*Analog Engineer's Circuit*

# *Voltage-to-current (V-I) converter circuit with a Darlington transistor*

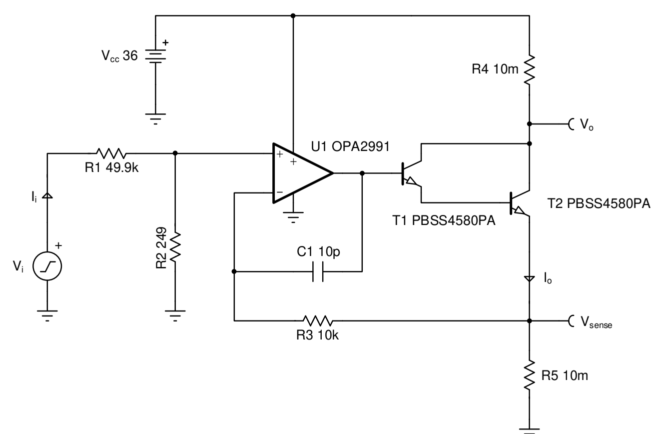
*Amplifiers*

## Design Goals

| Input | | | Output | | | Supply | |
|---|---|---|---|---|---|---|---|
| $V_{iMin}$ | $V_{iMax}$ | $I_{iMax}$ | $I_{oMin}$ | $I_{oMax}$ | $P_{R5Max}$ | $V_{cc}$ | $V_{ee}$ |
| 0V | 10V | 200µA | 0A | 5A | 0.25W | 36V | 0V |

## Design Description

This high-side voltage-to-current (V-I) converter delivers a well-regulated current to a load, $R_4$. The circuit accepts an input voltage from 0V to 10V and converts it to an output current from 0A to 5A. The current is regulated by feeding the voltage across a low-side, current-sense resistor back to the op amp. The output Darlington pair allows for higher current gain than when using a single, discrete transistor.




## Design Notes

1. A resistor divider, formed by $R_1$ and $R_2$, is implemented at the input to limit the full-scale voltage at the non-inverting terminal of the amplifier and the output sense resistor ($R_5$).
2. The high current gain of the Darlington pair reduces the demand on the output current of the op amp.
3. Smaller values of $R_4$ and $R_5$ lead to an increased load compliance voltage and a reduction in power dissipated in the full-scale, output state.
4. Feedback components $R_3$ and $C_1$ provide frequency compensation to ensure the stability of the circuit during transients. They also help reduce noise. $R_3$ provides a DC feedback path directly at the current setting resistor, $R_5$, and $C_1$ provides a high-frequency feedback path that bypasses the NPN pair.
5. The input bias current will flow through $R_3$, which will cause a DC error. Therefore, ensure that this error is minimal compared to the offset voltage of the op amp.
6. Select an op amp whose linear output voltage swing includes at least $2 \times V_{be}+V_{sense}$. The output voltage of the op amp will be greater than the voltage at the sense resistor by approximaly double the base-to-emitter voltage, $V_{be}$.
7. Use the op amp in its linear operating region, specified under the $A_{OL}$ test conditions of the data sheet.
8. If needed, an isolation resistor may be placed between the high-frequency feedback path and the base of T1 for stability.

### Design Steps

The transfer function of this circuit is provided in the following steps:

$$I_o = V_i \times \frac{R_2}{R_5 \times (R_1 + R_2)}$$

1. Using the specifications for the maximum output power dissipation and the maximum output current, determine the maximum value of $V_{sense}$.

$$V_{R5Max} = V_{senseMax} = \frac{P_{R5Max}}{I_{oMax}} = \frac{0.25\ W}{5A} = 50mV$$

2. Calculate the sense resistance, $R_5$.

$$R_5 = \frac{V_{senseMax}}{I_{oMax}} = \frac{50mV}{5A} = 10m\Omega$$

3. Select values for $R_1$ and $R_2$ based on the maximum allowable input current, $I_{iMax}$, and the desired $V_{senseMax}$ voltage.

$$R_1 = \frac{V_{senseMax}}{I_{iMax}} = \frac{50mV}{200\mu A} = 250\Omega \approx 249\Omega\text{(Standard Value)}$$

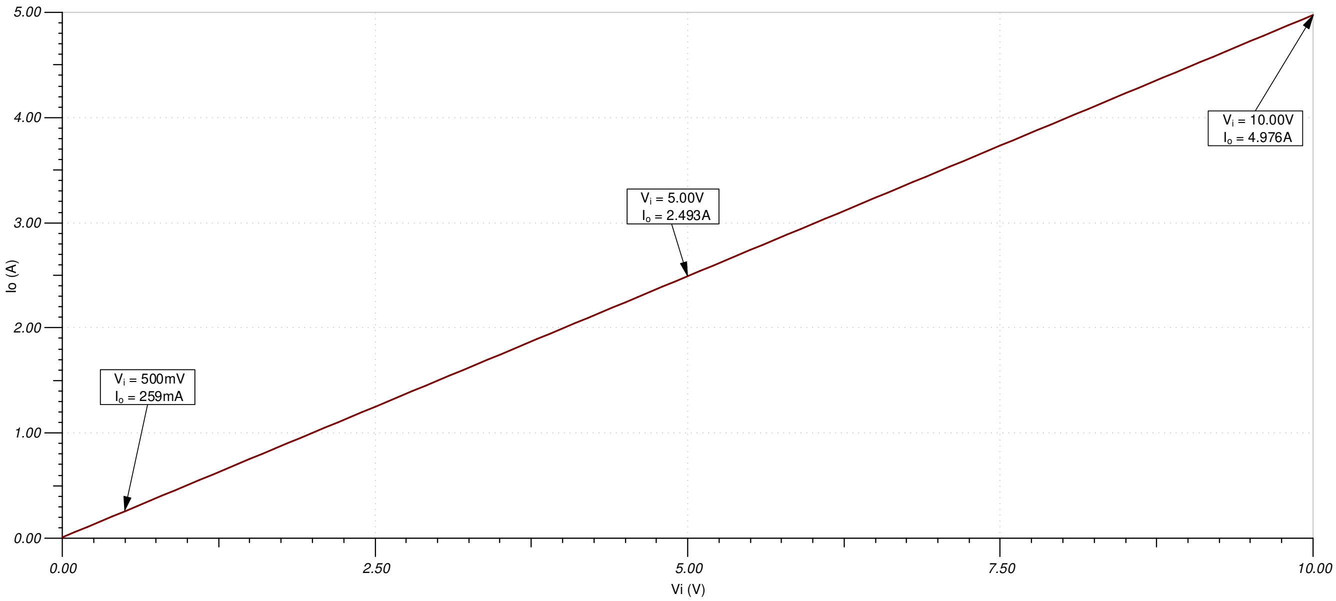
$$V_{senseMax} = V_{iMax} \times \left(\frac{R_2}{R_1 + R_2}\right)$$

$$R_2 = 49.6k\Omega \approx 49.9k\Omega\ \text{(Standard Value)}$$

4. See the Design References section [2] for the design procedure on how to properly size the compensation components, $R_3$ and $C_1$.

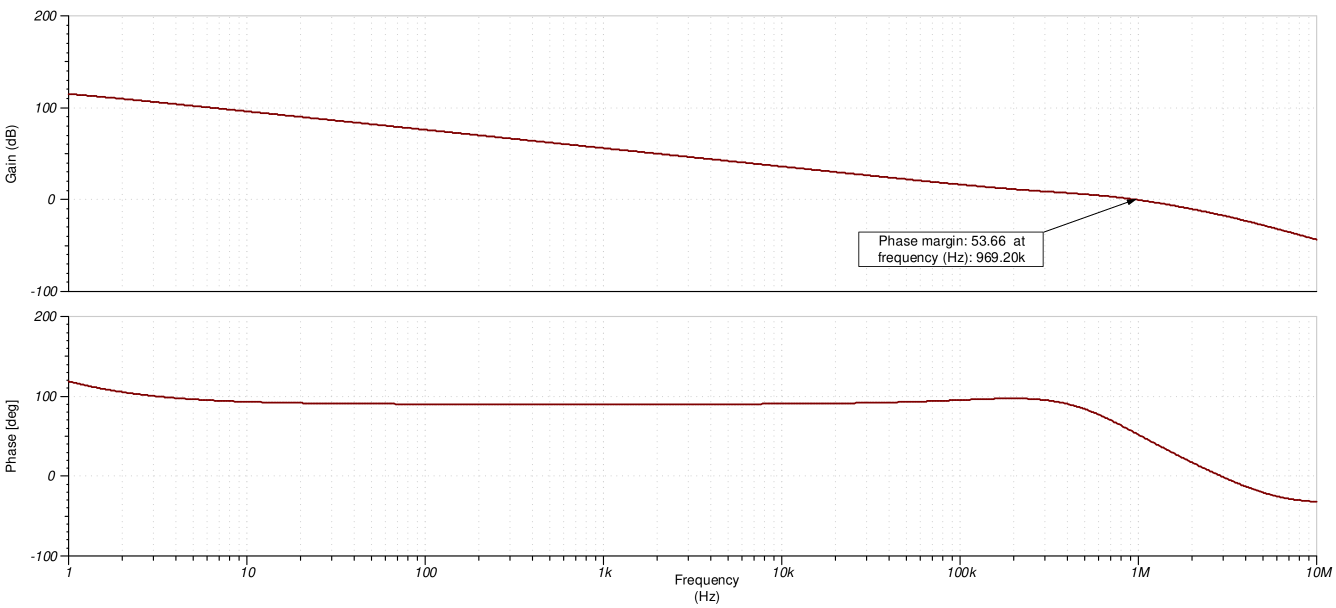
## Design Simulations

### DC Simulation Results

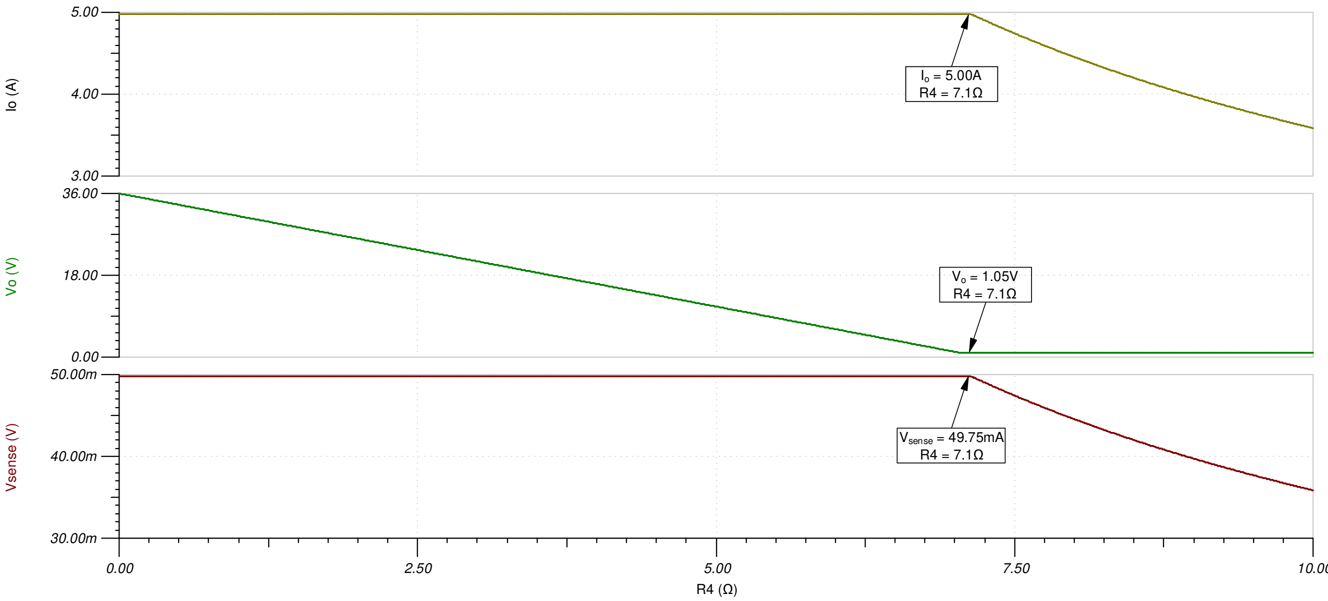



### Loop Stability Simulation Results

Loop gain phase is 53 degrees.



## Compliance Voltage Simulation Results



## Design References

1. See Analog Engineer's Circuit Cookbooks for TI's comprehensive circuit library.
2. TI Precision Labs

## Design Featured Op Amp

| OPA2991 | |
|---|---|
| $V_{ss}$ | 2.7V to 40V |
| $V_{inCM}$ | Rail-to-rail |
| $V_{out}$ | Rail-to-rail |
| $V_{os}$ | 125µV |
| $I_q$ | 560µA |
| $I_b$ | 10pA |
| UGBW | 4.5MHz |
| SR | 21V/µs |
| #Channels | 1, 2, 4 |
| www.ti.com/product/opa2991 | |

## Design Alternate Op Amp

| OPA197 | |
|---|---|
| $V_{ss}$ | 4.5V to 36V |
| $V_{inCM}$ | Rail-to-rail |
| $V_{out}$ | Rail-to-rail |
| $V_{os}$ | 25µV |
| $I_q$ | 1mA |
| $I_b$ | 5pA |
| UGBW | 10MHz |
| SR | 20V/µs |
| #Channels | 1, 2, 4 |
| www.ti.com/product/opa197 | |

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