

# Low-Power, Bidirectional Current-Sensing Circuit



Chuck Sins

## Design Goals

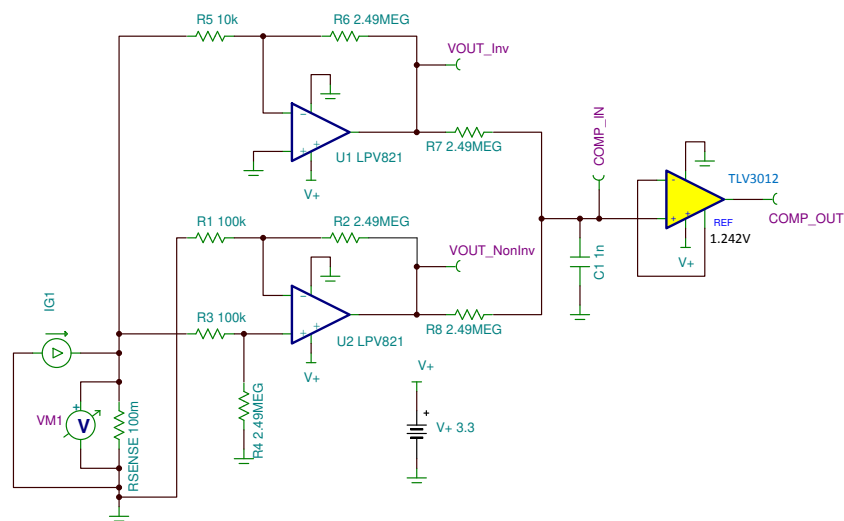
Overcurrent Levels		Supply	
$I_{IN} \text{ (min)}$	$I_{IN} \text{ (max)}$	V+	V–
–0.1A	1.0A	3.3V	0V

## Design Description

This low-power, low-side, bidirectional current sensing method uses two nano-power, zero-drift amplifiers (LPV821) and one micro-power comparator with an integrated, precision reference (TLV3012). This circuit is well-suited for battery powered devices where charging current and system current need to be monitored accurately. The gain of U1 and U2 are set independently.

As shown in the application circuit, the LPV821 amplifiers are connected out of phase across  $R_{SENSE}$  to amplify the currents of opposite polarity. Amplifier U2 linearly amplifies the charging (positive) current while amplifier U1 linearly amplifies the system (negative) current. When U2 is monitoring the positive current, U1 drives its output to ground. Similarly, U2 drives its output to ground when U1 monitors the negative current. The amplifier outputs are ORed together with resistors  $R_7$  and  $R_8$  while U1 or U2 provide the ground reference creating a single output voltage for the comparator to monitor.

If a regulated supply or reference is already available in the system, the TLV3012 can be replaced by a nano-power comparator such as the TLV7031. Moreover, if the charging current and system current have equal magnitudes, the gains of amplifier U1 and U2 can be set equal to each other. Even with the gains of the amplifiers being equal, ORing the amplifier outputs allows one comparator to detect overcurrent conditions for both charging and system current.



## Design Notes

1. To minimize errors, utilize precision resistors and set  $R_1 = R_3$ ,  $R_2 = R_4$ , and  $R_7 = R_8$ .
2. Select  $R_{SENSE}$  to minimize the voltage drop at max current and to reduce amplifier offset error when monitoring minimum current levels.
3. Select the amplifier gains so COMP\_IN reaches 1.242V when the charging and system currents reach critical levels and avoid operating the amplifiers outside of their linear range.

## Design Steps

1. Determine the transfer equation given  $R_1 = R_3$ ,  $R_2 = R_4$ , and  $R_7 = R_8$ .

Inverted Path:

$$\text{COMP\_IN} = -I_{G1} \times R_{SENSE} \times \left(-\frac{R_6}{R_5}\right) \times \left(\frac{R_8}{R_7 + R_8}\right)$$

Non-Inverted Path:

$$\text{COMP\_IN} = I_{G1} \times R_{SENSE} \times \left(\frac{R_4}{R_3 + R_4}\right) \times \left(\frac{R_1 + R_2}{R_1}\right) \times \left(\frac{R_7}{R_7 + R_8}\right)$$

2. Select the SENSE resistor value assuming a maximum voltage drop ( $V_{SENSE}$ ) of 100mV when charging at 1A and a minimum system current of 10mA.

$$R_{SENSE}(\text{max}) = \frac{V_{SENSE}(\text{max})}{I_{G1}(\text{max})} = \frac{100 \text{ mV}}{1\text{A}} = 100 \text{ m}\Omega$$

$$\text{with } I_{G1}(\text{min}) = 10\text{mA}, \quad V_{SENSE} = 10\text{mA} \times 100\text{m}\Omega = 1 \text{ mV} > V_{OS}(\text{max}) = 10 \mu\text{V}$$

3. Select ORing resistor  $R_7$  and  $R_8$  to generate COMP\_IN.
  - a. An equal attenuation factor of two is applied to the input of the comparator with  $R_7 = R_8$ . Choose large values to minimize current consumption from the output of the amplifiers.
  - b. Special care must be taken when validating the voltage at COMP\_IN. Since  $R_7$  and  $R_8$  are large impedance values, the input impedance of an oscilloscope probe or the input to a digital voltmeter can alter the measured voltage. Common probe and voltmeter input impedances are 10M $\Omega$  and this attenuates the signal measured.

$$R_7 = R_8 = 2.49\text{M}\Omega,$$

$$\text{COMP\_IN} = (V_{OUT\_Inv} \text{ or } V_{OUT\_NonInv}) \div 2$$

4. Select the amplifier gain such that COMP\_IN reaches 1.242V when the currents reach the critical threshold.

$$\text{Gain} = \frac{2 \times \text{Comparator REF}}{R_{SENSE} \times |I_{G1}(\text{max})|}$$

$$\text{Gain}(\text{Inv}) = \frac{2 \times 1.242}{0.1 \times (-0.1)} = \frac{(-R_6)}{R_5} \approx -249 \frac{\text{V}}{\text{V}}$$

$$\text{Gain}(\text{NonInv}) = \frac{2 \times 1.242}{0.1 \times 1.0} = \frac{R_4}{R_3 + R_4} \times \frac{R_1 + R_2}{R_1} \approx 24.9 \frac{\text{V}}{\text{V}}$$

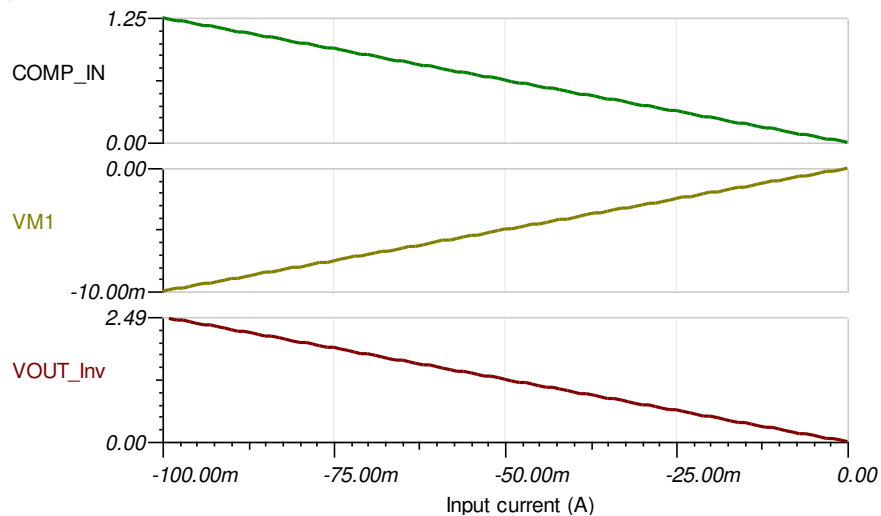
$$R_1 = R_3 = 100\text{k}\Omega \text{ (Standard Value)}$$

$$R_5 = 10\text{k}\Omega \text{ (Standard Value)}$$

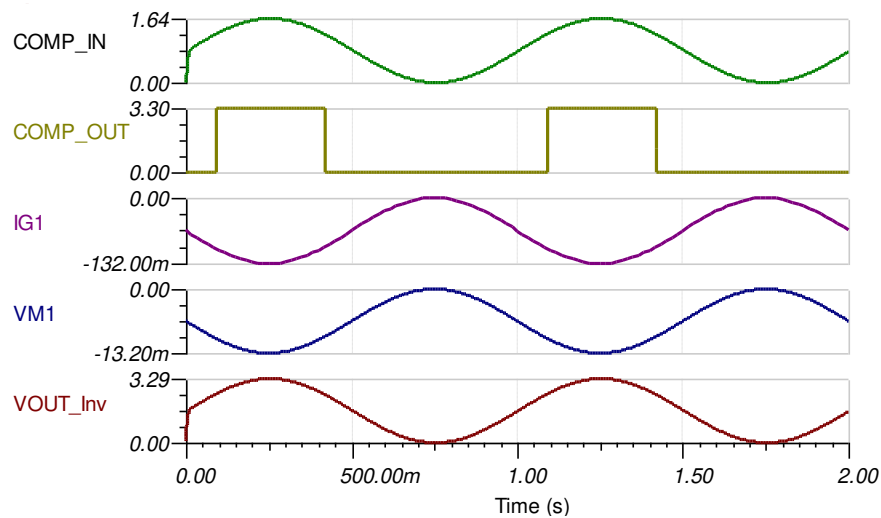
$$R_2 = R_4 = R_6 = 2.49\text{M}\Omega \text{ (Standard Value)}$$

## Design Simulations

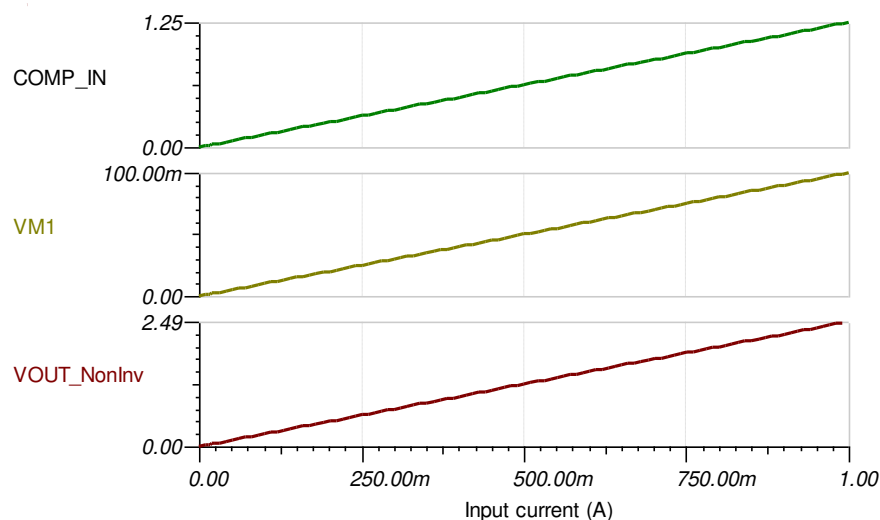
### DC Simulation Results (VOUT\_Inv)



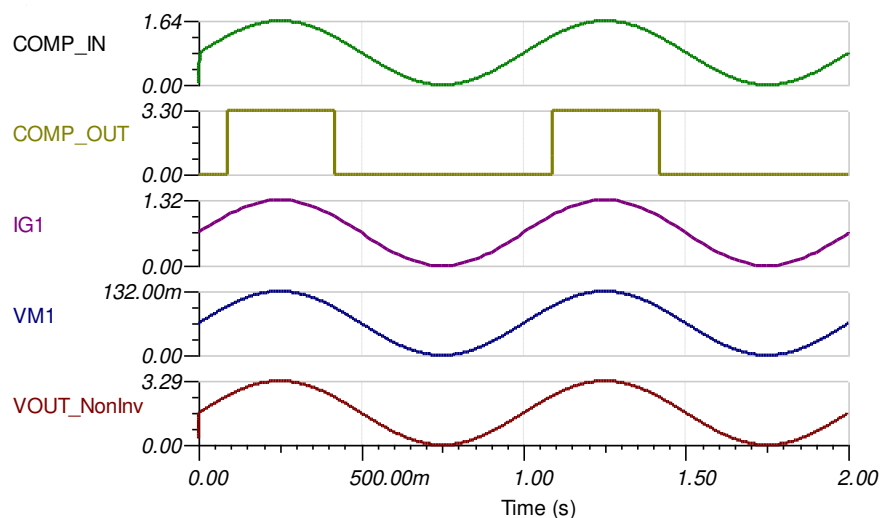
### Transient Simulation Results (VOUT\_Inv)



## DC Simulation Results (VOUT\_NonInv)



## Transient Simulation Results (VOUT\_NonInv)



## Tech Note and Blog References

Texas Instruments, [Advantages of Using Nanopower Zero Drift Amp for Mobile Phone Battery Monitoring](#), application note

Texas Instruments, [Current Sensing in No-Neutral Light Switches](#), technology brief

Texas Instruments, [GPIO Pins Power Signal Chain in Personal Electronics Running on Li-Ion Batteries](#), application brief

## Design Featured Op Amp

LPV821	
$V_S$	1.7V to 3.6V
Input $V_{CM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	1.5 $\mu$ V
$V_{os}$ Drift	20nV/ $^{\circ}$ C
$I_q$	650nA/Ch
$I_b$	7pA
UGBW	8kHz
#Channels	1
<a href="#">LPV821</a>	

## Design Alternate Op Amp

TLVx333	
$V_S$	1.8V to 5.5V
Input $V_{CM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	2 $\mu$ V
$V_{os}$ Drift	20nV/ $^{\circ}$ C
$I_q$	17 $\mu$ A/Ch
$I_b$	70pA
UGBW	350kHz
#Channels	1, 2, and 4
<a href="#">TLV333</a>	

## Trademarks

All trademarks are the property of their respective owners.

## Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (February 2019) to Revision B (October 2024)	Page
• Updated the format for tables, figures, and cross-references throughout the document.....	1

Changes from Revision * (March 2018) to Revision A (February 2019)	Page
• Changed title and changed title role to "Amplifiers" and added link to circuit cookbook landing page.....	1

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2024, Texas Instruments Incorporated