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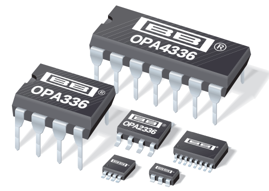


OPA336
OPA2336
OPA4336

SINGLE-SUPPLY, *Micro*POWER CMOS OPERATIONAL AMPLIFIERS
MicroAmplifier™ Series

FEATURES

- **SINGLE SUPPLY OPERATION**
- **RAIL-TO-RAIL OUTPUT (within 3mV)**
- ***Micro*POWER: I_Q = 20µA/Amplifier**
- ***Micro*SIZE PACKAGES**
- **LOW OFFSET VOLTAGE: 125µV max**
- **SPECIFIED FROM V_S = 2.3V to 5.5V**
- **SINGLE, DUAL, AND QUAD VERSIONS(1)**

APPLICATIONS

- **BATTERY POWERED INSTRUMENTS**
- **PORTABLE DEVICES**
- **HIGH IMPEDANCE APPLICATIONS**
- **PHOTODIODE PRE-AMPS**
- **PRECISION INTEGRATORS**
- **MEDICAL INSTRUMENTS**
- **TEST EQUIPMENT**

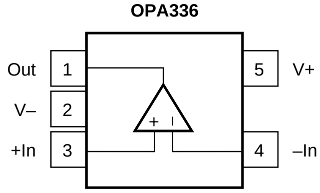
DESCRIPTION

OPA336 series micropower CMOS operational amplifiers are designed for battery powered applications. They operate on a single supply with operation as low as 2.1V. The output is rail-to-rail and swings to within 3mV of the supplies with a 100kΩ load. The common-mode range extends to the negative supply—ideal for single-supply applications. Single, dual, and quad versions have identical specifications for maximum design flexibility.

In addition to small size and low quiescent current (20µA/amplifier), they feature low offset voltage (125µV max), low input bias current (1pA), and high open-loop gain (115dB). Dual and quad designs feature completely independent circuitry for lowest crosstalk and freedom from interaction.

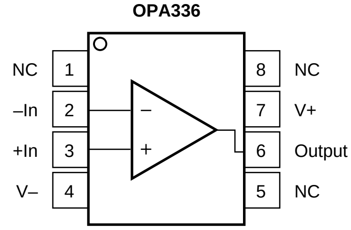
OPA336 packages are the tiny 5-lead SOT-23-5 surface mount, SO-8 surface-mount, and 8-pin DIP. OPA2336 comes in the miniature MSOP-8 surface-mount, SO-8 surface-mount, and 8-pin DIP packages. OPA4336 packages are the space-saving SSOP-16 surface-mount and the 14-pin DIP. All are specified from –40°C to +85°C and operate from –55°C to +125°C. A macromodel is available for design analysis.

OPA336



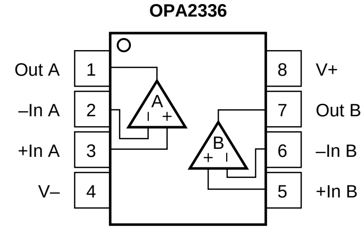
SOT-23-5

OPA336



8-Pin DIP, SO-8

OPA2336



8-Pin DIP, SO-8, MSOP-8

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 PDS-1380C Printed in U.S.A. August, 1997

SPECIFICATIONS: V_S = 2.3V to 5.5V

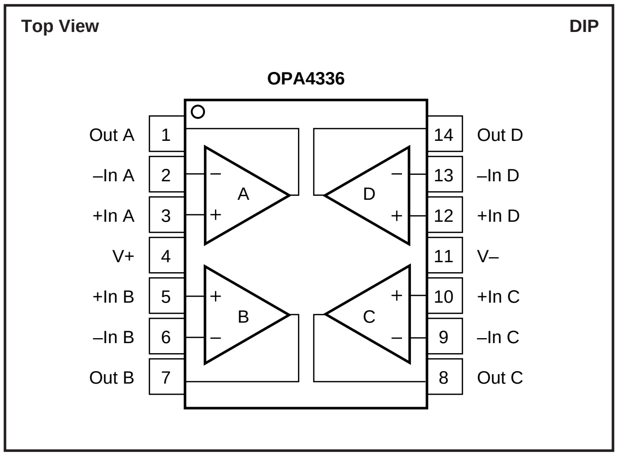
At T_A = +25°C, and R_L = 25kΩ connected to V_S/2, unless otherwise noted.
Boldface limits apply over the specified temperature range, –40°C to +85°C. V_S = +5V.

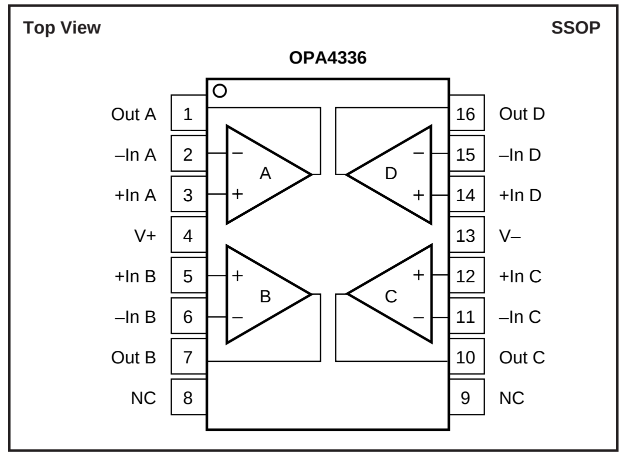
PARAMETER		CONDITION	OPA336N, P, U OPA2336E, P, U			OPA336NA, PA, UA OPA2336EA, PA, UA OPA4336EA, PA			UNITS
			MIN	TYP(1)	MAX	MIN	TYP(1)	MAX	
OFFSET VOLTAGE									
Input Offset Voltage	V_{OS}			±60	±125		*	±500	μV
vs Temperature	dV_{OS}/dT			**±1.5**			*		μV/°C
vs Power Supply	PSRR	V_S = 2.3V to 5.5V		25	100		*	*	μV/V
T_A = –40°C to +85°C		V_S = 2.3V to 5.5V			**130**			*	μV/V
Channel Separation, dc				0.1			*		μV/V
INPUT BIAS CURRENT									
Input Bias Current	I_B			±1	±10		*	*	pA
T_A = –40°C to +85°C					**±60**			*	pA
Input Offset Current	I_{OS}			±1	±10		*	*	pA
NOISE									
Input Voltage Noise, f = 0.1 to 10Hz				3			*		μVp-p
Input Voltage Noise Density, f = 1kHz	e_n			40			*		nV/√Hz
Current Noise Density, f = 1kHz	i_n			30			*		fA/√Hz
INPUT VOLTAGE RANGE									
Common-Mode Voltage Range	V_{CM}		–0.2		(V+) –1	*		*	V
Common-Mode Rejection Ratio	CMRR	–0.2V < V_{CM} < (V+) –1V	80	90		76	86		dB
T_A = –40°C to +85°C		–0.2V < V_{CM} < (V+) –1V	**76**			**74**			dB
INPUT IMPEDANCE									
Differential				10^{13} || 2			*		Ω || pF
Common-Mode				10^{13} || 4			*		Ω || pF
OPEN-LOOP GAIN									
Open-Loop Voltage Gain	A_{OL}	R_L = 25kΩ, 100mV < V_O < (V+) –100mV	100	115		90	*		dB
T_A = –40°C to +85°C		R_L = 25kΩ, 100mV < V_O < (V+) –100mV	**100**			**90**			dB
		R_L = 5kΩ, 500mV < V_O < (V+) –500mV	90	106		*	*		dB
T_A = –40°C to +85°C		R_L = 5kΩ, 500mV < V_O < (V+) –500mV	**90**			*			dB
FREQUENCY RESPONSE									
Gain-Bandwidth Product	GBW	V_S = 5V, G = 1		100			*		kHz
Slew Rate	SR	V_S = 5V, G = 1		0.03			*		V/μs
Overload Recovery Time		V_{IN} • G = V_S		100			*		μs
OUTPUT									
Voltage Output Swing from Rail(2)		R_L = 100kΩ, A_{OL} ≥ 70dB		3			*		mV
		R_L = 25kΩ, A_{OL} ≥ 90dB		20	100		*	*	mV
T_A = –40°C to +85°C		R_L = 25kΩ, A_{OL} ≥ 90dB			**100**			*	mV
		R_L = 5kΩ, A_{OL} ≥ 90dB		70	500		*	*	mV
T_A = –40°C to +85°C		R_L = 5kΩ, A_{OL} ≥ 90dB			**500**			*	mV
Short-Circuit Current	I_{SC}			±5			*		mA
Capacitive Load Drive	C_{LOAD}			See Text			*		pF
POWER SUPPLY									
Specified Voltage Range	V_S		2.3		5.5	*		*	V
Minimum Operating Voltage				2.1			*		V
Quiescent Current (per amplifier)	I_Q	I_O = 0		20	32		*	*	μA
T_A = –40°C to +85°C		I_O = 0			**36**			*	μA
TEMPERATURE RANGE									
Specified Range			–40		+85	*		*	°C
Operating Range			–55		+125	*		*	°C
Storage Range			–55		+125	*		*	°C
Thermal Resistance	θ_{JA}								
SOT-23-5 Surface-Mount				200			*		°C/W
MSOP-8 Surface-Mount				150			*		°C/W
SO-8 Surface-Mount				150			*		°C/W
8-Pin DIP				100			*		°C/W
SSOP-16 Surface-Mount				100			*		°C/W
14-Pin DIP				80			*		°C/W

*Specifications same as OPA2336E, P, U.

NOTES: (1) V_S = +5V. (2) Output voltage swings are measured between the output and positive and negative power supply rails.

PIN CONFIGURATIONS





ABSOLUTE MAXIMUM RATINGS(1)

Supply Voltage	5.5V
Signal Input Terminals, Voltage(2)	(V–) –0.3V to (V+) +0.3V
Current(2)	10mA
Output Short-Circuit(3)	Continuous
Operating Temperature	–55°C to +125°C
Storage Temperature	–55°C to +125°C
Junction Temperature	150°C
Lead Temperature (soldering, 10s)	300°C

NOTES: (1) Stresses above these ratings may cause permanent damage. (2) Input terminals are diode-clamped to the power supply rails. Input signals that can swing more than 0.3V beyond the supply rails should be current-limited to 10mA or less. (3) Short-circuit to ground, one amplifier per package.

ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

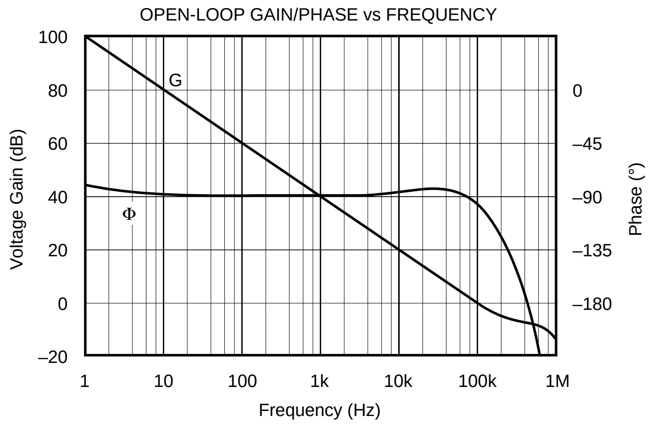
PACKAGE/ORDERING INFORMATION

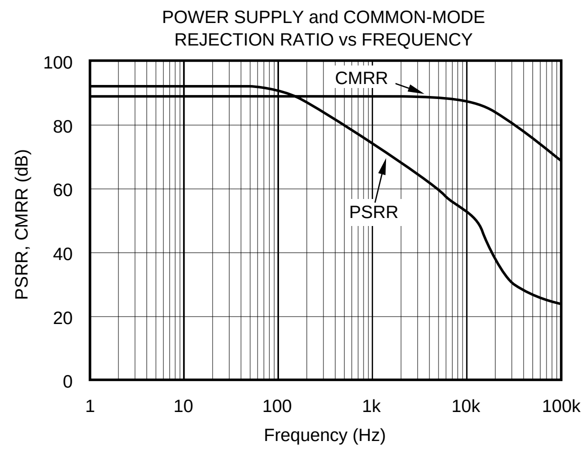
PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER(1)	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER(2)	TRANSPORT MEDIA
Single						
OPA336NA	5-Lead SOT-23-5	331	–40°C to +85°C	A36(3)	OPA336NA-250	Tape and Reel
"	"	"	"	"	OPA336NA-3K	Tape and Reel
OPA336N	5-Lead SOT-23-5	331	–40°C to +85°C	A36(3)	OPA336N-250	Tape and Reel
"	"	"	"	"	OPA336N-3K	Tape and Reel
OPA336PA	8-Pin DIP	006	–40°C to +85°C	OPA336PA	OPA336PA	Rails
OPA336P	8-Pin DIP	006	–40°C to +85°C	OPA336P	OPA336P	Rails
OPA336UA	SO-8 Surface-Mount	182	–40°C to +85°C	OPA336UA	OPA336UA	Rails(4)
OPA336U	SO-8 Surface-Mount	182	–40°C to +85°C	OPA336U	OPA336U	Rails(4)
Dual						
OPA2336PA	8-Pin DIP	006	–40°C to +85°C	OPA2336PA	OPA2336PA	Rails
OPA2336P	8-Pin DIP	006	–40°C to +85°C	OPA2336P	OPA2336P	Rails
OPA2336UA	SO-8 Surface-Mount	182	–40°C to +85°C	OPA2336UA	OPA2336UA	Rails(4)
OPA2336U	SO-8 Surface-Mount	182	–40°C to +85°C	OPA2336U	OPA2336U	Rails(4)
OPA2336EA	MSOP-8 Surface-Mount	337	–40°C to +85°C	B36(3)	OPA2336EA-250	Tape and Reel
"	"	"	"	"	OPA2336EA-2500	Tape and Reel
OPA2336E	MSOP-8 Surface-Mount	337	–40°C to +85°C	B36(3)	OPA2336E-250	Tape and Reel
"	"	"	"	"	OPA2336E-2500	Tape and Reel
Quad						
OPA4336EA	SSOP-16 Surface-Mount	322	–40°C to +85°C	OPA4336EA	OPA4336EA-250	Tape and Reel
"	"	"	"	"	OPA4336EA-2500	Tape and Reel
OPA4336PA	14-Pin DIP	010	–40°C to +85°C	OPA4336PA	OPA4336PA	Rails

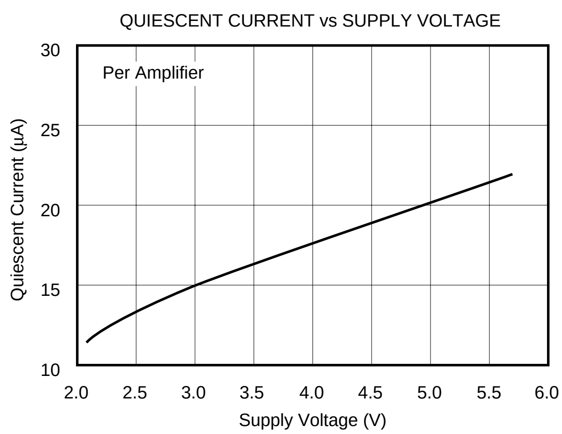
NOTES: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book. (2) Models with -250, -2500, and -3K are available only in Tape and Reel in the quantities indicated (e.g., -250 indicates 250 devices per reel). Ordering 3000 pieces of "OPA336NA-3K" will get a single 3000 piece Tape and Reel. For detailed Tape and Reel mechanical information, refer to Appendix B of Burr-Brown IC Data Book. (3) Grade will be marked on the Reel. (4) SO-8 models also available in Tape and Reel.

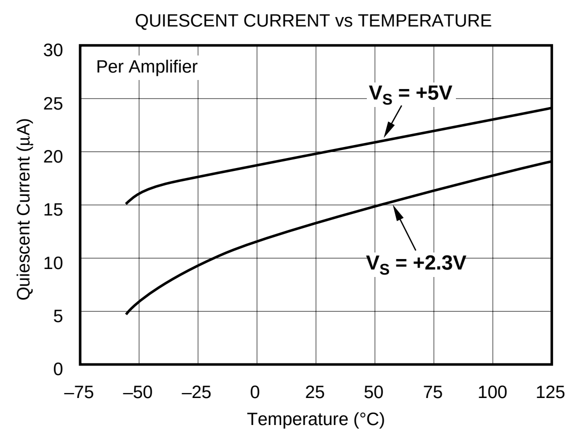
TYPICAL PERFORMANCE CURVES

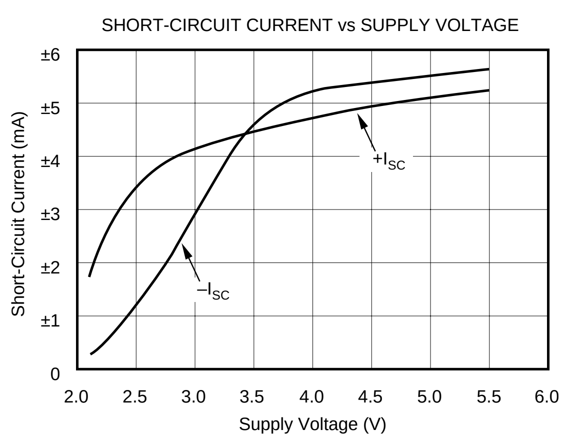
At T_A = +25°C, V_S = +5V, and R_L = 25kΩ connected to $V_S/2$, unless otherwise noted.

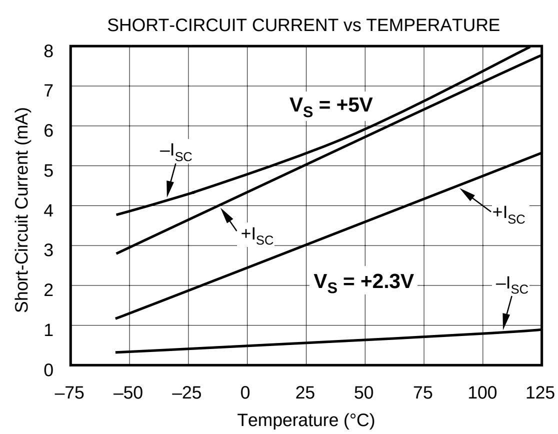








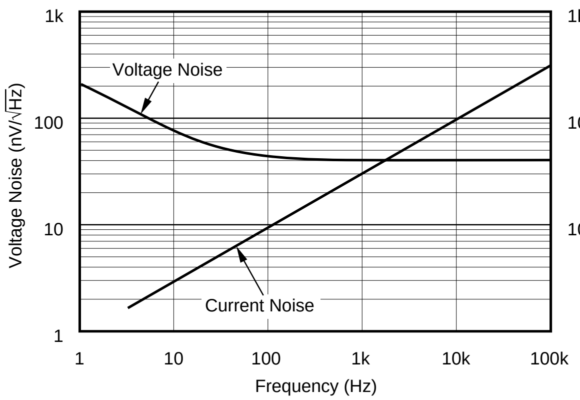




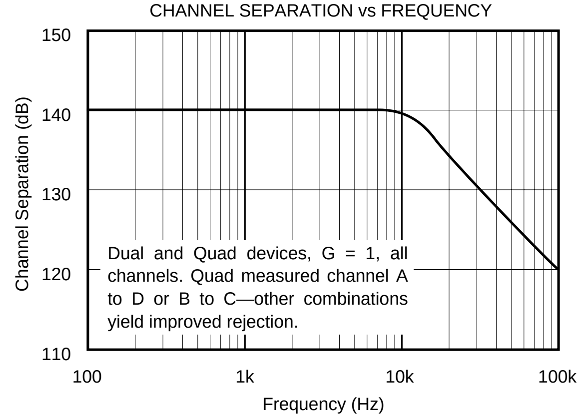
TYPICAL PERFORMANCE CURVES (CONT)

At $T_A = +25°C$, $V_S = +5V$, and $R_L = 25kΩ$ connected to $V_S/2$, unless otherwise noted.

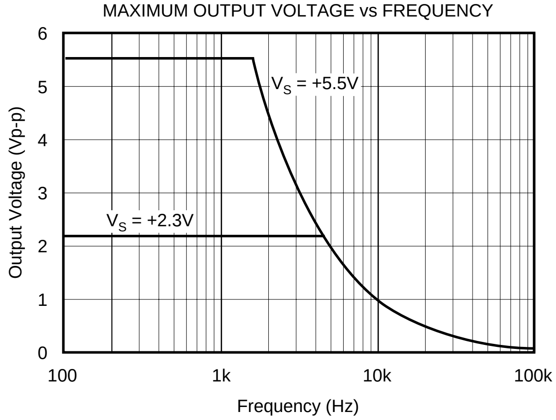
INPUT VOLTAGE AND CURRENT NOISE
SPECTRAL DENSITY vs FREQUENCY



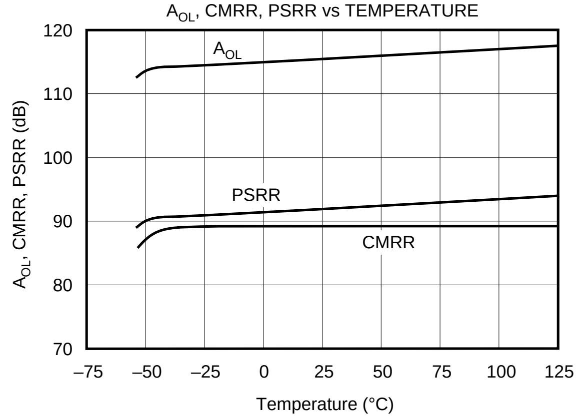
CHANNEL SEPARATION vs FREQUENCY



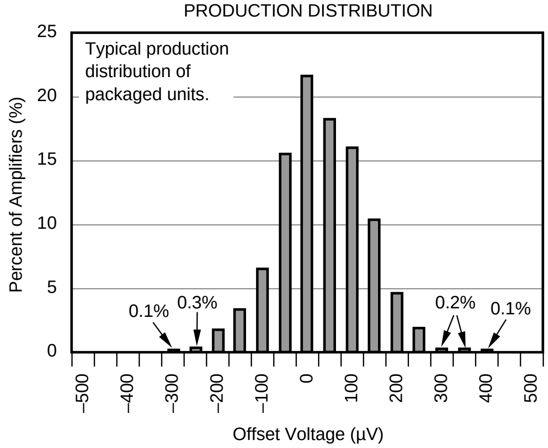
MAXIMUM OUTPUT VOLTAGE vs FREQUENCY



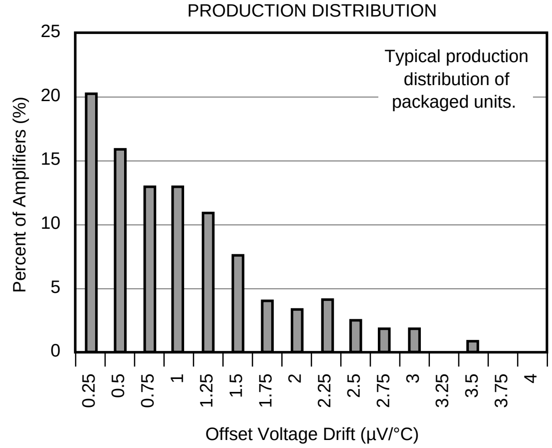
A_{OL}, CMRR, PSRR vs TEMPERATURE



OFFSET VOLTAGE
PRODUCTION DISTRIBUTION



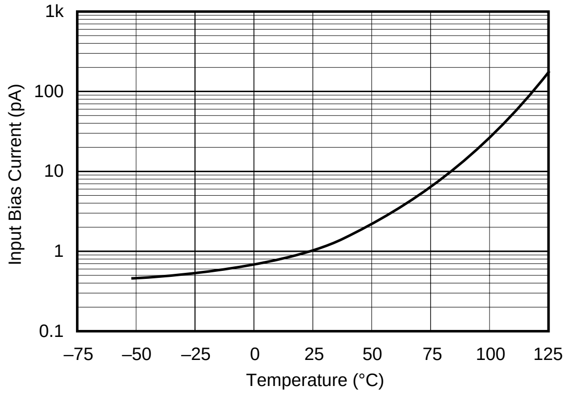
OFFSET VOLTAGE DRIFT MAGNITUDE
PRODUCTION DISTRIBUTION



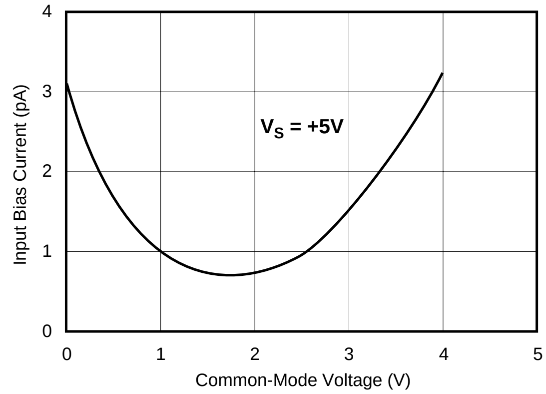
TYPICAL PERFORMANCE CURVES (CONT)

At $T_A = +25°C$, $V_S = +5V$, and $R_L = 25k\Omega$ connected to $V_S/2$, unless otherwise noted.

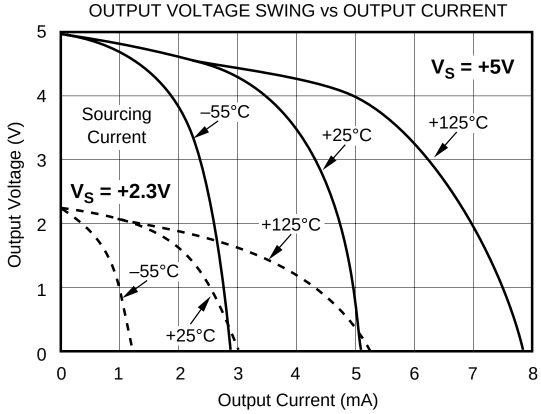
INPUT BIAS CURRENT vs TEMPERATURE



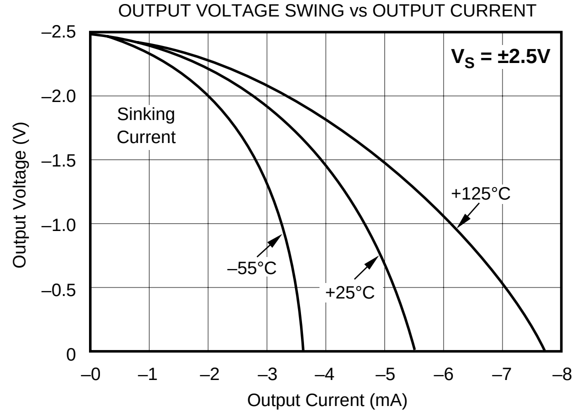
INPUT BIAS CURRENT
vs INPUT COMMON-MODE VOLTAGE



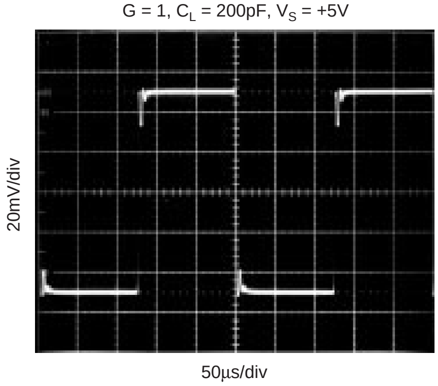
OUTPUT VOLTAGE SWING vs OUTPUT CURRENT



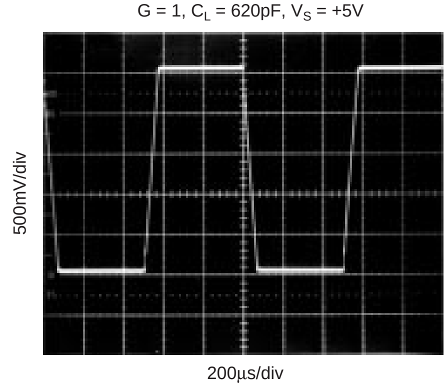
OUTPUT VOLTAGE SWING vs OUTPUT CURRENT



SMALL-SIGNAL STEP RESPONSE
G = 1, C_L = 200pF, V_S = +5V



LARGE-SIGNAL STEP RESPONSE
G = 1, C_L = 620pF, V_S = +5V



APPLICATIONS INFORMATION

OPA336 series op amps are fabricated on a state-of-the-art 0.6 micron CMOS process. They are unity-gain stable and suitable for a wide range of general purpose applications. Power supply pins should be bypassed with 0.01µF ceramic capacitors. OPA336 series op amps are protected against reverse battery voltages.

OPERATING VOLTAGE

OPA336 series op amps can operate from a +2.1V to +5.5V single supply with excellent performance. Most behavior remains unchanged throughout the full operating voltage range. Parameters which vary significantly with operating voltage are shown in the typical performance curves. OPA336 series op amps are fully specified for operation from +2.3V to +5.5V; a single limit applies over the supply range. In addition, many parameters are guaranteed over the specified temperature range, –40°C to +85°C.

INPUT VOLTAGE

The input common-mode range of OPA336 series op amps extends from (V–) –0.2V to (V+) –1V. For normal operation, inputs should be limited to this range. The absolute maximum input voltage is 300mV beyond the supplies. Thus, inputs greater than the input common-mode range but less than maximum input voltage, while not valid, will not cause any damage to the op amp. Furthermore, the inputs may go beyond the power supplies without phase inversion (Figure 1) unlike some other op amps.

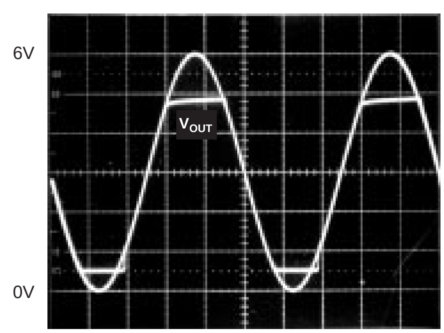


FIGURE 1. No Phase Inversion with Inputs Greater than the Power Supply Voltage.

Normally, input bias current is approximately 1pA. However, input voltages exceeding the power supplies can cause excessive current to flow in or out of the input pins. Momentary voltages greater than the power supply can be tolerated as long as the current on the input pins is limited to 10mA. This is easily accomplished with an input resistor as shown in Figure 2.

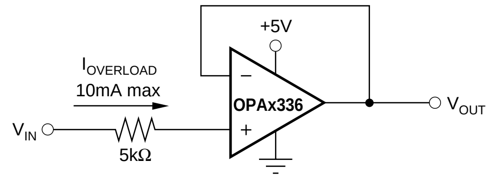


FIGURE 2. Input Current Protection for Voltages Exceeding the Supply Voltage.

CAPACITIVE LOAD AND STABILITY

OPA336 series op amps can drive a wide range of capacitive loads. However, all op amps under certain conditions may become unstable. Op amp configuration, gain, and load value are just a few of the factors to consider when determining stability.

When properly configured, OPA336 series op amps can drive approximately 10,000pF. An op amp in unity gain configuration is the most vulnerable to capacitive load. The capacitive load reacts with the op amp's output resistance, along with any additional load resistance, to create a pole in the response which degrades the phase margin. In unity gain, OPA336 series op amps perform well with a pure capacitive load up to about 300pF. Increasing gain enhances the amplifier's ability to drive loads beyond this level.

One method of improving capacitive load drive in the unity gain configuration is to insert a 50Ω to 100Ω resistor inside the feedback loop as shown in Figure 3. This reduces ringing with large capacitive loads while maintaining DC accuracy.

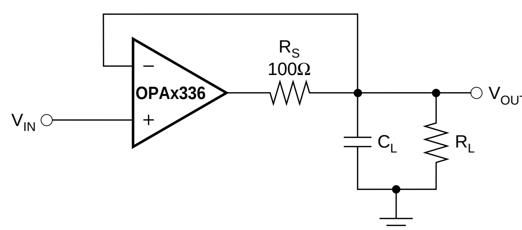


FIGURE 3. Series Resistor in Unity-Gain Configuration Improves Capacitive Load Drive.

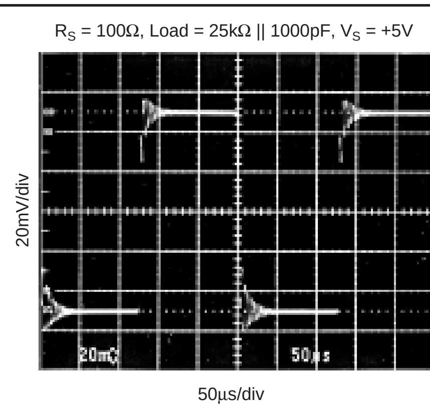


FIGURE 4. Small-Signal Step Response Using Series Resistor to Improve Capacitive Load Drive.

For example, with R_L = 25kΩ, OPA336 series op amps perform well with capacitive loads in excess of 1000pF (Figure 4). Without R_S, capacitive load drive is typically 350pF for these conditions (see Figure 5).

Alternatively, the resistor may be connected in series with the output outside of the feedback loop. However, if there is a resistive load parallel to the capacitive load, it and the series resistor create a voltage divider. This introduces a DC error at the output. However, this error may be insignificant. For instance, with R_L = 100kΩ and R_S = 100Ω, there is only about a 0.1% error at the output.

Figure 5 shows the recommended operating regions for the OPA336. Decreasing the load resistance generally improves capacitive load drive. Figure 5 also illustrates how stability differs depending on where the resistive load is connected. With G = +1 and R_L = 10kΩ connected to $V_S/2$, the OPA336 can typically drive 500pF. Connecting the same load to ground improves capacitive load drive to 1000pF.

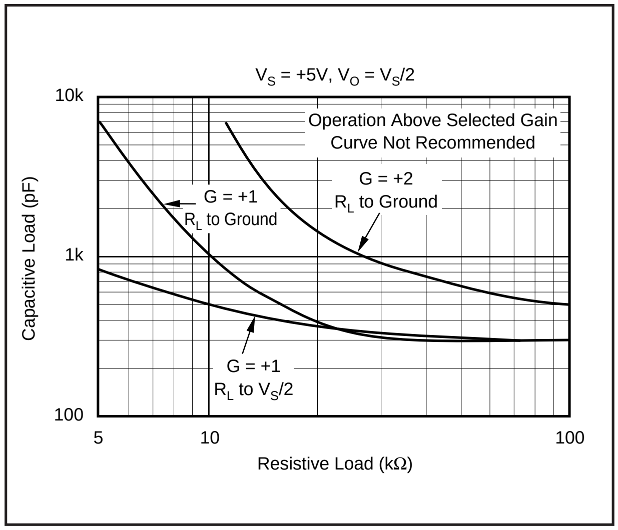


FIGURE 5. Stability—Capacitive Load vs Resistive Load.

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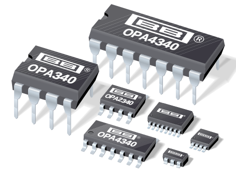


OPA340
OPA2340
OPA4340

SINGLE-SUPPLY, RAIL-TO-RAIL OPERATIONAL AMPLIFIERS
*Micro*Amplifier™ Series

FEATURES

- RAIL-TO-RAIL INPUT
- RAIL-TO-RAIL OUTPUT (within 1mV)
- *Micro*SIZE PACKAGES
- WIDE BANDWIDTH: 5.5MHz
- HIGH SLEW RATE: 6V/µs
- LOW THD+NOISE: 0.0007% (f = 1kHz)
- LOW QUIESCENT CURRENT: 750µA/channel
- SINGLE, DUAL, AND QUAD

APPLICATIONS

- DRIVING A/D CONVERTERS
- PCMCIA CARDS
- DATA ACQUISITION
- PROCESS CONTROL
- AUDIO PROCESSING
- COMMUNICATIONS
- ACTIVE FILTERS
- TEST EQUIPMENT

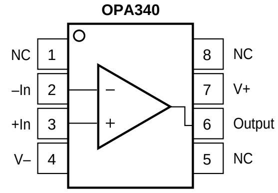
DESCRIPTION

OPA340 series rail-to-rail CMOS operational amplifiers are optimized for low voltage, single supply operation. Rail-to-rail input/output and high speed operation make them ideal for driving sampling analog-to-digital converters. They are also well suited for general purpose and audio applications as well as providing I/V conversion at the output of D/A converters. Single, dual, and quad versions have identical specifications for design flexibility.

The OPA340 series operates on a single supply as low as 2.5V with an input common-mode voltage range that extends 500mV below ground and 500mV above the positive supply. Output voltage swing is to within 1mV of the supply rails with a 100kΩ load. They offer excellent dynamic response (BW = 5.5MHz, SR = 6V/µs), yet quiescent current is only 750µA. Dual and quad designs feature completely independent circuitry for lowest crosstalk and freedom from interaction.

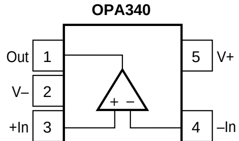
The single (OPA340) packages are the tiny 5-lead SOT-23-5 surface mount, SO-8 surface mount, and 8-pin DIP. The dual (OPA2340) comes in the miniature MSOP-8 surface mount, SO-8 surface mount, and 8-pin DIP packages. The quad (OPA4340) packages are the space-saving SSOP-16 surface mount, SO-14 surface mount, and the 14-pin DIP. All are specified from –40°C to +85°C and operate from –55°C to +125°C. A SPICE macromodel is available for design analysis.

OPA340



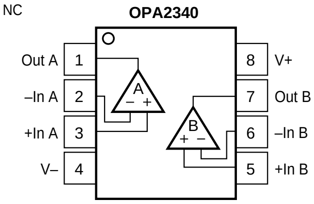
8-Pin DIP, SO-8

OPA340



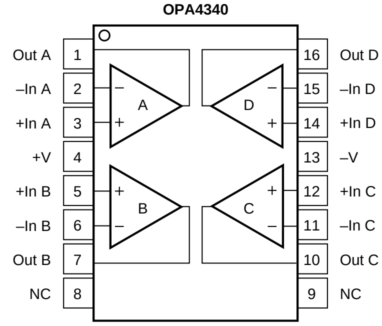
SOT-23-5

OPA2340



8-Pin DIP, SO-8, MSOP-8

OPA4340



SSOP-16

International Airport Industrial Park • Mailing Address: PO Box 11400, Tucson, AZ 85734 • Street Address: 6730 S. Tucson Blvd., Tucson, AZ 85706 • Tel: (520) 746-1111 • Twx: 910-952-1111
Internet: http://www.burr-brown.com/ • FAXLine: (800) 548-6133 (US/Canada Only) • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

PDS-1404C

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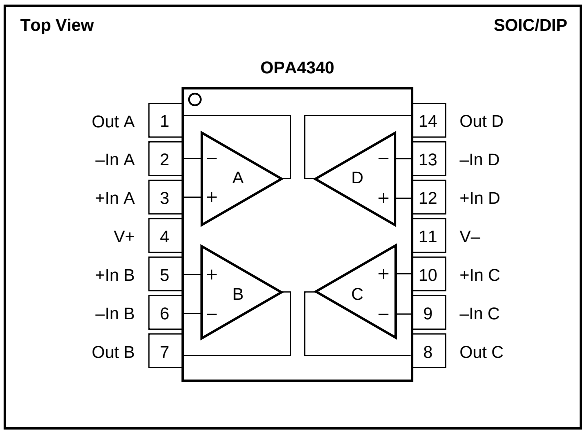
SPECIFICATIONS: V_S = 2.7V to 5V

At T_A = +25°C, R_L = 10kΩ connected to V_S/2 and V_{OUT} = V_S/2, unless otherwise noted.
Boldface limits apply over the specified temperature range, T_A = –40°C to +85°C. V_S = 5V.

PARAMETER		CONDITION	OPA340NA, PA, UA OPA2340EA, PA, UA OPA4340EA, PA, UA MIN	TYP(1)	MAX	UNITS
OFFSET VOLTAGE						
Input Offset Voltage	V_{OS}	V_S = 5V		±150	±500	µV
vs Temperature	dV_{OS}/dT			**±2.5**		µV/°C
vs Power Supply	PSRR	V_S = 2.7V to 5.5V, V_{CM} = 0V		30	120	µV/V
T_A = –40°C to +85°C		V_S = 2.7V to 5.5V, V_{CM} = 0V			**120**	µV/V
Channel Separation, dc				0.2		µV/V
INPUT BIAS CURRENT						
Input Bias Current	I_B			±0.2	±10	pA
T_A = –40°C to +85°C					**±60**	pA
Input Offset Current	I_{OS}			±0.2	±10	pA
NOISE						
Input Voltage Noise, f = 0.1 to 50kHz				8		µVrms
Input Voltage Noise Density, f = 1kHz	e_n			25		nV/√Hz
Current Noise Density, f = 1kHz	i_n			3		fA/√Hz
INPUT VOLTAGE RANGE						
Common-Mode Voltage Range	V_{CM}		–0.3		(V+) +0.3	V
Common-Mode Rejection Ratio	CMRR	–0.3V < V_{CM} < (V+) –1.8V	80	92		dB
		V_S = 5V, –0.3V < V_{CM} < 5.3V	70	84		dB
		V_S = 2.7V, –0.3V < V_{CM} < 3V	66	80		dB
INPUT IMPEDANCE						
Differential				10^{13} || 3		Ω || pF
Common-Mode				10^{13} || 6		Ω || pF
OPEN-LOOP GAIN						
Open-Loop Voltage Gain	A_{OL}	R_L = 100kΩ, 5mV < V_O < (V+) –5mV	106	124		dB
T_A = –40°C to +85°C		R_L = 100kΩ, 5mV < V_O < (V+) –5mV	**106**			dB
		R_L = 10kΩ, 50mV < V_O < (V+) –50mV	100	120		dB
T_A = –40°C to +85°C		R_L = 10kΩ, 50mV < V_O < (V+) –50mV	**100**			dB
		R_L = 2kΩ, 200mV < V_O < (V+) –200mV	94	114		dB
T_A = –40°C to +85°C		R_L = 2kΩ, 200mV < V_O < (V+) –200mV	**94**			dB
FREQUENCY RESPONSE						
Gain-Bandwidth Product	GBW	G = 1		5.5		MHz
Slew Rate	SR	V_S = 5V, G = 1, C_L = 100pF		6		V/µs
Settling Time, 0.1%		V_S = 5V, 2V Step, C_L = 100pF		1		µs
0.01%		V_S = 5V, 2V Step, C_L = 100pF		1.6		µs
Overload Recovery Time		V_{IN} • G = V_S		0.2		µs
Total Harmonic Distortion + Noise	THD+N	V_S = 5V, V_O = 3Vp-p(2), G = 1, f = 1kHz		0.0007		%
OUTPUT						
Voltage Output Swing from Rail(3)		R_L = 100kΩ, A_{OL} ≥ 106dB		1	5	mV
T_A = –40°C to +85°C		R_L = 100kΩ, A_{OL} ≥ 106dB			**5**	mV
		R_L = 10kΩ, A_{OL} ≥ 100dB		10	50	mV
T_A = –40°C to +85°C		R_L = 10kΩ, A_{OL} ≥ 100dB			**50**	mV
		R_L = 2kΩ, A_{OL} ≥ 94dB		40	200	mV
T_A = –40°C to +85°C		R_L = 2kΩ, A_{OL} ≥ 94dB			**200**	mV
Short-Circuit Current	I_{SC}			±50		mA
Capacitive Load Drive	C_{LOAD}			See Typical Curve		
POWER SUPPLY						
Specified Voltage Range	V_S		2.7		5	V
Operating Voltage Range				2.5 to 5.5		V
Quiescent Current (per amplifier)	I_Q	I_O = 0, V_S = +5V		750	950	µA
T_A = –40°C to +85°C		I_O = 0, V_S = +5V			**1100**	µA
TEMPERATURE RANGE						
Specified Range			–40		+85	°C
Operating Range			–55		+125	°C
Storage Range			–55		+125	°C
Thermal Resistance	θ_{JA}					
SOT-23-5 Surface Mount				200		°C/W
MSOP-8 Surface Mount				150		°C/W
SO-8 Surface Mount				150		°C/W
8-Pin DIP				100		°C/W
SSOP-16 Surface Mount				100		°C/W
SO-14 Surface Mount				100		°C/W
14-Pin DIP				80		°C/W

NOTES: (1) V_S = +5V. (2) V_{OUT} = 0.25V to 3.25V. (3) Output voltage swings are measured between the output and power supply rails.

PIN CONFIGURATIONS



ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ABSOLUTE MAXIMUM RATINGS(1)

Supply Voltage	5.5V
Signal Input Terminals, Voltage(2)	(V–) –0.5V to (V+) +0.5V
Current(2)	10mA
Output Short-Circuit(3)	Continuous
Operating Temperature	–55°C to +125°C
Storage Temperature	–55°C to +125°C
Junction Temperature	150°C
Lead Temperature (soldering, 10s)	300°C

NOTES: (1) Stresses above these ratings may cause permanent damage. (2) Input terminals are diode-clamped to the power supply rails. Input signals that can swing more than 0.5V beyond the supply rails should be current-limited to 10mA or less. (3) Short-circuit to ground, one amplifier per package.

PACKAGE/ORDERING INFORMATION

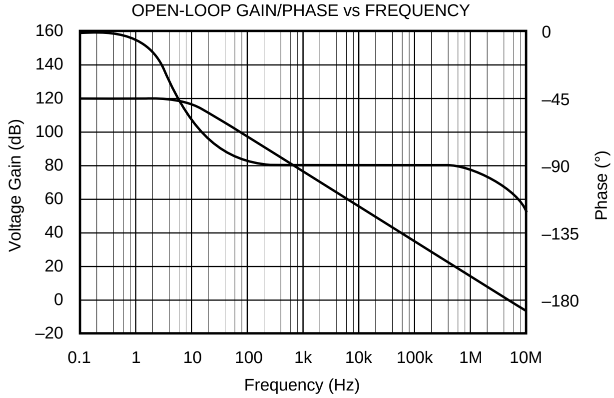
PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER(1)	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER(2)	TRANSPORT MEDIA
Single						
OPA340NA	5-Lead SOT-23-5	331	–40°C to +85°C	A40	OPA340NA-250	Tape and Reel
"	"	"	"	"	OPA340NA-3K	Tape and Reel
OPA340PA	8-Pin DIP	006	–40°C to +85°C	OPA340PA	OPA340PA	Rails
OPA340UA	SO-8 Surface-Mount	182	–40°C to +85°C	OPA340UA	OPA340UA	Rails(3)
Dual						
OPA2340EA	MSOP-8 Surface-Mount	337	–40°C to +85°C	A40A	OPA2340EA-250	Tape and Reel
"	"	"	"	"	OPA2340EA-2500	Tape and Reel
OPA2340PA	8-Pin DIP	006	–40°C to +85°C	OPA2340PA	OPA2340PA	Rails
OPA2340UA	SO-8 Surface-Mount	182	–40°C to +85°C	OPA2340UA	OPA2340UA	Rails(3)
Quad						
OPA4340EA	SSOP-16 Surface-Mount	322	–40°C to +85°C	OPA4340EA	OPA4340EA-250	Tape and Reel
"	"	"	"	"	OPA4340EA-2500	Tape and Reel
OPA4340PA	14-Pin DIP	010	–40°C to +85°C	OPA4340PA	OPA4340PA	Rails
OPA4340UA	SO-14 Surface Mount	235	–40°C to +85°C	OPA4340UA	OPA4340UA	Rails(3)

NOTES: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book. (2) Models with -250, -2500, and -3K are available only in Tape and Reel in the quantities indicated (e.g., -250 indicates 250 devices per reel). Ordering 3000 pieces of “OPA340NA-3K” will get a single 3000 piece Tape and Reel. For detailed Tape and Reel mechanical information, refer to Appendix B of Burr-Brown IC Data Book. (3) SO-8 and SO-14 models also available in Tape and Reel.

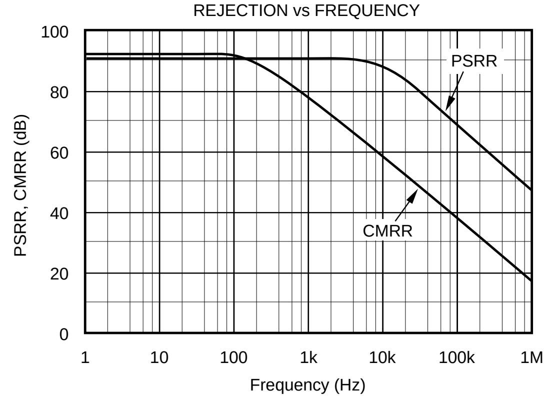
TYPICAL PERFORMANCE CURVES

At T_A = +25°C, V_S = +5V, and R_L = 10kΩ connected to V_S/2, unless otherwise noted.

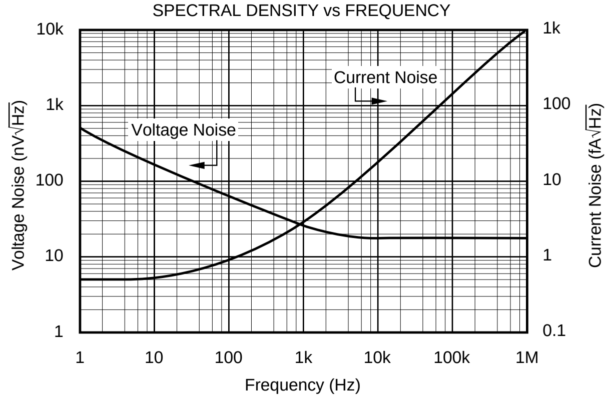
OPEN-LOOP GAIN/PHASE vs FREQUENCY



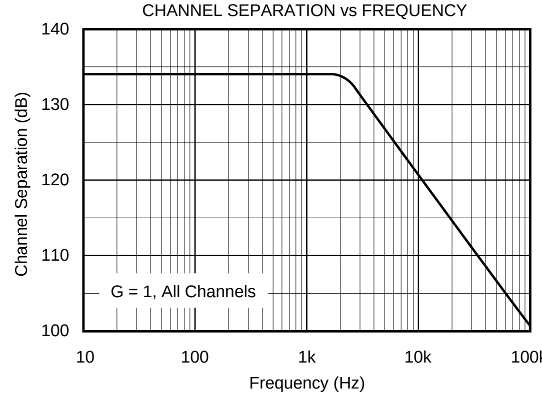
POWER SUPPLY and COMMON-MODE REJECTION vs FREQUENCY



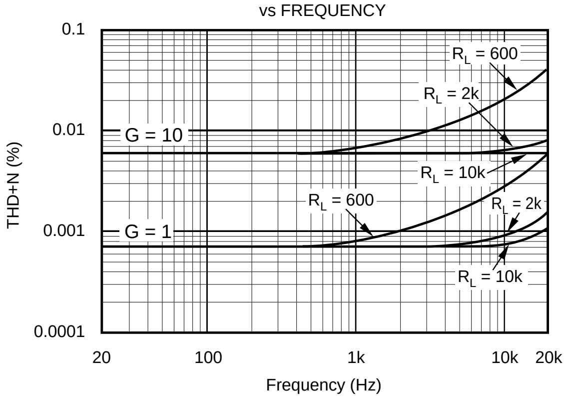
INPUT VOLTAGE AND CURRENT NOISE SPECTRAL DENSITY vs FREQUENCY



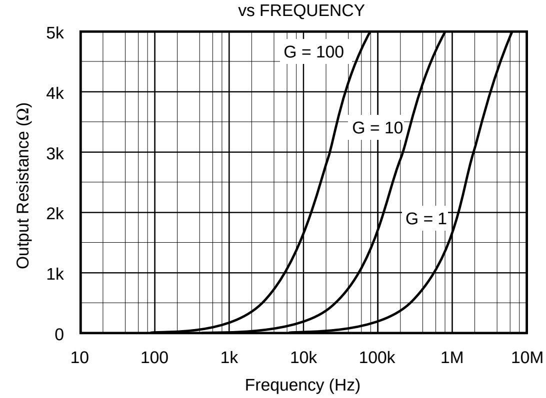
CHANNEL SEPARATION vs FREQUENCY



TOTAL HARMONIC DISTORTION + NOISE vs FREQUENCY



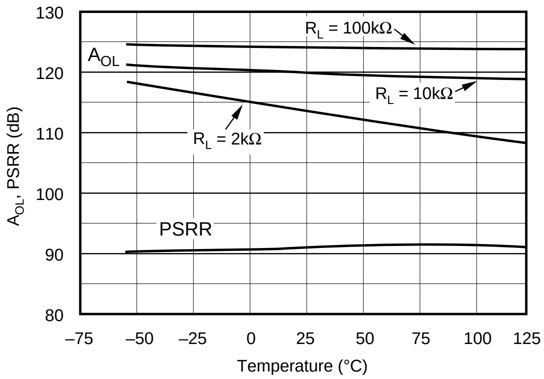
CLOSED-LOOP OUTPUT IMPEDANCE vs FREQUENCY



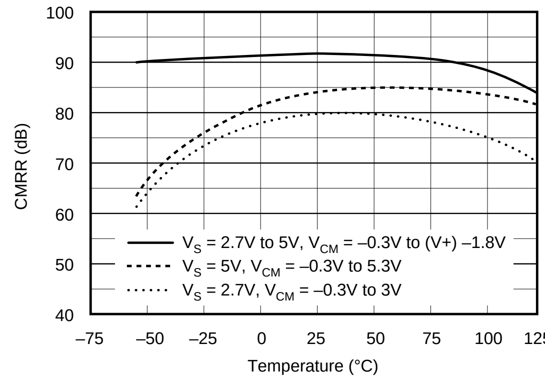
TYPICAL PERFORMANCE CURVES (CONT)

At T_A = +25°C, V_S = +5V, and R_L = 10kΩ connected to V_S/2, unless otherwise noted.

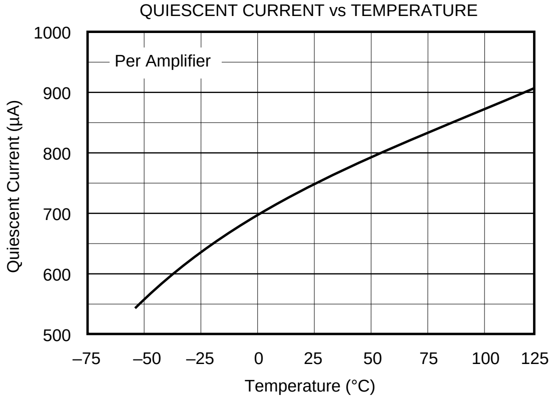
OPEN-LOOP GAIN AND POWER SUPPLY REJECTION vs TEMPERATURE



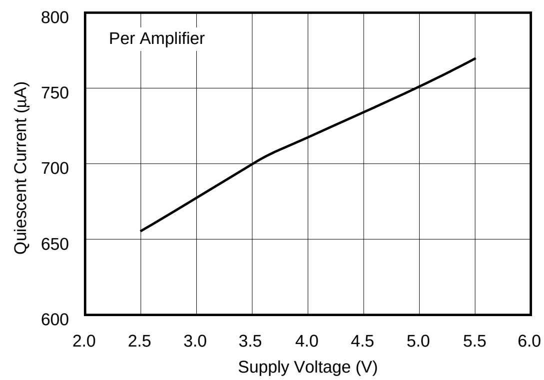
COMMON-MODE REJECTION vs TEMPERATURE



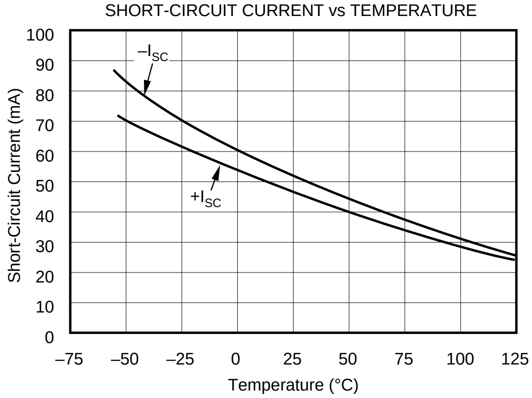
QUIESCENT CURRENT vs TEMPERATURE



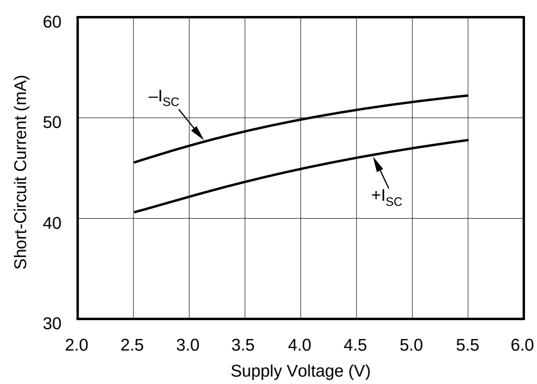
QUIESCENT CURRENT vs SUPPLY VOLTAGE



SHORT-CIRCUIT CURRENT vs TEMPERATURE

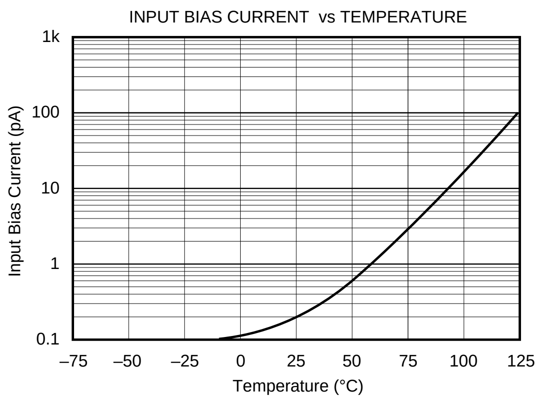


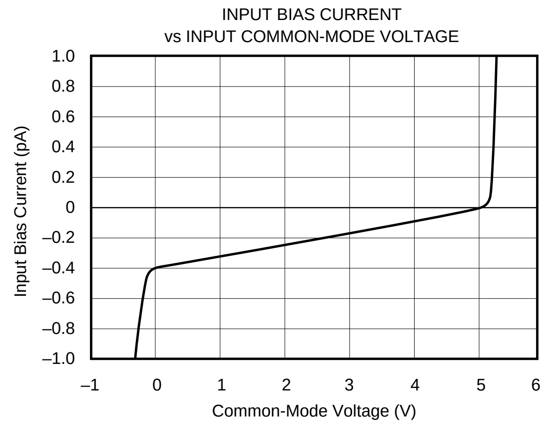
SHORT-CIRCUIT CURRENT vs SUPPLY VOLTAGE

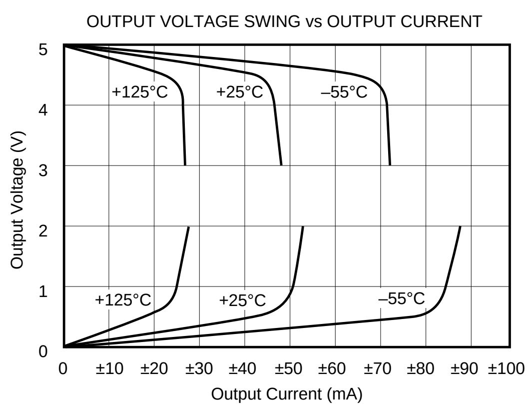


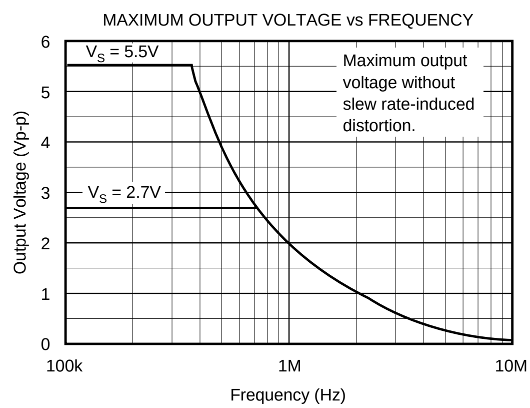
TYPICAL PERFORMANCE CURVES (CONT)

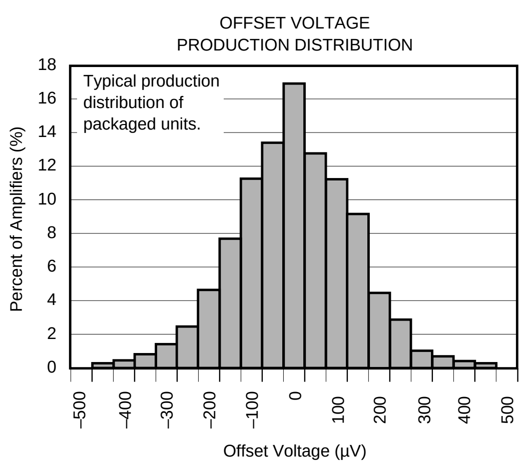
At T_A = +25°C, V_S = +5V, and R_L = 10kΩ connected to V_S/2, unless otherwise noted.

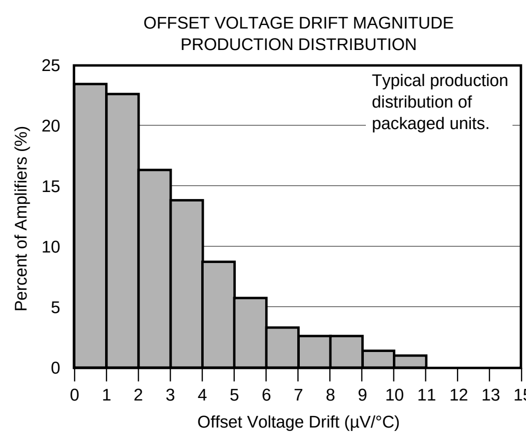






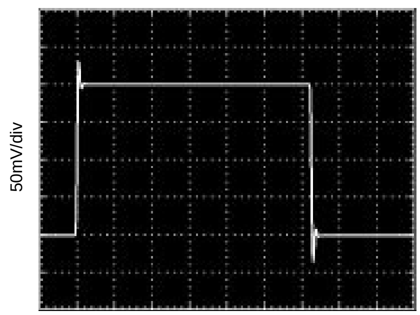


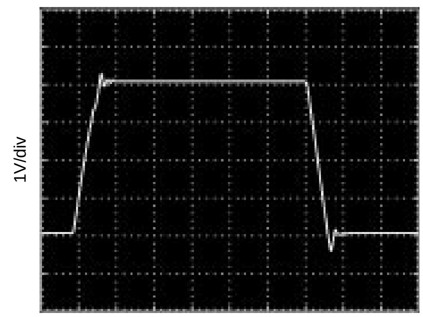


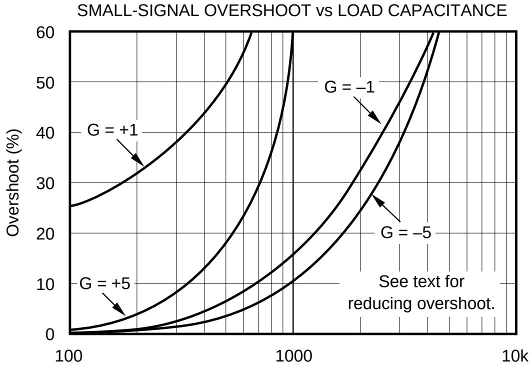


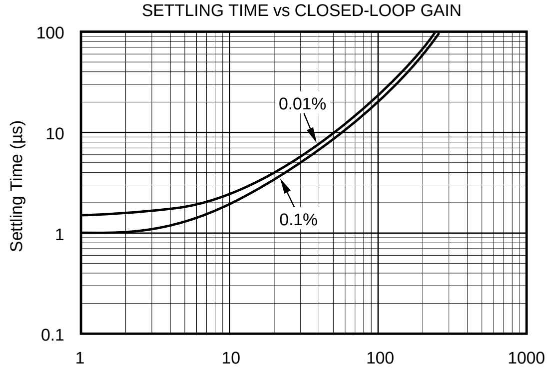
TYPICAL PERFORMANCE CURVES (CONT)

At T_A = +25°C, V_S = +5V, and R_L = 10kΩ connected to V_S/2, unless otherwise noted.









APPLICATIONS INFORMATION

OPA340 series op amps are fabricated on a state-of-the-art 0.6 micron CMOS process. They are unity-gain stable and suitable for a wide range of general purpose applications. Rail-to-rail input/output make them ideal for driving sampling A/D converters. In addition, excellent ac performance makes them well-suited for audio applications. The class AB output stage is capable of driving 600Ω loads connected to any point between V+ and ground.

Rail-to-rail input and output swing significantly increases dynamic range, especially in low supply applications. Figure 1 shows the input and output waveforms for the OPA340 in unity-gain configuration. Operation is from a single +5V supply with a 10kΩ load connected to $V_S/2$. The input is a 5Vp-p sinusoid. Output voltage is approximately 4.98Vp-p.

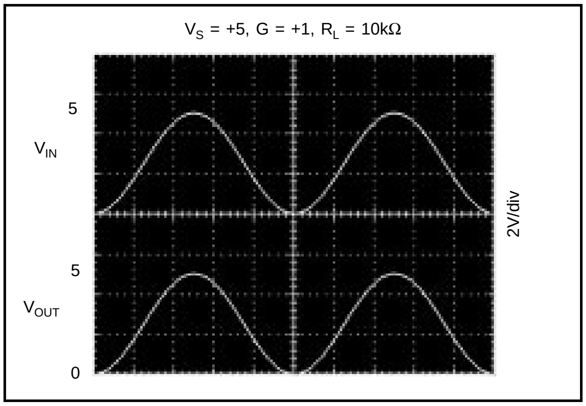


FIGURE 1. Rail-to-Rail Input and Output.

Power supply pins should be bypassed with 0.01µF ceramic capacitors.

OPERATING VOLTAGE

OPA340 series op amps are fully specified from +2.7V to +5V. However, supply voltage may range from +2.5V to +5.5V. Parameters are guaranteed over the specified supply range—a unique feature of the OPA340 series. In addition, many specifications apply from –40°C to +85°C. Most behavior remains virtually unchanged throughout the full operating voltage range. Parameters which vary significantly with operating voltages or temperature are shown in the typical performance curves.

RAIL-TO-RAIL INPUT

The input common-mode voltage range of the OPA340 series extends 500mV beyond the supply rails. This is achieved with a complementary input stage—an N-channel input differential pair in parallel with a P-channel differential pair (see Figure 2). The N-channel pair is active for input voltages close to the positive rail, typically (V+) –1.3V to 500mV above the positive supply, while the P-channel pair is on for inputs from 500mV below the negative supply to approximately (V+) –1.3V. There is a small transition region, typically (V+) –1.5V to (V+) –1.1V, in which both pairs are on. This 400mV transition region can vary ±300mV with process variation. Thus, the transition region (both stages on) can range from (V+) –1.8V to (V+) –1.4V on the low end, up to (V+) –1.2V to (V+) –0.8V on the high end.

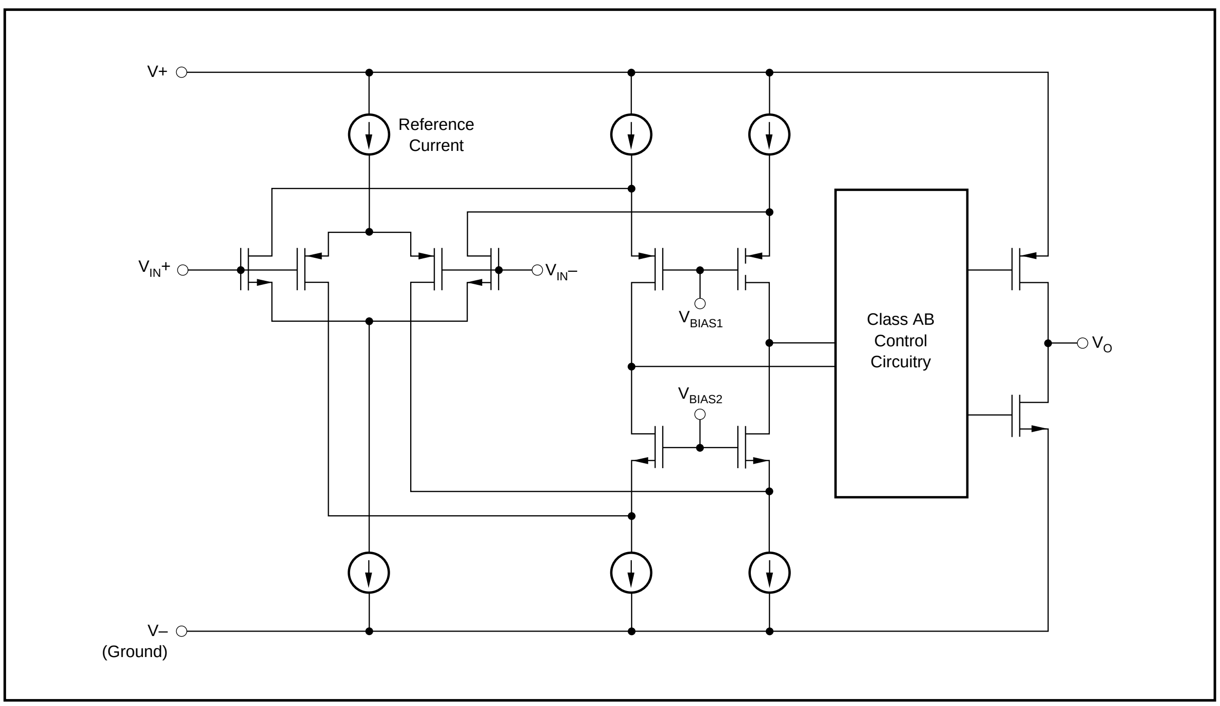


FIGURE 2. Simplified Schematic.

OPA340 series op amps are laser-trimmed to the reduce offset voltage difference between the N-channel and P-channel input stages, resulting in improved common-mode rejection and a smooth transition between the N-channel pair and the P-channel pair. However, within the 400mV transition region PSRR, CMRR, offset voltage, offset drift, and THD may be degraded compared to operation outside this region.

A double-folded cascode adds the signal from the two input pairs and presents a differential signal to the class AB output stage. Normally, input bias current is approximately 200fA, however, input voltages exceeding the power supplies by more than 500mV can cause excessive current to flow in or out of the input pins. Momentary voltages greater than 500mV beyond the power supply can be tolerated if the current on the input pins is limited to 10mA. This is easily accomplished with an input resistor as shown in Figure 3. Many input signals are inherently current-limited to less than 10mA, therefore, a limiting resistor is not required.

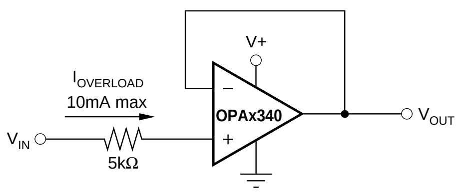


FIGURE 3. Input Current Protection for Voltages Exceeding the Supply Voltage.

RAIL-TO-RAIL OUTPUT

A class AB output stage with common-source transistors is used to achieve rail-to-rail output. For light resistive loads (>50kΩ), the output voltage is typically a few millivolts from the supply rails. With moderate resistive loads (2kΩ to 50kΩ), the output can swing to within a few tens of millivolts from the supply rails and maintain high open-loop gain. See the typical performanc curve "Output Voltage Swing vs Output Current."

CAPACITIVE LOAD AND STABILITY

OPA340 series op amps can drive a wide range of capacitive loads. However, all op amps under certain conditions may become unstable. Op amp configuration, gain, and load value are just a few of the factors to consider when determining stability. An op amp in unity gain configuration is the most susceptible to the effects of capacitive load. The capacitive load reacts with the op amp's output resistance, along with any additional load resistance, to create a pole in the small-signal response which degrades the phase margin. In unity gain, OPA340 series op amps perform well, with a pure capacitive load up to approximately 1000pF. Increasing gain enhances the amplifier's ability to drive more capacitance. See the typical performance curve "Small-Signal Overshoot vs Capacitive Load."

One method of improving capacitive load drive in the unity gain configuration is to insert a 10Ω to 20Ω resistor in series with the output, as shown in Figure 4. This significantly reduces ringing with large capacitive loads. However, if there is a resistive load in parallel with the capacitive load, it creates a voltage divider introducing a dc error at the output and slightly reduces output swing. This error may be insignificant. For instance, with $R_L = 10k\Omega$ and $R_S = 20\Omega$, there is only about a 0.2% error at the output.

DRIVING A/D CONVERTERS

OPA340 series op amps are optimized for driving medium speed (up to 100kHz) sampling A/D converters. However, they also offer excellent performance for higher speed converters. The OPA340 series provides an effective means of buffering the A/D's input capacitance and resulting charge injection while providing signal gain.

Figures 5 and 6 show the OPA340 driving an ADS7816. The ADS7816 is a 12-bit, micro-power sampling converter in the tiny MSOP-8 package. When used with the miniature package options of the OPA340 series, the combination is ideal for space-limited and low power applications. For further information consult the ADS7816 data sheet.

With the OPA340 in a noninverting configuration, an RC network at the amplifier's output can be used to filter high frequency noise in the signal (Figure 5). In the inverting configuration, filtering may be accomplished with a capacitor across the feedback resistor (Figure 6).

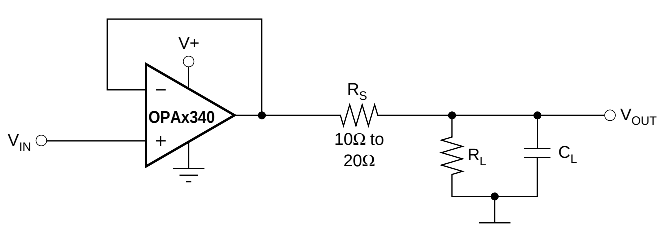


FIGURE 4. Series Resistor in Unity-Gain Configuration Improves Capacitive Load Drive.

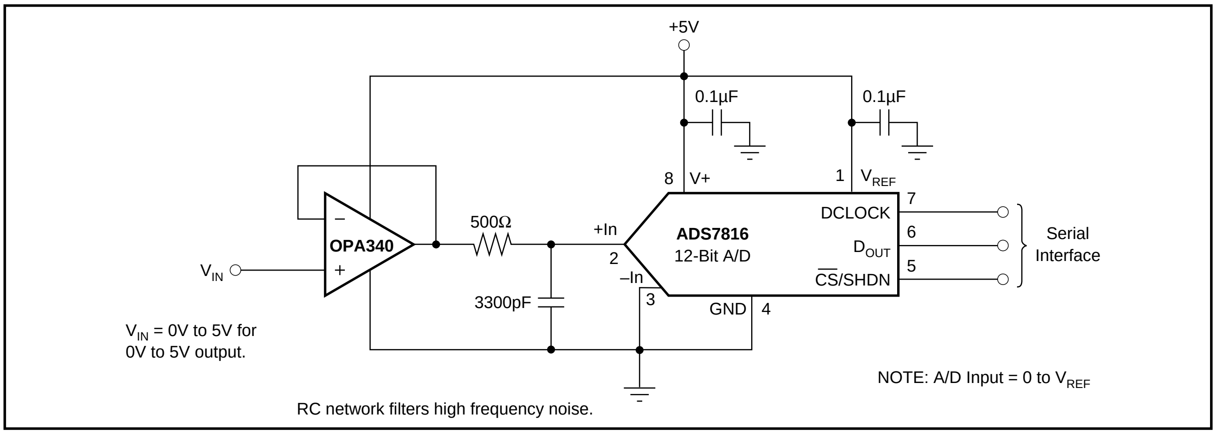


FIGURE 5. OPA340 in Noninverting Configuration Driving ADS7816.

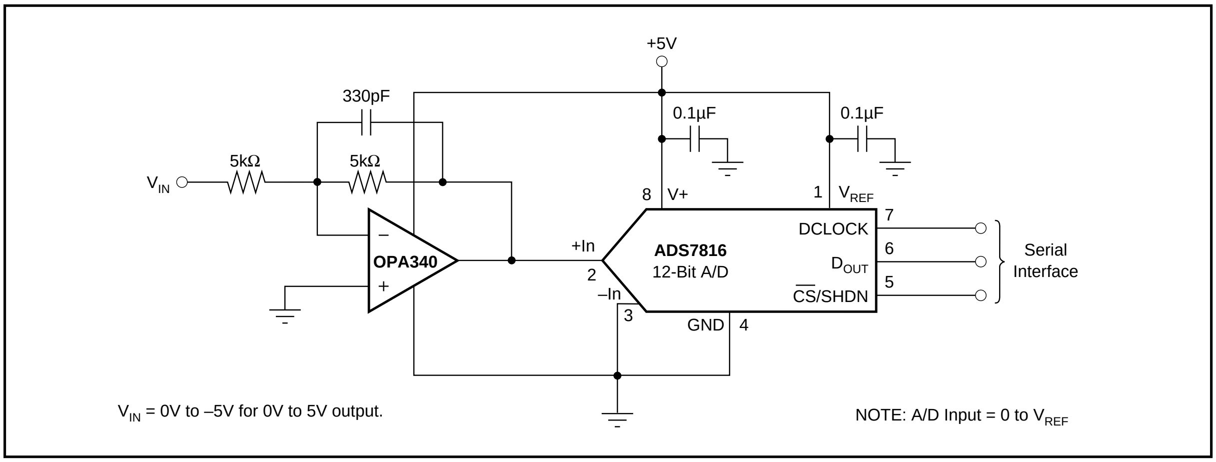


FIGURE 6. OPA340 in Inverting Configuration Driving ADS7816.

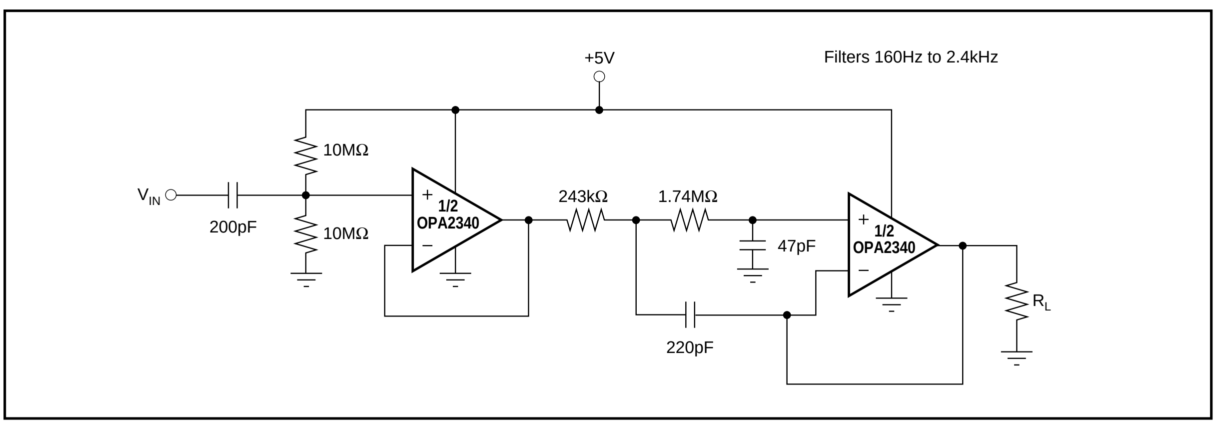


FIGURE 7. Speech Bandpass Filter.

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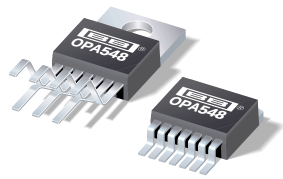


OPA548

www.burr-brown.com/databook/OPA548.html

High-Voltage, High-Current OPERATIONAL AMPLIFIER

FEATURES

- **WIDE SUPPLY RANGE**
  Single Supply: +8V to +60V
  Dual Supply: ±4V to ±30V
- **HIGH OUTPUT CURRENT:**
  3A Continuous
  5A Peak
- **WIDE OUTPUT VOLTAGE SWING**
- **FULLY PROTECTED:**
  Thermal Shutdown
  Adjustable Current Limit
- **OUTPUT DISABLE CONTROL**
- **THERMAL SHUTDOWN INDICATOR**
- **HIGH SLEW RATE: 10V/µs**
- **LOW QUIESCENT CURRENT**
- **PACKAGES:**
  7-Lead TO-220
  7-Lead DDPAK Surface-Mount

APPLICATIONS

- **VALVE, ACTUATOR DRIVER**
- **SYNCHRO, SERVO DRIVER**
- **POWER SUPPLIES**
- **TEST EQUIPMENT**
- **TRANSDUCER EXCITATION**
- **AUDIO AMPLIFIER**

DESCRIPTION

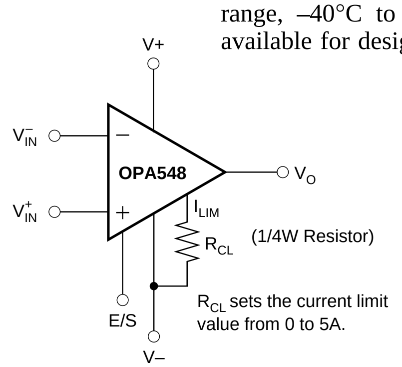
The OPA548 is a low cost, high-voltage/high-current operational amplifier ideal for driving a wide variety of loads. A laser-trimmed monolithic integrated circuit provides excellent low-level signal accuracy and high output voltage and current.

The OPA548 operates from either single or dual supplies for design flexibility. In single supply operation, the input common-mode range extends below ground.

The OPA548 is internally protected against over-temperature conditions and current overloads. In addition, the OPA548 was designed to provide an accurate, user-selected current limit. Unlike other designs which use a “power” resistor in series with the output current path, the OPA548 senses the load indirectly. This allows the current limit to be adjusted from 0 to 5A with a resistor/potentiometer or controlled digitally with a voltage-out or current-out DAC.

The Enable/Status (E/S) pin provides two functions. An input on the pin not only disables the output stage to effectively disconnect the load but also reduces the quiescent current to conserve power. The E/S pin output can be monitored to determine if the OPA548 is in thermal shutdown.

The OPA548 is available in an industry-standard 7-lead staggered TO-220 package and a 7-lead DDPAK surface-mount plastic power package. The copper tab allows easy mounting to a heat sink or circuit board for excellent thermal performance. It is specified for operation over the extended industrial temperature range, –40°C to +85°C. A SPICE macromodel is available for design analysis.



International Airport Industrial Park • Mailing Address: PO Box 11400, Tucson, AZ 85734 • Street Address: 6730 S. Tucson Blvd., Tucson, AZ 85706 • Tel: (520) 746-1111 • Twx: 910-952-1111
Internet: http://www.burr-brown.com/ • FAXLine: (800) 548-6133 (US/Canada Only) • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

 PDS-1389B Printed in U.S.A. October, 1997

SPECIFICATIONS

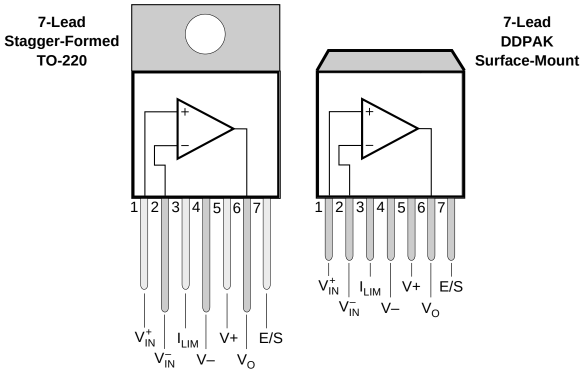
At T_{CASE} = +25°C, V_S = ±30V and E/S pin open, unless otherwise noted.

PARAMETER	CONDITION	OPA548T, F MIN	TYP	MAX	UNITS
OFFSET VOLTAGE					
Input Offset Voltage	V_{CM} = 0, I_O = 0		±2	±10	mV
vs Temperature	T_A = –40°C to +85°C		±30		µV/°C
vs Power Supply	V_S = ±4V to ±30V		30	100	µV/V
INPUT BIAS CURRENT(1)					
Input Bias Current(2)	V_{CM} = 0V		–100	–500	nA
vs Temperature	T_A = –40°C to +85°C		±0.5		nA/°C
Input Offset Current	V_{CM} = 0V		±5	±50	nA
NOISE					
Input Voltage Noise Density, f = 1kHz			90		$nV/\sqrt{Hz}$
Current Noise Density, f = 1kHz			200		$fA/\sqrt{Hz}$
INPUT VOLTAGE RANGE					
Common-Mode Voltage Range: Positive	Linear Operation	(V+) –3	(V+) –2.3		V
Negative	Linear Operation	(V–) –0.1	(V–) –0.2		V
Common-Mode Rejection	V_{CM} = (V–) –0.1V to (V+) –3V	80	95		dB
INPUT IMPEDANCE					
Differential			10^7 || 6		Ω || pF
Common-Mode			10^9 || 4		Ω || pF
OPEN-LOOP GAIN					
Open-Loop Voltage Gain	V_O = ±25V, R_L = 1kΩ	90	98		dB
	V_O = ±25V, R_L = 8Ω		90		dB
FREQUENCY RESPONSE					
Gain-Bandwidth Product	R_L = 8Ω		1		MHz
Slew Rate	G = 1, 50Vp-p, R_L = 8Ω		10		V/µs
Full Power Bandwidth			See Typical Curve		kHz
Settling Time: ±0.1%	G = –10, 50V Step		15		µs
Total Harmonic Distortion + Noise, f = 1kHz	R_L = 8Ω, G = +3, Power = 10W		0.02(3)		%
OUTPUT					
Voltage Output, Positive	I_O = 3A	(V+) –4.1	(V+) –3.7		V
Negative	I_O = –3A	(V–) +3.7	(V–) +3.3		V
Positive	I_O = 0.6A	(V+) –2.4	(V+) –2.1		V
Negative	I_O = –0.6A	(V–) +1.3	(V–) +1.0		V
Maximum Continuous Current Output: dc		±3			A
ac		3			Arms
Leakage Current, Output Disabled, dc			See Typical Curve		
Output Current Limit					
Current Limit Range			0 to ±5		A
Current Limit Equation			I_{LIM} = (15000)(4.75)/(13750Ω + R_{CL})		A
Current Limit Tolerance(1)	R_{CL} = 14.8kΩ (I_{LIM} = ±2.5A), R_L = 8Ω		±100	±250	mA
Capacitive Load Drive			See Typical Curve(4)		
OUTPUT ENABLE /STATUS (E/S) PIN					
Shutdown Input Mode					
$V_{E/S}$ High (output enabled)	E/S Pin Open or Forced High	(V–) +2.4			V
$V_{E/S}$ Low (output disabled)	E/S Pin Forced Low			(V–) +0.8	V
$I_{E/S}$ High (output enabled)	E/S Pin High		–65		µA
$I_{E/S}$ Low (output disabled)	E/S Pin Low		–70		µA
Output Disable Time			1		µs
Output Enable Time			3		µs
Thermal Shutdown Status Output					
Normal Operation	Sourcing 20µA	(V–) +2.4	(V–) +3.5		V
Thermally Shutdown	Sinking 5µA, T_J > 160°C		(V–) +0.35	(V–) +0.8	V
Junction Temperature, Shutdown			+160		°C
Reset from Shutdown			+140		°C
POWER SUPPLY					
Specified Voltage			±30		V
Operating Voltage Range		±4		±30	V
Quiescent Current	I_{LIM} Connected to V–, I_O = 0		±17	±20	mA
Quiescent Current, Shutdown Mode	I_{LIM} Connected to V–, I_O = 0		±6		mA
TEMPERATURE RANGE					
Specified Range		–40		+85	°C
Operating Range		–40		+125	°C
Storage Range		–55		+125	°C
Thermal Resistance, θ_{JC}					
7-Lead DDPAK, 7-Lead TO-220	f > 50Hz		2		°C/W
7-Lead DDPAK, 7-Lead TO-220	dc		2.5		°C/W
Thermal Resistance, θ_{JA}					
7-Lead DDPAK, 7-Lead TO-220	No Heat Sink		65		°C/W

NOTES: (1) High-speed test at T_J = +25°C. (2) Positive conventional current flows into the input terminals. (3) See “Total Harmonic Distortion+Noise vs Frequency” in the Typical Performance Curves section for additional power levels. (4) See “Small-Signal Overshoot vs Load Capacitance” in the Typical Performance Curves section.

CONNECTION DIAGRAMS

Top Front View



NOTE: Tabs are electrically connected to V– supply.

ABSOLUTE MAXIMUM RATINGS[1]

Output Current	See SOA Curve
Supply Voltage, V+ to V–	60V
Input Voltage	(V–)–0.5V to (V+)+0.5V
Input Shutdown Voltage	V+
Operating Temperature	–40°C to +125°C
Storage Temperature	–55°C to +125°C
Junction Temperature	150°C
Lead Temperature (soldering 10s)[2]	300°C

NOTE: (1) Stresses above these ratings may cause permanent damage. (2) Vapor-phase or IR reflow techniques are recommended for soldering the OPA548F surface mount package. Wave soldering is not recommended due to excessive thermal shock and "shadowing" of nearby devices.

PACKAGE/ORDERING INFORMATION

PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER[1]	TEMPERATURE RANGE
OPA548T	7-Lead Stagger-Formed TO-220	327	–40°C to +85°C
OPA548F[2]	7-Lead DDPAK Surface-Mount	328	–40°C to +85°C

NOTE: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book. (2) Available on Tape and Reel.

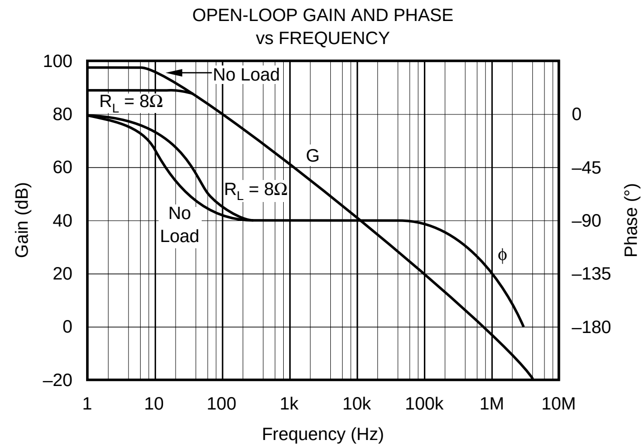
ELECTROSTATIC DISCHARGE SENSITIVITY

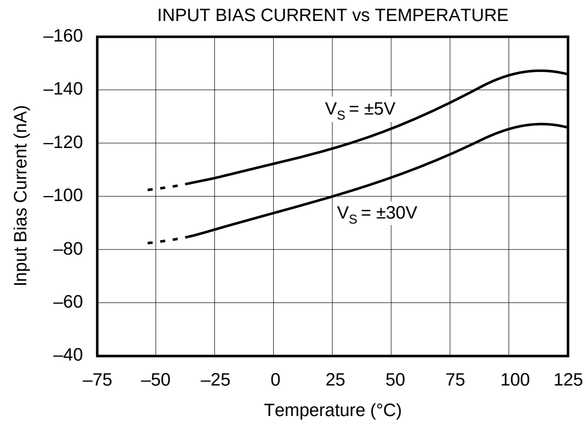
This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

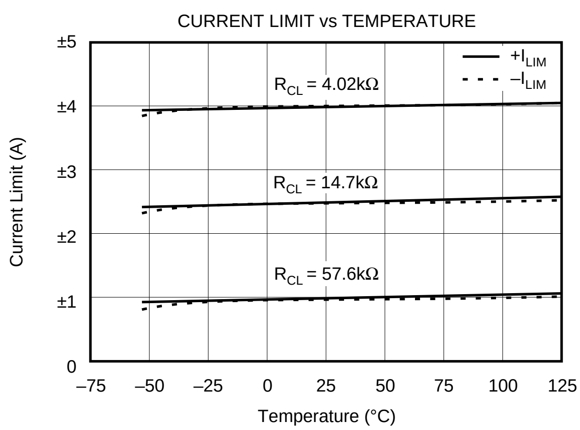
ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

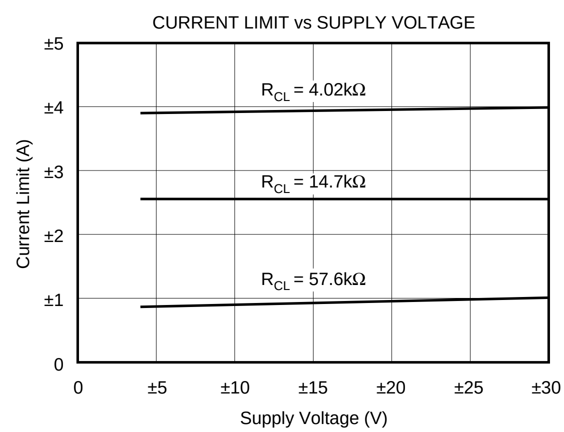
TYPICAL PERFORMANCE CURVES

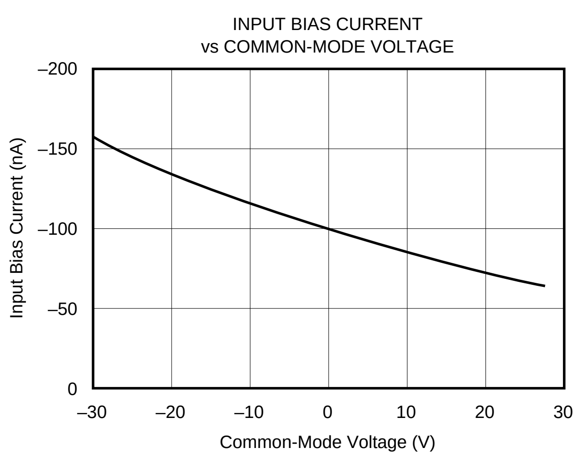
At T_{CASE} = +25°C, V_S = ±30V and E/S pin open, unless otherwise noted.

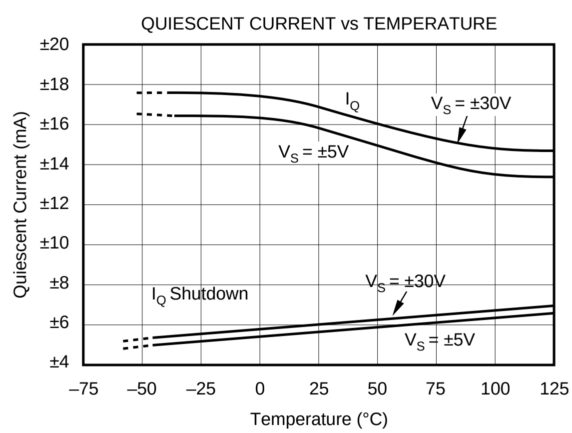






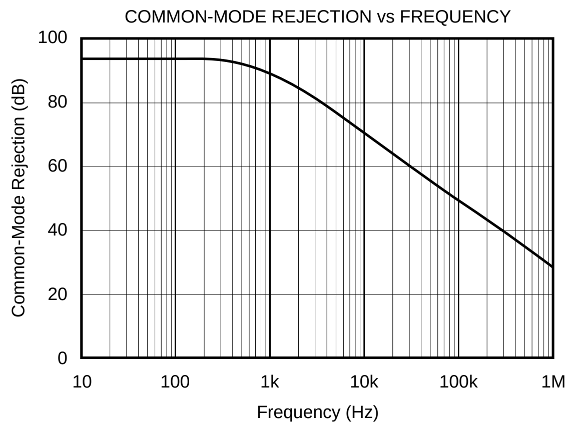


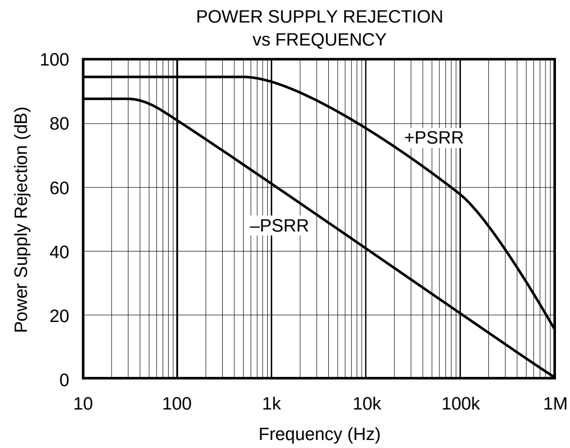


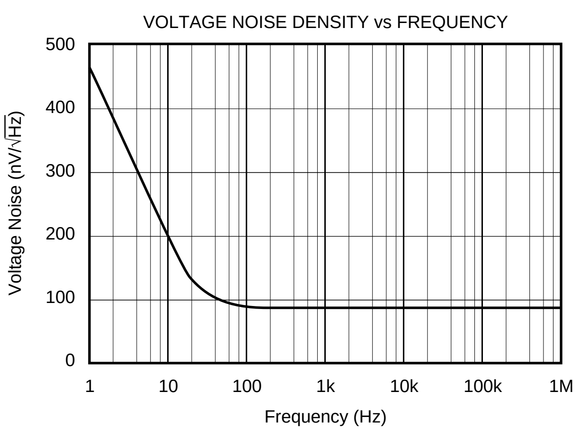


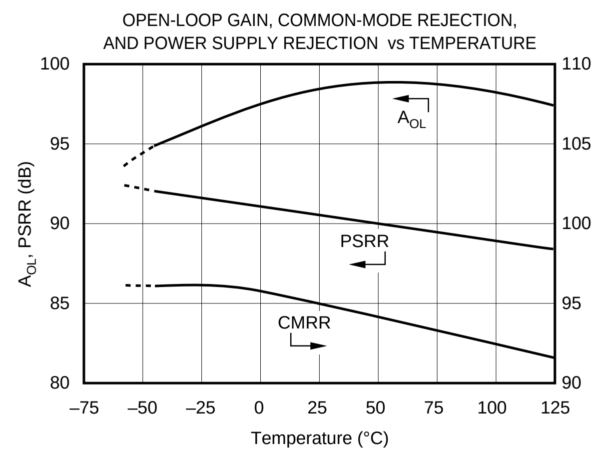
TYPICAL PERFORMANCE CURVES (CONT)

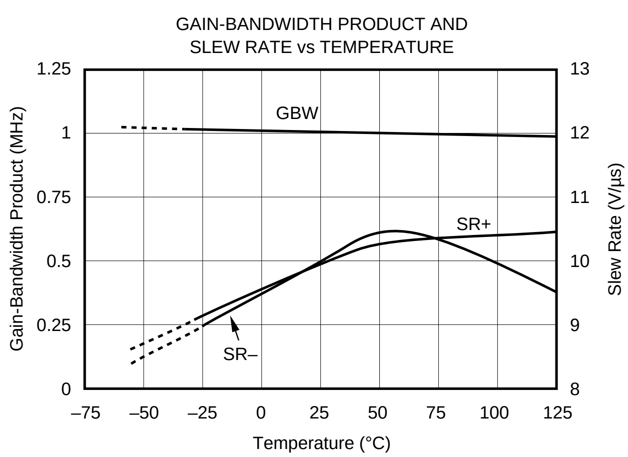
At T_{CASE} = +25°C, V_S = ±30V and E/S pin open, unless otherwise noted.

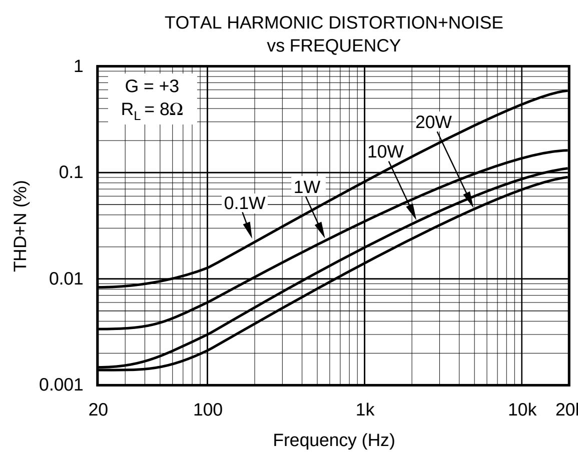








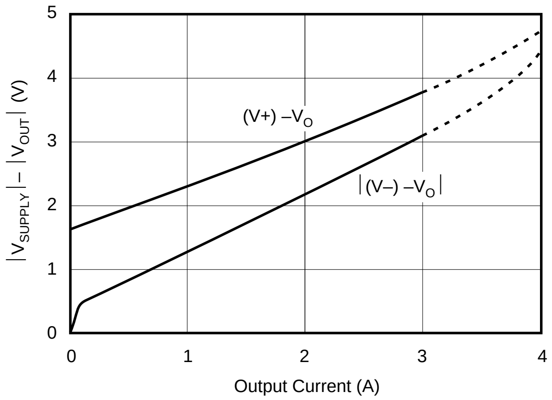




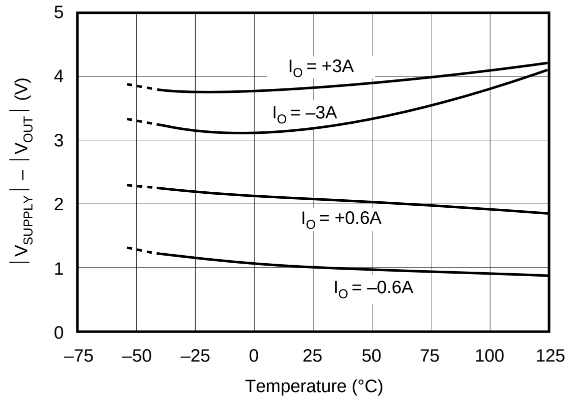
TYPICAL PERFORMANCE CURVES (CONT)

At T_{CASE} = +25°C, V_S = ±30V and E/S pin open, unless otherwise noted.

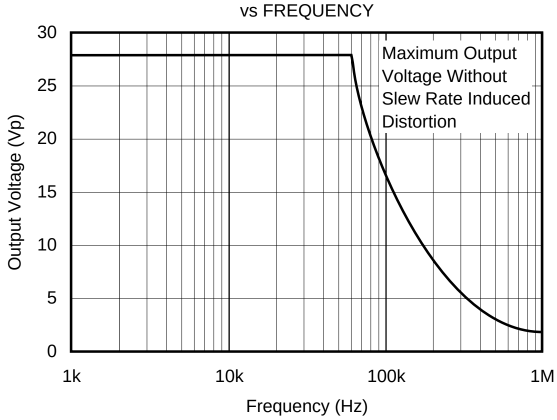
OUTPUT VOLTAGE SWING vs OUTPUT CURRENT



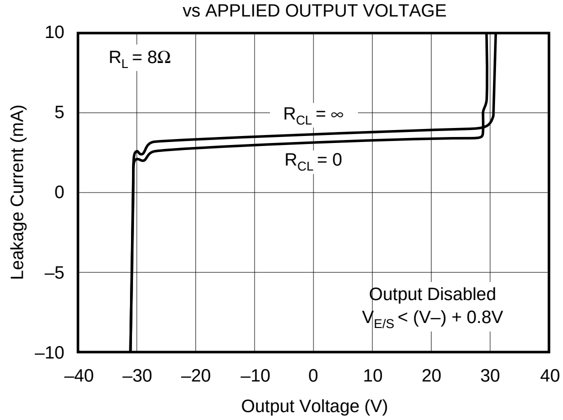
OUTPUT VOLTAGE SWING vs TEMPERATURE



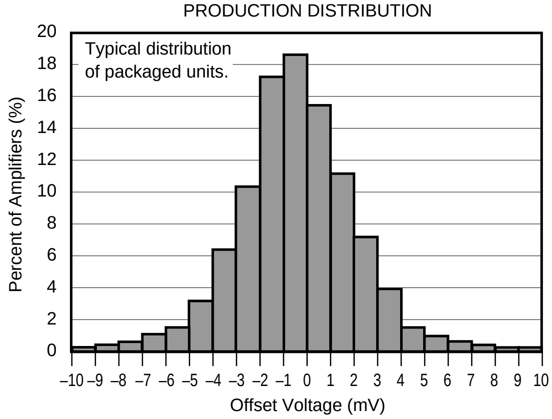
MAXIMUM OUTPUT VOLTAGE SWING
vs FREQUENCY



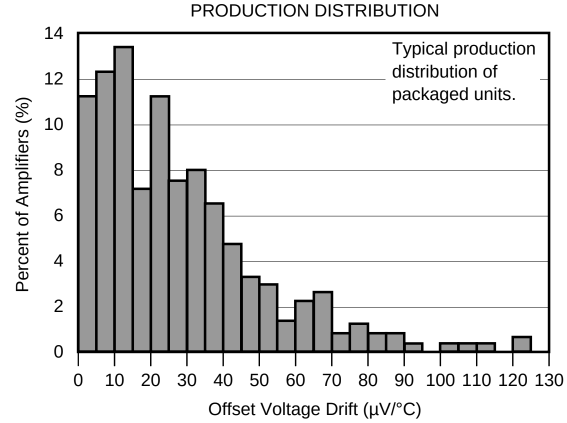
OUTPUT LEAKAGE CURRENT
vs APPLIED OUTPUT VOLTAGE



OFFSET VOLTAGE
PRODUCTION DISTRIBUTION



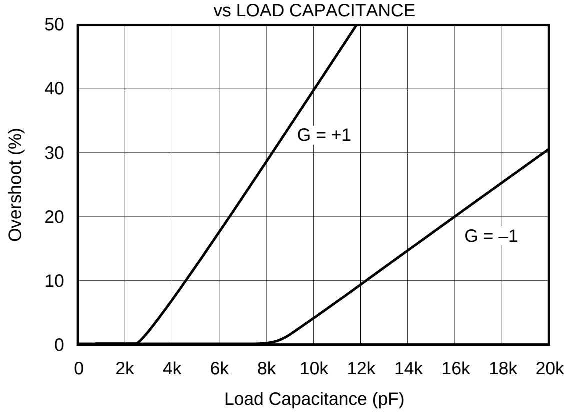
OFFSET VOLTAGE DRIFT
PRODUCTION DISTRIBUTION



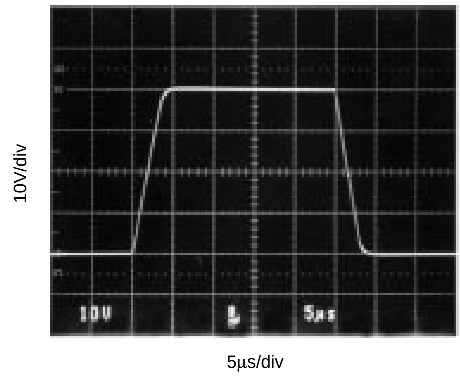
TYPICAL PERFORMANCE CURVES (CONT)

At T_{CASE} = +25°C, V_S = ±30V and E/S pin open, unless otherwise noted.

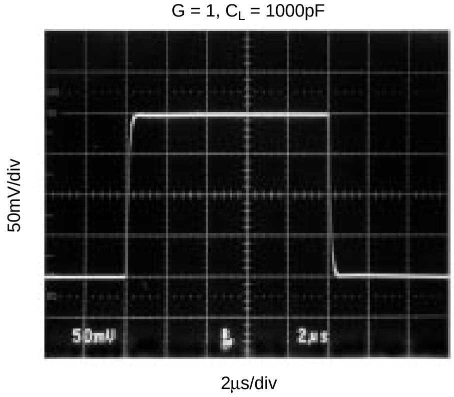
SMALL-SIGNAL OVERSHOOT vs LOAD CAPACITANCE



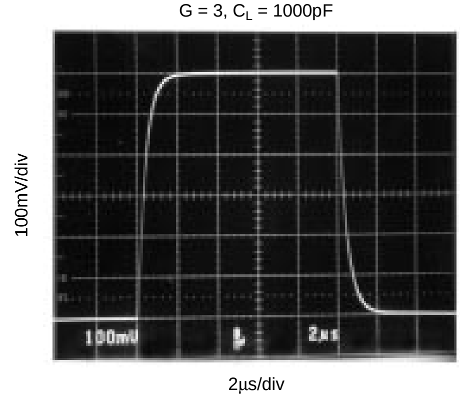
LARGE-SIGNAL STEP RESPONSE
G = 3, C_L = 1000pF, R_L = 8Ω



SMALL-SIGNAL STEP RESPONSE
G = 1, C_L = 1000pF



SMALL-SIGNAL STEP RESPONSE
G = 3, C_L = 1000pF



APPLICATIONS INFORMATION

Figure 1 shows the OPA548 connected as a basic non-inverting amplifier. The OPA548 can be used in virtually any op amp configuration.

Power supply terminals should be bypassed with low series impedance capacitors. The technique shown, using a ceramic and tantalum type in parallel is recommended. In addition, we recommend a 0.01µF capacitor between V+ and V– as close to the OPA548 as possible. Power supply wiring should have low series impedance.

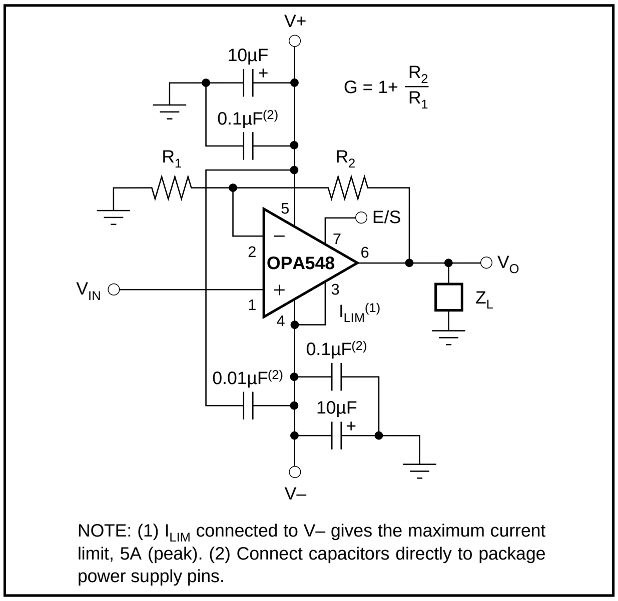


FIGURE 1. Basic Circuit Connections.

POWER SUPPLIES

The OPA548 operates from single (+8V to +60V) or dual (±4V to ±30V) supplies with excellent performance. Most behavior remains unchanged throughout the full operating voltage range. Parameters which vary significantly with operating voltage are shown in the typical performance curves.

Some applications do not require equal positive and negative output voltage swing. Power supply voltages do not need to be equal. The OPA548 can operate with as little as 8V between the supplies and with up to 60V between the supplies. For example, the positive supply could be set to 55V with the negative supply at –5V, or vice-versa.

ADJUSTABLE CURRENT LIMIT

The OPA548 features an accurate, user-selected current limit. Current limit is set from 0 to 5A by controlling the input to the I_{LIM} pin. Unlike other designs which use a power resistor in series with the output current path, the OPA548 senses the load indirectly. This allows the current limit to be set with a 0 to 330µA control signal. In contrast, other designs require a limiting resistor to handle the full output current (5A in this case).

With the OPA548, the simplest method for adjusting the current limit uses a resistor or potentiometer connected between the I_{LIM} pin and V– according to the equation:

$$R_{CL} = \frac{(15000)(4.75)}{I_{LIM}} - 13750\Omega$$

The low level control signal (0 to 330µA) also allows the current limit to be digitally controlled.

Figure 3 shows a simplified schematic of the internal circuitry used to set the current limit. Leaving the I_{LIM} pin open programs the output current to zero, while connecting I_{LIM} directly to V– programs the maximum output current limit, typically 5A.

SAFE OPERATING AREA

Stress on the output transistors is determined both by the output current and by the output voltage across the conducting output transistor, $V_S - V_O$. The power dissipated by the output transistor is equal to the product of the output current and the voltage across the conducting transistor, $V_S - V_O$. The Safe Operating Area (SOA curve, Figure 2) shows the permissible range of voltage and current.

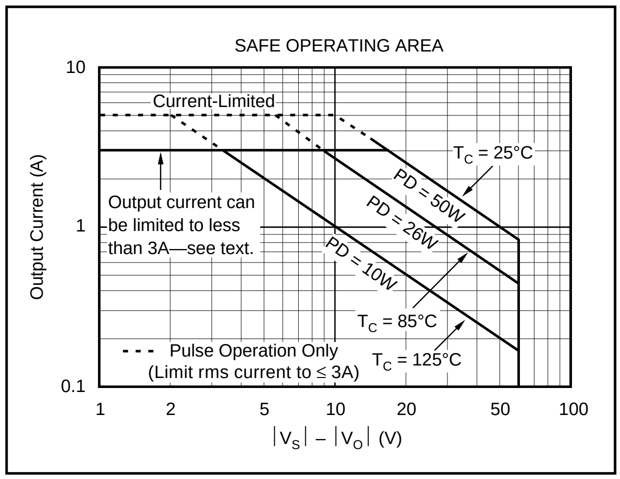
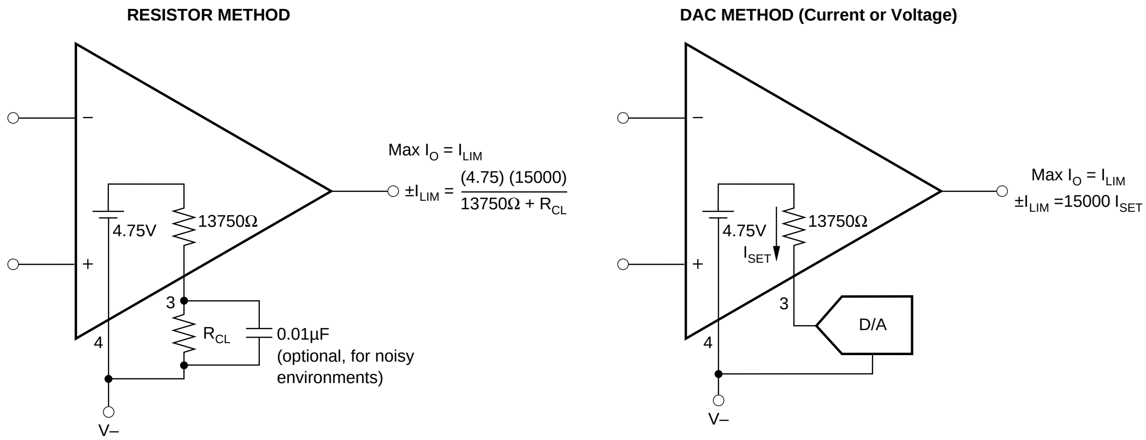


FIGURE 2. Safe Operating Area.

The safe output current decreases as $V_S - V_O$ increases. Output short-circuits are a very demanding case for SOA. A short-circuit to ground forces the full power supply voltage (V+ or V–) across the conducting transistor. Increasing the case temperature reduces the safe output current that can be tolerated without activating the thermal shutdown circuit of the OPA548. For further insight on SOA, consult Application Bulletin AB-039.

AMPLIFIER MOUNTING

Figure 4 provides recommended solder footprints for both the TO-220 and DDPAK power packages. The tab of both packages is electrically connected to the negative supply, V–. It may be desirable to isolate the tab of TO-220 package from its



$$R_{CL} = \frac{15000\ (4.75V)}{I_{LIM}} - 13750\Omega$$

$I_{SET} = I_{LIM}/15000$

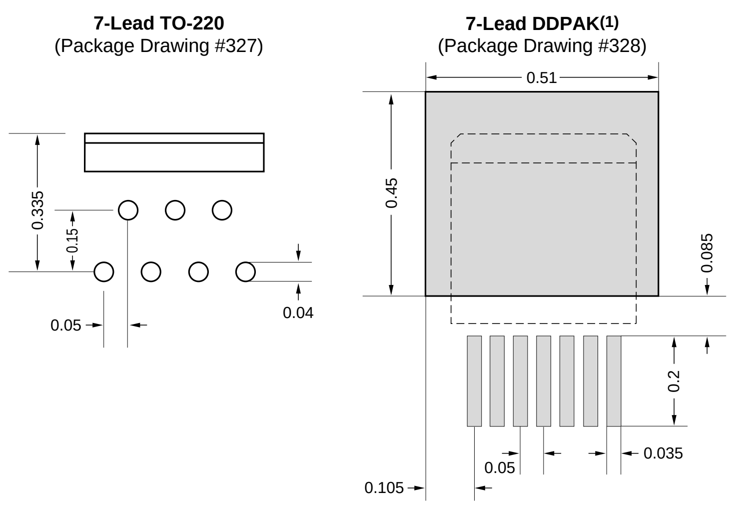
$V_{SET} = (V-) + 4.75V - (13750\Omega)\ (I_{LIM})/15000$

OPA547 CURRENT LIMIT: 0 to 5A

DESIRED CURRENT LIMIT	RESISTOR[(1)] (R_{CL})	CURRENT (I_{SET})	VOLTAGE (V_{SET})
0A	I_{LIM} Open	0µA	(V–) + 4.75V
1A	57.6kΩ	67µA	(V–) + 3.8V
2.5A	14.7kΩ	167µA	(V–) + 2.5V
3A	10kΩ	200µA	(V–) + 2V
4A	4.02kΩ	267µA	(V–) + 1.1V
5A	I_{LIM} Connected to V–	333µA	(V–)

NOTE: (1) Resistors are nearest standard 1% values.

FIGURE 3. Adjustable Current Limit.



Mean dimensions in inches. Refer to end of data sheet or Appendix C of Burr-Brown Data Book for tolerances and detailed package drawings.

NOTE: (1) For improved thermal performance increase footprint area. See Figure 6, "Thermal Resistance vs Circuit Board Copper Area".

FIGURE 4. TO-220 and DDPAK Solder Footprints.

mounting surface with a mica (or other film) insulator (see Figure 5). For lowest overall thermal resistance it is best to isolate the entire heat sink/OPA548 structure from the mounting surface rather than to use an insulator between the semiconductor and heat sink.

For best thermal performance, the tab of the DDPAK surface-mount version should be soldered directly to a circuit board copper area. Increasing the copper area improves heat dissipation. Figure 6 shows typical thermal resistance from junction-to-ambient as a function of the copper area

POWER DISSIPATION

Power dissipation depends on power supply, signal, and load conditions. For dc signals, power dissipation is equal to the product of output current times the voltage across the

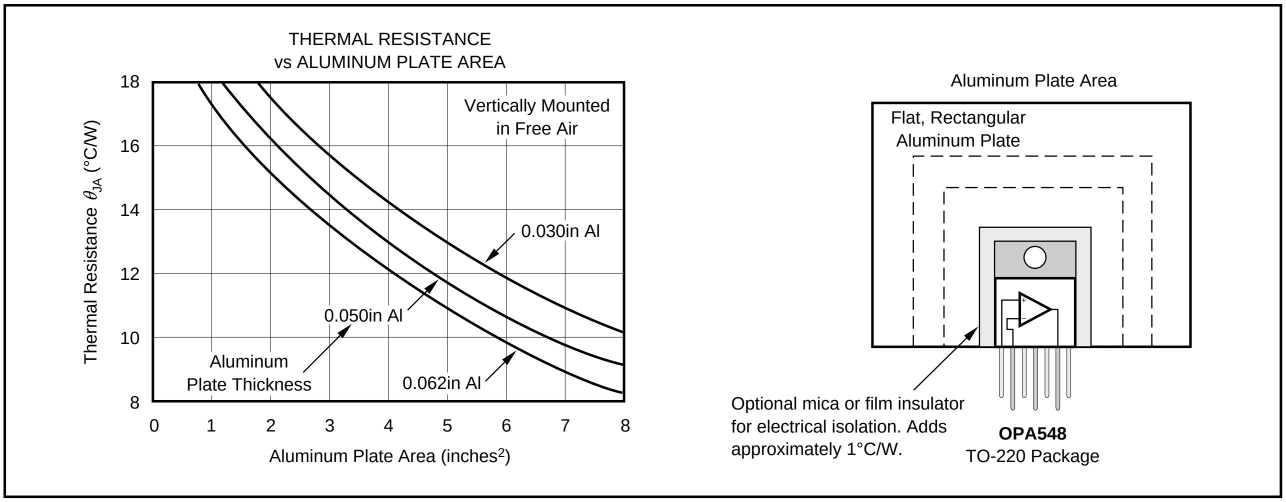


FIGURE 5. TO-220 Thermal Resistance vs Aluminum Plate Area.

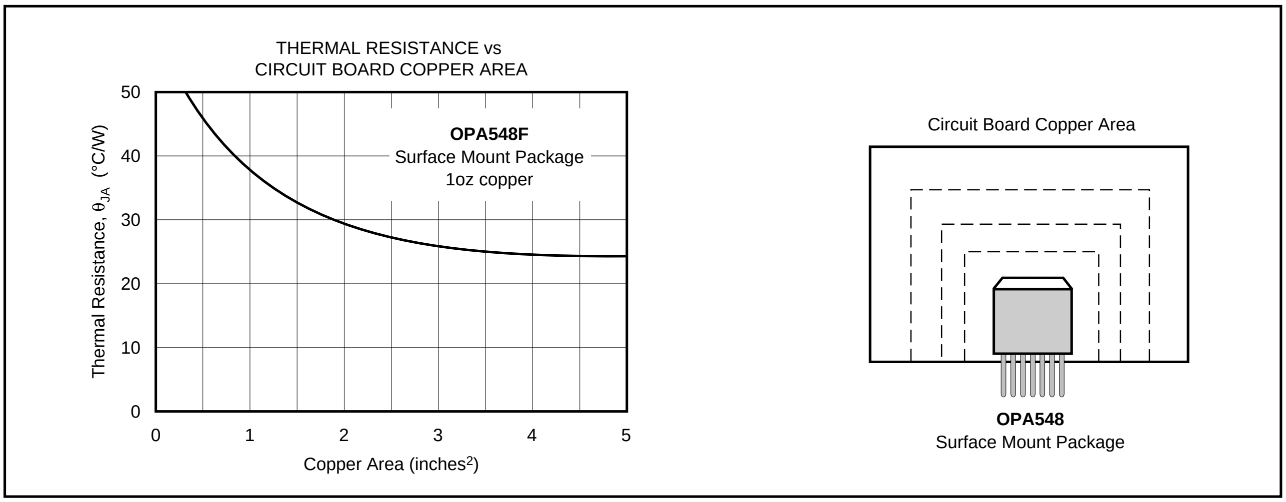


FIGURE 6. DDPAK Thermal Resistance vs Circuit Board Copper Area.

conducting output transistor. Power dissipation can be minimized by using the lowest possible power supply voltage necessary to assure the required output voltage swing.

For resistive loads, the maximum power dissipation occurs at a dc output voltage of one-half the power supply voltage. Dissipation with ac signals is lower. Application Bulletin AB-039 explains how to calculate or measure power dissipation with unusual signals and loads.

THERMAL PROTECTION

Power dissipated in the OPA548 will cause the junction temperature to rise. The OPA548 has thermal shutdown circuitry that protects the amplifier from damage. The thermal protection circuitry disables the output when the junction temperature reaches approximately 160°C, allowing the device to cool. When the junction temperature cools to approximately 140°C, the output circuitry is again enabled. Depending on load and signal conditions, the thermal protection circuit may cycle on and off. This limits the dissipation of the amplifier but may have an undesirable effect on the load.

Any tendency to activate the thermal protection circuit indicates excessive power dissipation or an inadequate heat sink. For reliable operation, junction temperature should be limited to 125°C, maximum. To estimate the margin of safety in a complete design (including heat sink) increase the ambient temperature until the thermal protection is triggered. Use worst-case load and signal conditions. For good reliability, thermal protection should trigger more than 35°C above the maximum expected ambient condition of your application. This produces a junction temperature of 125°C at the maximum expected ambient condition.

The internal protection circuitry of the OPA548 was designed to protect against overload conditions. It was not intended to replace proper heat sinking. Continuously running the OPA548 into thermal shutdown will degrade reliability.

HEAT SINKING

Most applications require a heat sink to assure that the maximum operating junction temperature (125°C) is not exceeded. In addition, the junction temperature should be kept as low as possible for increased reliability. Junction temperature can be determined according to the equation:

$$T_J = T_A + P_D\theta_{JA} \quad (1)$$

$$\text{where, } \theta_{JA} = \theta_{JC} + \theta_{CH} + \theta_{HA} \quad (2)$$

T_J = Junction Temperature (°C)
T_A = Ambient Temperature (°C)
P_D = Power Dissipated (W)
θ_{JC} = Junction-to-Case Thermal Resistance (°C/W)
θ_{CH} = Case-to-Heat Sink Thermal Resistance (°C/W)
θ_{HA} = Heat Sink-to-Ambient Thermal Resistance (°C/W)
θ_{JA} = Junction-to-Air Thermal Resistance (°C/W)

Figure 7 shows maximum power dissipation versus ambient temperature with and without the use of a heat sink. Using a heat sink significantly increases the maximum power dissipation at a given ambient temperature as shown.

The difficulty in selecting the heat sink required lies in determining the power dissipated by the OPA548. For dc output into a purely resistive load, power dissipation is simply the load current times the voltage developed across the conducting output transistor, $P_D = I_L(V_s–V_O)$. Other loads are not as simple. Consult Application Bulletin AB-039 for further insight on calculating power dissipation. Once power dissipation for an application is known, the proper heat sink can be selected.

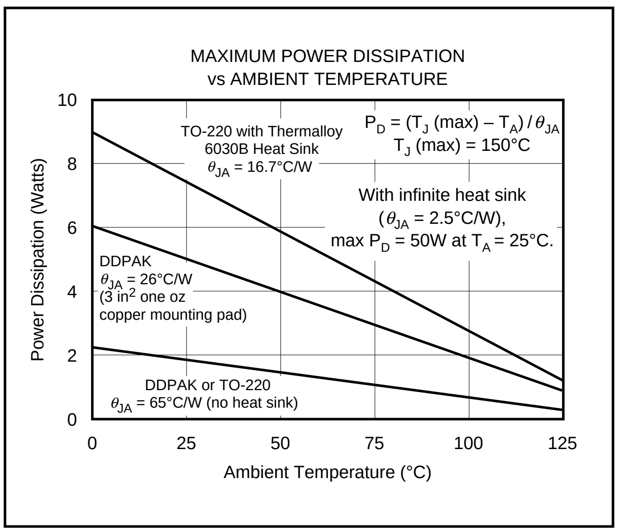


FIGURE 7. Maximum Power Dissipation vs Ambient Temperature.

Heat Sink Selection Example

A TO-220 package is dissipating 5 Watts. The maximum expected ambient temperature is 40°C. Find the proper heat sink to keep the junction temperature below 125°C (150°C minus 25°C safety margin).

Combining equations (1) and (2) gives:

$$T_J = T_A + P_D(\theta_{JC} + \theta_{CH} + \theta_{HA}) \quad (3)$$

T_J, T_A, and P_D are given. θ_{JC} is provided in the specification table, 2.5°C/W (dc). θ_{CH} can be obtained from the heat sink manufacturer. Its value depends on heat sink size, area, and material used. Semiconductor package type, mounting screw torque, insulating material used (if any), and thermal joint compound used (if any) also affect θ_{CH}. A typical θ_{CH} for a TO-220 mounted package is 1°C/W. Now we can solve for θ_{HA}:

$$\theta_{HA} = \frac{T_J - T_A}{P_D} - (\theta_{JC} + \theta_{CH})$$

$$\theta_{HA} = \frac{125°C - 40°C}{5W} - (2.5°C/W + 1°C/W) = 13.5°C/W$$

To maintain junction temperature below 125°C, the heat sink selected must have a θ_{HA} less than 14°C/W. In other words, the heat sink temperature rise above ambient must be less than 67.5°C (13.5°C/W x 5W). For example, at 5 Watts Thermalloy model number 6030B has a heat sink temperature rise of 66°C above ambient (θ_{HA} = 66°C/5W = 13.2°C/W), which is below the 67.5°C required in this example. Figure 7 shows power dissipation versus ambient temperature for a TO-220 package with a 6030B heat sink.

Another variable to consider is natural convection vs forced convection air flow. Forced-air cooling by a small fan can lower θ_{CA} ($\theta_{CH} + \theta_{HA}$) dramatically. Heat sink manufactures provide thermal data for both of these cases. For additional information on determining heat sink requirements, consult Application Bulletin AB-038.

As mentioned earlier, once a heat sink has been selected the complete design should be tested under worst-case load and signal conditions to ensure proper thermal protection.

ENABLE/STATUS (E/S) PIN

The Enable/Status Pin provides two functions: forcing this pin low disables the output stage, or, E/S can be monitored to determine if the OPA548 is in thermal shutdown. One or both of these functions can be utilized on the same device using single or dual supplies. For normal operation (output enabled), the E/S pin can be left open or pulled high (at least 2.4V above the negative rail). A small value capacitor connected between the E/S pin and V– may be required for noisy applications.

Output Disable

A unique feature of the OPA548 is its output disable capability. This function not only conserves power during idle periods (quiescent current drops to approximately 6mA) but also allows multiplexing in low frequency (f<20kHz), multichannel applications. Signals greater than 20kHz may cause leakage current to increase in devices that are shutdown. Figure 18 shows the two OPA548s in a switched amplifier configuration. The on/off state of the two amplifiers is controlled by the voltage on the E/S pin.

To disable the output, the E/S pin is pulled low, no greater than 0.8V above the negative rail. Typically the output is shutdown in 1µs. Figure 8 provides an example of how to implement this function using a single supply. Figure 9 gives a circuit for dual supply applications. To return the output to an enabled state, the E/S pin should be disconnected (open) or pulled to at least (V–) + 2.4V. It should be noted that pulling the E/S pin high (output enabled) does not disable internal thermal shutdown.

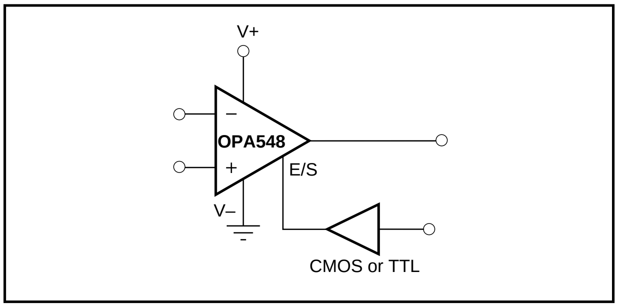


FIGURE 8. Output Disable with a Single Supply.

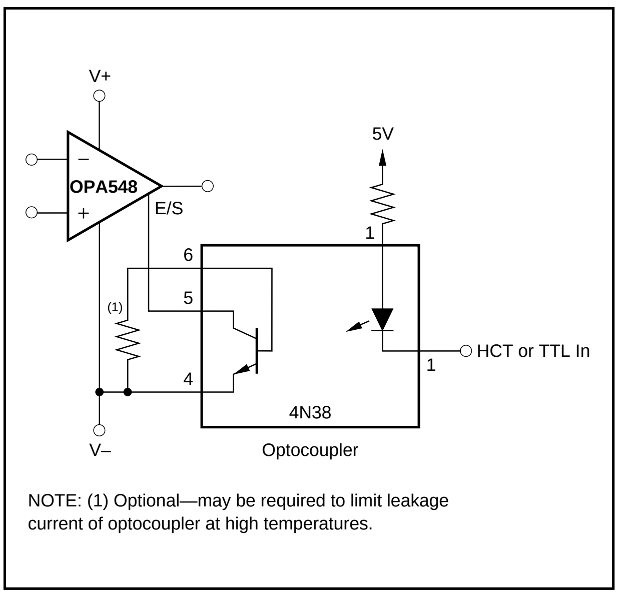


FIGURE 9. Output Disable with Dual Supplies.

Thermal Shutdown Status

Internal thermal shutdown circuitry shuts down the output when the die temperature reaches approximately 160°C, resetting when the die has cooled to 140°C. The E/S pin can be monitored to determine if shutdown has occurred. During normal operation the voltage on the E/S pin is typically 3.5V above the negative rail. Once shutdown has occurred this voltage drops to approximately 350mV above the negative rail.

Figure 10 gives an example of monitoring shutdown in a single supply application. Figure 11 provides a circuit for dual supplies. External logic circuitry or an LED could be used to indicate if the output has been thermally shutdown, see Figure 16.

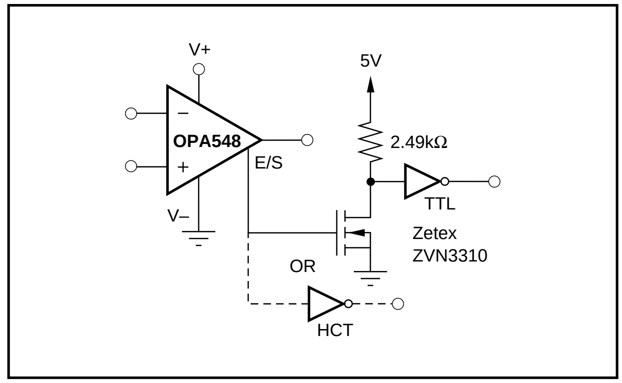


FIGURE 10. Thermal Shutdown Status with a Single Supply.

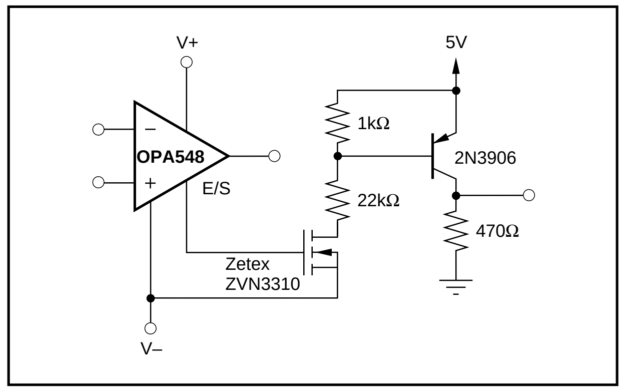


FIGURE 11. Thermal Shutdown Status with Dual Supplies.

Output Disable and Thermal Shutdown Status

As mentioned earlier, the OPA548's output can be disabled and the disable status can be monitored simultaneously. Figures 12 and 13 provide examples interfacing to the E/S pin while using a single supply and dual supplies, respectively.

OUTPUT STAGE COMPENSATION

The complex load impedances common in power op amp applications can cause output stage instability. For normal operation output compensation circuitry is typically not required. However, if the OPA548 is intended to be driven into current limit, an R/C network may be required. Figure 14 shows an output series R/C compensation (snubber) network which generally provides excellent stability.

A snubber circuit may also enhance stability when driving large capacitive loads (>1000pF) or inductive loads (motors, loads separated from the amplifier by long cables). Typically 3Ω to 10Ω in series with 0.01µF to 0.1µF is adequate. Some variations in circuit value may be required with certain loads.

OUTPUT PROTECTION

Reactive and EMF-generating loads can return load current to the amplifier, causing the output voltage to exceed the power supply voltage. This damaging condition can

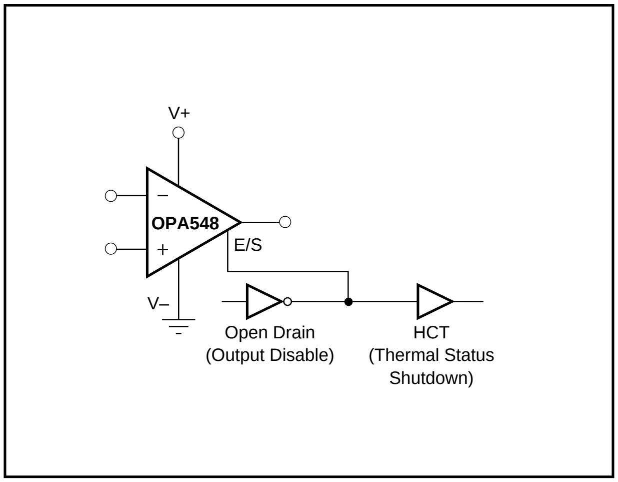


FIGURE 12. Output Disable and Thermal Shutdown Status with a Single Supply.

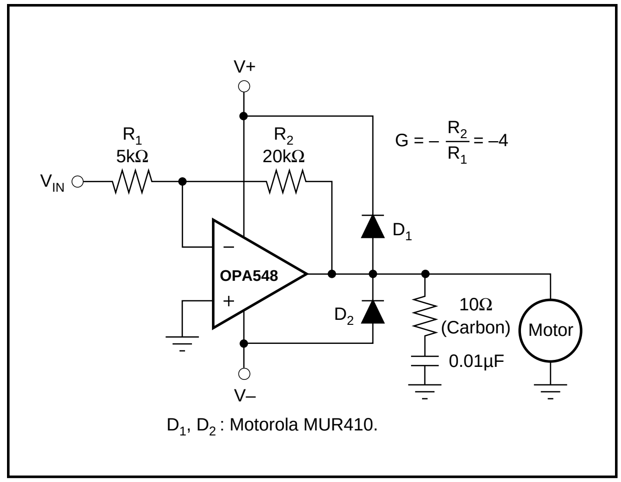


FIGURE 14. Motor Drive Circuit.

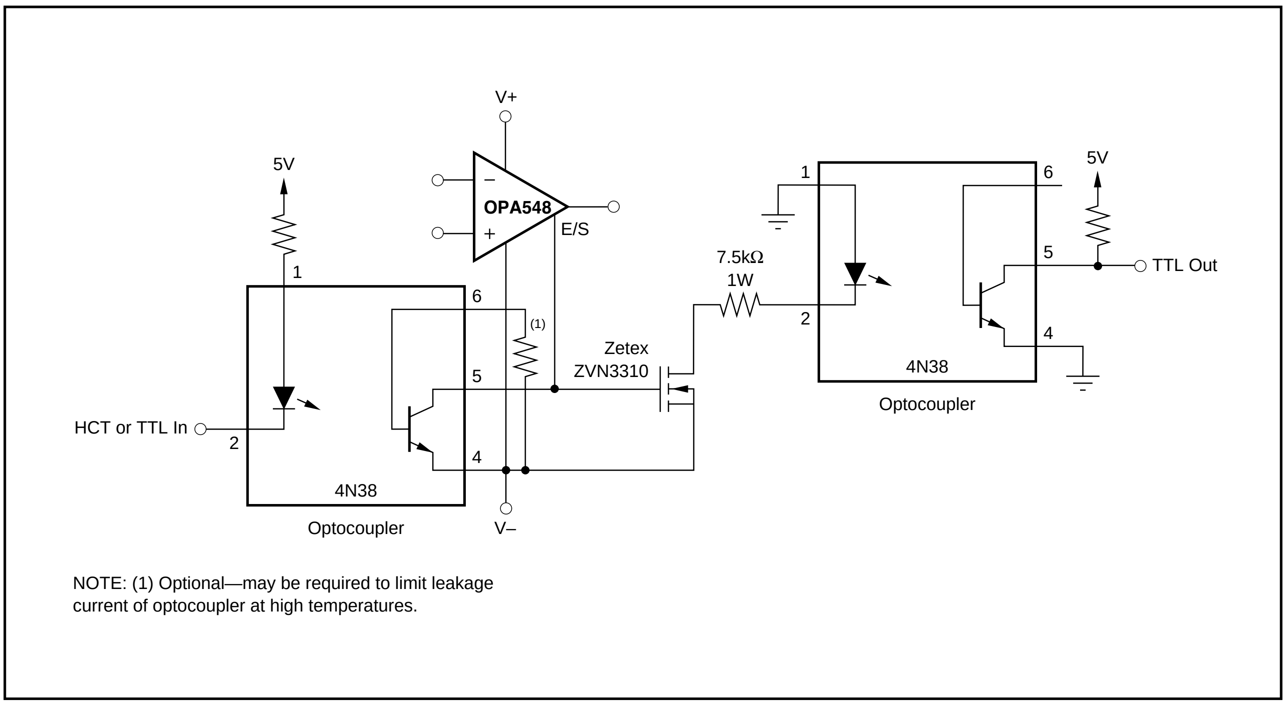


FIGURE 13. Output Disable and Thermal Shutdown Status with Dual Supplies.

be avoided with clamp diodes from the output terminal to the power supplies as shown in Figure 14. Schottky rectifier diodes with a 5A or greater continuous rating are recommended.

VOLTAGE SOURCE APPLICATION

Figure 15 illustrates how to use the OPA548 to provide an accurate voltage source with only three external resistors. First, the current limit resistor, R_{CL}, is chosen according to the desired output current. The resulting voltage at the I_{LIM} pin is constant and stable over temperature. This voltage, V_{CL}, is connected to the noninverting input of the op amp and used as a voltage reference, thus eliminating the need for an external reference. The feedback resistors are selected to gain V_{CL} to the desired output voltage level.

PROGRAMMABLE POWER SUPPLY

A programmable source/sink power supply can easily be built using the OPA548. Both the output voltage and output current are user-controlled. Figure 16 shows a circuit using potentiometers to adjust the output voltage and current while Figure 17 uses digital-to-analog converters. An LED tied to the E/S pin through a logic gate indicates if the OPA548 is in thermal shutdown.

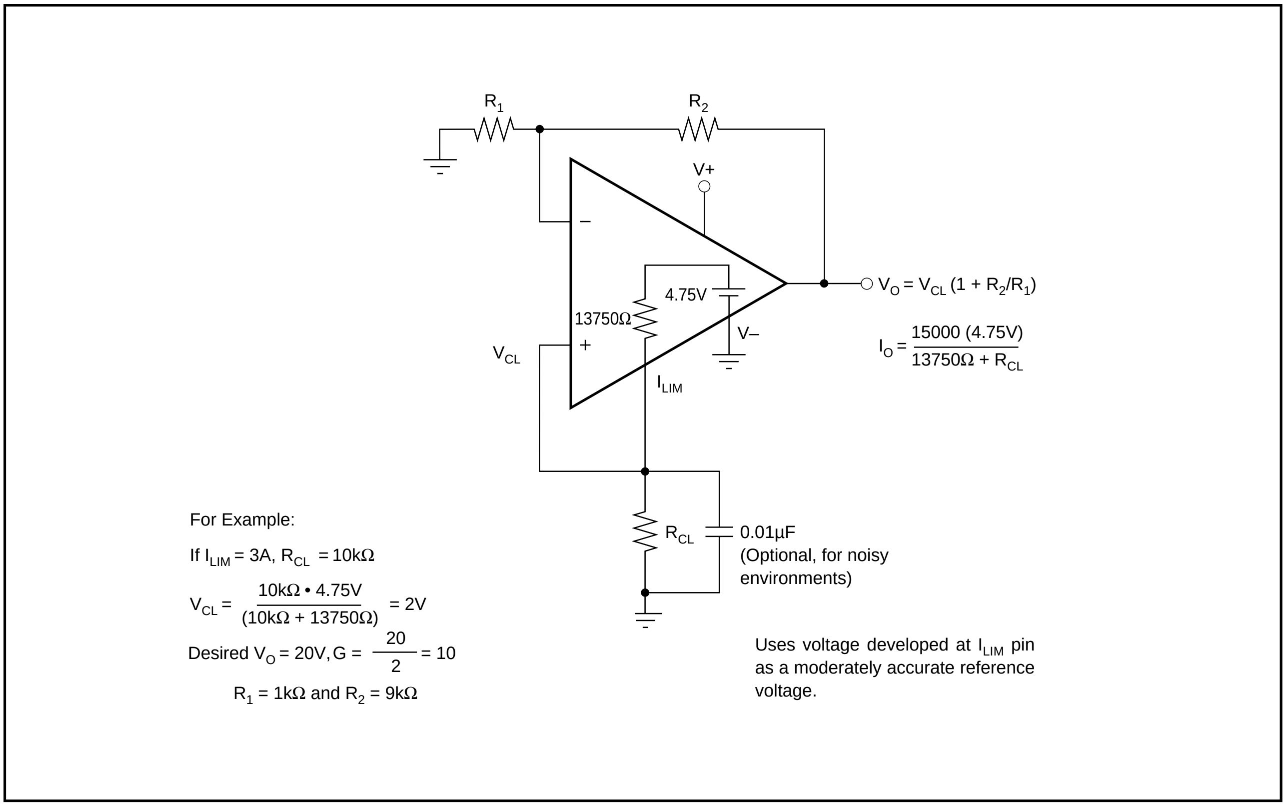


FIGURE 15. Voltage Source.

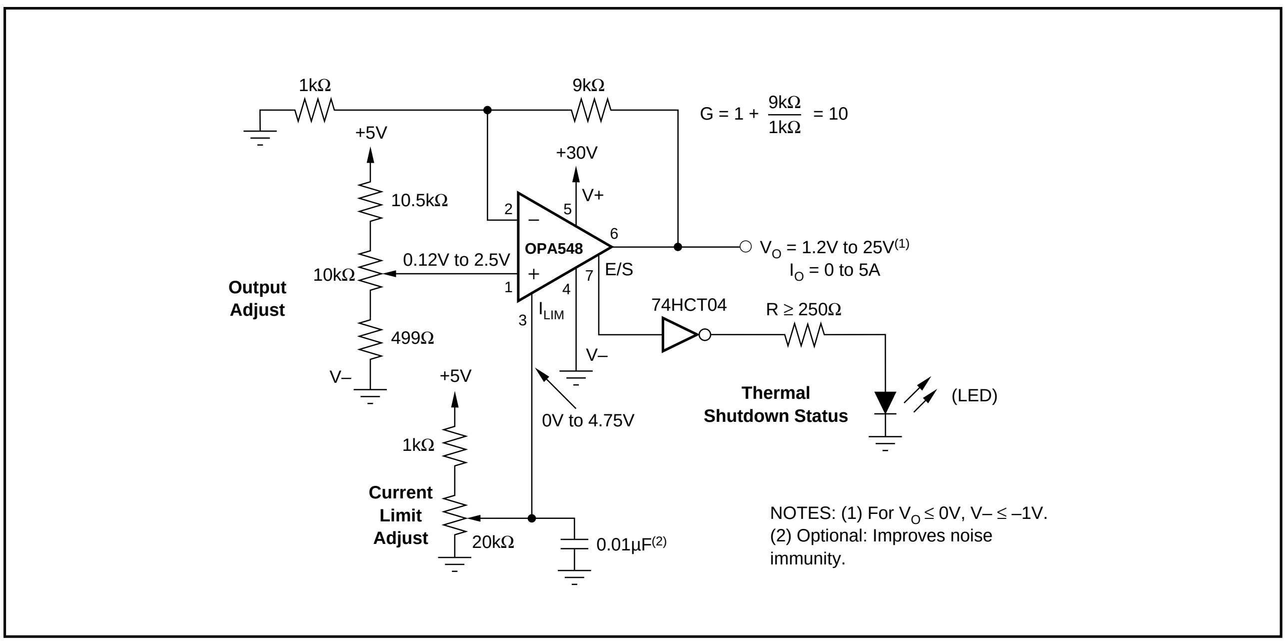
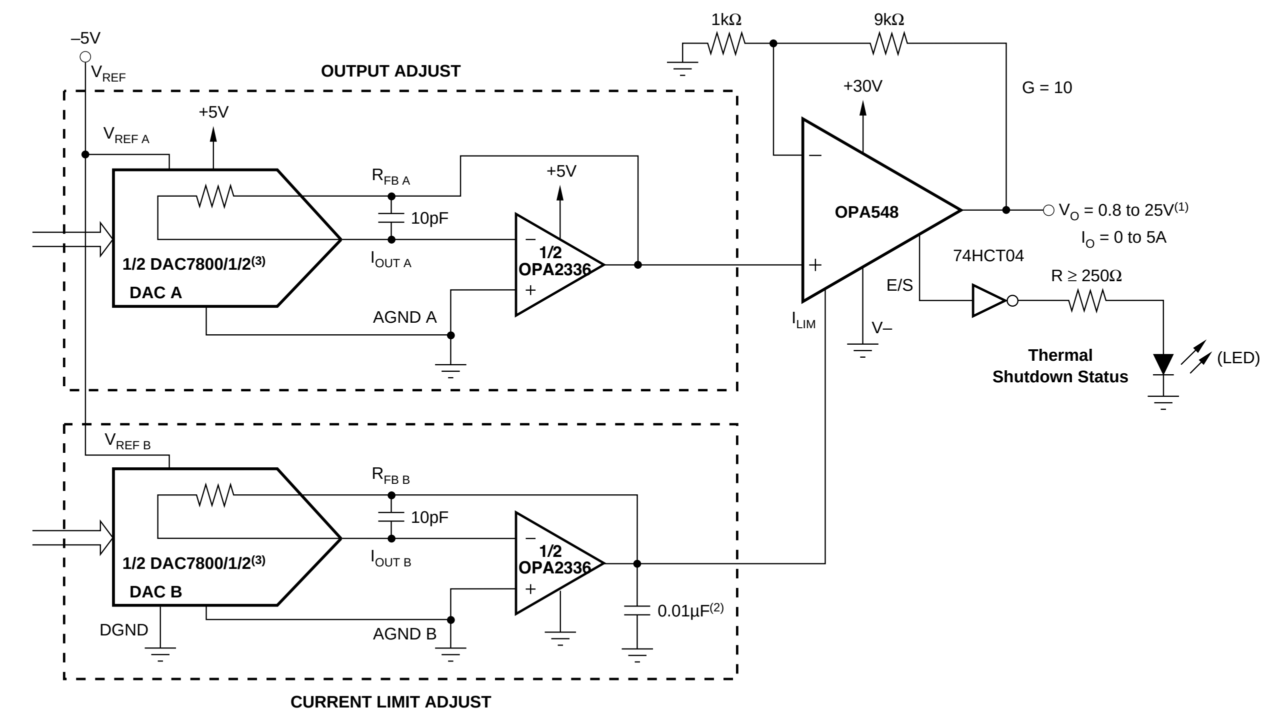
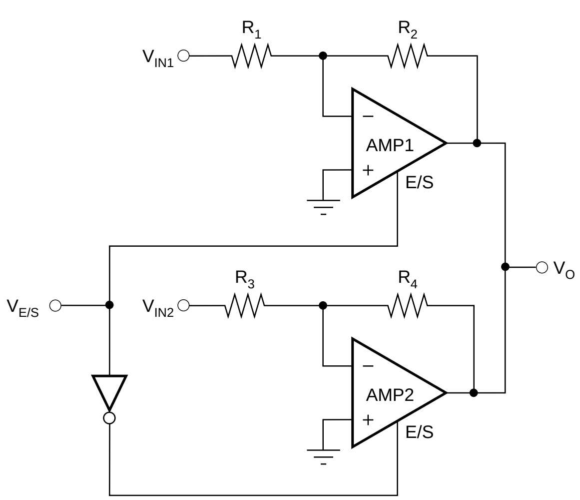


FIGURE 16. Resistor-Controlled Programmable Power Supply.



NOTES: (1) For $V_O \leq 0V$, $V- \leq -1V$. (2) Optional, improves noise immunity. (3) Chose DAC780X based on digital interface: DAC7800 - 12-bit interface, DAC7801 - 8-bit interface + 4 bits, DAC7802 - serial interface. (4) Can use OPA2237, I_O = 100mA to 5A.

FIGURE 17. Digitally-Controlled Programmable Power Supply.



$V_{E/S} >$ (V–) +2.4V: Amp 1 is on, Amp 2 if off

$\rightarrow V_O = -V_{IN1}\left(\frac{R_2}{R_1}\right)$

$V_{E/S} <$ (V–) +2.4V: Amp 2 is on, Amp 1 if off

$\rightarrow V_O = -V_{IN2}\left(\frac{R_4}{R_3}\right)$

FIGURE 18. Switched Amplifier.

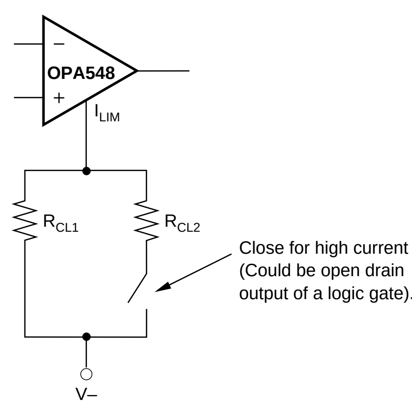


FIGURE 19. Multiple Current Limit Values.

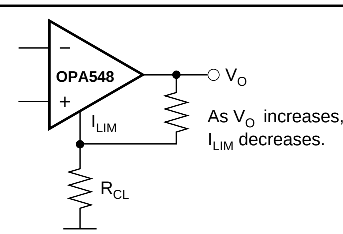
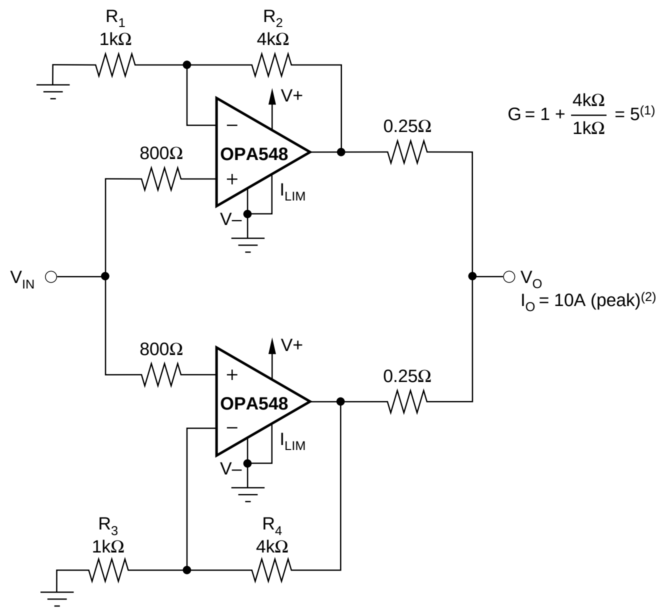


FIGURE 20. Single Quadrant V • I Limiting.



NOTES: (1) Works well for G < 10. Input offset causes output current to flow between amplifiers with G > 10. Gains (resistor ratios) of the two amplifiers should be carefully matched to ensure equal current sharing. (2) As configured (I_{LIM} connected to V–) output current limit is set to 10A (peak). Each amplifier is limited to 5A (peak). Other current limit values may be obtained, see Figure 3, "Adjustable Current Limit".

FIGURE 21. Parallel Output for Increased Output Current.