Analog Engineer's Circuit Amplifiers

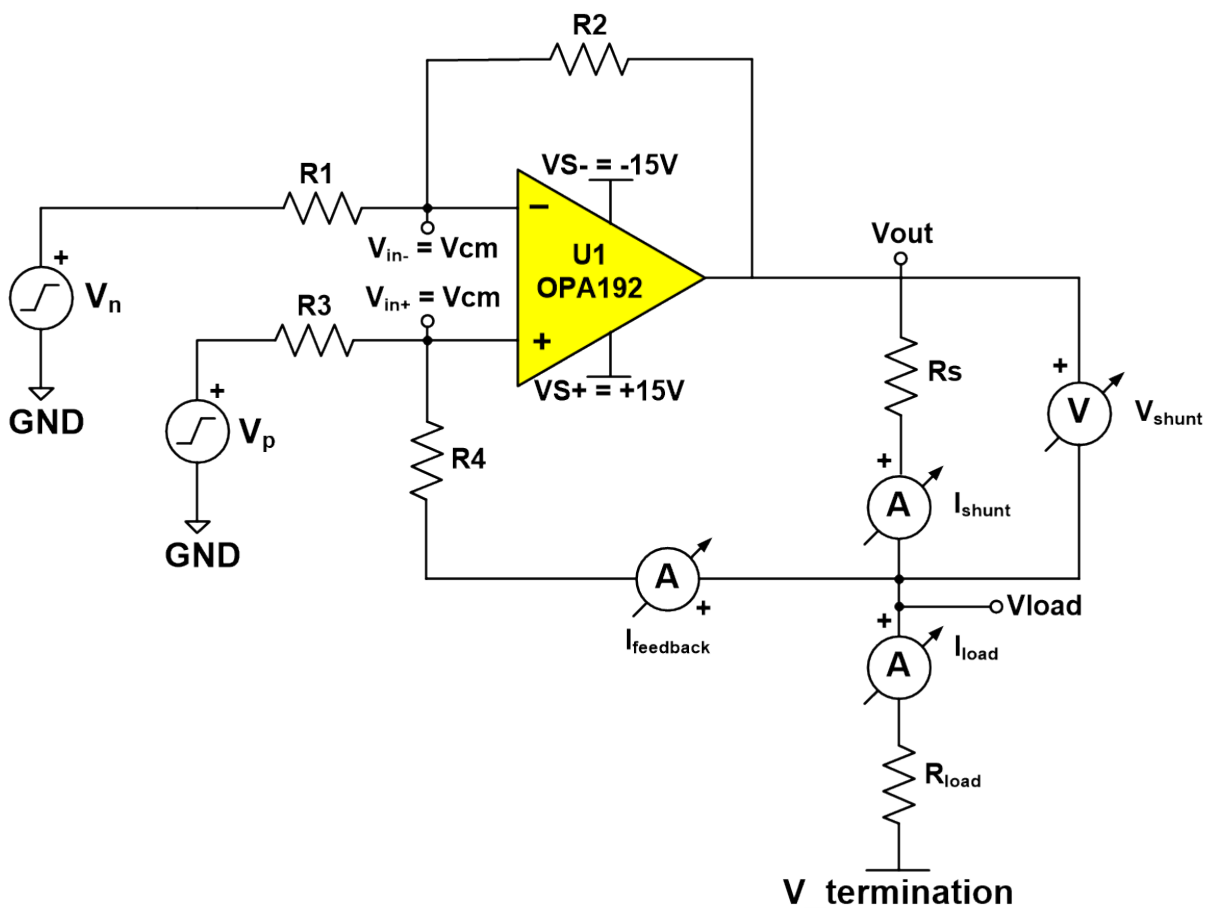
"Improved" Howland current pump circuit

Design Goals

Input V_{in} ($V_p - V_n$)		Output		Supply		
V_{inMin}	V_{inMax}	I_{Min}	I_{Min}	VS+	VS-	V_{ref}
–5V	5V	–25mA	25mA	15V	–15V	0V

Design Description

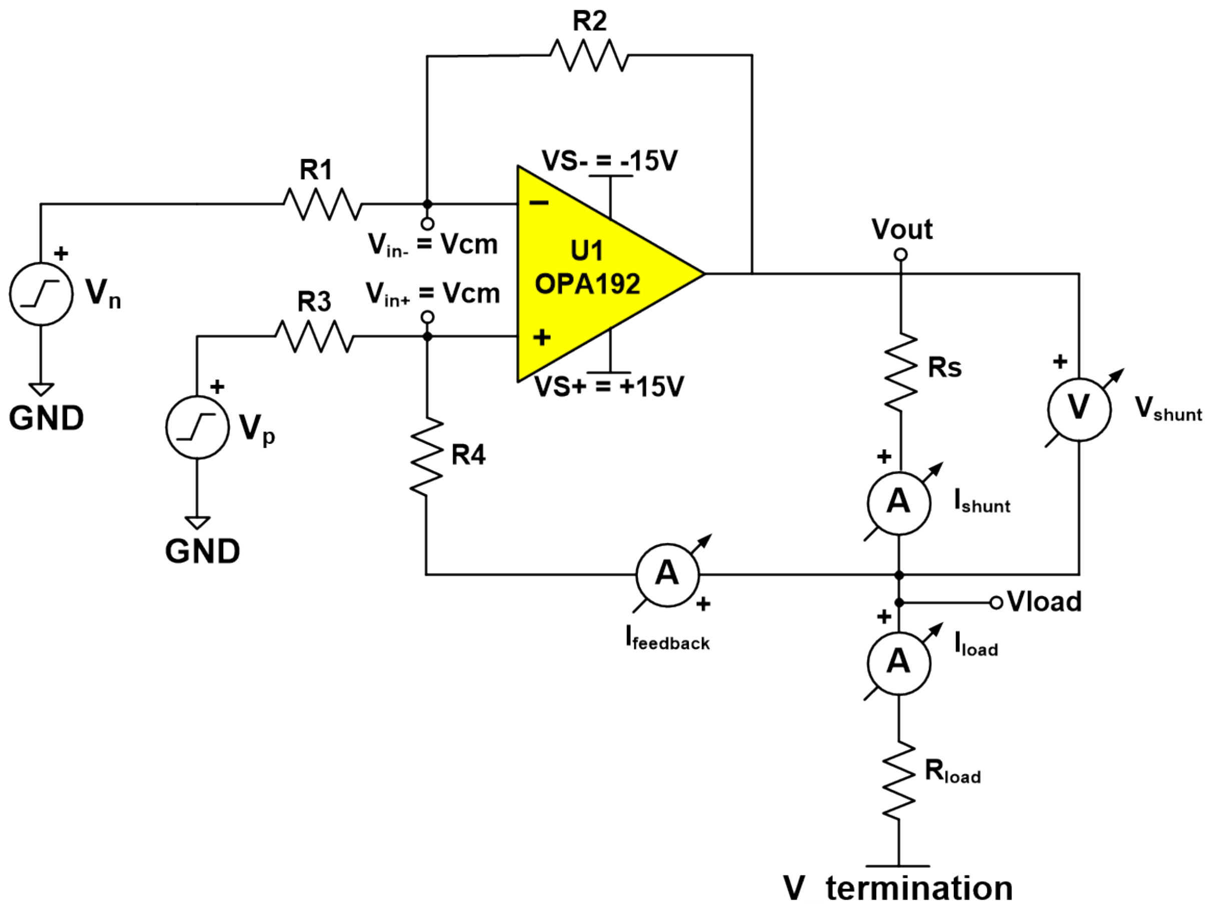
The "Improved" Howland current pump is a circuit that uses a difference amplifier to impose a voltage across a shunt resistor (Rs), creating a voltage-controlled bipolar (source or sink) current source capable of driving a wide range of load resistance. See the *AN-1515 A Comprehensive Study of the Howland Current Pump Application Report* for more information on the functionality of the "Improved" Howland current pump.



Design Notes

1. Ensure common-mode voltages at the inputs (V_{cm} nodes) of the op amp are within the V_{cm} range listed under Electrical Characteristics in the data sheet of the op amp.
2. Refer to the typical “Output Voltage Swing vs. Output Current” graphs in the data sheet of the op amp to account for output swing from rails (V_{out} node).
3. Resistor mismatch will contribute gain error and degrade CMRR of the circuit.
4. Error in final results can be expected due to $I_{feedback}$ current. Placing high-value resistors will limit the effect of this current, but will add thermal noise to the circuit. Possible bandwidth limitations and stability issues caused by large resistances and parasitic capacitances in the circuit also become more prevalent.
5. In an ideal “Improved” Howland current pump, resistor R4 is usually set equal to R2-Rs, which slightly alters the feedback network but results in the expected I_{load} value. Accuracy of these resistors will limit the effectiveness of the technique at reducing errors.
6. Special precautions should be taken when driving reactive loads.
7. A typical design procedure first calculates the gain for a known output current and shunt resistor; then sets R1 and scales R2 through R4 accordingly. This can be an iterative process.

Design Steps



- Calculating gain (G) for a given I_{load} and shunt resistor:

$$G(V/V) = \frac{I_{load} \times R_S}{V_p - V_n}$$

$$G(V/V) = \frac{R2}{R1}, \quad \frac{R2}{R1} = \frac{R4 + R_S}{R3}$$

- Ensure V_{out} is within the voltage output swing from rails (V_{out_Min}, V_{out_Max}) of the op amp at a specific output current specified in the data sheet of the op amp:

$$V_{out\_Min} < V_{out} < V_{out\_Max}$$

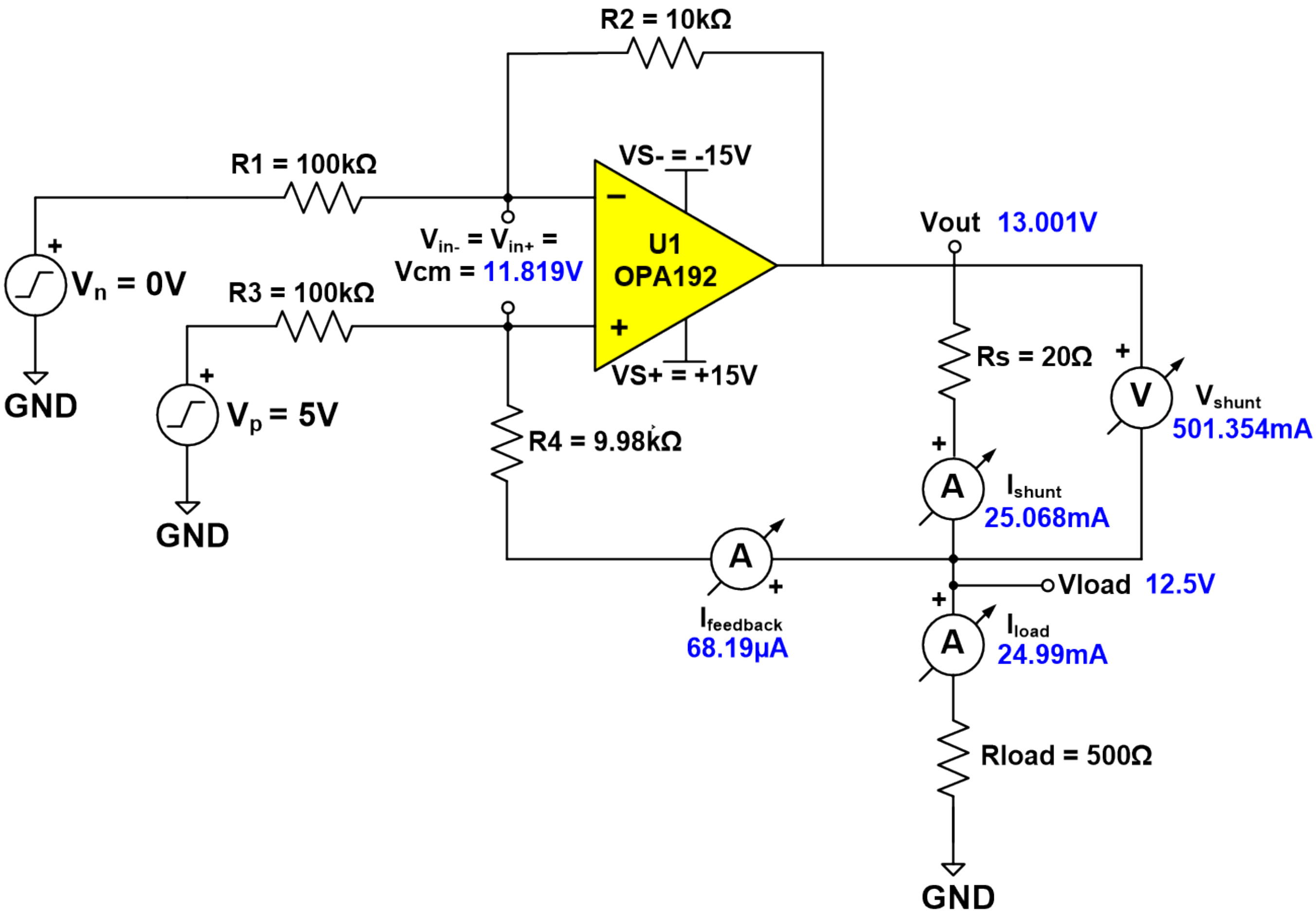
$$U1\_V_{out} = V_{termination} + (I_{load} \times R_{load}) + V_{shunt}$$

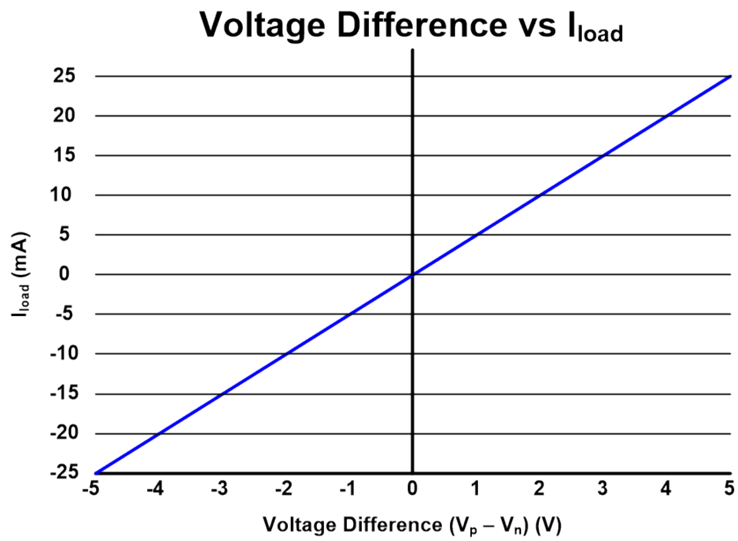
Design Simulations

A design goal of ±25mA of output current from an input voltage difference of ±5V and a 500-Ω load results in a V_{load} value of ±12.5V assuming a $V_{termination}$ voltage of 0V. The remaining ±2.5 volts must accommodate the selected output swing-to-rail of the op amp as well as the maximum voltage across the shunt. For these reasons, a 20-Ω shunt resistor and a gain of 1/10 (V/V) was chosen.

A DC input voltage difference sweep is simulated with a fixed Vn input of 0V and the Vp input swept from –5V to 5V. As the following image shows, the input common-mode range, output swing-to-rail, and output current are within the specifications of the selected op amp. The configuration and results are seen in the following images.

DC Simulation Results




Voltage Difference vs Iload
25
20
15
10
5
0
-5
-10
-15
-20
-25
Iload (mA)
-5
-4
-3
-2
-1
0
1
2
3
4
5
Voltage Difference (Vp – Vn) (V)

Design References

See the Analog Engineer's Circuit Cookbooks for TI's comprehensive circuit library.

See the *AN-1515 A Comprehensive Study of the Howland Current Pump Application Report* for more information on the functionality of the “Improved” Howland current pump resource.

The TI E2E support forum on *Difference Amplifiers* contains information on the importance of matching difference amplifier resistors.

Design Featured Op Amp

OPA192	
V_{ss}	4.5V–36V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	5µV
I_q	1mA
I_b	5pA
UGBW	10MHz
SR	20V/µs
#Channels	1
www.ti.com/product/OPA192	

Design Alternate Op Amp

OPA990	
V_{ss}	2.7V–40V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	0.3mV
I_q	130µA
I_b	10pA
UGBW	1.1MHz
SR	4.5V/µs
#Channels	1
www.ti.com/product/OPA990	