This current source is very temperature-stable; the output current varies by less than 1% over the temperature range -55°C to +100°C. This is possible because the transistor is biased by an LED, whose forward voltage drop has a temperature coefficient of -2mV/°C, the same as the base-emitter voltage of a silicon transistor. Hence near-perfect temperature compensation is possible, a great improvement over conventional methods of biasing with zener diodes.

The circuit values shown give an output current of about 1mA, though wide variation is possible by altering the value of emitter resistance. They are good for supply voltages in the range 25V to 5V.
Two-terminal current controller

This is an adaptation of Williams' well-known ring-of-two to produce an adjustable current regulator or limiter for use in test circuits or incorporation into power supplies. Its particularly low minimum voltage drop, around 1.4V, is obtainable by combining germanium alloy transistors and forward-biased silicon diodes.

The ring-of-two uses transistors $T_1$ and $T_2$, drawing a nearly constant current over a wide range of voltage. If only a small controllable current is required, this may be adjusted by varying either $R_x$ or $R_y$, or both. It is desirable to keep the ring-of-two transistors as cool as possible, and so $T_1$ and $T_2$ are added. The current in this pair is adjusted by means of $R_x$. Transistor $T_3$, in heavier transistor and carries the major part of the total current whereas $T_4$, like $T_1$ and $T_2$, operates at low current for stability.

J. F. Holland,
London SW15.
A precision voltage-controlled current source can be made by placing a pair of complementary field-effect transistors in the feedback loop of an operational amplifier. The resulting circuit will have a differential input, as well as a bipolar output current that can be used to drive either grounded or floating loads. From signals of up to ±10 volts, the circuit develops a ±10-milliampere output, accurate to within ±0.01%.

Signal voltages are usually derived from control voltages, but sometimes it is better to derive signal currents from the control voltages for a testing or driving certain loads. For example, a voltage-controlled current source can provide a simple programmable bias current for transistor testing. Or it can be used for resistance measurement, since contact resistance will not affect the test signal supplied by a current source. A current output is also needed for process-control instrumentation or for driving a meter or a dc torque motor.

These varying applications may involve unipolar or bipolar output currents, single-ended or differential inputs, grounded or floating loads or sources, and varying degrees of accuracy. The circuit shown in the diagram can satisfy all of these requirements, and it is simpler than many previous not-as-versatile current sources.1,2

The circuit here consists of opposing FET current sources that are controlled by high-gain feedback around an op amp. The difference in FET currents produces the output current, and this difference current is controlled by summing the feedback, at the amplifier input, from the current-sensing source resistors (Rs). At feedback equilibrium, the sum of the two feedback signals is directly related to the differential input signal. The circuit's output current is given by:

\[ I_o = -\frac{nE_i}{R_s} \]

where \( n \) represents the desired resistance-ratio factor. Differential inputs and high power-supply rejection are provided by an attenuator network at the inverting amplifier input; it matches the feedback network

---

Current drive. Voltage-controlled current source can accept a single-ended or differential input, supply a unipolar or bipolar output, and handle a grounded or floating load or source. The difference current developed by the complementary FETs is sensed by resistors \( R_s \) and fed back to the amplifier input, where it is summed with the input signal voltage. Both FET gates are driven from the op-amp supply terminals.
nected to the other amplifier input. This is analogous to
the attached input and feedback networks connected to
an op amp to form the common difference amplifier.2

To simplify biasing and improve large-signal band-
width, the gates of both FETs are driven from the op-
amp supply terminals, rather than from the op-amp
output terminal. Quiescent biasing for the FETs is ob-
tained from the quiescent current drains of the op amp,
and no level-shifting bias must be set up from the am-
plifier to the FETs.

Large-signal bandwidth is also improved by the re-
duced output swing required from the amplifier. Only a
1-Volt swing is needed across amplifier load resistor Rl,
to obtain the rated output current, which is drawn
through the supply terminals for maximum drive to the
FETs.

Additionally, the lower amplifier output swing is not
as greatly bandwidth-limited by the amplifier slewing-
rate limit, as it is in other designs. Optimum bandwidth
is achieved by making resistor R1 small enough to limit
output swing without excessively lowering amplifier
gain. Large-signal bandwidth is then limited by the am-
plifier's maximum common-mode swing rate.

The circuit's output current is controlled by the input
voltage to within the accuracies of the resistors selected
and within the gain-bandwidth and power-supply-rejec-
tion limitations of the op amp used. Most accuracy limi-
tations caused by the FETs are overcome by the feed-
back, except for the small contributions from gate-drain
leakage currents.

Output current is limited to the input level of the FETs
but can be boosted by using the transconductance mul-
tiplying technique sometimes employed for common
FET controlled current sources.3 Output impedance is
multiplied, through the feedback, from that of the FETs
to the practical limit imposed by stray and parasitic ef-
facts—16 μ around 100 ohms shunted by 10 picofarads.

By virtue of the circuit's differential inputs, commo-
mode signals are eliminated by a common-mode rejec-
tion that is adjustable to over 90 decibels. The primary
common-mode-rejection limitations are the accuracies
of the resistor ratios and the resistor matches, except for
the noncritical match between the FET gate resistors
(Rg).

The common-mode rejection can be adjusted by trim-
ing the input resistors. Prior to this adjustment, any
desired nulling of the offset voltage should be performed
by trimming the resistors denoted as Rb.

References
2. D. Yamaoka, J. Shikuma, and Y. Hasegawa: "Operational Amplifiers: Design and Appli-

Wireless World, December 1973

Self-star for ring of two

A common method of providing self-
starting for the ring-of-two circuit is to
connect a resistor between the bases of
the two transistors. This has the disadvant-
age that it reduces the stabilizing ratio. The
circuit shown here also has an active resistor
for self-starting but there is no degradation
of the performance. Any change in the
current through the starting resistor R is
cancelled out by a change in the current
through Tr, and there is no net effect on
the normal operation of the circuit, pro-
vided of course that there is still a reason-
able current through Tr. Even a value as
low as 3 mg produced no noticeable altera-
tion of the performance of the circuit
shown in the diagram, while a 1 kg resistor
between the bases reduced the stabilization
from 3 x 106 to 2 x 104.

Floating current source drives automatized test fixture

by Richard M. Fisher
ADP Security Systems, Ottawa, N. J.

This generator provides a programmable current to drive any load, making the unit ideal for production-line testing. Because the constant-current source floats—that is, it is not connected to ground—it can drive loads energized either by positive or by negative potentials of as much as 90 volts.

The output current is resolved to 50 microamperes by the 10-bit input to a digital-to-analog converter (a). The maximum current that can be delivered to the load is slightly more than 50 milliamperes.

As shown, the 10-bit command input is transferred to the d-a device through optocouplers, thus isolating the DAC-10Z from ground paths under virtually all conditions. Note the 5+, +15-, and -15-V potentials for the generator are obtained from circuitry associated with the isolated secondary winding of the transformer in the power supply.

Operational amplifier A1 inverts and scales the output of the d-a converter. The maximum output voltage from the converter is -9.99 volts and results in a full-scale output voltage of 5.115 V (from A2). A2, in conjunction with R1 (= 100 ohms), thus provides a full-scale output current of 51.150 mA.

The V- groove MOS field-effect transistor, Q2, serves as a voltage-to-current converter. Q1 performs the conversion at high accuracy, because the V-MOS device requires no gate current.

As for using the current source, implementation is easy with any energizing potential. If the device—the load—under test is driven by a positive voltage (b), it is necessary to connect the generator's positive output to the supply voltage. The negative port of the generator is brought to the load.

For negative potentials, the situation is similar, with source's positive terminal being connected to the load as shown. The negative port is connected to the supply voltage.

Ground free. Programmable current source (a) has balanced output for driving active loads energized by either positive or negative potentials (b). 10-bit digital control provides sources with resolution of 50 µA. Unit's full-scale output is slightly greater than 50 mA.
Althouß the single operational amplifier configured with the usual input and feedback resistors provides a passable voltage-controlled current source in low-energy applications, circuit stability and component sensitiv-
y problems may be encountered in actual operation. Christopher S. Tocci
of Krohn-Hite Corp., Avon, Mass., suggests a better idea—use two op
amps and a sensing resistor to eliminate the compensating networks
normally required with one-chip sources and to strain extremely high
output impedance without closely matched resistors.

At the inputs, Tocci connects the control voltage to the noninverting input
of an op amp, $A_1$. $A_1$'s output is connected to the noninverting input
of a second op amp, $A_2$, which in turn is connected to $A_1$'s remaining
input. The sensing resistor is placed across $A_2$'s inputs, with the load
connected from $A_2$'s inverting input to ground.

The transfer function for this circuit is $I_{o} = V_{i}/A_{1}R$, where $V_{i}$ is in
volts, $A_1$ is the differential gain of op amp $A_1$, and $R$, the sensing resistor,
is in ohms. The output impedance is $Z_{o} = RAA_{1}$, where $A$ is the
open-loop gain of op amp $A_2$. 
Low-current source

It is possible to use a reverse-biased germanium diode as a voltage independent current source for loading shunt transistors. Advantages of this method are low voltage lost across the source when compared with FETs and similar sources, it is cheap, and the diode \( i_d \) increases with temperature in much the same manner as the \( h_{fe} \), \( i_e \), in a transistor. The low point allows reliable micro-power circuits to operate over a wide temperature range at optimum current drain. This principle was applied in the amplifier circuit shown. The diode leakage current is arranged to be greater than the collector-emitter leakage of the transistor, permitting linear operation. Performance figures are a voltage gain of 50, a −3db bandwidth from 16Hz to 4kHz, a maximum output into 1kΩ of 390mV pk−pk (at 300Ω), an input impedance of 10kΩ (50KΩ), and a consumption of 20–40μW.

Owing to manufacturing tolerances the operating point can only be guaranteed to within a decade or two, and the diode capacitance is extremely non-linear at low reverse voltage.

M. G. Bailer.
Floating current source drives automatized test fixture

by Richard M. Fisher
ADT Security Systems, Clifton, N. J.

This generator provides a programmable current to drive any load, making the unit ideal for production-line testing. Because the constant-current source floats—that is, is not connected to ground—it can drive loads energized either by positive or by negative potentials of as much as 90 volts.

The output current is resolved to 50 microamperes by the 10-bit input to a digital-to-analog converter (a). The maximum current that can be delivered to the load is slightly more than 50 milliamperes.

As shown, the 10-bit command input is transferred to the d-a device through optocouplers, thus isolating the DAC-10Z from ground paths under virtually all conditions. Note the 5-, +15-, and -15-V potentials for the generator are obtained from circuitry associated with the isolated secondary winding of the transformer in the power supply.

Operational amplifier A₁ inverts and scales the output of the d-a converter. The maximum output voltage from the converter is -9.99 volts and results in a full-scale output voltage of 5.115 V from A₁. A₂, in conjunction with R₁ (100 ohms), thus provides a full-scale output current of 51.150 mA.

The V-groove MOS field-effect transistor, Q₁, serves as a voltage-to-current converter. Q₂ performs the conversion at high accuracy, because the V-MOS device requires no gate current.

As for using the current source, implementation is easy with any energizing potential. If the device—the load—under test is driven by a positive voltage, (b), it is necessary to connect the generator's positive output to the supply voltage. The negative port of the generator is brought to the load. For negative potentials, the situation is similar, with source's positive terminal being connected to the load as shown. The negative port is connected to the supply voltage.

Ground free. Programmable current source (a) has balanced output for driving active loads energized by either positive or negative potentials (b). 10-bit digital control provides source with resolution of 50 µA. Unit's full-scale output is slightly greater than 50 mA.

116 Electronics / August 2, 1979
Split current source damps reactive load oscillations

by Yshay Netzer
Hafla, Israel

A standard bilateral current source of the type shown in the first part of the figure (a) will often generate oscillations in circuit leads that are grounded and have an impedance \( Z_0 \) that is not purely resistive. Inductive loads such as cathode-ray-tube deflection yokes and torque motors are best driven by the modified circuit shown in the second part of the figure (b). Adding the differential amplifier and feedback network to the circuit eliminates undesirable responses while ensuring that the output current will be virtually independent of the load impedance.

When the load is reactive, it may cause the circuit's step response to be underdamped and consequently unstable, with the result that the output current will become dependent on the load impedance. As shown in the equation in (a), the output current is dependent on the circuit transfer function, which is:

\[
G(s) = \frac{V(s)}{I_{out}(s)} = \frac{1}{s^2 + 2\zeta \omega_n s + \omega_n^2}
\]

where \( \omega_n \) is the natural undamped frequency of the circuit, \( K \) is a constant, and \( \zeta \) is the damping factor.

The various parameters are determined by circuit constants \( K \), \( R_0 \), and \( Z_0 \). Of particular importance is the fact that once determined by the circuit configuration, \( \zeta \) cannot be modified, and that is why oscillations can result. Furthermore, the oscillations may be impossible to eliminate in the standard circuit because adding components may affect the output impedance, making any type of compensation impractical.

The circuit in (b) circumvents the problem by splitting the current source into two parts:

- A balanced difference amplifier \( (A_v) \), which converts the load current into a single-ended voltage feedback signal.
- A power amplifier \( (A_t) \), which, aside from assuming its original function, reduces the effect of \( Z_0 \) upon \( I_t \) by making use of the feedback voltage.

Note that by adding the feedback network, resistor \( R_0 \) has been introduced to the circuit, and therein lies the major advantage of this circuit. \( R_0 \) can vary (compensate) \( \zeta \) right down to its optimum value (2/3 in this case), without disturbing the proportional relation of \( V_0 \) to \( I_t \) throughout the useful range of the circuit; that is, below \( \omega_n \). The basic transfer function of the circuit is not
altered by the modified configuration, either.

The value of $R_C$ is best found experimentally while observing the circuit response to a square wave input.

Note that the constant, $K_c$, in $G(s)$ will be slightly smaller than its original value because of the feedback current through $R_C$. 
Bipolar current mirror scales, inverts signals
by Henry E. Santana
November 28, 1967
Lowood, Calif.

A pair of operational amplifiers and a few resistors build
this precision current mirror. Though simple and low in
cost, the circuit excels the usual designs because it not
only offers true bipolar operation but also can scale and/or invert any ac or dc input signal.

Input currents are applied to op amp A1, which is
biased by Vcc. If Ia is generated by a constant current
source, Vout may be brought to zero. Otherwise, it should be
set to some arbitrary value to maintain circuit bias.

A current-to-voltage converter at the input and a
circuit to-current converter at the output comprise the
current mirror. As a consequence of the configuration,
the current appearing at the output of A will thus be:

\[ \text{Vout} = \text{Vin} + \text{IaR1} \]

for R1 >> R3 and R4. The voltage applied to the output
circuit is therefore:

\[ \text{V1} - \text{V1} = \text{IaR1} \]

Writing the nodal equations for V1, V2, and V3 yields
these results:

\[ Ia = V1(1/R1 + 1/R2) + V3(1/R3) + V2(1/R4) \]

\[ V1 = A3(V2 - V3) = (GB)(V2 - V3) \]

\[ V3 = V1(1 + a) + V3(1 + a) \]

where GB is A3's gain-bandwidth product. Substituting
V3 and V1 into the equation for Ia, it is seen that Ia =
(R3/R4)Ia, given that a = b and k = GB/(1 + b).

The output impedance can be set, within limits, by
selection of aR4 and bR4. The output impedance is:

\[ Z_{out} = \left[ \frac{a}{1 + 2} \right] \left( S + \frac{GB}{1 + b} \right) \]

Since a must equal b for the circuit to work, this
equation simplifies to Z_{out}(s) = \left[ \frac{1}{1 + 2} \right] \left( S + \frac{GB}{1 + b} \right) \]

and no other assumptions about resistor ratios are made.

In addition to its use as a scaled current mirror, the
circuit will find other not-so-obvious applications. Such
an example is its use as a capacitance multiplier (b).

[Diagram of circuit with labels and connections]

lotechnics / February 14, 1968
A bipolar constant-current source that has a grounded voltage source and a grounded load is usually limited in accuracy and internal impedance by the degree of matching of two or more resistors. For the circuit below, however, no matched resistors are required; linearity and internal impedance are determined solely by the operational amplifier's gain, offset, and power-supply rejection ratio. This circuit takes advantage of the fact that the op amp's power supply can usually be floated.

To understand the operation of the circuit, remember that no current to speak of flows into the input terminals of the op amp under feedback conditions, and no voltage difference exists across the terminals. Thus, the op amp drives the common terminal of the power supply to the voltage level established at the inverting input. This voltage appears across the reference resistor $R_5$. It is set to a suitably low value by input attenuator $R_4$ and $R_6$ to avoid thermally induced errors caused by power dissipated in the reference resistor. The values of $R_4$ and $R_6$ are chosen to provide a convenient scale factor. The reference current thus established is exactly equal to the current flowing in the load, and therefore the load current is

$$I_{L} = -I_{f} = \frac{V_{in}}{R_4 + R_6}$$

The value of load current does not depend upon the value of load resistance and can be controlled by the value of $V_{in}$.

The minus sign in the expression for load current indicates the degenerative feedback action of the circuit. If $I_{f}$ increases, the extra voltage drop through $R_5$ drives the noninverting input of the op amp lower and thus decreases the output.

Resistor $R_6$ is made equal to the parallel combination of $R_4$ and $R_6$ to minimize any error caused by input bias current. For the values shown in the figure, input voltages ±10 volts produce current outputs up to ±10 milliamperes.

This circuit has been used for over a year to supply current to electromagnets. In this application it is boosted by an emitter follower for greater output current and more voltage compliance.
Milliampere current source is voltage-controlled

by William J. Mund
Concordia University, Department of Psychology, Montreal, Canada

The constant small positive or negative current produced by this voltage-controlled source is useful for a variety of low-level measurements. As the current also has a virtually linear relationship with the input voltage, it may be modulated as desired by a given input waveform or, still more usefully, be put under microprocessor control to create an automated test system.

As seen in (a), incoming signals in the range of 0 to 10 volts are buffered by the LM358 micropower operational amplifier A₁ and then introduced to A₂, which with transistor Q₁, makes the current-monitoring feedback circuit. For a given input voltage, A₂ amplifies and inverts Q₁’s emitter-to-base voltage variations, so that any increase or decrease in current due to temperature or load variations is counteracted. As a result, the current will rise linearly from zero to I_max, where I_max is determined by resistor R, with the variation of I for a given Vᵣ being about 2%. In this circuit, the maximum attainable value of I_max is approximately 4 milliamperes, obtained with a 1.5-kilohm load impedance.

Calibration of the circuit is simple. Potentiometer R needs only be adjusted to null the output current for Vᵣ = 0. For convenience in setting the output current, an oscilloscope can be placed across a 1-kΩ resistor.

The layout for this circuit’s counterpart, a negative current sink, is similar, as shown in (b). Q₂ becomes an npn transistor, the supply potential on the circuit is reversed, and an inverting stage is added at the input.

Although the circuit is relatively insensitive to variations in the supply voltage, use of a regulated power supply of the simple series type is recommended.

Milliampere magnitudes. The circuit’s input voltage sets a constant output current to within 5% of the desired value, adjustable from 0 to 4 mA if R = 1.5 kΩ. Its linear response makes it attractive for microprocessor-based (automated) tests and measurements. The positive source in (a) or negative sink in (b) is simply calibrated by means of resistor R, and an oscilloscope monitor.
Bilateral current source is digitally programable
by Andrew Olesin
Semiconductor Corp.

Engineers use adjustable current sources for measuring device characteristics such as transistor beta or diode-breakdown voltage. To automate the procedure, a digitally controlled current source that can be programmed for currents of ±1 nanoampere to ±1 milliamperes can be made from two operational amplifiers and a multiplexer. The digital inputs can be directly driven by transistor-transistor logic or complementary-MOS, and the polarity of the input voltage determines whether the circuit is a current source or a current sink.

The basic bilateral current source is shown in Fig. 1. Operational amplifier A2 is a high-input-impedance voltage follower, that drives the node where voltages $V_{ox}$ and $V_{OUT}$ are summed. The node voltages are

$$V_a = \frac{(V_{OUT} + V_{IN})}{2}$$

$$V_i = V_iL + \frac{(R_I/R_D)}{2}$$  

This last equation shows that the voltage across resistor $R_{OUT}$ equals $V_{OUT}$, therefore, because $A_2$ has a high input impedance,

$$I_{OUT} = \frac{V_{OUT}}{R_{OUT}}$$

Maximum output current is limited by the current available from op amp $A_1$ at its maximum output volt-

1. Current source. Basic circuit provides output current $I_{OUT}$ and $V_{OUT}$, direction of current is given by sign of $V_{IN}$. Resistance $R_{OUT}$ can be made digitally adjustable, as shown in Fig. 2.

2. Programable. C-MOS multiplexer connects various resistors into circuit to serve as $R_{OUT}$. Thus current is adjusted by digital control.

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Constant Current Source

J Macaulay

The circuit shown will provide 3 preset currents which will remain constant despite variations of ambient temperature or line voltage.

ZD1 produces a temperature stable reference voltage which is applied to the non-inverting input of IC1. 100% DC feedback is applied from the output to the inverting input holding the voltage at Q2's emitter at the same potential as the non-inverting input.

The current flowing into the load therefore is defined solely by the resistor selected by S1. With the values employed here, a preset current of 10mA, 100mA or 1A can be selected. Q2 should be mounted on a suitable heatsink.
Voltage-to-current converter handles bilateral signals

by Kevin Shah
General Motors Proving Ground, Milford, Mich.

Sending an analog voltage from one point to another via a slip ring and brush assembly often causes distortion in instrumentation applications, because of the attendant voltage drops across the variable resistances encountered and also because of induced noise. By converting the voltage to a current before transmission (and back to a voltage at the receiving end), however, these circuits eliminate those problems. And unlike converters that generate a problem of their own—their inability to handle bilateral input signals—this one will transform a ±10-volt signal into a ±10 milliampere current at the transmitter and recover the ±10-v signal at the receiver.

At the transmitter, input voltage $V_I$ is applied to one branch of a summing-amplifier circuit consisting of $A_1$, $R_1$, $R_2$, and $R_3$. The other branch is driven by $V_L$, which is the transmitter's output voltage. As a consequence of this feedback arrangement, the voltage from inverting amplifier $A_2$ is $V_I - V_L$.

Current booster $Q_1-Q_2$, which is part of $A_2$'s feedback resistor network, provides a low-impedance source for generating a current, $I_L$, with $Q_1$ becoming active for positive input voltages and $Q_2$ active for negative input voltages. Thus, $I_L = (V_I + V_L) - V_L)/R_3 = V_I/R_3$, and therefore the output current is a function of input voltage $V_I$ only.

At the receiver, $A_3$, $Q_3$, and $Q_4$ detect input current $I_L$ and convert it to a voltage, $-V_L$. Note that the two-transistor arrangement similar to that employed in the transmitter is again required to process the bilateral input current encountered. $A_3$ acts as an inverting amplifier so that the output signal, $V_O$, is recovered.

Communicating current. Converter (a) transforms bilateral analog voltages into corresponding currents for high-accuracy transmissions over high-resistance networks. Receiving converter (b) performs inverse operation to recover input voltage. Low-cost op-amps and transistors are used throughout. Beckman package in (a) and (b) provides low-cost source of matched resistors required for very precise conversions.

Electronics / May 10, 1979
VOLTAGE CONTROLLED CURRENT SOURCE

The voltage follower IC1, buffered by TR1 provides a current at the collector proportional to the input voltage due to R1. This current is applied to R2 which means that the voltage across it will be Vin*R1.

IC2 forces the voltage across R3 to equal that across R2. The zener prevents IC2's inputs from operating at the supply rail.

In this circuit the input voltage is generated relative to the 0V rail. For maximum output voltage capability the voltage across R2 and R3 at the maximum proposed output current should be kept small. However offsets in the IC's have more effect on the linearity as the max resistance of VR2 becomes smaller – these should be nulled out.
An exponential current source can be used to drive a linear vCO.
The vCO then has a 1 V/octave response.
Devices all powered from a 12 V.
*Matched transistors in thermal contact.
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Voltage-to-current Converters

Source
I = \( \frac{V_n}{R} \)

Sink
I = \( \frac{V_n}{R} \)
VOLTAGE TO CURRENT CONVERTER

The virtual earth of an op-amp and the current source characteristic of a transistor can be combined to produce a precision linear voltage to current converter. Consider the 'SOURCE' circuit. A positive voltage is applied and the op-amp adjusts itself to that a 'virtual earth' condition is maintained. This means that a current \( i \) flows through the input resistor \( R \), where \( i = \frac{V_{in}}{R} \). Now this current has got to go somewhere, and so it flows through the PNP transistor and comes out of the collector and into its load. Thus, the input voltage generates a current which is linearly proportional to it. There are, however, three sources of error that will affect this linearity. First the input offset voltage of the op-amp may become significant at low levels of \( V_{in} \). Second, the input bias current may well rob a lot of the current when \( V_{in} \) is low. Third, the base current of the transistor must be subtracted from the final output current. Note that the current gain of the transistor will change with collector current variations, and so the base current loss is not a fixed percentage. However, a precise voltage to current converter can be made using an op-amp with a FET input so that the bias current is low. Also, an input balance can be used to zero out the input offset voltage, and if a FET is used to replace the bipolar transistor, then the base current problem can be removed.

The 'SINK' circuit merely swaps the transistor for an NPN type. Note that the input voltage now must be negative.

Fig. 14. Precision linear voltage to current converters.
RS232-to-20-mA Converter

Q. Do you have the schematic diagram of a simple circuit that I can use to interface an RS-232 data output port to a 20-mA, current-loop printer? —Michael Harrison, Falls Church, VA.

A. The circuit shown in the figure will allow you to use your 20-mA printer with your output port. It can be assembled for next to nothing if you have a decent junk box. Even if you have to buy all the components at retail, total construction cost will be less than $5.00. Transistor type numbers are not critical — just about any garden-various n-p-n and p-p-n silicon devices can be used. Transistor Q1 and its associated passive components function as an RS-232-to-TTL level converter. Inversion is performed by Q2. Q3 is a keyed 20-mA current source. Power for the circuit can usually be tapped from one of the system components. Current demand is very small.

Open-Collector Logic

Q. What is the difference between "normal" TTL gates such as the 7400 or
Cascading two μA723 precision voltage regulators in such a way as to enable them to monitor both output voltage and load current yields a circuit that can generate a constant-voltage, constant-current output. Output voltage can be adjusted over a range of 0 to 15 volts at a load current that is selectable from 0 to 3 amperes with the configuration shown.

In this circuit, output voltage is controlled by A2, which monitors load voltage with the aid of the associated network that is connected to the ports of its error-voltage amplifier (pins 4, 5, and 6). Any change in load current is detected by A3, which acts to generate a signal at its Vout port.

The current-limit input of A3 is then activated, and thus the current-limiting transistor internal to A3, which acts as a shunt across the error amplifier, can control the amount of driving current supplied to pass transistor Q2 at the set output voltage.

The output voltage is adjusted by R5. The value of R5 is approximately 1 kΩ for each volt appearing at the load R1. Because R1 = R4,

\[ V_{out} = K_1 R_1 V_{ref} \]

where \( K_1 = 1/2R_0 \).

Output current is adjusted by R0, the value of which will increase 1 kΩ for every 100-milliamperes increase in load current. Assuming R4 = R1, then it can be shown that:

\[ I_{out} = K_0 R_0 V_{ref} \]

where \( K_0 = 1/2R_0 R_0 \).

Zener diode D2 allows selection of the output current down to zero. Diodes D3 and D4 provide well-defined switching thresholds for A1 and Q2 to enhance the circuit’s response time to a changing output current and/or voltage.

*Designers’ checklist is a regular feature in Electronics. We invite readers to submit original and unpublished circuit ideas and solutions to design problems. Customarily but thoroughly the circuit’s operating principle and purpose. We’ll pay $50 for each item published.*

**Steady.** Cascaded regulators, one for monitoring load voltage, the other for current, form circuit that generates constant-voltage, constant-current output. Current and voltage are adjustable from zero. Maximum output voltage is 15 V; current limit depends on Q2’s rating.

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