Single-Supply, Low Cost Instrumentation Amplifier

AD8223

FEATURES

- Gain set with 1 resistor
  - Gain = 5 to 1000
- Inputs
  - Voltage range to 150 mV below negative rail
  - 25 nA maximum input bias current
  - 30 nV/√Hz, RTI noise @ 1 kHz
- Power supplies
  - Dual supply: ±2 V to ±12 V
  - Single supply: 3 V to 24 V
  - 500 µA maximum supply current

APPLICATIONS

- Low power medical instrumentation
- Transducer interface
- Thermocouple amplifiers
- Industrial process controls
- Difference amplifiers
- Low power data acquisition

CONNECTION DIAGRAM

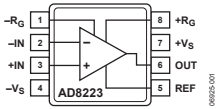

Figure 1. 8-Lead SOIC (R) and 8-Lead MSOP (RM) Packages

Table 1. Instrumentation Amplifiers by Category

General-Purpose	Zero Drift	Mil Grade	Low Power	High Voltage PGA
AD8220[1]	AD8231[1]	AD620	AD627[1]	AD8250
AD8221	AD8553[1]	AD621	AD623[1]	AD8251
AD8222	AD8555[1]	AD524	AD8223	AD8253
AD8224[1]	AD8556[1]	AD526		
AD8228	AD8557[1]	AD624		

[1] Rail-to-rail output.

GENERAL DESCRIPTION

The AD8223 is an integrated single-supply instrumentation amplifier that delivers rail-to-rail output swing on a single supply (3 V to 24 V). The AD8223 conforms to the 8-lead industry standard pinout configuration.

The AD8223 is simple to use: one resistor sets the gain. With no external resistor, the AD8223 is configured for G = 5. With an external resistor, the AD8223 can be programmed for gains up to 1000.

The AD8223 has a wide input common-mode range and can amplify signals that have a 150 mV common-mode voltage below ground. Although the design of the AD8223 is optimized to operate from a single supply, the AD8223 still provides excellent performance when operated from a dual voltage supply (±2 V to ±12 V).

Low power consumption (1.5 mW at 3 V), wide supply voltage range, and rail-to-rail output swing make the AD8223 ideal for battery-powered applications. The rail-to-rail output stage maximizes the dynamic range when operating from low supply voltages. The AD8223 replaces discrete instrumentation amplifier designs and offers superior linearity, temperature stability, and reliability in a minimum of space.

Rev. 0

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DUAL SUPPLY

T_A = 25°C, $-V_S$ = −12 V, $+V_S$ = +12 V, and R_L = 10 kΩ to ground, unless otherwise noted.[1]

Table 3.

Parameter	Conditions	AD8223A Min	AD8223A Typ	AD8223A Max	AD8223B Min	AD8223B Typ	AD8223B Max	Unit
COMMON-MODE REJECTION RATIO								
DC to 60 Hz with 1 kΩ Source Imbalance	V_{CM} = −10 V to 10 V							
G = 5		80			86			dB
G = 10		86			90			dB
G = 100		90			96			dB
G = 1000		90			96			dB
NOISE	$V_{IN+} = V_{IN-} = V_{REF}$ = 0 V							
Voltage Noise, 1 kHz								
G = 5			50			50		nV/√Hz
G = 1000			30			30		nV/√Hz
RTI, 0.1 Hz to 10 Hz								
G = 5			1.0			1.0		µV p-p
G = 1000			0.6			0.6		µV p-p
Current Noise, 1 kHz			70			70		fA/√Hz
0.1 Hz to 10 Hz			1.2			1.2		pA p-p
VOLTAGE OFFSET	Total RTI error = $V_{OSI} + V_{OSO}/G$							
Input Offset, V_{OSI}				250			100	µV
Over Temperature	T_A = −40°C to +85°C			400			160	µV
Average TC	T_A = −40°C to +85°C			2			1	µV/°C
Output Offset, V_{OSO}				1500			1000	µV
Over Temperature	T_A = −40°C to +85°C			2000			1500	µV
Average TC	T_A = −40°C to +85°C			15			10	µV/°C
Offset Referred to Input vs. Supply (PSR)	$+V_S$ = 5 V to 12 V, $-V_S$ = −5 V to −12 V							
G = 5		80			86			dB
G = 10		86			90			dB
G = 100		90			96			dB
G = 1000		90			96			dB
INPUT CURRENT								
Input Bias Current		5	12	25	5	12	25	nA
Over Temperature	T_A = −40°C to +85°C	5		28	5		28	nA
Average Temperature Coefficient	T_A = −40°C to +85°C		50			50		pA/°C
Input Offset Current			0.25	2		0.25	2	nA
Over Temperature	T_A = −40°C to +85°C			2.5			2.5	nA
Average Temperature Coefficient	T_A = −40°C to +85°C		5			5		pA/°C
DYNAMIC RESPONSE								
Small Signal −3 dB Bandwidth								
G = 5			200			200		kHz
G = 10			200			200		kHz
G = 100			70			70		kHz
G = 1000			7			7		kHz
Slew Rate			0.3			0.3		V/µs
Settling Time to 0.01%	Step size = 10 V							
G = 5			30			30		µs
G = 10			30			30		µs
G = 100			30			30		µs
G = 1000			150			150		µs

Parameter	Conditions	AD8223A Min	AD8223A Typ	AD8223A Max	AD8223B Min	AD8223B Typ	AD8223B Max	Unit
GAIN	G = 5 + (80 kΩ/R_G)							
Gain Range		5		1000	5		1000	V/V
Gain Error[2]	V_{OUT} = −10 V to +10 V							
G = 5				0.07			0.02	%
G = 10			0.10	0.3		0.10	0.2	%
G = 100			0.10	0.3		0.10	0.3	%
G = 1000			0.10	0.3		0.10	0.3	%
Nonlinearity	V_{OUT} = −10 V to +10 V							
G = 5			5			5		ppm
G = 1000			30			30		ppm
Gain vs. Temperature	T_A = −40°C to +85°C							
G = 5				10			2	ppm/°C
G > 5[1]			50			50		ppm/°C
INPUT								
Input Impedance								
Differential			2||2			2||2		GΩ||pF
Common-Mode			2||2			2||2		GΩ||pF
Common-Mode Input Voltage Range[3]	V_{IN+} = V_{IN-}	($-V_S$) − 0.15		($+V_S$) − 1.5	($-V_S$) − 0.15		($+V_S$) − 1.5	V
OUTPUT								
Output Swing	R_L = 10 kΩ to ground	($-V_S$) + 0.3		($+V_S$) − 0.8	($-V_S$) + 0.3		($+V_S$) − 0.8	V
	R_L = 100 kΩ to ground	($-V_S$) + 0.1		($+V_S$) − 0.3	($-V_S$) + 0.1		($+V_S$) − 0.3	V
REFERENCE INPUT								
R_{IN}			60	±20%		60	±20%	kΩ
I_{IN}	V_{IN+} = V_{IN-} = V_{REF} = 0 V		+10	+20		+10	+20	μA
Voltage Range		$-V_S$		$+V_S$	$-V_S$		$+V_S$	V
Gain to Output			1 ± 0.0002			1 ± 0.0002		V
POWER SUPPLY								
Operating Range		±2		±12	±2		±12	V
Quiescent Current				650			650	μA
Over Temperature	T_A = −40°C to +85°C			850			850	μA
TEMPERATURE RANGE								
For Specified Performance		−40		+85	−40		+85	°C

[1] Because maximum supply voltage is 24 V between the negative and positive supply, these specifications at ±12V are at the part's limit. Operation at a nominal supply voltage slightly less than ±12 V is recommended to allow for power supply tolerances.
[2] Does not include effects of external resistor, R_G.
[3] Total input range depends on common-mode voltage, differential voltage, and gain. See Figure 18 through Figure 21 and the Input Voltage Range section in the Theory of Operation section for more information.

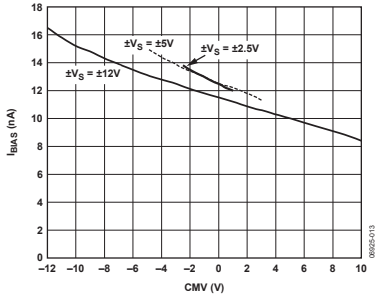


Figure 9. I_{BIAS} vs. CMV

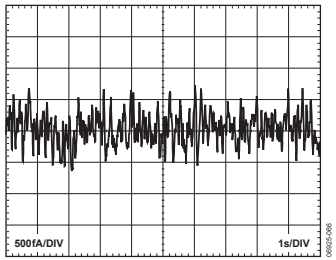


Figure 10. 0.1 Hz to 10 Hz Current Noise

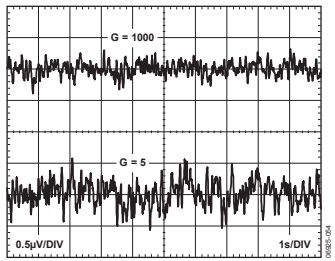


Figure 11. 0.1 Hz to 10 Hz RTI and RTO Voltage Noise

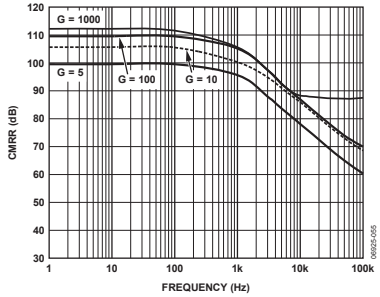


Figure 12. CMRR vs. Frequency, $\pm V_S$ = ±12

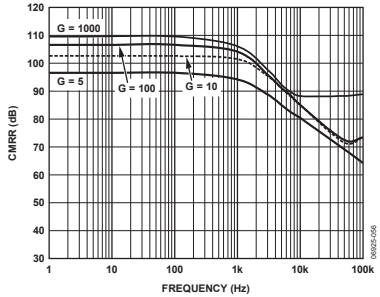


Figure 13. CMRR vs. Frequency, $+V_S$ = +5 V

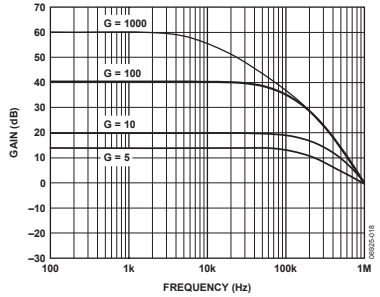


Figure 14. Gain vs. Frequency, $\pm V_S$ = ±12 V

THEORY OF OPERATION

AMPLIFIER ARCHITECTURE

The AD8223 is an instrumentation amplifier based on a classic 3-op amp approach, modified to ensure operation even at common-mode voltages at the negative supply rail. The architecture allows lower voltage offsets, better CMRR, and higher gain accuracy than competing instrumentation amplifiers in its class.

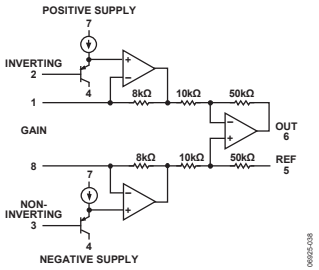


Figure 31. Simplified Schematic

Figure 31 shows a simplified schematic of the AD8223. The AD8223 has three stages. In the first stage, the input signal is applied to PNP transistors. These PNP transistors act as voltage buffers and allow input voltages below ground. The second stage consists of a pair of 8 kΩ resistors, the R_G resistor, and a pair of amplifiers. This stage allows the amplification of the AD8223 to be set with a single external resistor. The third stage is a differential amplifier composed of an op amp, two 10 kΩ resistors, and two 50 kΩ resistors. This stage removes the common-mode signal and applies an additional gain of 5.

The transfer function of the AD8223 is

$$V_{OUT} = G(V_{IN+} - V_{IN-}) + V_{REF}$$

where:

$$G = 5 + \frac{80\ \text{k}\Omega}{R_G}$$

GAIN SELECTION

Placing a resistor across the R_G terminals sets the gain of the AD8223, which can be calculated by referring to Table 7 or by using the following gain equation:

$$R_G = \frac{80\ \text{k}\Omega}{G - 5}$$

Table 7. Gains Achieved Using 1% Resistors

1% Standard Table Value of R_G (Ω)	Desired Gain	Calculated Gain
26.7 k	8	7.99
15.8 k	10	10.1
5.36 k	20	19.9
2.26 k	40	40.4
1.78 k	50	49.9
845	100	99.7
412	200	199
162	500	499
80.6	1000	998

The AD8223 defaults to G = 5 when no gain resistor is used. Add the tolerance and gain drift of the R_G resistor to the specifications of the AD8223 to determine the total gain accuracy of the system. When the gain resistor is not used, gain depends only on internal resistor matching, so gain error and gain drift are minimal.

INPUT VOLTAGE RANGE

The 3-op amp architecture of the AD8223 applies gain and then removes the common-mode voltage. Therefore, internal nodes in the AD8223 experience a combination of both the gained signal and the common-mode signal. This combined signal can be limited by the voltage supplies even when the individual input and output signals are not. To determine whether the signal can be limited, refer to Figure 18 through Figure 21. Alternatively, use the parameters in the Specifications section to verify that the input and output are not limited and then use the following formula to make sure the internal nodes are not limited.

To check if it is limited by the internal nodes,

$$-V_S + 0.01\ \text{V} < 0.6 + V_{CM} \pm \frac{|V_{DIFF}| \times Gain}{10} < +V_S - 0.1\ \text{V}$$

If more common-mode range is required, a solution is to apply less gain in the instrumentation amplifier and more in a later stage.

TEXAS INSTRUMENTS
LM7171
SNOS760C – MAY 1999 – REVISED SEPTEMBER 2014

LM7171 Very High Speed, High Output Current, Voltage Feedback Amplifier

1 Features

- (Typical Unless Otherwise Noted)
- Easy-to-Use Voltage Feedback Topology
- Very High Slew Rate: 4100 V/μs
- Wide Unity-Gain Bandwidth: 200 MHz
- −3 dB Frequency @ A_V = +2: 220 MHz
- Low Supply Current: 6.5 mA
- High Open Loop Gain: 85 dB
- High Output Current: 100 mA
- Differential Gain and Phase: 0.01%, 0.02°
- Specified for ±15V and ±5V Operation

2 Applications

- HDSL and ADSL Drivers
- Multimedia Broadcast Systems
- Professional Video Cameras
- Video Amplifiers
- Copiers/Scanners/Fax
- HDTV Amplifiers
- Pulse Amplifiers and Peak Detectors
- CATV/Fiber Optics Signal Processing

3 Description

The LM7171 is a high speed voltage feedback amplifier that has the slewing characteristic of a current feedback amplifier, yet it can be used in all traditional voltage feedback amplifier configurations. The LM7171 is stable for gains as low as +2 or −1. It provides a very high slew rate at 4100V/μs and a wide unity-gain bandwidth of 200 MHz while consuming only 6.5 mA of supply current. It is ideal for video and high speed signal processing applications such as HDSL and pulse amplifiers. With 100 mA output current, the LM7171 can be used for video distribution, as a transformer driver or as a laser diode driver.

Operation on ±15 V power supplies allows for large signal swings and provides greater dynamic range and signal-to-noise ratio. The LM7171 offers low SFDR and THD, ideal for ADC/DAC systems. In addition, the LM7171 is specified for ±5 V operation for portable applications.

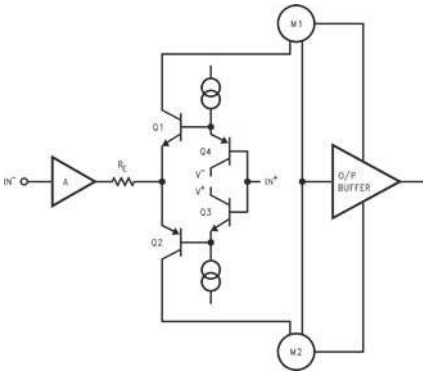
The LM7171 is built on TI's advanced VIP™ III (Vertically integrated PNP) complementary bipolar process.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM7171	SOIC (8)	4.90 mm × 3.91 mm
LM7171	PDIP (8)	9.81 mm × 6.35 mm

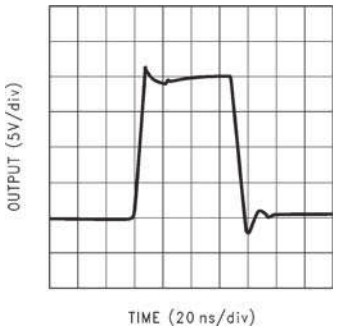
(1) For all available packages, see the orderable addendum at the end of the datasheet.

Simplified Schematic Diagram



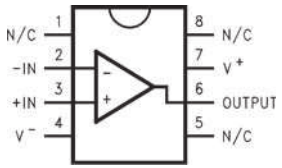
Note: M1 and M2 are current mirrors.

Large Signal Pulse Response
A_V = +2, V_S = ±15V



5 Pin Configuration and Functions

8-Pin
Package D
(Top View)



Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
N/C	1	–	No Connection
-IN	2	I	Inverting Power Supply
+IN	3	I	Non-inverting Power Supply
V-	4	I	Supply Voltage
N/C	5	–	No Connection
OUTPUT	6	O	Output
V+	7	I	Supply Voltage
N/C	8	–	No Connection

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) (1)

	MIN	MAX	UNIT
Supply Voltage (V^+–V^-)		36	V
Differential Input Voltage (2)		±10	V
Output Short Circuit to Ground (3)	Continuous		
Maximum Junction Temperature (4)		150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) Input differential voltage is applied at V_S = ±15V.
(3) Applies to both single-supply and split-supply operation. Continuous short circuit operation at elevated ambient temperature can result in exceeding the maximum allowed junction temperature of 150°C.
(4) The maximum power dissipation is a function of $T_{J(MAX)}$, $R_{\theta JA}$, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(MAX)}–T_A)/R_{\theta JA}$. All numbers apply for packages soldered directly into a PC board.

6.2 Handling Ratings

			MIN	MAX	UNIT
T_{stg}	Storage temperature range		−65	+150	°C
$V_{(ESD)}$	Electrostatic discharge (1)	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins (2)		2500	V

(1) Human body model, 1.5 kΩ in series with 100 pF.
(2) JEDEC document JEP155 states that 2500-V HBM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions (1)

over operating free-air temperature range (unless otherwise noted)

	MIN	TYP	MAX	UNIT
Supply Voltage		5.5V ≤ V_S ≤ 36		V
Operating Temperature Range: LM7171AI, LM7171BI	−40		+85	°C

(1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not specified. For ensured specifications and the test conditions, see the Electrical Characteristics.

6.4 Thermal Information

THERMAL METRIC (1)		P (PDIP)	D (SOIC)	UNIT
		8 PINS	8 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	108°	172°	°C/W

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.

6.5 ±15V DC Electrical Characteristics

Unless otherwise noted, all limits are specified for V^+ = +15 V, V^- = –15 V, V_{CM} = 0V, and R_L = 1 kΩ. **Boldface** limits apply at the temperature extremes

	PARAMETER	TEST CONDITIONS	TYP (1)	LM7171AI LIMIT (2)	LM7171BI LIMIT (2)	UNIT
V_{OS}	Input Offset Voltage		0.2	1	3	mV
				4	**7**	max
TC V_{OS}	Input Offset Voltage Average Drift		35			µV/°C
I_B	Input Bias Current		2.7	10	10	µA
				12	**12**	max
I_{OS}	Input Offset Current		0.1	4	4	µA
				6	**6**	max
R_{IN}	Input Resistance	Common Mode	40			MΩ
		Differential Mode	3.3			
R_O	Open Loop Output Resistance		15			Ω
CMRR	Common Mode Rejection Ratio	V_{CM} = ±10V	105	85	75	dB
				80	**70**	min
PSRR	Power Supply Rejection Ratio	V_S = ±15V to ±5V	90	85	75	dB
				80	**70**	min
V_{CM}	Input Common-Mode Voltage Range	CMRR > 60 dB	±13.35			V
A_V	Large Signal Voltage Gain (3)	R_L = 1 kΩ	85	80	75	dB
				75	**70**	min
		R_L = 100Ω	81	75	70	dB
				70	**66**	min
V_O	Output Swing	R_L = 1 kΩ	13.3	13	13	V
				12.7	**12.7**	min
			−13.2	−13	−13	V
				−12.7	**−12.7**	max
		R_L = 100Ω	11.8	10.5	10.5	V
				9.5	**9.5**	min
			−10.5	−9.5	−9.5	V
				−9	**−9**	max
	Output Current (Open Loop) (4)	Sourcing, R_L = 100Ω	118	105	105	mA
				95	**95**	min
		Sinking, R_L = 100Ω	105	95	95	mA
				90	**90**	max
	Output Current (in Linear Region)	Sourcing, R_L = 100Ω	100			mA
		Sinking, R_L = 100Ω	100			
I_{SC}	Output Short Circuit Current	Sourcing	140			mA
		Sinking	135			
I_S	Supply Current		6.5	8.5	8.5	mA
				9.5	**9.5**	max

(1) Typical values represent the most likely parametric norm.
(2) All limits are specified by testing or statistical analysis.
(3) Large signal voltage gain is the total output swing divided by the input signal required to produce that swing. For V_S = ±15V, V_{OUT} = ±5V. For V_S = ±5V, V_{OUT} = ±1V.
(4) The open loop output current is specified, by the measurement of the open loop output voltage swing, using 100Ω output load.

6.6 ±15V AC Electrical Characteristics

Unless otherwise noted, all limits are specified for V^+ = +15V, V^- = −15V, V_{CM} = 0V, and R_L = 1 kΩ.

	PARAMETER	CONDITIONS	TYP (1)	LM7171AI LIMIT (2)	LM7171BI LIMIT (2)	UNIT
SR	Slew Rate (3)	A_V = +2, V_{IN} = 13 V_{PP}	4100			V/µs
		A_V = +2, V_{IN} = 10 V_{PP}	3100			
	Unity-Gain Bandwidth		200			MHz
	−3 dB Frequency	A_V = +2	220			MHz
φ_m	Phase Margin		50			Deg
t_s	Settling Time (0.1%)	A_V = −1, V_O = ±5V R_L = 500Ω	42			ns
t_p	Propagation Delay	A_V = −2, V_{IN} = ±5V, R_L = 500Ω	5			ns
A_D	Differential Gain (4)		0.01%			
φ_D	Differential Phase (4)		0.02			Deg
	Second Harmonic Distortion (5)	f_{IN} = 10 kHz	−110			dBc
		f_{IN} = 5 MHz	−75			dBc
	Third Harmonic Distortion (5)	f_{IN} = 10 kHz	−115			dBc
		f_{IN} = 5 MHz	−55			dBc
e_n	Input-Referred Voltage Noise	f = 10 kHz	14			nV/√Hz
i_n	Input-Referred Current Noise	f = 10 kHz	1.5			pA/√Hz

(1) Typical values represent the most likely parametric norm.
(2) All limits are specified by testing or statistical analysis.
(3) Slew Rate is the average of the raising and falling slew rates.
(4) Differential gain and phase are measured with A_V = +2, V_{IN} = 1 V_{PP} at 3.58 MHz and both input and output 75Ω terminated.
(5) Harmonics are measured with V_{IN} = 1 V_{PP}, A_V = +2 and R_L = 100Ω.

Typical Performance Characteristics (continued)

unless otherwise noted, T_A= 25°C

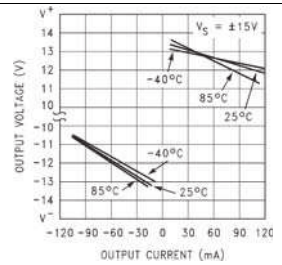


Figure 7. Output Voltage vs. Output Current

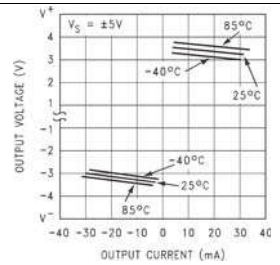


Figure 8. Output Voltage vs. Output Current

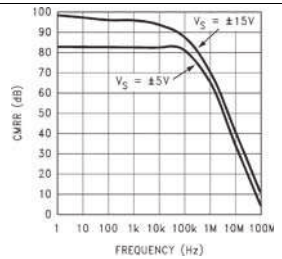


Figure 9. CMRR vs. Frequency

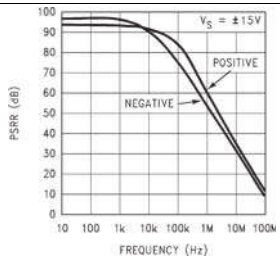


Figure 10. PSRR vs. Frequency

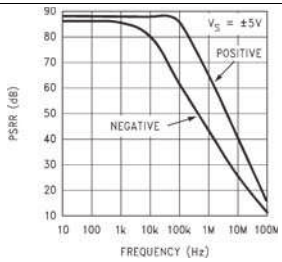


Figure 11. PSRR vs. Frequency

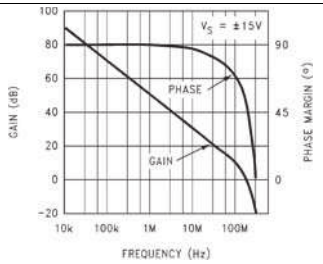


Figure 12. Open Loop Frequency Response

7.5 Compensation For Input Capacitance

The combination of an amplifier's input capacitance with the gain setting resistors adds a pole that can cause peaking or oscillation. To solve this problem, a feedback capacitor with a value

$$C_F > (R_G \times C_{IN})/R_F \quad (1)$$

can be used to cancel that pole. For LM7171, a feedback capacitor of 2 pF is recommended. Figure 54 illustrates the compensation circuit.

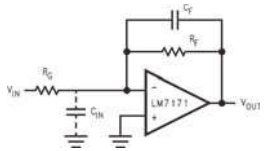


Figure 54. Compensating for Input Capacitance

7.6 Application Circuit

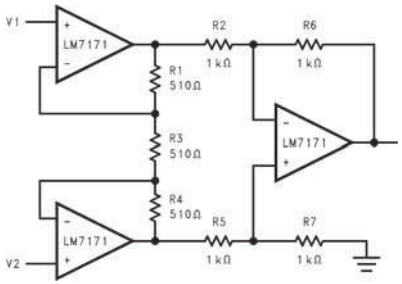


Figure 55. Fast Instrumentation Amplifier

$$V_{IN} = V_2 - V_1$$

if R6 = R2, R7 = R5, and R1 = R4

$$\frac{V_{OUT}}{V_{IN}} = \frac{R6}{R2}\left(1 + 2\frac{R1}{R3}\right) = 3$$

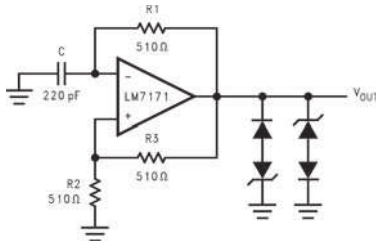


Figure 56. Multivibrator