Nano-Power Transimpedance Amplifier (TIA)

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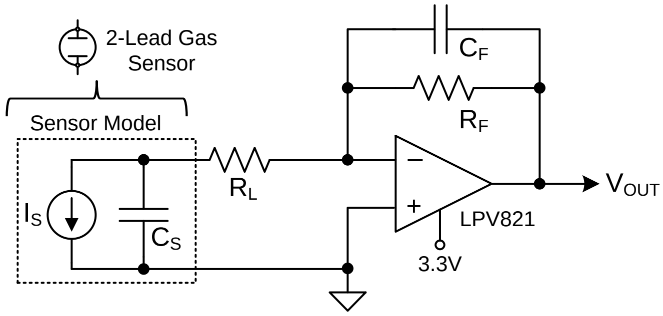
Design Goals

OVER CURRENT LEVELS		Signal Path Requirement	SUPPLY	
I_S (min)	I_S (max)	CL Bandwidth	V+	V–
50 nA	25 µA	> 1Hz	3.3V	0V

Design Description

The basic transimpedance circuit for amplifying and filtering the output current of a sensor is shown below. The transimpedance amplifier configuration converts the current of the sensor (I_S) to a voltage with a gain set by the feedback resistor R_F. The combination of R_F and C_F controls the closed loop bandwidth of the circuit by limiting the transimpedance gain at elevated frequencies, while the combination of current source I_S and capacitor C_S represents a simplified model for the sensor to be monitored. Typical sensor model values for C_S are in the mF range. R_L is a manufacturer recommended load resistance for the sensor and the value ranges from 10 to 100Ω. In addition to filtering noise, a minimum value for C_F is required for circuit stability.



An electrochemical gas sensor is a good example of a sensor that requires a transimpedance amplifier. The sensor transduces gas concentration levels (for example carbon monoxide (CO)) into current. The output current ranges from the 10's of nA's to 10's of µA's. Because electrochemical gas sensors are noisy, a low-pass filtering function is necessary to limit the noise bandwidth of the system before driving the input to a comparator and/or an analog-to-digital converter (ADC). Gas sensors typically have response times in the seconds range. So setting the circuit bandwidth to greater than 1Hz is appropriate.

Due to gas sensors' slow response to changes in gas concentration, a high bandwidth signal path is not required. Therefore, a precision, nano-power, low-bandwidth operational amplifier such as the LPV821 is selected. Another key aspect for this application is low input offset voltage on the operational amplifier to reduce dead-band in the amplifier output. Dead-band equates to the time when the sensor output is not recognized at the amplifier output. Voltage offset is bipolar in nature, with some devices having positive offset while others have negative. In the case of negative offset, changes in sensor output current can not be reliably seen until the negative offset voltage is overcome. Likewise, low offset voltage limits voltage shifts due to the internal resistance of the gas sensor. Lastly, low input bias current is important to minimize sensor measurement errors when measuring low gas concentration levels. The LPV821 is a zero-drift amplifier with 650 nA of quiescent current, µV's of input offset, nV's of offset drift over temperature, and pA's of input bias current.

Design Notes

1. Select gain resistor R_F such that the amplifier output remains within the linear range as specified by the amplifier open-gain (AOL) specification. For the LPV821, V_{OUT} must be limited to $V_{OUT} \leq (V+) - 0.1$ V.
2. Calculate the minimum C_F value where stability of the transimpedance amplifier circuit is ensured.
3. Select C_F such that the amplifier closed loop bandwidth is greater than 1Hz. For gas sensors, the response time of the sensor is typically 10 seconds, so choosing a bandwidth 10x faster will accommodate the sensor speed appropriately while still limiting sensor noise.

Design Steps

1. Select gain resistor R_F such that the max sensor current output of 25 µA does not cause the amplifier output (V_{OUT}) to exceed 3.2 V ((V+) - 0.1)

$$R_F < \frac{V_{OUT}(\max)}{I_S(\max)}$$

$$R_F < \frac{3.3 - 0.1}{25\mu} = 128\ \text{k}\Omega$$

$$\text{select } R_F = 127\ \text{k}\Omega$$

(closest real world value)

(1)

2. Calculate the minimum C_F for circuit stability using R_F = 127 kΩ, C_S = 1 mF, and LPV821 GBW = 8 kHz.

$$C_F > \frac{1}{4\pi R_F GBW} \times \left(1 + \sqrt{8\pi R_F C_S GBW}\right)$$

$$C_F > \frac{1}{4\pi(127k)(8k)} \times \left(1 + \sqrt{8\pi(127k)(1m)(8k)}\right)$$

$$C_F > 400\ \text{nF}$$

$$\text{select } C_F = 1\ \mu\text{F}$$

(guarantee circuit stability)

(2)

3. Test low-pass frequency pole value (f_P) using R_F = 127 k and C_F = 1 µF to make sure it is greater than 1 Hz. If f_P is lower than 1 Hz, reduce the value of C_F to the minimum allowable C_F value from Equation 2. However, if the minimum C_F value does not meet the target circuit bandwidth, the gain setting R_F value will need to be reduced or an amplifier with higher GBW will need to be selected.

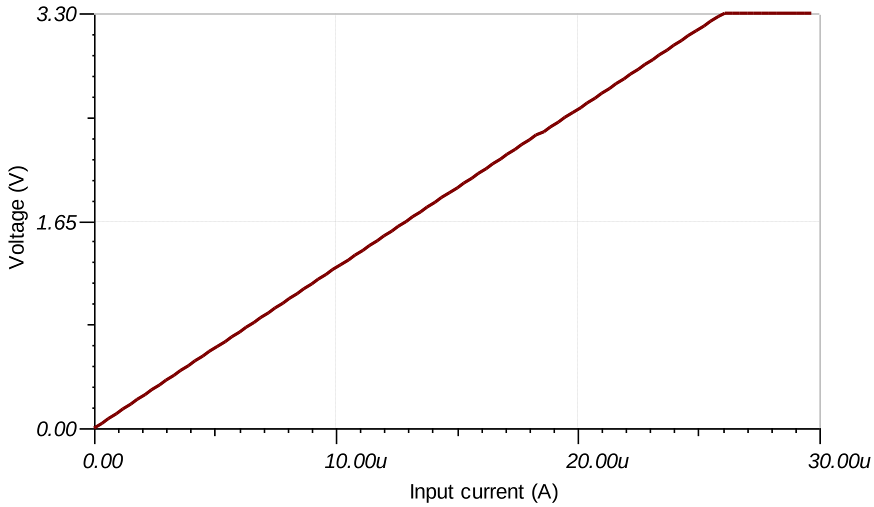
$$f_P = \frac{1}{2\pi R_F C_F}$$

$$f_P = \frac{1}{2\pi(127k)(1\mu)} = 1.25\ \text{Hz}$$

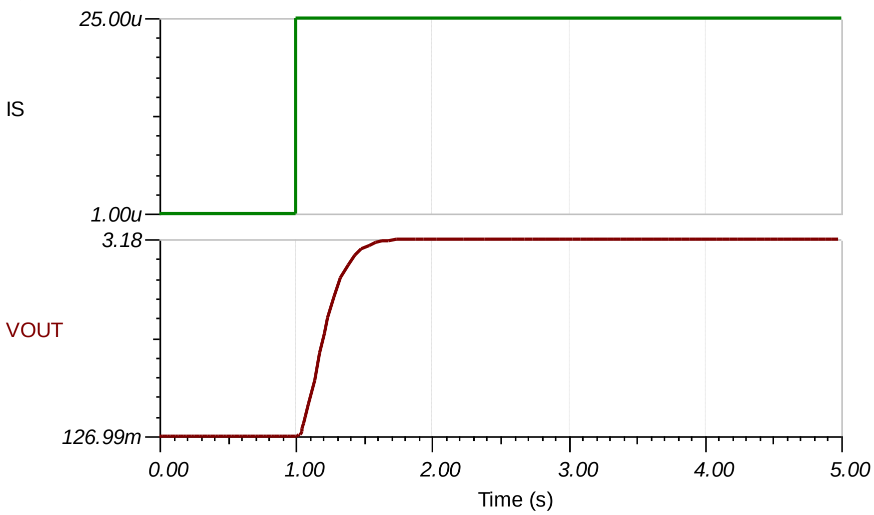
(3)

Design Simulations

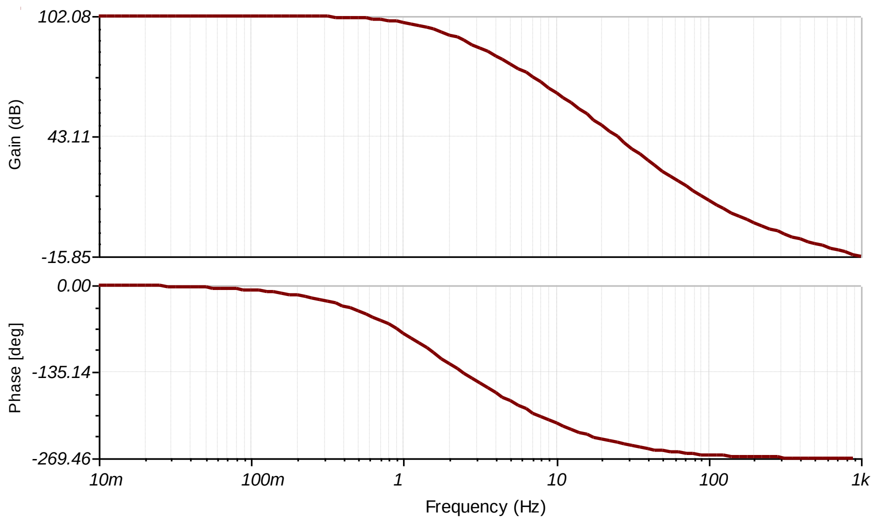
DC Simulation Results



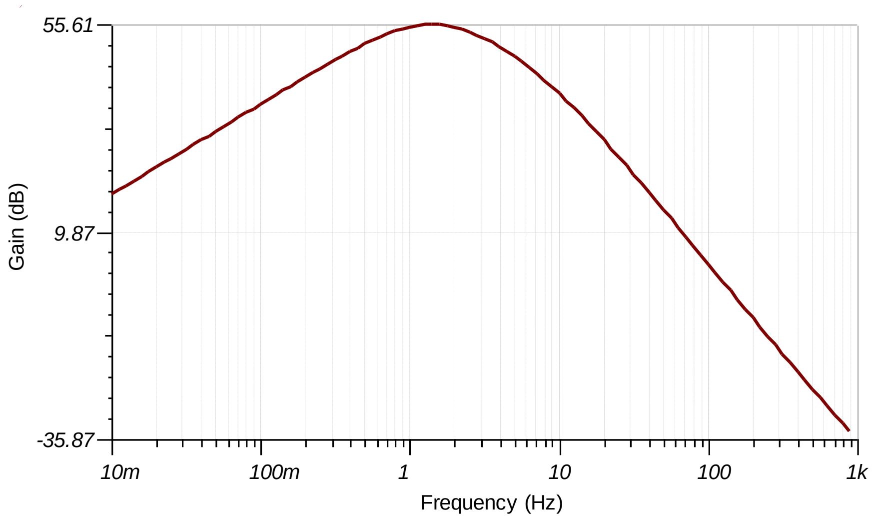
Transient Step Response Simulation Results



AC Simulation Results



Noise Simulation Results



TI Design, Tech Note, and Blog References

See Always-on Low-power Gas Sensing with 10+ Year Coin Cell Battery Life Reference Design TIDA-00756.

See Micropower Electrochemical Gas Sensor Amplifier Reference Design TIDA-00854.

See Extend Battery Life and Simplify Calibration in Gas Sensing Applications SBAA240A.

See Advantages of Using Nanopower Zero Drift Amp for Mobile Phone Battery Monitoring SNOA977.

See GPIO Pins Power Signal Chain in Personal Electronics Running on Li-Ion Batteries SNOA983.

See Current Sensing Using NanoPower Op Amps Blog.

Design Featured Op Amp

LPV821	
V_S	1.7 V to 3.6 V
Input V_{CM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	1.5 µV
V_{os} Drift	20 nV/°C
I_q	650 nA/Ch
I_b	7 pA
UGBW	8 kHz
#Channels	1
LPV821	

Design Alternate Op Amp

LPV811	
V_S	1.6 V to 5.5 V
Input V_{CM}	(V-) only
V_{out}	Rail-to-rail
V_{os}	60 µV
V_{os} Drift	1 µV/°C
I_q	450 nA/Ch
I_b	100 fA
UGBW	8 kHz
#Channels	1, 2
LPV811	

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