90MHz, 22V/µs 16-Bit Accurate Operational Amplifier

FEATURES

- **90MHz Gain Bandwidth, f = 100kHz**
- **22V/µs Slew Rate**
- **Settling Time: 900ns (A_V = –1, 150µV, 10V Step)**
- Low Distortion, –96.5dB for 100kHz, $10V_{P-P}$
- Maximum Input Offset Voltage: 75µV
- Maximum Input Offset Voltage Drift: 2µV/°C
- Maximum (–) Input Bias Current: 10nA
- Minimum DC Gain: 1000V/mV
- Minimum Output Swing into 2k: ±12.8V
- Unity Gain Stable
- Input Noise Voltage: $5nV/\sqrt{Hz}$
- Input Noise Current: $0.6pA/\sqrt{Hz}$
- Total Input Noise Optimized for $1k < R_S < 20k$
- Specified at ±5V and ±15V

APPLICATIONS

- 16-Bit DAC Current-to-Voltage Converter
- Precision Instrumentation
- ADC Buffer
- Low Distortion Active Filters
- High Accuracy Data Acquisition Systems
- Photodiode Amplifiers

DESCRIPTION

The LT®1468 is a precision high speed operational amplifier with 16-bit accuracy and 900ns settling to 150µV for 10V signals. This unique blend of precision and AC performance makes the LT1468 the optimum choice for high accuracy applications such as DAC current-to-voltage conversion and ADC buffers. The initial accuracy and drift characteristics of the input offset voltage and inverting input bias current are tailored for inverting applications.

The 90MHz gain bandwidth ensures high open-loop gain at frequency for reducing distortion. In noninverting applications such as an ADC buffer, the low distortion and DC accuracy allow full 16-bit AC and DC performance.

The 22V/µs slew rate of the LT1468 improves large-signal performance in applications such as active filters and instrumentation amplifiers compared to other precision op amps.

The LT1468 is manufactured on Linear Technology's complementary bipolar process.

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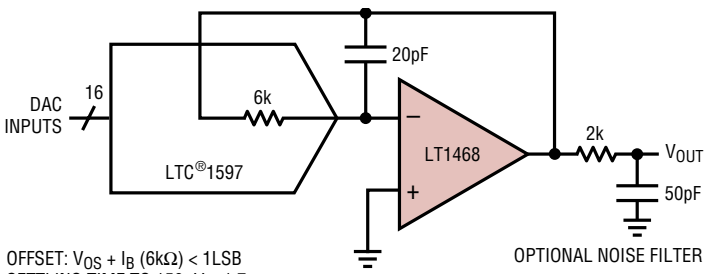
TYPICAL APPLICATION

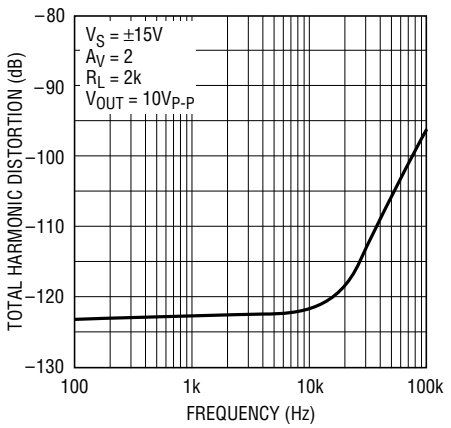
16-Bit DAC I-to-V Converter



OFFSET: $V_{OS} + I_B$ (6kΩ) < 1LSB
SETTLING TIME TO 150µV = 1.7µs
SETTLING LIMITED BY 6k AND 20pF TO COMPENSATE DAC OUTPUT CAPACITANCE

1468 TA01

Total Harmonic Distortion vs Frequency



1468 TA02

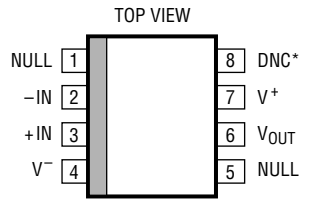
sales@prom-elec.com / ООО ПРОМЭЛЕКТРОНИКА

ABSOLUTE MAXIMUM RATINGS

(Note 1)

Total Supply Voltage (V^+ to V^-) 36V
Maximum Input Current (Note 2) 10mA
Output Short-Circuit Duration (Note 3) ..... Indefinite
Operating Temperature Range ..... –40°C to 85°C
Specified Temperature Range (Note 4) ... –40°C to 85°C
Junction Temperature ..... 150°C
Storage Temperature Range ..... –65°C to 150°C
Lead Temperature (Soldering, 10 sec) ..... 300°C

PACKAGE/ORDER INFORMATION



N8 PACKAGE
8-LEAD PDIP

S8 PACKAGE
8-LEAD PLASTIC SO

*DO NOT CONNECT

T_{JMAX} = 150°C, θ_{JA} = 130°C/W (N8)
T_{JMAX} = 150°C, θ_{JA} = 190°C/W (S8)

ORDER PART NUMBER
LT1468CN8 LT1468CS8 LT1468IN8 LT1468IS8
S8 PART MARKING
1468 1468I

Consult factory for Military Grade parts.

ELECTRICAL CHARACTERISTICS

T_A = 25°C, V_{CM} = 0V unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	V_{SUPPLY}		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage		±15V ±5V			30 50	75 175	µV µV
I_{OS}	Input Offset Current		±5V to ±15V			13	50	nA
I_B^-	Inverting Input Bias Current		±5V to ±15V			3	±10	nA
I_B^+	Noninverting Input Bias Current		±5V to ±15V			–10	±40	nA
	Input Noise Voltage	0.1Hz to 10Hz	±5V to ±15V			0.3		μV_{P-P}
e_n	Input Noise Voltage	f = 10kHz	±5V to ±15V			5		$nV/\sqrt{Hz}$
i_n	Input Noise Current	f = 10kHz	±5V to ±15V			0.6		$pA/\sqrt{Hz}$
R_{IN}	Input Resistance	V_{CM} = ±12.5V Differential	±15V ±15V		100 50	240 150		MΩ kΩ
C_{IN}	Input Capacitance		±15V			4		pF
	Input Voltage Range +		±15V ±5V		12.5 2.5	13.5 3.5		V V
	Input Voltage Range –		±15V ±5V			–14.3 –4.3	–12.5 –2.5	V V
CMRR	Common Mode Rejection Ratio	V_{CM} = ±12.5V V_{CM} = ±2.5V	±15V ±5V		96 96	110 112		dB dB
PSRR	Power Supply Rejection Ratio	V_S = ±4.5V to ±15V			100	112		dB
A_{VOL}	Large-Signal Voltage Gain	V_{OUT} = ±12.5V, R_L = 10k V_{OUT} = ±12.5V, R_L = 2k V_{OUT} = ±2.5V, R_L = 10k V_{OUT} = ±2.5V, R_L = 2k	±15V ±15V ±5V ±5V		1000 500 1000 500	9000 5000 6000 3000		V/mV V/mV V/mV V/mV
V_{OUT}	Output Swing	R_L = 10k R_L = 2k R_L = 10k R_L = 2k	±15V ±15V ±5V ±5V		±13.0 ±12.8 ±3.0 ±2.8	±13.6 ±13.5 ±3.6 ±3.5		V V V V
I_{OUT}	Output Current	V_{OUT} = ±12.5V V_{OUT} = ±2.5V	±15V ±5V		±15 ±15	±22 ±22		mA mA
I_{SC}	Short-Circuit Current	V_{OUT} = 0V, V_{IN} = ±0.2V	±15V		±25	±40		mA

ELECTRICAL CHARACTERISTICS

T_A = 25°C, V_{CM} = 0V unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	V_{SUPPLY}		MIN	TYP	MAX	UNITS
SR	Slew Rate	A_V = –1, R_L = 2k (Note 5)	±15V ±5V		15 11	22 17		V/µs V/µs
	Full-Power Bandwidth	10V Peak, (Note 6) 3V Peak, (Note 6)	±15V ±5V			350 900		kHz kHz
GBW	Gain Bandwidth	f = 100kHz, R_L = 2k	±15V ±5V		60 55	90 88		MHz MHz
THD	Total Harmonic Distortion	A_V = 2, V_O = 10V_{P-P}, f = 1kHz A_V = 2, V_O = 10V_{P-P}, f = 100kHz	±15V ±15V			0.00007 0.0015		% %
t_r, t_f	Rise Time, Fall Time	A_V = 1, 10% to 90%, 0.1V	±15V ±5V			11 12		ns ns
	Overshoot	A_V = 1, 0.1V	±15V ±5V			30 35		% %
	Propagation Delay	A_V = 1, 50% V_{IN} to 50% V_{OUT}, 0.1V	±15V ±5V			9 10		ns ns
t_s	Settling Time	10V Step, 0.01%, A_V = –1 10V Step, 150µV, A_V = –1 5V Step, 0.01%, A_V = –1	±15V ±15V ±5V			760 900 770		ns ns ns
R_O	Output Resistance	A_V = 1, f = 100kHz	±15V			0.02		Ω
I_S	Supply Current		±15V ±5V			3.9 3.6	5.2 5.0	mA mA

0°C ≤ T_A ≤ 70°C, V_{CM} = 0V unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	V_{SUPPLY}		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage		±15V ±5V	● ●			150 250	µV µV
	Input V_{OS} Drift	(Note 7)	±5V to ±15V	●		0.7	2.0	µV/°C
I_{OS}	Input Offset Current		±5V to ±15V	●			65	nA
	Input Offset Current Drift		±5V to ±15V			60		pA/°C
I_B^-	Inverting Input Bias Current		±5V to ±15V	●			±15	nA
	Negative Input Current Drift		±5V to ±15V			40		pA/°C
I_B^+	Noninverting Input Bias Current		±5V to ±15V	●			±50	nA
CMRR	Common Mode Rejection Ratio	V_{CM} = ±12.5V V_{CM} = ±2.5V	±15V ±5V	● ●	94 94			dB dB
PSRR	Power Supply Rejection Ratio	V_S = ±4.5V to ±15V		●	98			dB
A_{VOL}	Large-Signal Voltage Gain	V_{OUT} = ±12.5V, R_L = 10k V_{OUT} = ±12.5V, R_L = 2k V_{OUT} = ±2.5V, R_L = 10k V_{OUT} = ±2.5V, R_L = 2k	±15V ±15V ±5V ±5V	● ● ● ●	500 250 500 250			V/mV V/mV V/mV V/mV
V_{OUT}	Output Swing	R_L = 10k R_L = 2k R_L = 10k R_L = 2k	±15V ±15V ±5V ±5V	● ● ● ●	±12.9 ±12.7 ±2.9 ±2.7			V V V V
I_{OUT}	Output Current	V_{OUT} = ±12.5V V_{OUT} = ±2.5V	±15V ±5V	● ●	±12.5 ±12.5			mA mA
I_{SC}	Short-Circuit Current	V_{OUT} = 0V, V_{IN} = ±0.2V	±15V	●	±17			mA
SR	Slew Rate	A_V = –1, R_L = 2k (Note 5)	±15V ±5V	● ●	13 9			V/µs V/µs

ELECTRICAL CHARACTERISTICS

0°C ≤ T_A ≤ 70°C, V_{CM} = 0V unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	V_{SUPPLY}		MIN	TYP	MAX	UNITS
GBW	Gain Bandwidth	f = 100kHz, R_L = 2k	±15V ±5V	● ●	55 50			MHz MHz
I_S	Supply Current		±15V ±5V	● ●			6.5 6.3	mA mA

–40°C ≤ T_A ≤ 85°C, V_{CM} = 0V unless otherwise noted (Note 4).

SYMBOL	PARAMETER	CONDITIONS	V_{SUPPLY}		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage		±15V ±5V	● ●			230 330	µV µV
	Input V_{OS} Drift	(Note 7)	±5V to ±15V	●		0.7	2.5	µV/°C
I_{OS}	Input Offset Current		±5V to ±15V	●			80	nA
	Input Offset Current Drift		±5V to ±15V			120		pA/°C
I_B^-	Inverting Input Bias Current		±5V to ±15V	●			±30	nA
	Negative Input Current Drift		±5V to ±15V			80		pA/°C
I_B^+	Noninverting Input Bias Current		±5V to ±15V	●			±60	nA
CMRR	Common Mode Rejection Ratio	V_{CM} = ±12.5V V_{CM} = ±2.5V	±15V ±5V	● ●	92 92			dB dB
PSRR	Power Supply Rejection Ratio	V_S = ±4.5V to ±15V		●	96			dB
A_{VOL}	Large-Signal Voltage Gain	V_{OUT} = ±12V, R_L = 10k V_{OUT} = ±10V, R_L = 2k V_{OUT} = ±2.5V, R_L = 10k V_{OUT} = ±2.5V, R_L = 2k	±15V ±15V ±5V ±5V	● ● ● ●	300 150 300 150			V/mV V/mV V/mV V/mV
V_{OUT}	Output Swing	R_L = 10k R_L = 2k R_L = 10k R_L = 2k	±15V ±15V ±5V ±5V	● ● ● ●	±12.8 ±12.6 ±2.8 ±2.6			V V V V
I_{OUT}	Output Current	V_{OUT} = ±12.5V V_{OUT} = ±2.5V	±15V ±5V	● ●	±7 ±7			mA mA
I_{SC}	Short-Circuit Current	V_{OUT} = 0V, V_{IN} = ±0.2V	±15V	●	±12			mA
SR	Slew Rate	A_V = –1, R_L = 2k (Note 5)	±15V ±5V	● ●	9 6			V/µs V/µs
GBW	Gain Bandwidth	f = 100kHz, R_L = 2k	±15V ±5V	● ●	45 40			MHz MHz
I_S	Supply Current		±15V ±5V	● ●			7.0 6.8	mA mA

The ● denotes specifications that apply over the full operating temperature range.

Note 1: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

Note 2: The inputs are protected by back-to-back diodes and two 100Ω series resistors. If the differential input voltage exceeds 0.7V, the input current should be limited to 10mA. Input voltages outside the supplies will be clamped by ESD protection devices and input currents should also be limited to 10mA.

Note 3: A heat sink may be required to keep the junction temperature below absolute maximum when the output is shorted indefinitely.

Note 4: The LT1468C is guaranteed to meet specified performance from 0°C to 70°C and is designed, characterized and expected to meet these extended temperature limits, but is not tested at –40°C and at 85°C. The LT1468I is guaranteed to meet the extended temperature limits.

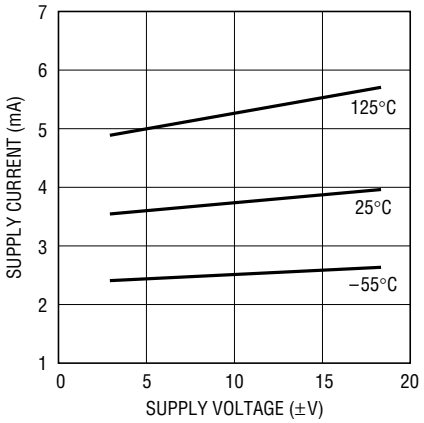
Note 5: Slew rate is measured between ±8V on the output with ±12V input for ±15V supplies and ±2V on the output with ±3V input for ±5V supplies.

Note 6: Full power bandwidth is calculated from the slew rate measurement: FPBW = $SR/2\pi V_P$

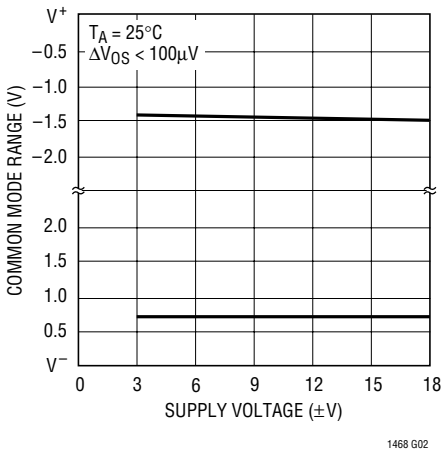
Note 7: This parameter is not 100% tested.

TYPICAL PERFORMANCE CHARACTERISTICS

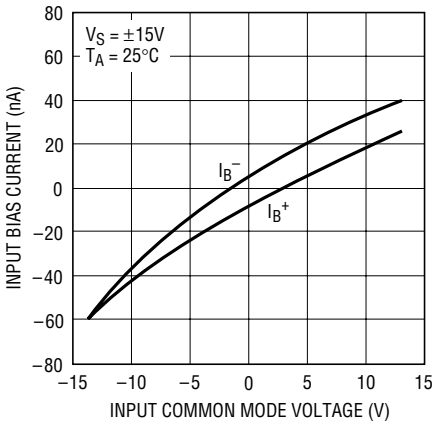
Supply Current vs Supply Voltage and Temperature



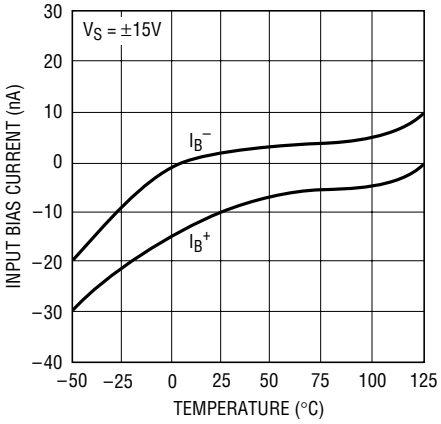
Input Common Mode Range vs Supply Voltage



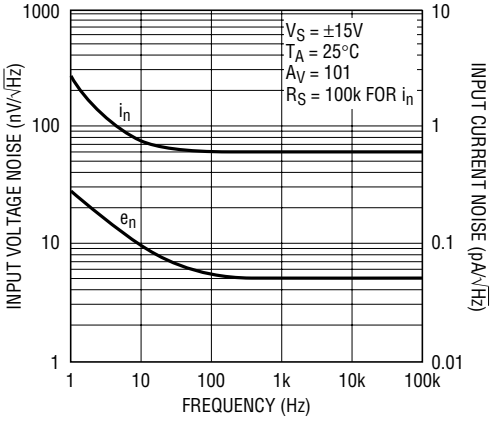
Input Bias Current vs Input Common Mode Voltage



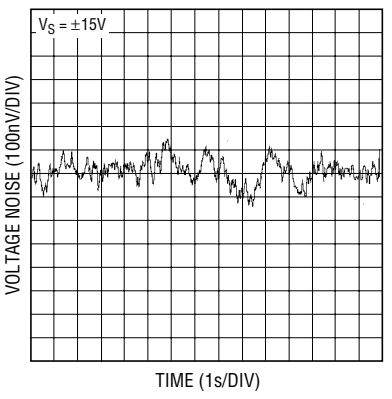
Input Bias Current vs Temperature



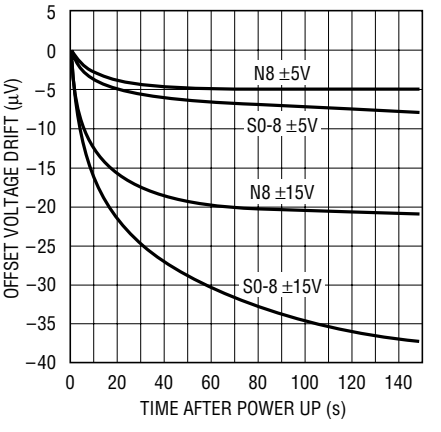
Input Noise Spectral Density



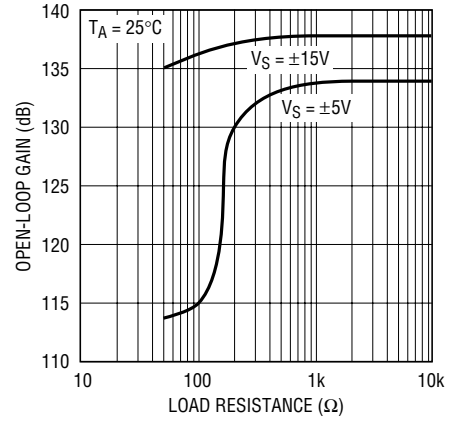
0.1Hz to 10Hz Voltage Noise



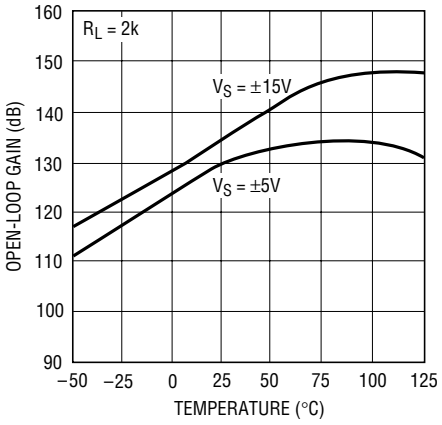
Warm-Up Drift vs Time



Open-Loop Gain vs Resistive Load

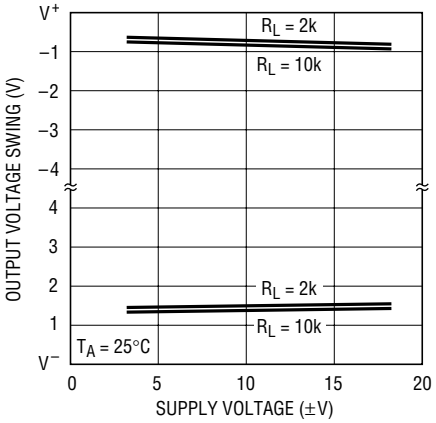


Open-Loop Gain vs Temperature



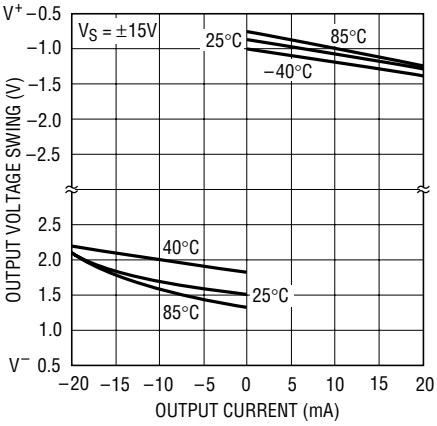
TYPICAL PERFORMANCE CHARACTERISTICS

Output Voltage Swing vs Supply Voltage



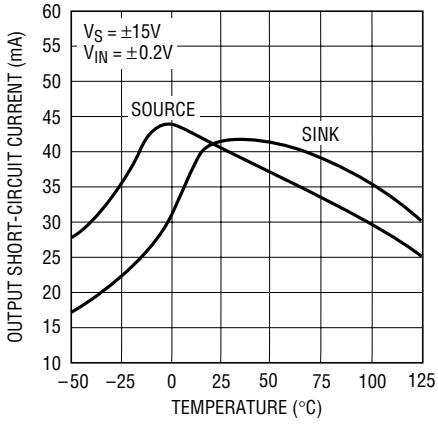
1468 G10

Output Voltage Swing vs Load Current



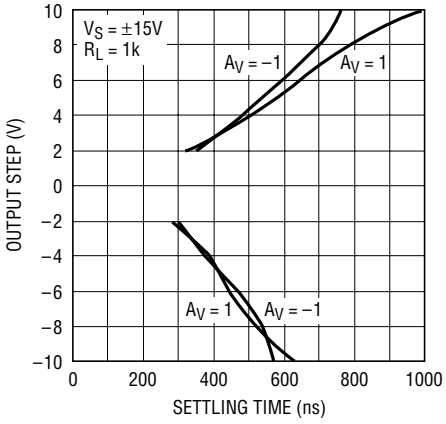
1468 G11

Output Short-Circuit Current vs Temperature



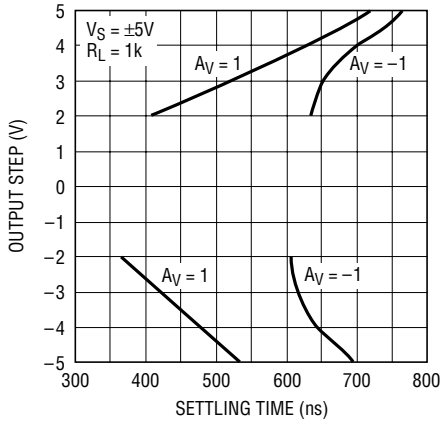
1468 G12

Settling Time to 0.01% vs Output Step, $V_S = \pm 15V$



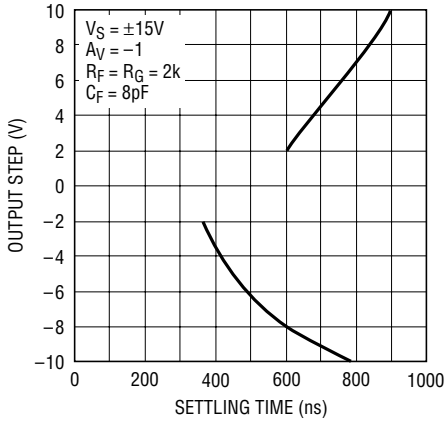
1468 G13

Settling Time to 0.01% vs Output Step, $V_S = \pm 5V$



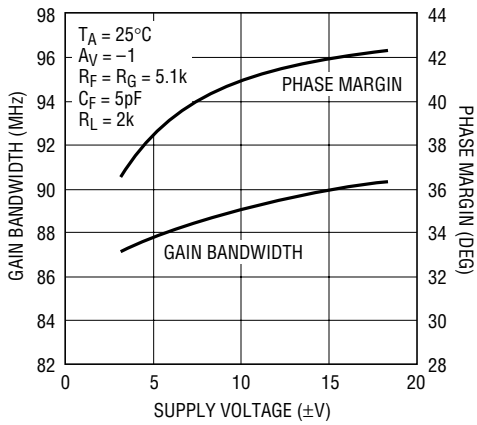
1468 G14

Settling Time to 150µV vs Output Step



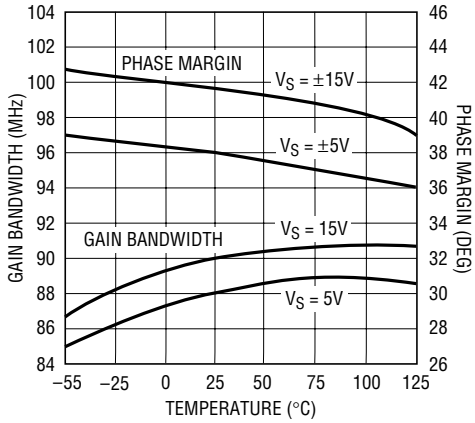
1468 G15

Gain Bandwidth and Phase Margin vs Supply Voltage



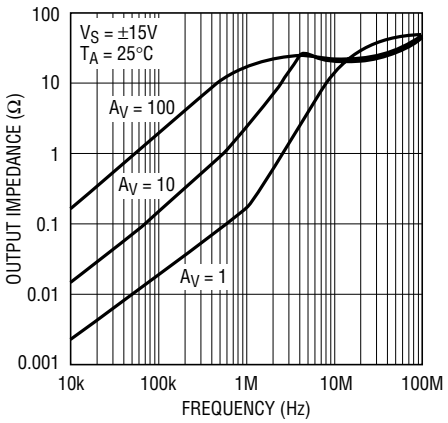
1468 G17

Gain Bandwidth and Phase Margin vs Temperature



1468 G18

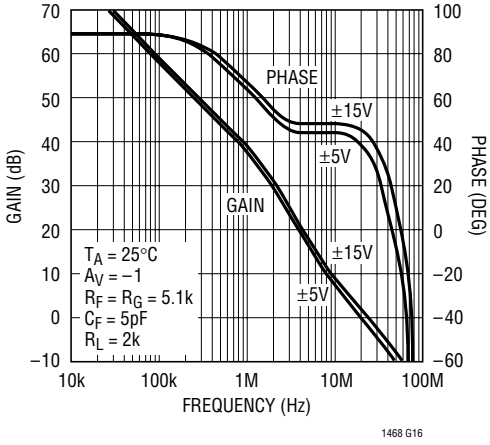
Output Impedance vs Frequency



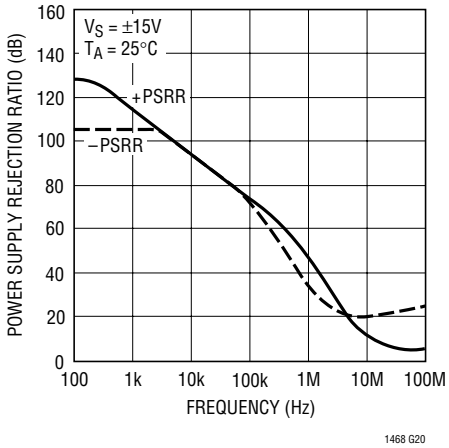
1468 G19

TYPICAL PERFORMANCE CHARACTERISTICS

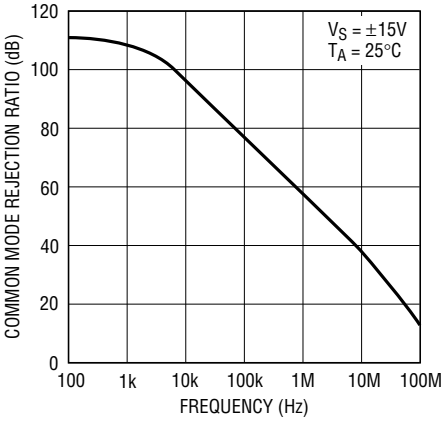
Gain and Phase vs Frequency



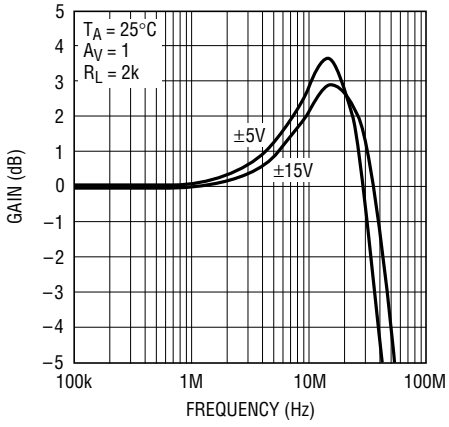
Power Supply Rejection Ratio vs Frequency



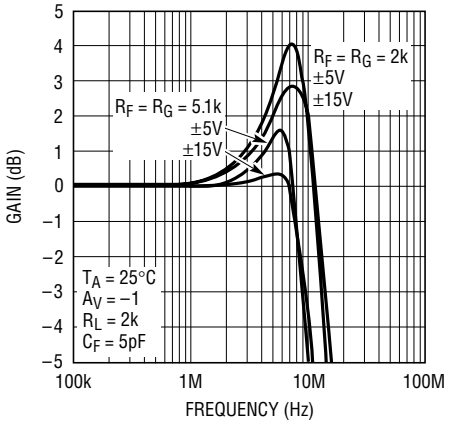
Common Mode Rejection Ratio vs Frequency



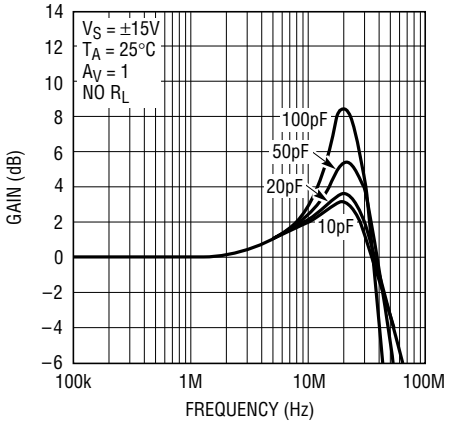
Frequency Response vs Supply Voltage, A_V = 1



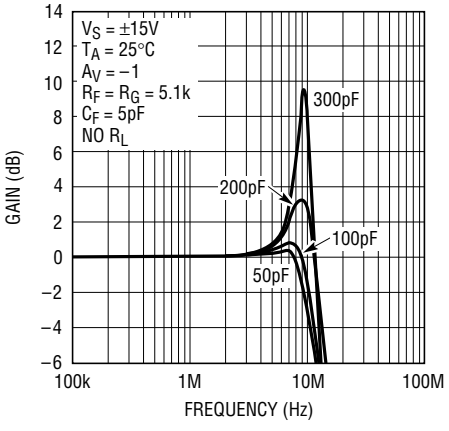
Frequency Response vs Supply Voltage, A_V = –1



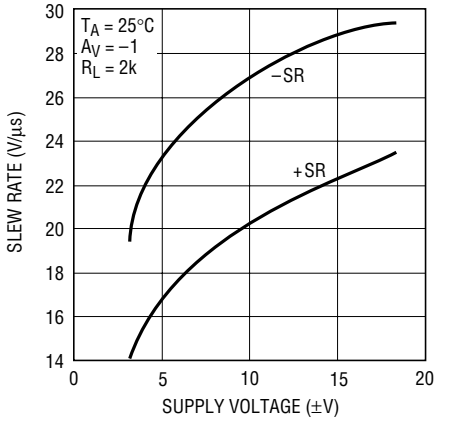
Frequency Response vs Capacitive Load, A_V = 1



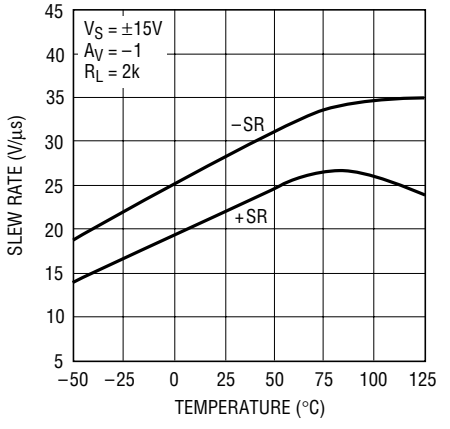
Frequency Response vs Capacitive Load, A_V = –1



Slew Rate vs Supply Voltage

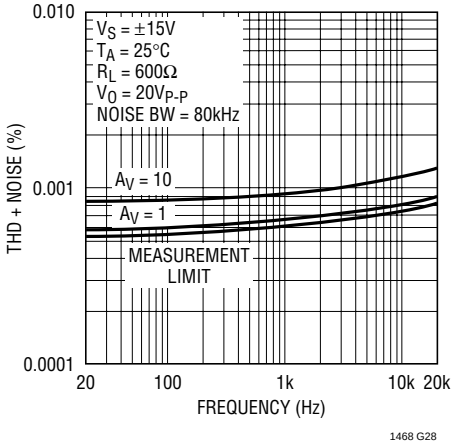


Slew Rate vs Temperature

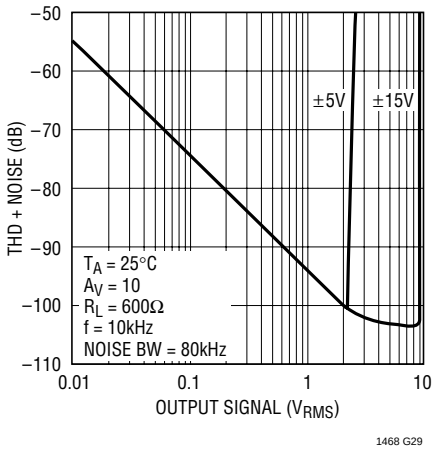


TYPICAL PERFORMANCE CHARACTERISTICS

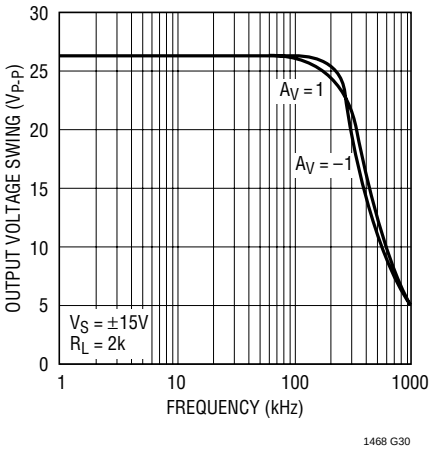
Total Harmonic Distortion + Noise vs Frequency



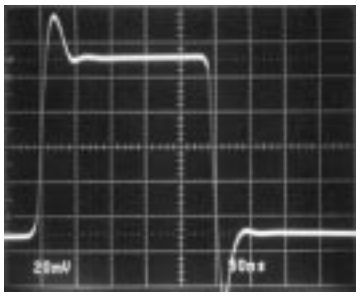
Total Harmonic Distortion + Noise vs Amplitude



Undistorted Output Swing vs Frequency, ±15V

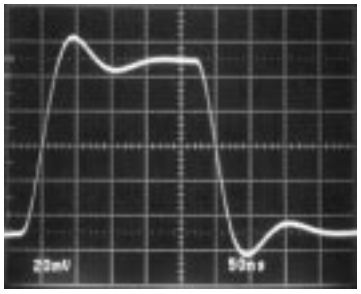


Small-Signal Transient, A_V = 1



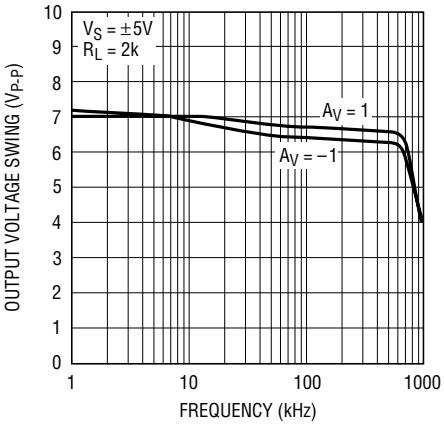
V_S = ±15V

Small-Signal Transient, A_V = –1

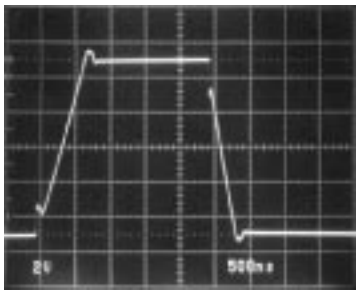


V_S = ±15V

Undistorted Output Swing vs Frequency, ±5V

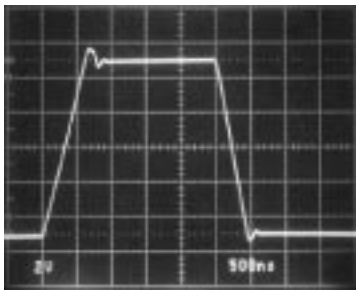


Large-Signal Transient, A_V = 1



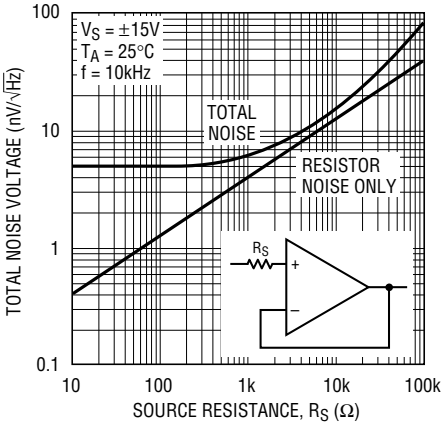
V_S = ±15V

Large-Signal Transient, A_V = –1



V_S = ±15V

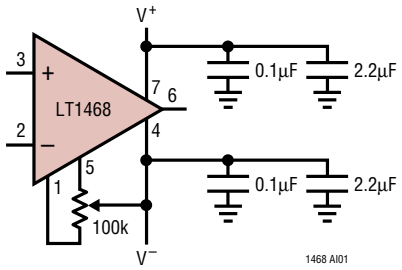
Total Noise vs Unmatched Source Resistance



APPLICATIONS INFORMATION

The LT1468 may be inserted directly into many operational amplifier applications improving both DC and AC performance, provided that the nulling circuitry is removed. The suggested nulling circuit for the LT1468 is shown below.

Offset Nulling



Layout and Passive Components

The LT1468 requires attention to detail in board layout in order to maximize DC and AC performance. For best AC results (for example fast settling time) use a ground plane, short lead lengths, and RF-quality bypass capacitors (0.01µF to 0.1µF) in parallel with low ESR bypass capacitors (1µF to 10µF tantalum). For best DC performance, use "star" grounding techniques, equalize input trace lengths and minimize leakage (i.e., 1.5GΩ of leakage between an input and a 15V supply will generate 10nA—equal to the maximum I_B^- specification.)

Board leakage can be minimized by encircling the input circuitry with a guard ring operated at a potential close to that of the inputs. For inverting configurations tie the ring to ground, in noninverting connections tie the ring to the inverting input (note the input capacitance will increase which may require a compensating capacitor as discussed below.)

Microvolt level error voltages can also be generated in the external circuitry. Thermocouple effects caused by temperature gradients across dissimilar metals at the contacts to the inputs can exceed the inherent drift of the amplifier. Air currents over device leads should be minimized, package leads should be short, and the two input leads should be as close together as possible and maintained at the same temperature.

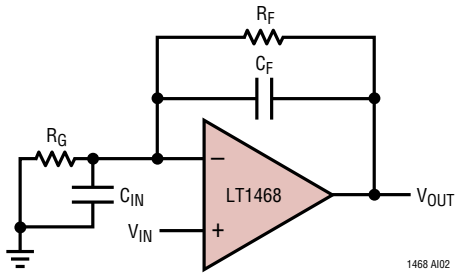
Make no connection to Pin 8. This pin is used for factory trim of the inverting input current.

The parallel combination of the feedback resistor and gain setting resistor on the inverting input can combine with the input capacitance to form a pole that can cause peaking or even oscillations. For feedback resistors greater than 2k, a feedback capacitor of the value:

$$C_F > (R_G)(C_{IN}/R_F)$$

should be used to cancel the input pole and optimize dynamic performance. For applications where the DC noise gain is one, and a large feedback resistor is used, C_F should be greater than or equal to C_{IN}. An example would be a DAC I-to-V converter as shown on the front page of this data sheet where the DAC can have many tens of pF of output capacitance. Another example would be a gain of –1 with 5k resistors; a 5pF to 10pF capacitor should be added across the feedback resistor. The frequency response in a gain of –1 is shown in the Typical Performance curves with 2k and 5.1k resistors with a 5pF feedback capacitor.

Nulling Input Capacitance



Input Considerations

Each input of the LT1468 is protected with a 100Ω series resistor and back-to-back diodes across the bases of the input devices. If the inputs can be pulled apart, the input current should be limited to less than 10mA with an external series resistor. Each input also has two ESD clamp diodes—one to each supply. If an input is driven above the supply, limit the current with an external resistor to less than 10mA.

The LT1468 employs bias current cancellation at the inputs. The inverting input current is trimmed at zero common mode voltage to minimize errors in inverting applications such as I-to-V converters. The noninverting input current is not trimmed and has a wider variation and therefore a larger maximum value. As the input offset

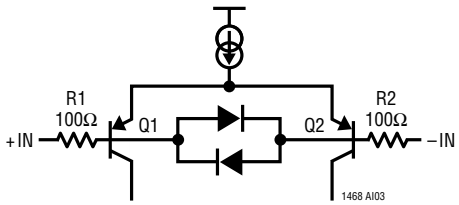
APPLICATIONS INFORMATION

current can be greater than either input current, the use of balanced source resistance is NOT recommended as it actually degrades DC accuracy and also increases noise.

The input bias currents vary with common mode voltage as shown in the Typical Performance Characteristics. The cancellation circuitry was not designed to track this common mode voltage because the settling time would have been adversely affected.

The LT1468 inputs can be driven to the negative supply and to within 0.5V of the positive supply without phase reversal. As the input moves closer than 0.5V to the positive supply, the output reverses phase.

Input Stage Protection



Total Input Noise

The curve of Total Noise vs Unmatched Source Resistance in the Typical Performance Characteristics shows that with source resistance below 1k, the voltage noise of the amplifier dominates. In the 1k to 20k region the increase in noise is due to the source resistance. Above 20k the input current noise component is larger than the resistor noise.

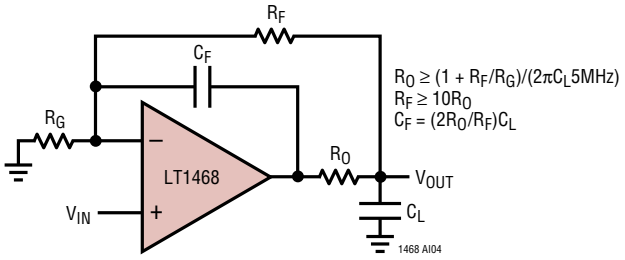
Capacitive Loading

The LT1468 drives capacitive loads of up to 100pF in unity gain and 300pF in a gain of –1. When there is a need to drive a larger capacitive load, a small series resistor should be inserted between the output and the load. In addition, a capacitor should be added between the output and the inverting input as shown in Driving Capacitive Loads.

Settling Time

The LT1468 is a single stage amplifier with an optimal thermal layout that leads to outstanding settling performance. Measuring settling, even at the 12-bit level is very challenging, and at the 16-bit level requires a great deal of subtlety and expertise. Fortunately, there are two

Driving Capacitive Loads



excellent Linear Technology reference sources for settling measurements, Application Notes 47 and 74. Appendix B of AN47 is a vital primer on 12-bit settling measurements, and AN74 extends the state of the art while concentrating on settling time with a 16-bit current output DAC input.

The 150μV settling curve in the Typical Performance Characteristics is measured using the Differential Amplifier method of AN74 followed by a clamped, nonsaturating gain of 100. The total gain of 500 allows a resolution of 100μV/DIV with an oscilloscope setting of 0.05V/DIV

The settling of the DAC I-to-V converter on the front page was measured using the exact methods of AN74. The optimum nulling of the DAC output capacitance requires 20pF across the 6k feedback resistor. The theoretical limit for 16-bit settling is 11.1 times this RC time constant or 1.33μs. The actual settling time is 1.7μs at the output of the LT1468. The LT1468 is the fastest Linear Technology amplifier in this application.

The optional noise filter adds a slight delay of 100ns, but reduces the noise bandwidth to 1.6MHz which increases the output resolution for 16-bit accuracy.

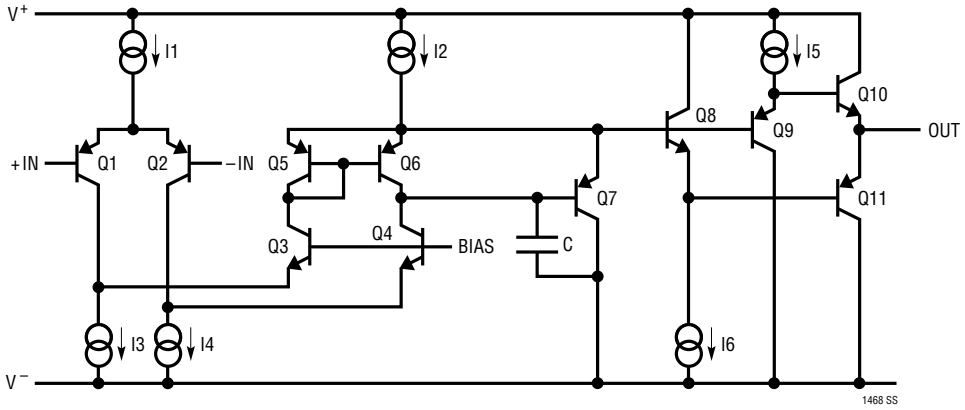
Distortion

The LT1468 has outstanding distortion performance as shown in the Typical Performance curves of Total Harmonic Distortion + Noise vs Frequency and Amplitude. The high open-loop gain and inherently balanced architecture reduce errors to yield 16-bit accuracy to frequencies as high as 100kHz. An example of this performance is the Typical Application titled 100kHz Low Distortion Bandpass Filter. This circuit is useful for cleaning up the output of a high performance signal generator such as the B & K type 1051 or HP3326A.

APPLICATIONS INFORMATION

Another key application for LT1468 is buffering the input to a 16-bit A/D converter. In a gain of 1 or 2 this straightforward circuit provides uncorrupted AC and DC levels to the converter, while buffering the A/D input sample-and-hold circuit from high source impedance which can reduce the maximum sampling rate. The front page graph shows better than 16-bit distortion for a gain of 2 with a $10V_{P-P}$ output.

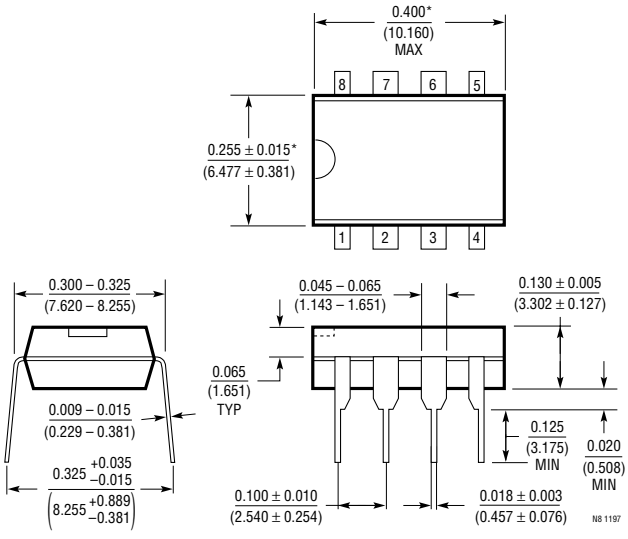
SIMPLIFIED SCHEMATIC



PACKAGE DESCRIPTION

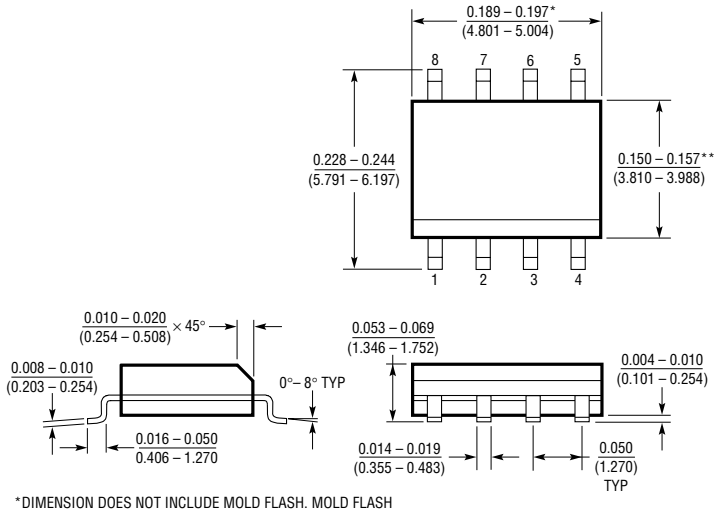
Dimensions in inches (millimeters) unless otherwise noted.

N8 Package
8-Lead PDIP (Narrow 0.300)
(LTC DWG # 05-08-1510)



*THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.010 INCH (0.254mm)

S8 Package
8-Lead Plastic Small Outline (Narrow 0.150)
(LTC DWG # 05-08-1610)



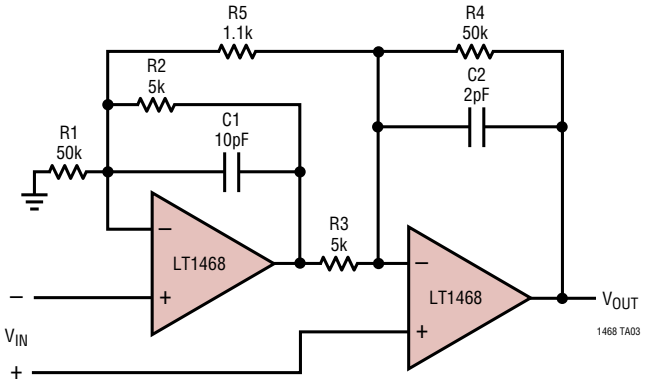
*DIMENSION DOES NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE
**DIMENSION DOES NOT INCLUDE INTERLEAD FLASH. INTERLEAD FLASH SHALL NOT EXCEED 0.010" (0.254mm) PER SIDE

LINEAR TECHNOLOGY

Information furnished by Linear Technology Corporation is believed to be accurate and reliable. However, no responsibility is assumed for its use. Linear Technology Corporation makes no representation that the interconnection of its circuits as described herein will not infringe on existing patent rights.

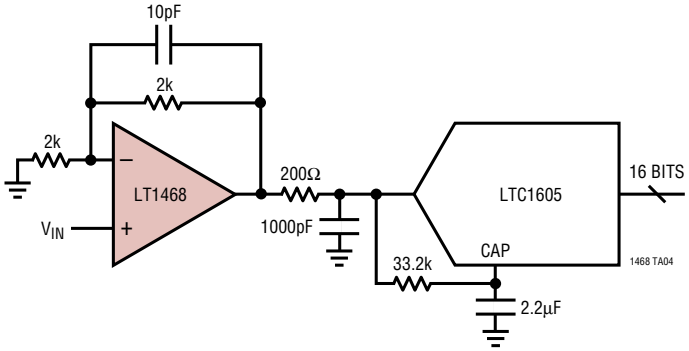
TYPICAL APPLICATIONS

Instrumentation Amplifier

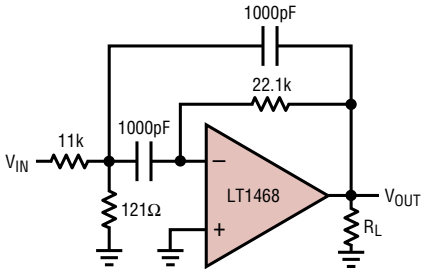


GAIN = [R4/R3][1 + (1/2)(R2/R1 + R3/R4) + (R2 + R3)/R5] = 102
TRIM R5 FOR GAIN
TRIM R1 FOR COMMON MODE REJECTION
BW = 480kHz

16-Bit ADC Buffer



100kHz Low Distortion Bandpass Filter



f_O = 100kHz
Q = 7
A_V = –1

100kHz Distortion

SIGNAL LEVEL	R_L	2ND HARMONIC	3RD HARMONIC
$1V_{RMS}$	1M	–106dB	–103dB
$2V_{RMS}$	1M	–105dB	–105dB
$3.5V_{RMS}$	1M	–106dB	–104dB
$1V_{RMS}$	2k	–103dB	–103dB
$2V_{RMS}$	2k	–99dB	–103dB
$3.5V_{RMS}$	2k	–96.5dB	–102dB

1468 TA05

RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT1167	Precision Instrumentation Amplifier	Single Resistor Gain Set, 0.04% Max Gain Error, 10ppm Max Gain Nonlinearity
LTC1595/LTC1596	16-Bit Serial Multiplying I_{OUT} DACs	±1LSB Max INL/DNL, Low Glitch, DAC8043 16-Bit Upgrade
LTC1597	16-Bit Parallel Multiplying I_{OUT} DAC	±1LSB Max INL/DNL, Low Glitch, On-Chip Bipolar Resistors
LTC1604	16-Bit, 333ksps Sampling ADC	±2.5V Input, SINAD = 90dB, THD = –100dB
LTC1605	Single 5V, 16-Bit, 100ksps Sampling ADC	Low Power, ±10V Inputs, Parallel/Byte Interface

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