19-2048; Rev 0; 4/01

MAXIM

# Low-Cost, SC70, Voltage-Output, High-Side Current-Sense Amplifier



## General Description

The MAX4073 low-cost, high-side current-sense amplifier features a voltage output that eliminates the need for gain-setting resistors making it ideal for cell phones, notebook computers, PDAs, and other systems where current monitoring is crucial. High-side current monitoring does not interfere with the ground path of the battery charger making the MAX4073 particularly useful in battery-powered systems. The input common-mode range of +2V to +28V is independent of the supply voltage. The MAX4073's wide 1.8MHz bandwidth makes it suitable for use inside battery-charger control loops.

The combination of three gain versions and a selectable external-sense resistor sets the full-scale current reading. The MAX4073 offers a high level of integration, resulting in a simple and compact current-sense solution.

The MAX4073 operates from a +3V to +28V single supply and draws only 0.5mA of supply current. This device is specified over the automotive operating temperature range (-40°C to +125°C) and is available in a space-saving 5-pin SC70 package (half the size of the SOT23).

For a similar device in a 6-pin SOT23 with a wider common-mode voltage range (0 to +28V), see the MAX4173 data sheet.

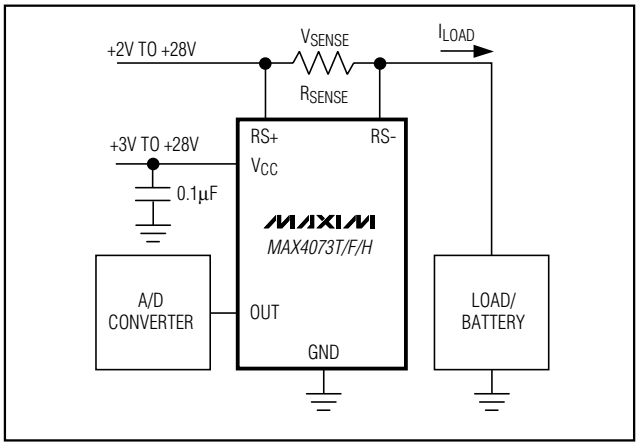
## Applications

Cell Phones
Notebook Computers
Portable/Battery-Powered Systems
Smart Battery Packs/Chargers
PDAs
Power Management Systems
PA Bias Control
General System/Board-Level Current Monitoring
Precision Current Sources

## Features

- **Low-Cost, Compact, Current-Sense Solution**
- **Three Gain Versions Available**
  **+20V/V (MAX4073T)**
  **+50V/V (MAX4073F)**
  **+100V/V (MAX4073H)**
- **±1.0% Full-Scale Accuracy**
- **500µA Supply Current**
- **Wide 1.8MHz Bandwidth**
- **+3V to +28V Operating Supply**
- **Wide +2V to +28V Common-Mode Range Independent of Supply Voltage**
- **Automotive Temperature Range (-40°C to +125°C)**
- **Available in Space-Saving 5-Pin SC70 Package**

## Typical Operating Circuit




***Pin Configurations appear at end of data sheet.***

## Ordering Information

| PART | TEMP. RANGE | PIN-PACKAGE | GAIN (V/V) | TOP MARK |
|---|---|---|---|---|
| **MAX4073T**AXK-T | -40°C to +125°C | 5 SC70-5 | 20 | ACM |
| MAX4073TAUT-T | -40°C to +125°C | 6 SOT23-6 | 20 | AAUE |
| **MAX4073F**AXK-T | -40°C to +125°C | 5 SC70-5 | 50 | ACN |
| MAX4073FAUT-T | -40°C to +125°C | 6 SOT23-6 | 50 | AAUF |
| **MAX4073H**AXK-T | -40°C to +125°C | 5 SC70-5 | 100 | ACO |
| MAX4073HAUT-T | -40°C to +125°C | 6 SOT23-6 | 100 | AAUG |



***For pricing, delivery, and ordering information, please contact Maxim/Dallas Direct! at 1-888-629-4642, or visit Maxim's website at www.maxim-ic.com.***

# Low-Cost, SC70, Voltage-Output, High-Side Current-Sense Amplifier

## ABSOLUTE MAXIMUM RATINGS

$V_{CC}$ to GND .....-0.3V to +30V
RS+, RS- to GND .....-0.3V to +30V
OUT to GND .....-0.3V to ($V_{CC}$ + 0.3V)
Output Short-Circuit to GND .....Continuous
Differential Input Voltage ($V_{RS+}$ - $V_{RS-}$) .....±5V
Current Into Any Pin.....±20mA
Continuous Power Dissipation ($T_A$ = +70°C)
5-pin SC70 (derate 2.27mW/°C above +70°C).....200mW
6-pin SOT23 (derate 8.7mW/°C above +70°C).....696mW

Operating Temperature Range .....-40°C to +125°C
Junction Temperature.....+150°C
Storage Temperature Range .....-65°C to +150°C
Lead Temperature (soldering, 10s) .....+300°C

*Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

## ELECTRICAL CHARACTERISTICS

($V_{RS+}$ = +2V to +28V, $V_{SENSE}$ = ($V_{RS+}$ - $V_{RS-}$) = 0, $V_{CC}$ = +3V to +28V, $T_A$ = $T_{MIN}$ to $T_{MAX}$, unless otherwise noted. Typical values are at $T_A$ = +25°C.) (Note 1)

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| Operating Voltage Range | $V_{CC}$ | (Note 2) | | 3 | | 28 | V |
| Common-Mode Input Range | $V_{CMR}$ | (Note 3) | | 2 | | 28 | V |
| Common-Mode Rejection | CMR | $V_{SENSE}$ = 100mV, $V_{CC}$ = 12V | | | 90 | | dB |
| Supply Current | $I_{CC}$ | $V_{CC}$ = 28V | | | 0.5 | 1.2 | mA |
| Leakage Current | $I_{RS+}$/$I_{RS-}$ | $V_{CC}$ = 0, $V_{RS+}$ = 28V | | | 0.05 | 1 | µA |
| Input Bias Current | $I_{RS+}$ | | | | 20 | 60 | µA |
| | $I_{RS-}$ | | | | 40 | 120 | |
| Full-Scale Sense Voltage | $V_{SENSE}$ | $V_{SENSE}$ = ($V_{RS+}$ - $V_{RS-}$) | | | 150 | | mV |
| Total OUT Voltage Error (Note 4) | | $V_{SENSE}$ = 100mV, $V_{CC}$ = 12V, $V_{RS+}$ = 2V | | | ±1.0 | | % |
| | | $V_{SENSE}$ = 100mV, $V_{CC}$ = 12V, $V_{RS+}$ = 12V, $T_A$ = +25°C | | | ±1.0 | ±5.0 | |
| | | $V_{SENSE}$ = 100mV, $V_{CC}$ = 12V, $V_{RS+}$ = 12V, $T_A$ = $T_{MIN}$ to $T_{MAX}$ | | | | ±7.0 | |
| | | $V_{SENSE}$ = 100mV, $V_{CC}$ = 28V, $V_{RS+}$ = 28V, $T_A$ = +25°C | | | ±1.0 | ±5.0 | |
| | | $V_{SENSE}$ = 100mV, $V_{CC}$ = 28V, $V_{RS+}$ = 28V, $T_A$ = $T_{MIN}$ to $T_{MAX}$ | | | | ±8.5 | |
| | | $V_{SENSE}$ = 6.25mV (Note 5); $V_{CC}$ = 12V, $V_{RS+}$ = 12V | | | ±7.5 | | |
| Extrapolated Input Offset Voltage | $V_{OS}$ | $V_{CC}$ = $V_{RS+}$ = 12V, $V_{SENSE}$ > 10mV | | | 1.0 | | mV |
| OUT High Voltage | ($V_{CC}$ - $V_{OH}$) | $V_{SENSE}$ = 150mV | MAX4073T, $V_{CC}$ = 3V | | 0.8 | 1.2 | V |
| | | | MAX4073F, $V_{CC}$ = 7.5V | | | | |
| | | | MAX4073H, $V_{CC}$ = 15V | | | | |

## ELECTRICAL CHARACTERISTICS (continued)

($V_{RS+}$ = +2V to +28V, $V_{SENSE}$ = ($V_{RS+}$ - $V_{RS-}$) = 0, $V_{CC}$ = +3V to +28V, $T_A$ = $T_{MIN}$ to $T_{MAX}$, unless otherwise noted. Typical values are at $T_A$ = +25°C.) (Note 1)

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| Bandwidth | BW | $V_{CC}$ = 12V, $V_{RS+}$ = 12V, $C_{LOAD}$ = 5pF | MAX4073T, $V_{SENSE}$ = 100mV | | 1.8 | | MHz |
| | | | MAX4073F, $V_{SENSE}$ = 100mV | | 1.7 | | |
| | | | MAX4073H, $V_{SENSE}$ = 100mV | | 1.6 | | |
| | | | MAX4073T/F/H $V_{SENSE}$ = 6.25mV (Note 5) | | 600 | | kHz |
| Gain | AV | MAX4073T | | | 20 | | V/V |
| | | MAX4073F | | | 50 | | |
| | | MAX4073H | | | 100 | | |
| Gain Accuracy | ΔAV | $V_{CC}$ = 12V, $V_{RS+}$ = 12V, $V_{SENSE}$ = 10mV to 150mV, MAX4073T/F | $T_A$ = +25°C | | ±1.0 | ±4.5 | % |
| | | | $T_A$ = $T_{MIN}$ to $T_{MAX}$ | | | ±6.5 | |
| | | $V_{CC}$ = 12V, $V_{RS+}$ = 12V, $V_{SENSE}$ = 10mV to 100mV, MAX4073H | $T_A$ = +25°C | | ±1.0 | ±4.5 | |
| | | | $T_A$ = $T_{MIN}$ to $T_{MAX}$ | | | ±6.5 | |
| OUT Settling Time to 1% of Final Value | | $V_{CC}$ = 12V $V_{RS+}$ = 12V $C_{LOAD}$ = 5pF | $V_{SENSE}$ = 6.25mV to 100mV | | 400 | | ns |
| | | | $V_{SENSE}$ = 100mV to 6.25mV | | 800 | | |
| Output Resistance | ROUT | | | | 12 | | kΩ |
| Power-Supply Rejection Ratio | PSRR | $V_{CC}$ = 3V to 28V | $V_{SENSE}$ = 60mV, MAX4073T | 70 | 78 | | dB |
| | | | $V_{SENSE}$ = 24mV, MAX4073F | 70 | 85 | | |
| | | | $V_{SENSE}$ = 12mV, MAX4073H | 70 | 90 | | |
| Power-Up Time (Note 6) | | $C_{LOAD}$ = 5pF, $V_{SENSE}$ = 100mV | | | 5 | | µs |
| Saturation Recovery Time (Note 7) | | $V_{CC}$ = 12V, $V_{RS+}$ = 12V, $C_{LOAD}$ = 5pF | | | 5 | | µs |

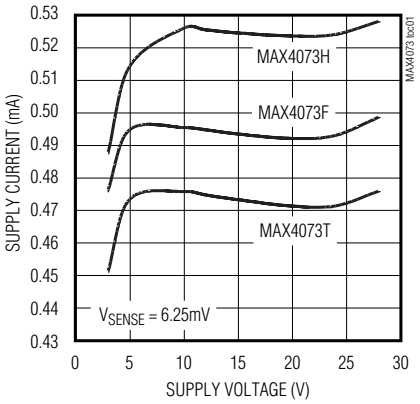
**Note 1:** All devices are 100% production tested at $T_A$ = +25°C. All temperature limits are guaranteed by design.
**Note 2:** Inferred from PSRR test.
**Note 3:** Inferred from OUT Voltage Error test.
**Note 4:** Total OUT Voltage Error is the sum of the gain and offset errors.
**Note 5:** 6.25mV = 1/16 of 100mV full-scale sense voltage.
**Note 6:** Output settles to within 1% of final value.
**Note 7:** The device will not experience phase reversal when overdriven.

# Low-Cost, SC70, Voltage-Output, High-Side Current-Sense Amplifier

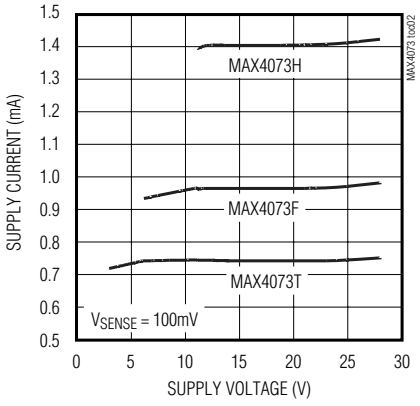
## Typical Operating Characteristics

($V_{CC}$ = +12V, $V_{RS+}$ = +12V, $V_{SENSE}$ = 100mV, $C_L$ = 5pF, $T_A$ = +25°C, unless otherwise noted.)

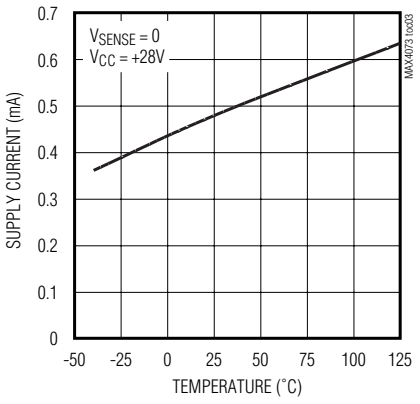
**SUPPLY CURRENT vs. SUPPLY VOLTAGE**



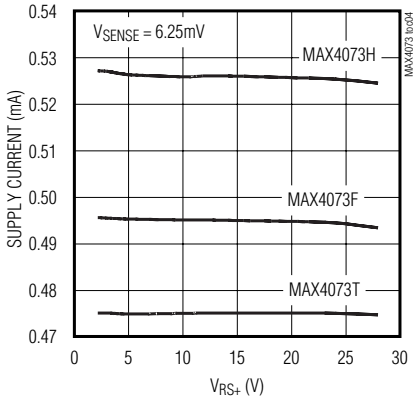

**SUPPLY CURRENT vs. SUPPLY VOLTAGE**



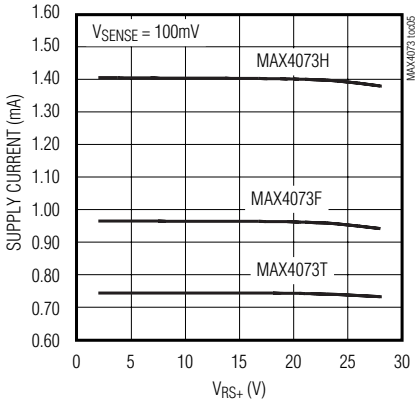

**SUPPLY CURRENT vs. TEMPERATURE**



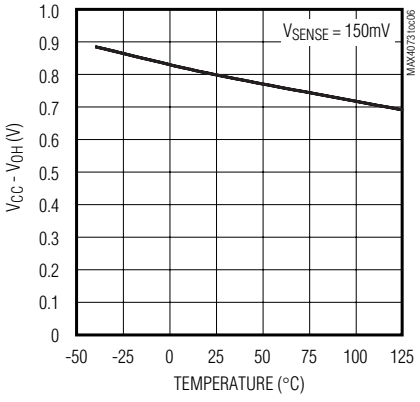

**SUPPLY CURRENT vs. $V_{RS+}$ VOLTAGE**



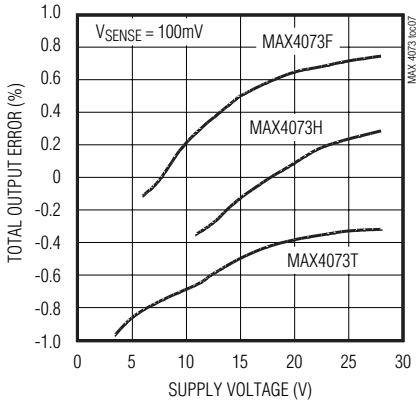

**SUPPLY CURRENT vs. $V_{RS+}$ VOLTAGE**



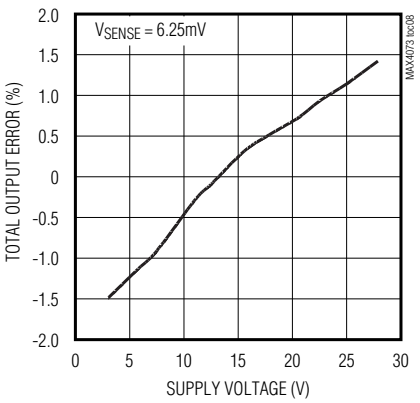

**OUTPUT HIGH VOLTAGE ($V_{CC}$ - $V_{OH}$) vs. TEMPERATURE**



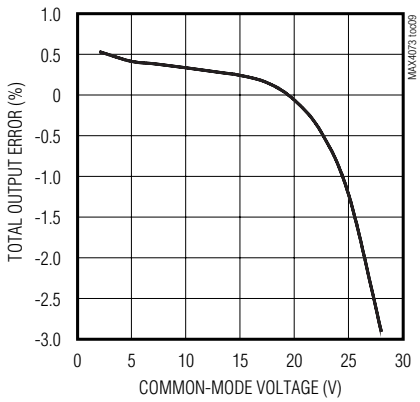

**TOTAL OUTPUT ERROR vs. SUPPLY VOLTAGE**




**TOTAL OUTPUT ERROR vs. SUPPLY VOLTAGE**



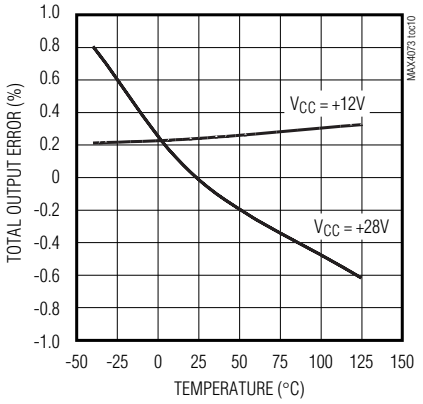

**TOTAL OUTPUT ERROR vs. COMMON-MODE VOLTAGE**



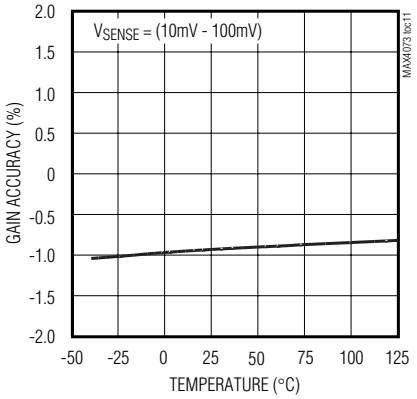
## Typical Operating Characteristics (continued)

($V_{CC}$ = +12V, $V_{RS+}$ = +12V, $V_{SENSE}$ = 100mV, $C_L$ = 5pF, $T_A$ = +25°C, unless otherwise noted.)

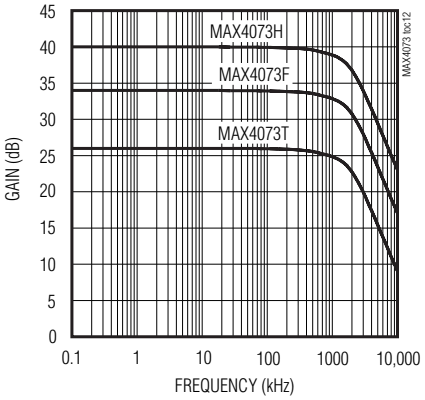
**TOTAL OUTPUT ERROR vs. TEMPERATURE**



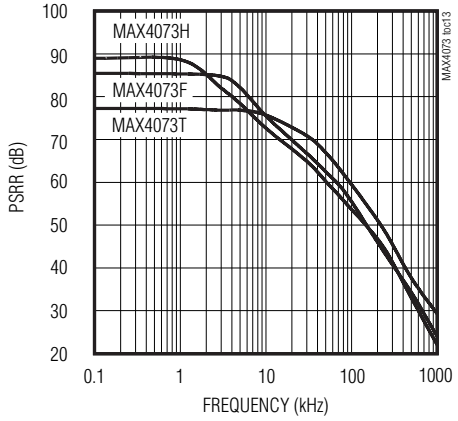

**GAIN ACCURACY vs. TEMPERATURE**



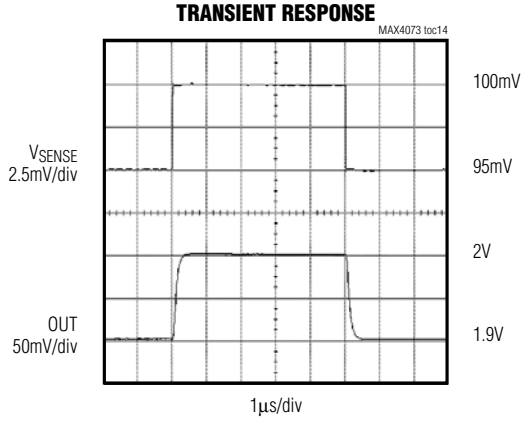

**SMALL-SIGNAL GAIN vs. FREQUENCY**



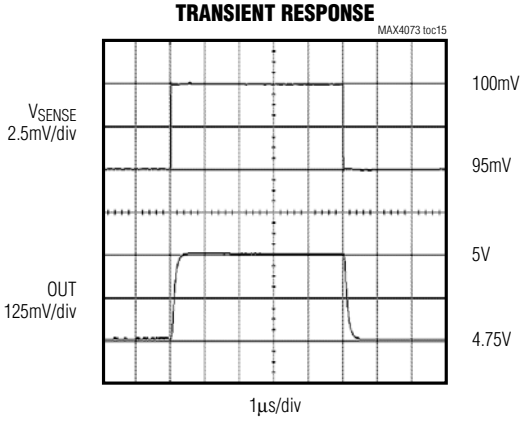

**POWER-SUPPLY REJECTION RATIO vs. FREQUENCY**



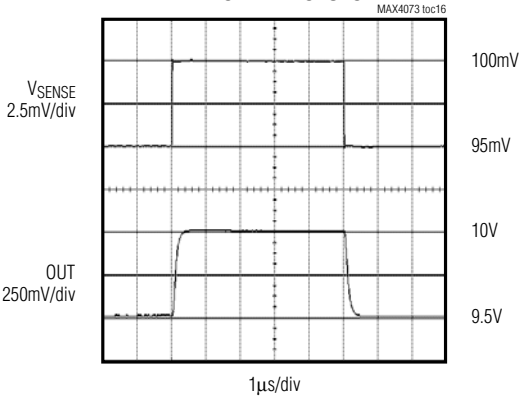

**MAX4073T SMALL-SIGNAL TRANSIENT RESPONSE**




**MAX4073F SMALL-SIGNAL TRANSIENT RESPONSE**




**MAX4073H SMALL-SIGNAL TRANSIENT RESPONSE**

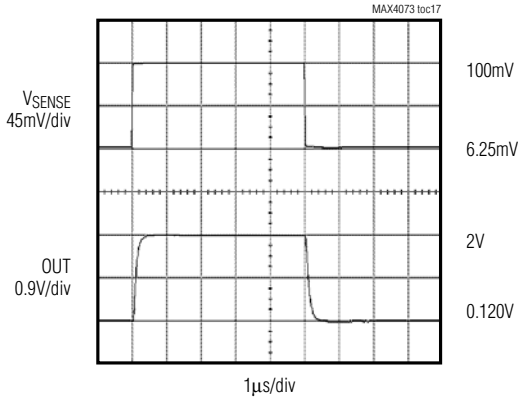


# Low-Cost, SC70, Voltage-Output, High-Side Current-Sense Amplifier

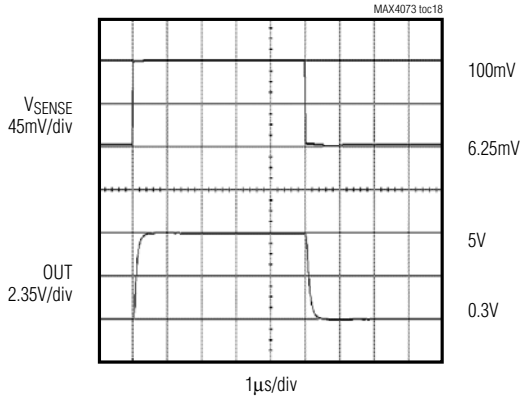
## Typical Operating Characteristics (continued)

($V_{CC}$ = +12V, $V_{RS+}$ = +12V, $V_{SENSE}$ = 100mV, $C_L$ = 5pF, $T_A$ = +25°C, unless otherwise noted.)

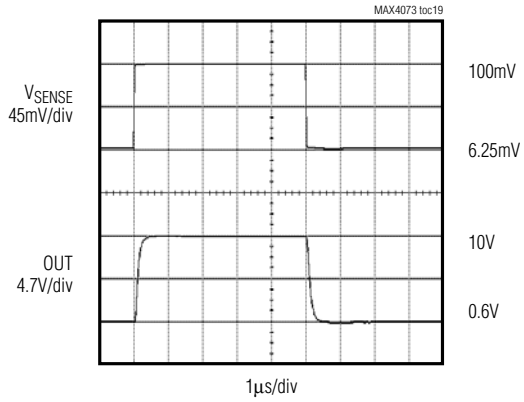
**MAX4073T LARGE-SIGNAL TRANSIENT RESPONSE**



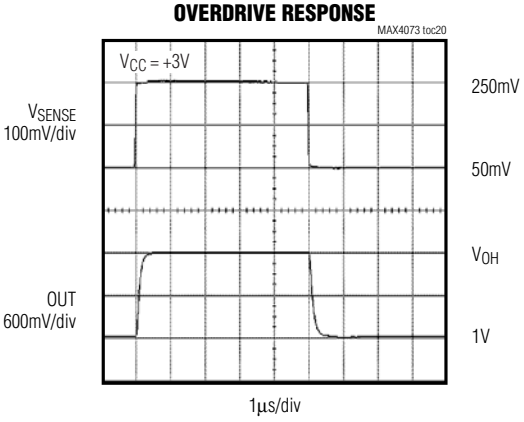

**MAX4073F LARGE-SIGNAL TRANSIENT RESPONSE**



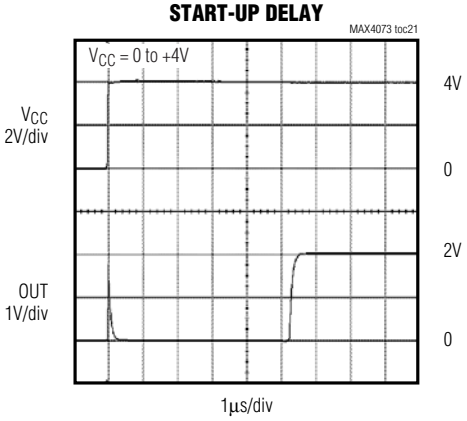

**MAX4073H LARGE-SIGNAL TRANSIENT RESPONSE**




**MAX4073T OVERDRIVE RESPONSE**




**MAX4073T START-UP DELAY**



## Pin Description

| PIN | | NAME | FUNCTION |
|---|---|---|---|
| SOT23-6 | SC70-5 | | |
| 1, 2 | 2 | GND | Ground |
| 3 | 3 | $V_{CC}$ | Supply Voltage Input. Bypass to GND with a 0.1µF capacitor. |
| 4 | 4 | RS+ | Power-Side Connection to the External Sense Resistor |
| 5 | 5 | RS- | Load-Side Connection to the External Sense Resistor |
| 6 | 1 | OUT | Voltage Output. $V_{OUT}$ is proportional to $V_{SENSE}$. Output impedance is approximately 12kΩ. |

## Detailed Description

The MAX4073 high-side current-sense amplifier features a +2V to +28V input common-mode range that is independent of supply voltage. This feature allows the monitoring of current out of a battery as low as +2V and also enables high-side current sensing at voltages greater than the supply voltage ($V_{CC}$).

The MAX4073 operates as follows: current from the source flows through $R_{SENSE}$ to the load (Figure 1). Since the internal-sense amplifier's inverting input has high impedance, negligible current flows through RG2 (neglecting the input bias current). Therefore, the sense amplifier's inverting-input voltage equals $V_{SOURCE}$ - ($I_{LOAD}$)($R_{SENSE}$). The amplifier's open-loop gain forces its noninverting input to the same voltage as the inverting input. Therefore, the drop across RG1 equals ($I_{LOAD}$)($R_{SENSE}$). Since $I_{RG1}$ flows through RG1, $I_{RG1}$ = ($I_{LOAD}$)($R_{SENSE}$) / RG1. The internal current mirror multiplies $I_{RG1}$ by a current gain factor, β, to give $I_{RGD}$ = β × $I_{RG1}$. Solving $I_{RGD}$ = β × ($I_{LOAD}$)($R_{SENSE}$) / RG1. Assuming infinite output impedance, $V_{OUT}$ = ($I_{RGD}$)(RGD). Substituting in for $I_{RGD}$ and rearranging, $V_{OUT}$ = β × (RGD / RG1)($R_{SENSE}$ × $I_{LOAD}$). The parts gain equals β × RGD / RG1. Therefore, $V_{OUT}$ = (GAIN) ($R_{SENSE}$) ($I_{LOAD}$), where GAIN = 20V/V for MAX4073T, GAIN = 50V/V for MAX4073F, and GAIN = 100V/V for MAX4073H.

Set the full-scale output range by selecting $R_{SENSE}$ and the appropriate gain version of the MAX4073.

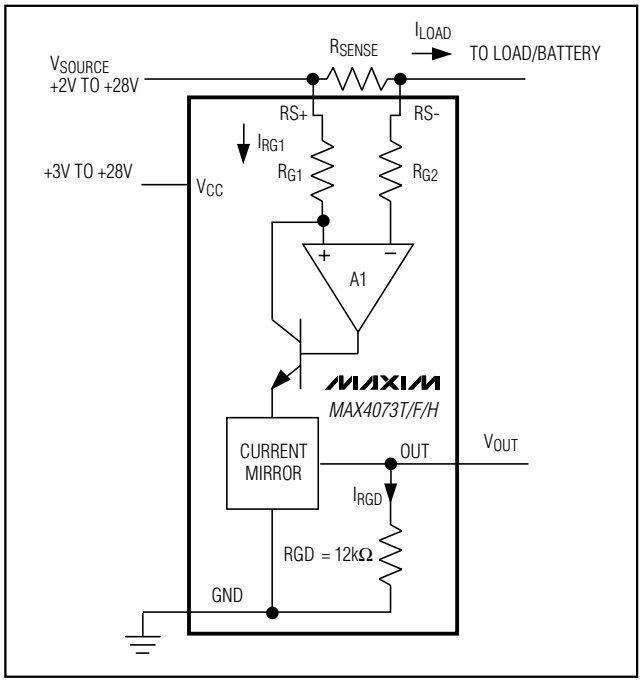



*Figure 1. Functional Diagram*

## Applications Information

### Recommended Component Values

The MAX4073 senses a wide variety of currents with different sense resistor values. Table 1 lists common resistor values for typical operation of the MAX4073.

### Choosing $R_{SENSE}$

To measure lower currents more accurately, use a large value for $R_{SENSE}$. The larger value develops a higher-sense voltage that reduces offset voltage errors of the internal op amp. Typical sense voltages range between 10mV and 150mV.

In applications monitoring very high currents, $R_{SENSE}$ must be able to dissipate the $I^2R$ losses. If the resistor's rated power dissipation is exceeded, its value may drift or it may fail altogether, causing a differential voltage across the terminals in excess of the absolute maximum ratings (±5V).

If $I_{SENSE}$ has a large high-frequency component, minimize the inductance of $R_{SENSE}$. Wire-wound resistors have the highest inductance, metal-film resistors are

# Low-Cost, SC70, Voltage-Output, High-Side Current-Sense Amplifier

somewhat better, and low-inductance metal-film resistors are best suited for these applications.

For $V_{SENSE}$ = 100mV, full-scale output voltage can be 2V, 5V, or 10V depending on the gain. For proper operation, ensure $V_{CC}$ exceeds the full-scale output voltage by 1.2V (see Output High Voltage ($V_{CC}$ - $V_{OH}$) vs. Temperature in the *Typical Operating Characteristics*).

### Using a PCB Trace as $R_{SENSE}$

If the cost of $R_{SENSE}$ is an issue and accuracy is not critical, use the alternative solution shown in Figure 2. This solution uses copper PC board traces to create a sense resistor. The resistivity of a 0.1-inch-wide trace of 2-ounce copper is approximately 30mΩ/ft. The resistance-temperature coefficient of copper is fairly high (approximately 0.4%/°C), so systems that experience a wide temperature variance must compensate for this effect. In addition, do not exceed the maximum power dissipation of the copper trace.

For example, the MAX4073T (with a maximum load current of 10A and an $R_{SENSE}$ of 5mΩ) creates a full-scale $V_{SENSE}$ of 50mV that yields a maximum $V_{OUT}$ of 1V. $R_{SENSE}$ in this case requires about 2 inches of 0.1 inch-wide copper trace.

### Output Impedance

The output of the MAX4073 is a current source driving a 12kΩ resistance. Resistive loading added to OUT reduces the output gain of the MAX4073. To minimize output errors for most applications, connect OUT to a high-impedance input stage. When output buffering is required, choose an op amp with a common-mode input range and an output voltage swing that includes ground when operating with a single supply. The op amp's supply voltage range should be at least as high as any voltage the system may encounter.

The percent error introduced by output loading is determined with the following formula:

$$\%_{ERROR} = 100\left(\frac{R_{LOAD}}{12k\Omega + R_{LOAD}} - 1\right)$$

where $R_{LOAD}$ is the external load applied to OUT.

### Current Source Circuit

Figure 3 shows a block diagram using the MAX4073 with a switching regulator to make a current source.

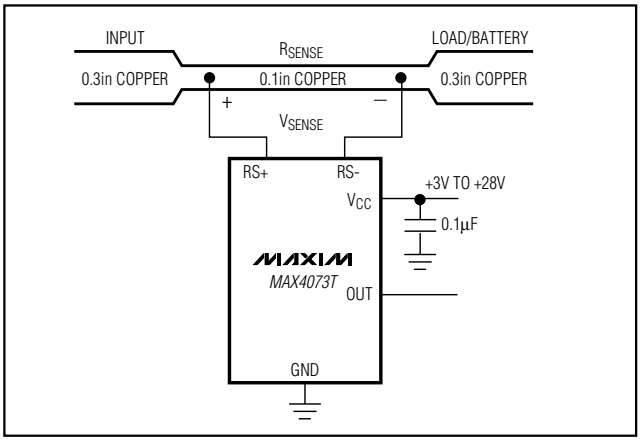



*Figure 2. MAX4073T Connections Showing Use of PC Board*

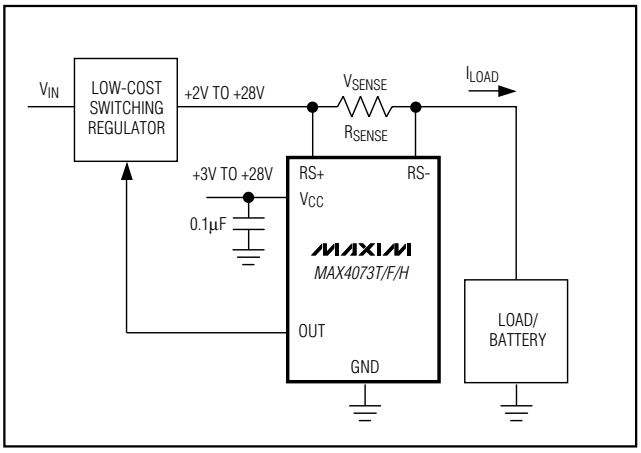
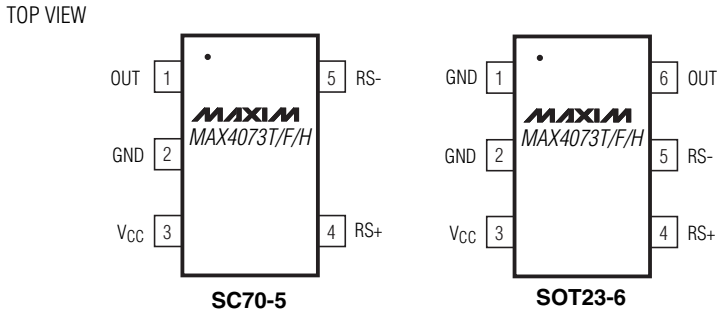



*Figure 3. Current Source*

**Table 1. Recommended Component Values**

| FULL-SCALE LOAD CURRENT $I_{LOAD}$ (A) | CURRENT-SENSE RESISTOR $R_{SENSE}$ (mΩ) | GAIN | FULL-SCALE OUTPUT VOLTAGE (FULL-SCALE $V_{SENSE}$ = 100mV) $V_{OUT}$ (V) |
|---|---|---|---|
| 0.1 | 1000 | 20 | 2.0 |
| | | 50 | 5.0 |
| | | 100 | 10.0 |
| 1 | 100 | 20 | 2.0 |
| | | 50 | 5.0 |
| | | 100 | 10.0 |
| 5 | 20 | 20 | 2.0 |
| | | 50 | 5.0 |
| | | 100 | 10.0 |
| 10 | 10 | 20 | 2.0 |
| | | 50 | 5.0 |
| | | 100 | 10.0 |

## Pin Configurations



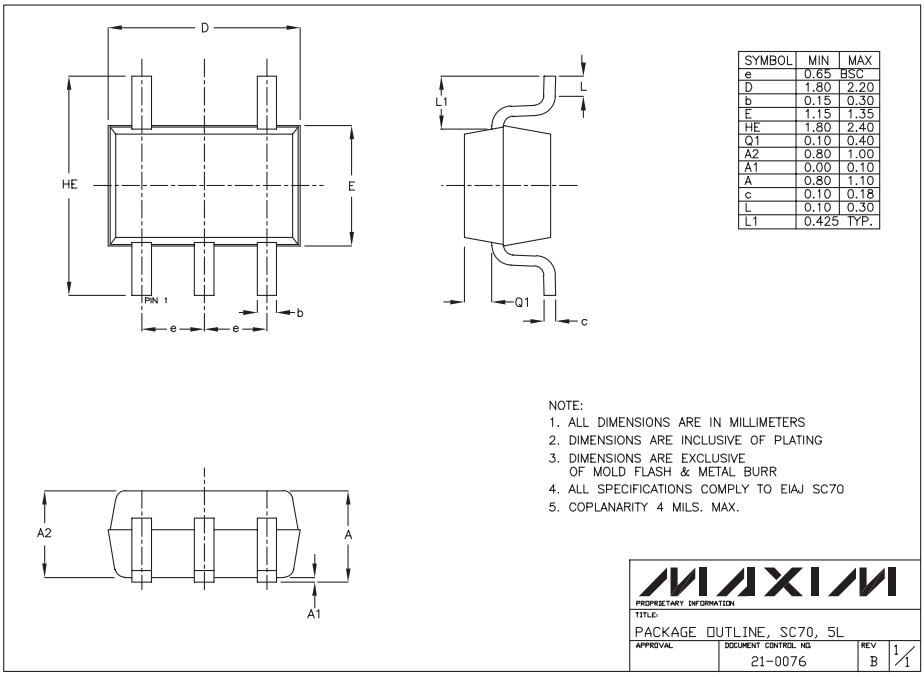

## Chip Information

TRANSISTOR COUNT: 187

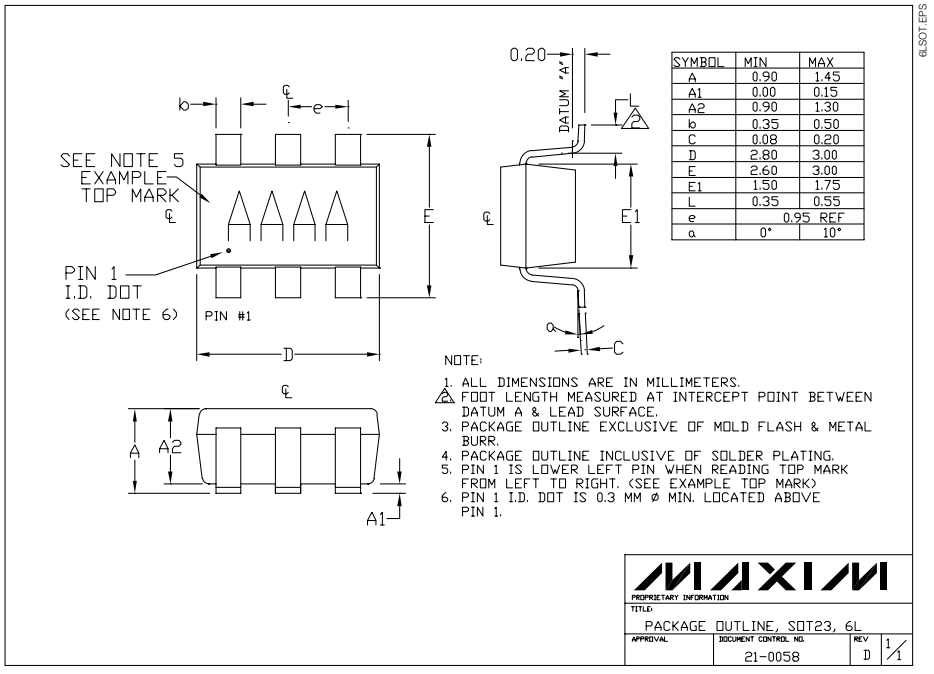
PROCESS: Bipolar

# Low-Cost, SC70, Voltage-Output, High-Side Current-Sense Amplifier

## Package Information




| SYMBOL | MIN | MAX |
|---|---|---|
| e | 0.65 | BSC |
| D | 1.80 | 2.20 |
| b | 0.15 | 0.30 |
| E | 1.15 | 1.35 |
| HE | 1.80 | 2.40 |
| Q1 | 0.10 | 0.40 |
| A2 | 0.80 | 1.00 |
| A1 | 0.00 | 0.10 |
| A | 0.80 | 1.10 |
| c | 0.10 | 0.18 |
| L | 0.10 | 0.30 |
| L1 | 0.425 | TYP. |




| SYMBOL | MIN | MAX |
|---|---|---|
| A | 0.90 | 1.45 |
| A1 | 0.00 | 0.15 |
| A2 | 0.90 | 1.30 |
| b | 0.35 | 0.50 |
| C | 0.08 | 0.20 |
| D | 2.80 | 3.00 |
| E | 2.60 | 3.00 |
| E1 | 1.50 | 1.75 |
| L | 0.35 | 0.55 |
| e | 0.95 REF | |
| α | 0° | 10° |

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