General Description

The LTC321H of single-channel amplifier provides input offset voltage correction for low offset (maximum 600 µV) and drift (1 µV/℃) through the use of proprietary techniques. Featuring rail-to-rail input and output swings, and low quiescent current (typical 90 µA) combined with a wide bandwidth of 1.2 MHz and very low noise (30 nV/√Hz at 1 kHz) makes this family very attractive for a variety of battery-powered applications such as handsets, tablets, notebooks, and portable medical devices. The low input bias current supports these amplifiers to be used in applications with mega-ohm source impedances.

The robust design of the LTC321H amplifier provides ease-of-use to the circuit designer: unity-gain stability with capacitive loads of up to 500 pF, integrated RF/EMI rejection filter, no phase reversal in overdrive conditions, and high electro-static discharge (ESD) protection (4-kV HBM).

The LTC321H amplifier is optimized for operation at voltages as low as +1.8 V (±0.9 V) and up to +5.5 V (±2.75 V) at the temperature range of 0 ℃ to 70 ℃, and operation at voltages from +2.0 V (±1.0 V) to +5.5 V (±2.75 V) over the extended temperature range of −40 ℃ to +125 ℃.

The LTC321H is available in both SOT23-5 and SC70-5 packages.

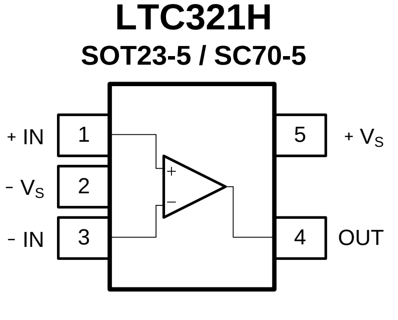
Features and Benefits

- 1.2 MHz GBW for Unity-Gain Stable
- Precision: ±600 µV Maximum Input Offset Voltage
- Low Noise: 30 nV/√Hz at 1 kHz
- Micro-Power: 90 µA Supply Current Per Amplifier
- Single 1.8 V to 5.5 V Supply Voltage Range at 0 ℃ to 70 ℃
- Rail-to-Rail Input and Output
- Internal RF/EMI Filter
- Extended Temperature Range: −40℃ to +125℃

Applications

- Battery-Powered Instruments:
  - Consumer, Industrial, Medical, Notebooks
- Wireless Charger
- Audio Outputs
- Sensor Signal Conditioning:
  - Sensor Interfaces, Loop-Powered, Active Filters
- Wireless Sensors:
  - Home Security, Remote Sensing, Wireless Metering

Pin Configurations (Top View)



Pin Description

Symbol	Description
–IN	Inverting input of the amplifier. The voltage range is from (V_{S-} – 0.1V) to (V_{S+} + 0.1V).
+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 2.0V to 5.5V. Split supplies are possible as long as the voltage between V_{S+} and V_{S-} is from 2.0V to 5.5V.
$-V_S$	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 2.0V to 5.5V.
OUT	Amplifier output.

Ordering Information

Type Number	Package Name	Package Quantity	Marking Code
LTC321HXT5/R6	SOT23-5	Tape and Reel, 3 000	321xxx
LTC321HXC5/R6	SC70-5	Tape and Reel, 3 000	321xxx

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
Signal Input Terminals: Voltage, Current	V_{S-} – 0.5V to V_{S+} + 0.5V, ±20mA
Output Short-Circuit	Continuous
Storage Temperature Range	–65℃ to +150℃
Junction Temperature	150℃
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
OFFSET VOLTAGE						
V_{OS}	Input offset voltage			±200	±600	µV
V_{OS} TC	Offset voltage drift	T_A = −40 to +125 ℃		±1	**3.5**	µV/℃
PSRR	Power supply rejection ratio	V_S = 2.0 to 5.5 V, V_{CM} < V_{S+} − 2V	80	110		dB
		T_A = −40 to +125 ℃	**75**			
INPUT BIAS CURRENT						
I_B	Input bias current			1		pA
		T_A = +85 ℃		150		
		T_A = +125 ℃		500		
I_{OS}	Input offset current			5		pA
NOISE						
V_n	Input voltage noise	f = 0.1 to 10 Hz		6		$µV_{P-P}$
e_n	Input voltage noise density	f = 10 kHz		27		nV/√Hz
		f = 1 kHz		30		
I_n	Input current noise density	f = 1 kHz		10		fA/√Hz
INPUT VOLTAGE						
V_{CM}	Common-mode voltage range		V_{S-}−0.1		V_{S+}+0.1	V
CMRR	Common-mode rejection ratio	V_S = 5.5 V, V_{CM} = −0.1 to 5.6 V	78	92		dB
		V_{CM} = 0 to 5.3 V, T_A = −40 to +125 ℃	**72**			
		V_S = 2.0 V, V_{CM} = −0.1 to 2.1 V	72	83		
		V_{CM} = 0 to 1.8 V, T_A = −40 to +125 ℃	**66**			
INPUT IMPEDANCE						
C_{IN}	Input capacitance	Differential		2.0		pF
		Common mode		3.5		
OPEN-LOOP GAIN						
A_{VOL}	Open-loop voltage gain	R_L = 50 kΩ, V_O = 0.05 to 3.5 V	90	105		dB
		T_A = −40 to +125 ℃	**85**			
		R_L = 2 kΩ, V_O = 0.15 to 3.5 V	85	100		
		T_A = −40 to +125 ℃	**80**			
FREQUENCY RESPONSE						
GBW	Gain bandwidth product			1.2		MHz
SR	Slew rate	G = +1, C_L = 100 pF, V_O = 1.5 to 3.5 V		1		V/µs
THD+N	Total harmonic distortion + noise	G = +1, f = 1 kHz, V_O = 1 V_{RMS}		0.005		%
t_S	Settling time	To 0.1%, G = +1, 1V step		1.5		µs
		To 0.01%, G = +1, 1V step		1.8		
t_{OR}	Overload recovery time	To 0.1%, V_{IN} * Gain > V_S		2.5		µs

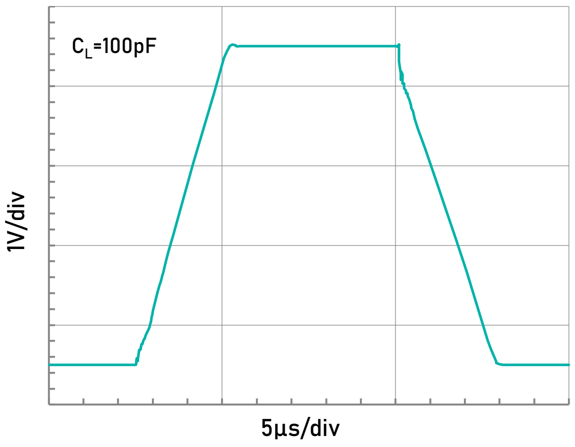
Electrical Characteristics (continued)

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 ℃.

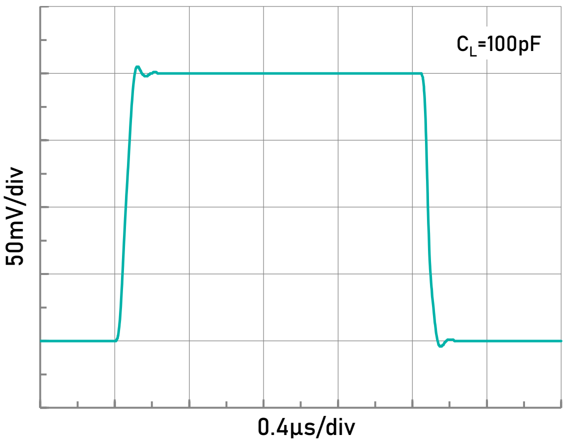
Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
OUTPUT						
V_{OH}	High output voltage swing	R_L = 50 kΩ	V_{S+}−6	V_{S+}−3		mV
		R_L = 2 kΩ	V_{S+}−100	V_{S+}−65		
V_{OL}	Low output voltage swing	R_L = 50 kΩ		V_{S-}+2	V_{S-}+4	mV
		R_L = 2 kΩ		V_{S-}+42	V_{S-}+65	
I_{SC}	Short-circuit current	Source current through 10Ω		40		mA
		Sink current through 10Ω		50		
POWER SUPPLY						
V_S	Operating supply voltage	T_A = 0 to +70 ℃	1.8		5.5	V
		T_A = −40 to +125 ℃	**2.0**		**5.5**	
I_Q	Quiescent current (per amplifier)			90	135	μA
		T_A = −40 to +125 ℃			**170**	
THERMAL CHARACTERISTICS						
T_A	Operating temperature range		−40		+125	℃
$θ_{JA}$	Package Thermal Resistance	SC70-5		333		℃/W
		SOT23-5		190		

Typical Performance Characteristics

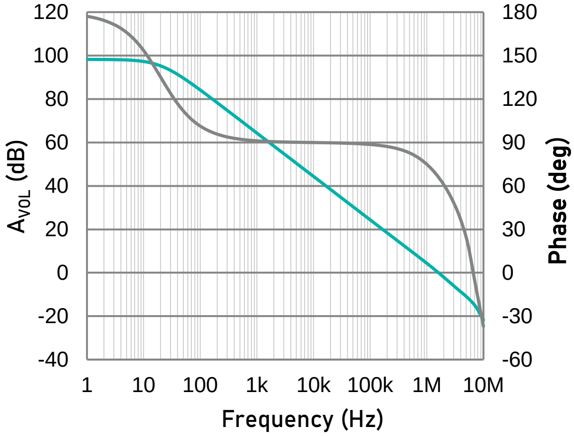
At T_A = +25°C, V_{CM} = V_S/2, and R_L = 10kΩ connected to V_S/2, unless otherwise noted.



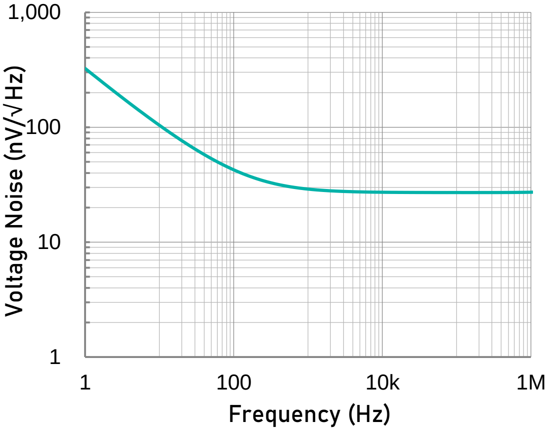
Large Signal Step Response.



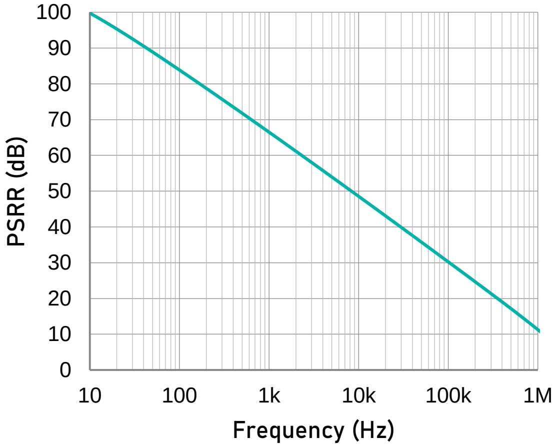
Small Signal Step Response.



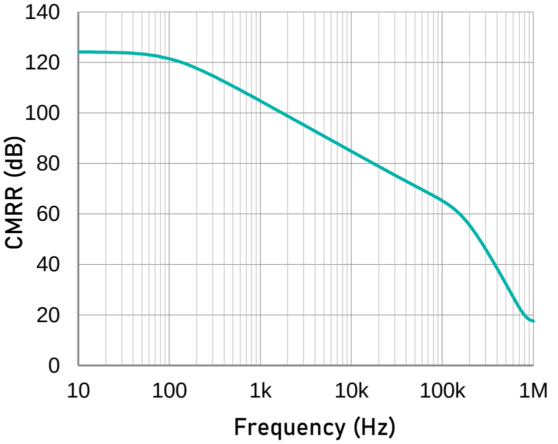
Open-loop Gain and Phase as a function of Frequency.



Input Voltage Noise Spectral Density as a function of Frequency.



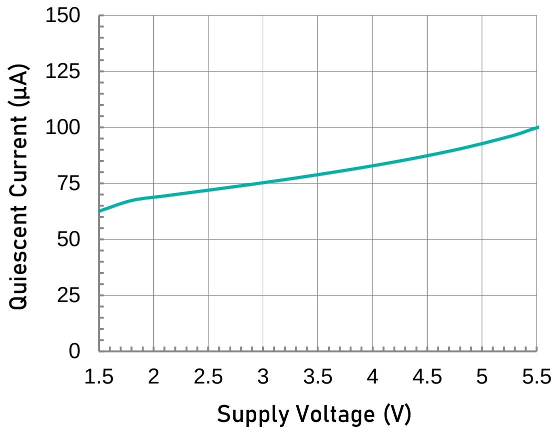
Power Supply Rejection Ratio as a function of Frequency.



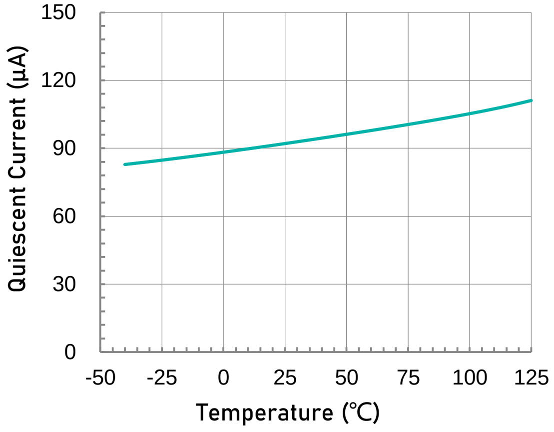
Common-mode Rejection Ratio as a function of Frequency.

Typical Performance Characteristics (continued)

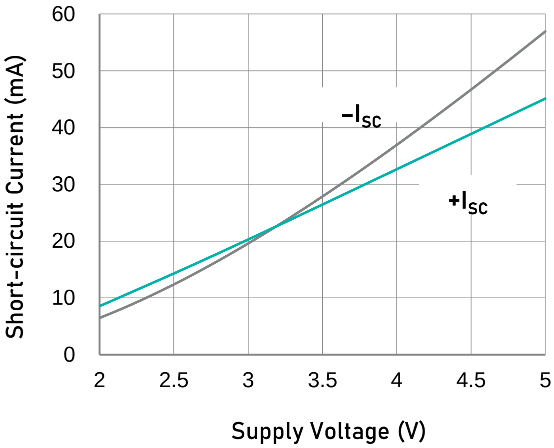
At T_A = +25℃, V_{CM} = V_S/2, and R_L = 10kΩ connected to V_S/2, unless otherwise noted.



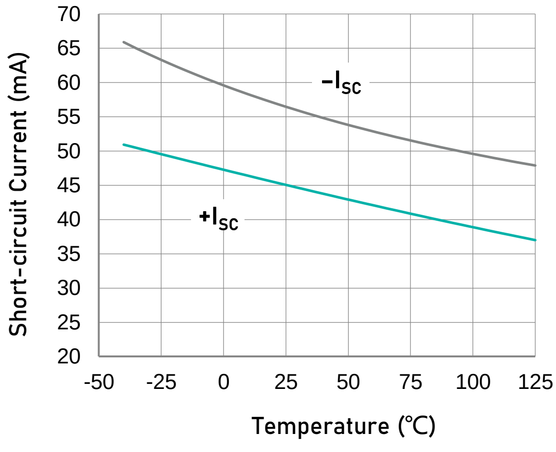
Quiescent Current as a function of Supply Voltage.



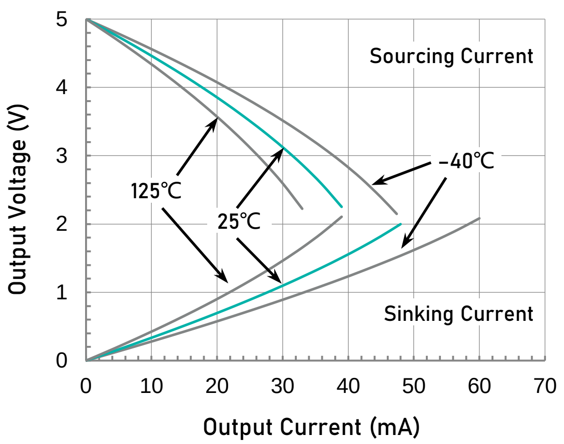
Quiescent Current as a function of Temperature.



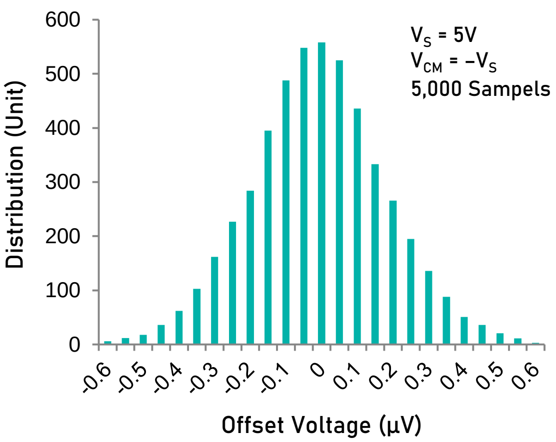
Short-circuit Current as a function of Supply Voltage.



Short-circuit Current as a function of Temperature.



Output Voltage Swing as a function of Output Current.



Offset Voltage Production Distribution

Application Notes

LOW INPUT BIAS CURRENT

The LTC321H device is a CMOS op-amp and features very low input offset voltage and input bias current. 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 LTC321H's input bias current at +25℃ (±1pA, 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.

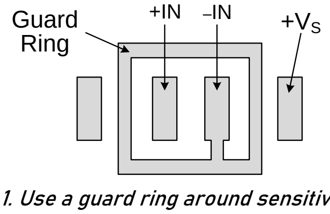


Figure 1. Use a guard ring around sensitive pins

GROUND SENSING AND RAIL TO RAIL

The input common-mode voltage range of the LTC321H amplifier extends 100mV 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-} – 0.1V) to (V_{S+} + 0.1V), the LTC321H op-amp 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.

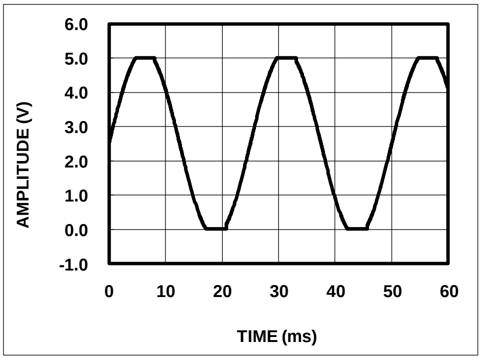


Figure 2. No Phase Inversion with Inputs Greater Than the Power-Supply Voltage

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 LTC321H can directly drive 500 pF 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.

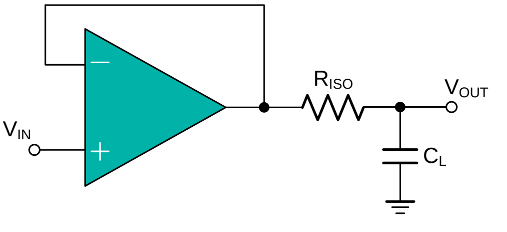


Figure 3. Indirectly Driving Heavy Capacitive Load

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)

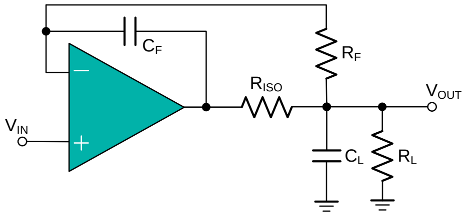


Figure 4. Indirectly Driving Heavy Capacitive Load with DC Accuracy

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 LTC321H amplifier operates from either a single +2.0V to +5.5V supply or dual ±1.0V to ±2.75V 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 LTC321H 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

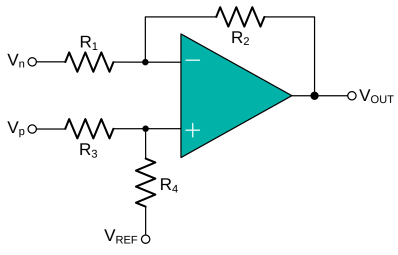
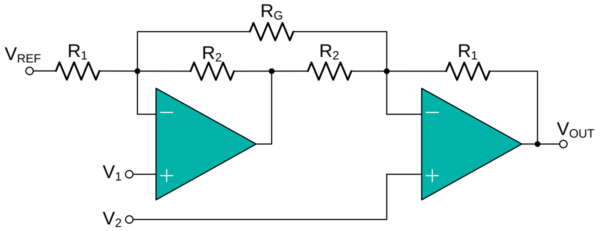


Figure 5. Differential Amplifier

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

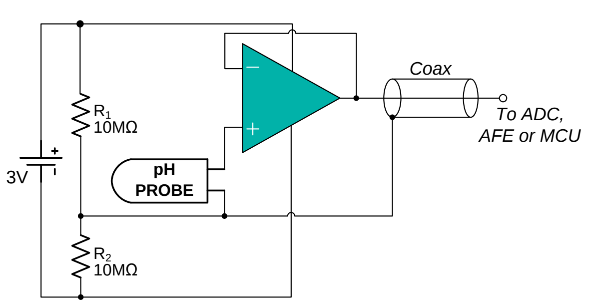


$$V_{OUT} = (V_1 - V_2)(1 + \frac{R_1}{R_2} + \frac{2R_1}{R_G}) + V_{REF}$$

Figure 6. Instrumentation Amplifier

The LTC321H amplifier is well suited for conditioning sensor signals in battery-powered applications. Figure 6 shows a two op-amp instrumentation amplifier, using the LTC321H op-amp. 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 LTC321H amplifier 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 LTC321H 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 $2\pi f V_{PP}$ 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.

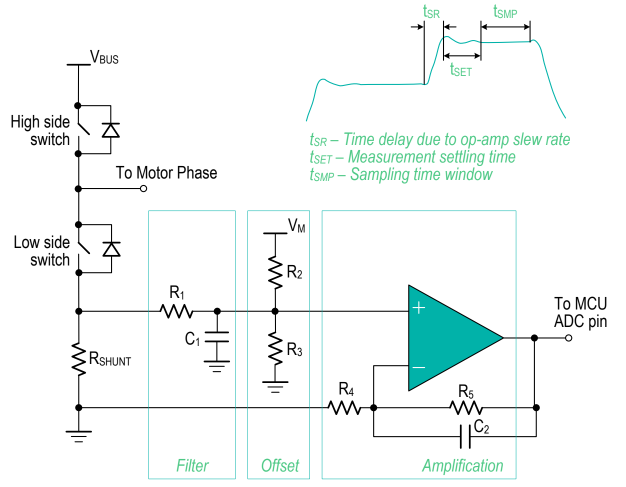
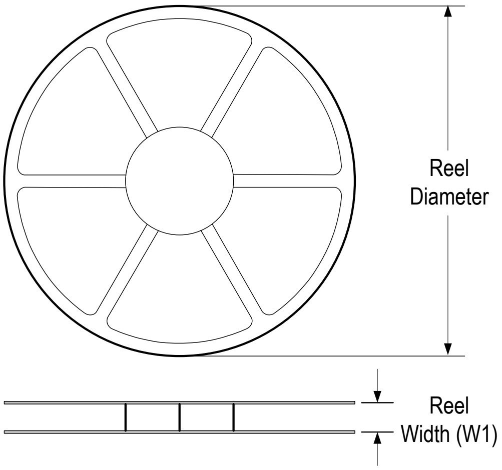


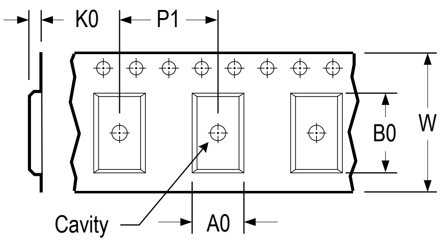
Figure 8. Current Shunt Monitor Circuit

Tape and Reel Information

REEL DIMENSIONS

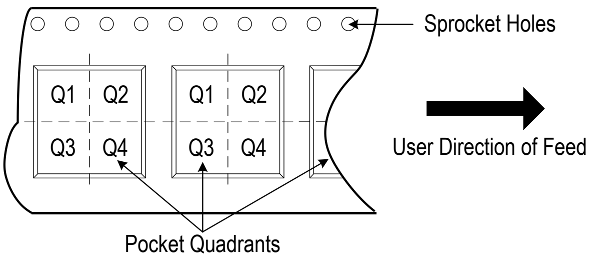


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

QUADRANT ASSIGNMENTS FOR PIN 1 ORIETATION IN TAPE

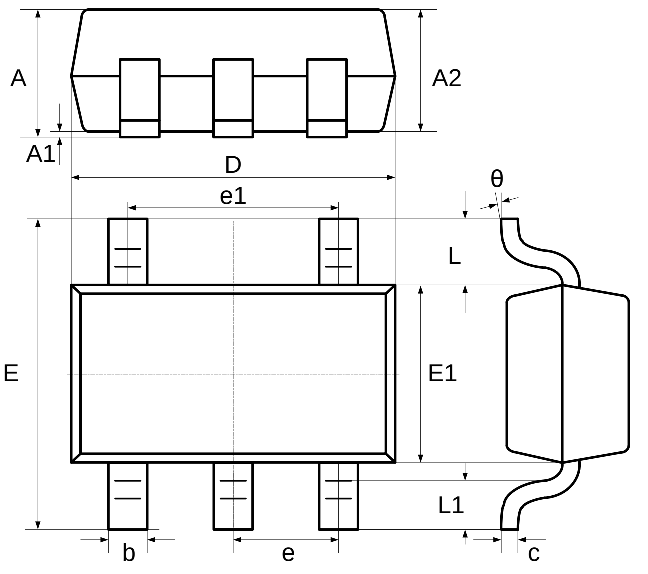


* All dimensions are nominal

Device	Package Type	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin 1 Quadrant
LTC321HXT5/R6	SOT23	5	3 000	178	9.0	3.3	3.2	1.5	4.0	8.0	Q3

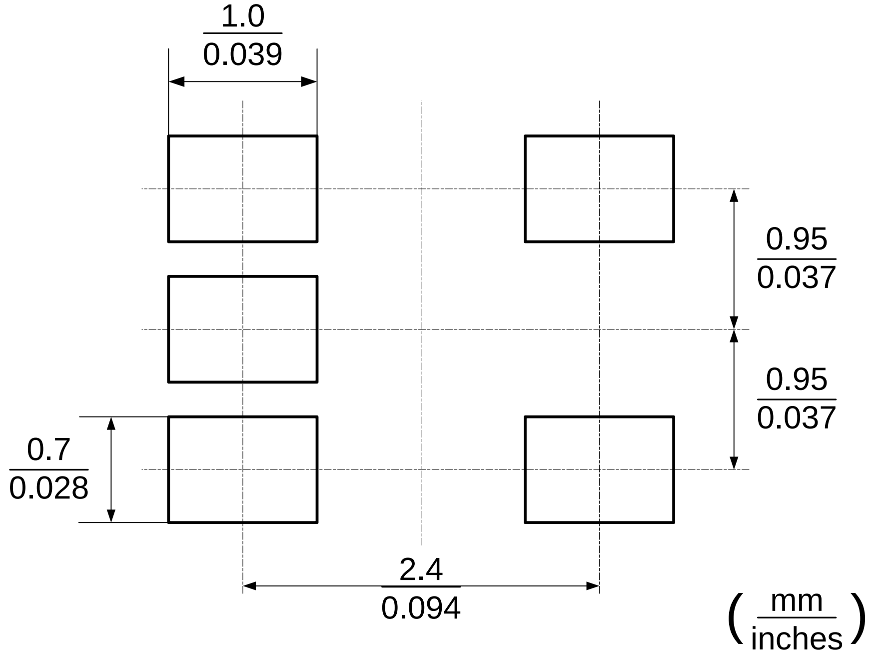
Package Outlines

DIMENSIONS, SOT23-5



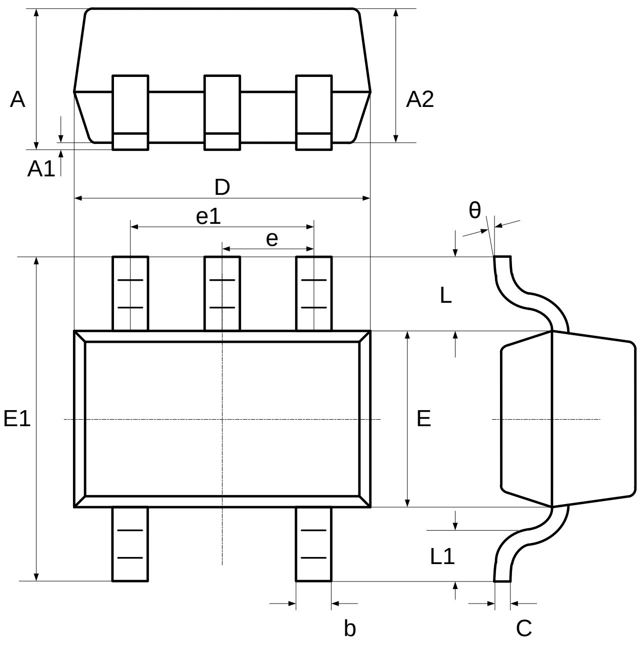
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	-	1.35	-	0.053
A1	0.00	0.15	0.000	0.006
A2	1.00	1.20	0.039	0.047
b	0.35	0.45	0.014	0.018
c	0.14	0.20	0.006	0.008
D	2.82	3.02	0.111	0.119
E1	1.526	1.726	0.060	0.068
E	2.60	3.00	0.102	0.118
e	0.95 BSC		0.037 BSC	
e1	1.90 BSC		0.075 BSC	
L	0.60 REF		0.024 REF	
L1	0.30	0.60	0.012	0.024
θ	0°	8°	0°	8°

RECOMMENDED SOLDERING FOOTPRINT, SOT23-5



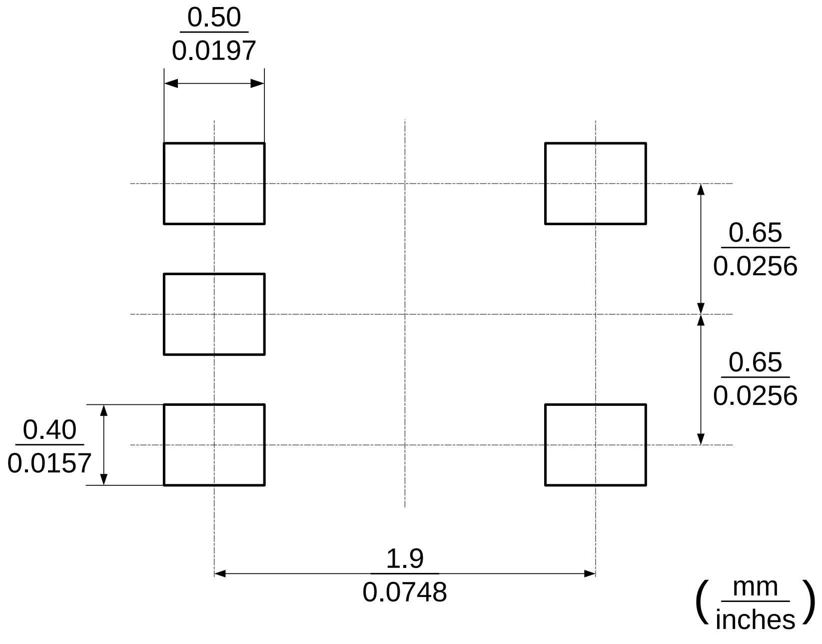
Package Outlines (continued)

DIMENSIONS, SC70-5 (SOT353)



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.90	1.10	0.035	0.043
A1	0.00	0.10	0.000	0.004
A2	0.90	1.00	0.035	0.039
b	0.15	0.35	0.006	0.014
C	0.08	0.15	0.003	0.006
D	2.00	2.20	0.079	0.087
E	1.15	1.35	0.045	0.053
E1	2.15	2.45	0.085	0.096
e	0.65 typ.		0.026 typ.	
e1	1.20	1.40	0.047	0.055
L	0.525 ref.		0.021 ref.	
L1	0.26	0.46	0.010	0.018
θ	0°	8°	0°	8°

RECOMMENDED SOLDERING FOOTPRINT, SC70-5 (SOT353)



IMPORTANT NOTICE

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