

Signals-From-Noise Current Sources

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There are times when it is necessary to generate a precise current. It may be for some sensor that specifies a current stimulus. It may be a constant current source, or it may change as a function of some input voltage. A variable current source controlled by a voltage is sometimes referred to as a transconductance amplifier. Several different types of current sources are described here.

Instrumentation Amplifier Current Source

A current source can easily be constructed with an instrumentation amplifier (Fig. 1).

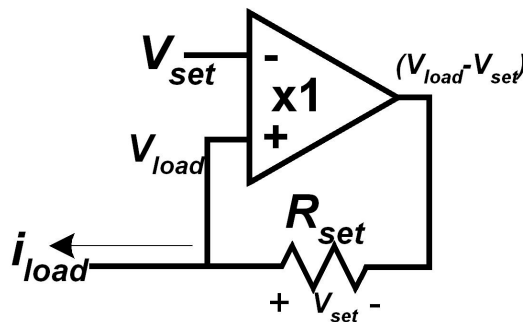


Fig. 1: Instrumentation Amplifier Current Source

An instrumentation amplifier is a device with two inputs and usually a single output. The output is defined as the difference of its inputs multiplied by some gain. It uses the same symbol as an op amp. To distinguish it from an op amp, its gain value is displayed. Its transfer function is defined as:

$$V_{out} = Gain \cdot (V_{in_{pos}} - V_{in_{neg}})$$

With its gain set to one, the output is the difference of the inputs. The output voltage is always V_{set} below the load voltage, V_{load} . The load current is defined as:

$$i_{load} = \frac{V_{out} - V_{load}}{R_{set}} = \frac{(V_{load} - V_{set}) - V_{load}}{R_{set}} = -\frac{V_{set}}{R_{set}}$$

The resistor is connected from the output to the positive input. This is another example of how positive feedback isn't always necessarily bad and sometimes can actually be good. Although there is positive feedback, with a unity gain and the attenuation of the feedback resistor, the loop gain is guaranteed to be less than one. The amount of current is limited to what the instrumentation amplifier can supply. This topology is not widely known, or used, primarily because of the high cost of instrumentation amplifiers. Still it is a good technique to store away in your collection of "techniques I may one day have a need for."

Op Amp Amplifier Current Source

Op Amps are a lot more affordable but any topology that uses one must be able to generate a differential x1 gain. Using a diode as a reference voltage can do this (Fig. 2).

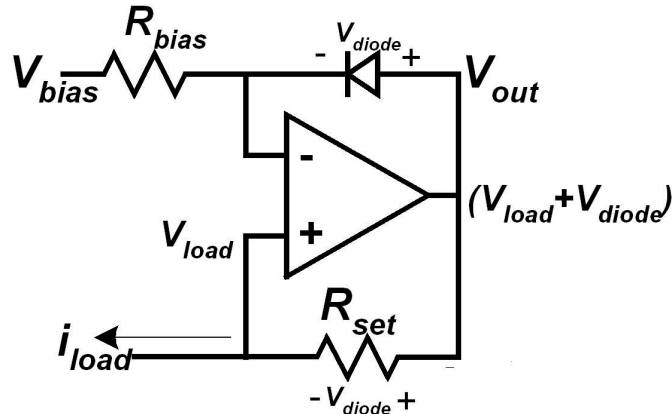


Fig. 2: Op Amp Current Source With Diode Reference Voltage

The bias current passing through the diode is causing the op-amp negative input to be a diode drop below the output:

$$V_{load} = V_{out} - V_{diode}$$

Negative feedback causes the two inputs to match by making the op amp adjust its output so that the output voltage is a diode drop larger than the load voltage. To keep the diode forward biased the load voltage can never be smaller than the bias voltage.

The resistor is connected from the output to the positive input. Again the voltage across it is a diode drop. This resistance sets the current value as:

$$i_{load} = \frac{V_{out} - V_{load}}{R_{set}} = \frac{V_{out} - (V_{out} - V_{diode})}{R_{set}} = \frac{V_{diode}}{R_{set}}$$

Now, you may wonder how the circuit is still working if the resistor is providing positive and negative feedback. Well, it is true that the resistor provides positive feedback, but the load resistance will reduce it to less than unity. However the negative feedback is not attenuated (only knocked down a bit) so there is more negative feedback than positive feedback for a net negative feedback. The diode only conducts current when the bias voltage is less than the load voltage.

This is an easy circuit to build. Its primary limitation is that diodes make pretty crummy voltage references. Their voltage drop is a function of temperature. Still there are many applications where this is good enough. This current source only allows for a single set voltage value. But there are applications that require a voltage-controlled current source.

Voltage-Controlled Op Amp Amplifier Current Source

It is easy to make an op amp have a gain of two. Suppose the feedback resistor is actually a divider. The load voltage is gained by two but then is attenuated back down to unity (Fig. 3).

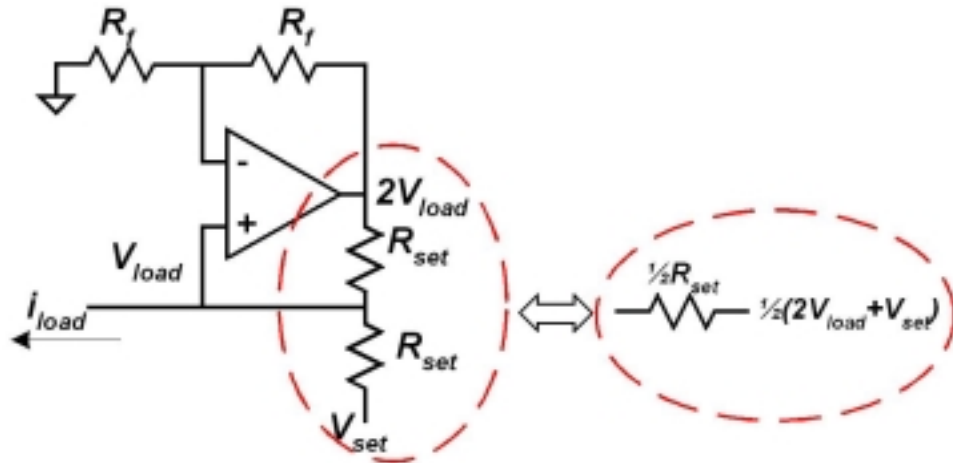


Fig. 3: Op Amp Variable Current Source

The output of the op amp is twice the load voltage and then attenuated with a pair of set resistors. Using the Thévenin equivalent for this divider, <http://www.facstaff.bucknell.edu/mastascu/eLessonsHTML/Source/Source2.html> it is straightforward to solve for the load current. It is shown as:

$$i_{load} = \frac{\frac{1}{2}(2 \cdot V_{load} + V_{set}) - V_{load}}{\frac{1}{2}R_{set}} = \frac{\frac{1}{2}V_{set}}{\frac{1}{2}R_{set}} = \frac{V_{set}}{R_{set}}$$

This circuit has the advantages of allowing for a variable set voltage while using only a single op amp. Its biggest disadvantage is its limited range. The output voltage is twice the load voltage. An op amp, with ± 5 V supplies and a rail-to-rail output will only support a V_{load} range of ± 2.5 V.

Improved Voltage-Controlled Op Amp Amplifier Current Source

Suppose, instead of attenuating the signal after it has been doubled, we attenuate it before. This will take care of the range limitations (Fig. 4).

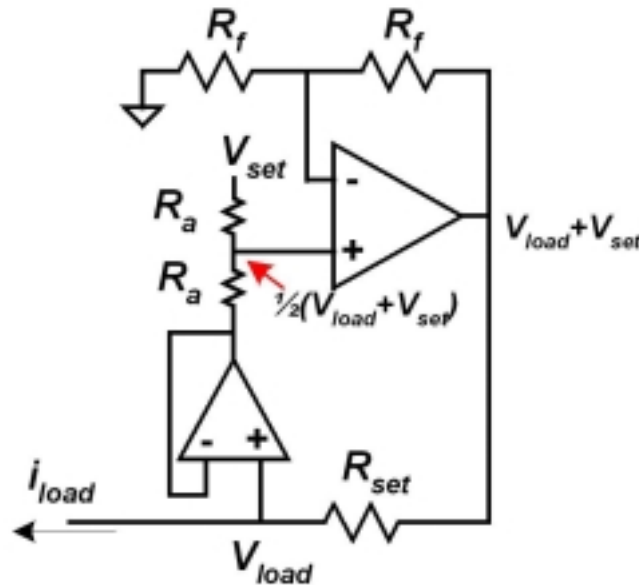


Fig. 4: Improved Op Amp Variable Current Source

In this improved circuit, the sensed value is half of the load and set voltages. The gain of two makes the output the sum of set and load voltage for fixed value across of V_{set} across R_{set} . The voltage at the output of the op amp is a more manageable set voltage above the load voltage. Given the example before with an op amp, with ± 5 V supplies and a rail-to-rail output, let's say a set voltage of 0.5 V, this design will support a V_{load} range of ± 4.5 V. The biggest limitation of this design is that it uses two op amps. The second op amp is used to isolate the load voltage from the resistance of R_{set} . If you're hardware-constrained, budget-constrained, or just stubbornly cheap, there are also ways of isolating this signal without an additional op amp.

Improved Voltage-Controlled Single Op Amp Amplifier Current Source

The current source just discussed used a second op amp to buffer the load voltage from the attenuator. Configured as a buffer this op amp ideally has infinite input impedance and zero output impedance. This is quite satisfactory if infinite isolation is needed. But how high is infinite?

As engineers we are trained to reduce problems down to their most simple state. What separates engineering from science is that *close enough* is good enough. Our standard practice is to use a simpler model with an acceptable error over a more complex, and accurate, model. This would seem sacrilegious to a physicist but then their models are usually built around concepts like perfect spheres, infinitely long wires, and point masses.

Unfortunately, dealing with complex problems in the real world, where budgets and schedules are quite finite, requires us to use models that are as simple as practical for a given situation. In fact, knowing how simple to go is a hallmark of a good engineer.

With this in mind I have come up with a working definition of **infinite** as *too large to cause problems* and an effective equivalent of **zero** as *too small to be noticed*, a definition that varies with each particular problem. By this definition, acceptable isolation can be achieved by selecting attenuator resistors much larger than the set resistance. One very suitable topology that delivers this is shown in Fig. 5.

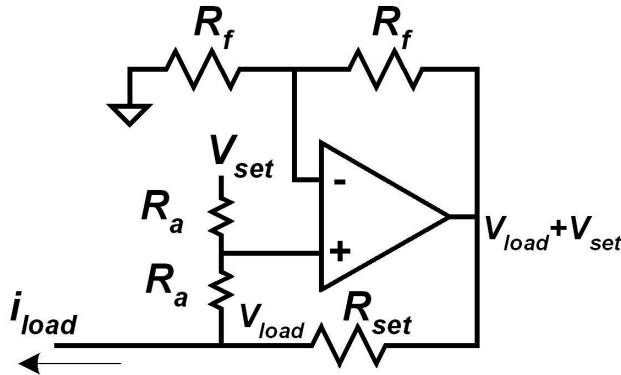


Fig. 5: Improved Single Op Amp Variable Current Source

For this topology there will be an interaction between the attenuator resistors and the set resistor. The load current is defined as:

$$i_{load} = \frac{(V_{load} + V_{set}) - V_{load}}{R_{set}} + \frac{V_{set} - V_{load}}{2 \cdot R_a} = \frac{V_{set}}{R_{set}} + \frac{V_{set} - V_{load}}{2 \cdot R_a}$$

Isolating the two voltage terms results in:

$$i_{load} = \frac{V_{set}}{R_{set} \parallel 2 \cdot R_a} - \frac{V_{load}}{2 \cdot R_a}$$

Removing the isolation buffer causes the current to increase slightly while there is now a parasitic impedance. A model of it is in Fig. 6.

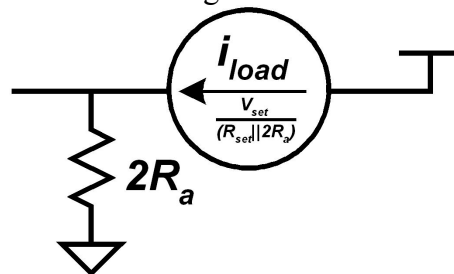


Fig. 6: Model of Current Source Shown in Fig. 5

Suppose you want to make a 20 mA current source, deciding on a 1 V set voltage and 49.9 Ω 1% set resistor (real value). You make the attenuator resistors each be 1 MΩ. 2 MΩ in parallel with 49.9 Ω is, effectively, 49.9 Ω (49.89887550). The parasitic impedance is 2 MΩ.

Switched-Capacitor Voltage-Controlled Single Op Amp Amplifier Current Source

A differential amplifier is very simple to build using switched capacitors (Fig. 7).

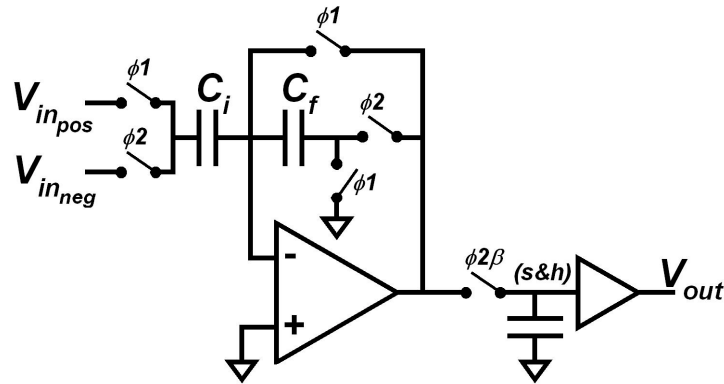


Fig. 7: Switched-Capacitor Differential Amplifier

This is a two phased clock system with:

ϕ_1 being for acquisition of voltages

ϕ_2 being for transfer of charge

The clocks are feeding the op amp are run in what I like to call under-lapped, or break-before-make mode, to guarantee that both phase switches are never simultaneously on, even momentarily, at the same time.

During the voltage acquisition phase, the output of the op amp is directly connected to the negative input. This negative feedback causes it to be at the same potential as the positive input (ground). The adjacent side of the input capacitor is set to V_{in_pos} while adjacent side of the one side of the feedback capacitor is also set to ground.

During the charge transfer phase the input is changed to V_{in_neg} . For the voltage to change there must be some moment of charge. This relationship is defined by:

$$q = C_i \cdot (V_{in_pos} - V_{in_neg})$$

This charge must flow through the feedback capacitor. This is accomplished by changing V_{out} as expressed in the equation below.

$$q = V_{out} \cdot C_f = C_i \cdot (V_{in_pos} - V_{in_neg}) \quad V_{out} = \frac{C_i}{C_f} \cdot (V_{in_pos} - V_{in_neg})$$

A sample and hold circuit is included to sample this output at the end of the charge transfer phase to convert it to a continuous signal.

The circuit's gain is a function of the ratio of the two capacitors. If these capacitor have the same value the gain is one.

For a better understanding of switched capacitor circuits I recommend application note AN2041 (Understanding Switched Capacitor Analog Blocks) available from Cypress http://www.cypress.com/portal/server.pt?space=CommunityPage&control=SetCommunity&CommunityID=285&PageID=552&shortlink=DA_239418&REF=SCH&CID=ILC-shortlinks&shk=DA_239418&REF=SCH

Using a Cypress CY8C27x74 programmable system on a chip <http://www.cypress.com/portal/server.pt?space=CommunityPage&control=SetCommunity&CommunityID=209&PageID=259&fid=24&rpn=CY8C27443&ref=drs> it is possible to build such a circuit with a single switched capacitor analog block (Fig. 7).

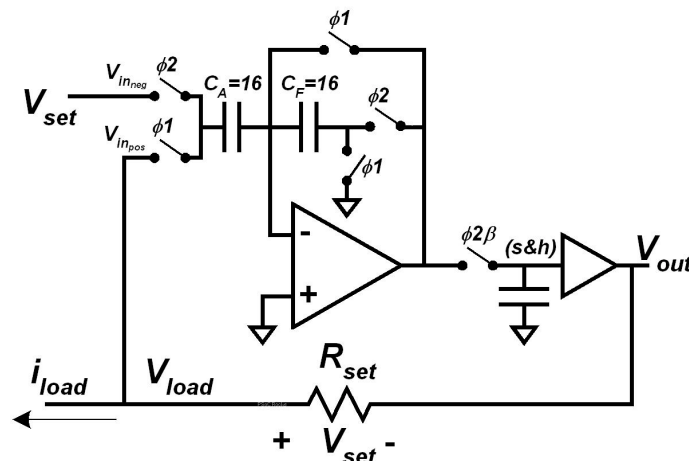


Fig. 7: Switched-Capacitor Differential Amplifier Current Source

This amplifier's output buffer will source or sink 40 mA for outputs up to 0.75 V away from the rails. It is possible to implement up to four of these current sources with this particular part.

There are many ways to build a current source that exploits unity gain and positive feedback.

Amazing as it is, I was able to cover this subject in only a single installment. Next month will be on the subject of slew-limited filters. These are non-linear filters that can be very useful in certain applications. This is also something they didn't teach in college.

Postscript

Knowing different circuit topologies is a by-product of lacking the peculiar cognitive skills and predatory instincts required for survival in the management world, leaving one no other option than to stay technical. The longer you stay technical, the more tricks you learn. If you stay technical long enough, the people that taught you these tricks die and then you can take credit for them yourself. Comments are welcome. So are questions. Feel free to contact me at dvw@cypress.com.

About The Author

Dave Van Ess is a Principal Application Engineer at Cypress Semiconductor. He is an electrical engineer with experience in hardware, software, and analog design. Dave joined Cypress in 2000. He has nine patents for medical systems, signal processing design, and PSoC digital block enhancements. He has written numerous User Modules, application notes, and articles. He graduated sigma cum barely with his BSEE from the University of California, Berkeley, 1977.

An engineer by training, a poet by temperament, an outlaw in Nebraska, and a heck of a nice guy, Dave has worked in many different industries. His work experience includes test and measurement equipment, measurement and control systems for high energy physics research, and underwater acoustic transmitters and receivers deployed in open sea and arctic ice fields. Electrons fear him! Women revere him!

