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.

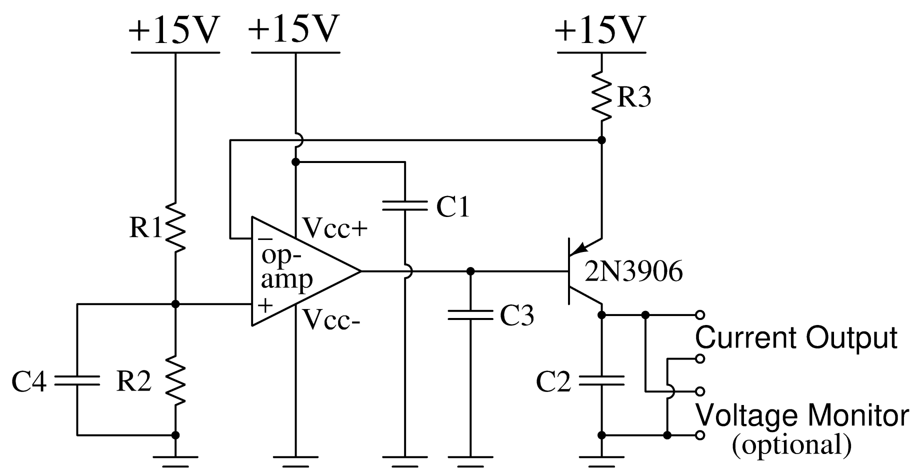

Figure 1: A simple constant current source using an op-amp. The op-amp can be any general purpose op-amp. For Physics 240 we will use the TL3472. C1, the bypass capacitor on the power supply line, is usually necessary for stable operation. C1 is typically 0.1 μF. C2, C3, and C4 in combination with associated 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.

The operation of this circuit is fairly straightforward. The function and selection of the individual components of the circuit are described below.

R1 and R2 A voltage divider composed of R1 and R2 provides a reference voltage, V_{ref}, at the non-inverting input of the op-amp.

When selecting resistors, it is usually necessary to verify the power rating and power consumption for the selected value. If we assume that R1 and R2 could both experience a voltage of 15 V (worst case), we can place limits on acceptable values. The resistors we use are rated at 1/4 W continuous power. At this power the resistor will warm significantly, which will also slightly change the value of the resistor. If we design for 1/8 W, we can reduce the amount of heating and have a more stable value.

Since $P = V^2/R$, $R_{\mathrm{min}} = V_{\mathrm{max}}^2/P_{\mathrm{max}}$. Assuming $V_{\mathrm{max}} = 15\,\mathrm{V}$ and $P_{\mathrm{max}} = 1/8\,\mathrm{W}$ we can determine the ***minimum recommended values*** for R1 and R2.

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

2N3906 transistor A bipolar transistor like the 2N3906 is a current amplifier. The emitter-collector current will be the parameter $\mathrm{h_{FE}}$ times the emitter-base current. For the 2N3906 $\mathrm{h_{FE}}$ is about 175 (range of 60 to 300).

The op-amp can vary the emitter-base current by changing the base voltage on the 2N3906 transistor. 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 the emitter voltage. The emitter-collector voltage is usually greater then about 0.3 V.

The maximum current for a 2N3906 transistor is about 100 mA. Do not try to design the circuit for larger currents.

R3 The voltage feedback circuit for the op-amp is comprised of R3, the 2N3906 transistor, and the connection from the emitter of the transistor to the inverting input. The combination of the value of R3 and V_{ref} provided to the noninverting input by R1 and R2 determine the output current of the supply.

- The op-amp will act to make the voltage difference between the inverting and noninverting inputs as small as possible. Nominally, the voltage at the emitter will be equal to V_{ref} if the circuit is working properly.

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

$$\begin{aligned} i_{\mathrm{out}}\mathrm{R3} &= \mathrm{Vcc+} - V_{\mathrm{ref}} \\ i_{\mathrm{out}} &= \frac{\mathrm{Vcc+} - V_{\mathrm{ref}}}{\mathrm{R3}}. \end{aligned}$$

As with R1 and R2, you should check the power in R3. In this case $V_{\mathrm{max}} \approx \mathrm{Vcc+} - V_{\mathrm{ref}}$. Since you are designing for a constant current, you could use the equation $P = i_{\mathrm{out}}^2\,\mathrm{R3}$.

If the power is too large, you can put correct resistors in parallel to get the desired value of R3 with the power then divided between the resistors.

C1 Capacitor C1, known as a bypass capacitor, is connected between the power supply line (Vcc+) and ground. $0.1\,\mu$F 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***.

C2 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 $3\,\mathrm{k}\Omega$ and C2=$1.0\,\mu$F gives a value of $\tau = RC = 3\,\mathrm{ms}$ or $53\,\mathrm{Hz}$. The shortest expected variation time in your output current should be several times greater than τ.

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

C3 C3 is a $0.01\,\mu$F 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 $20\,\Omega$ depending on the feedback circuit. With a $0.01\,\mu$F capacitor the cutoff frequencies would be about $800\,\mathrm{kHz}$ (τ would be $0.2\,\mu$s).

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 $10,000\,\mathrm{pF}$.

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

"C5" If you operate this circuit with a bipolar power supply (*i.e.*, $15\,\mathrm{V}$ attached to Vcc+ and $-15\,\mathrm{V}$ 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 in the circuit.)

Current Output The load for the current supply attaches to the current output terminals. The lower terminal is connected to ground – the current will flow out of the top terminal and return to ground through the lower terminal.

Optional Voltage Monitor The circuit diagram includes an optional item labeled "Voltage Monitor". For some applications, this would not be included. Note that this output is connected in parallel with the current output to provide the voltage across the load element.

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.

Note: 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 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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