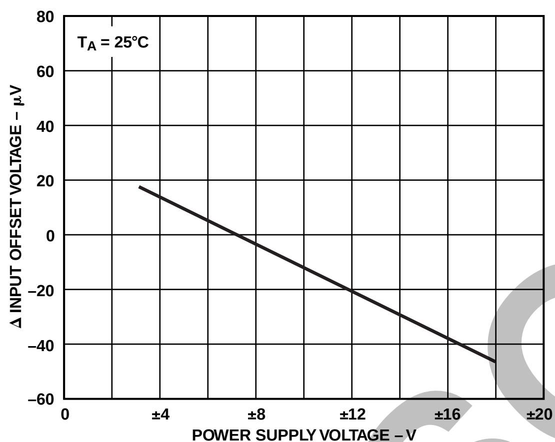
NOTE
Electrical tests are performed at wafer probe to the limits shown. Due to variations in assembly methods and normal yield loss, yield after packing is not guaranteed for standard product dice. Consult factory to negotiate specifications based on die lot qualification through sample lot assembly and testing.



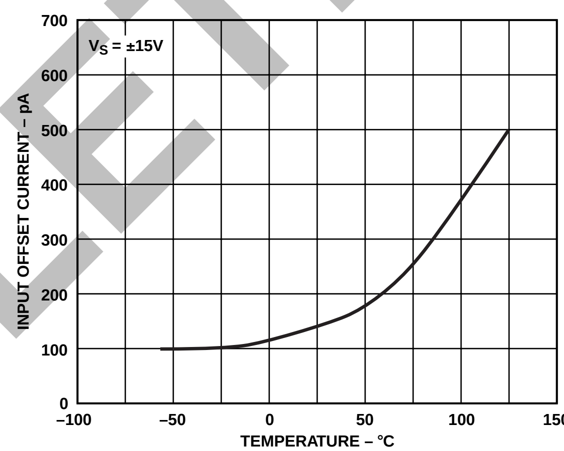
TPC 1. *Normalized Offset Voltage vs. Temperature*



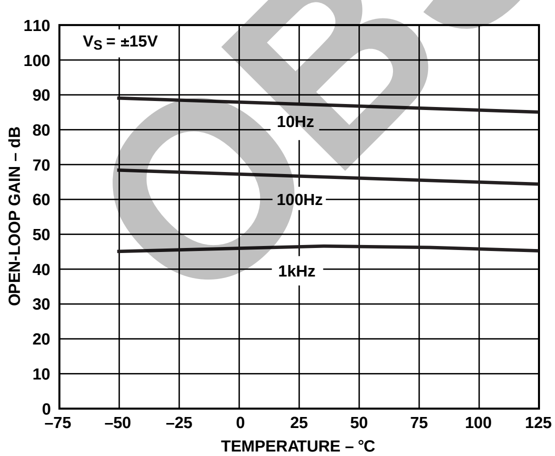
TPC 4. *Input Bias Current vs. Temperature*



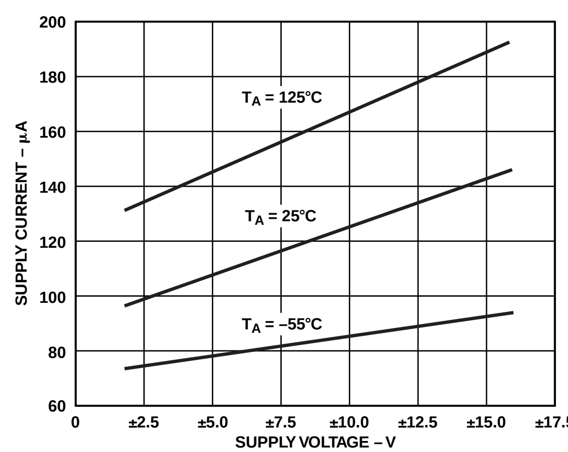
TPC 2. *Input Offset Voltage vs. Power Supply Voltage*



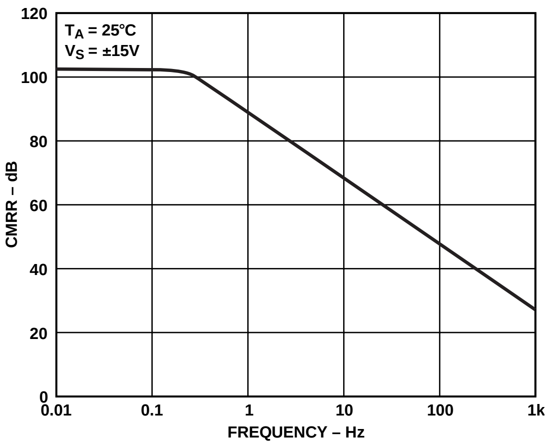
TPC 5. *Input Offset Current vs. Temperature*



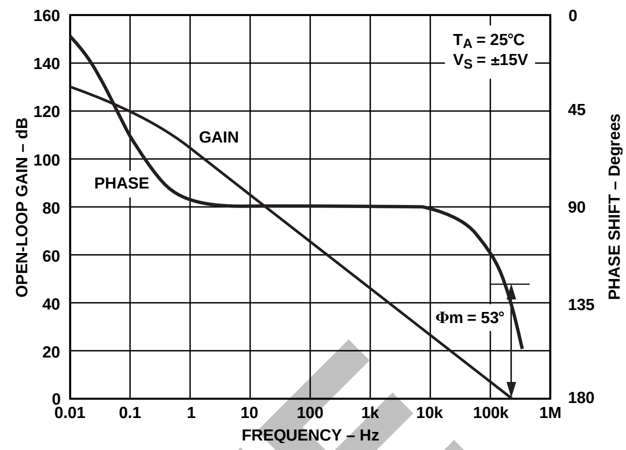
TPC 3. *Open-Loop Gain vs. Temperature*



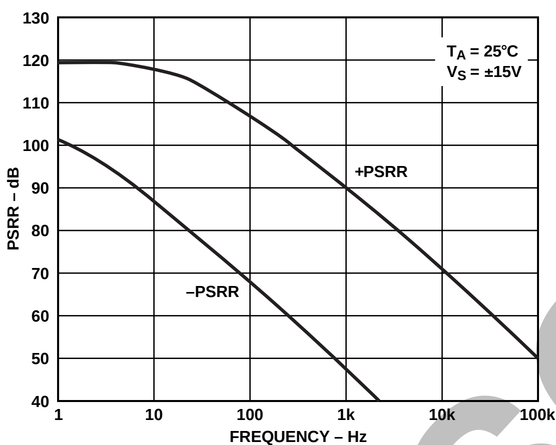
TPC 6. *Supply Current vs. Supply Voltage*



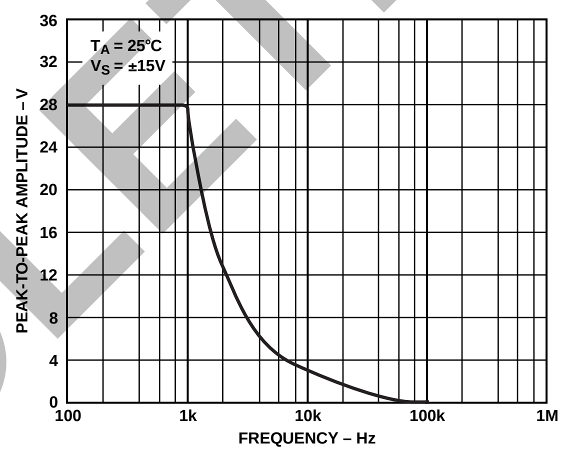
TPC 7. CMRR vs. Frequency



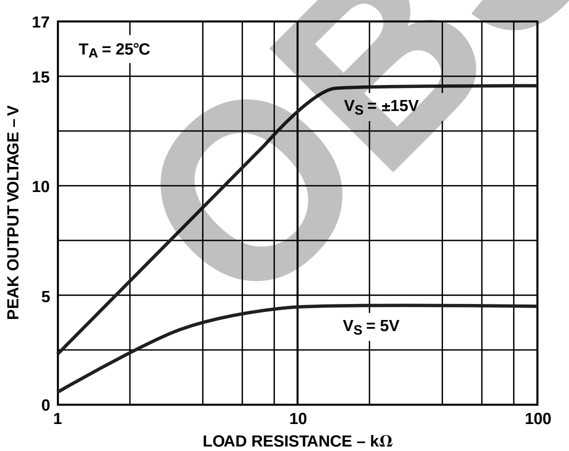
TPC 10. Open-Loop Voltage Gain and Phase vs. Frequency



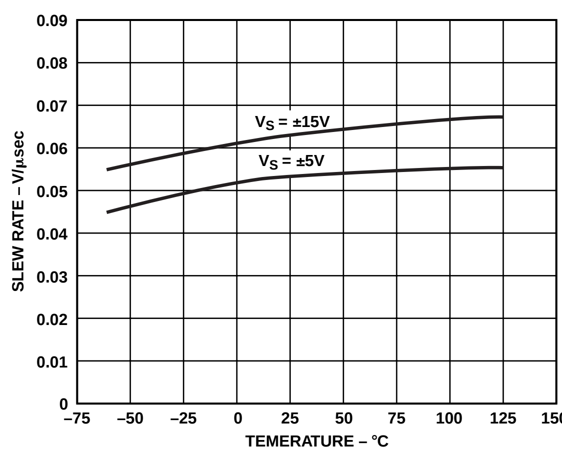
TPC 8. PSRR vs. Frequency



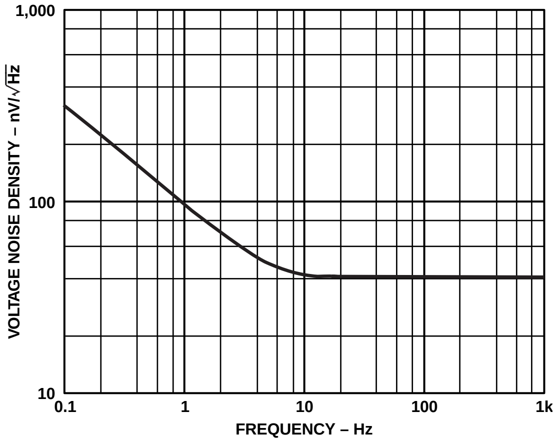
TPC 11. Maximum Output Swing vs. Frequency



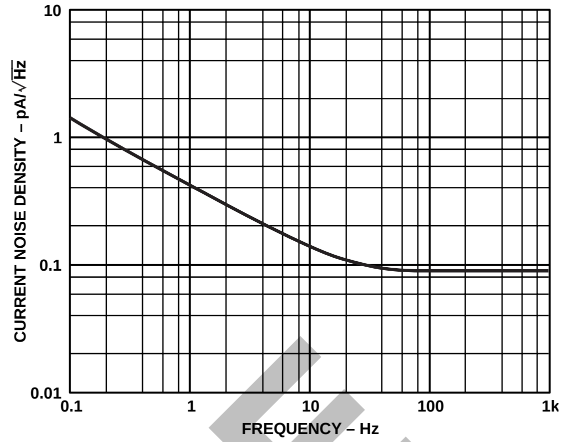
TPC 9. Maximum Output Voltage vs. Load Resistance



TPC 12. Slew Rate vs. Temperature



TPC 13. Voltage Noise Density vs. Frequency



TPC 14. Noise Density vs. Frequency

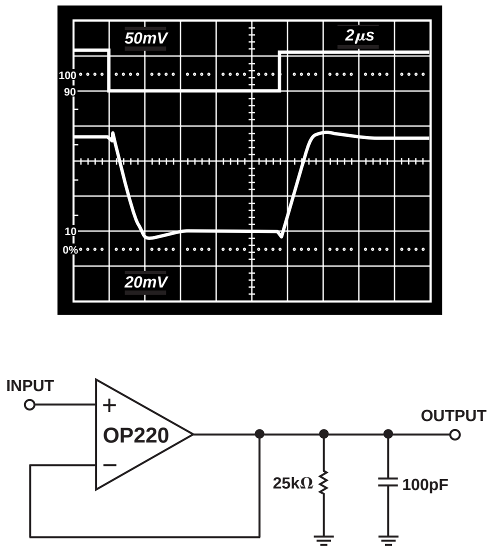


Figure 2. Small-Signal Transient Response

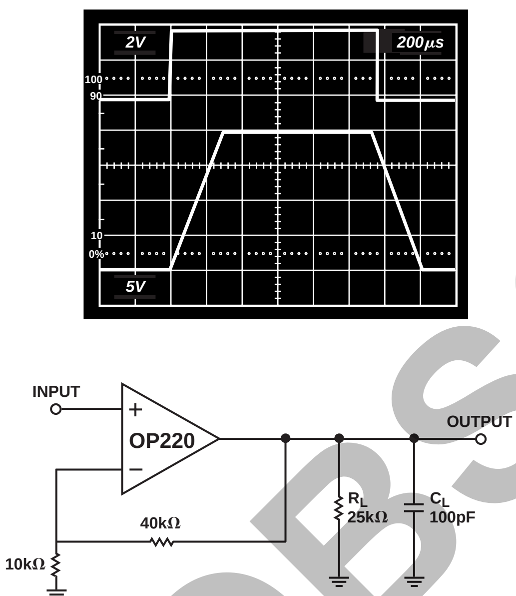


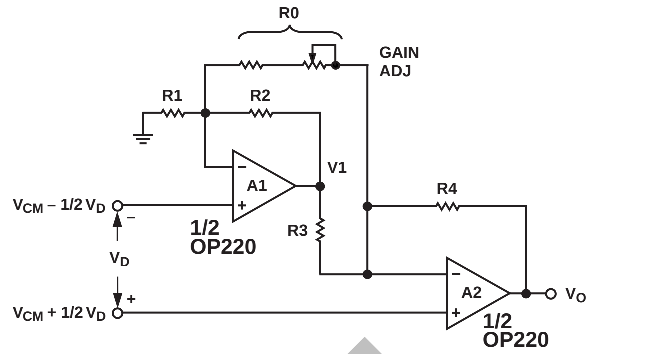
Figure 3. Large-Signal Transient Response

INSTRUMENTATION AMPLIFIER APPLICATIONS OF THE OP220

Two Op Amp Configuration

The excellent input characteristics of the OP220 make it ideal for use in instrumentation amplifier configurations where low-level differential signals are to be amplified. The low-noise, low input offsets, low drift, and high gain combined with excellent CMRR provide the characteristics needed for high-performance instrumentation amplifiers. In addition, the power supply current drain is very low.

The circuit of Figure 4 is recommended for applications where the common-mode input range is relatively low and differential gain will be in the range of 10 to 1,000. This two op amp instrumentation amplifier features independent adjustment of common-mode rejection and differential gain. Input impedance is very high since both inputs are applied to noninverting op amp inputs.



$$V_O = \frac{R4}{R3}\left[1+\frac{1}{2}\left(\frac{R2}{R1}+\frac{R3}{R4}\right)+\frac{R2+R3}{R0}\right]V_D + \frac{R4}{R3}\left(\frac{R3}{R4}-\frac{R2}{R1}\right)V_{CM}$$

$$\text{If } R1 = R2 = R3 = R4, \text{then } V_O = 2\left(1+\frac{R1}{R0}\right)V_D$$

Figure 4. Two Op Amp Instrumentation Amplifier Configuration

The input voltages are represented as a common-mode input V_{CM} plus a differential input V_D. The ratio R3/R4 is made equal to the ratio R2/R, to reject the common-mode input V_{CM}. The differential signal V_D is then amplified according to:

$$V_O = \frac{R4}{R3}\left(1+\frac{R3}{R4}+\frac{R2+R3}{R_O}\right)V_D, \text{where } \frac{R3}{R4} = \frac{R2}{R1}$$

Note that gain can be independently varied by adjusting R_O. From considerations of dynamic range, resistor tempco matching, and matching of amplifier response, it is generally best to make RX, R2, R3, and R4 approximately equal. Designating R1, R2, R3, and R4 as RN allows the output equation to be further simplified:

$$V_O = 2\left(1+\frac{R_N}{R_O}\right)V_D, \text{where } R_N = R1 = R2 = R3 = R4$$

Dynamic range is limited by A1 as well as A2; the output of A1 is:

$$V1 = -\left(1+\frac{R_N}{R_O}\right)V_D + 2\,V_{CM}$$

If the instrumentation amplifier were designed for a gain of 10 and maximum V_D of ±1 V, then R_N/R_O would need to be four and V_O would be a maximum of ±10 V. Amplifier A1 would have a maximum output of ±5 V plus 2 V_{CM}, thus a limit of ±10 V on the output of A1 would imply a limit of ±2.5 V on V_{CM}.

A nominal value of 100 kΩ for R_N is suitable for most applications. A range of 200 Ω to 25 kΩ for R_O will then provide a gain range of 10 to 1,000. The current through R_O is V_D/R_O, so the amplifiers must supply ±10 mV/200 Ω when the gain is at the maximum value of 1,000 and V_D is at ±10 mV.

Rejecting common-mode inputs is most important in accurately amplifying low-level differential signals. Two factors determine the CMR of this instrumentation amplifier configuration (assuming infinite gain):

1. CMRR of the op amps
2. Matching of the resistor network (R3/R4 = R2/R1)

In this instrumentation amplifier configuration, error due to CMRR effect is directly proportional to the differential CMRR of the op amps. For the OP220A/E, this combined CMRR is a minimum of 98 dB. A combined CMRR value of 100 dB and common-mode input range of ±2.5 V indicates a peak input-referred error of only ±25 μV.

Resistor matching is the other factor affecting CMRR. Defining Ad as the differential gain of the instrumentation amplifier and assuming that R1, R2, R3 and R4 are approximately equal (R_N will be the nominal value), then CMRR will be approximately A_D divided by $4\Delta R/R_N$. CMRR at differential gain of 100 would be 88 dB with resistor matching of 0.1%. Trimming R1 to make the ratio R3/R4 equal to R2/R1 will directly raise the CMRR until it is limited by linearity and resistor stability considerations.

The high open-loop gain of the OP220 is very important in achieving high accuracy in the two-op-amp instrumentation amplifier configuration. Gain error can be approximated by:

$$\text{Gain Error} = \frac{1}{1+\dfrac{A_D}{A_{02}}},\ \frac{A_D}{2A_{01}A_{02}} < 1$$

where A_D is the instrumentation amplifier differential gain and A_{02} is the open-loop gain of op amp A2. This analysis assumes equal values of R1, R2, R3, and R4. For example, consider an OP220 with A_{02} of 700 V/mV. If the differential gain A_D were set to 700, the gain error would be 1/1.001 which is approximately 0.1%.

Another effect of finite op amp gain is undesired feedthrough of common-mode input. Defining A_{01} as the open-loop gain of op amp A1, then the common-mode error (CME) at the output due to this effect will be approximately:

$$CME = \frac{2A_D}{1+\dfrac{A_D}{A_{01}}}\frac{1}{A_{01}}V_{CM}$$

For AD/A01, < 1, this simplifies to $(2\,A_D/A_{01}) \times V_{CM}$. If the op amp gain is 700 V/mV, V_{CM} is 2.5 V, and A_D is set to 700, then the error at the output due to this effect will be approximately 5 mV.

The OP220 offers a unique combination of excellent dc performance, wide input range, and low supply current drain that is particularly attractive for instrumentation amplifier design.

THREE OP AMP CONFIGURATION

A three op amp instrumentation amplifier configuration using the OP220 and OP777 is recommended for applications requiring high accuracy over a wide gain range. This circuit provides excellent CMR over a wide input range. As with the two op amp instrumentation amplifier circuits, tight matching of the two op amps provides a real boost in performance.

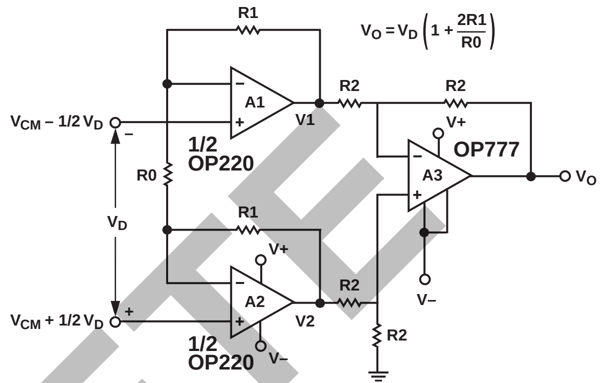


Figure 5. Three Op Amp Instrumentation Amplifier Using OP220 and OP777

A simplified schematic is shown in Figure 2. The input stage (A1 and A2) serves to amplify the differential input V_D without amplifying the common-mode voltage V_{CM}. The output stage then rejects the common-mode input. With ideal op amps and no resistor matching errors, the outputs of each amplifier will be:

$$V1 = -\left(1+\frac{2R1}{R_O}\right)\frac{V_D}{2} + V_{CM}$$

$$V2 = \left(1+\frac{2R1}{R_O}\right)\frac{V_D}{2} + V_{CM}$$

$$V_O = V2 - V1 = \left(1+\frac{2R1}{R_O}\right)V_D$$

$$V_O = A_D V_D$$

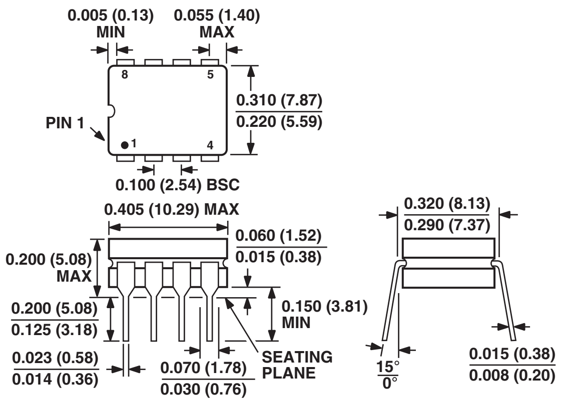
The differential gain A_D is 1 + 2R1/RO and the common-mode input V_{CM} is rejected.

This three op amp instrumentation amplifier configuration using an OP220 at the input and an OP777 at the output provides excellent performance over a wide gain range with very low power consumption. A gain range of 1 to 2,000 is practical and CMR of over 120 dB is readily achievable.

OUTLINE DIMENSIONS

8-Lead Ceramic DIP – Glass Hermatic Seal [CERDIP] (Q-8)

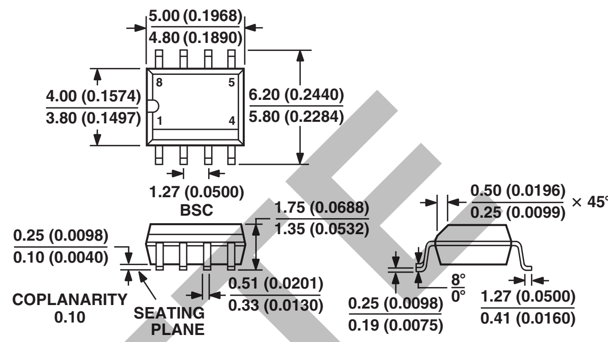
Dimensions shown in inches and (millimeters)



CONTROLLING DIMENSIONS ARE IN INCH; MILLIMETERS DIMENSIONS (IN PARENTHESES) ARE ROUNDED-OFF MILLIMETER EQUIVALENTS FOR REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN

8-Lead Standard Small Outline Package [SOIC] Narrow Body (RN-8)

Dimensions shown in millimeters and (inches)

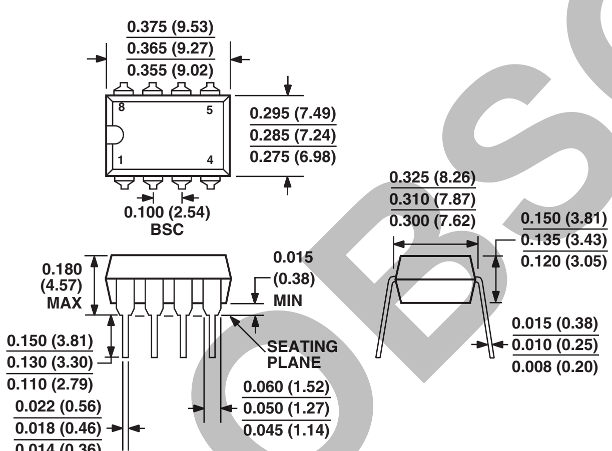


COMPLIANT TO JEDEC STANDARDS MS-012AA

CONTROLLING DIMENSIONS ARE IN MILLIMETERS; INCH DIMENSIONS (IN PARENTHESES) ARE ROUNDED-OFF MILLIMETER EQUIVALENTS FOR REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN

8-Lead Plastic Dual-in-Line Package [PDIP] (N-8)

Dimensions shown in inches and (millimeters)



COMPLIANT TO JEDEC STANDARDS MO-095AA

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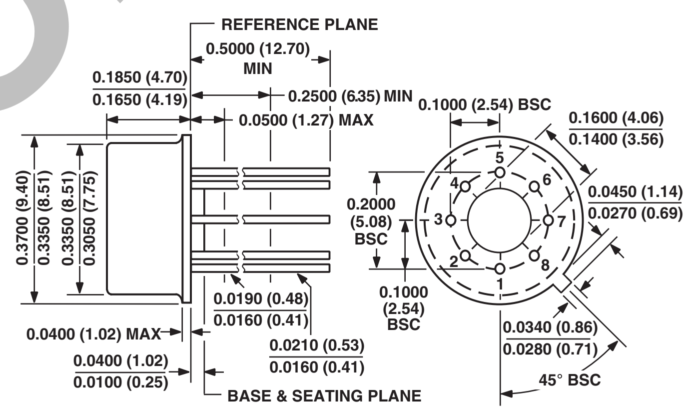
8-Lead Metal Can [TO-99] (H-08)

Dimensions shown in inches and (millimeters)



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Revision History

Location	Page

10/02—Data Sheet changed from REV. 0 to REV. A.

C00323–0–10/02(A)

PRINTED IN U.S.A.