



General Purpose CMOS Rail-to-Rail Amplifiers

AD8541/AD8542/AD8544

FEATURES

Single Supply Operation: +2.7 V to +5.5 V
Low Supply Current: 45 μ A/Amplifier
Wide Bandwidth: 1 MHz
No Phase Reversal
Low Input Currents: 4 pA
Unity Gain Stable
Rail-to-Rail Input and Output

APPLICATIONS

ASIC Input or Output Amplifier
Sensor Interface
Piezo Electric Transducer Amplifier
Medical Instrumentation
Mobile Communication
Audio Output
Portable Systems

GENERAL DESCRIPTION

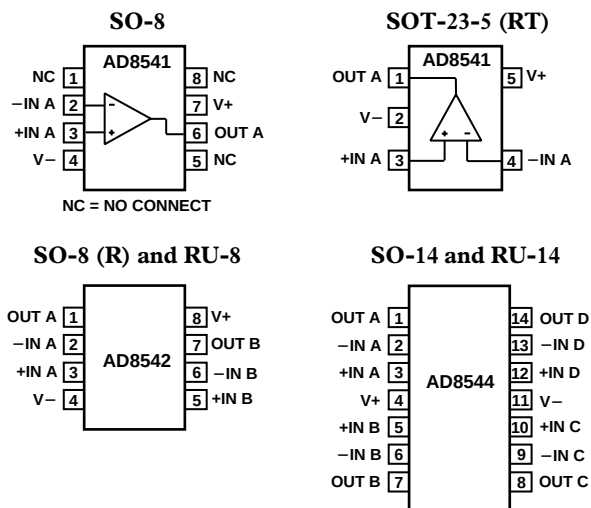
The AD8541/AD8542/AD8544 are single, dual and quad rail-to-rail input and output single supply amplifiers featuring very low supply current and 1 MHz bandwidth. All are guaranteed to operate from a +2.7 V single supply as well as a +5 V supply. These parts provide 1 MHz bandwidth at low current consumption of 45 μ A per amplifier.

Very low input bias currents enable the AD8541/AD8542/AD8544 to be used for integrators, photodiode amplifiers, piezo electric sensors and other applications with high source impedance. Supply current is only 45 μ A per amplifier, ideal for battery operation.

Rail-to-rail inputs and outputs are useful to designers buffering ASICs in single supply systems. The AD8541/AD8542/AD8544 are optimized to maintain high gains at lower supply voltages, making them useful for active filters and gain stages.

The AD8541/AD8542/AD8544 are specified over the extended industrial (-40°C to $+125^{\circ}\text{C}$) temperature range. The AD8541 is available in 8-lead SO and 5-lead SOT-23 packages. The AD8542 is available in 8-lead SO and 8-lead TSSOP surface mount packages. The AD8544 is available in 14-lead narrow SO-14 and 14-lead TSSOP surface mount packages. All TSSOP and SOT versions are available in tape and reel only.

PIN CONFIGURATIONS



REV. 0

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AD8541/AD8542/AD8544—SPECIFICATIONS

ELECTRICAL CHARACTERISTICS ($V_S = +2.7\text{ V}$, $V_{CM} = +1.35\text{ V}$, $T_A = +25^\circ\text{C}$ unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
INPUT CHARACTERISTICS						
Offset Voltage AD8541, AD8542	V _{OS}	−40°C ≤ T _A ≤ +125°C		1	6	mV
Input Bias Current	I _B	−40°C ≤ T _A ≤ +85°C		4	7	mV
Input Offset Current	I _{OS}	−40°C ≤ T _A ≤ +125°C			60	pA
					100	pA
				0.1	1,000	pA
					30	pA
Input Voltage Range		−40°C ≤ T _A ≤ +85°C			50	pA
Common-Mode Rejection Ratio	CMRR	−40°C ≤ T _A ≤ +125°C	0		500	pA
Large Signal Voltage Gain	A _{VO}	V _{CM} = 0 V to +2.7 V	40	45	+2.7	V
		−40°C ≤ T _A ≤ +125°C	38			dB
		R _L = 100 kΩ , V _O = +0.5 V to +2.2 V	100	500		V/mV
		−40°C ≤ T _A ≤ +85°C	50			V/mV
Offset Voltage Drift	ΔV _{OS} /ΔT	−40°C ≤ T _A ≤ +125°C				V/mV
Bias Current Drift	ΔI _B /ΔT	−40°C ≤ T _A ≤ +125°C		4		μV/°C
Offset Current Drift	ΔI _{OS} /ΔT	−40°C ≤ T _A ≤ +85°C		100		fA/°C
		−40°C ≤ T _A ≤ +125°C		2,000		fA/°C
		−40°C ≤ T _A ≤ +125°C		25		fA/°C
OUTPUT CHARACTERISTICS						
Output Voltage High	V _{OH}	I _L = 1 mA	+2.575	+2.65		V
Output Voltage Low	V _{OL}	−40°C ≤ T _A ≤ +125°C	+2.550			V
		I _L = 1 mA		35	100	mV
Output Current	I _{OUT}	−40°C ≤ T _A ≤ +125°C			125	mV
Closed Loop Output Impedance	Z _{OUT}	V _{OUT} = V _S − 1 V		15		mA
		±I _{SC}		±20		mA
		f = 200 kHz, A _V = 1		50		Ω
POWER SUPPLY						
Power Supply Rejection Ratio	PSRR	V _S = +2.5 V to +6 V	65	76		dB
Supply Current/Amplifier	I _{SY}	−40°C ≤ T _A ≤ +125°C	60			dB
		V _O = 0 V		38	55	μA
		−40°C ≤ T _A ≤ +125°C			75	μA
DYNAMIC PERFORMANCE						
Slew Rate	SR	R _L = 100 kΩ	0.4	0.75		V/μs
Settling Time	t _s	To 0.1% (1 V Step)		5		μs
Gain Bandwidth Product	GBP			980		kHz
Phase Margin	Φ _o			63		Degrees
NOISE PERFORMANCE						
Voltage Noise Density	e _n	f = 1 kHz		40		nV/√Hz
Current Noise Density	e _n	f = 10 kHz		38		nV/√Hz
	i _n			<0.1		pA/√Hz

Specifications subject to change without notice.

ELECTRICAL CHARACTERISTICS ($V_S = +3.0\text{ V}$, $V_{CM} = +1.5\text{ V}$, $T_A = +25^\circ\text{C}$ unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
INPUT CHARACTERISTICS						
Offset Voltage AD8541, AD8542	V_{OS}	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		1	6	mV
Input Bias Current	I_B	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		4	7	pA
Input Offset Current	I_{OS}	$-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$ $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$			60	pA
Input Voltage Range		$-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$ $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		0.1	100	pA
Common-Mode Rejection Ratio	CMRR	$V_{CM} = 0\text{ V to } +3\text{ V}$ $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	0	45	500	V
Large Signal Voltage Gain	A_{VO}	$R_L = 100\text{ k}\Omega$, $V_O = +0.5\text{ V to } +2.2\text{ V}$ $-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$ $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	100	500		dB
Offset Voltage Drift	$\Delta V_{OS}/\Delta T$	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		4		dB
Bias Current Drift	$\Delta I_B/\Delta T$	$-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$ $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		100		V/mV
Offset Current Drift	$\Delta I_{OS}/\Delta T$	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		2,000		V/mV
				25		V/mV
OUTPUT CHARACTERISTICS						
Output Voltage High	V_{OH}	$I_L = 1\text{ mA}$ $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	+2.875	+2.955		V
Output Voltage Low	V_{OL}	$I_L = 1\text{ mA}$ $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	+2.850	32	100	V
Output Current	I_{OUT} $\pm I_{SC}$	$V_{OUT} = V_S - 1\text{ V}$		18	125	mV
Closed Loop Output Impedance	Z_{OUT}	$f = 200\text{ kHz}$, $A_V = 1$		± 25		mV
				50		mA
POWER SUPPLY						
Power Supply Rejection Ratio	PSRR	$V_S = +2.5\text{ V to } +6\text{ V}$ $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	65	76		dB
Supply Current/Amplifier	I_{SY}	$V_O = 0\text{ V}$ $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	60	40	60	dB
					75	μA
DYNAMIC PERFORMANCE						
Slew Rate	SR	$R_L = 100\text{ k}\Omega$	0.4	0.8		V/ μs
Settling Time	t_S	To 0.01% (1 V Step)		5		μs
Gain Bandwidth Product	GBP			980		kHz
Phase Margin	Φ_O			64		Degrees
NOISE PERFORMANCE						
Voltage Noise Density	e_n	$f = 1\text{ kHz}$		42		$\text{nV}/\sqrt{\text{Hz}}$
	e_n	$f = 10\text{ kHz}$		38		$\text{nV}/\sqrt{\text{Hz}}$
Current Noise Density	i_n			<0.1		$\text{pA}/\sqrt{\text{Hz}}$

Specifications subject to change without notice.

AD8541/AD8542/AD8544—SPECIFICATIONS

ELECTRICAL CHARACTERISTICS ($V_S = +5.0\text{ V}$, $V_{CM} = +2.5\text{ V}$, $T_A = +25^\circ\text{C}$ unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
INPUT CHARACTERISTICS						
Offset Voltage AD8541, AD8542	V_{OS}	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		1	6	mV
Input Bias Current	I_B	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		4	7	mV
		$-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$			60	pA
		$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$			100	pA
Input Offset Current	I_{OS}	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		0.1	1,000	pA
		$-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$			30	pA
		$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$			50	pA
Input Voltage Range			0		500	pA
Common-Mode Rejection Ratio	CMRR	$V_{CM} = 0\text{ V to } +5\text{ V}$	40	48	+5	V
		$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	38			dB
Large Signal Voltage Gain	A_{VO}	$R_L = 100\text{ k}\Omega$, $V_O = +0.5\text{ V to } +2.2\text{ V}$	20	40		V/mV
		$-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$	10			V/mV
		$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	2			V/mV
Offset Voltage Drift	$\Delta V_{OS}/\Delta T$	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		4		$\mu\text{V}/^\circ\text{C}$
Bias Current Drift	$\Delta I_B/\Delta T$	$-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$		100		fA/ $^\circ\text{C}$
		$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		2,000		fA/ $^\circ\text{C}$
Offset Current Drift	$\Delta I_{OS}/\Delta T$	$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$		25		fA/ $^\circ\text{C}$
OUTPUT CHARACTERISTICS						
Output Voltage High	V_{OH}	$I_L = 1\text{ mA}$	+4.9	+4.965		V
		$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	+4.875			V
Output Voltage Low	V_{OL}	$I_L = 1\text{ mA}$		25	100	mV
		$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$			125	mV
Output Current	I_{OUT}	$V_{OUT} = V_S - 1\text{ V}$		30		mA
	$\pm I_{SC}$			± 60		mA
Closed Loop Output Impedance	Z_{OUT}	$f = 200\text{ kHz}$, $A_V = 1$		45		Ω
POWER SUPPLY						
Power Supply Rejection Ratio	PSRR	$V_S = +2.5\text{ V to } +6\text{ V}$	65	76		dB
		$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$	60			dB
Supply Current/Amplifier	I_{SY}	$V_O = 0\text{ V}$		45	65	μA
		$-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$			85	μA
DYNAMIC PERFORMANCE						
Slew Rate	SR	$R_L = 100\text{ k}\Omega$, $C_L = 200\text{ pF}$	0.45	0.92		V/ μs
Full-Power Bandwidth	BW _P	1% Distortion		70		kHz
Settling Time	t_s	To 0.1% (1 V Step)		6		μs
Gain Bandwidth Product	GBP			1,000		kHz
Phase Margin	Φ_o			67		Degrees
NOISE PERFORMANCE						
Voltage Noise Density	e_n	$f = 1\text{ kHz}$		42		$\text{nV}/\sqrt{\text{Hz}}$
	e_n	$f = 10\text{ kHz}$		38		$\text{nV}/\sqrt{\text{Hz}}$
Current Noise Density	i_n			<0.1		$\text{pA}/\sqrt{\text{Hz}}$

Specifications subject to change without notice.

AD8541/AD8542/AD8544

ABSOLUTE MAXIMUM RATINGS¹

Supply Voltage (V_S)	+6 V
Input Voltage	GND to V_S
Differential Input Voltage ²	± 6 V
Storage Temperature Range	
R, RT, RU Packages	-65°C to +150°C
Operating Temperature Range	
AD8541/AD8542/AD8544	-40°C to +125°C
Junction Temperature Range	
R, RT, RU Packages	-65°C to +150°C
Lead Temperature Range (Soldering, 60 sec)	+300°C

NOTES

¹Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those listed in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

²For supplies less than +6 V, the differential input voltage is equal to $\pm V_S$.

PACKAGE INFORMATION

Package Type	θ_{JA} ¹	θ_{JC}	Units
5-Lead SOT-23 (RT)	256	81	°C/W
8-Lead SOIC (R)	158	43	°C/W
8-Lead TSSOP (RU)	240	43	°C/W
14-Lead SOIC (R)	120	36	°C/W
14-Lead TSSOP (RU)	240	43	°C/W

NOTE

¹ θ_{JA} is specified for worst case conditions, i.e., θ_{JA} is specified for device soldered onto a circuit board for surface mount packages.

CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the AD8541/AD8542/AD8544 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option
AD8541AR	-40°C to +125°C	8-Lead SOIC	SO-8
AD8541ART ^{1,2}	-40°C to +125°C	5-Lead SOT-23	RT-5
AD8542AR	-40°C to +125°C	8-Lead SOIC	SO-8
AD8542ARU ³	-40°C to +125°C	8-Lead TSSOP	RU-8
AD8544AR	-40°C to +125°C	14-Lead SOIC	SO-14
AD8544ARU ³	-40°C to +125°C	14-Lead TSSOP	RU-14

NOTES

¹Available in 2,500 piece reels only.

²AD8541ART is marked A4A.

³Available in 3,500 or 10,000 piece reels.



AD8541/AD8542/AD8544—Typical Performance Characteristics

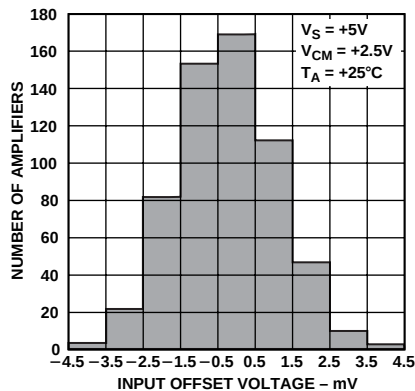


Figure 1. Input Offset Voltage Distribution

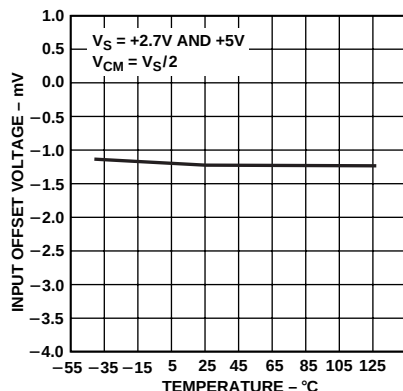


Figure 2. Input Offset Voltage vs. Temperature

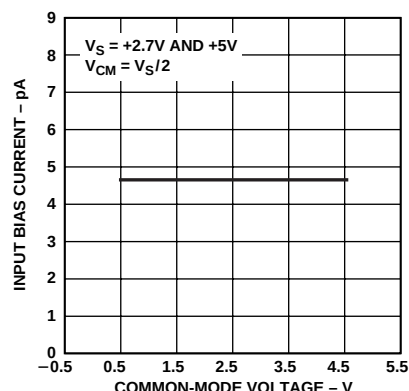


Figure 3. Input Bias Current vs. Common-Mode Voltage

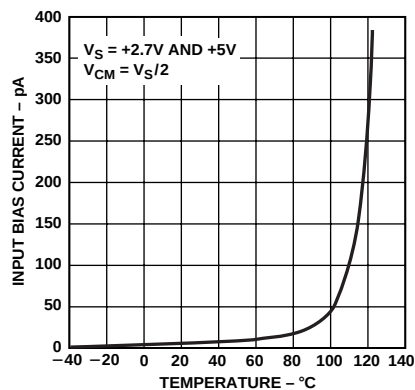


Figure 4. Input Bias Current vs. Temperature

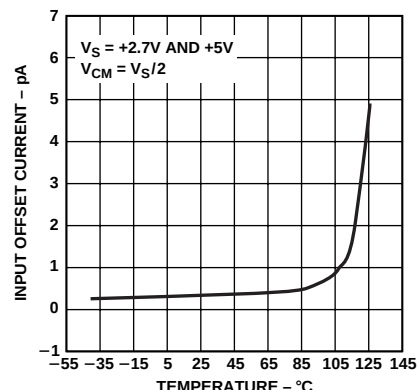


Figure 5. Input Offset Current vs. Temperature

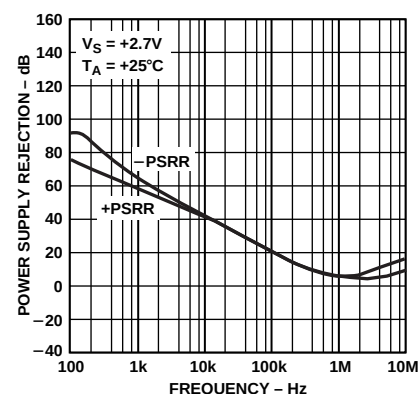


Figure 6. Power Supply Rejection Ratio vs. Frequency

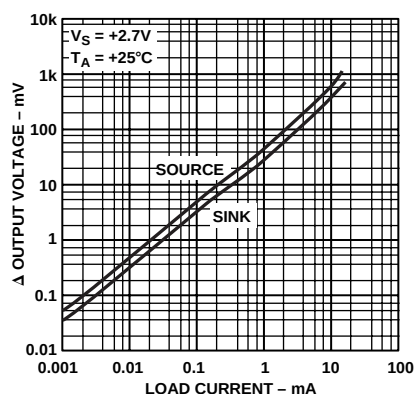


Figure 7. Output Voltage to Supply Rail vs. Load Current

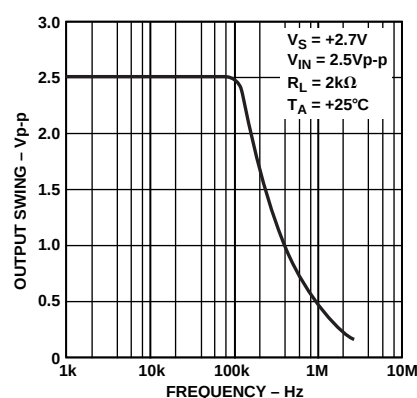


Figure 8. Closed-Loop Output Voltage Swing vs. Frequency

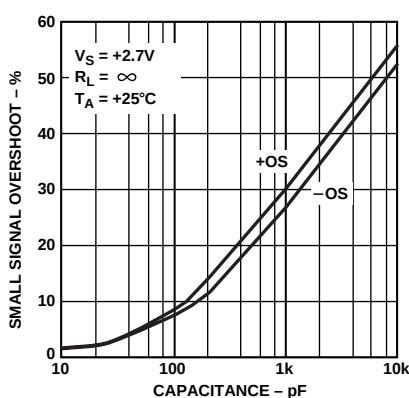


Figure 9. Small Signal Overshoot vs. Load Capacitance

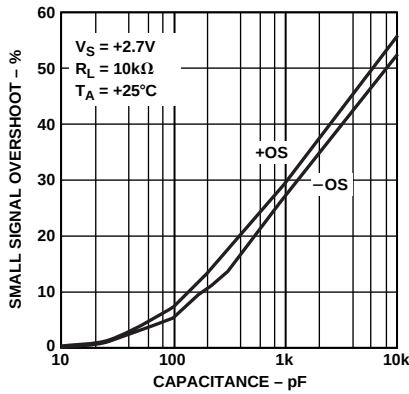


Figure 10. Small Signal Overshoot vs. Load Capacitance

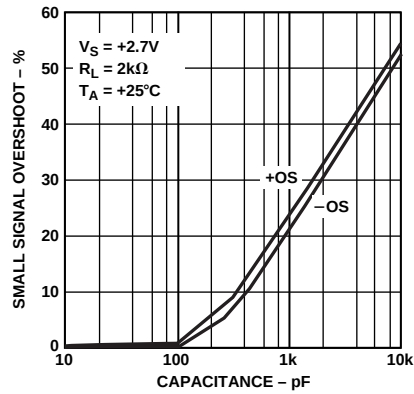


Figure 11. Small Signal Overshoot vs. Load Capacitance

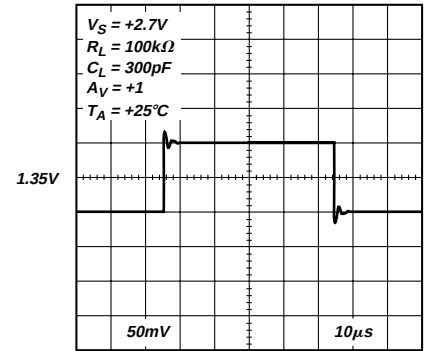


Figure 12. Small Signal Transient Response

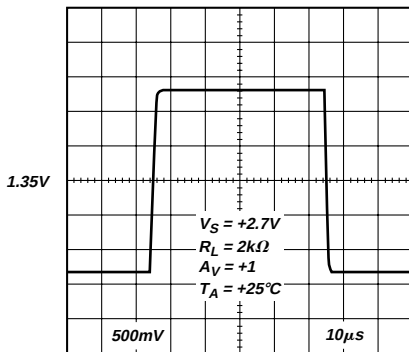


Figure 13. Large Signal Transient Response

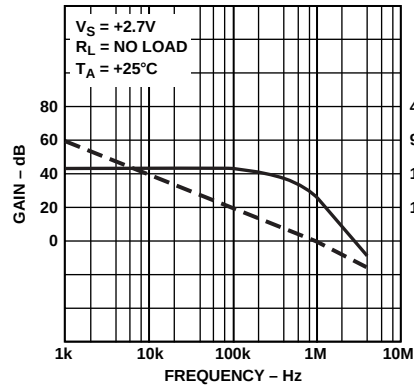


Figure 14. Open-Loop Gain and Phase vs. Frequency

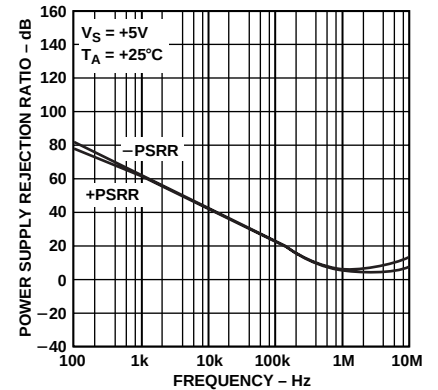


Figure 15. Power Supply Rejection Ratio vs. Frequency

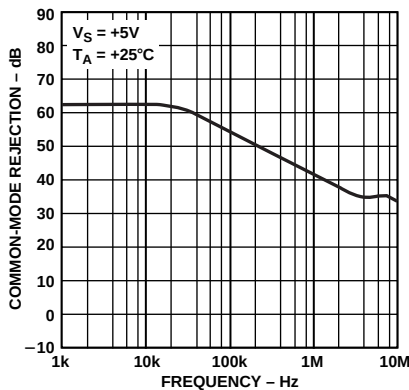


Figure 16. Common-Mode Rejection Ratio vs. Frequency

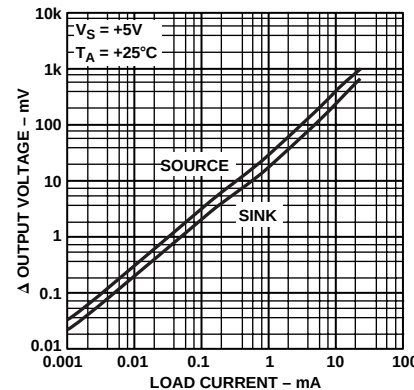


Figure 17. Output Voltage to Supply Rail vs. Frequency

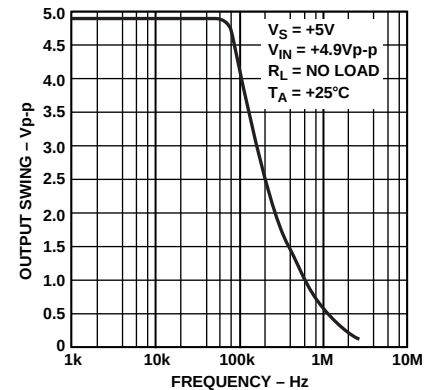


Figure 18. Closed Loop Output Voltage Swing vs. Frequency

AD8541/AD8542/AD8544

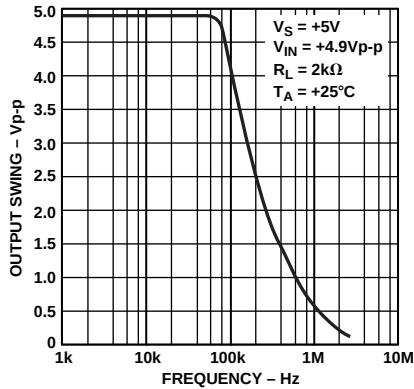


Figure 19. Closed-Loop Output Voltage Swing vs. Frequency

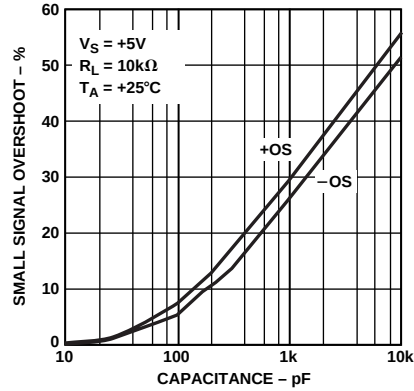


Figure 20. Small Signal Overshoot vs. Load Capacitance

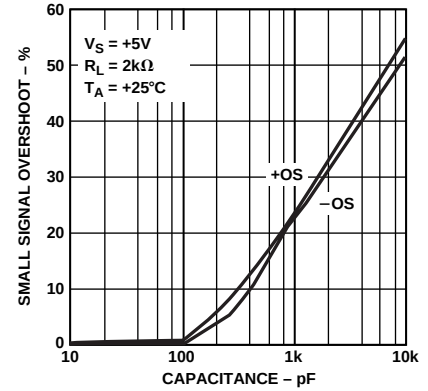


Figure 21. Small Signal Overshoot vs. Load Capacitance

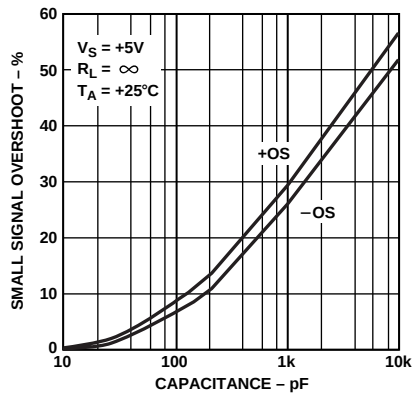


Figure 22. Small Signal Overshoot vs. Load Capacitance

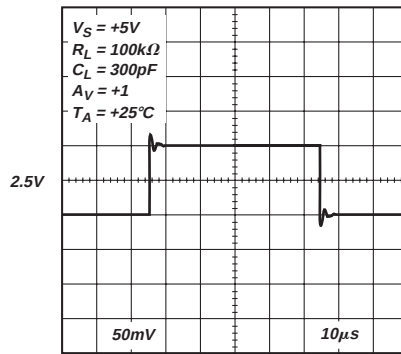


Figure 23. Small Signal Transient Response

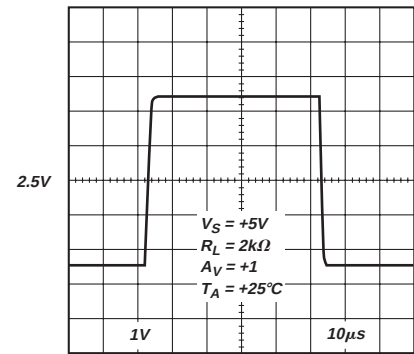


Figure 24. Large Signal Transient Response

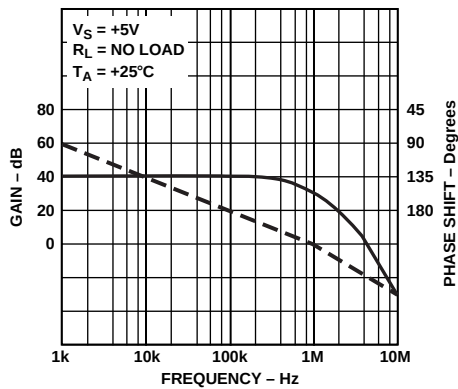


Figure 25. Open-Loop Gain & Phase vs. Frequency

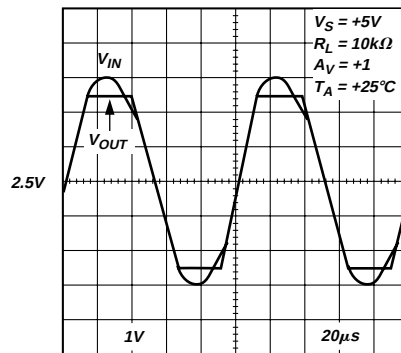


Figure 26. No Phase Reversal

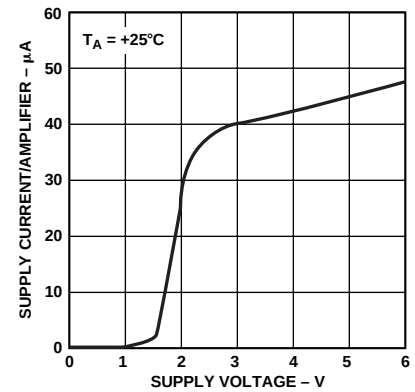


Figure 27. Supply Current per Amplifier vs. Supply Voltage

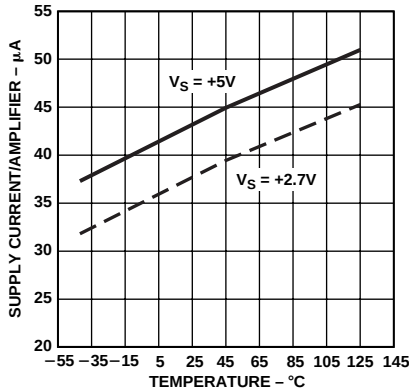


Figure 28. Supply Current per Amplifier vs. Temperature

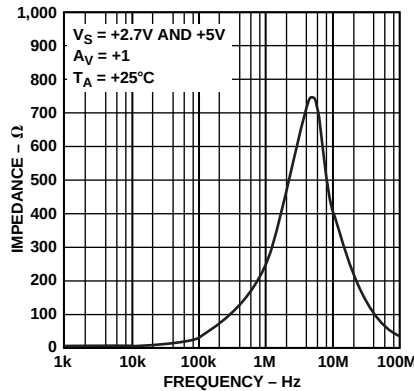


Figure 29. Closed-Loop Output Impedance vs. Frequency

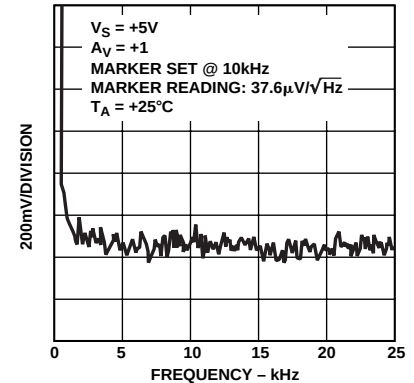


Figure 30. Voltage Noise

NOTES ON THE AD854x AMPLIFIERS

The AD8541/AD8542/AD8544 amplifiers are improved performance general purpose operational amplifiers. Performance has been improved over previous amplifiers in several ways.

Lower Supply Current for 1 MHz Gain Bandwidth

The AD854x series typically uses 45 microamps of current per amplifier. This is much less than the 200 μ A to 700 μ A used in earlier generation parts with similar performance. This makes the AD854x series a good choice for upgrading portable designs for longer battery life. Alternatively, additional functions and performance can be added at the same current drain.

Higher Output Current

At +5 V single supply, the short circuit current is typically 60 μ A. Even 1 V from the supply rail, the AD854x amplifiers can provide 30 mA, sourcing or sinking.

Sourcing and sinking is strong at lower voltages, with 15 mA available at +2.7 V, and 18 mA at 3.0 V. For even higher output currents, please see the Analog Devices AD8531/AD853/AD8534 parts, with output currents to 250 mA. Information on these parts is available from your Analog Devices representative, and datasheets are available at the Analog Devices website at www.analog.com.

Better Performance at Lower Voltages

The AD854x family parts have been designed to provide better ac performance, at 3.0 V and 2.7 V, than previously available parts. Typical gain-bandwidth product is close to 1 MHz at 2.7 V. Voltage gain at 2.7 V and 3.0 V is typically 500,000. Phase margin is typically over +60°C, making the part easy to use.

APPLICATIONS

Notch Filter

The AD8542 has very high open loop gain (especially with supply voltage below 4 V), which makes it useful for active filters of all types. For example, Figure 31 illustrates the AD8542 in the classic Twin-T Notch Filter design. The Twin-T Notch is desired for simplicity, low output impedance and minimal use of op amps. In fact, this notch filter may be designed with only one op amp if Q adjustment is not required. Simply remove U2 as illustrated in Figure 32. However, a major drawback to this circuit topology is ensuring that all the R's and C's closely match. The components must closely match or notch frequency offset and drift will cause

the circuit to no longer attenuate at the ideal notch frequency. To achieve desired performance, 1% or better component tolerances or special component screens are usually required. One method to desensitize the circuit-to-component mismatch is to increase R2 with respect to R1, which lowers Q. A lower Q increases attenuation over a wider frequency range, but reduces attenuation at the peak notch frequency.

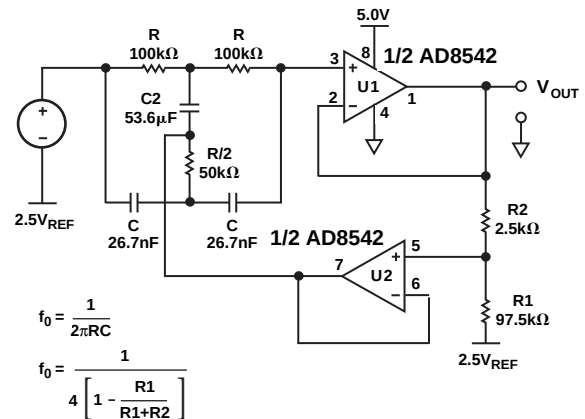


Figure 31. 60 Hz Twin-T Notch Filter, $Q = 10$

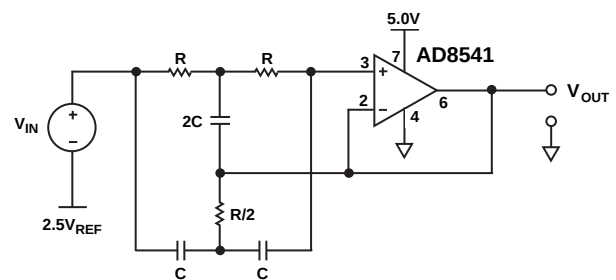


Figure 32. 60 Hz Twin-T Notch Filter, $Q = \infty$ (Ideal)

Figure 33 diagrams another example of the AD8542 in a notch filter circuit. The FNDNR notch filter has several unique features as compared to the Twin-T Notch including: less critical matching requirements; Q is directly proportional to a single resistor R1. While matching component values is still important, it is also much easier and/or less expensive to

AD8541/AD8542/AD8544

accomplish in the FNDR circuit. For example, the Twin-T Notch uses three capacitors with two unique values, whereas the FNDR circuit uses only two capacitors, which may be of the same value. U3 is simply a buffer that is added to lower the output impedance of the circuit.

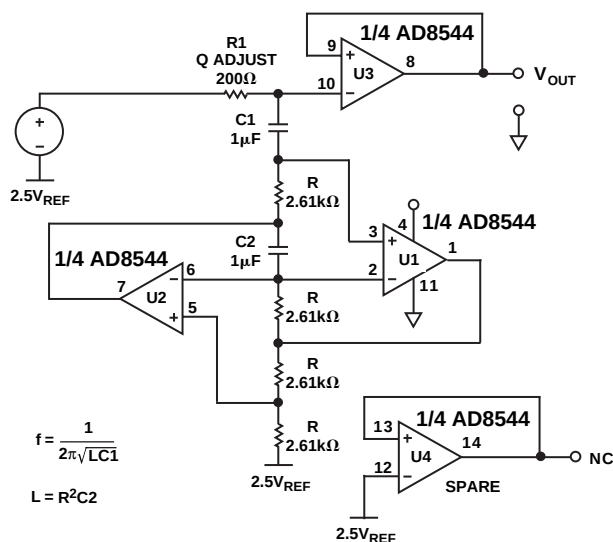


Figure 33. FNDR 60 Hz Notch Filter with Output Buffer

Comparator Function

A comparator function is a common application for a spare op amp in a quad package. Figure 34 illustrates 1/4 of the AD8544 as a comparator in a standard overload detection application. Unlike so many op amps, the AD854x family can double as comparator because this op amp family has rail-to-rail differential input range, rail-to-rail output, and a great speed vs. power ratio. R2 is used to introduce hysteresis. The AD854x when used as comparators have 5 μs propagation delay @ 5 V and 5 μs overload recovery time.

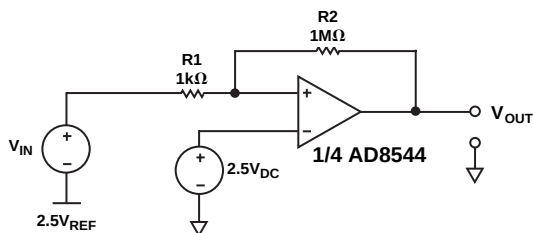


Figure 34. The AD854x Comparator Application—Overload Detector

Photodiode Application

The AD854x family has very high impedance with input bias current typically around 4 pA. This characteristic allows the

AD854x op amps to be used in photodiode applications and other applications that require high input impedance. Note that the AD854x has significant voltage offset, which can be removed by capacitive coupling or software calibration.

Figure 35, illustrates a photodiode or current measurement application. The feedback resistor is limited to 10 MΩ to avoid excessive output offset. Also note that a resistor is not needed on the noninverting input to cancel bias current offset, because the bias current related output offset is not significant when compared to the voltage offset contribution. For the best performance follow the standard high impedance layout techniques including: shield circuit, clean circuit board, put a trace connected to the noninverting input around the inverting input, and use separate analog and digital power supplies.

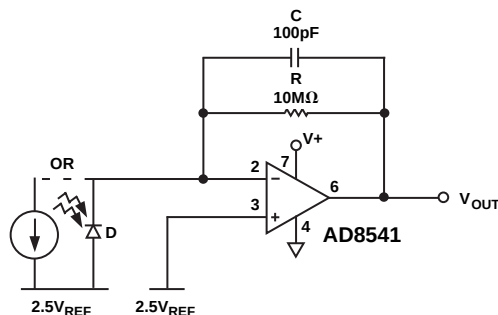


Figure 35. High Input Impedance Application—Photodiode Amplifier

REV. 0

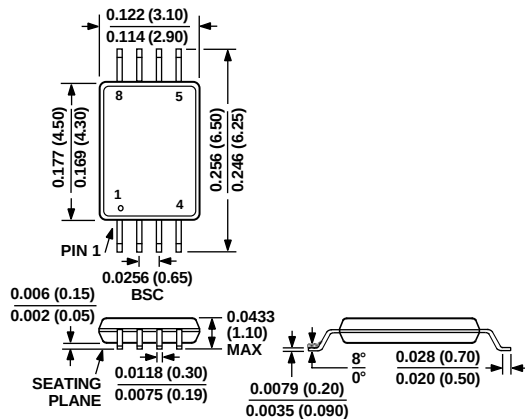
-11-

AD8541/AD8542/AD8544

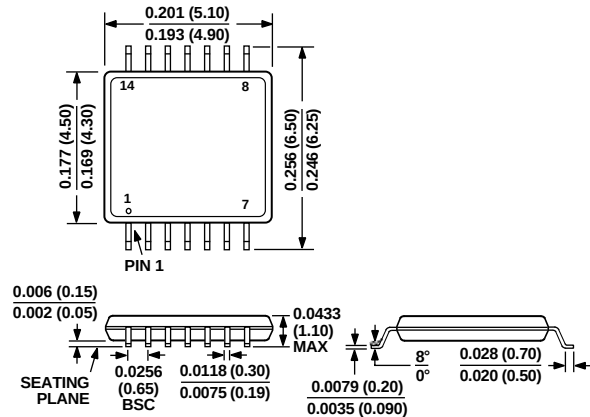
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

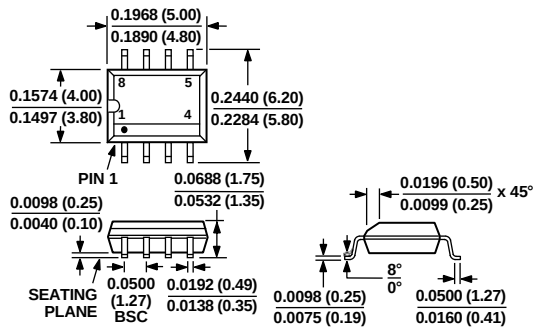
**8-Lead TSSOP
(RU-08)**



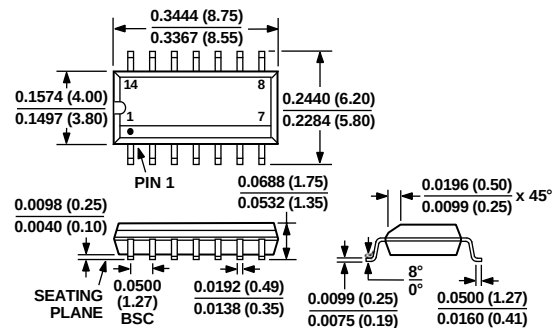
**14-Lead TSSOP
(RU-14)**



**8-Lead SOIC
(SO-8)**



**14-Lead SOIC
(SO-14)**



**5-Lead SOT-23
(RT Suffix)**

