A Constant-current Source

Frequently, such as when you want to measure temperature with a silicon diode, it is desirable to have an easily reproducible source of a constant current. Many laboratory power supplies can be used as constant current sources. The difficulties you may encounter are reproducibility or a requirement for very small currents.

The circuit in Figure 1 results in a reproducible current and can reliably provide currents in the µA range.

The operation of this circuit is fairly straightforward.

- The voltage divider made from R1 and R2 provides a reference voltage, \( V_{\text{ref}} \), at the non-inverting input of the op-amp.

  Note: When using the TL3472 op amp in this circuit, \( V_{\text{ref}} \) must be less than 13.2 V for a 15 V supply voltage.

- With negative feedback, as provided by this circuit, the op-amp will now do everything in its power to keep the inverting input at the same voltage (\( V_{\text{ref}} \)) as the non-inverting input.
  - A bipolar transistor is a current amplifier. The emitter-collector current will be the parameter \( h_{\text{FE}} \) times the emitter-base current. For the 2N3906 \( h_{\text{FE}} \) is about 175 (range of 60 to 300).
  - The op amp will vary the emitter-base current by changing the base voltage on the 2N3906 transistor. This will change the current through R3 until the inverting and non-inverting inputs are equal.

It will be able to maintain this current as long as the voltage on the upper terminal of the current output (the collector of the 2N3906) stays at least about 0.3 V below \( V_{\text{ref}} \).

When the circuit is operating properly and the design current is provided to a load, the base voltage should be about 0.6 V below \( V_{\text{ref}} \).

- The maximum current for a 2N3906 transistor is 100 mA. Do not try to design for an output current larger than this.

The output current (the current provided at the output terminals) is then set by

\[
\begin{align*}
i_{\text{out}} R3 &= V_{\text{cc}} + V_{\text{ref}} \\
i_{\text{out}} &= \frac{V_{\text{cc}} + V_{\text{ref}}}{R3}.
\end{align*}
\]
Figure 1: A simple constant current source using an op-amp. The op-amp can be any general purpose op-amp. For Physics 240 we will use the TL3472. C1, the bypass capacitor on the power supply line, is usually necessary for stable operation. C1 is typically 0.1 µF. C2, C3, and C4 in combination with associated resistors provide low-pass filters for high-frequency noise control. The two vertical lines, labeled “Vcc+” and “Vcc-” extending from the center of the op-amp symbol indicate the power supply connections. The upper one is for the positive supply and the lower one for the negative supply. Because all the voltages on the op-amp are positive, it is possible to run this circuit with a unipolar power supply (the negative supply input is grounded). If you connect Vcc- to −15 V, it is necessary also to provide a bypass capacitor to ground on that line.

You should consider the power in every resistor in the circuit. The resistors used in the Physics 240 lab are rated for 1/4 W. For continuous use, it is best to run the resistors below the maximum rated power.

If a maximum power of $P_{\text{max}} \approx 1/8 W$ is chosen and you assume that the entire supply voltage (15 V) will be applied to the resistor, the minimum resistance is $R \geq V^2/P_{\text{max}} = 8 V^2 = 1.8 \text{kΩ}$. This should be the minimum value for resistor R1 and R2.

The value for R3 is determined from $P_{\text{max}} = I^2 R$ where $I$ is your design output current. If you need more power, you can put several resistors in parallel.

The choices for the capacitors are a little more difficult to determine.

- Capacitor C1, known as a bypass capacitor, is connected between the power supply line (Vcc+) and ground. 0.1 µF is typical. This capacitor is absolutely necessary for loads that draw significant currents, especially if those currents
change rapidly. For low output currents, the supply may work properly without a bypass capacitor, but it is good practice to **always include bypass capacitors placed as near the power supply pins on integrated circuits as possible.**

- If you operate this circuit with a bipolar power supply (i.e., 15 V attached to Vcc+ and −15 V attached to Vcc−), you will also have to include a bypass capacitor between Vcc- and ground. (This would be labeled C5 if it were present on the circuit.)

- C2 is in parallel with the current output. This capacitor in combination with the output impedance of the current supply provides a low-pass filter to reduce high-frequency noise in the current.

  The value of this capacitor combines with the output impedance to set the cutoff frequency for the low-pass filter. The output impedance is approximately R3 in parallel with the effective impedance of your current load (such as a 1N4148 diode). Typical output impedances with a diode load are a few kΩ. Assuming a value of 3 kΩ and C2=1.0 µF gives a value of \( \tau = R C = 3 \text{ ms} \) or 53 Hz. The shortest expected variation time in your output current should be several times greater than \( \tau \).

  When you use a similar supply circuit to provide current for measuring the resistance of a superconductor, the load impedance is very small (about 0.1 Ω). It may be necessary to use a larger capacitor to achieve adequate filtering for this supply.

- C3 is a 0.01 µF capacitor from the base of the 2N3906 to ground. This combines with the output resistance of the op-amp to create a low-pass filter for the control signal applied to the base of the transistor.

  According to the data sheet for the TL3472, the output resistance is less than 20 Ω depending on the feedback circuit. With a 0.01 µF capacitor the cutoff frequencies would be about 800 kHz (\( \tau \) would be 0.2 µs).

  Note that op-amps don’t work well with large capacitive loads connected directly to the output. Trying to further lower the cutoff frequency of the low-pass filter composed of capacitor C3 and the output resistance of the op-amp too far may result in a sufficiently large value of C3 to make the op-amp unstable.

  The data sheet for the TL3472 specifies a maximum load capacitance of 10,000 pF.

- C4 is a 0.1 µF capacitor to filter power supply noise from \( V_{\text{ref}} \). If you set \( R1 = R2 = 2.2 \text{ kΩ} \), the output impedance of the divider circuit is 1.1 kΩ (R1 and R2 in parallel). This impedance combined with C4 gives \( \tau = 0.1 \text{ ms} \) and \( f = 1.4 \text{ kHz} \). A larger capacitance or larger values of R1 and R2 may be desirable to lower the cutoff frequency.

- Experience with this circuit has shown that you really want all four capacitors (C1, C2, C3, and C4) to avoid noisy or erratic operation.
1.0 Optional voltage monitor

Figure 1 includes an optional item labeled “Voltage Monitor”. For some applications, this would not be included.

For our temperature measurements, this should be included to provide a connection for monitoring the voltage across the diode to determine the temperature of the diode. Including this output for the temperature measurement diode will allow you to have a single set of clip leads attached to the diode. Having multiple clips on each lead of the diode will usually result in some frustration with clips coming off the leads.

2.0 Getting your circuit to work

If your constant current source doesn’t work after you finish assembling it, you probably want to consult the electronics section of The Art of Debugging (Content ⇒ The Art of Debugging in Learning Suite). Two common problems with the constant current sources are solder bridges between pins and cold solder joints. By methodically going through your circuit you should be able to find the errors.

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