LTC8541, LTC8542, LTC8544

1.1MHz, 70µA, CMOS RRIO Operational Amplifiers

General Description

The LTC8541 (single), LTC8542 (dual) and LTC8544 (quad) are low voltage micro power CMOS voltage feedback operational amplifiers. With an excellent bandwidth of 1.1MHz, a slew rate of 0.9V/µs, and a quiescent current of 70µA per amplifier at 5V, the LTC854x family can be designed into a wide range of applications.

The LTC854x op-amps are specifically designed for general-purpose applications with optimal performance. They have a wide input common-mode voltage range and output voltage swing, and the maximum input offset voltage are 3.5mV. These parts provide rail-to-rail output swing into heavy loads. The LTC854x family is specified for single or dual power supplies of +2.3V to +6.0V. All models are specified over the extended industrial temperature range of −40℃ to +125℃.

The LTC8541 is available in 5-lead SC70 and SOT-23, and 8-lead SOIC packages. The LTC8542 is available in 8-lead DFN2x2, MSOP and SOIC packages. The LTC8544 is available in 14-lead TSSOP and SOIC packages.

Features and Benefits

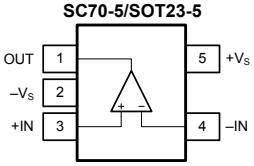
- High Gains of >102 dB for Active Filters and Gain Stages
- Low Offset Voltage: 3.5 mV Maximum with 2 µV/℃ Low Drift
- Gain-Bandwidth Product: 1.1MHz
- High Slew Rate: 0.9 V/µs
- Low Power: 70 µA per Amplifier Supply Current
- Settling Time to 0.1% with 2V Step: 4.1 µs
- Unity Gain Stable
- Very Low Input Bias Current: 1pA
- Rail-to-Rail Input and Output
  - Input Voltage Range: -0.2 to +5.2 V at 5V Supply
- Operating Power Supply: +2.3 to +6.0 V
- Operating Temperature Range: −40℃ to +125℃
- ESD Rating: HBM – 4kV, CDM – 2kV

Applications

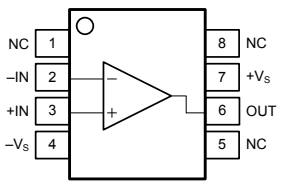
- Smoke/Gas/Environment Sensors
- Audio Outputs
- Active Filters
- ASIC Input or Output Amplifier
- Sensor Interfaces
- Portable Equipment
- Battery-Powered Instrumentation

Pin Configurations (Top View)

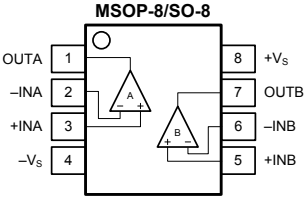
LTC8541
SC70-5/SOT23-5



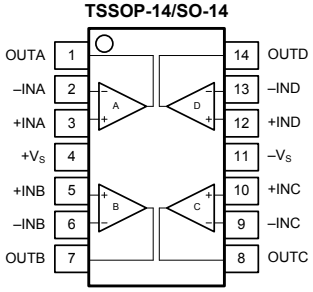
LTC8541
SO-8



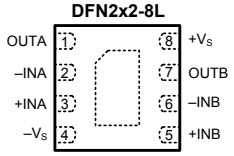
LTC8542
MSOP-8/SO-8



LTC8544
TSSOP-14/SO-14



LTC8542
DFN2x2-8L



Pin Description

Symbol	Description
–IN	Inverting input of the amplifier. The voltage range can go from (V_{S-} – 0.2V) to (V_{S+} + 0.2V).
+IN	Non-inverting input of the amplifier. This pin has the same voltage range as –IN.
$+V_S$	Positive power supply. The voltage is from 2.3V to 6.0V. Split supplies are possible as long as the voltage between V_{S+} and V_{S-} is between 2.3V and 6.0V. A bypass capacitor of 0.1µF as close to the part as possible should be used between power supply pins or between supply pins and ground.
$–V_S$	Negative power supply. It is normally tied to ground. It can also be tied to a voltage other than ground as long as the voltage between V_{S+} and V_{S-} is from 2.3V to 6.0V. If it is not connected to ground, bypass it with a capacitor of 0.1µF as close to the part as possible.
OUT	Amplifier output.
N/C	No internal connection.

Ordering Information

Type Number	Package Name	Package Quantity	Marking Code
LTC8541XC5/R6	SC70-5	Tape and Reel, 3 000	C41
LTC8541XT5/R6	SOT23-5	Tape and Reel, 3 000	C41
LTC8541XS8/R8	SO-8	Tape and Reel, 4 000	C41X
LTC8542XF8/R6	DFN2x2-8L	Tape and Reel, 3 000	C42
LTC8542XV8/R6	MSOP-8	Tape and Reel, 3 000	C42X
LTC8542XS8/R8	SO-8	Tape and Reel, 4 000	C42X
LTC8544XT14/R6	TSSOP-14	Tape and Reel, 3 000	C44X
LTC8544XS14/R5	SO-14	Tape and Reel, 2 500	C44X

Limiting Value

In accordance with the Absolute Maximum Rating System (IEC 60134).

Parameter	Absolute Maximum Rating
Supply Voltage, V_{S+} to V_{S-}	10.0V
Common-Mode Input Voltage	V_{S-} – 0.5V to V_{S+} + 0.5V
Storage Temperature Range	–65℃ to +150℃
Junction Temperature	160℃
Lead Temperature Range (Soldering 10 sec)	260℃
Electrostatic Discharge Voltage	HBM ±4 000V
	CDM ±2 000V
	MM ±400V

Electrical Characteristics

V_S = 5.0V, T_A = +25℃, V_{CM} = V_S/2, V_O = V_S/2, and R_L = 10kΩ connected to V_S/2, unless otherwise noted.
Boldface limits apply over the specified temperature range, T_A = −40 to +125 ℃.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
INPUT CHARACTERISTICS						
V_{OS}	Input offset voltage		-3.5	±0.5	+3.5	mV
	over Temperature		**-3.8**		**+3.8**	
V_{OS} TC	Offset voltage drift	**over Temperature**		**2**		µV/℃
I_B	Input bias current			1		pA
	over Temperature				**800**	
I_{OS}	Input offset current			1		pA
V_{CM}	Common-mode voltage range		V_{S-}–0.2		V_{S+}+0.2	V
CMRR	Common-mode rejection ratio	V_{CM} = 0.05V to 3.5V	80	97		dB
	over Temperature		**70**			
		V_{CM} = V_{S-}–0.1 to V_{S+}+0.1 V	70	82		
	over Temperature		**66**			
A_{VOL}	Open-loop voltage gain	R_L = 10kΩ, V_O = 0.05 to 3.5 V	102	116		dB
	over Temperature		**90**			
		R_L = 2kΩ, V_O = 0.15 to 3.5 V	93	108		
	over Temperature		**82**			
R_{IN}	Input resistance		100			GΩ
C_{IN}	Input capacitance	Differential		2.0		pF
		Common mode		3.5		
OUTPUT CHARACTERISTICS						
V_{OH}	High output voltage swing	R_L = 10kΩ		V_{S+}–5		mV
		R_L = 600Ω		V_{S+}–75		
V_{OL}	Low output voltage swing	R_L = 10kΩ		5		mV
		R_L = 600Ω		75		
Z_{OUT}	Closed-loop output impedance	f = 200kHz, G = +1		0.4		Ω
	Open-loop output impedance	f = 1MHz, I_O = 0		2.6		
I_{SC}	Short-circuit current	Source current through 10Ω		60		mA
		Sink current through 10Ω		45		
DYNAMIC PERFORMANCE						
GBW	Gain bandwidth product	f = 1kHz		1.1		MHz
Φ_M	Phase margin	C_L = 100pF		66		°
SR	Slew rate	G = +1, C_L = 100pF, V_O = 1.5V to 3.5V		0.9		V/µs
t_S	Settling time	To 0.1%, G = +1, 2V step		4.1		µs
		To 0.01%, G = +1, 2V step		5.1		
THD+N	Total harmonic distortion + noise	f = 1kHz, G = +1, V_O = $3V_{PP}$		0.0018		%

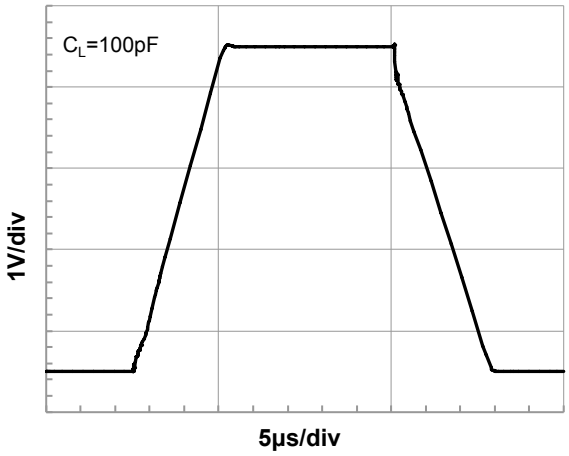
Electrical Characteristics (continued)

V_S = 5.0V, T_A = +25℃, V_{CM} = V_S/2, V_O = V_S/2, and R_L = 10kΩ connected to V_S/2, unless otherwise noted. ***Boldface limits apply over the specified temperature range, T_A = −40 to +125 ℃.***

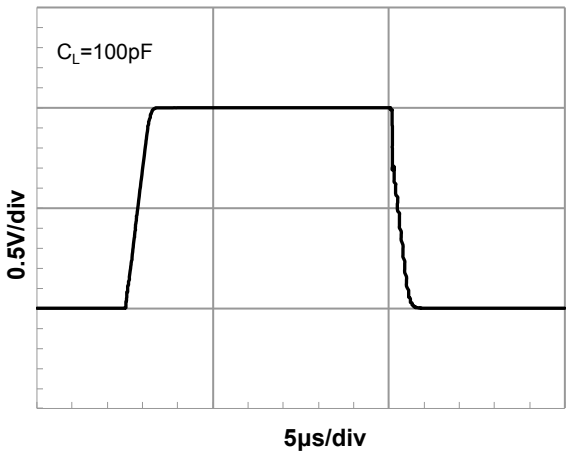
Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
NOISE PERFORMANCE						
V_n	Input voltage noise	f = 0.1 to 10 Hz		10		μV_{P-P}
e_n	Input voltage noise density	f = 1kHz		27		nV/√Hz
I_n	Input current noise density	f = 1kHz		4		fA/√Hz
POWER SUPPLY						
V_S	Operating supply voltage		2.3		6.0	V
PSRR	Power supply rejection ratio	V_S = 2.7V to 5.5V, V_{CM} < V_{S+} − 2V	82	102		dB
	over Temperature		**75**			
I_Q	Quiescent current (per amplifier)		58	70	84	µA
	over Temperature				**95**	
THERMAL CHARACTERISTICS						
T_A	Operating temperature range		-40		+125	℃
θ_{JA}	Package Thermal Resistance	SC70-5		333		℃/W
		SOT23-5		190		
		DFN2x2-8L		80		
		MSOP-8		216		
		SO-8		125		
		TSSOP-14		112		
		SO-14		115		

Typical Performance Characteristics

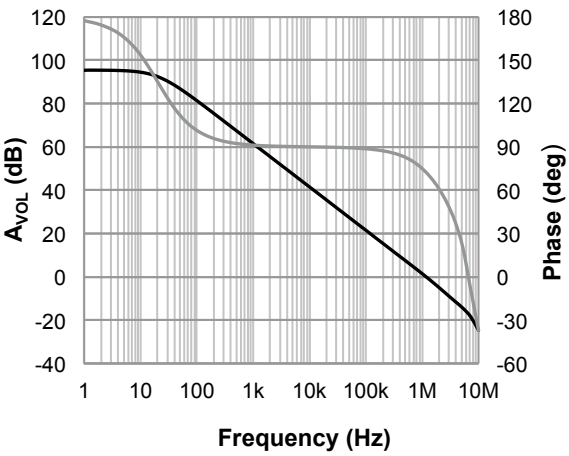
At T_A = +25℃, V_{CM} = V_S/2, and R_L = 10kΩ connected to V_S/2, unless otherwise noted.



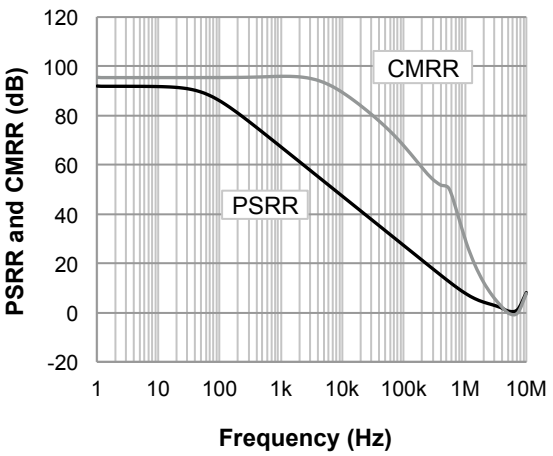
Large Signal Step Response.



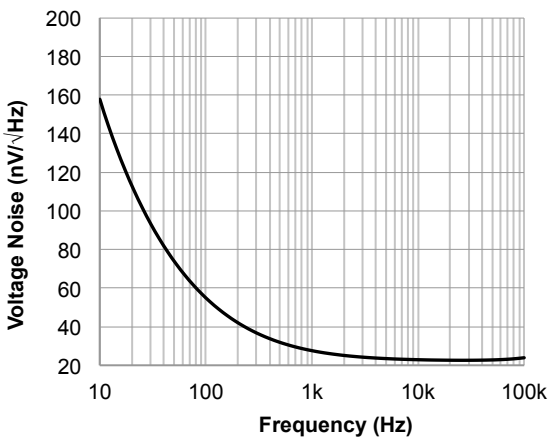
Small Signal Step Response.



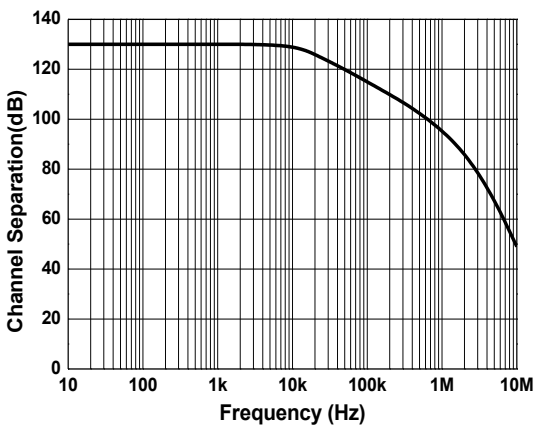
Open-loop Gain and Phase as a function of Frequency.



Power Supply and Common-mode Rejection Ratio as a function of Frequency.



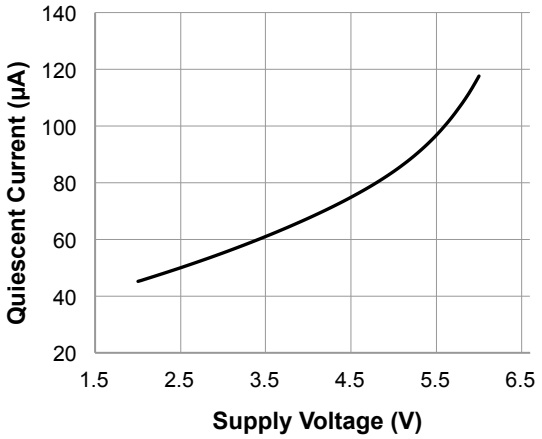
Input Voltage Noise Spectral Density as a function of Frequency.



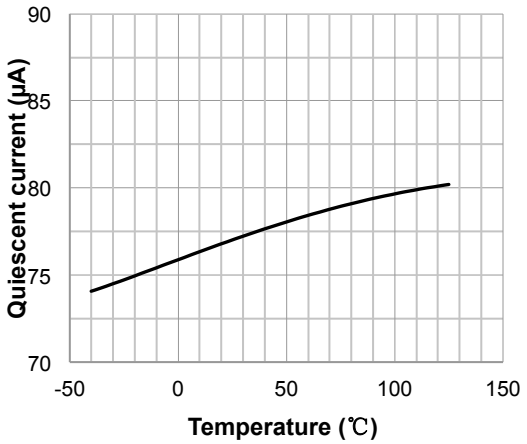
Channel Separation as a function of Frequency.

Typical Performance Characteristics (continued)

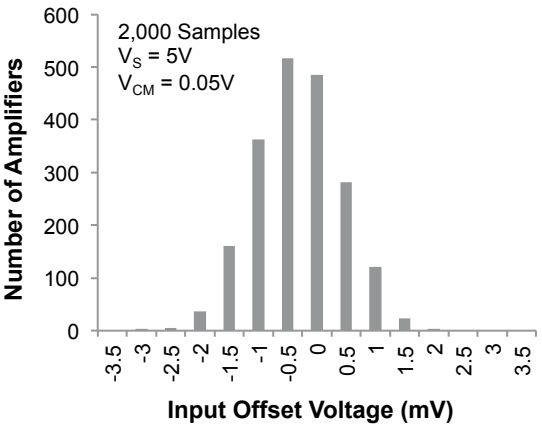
At T_A = +25℃, V_{CM} = V_S/2, and R_L = 10kΩ connected to V_S/2, unless otherwise noted.



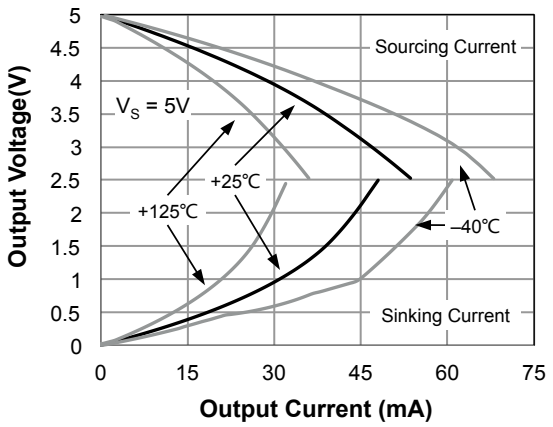
Quiescent Current as a function of Supply Voltage.



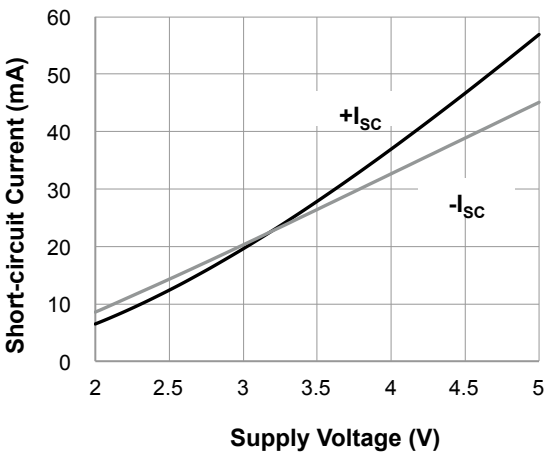
Quiescent Current as a function of Temperature.



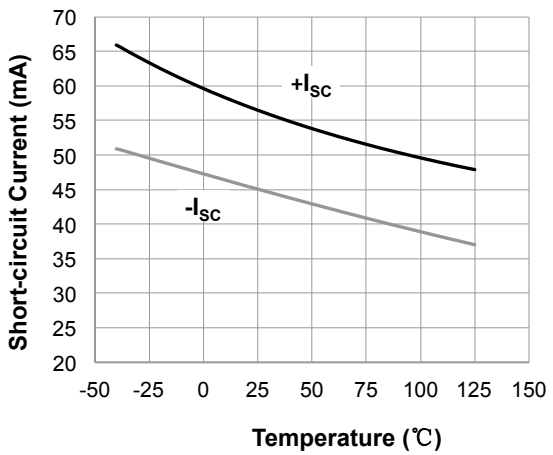
Input Offset Voltage Production Distribution.



Output Voltage Swing as a function of Output Current.



Short-circuit Current as a function of Supply Voltage.



Short-circuit Current as a function of Temperature.

Application Notes

LOW INPUT BIAS CURRENT

The LTC854x family is a CMOS op-amp family and features very low input bias current in pA range. The low input bias current allows the amplifiers to be used in applications with high resistance sources. Care must be taken to minimize PCB Surface Leakage. See below section on "PCB Surface Leakage" for more details.

PCB SURFACE LEAKAGE

In applications where low input bias current is critical, Printed Circuit Board (PCB) surface leakage effects need to be considered. Surface leakage is caused by humidity, dust or other contamination on the board. Under low humidity conditions, a typical resistance between nearby traces is $10^{12}\Omega$. A 5V difference would cause 5pA of current to flow, which is greater than the LTC854x's input bias current at +25℃ (±1fA, typical). It is recommended to use multi-layer PCB layout and route the op-amp's –IN and +IN signal under the PCB surface.

The effective way to reduce surface leakage is to use a guard ring around sensitive pins (or traces). The guard ring is biased at the same voltage as the sensitive pin. An example of this type of layout is shown in Figure 1 for Inverting Gain application.

1. For Non-Inverting Gain and Unity-Gain Buffer:
   a) Connect the non-inverting pin (+IN) to the input with a wire that does not touch the PCB surface.
   b) Connect the guard ring to the inverting input pin (–IN). This biases the guard ring to the Common Mode input voltage.
2. For Inverting Gain and Trans-impedance Gain Amplifiers (convert current to voltage, such as photo detectors):
   a) Connect the guard ring to the non-inverting input pin (+IN). This biases the guard ring to the same reference voltage as the op-amp (e.g., $V_S/2$ or ground).
   b) Connect the inverting pin (–IN) to the input with a wire that does not touch the PCB surface.

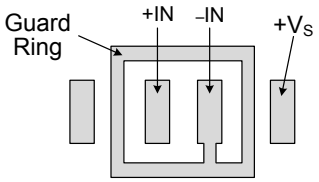


Figure 1. Use a guard ring around sensitive pins

GROUND SENSING AND RAIL TO RAIL

The input common-mode voltage range of the LTC854x series extends 200mV 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. For normal operation, inputs should be limited to this range. The absolute maximum input voltage is 500mV beyond the supplies. Inputs greater than the input common-mode range but less than the maximum input voltage, while not valid, will not cause any damage to the op-amp. Unlike some other op-amps, if input current is limited, the inputs may go beyond the supplies without phase inversion, as shown in Figure 2. Since the input common-mode range extends from (V_{S-} − 0.2V) to (V_{S+} + 0.2V), the LTC854x op-amps can easily perform 'true ground' sensing.

A topology of class AB output stage with common-source transistors is used to achieve rail-to-rail output. For light resistive loads (e.g. 100kΩ), the output voltage can typically swing to within 5mV from the supply rails. With moderate resistive loads (e.g. 10kΩ), the output can typically swing to within 10mV from the supply rails and maintain high open-loop gain. See the Typical Characteristic curve, Output Voltage Swing as a function of Output Current, for more information.

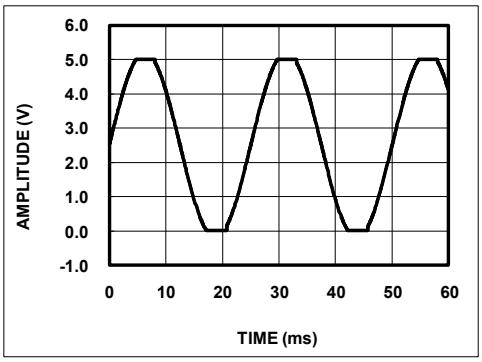


Figure 2. No Phase Inversion with Inputs Greater Than the Power-Supply Voltage

The maximum output current is a function of total supply voltage. As the supply voltage to the amplifier increases, the output current capability also increases. Attention must be paid to keep the junction temperature of the IC below 150℃ when the output is in continuous short-circuit. The output of the amplifier has reverse-biased ESD diodes connected to each supply. The output should not be forced more than 0.5V beyond either supply, otherwise current will flow through these diodes.

CAPACITIVE LOAD AND STABILITY

The LTC854x can directly drive 1nF in unity-gain without oscillation. The unity-gain follower (buffer) is the most sensitive configuration to capacitive loading. Direct capacitive loading reduces the phase margin of amplifiers and this results in ringing or even oscillation. Applications that require greater capacitive drive capability should use an isolation resistor between the output and the capacitive load like the circuit in Figure 3. The isolation resistor R_{ISO} and the load capacitor C_L form a zero to increase stability. The bigger the R_{ISO} resistor value, the more stable V_{OUT} will be. Note that this method results in a loss of gain accuracy because R_{ISO} forms a voltage divider with the R_L.

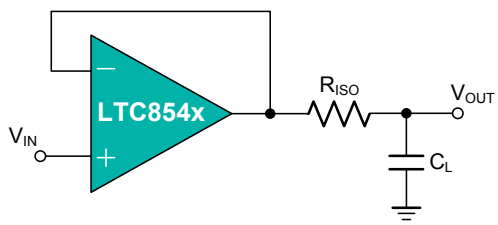


Figure 3. Indirectly Driving Heavy Capacitive Load

An improvement circuit is shown in Figure 4. It provides DC accuracy as well as AC stability. The R_F provides the DC accuracy by connecting the inverting signal with the output. The C_F and R_{ISO} serve to counteract the loss of phase margin by feeding the high frequency component of the output signal back to the amplifier's inverting input, thereby preserving phase margin in the overall feedback loop.

Application Notes (continued)

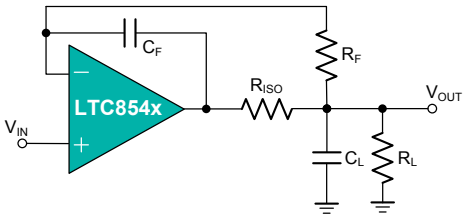


Figure 4. Indirectly Driving Heavy Capacitive Load with DC Accuracy

For no-buffer configuration, there are two others ways to increase the phase margin: (a) by increasing the amplifier's gain, or (b) by placing a capacitor in parallel with the feedback resistor to counteract the parasitic capacitance associated with inverting node.

POWER SUPPLY LAYOUT AND BYPASS

The LTC854x family operates from either a single +2.3V to +6.0V supply or dual ±1.15V to ±3.00V supplies. For single-supply operation, bypass the power supply V_S with a ceramic capacitor (i.e. 0.01µF to 0.1µF) which should be placed close (within 2mm for good high frequency performance) to the V_S pin. For dual-supply operation, both the V_{S+} and the V_{S-} supplies should be bypassed to ground with separate 0.1µF ceramic capacitors. A bulk capacitor (i.e. 2.2µF or larger tantalum capacitor) within 100mm to provide large, slow currents and better performance. This bulk capacitor can be shared with other analog parts.

Good PC board layout techniques optimize performance by decreasing the amount of stray capacitance at the op-amp's inputs and output. To decrease stray capacitance, minimize trace lengths and widths by placing external components as close to the device as possible. Use surface-mount components whenever possible. For the op-amp, soldering the part to the board directly is strongly recommended. Try to keep the high frequency big current loop area small to minimize the EMI (electromagnetic interfacing).

GROUNDING

A ground plane layer is important for the LTC854x circuit design. The length of the current path speed currents in an inductive ground return will create an unwanted voltage noise. Broad ground plane areas will reduce the parasitic inductance.

INPUT-TO-OUTPUT COUPLING

To minimize capacitive coupling, the input and output signal traces should not be parallel. This helps reduce unwanted positive feedback.

Typical Application Circuits

DIFFERENTIAL AMPLIFIER

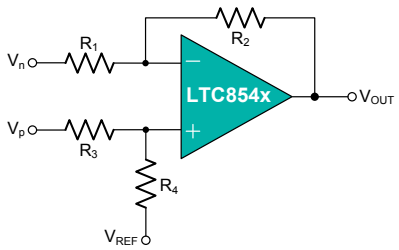
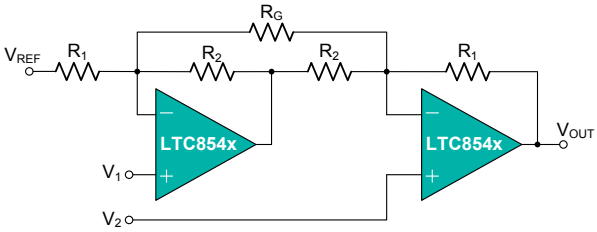


Figure 5. Differential Amplifier

The circuit shown in Figure 5 performs the difference function. If the resistors ratios are equal $R_4/R_3 = R_2/R_1$, then:

$$V_{OUT} = (V_p - V_n) \times R_2/R_1 + V_{REF}$$

INSTRUMENTATION AMPLIFIER

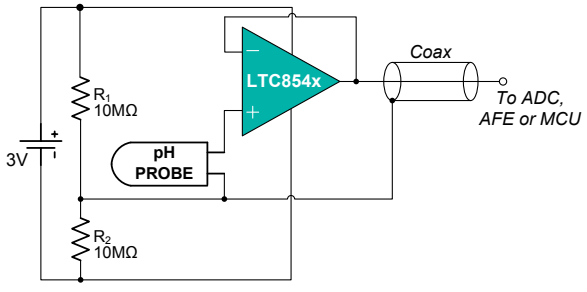


$$V_{OUT} = (V_1 - V_2)\left(1 + \frac{R_1}{R_2} + \frac{2R_1}{R_G}\right) + V_{REF}$$

Figure 6. Instrumentation Amplifier

The LTC854x family is well suited for conditioning sensor signals in battery-powered applications. Figure 6 shows a two op-amp instrumentation amplifier, using the LTC854x op-amps. The circuit works well for applications requiring rejection of common-mode noise at higher gains. The reference voltage (V_{REF}) is supplied by a low-impedance source. In single voltage supply applications, the V_{REF} is typically $V_S/2$.

BUFFERED CHEMICAL SENSORS



All components contained within the pH probe

Figure 7. Buffered pH Probe

The LTC854x family has input bias current in the pA range. This is ideal in buffering high impedance chemical sensors, such as pH probes. As an example, the circuit in Figure 7 eliminates expansive low-leakage cables that that is required to connect a pH probe (general purpose combination pH probes, e.g Corning 476540) to metering ICs such as ADC, AFE and/or MCU. A LTC854x op-amp and a lithium battery are housed in the probe assembly. A conventional low-cost coaxial cable can be used to carry the op-amp's output signal to subsequent ICs for pH reading.

SHUNT-BASED CURRENT SENSING AMPLIFIER

The current sensing amplification shown in Figure 8 has a slew rate of $2\pi fV_{PP}$ for the output of sine wave signal, and has a slew rate of $2fV_{PP}$ for the output of triangular wave signal. In most of motor control systems, the PWM frequency is at 10kHz to 20kHz, and one cycle time is 100µs for a 10kHz of PWM frequency. In current shunt monitoring for a motor phase, the phase current is converted to a phase voltage signal for ADC sampling. This sampling voltage signal must be settled before entering the ADC. As the Figure 8 shown, the total settling time of a current shunt monitor circuit includes: the rising edge delay time (t_{SR}) due to the op-amp's slew rate, and the measurement settling time (t_{SET}). For a 3-shunt solution in motor phase current sensing, if the smaller duty cycle of the PWM is defined at 45% (In fact, the phase with minimum PWM duty cycle, such as 5%, is not detected current directly, and it can be calculated from the other two phase currents), and the t_{SR} is required at 20% of a total time window for a phase current monitoring, in case of a 3.3V motor control system (3.3V MCU with 12-bit ADC), the op-amp's slew rate should be more than:

$$3.3V / (100\mu s \times 45\% \times 20\%) = 0.37\ V/\mu s$$

At the same time, the op-amp's bandwidth should be much greater than the PWM frequency, like 10 time at least.

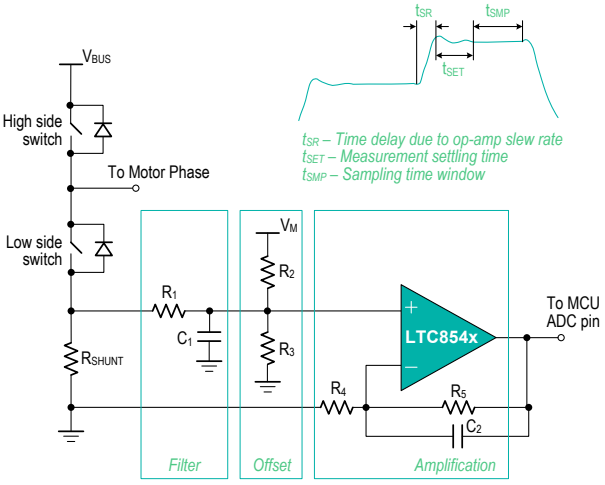
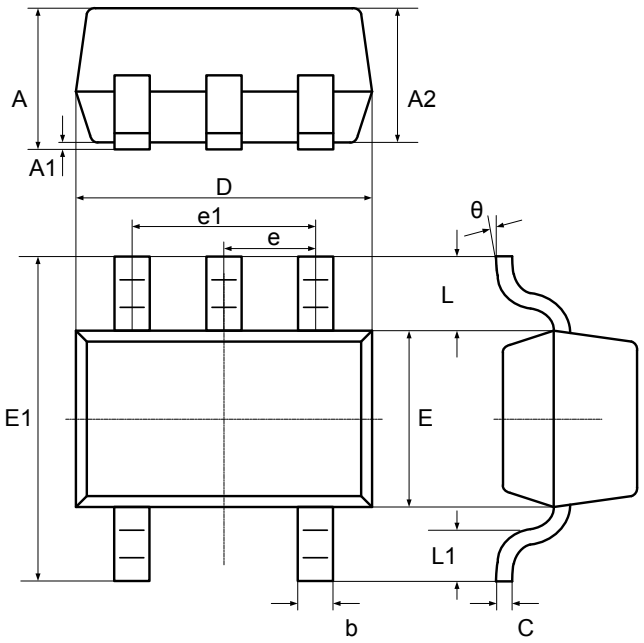


Figure 8. Current Shunt Monitor Circuit

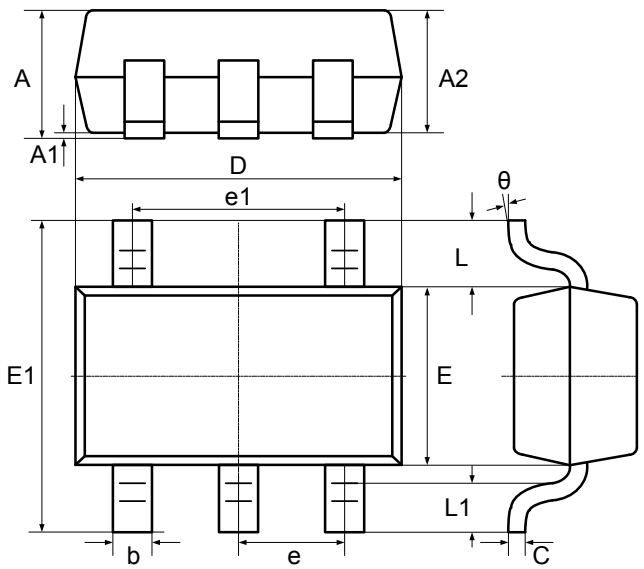
Package Outlines

SC70-5 (SOT353)



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.900	1.100	0.035	0.043
A1	0.000	0.100	0.000	0.004
A2	0.900	1.000	0.035	0.039
b	0.150	0.350	0.006	0.014
C	0.080	0.150	0.003	0.006
D	2.000	2.200	0.079	0.087
E	1.150	1.350	0.045	0.053
E1	2.150	2.450	0.085	0.096
e	0.650 typ.		0.026 typ.	
e1	1.200	1.400	0.047	0.055
L	0.525 ref.		0.021 ref.	
L1	0.260	0.460	0.010	0.018
θ	0°	8°	0°	8°

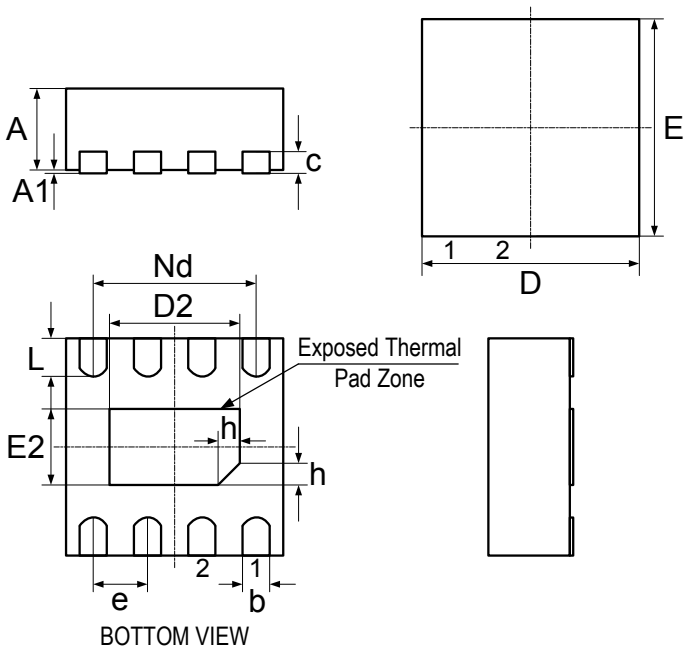
SOT23-5



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	1.040	1.350	0.042	0.055
A1	0.040	0.150	0.002	0.006
A2	1.000	1.200	0.041	0.049
b	0.380	0.480	0.015	0.020
c	0.110	0.210	0.004	0.009
D	2.720	3.120	0.111	0.127
E	1.400	1.800	0.057	0.073
E1	2.600	3.000	0.106	0.122
e	0.950 typ.		0.037 typ.	
e1	1.900 typ.		0.078 typ.	
L	0.700 ref.		0.028 ref.	
L1	0.300	0.600	0.012	0.024
θ	0°	8°	0°	8°

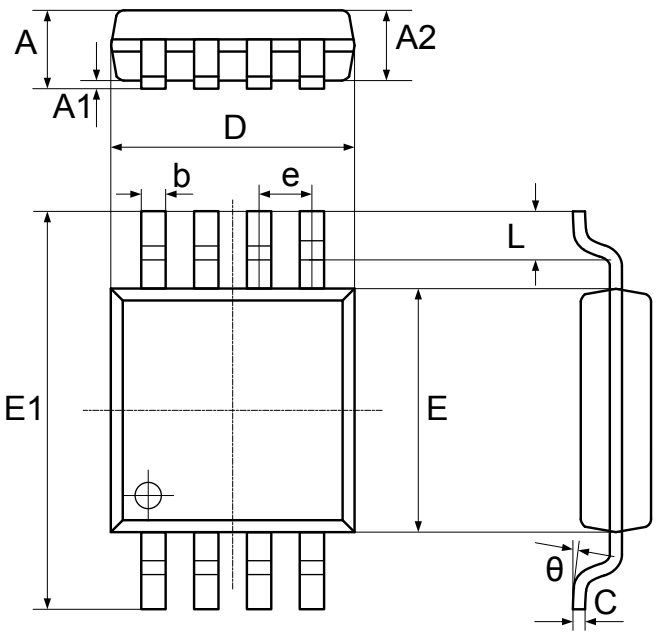
Package Outlines (continued)

DFN2x2-8L



Symbol	Millimeters		
	Min.	Nom.	Max.
A	0.70	0.75	0.80
A1	-	0.02	0.05
b	0.18	0.25	0.30
c	0.18	0.20	0.25
D	1.90	2.00	2.10
D2	1.10	1.20	1.30
Nd	1.50BSC		
E	1.90	2.00	2.10
E2	0.60	0.70	0.80
e	0.50BSC		
L	0.30	0.35	0.40
h	0.15	0.20	0.25

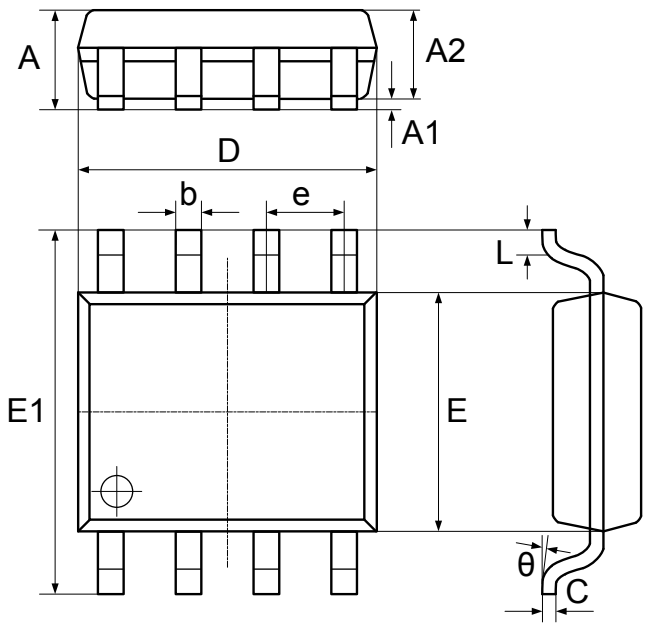
MSOP-8



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.800	1.100	0.033	0.045
A1	0.050	0.150	0.002	0.006
A2	0.750	0.950	0.031	0.039
b	0.290	0.380	0.012	0.016
C	0.150	0.200	0.006	0.008
D	2.900	3.100	0.118	0.127
E	2.900	3.100	0.118	0.127
E1	4.700	5.100	0.192	0.208
e	0.650 typ.		0.026 typ.	
L	0.400	0.700	0.016	0.029
θ	0°	8°	0°	8°

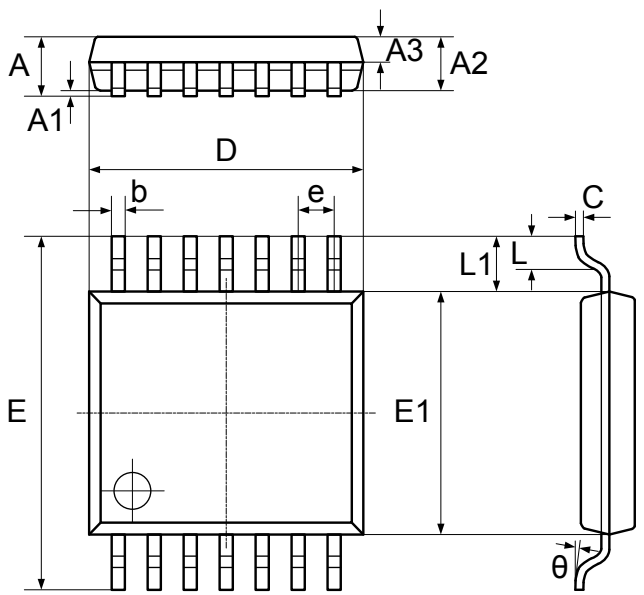
Package Outlines (continued)

SO-8



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	1.370	1.670	0.056	0.068
A1	0.070	0.170	0.003	0.007
A2	1.300	1.500	0.053	0.061
b	0.306	0.506	0.013	0.021
C	0.203 typ.		0.008 typ.	
D	4.700	5.100	0.192	0.208
E	3.820	4.020	0.156	0.164
E1	5.800	6.200	0.237	0.253
e	1.270 typ.		0.050 typ.	
L	0.450	0.750	0.018	0.306
θ	0°	8°	0°	8°

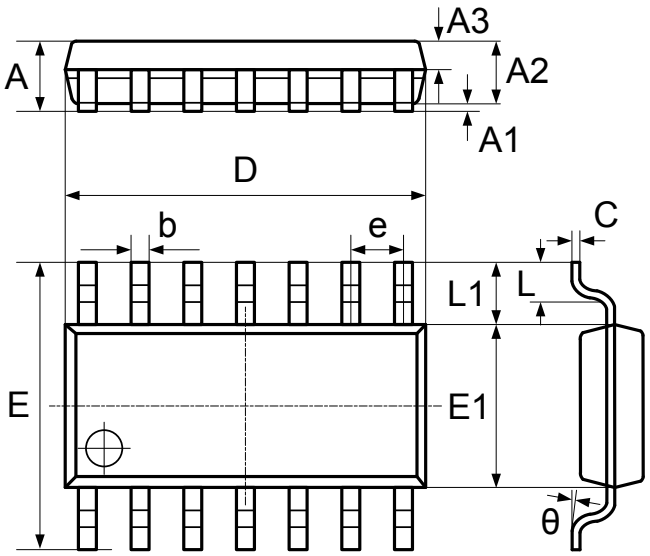
TSSOP-14



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	-	1.200	-	0.0472
A1	0.050	0.150	0.002	0.006
A2	0.900	1.050	0.037	0.043
A3	0.390	0.490	0.016	0.020
b	0.200	0.290	0.008	0.012
C	0.130	0.180	0.005	0.007
D	4.860	5.060	0.198	0.207
E	6.200	6.600	0.253	0.269
E1	4.300	4.500	0.176	0.184
e	0.650 typ.		0.0256 typ.	
L1	1.000 ref.		0.0393 ref.	
L	0.450	0.750	0.018	0.031
θ	0°	8°	0°	8°

Package Outlines (continued)

SO14



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	1.450	1.850	0.059	0.076
A1	0.100	0.300	0.004	0.012
A2	1.350	1.550	0.055	0.063
A3	0.550	0.750	0.022	0.031
b	0.406 typ.		0.017 typ.	
C	0.203 typ.		0.008 typ.	
D	8.630	8.830	0.352	0.360
E	5.840	6.240	0.238	0.255
E1	3.850	4.050	0.157	0.165
e	1.270 typ.		0.050 typ.	
L1	1.040 ref.		0.041 ref.	
L	0.350	0.750	0.014	0.031
θ	2°	8°	2°	8°