Analog Engineer's Circuit Amplifiers

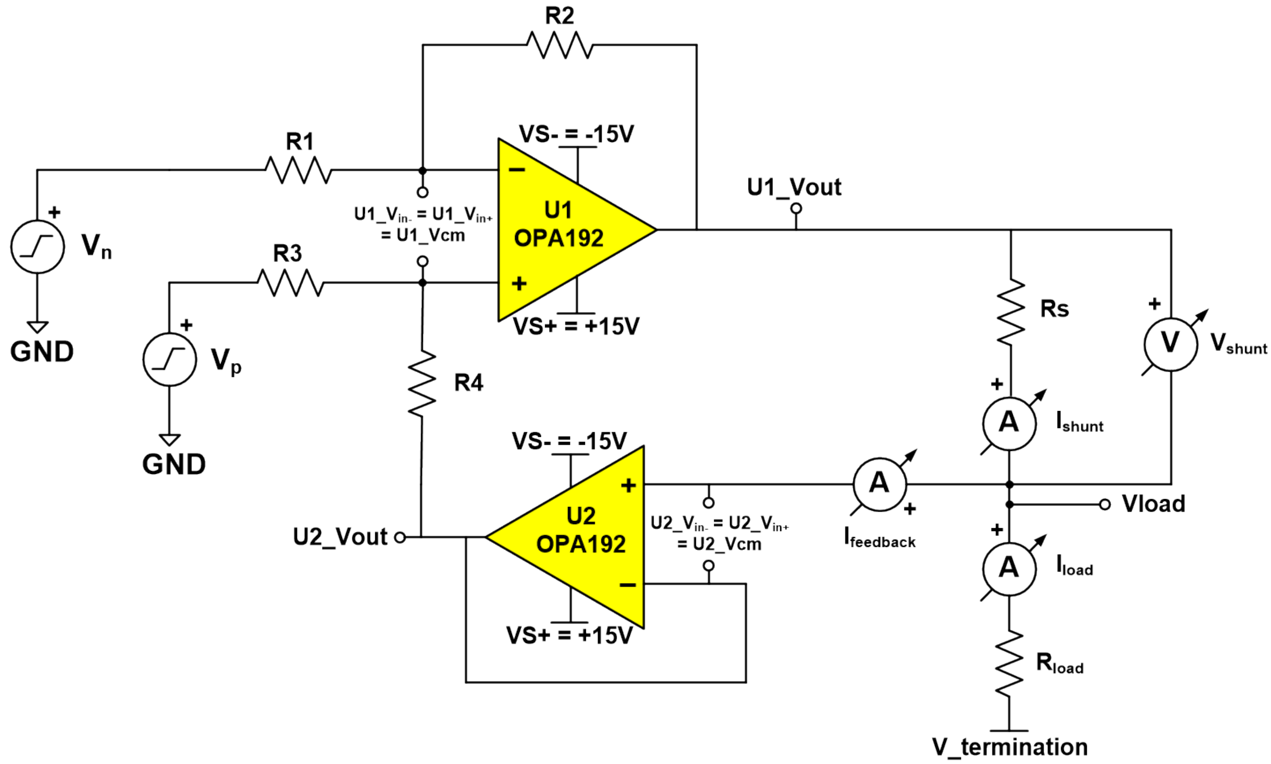
"Improved" Howland current pump with buffer circuit

Design Goals

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

Design Description

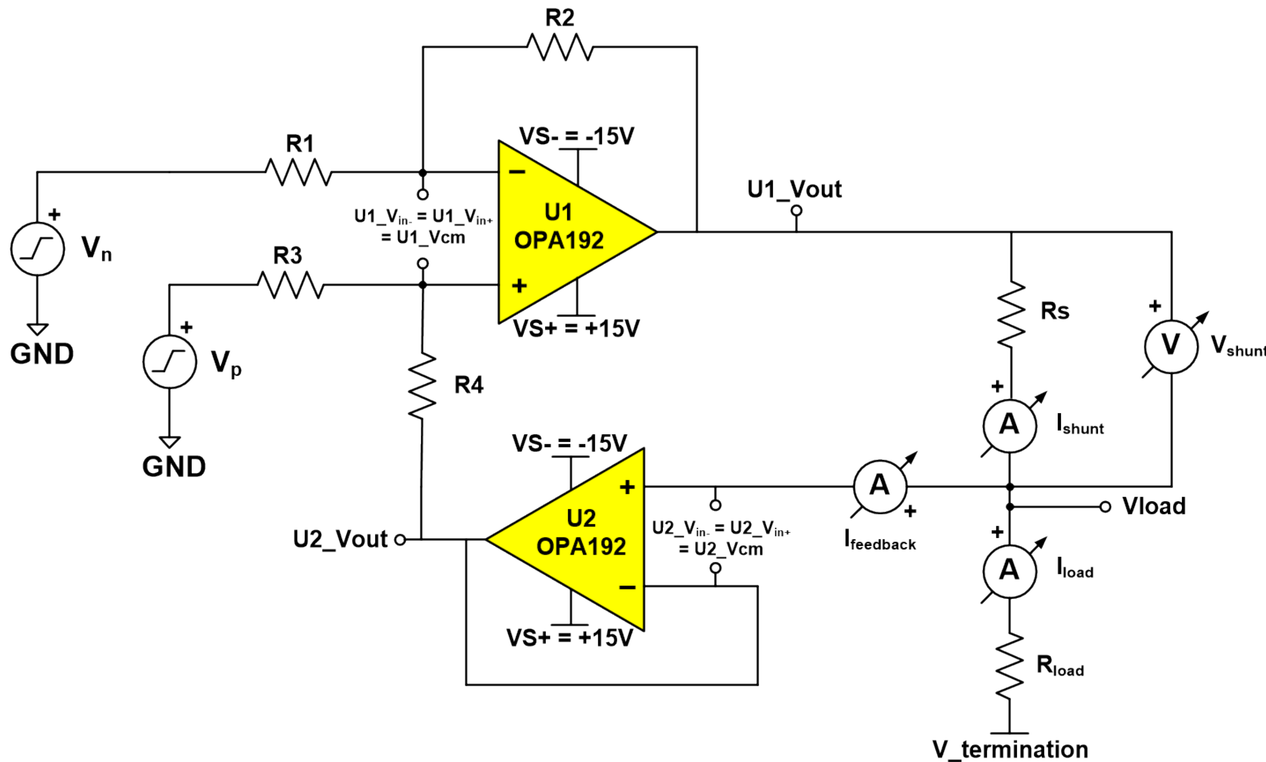
The "Improved" Howland current pump is a circuit that uses a difference amplifier to impose a voltage across a shunt resistor (Rs), creating a voltage-controlled bipolar (source or sink) current source capable of driving a wide range of load resistance. See the *AN-1515 A Comprehensive Study of the Howland 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 both op amps are within their 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 to account for output swing from rails (V_{out} nodes) for both op amps.
3. Resistor mismatch will contribute gain error and degrade CMRR of the circuit.
4. The buffer offers improved output impedance of the current source nearly eliminating $I_{feedback}$ current. This allows the use of smaller resistor values for R1 through R4, reducing thermal noise. Possible bandwidth limitations and stability issues caused by large resistances and parasitic capacitances in the circuit are also reduced.
5. Special precautions should be taken when driving reactive loads.
6. 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.
7. The figures use two OPA192 op amps, but in practice a single chip OPA2192 can be used.

Design Steps



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

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

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

2. Ensure V_{out} for both op amps are within their voltage output swing from rails (V_{out_Min}, V_{out_Max}) at a specific output current specified in the data sheet.The following formula can be used to calculate U1_V_{out} for U1 OPA192. U2_V_{out} for U2 OPA192 will be V_{load}.

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

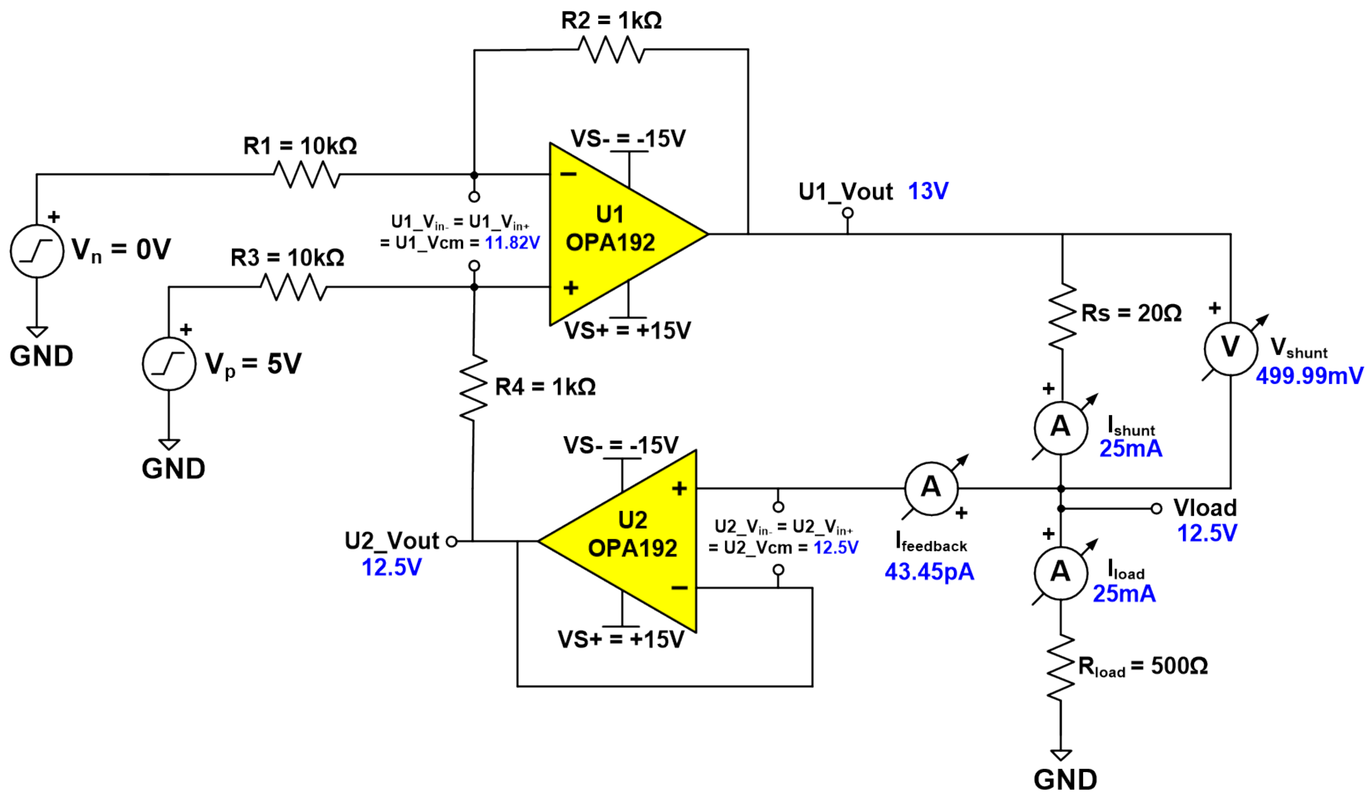
$$U1\_V_{out} = V_{termination} + (I_{load} \times R_{load}) + V_{shunt}$$

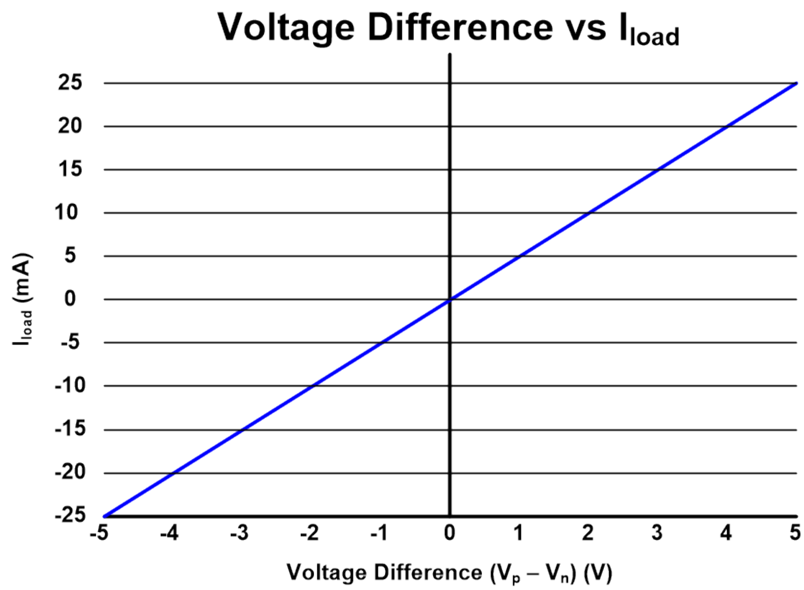
Design Simulations

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 output swing-to-rail of the selected 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. This V_{load} value is also within the voltage compliance range of the buffer.

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 amps. The configuration and results follow.

DC Simulation Results




Voltage Difference vs I_load
25
20
15
10
5
0
-5
-10
-15
-20
-25
I_load (mA)
-5
-4
-3
-2
-1
0
1
2
3
4
5
Voltage Difference (V_p – V_n) (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

OPA2192	
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	2
www.ti.com/product/OPA2192	

Design Alternate Op Amp

OPA2990	
V_{ss}	2.7V–40V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	0.3mV
I_q	120µA
I_b	10pA
UGBW	1.1MHz
SR	4.5V/µs
#Channels	2
www.ti.com/product/OPA2990	

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