## TEMPERATURE-STABLE CURRENT SOURCE

This current source is very temperature-stable; the output current varies by less then 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.
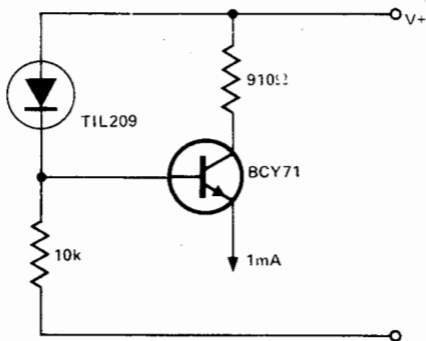
Two-terminal current controller

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 obtained by combining germanium alloy transistors and forward-biased silicon diodes.

The ring-of-two uses transistors Tr_1 and Tr_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_1 or R_2 or both. It is desirable to keep the ring-of-two transistors as cool as possible, and so Tr_3 and Tr_4 are added. The current in this pair is adjusted by means of R_3. Transistor Tr_4 is heavier transistor and carries the
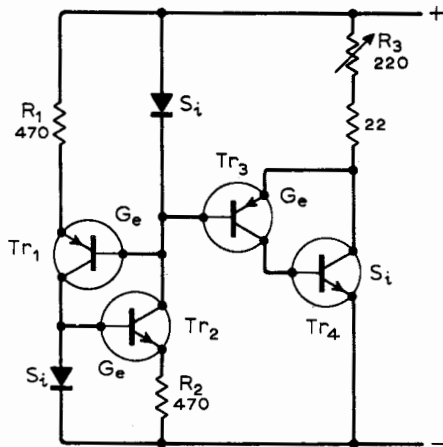
major part of the total current whereas Tr_3, like Tr_1 and Tr_2, operates at low current for stability.

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Controlled current source is versatile and precise

by Jerald Graeme
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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 either testing or driving certain loads. For example, a voltage-controlled current source can provide a simple programmable bias current for transistor testing.[1] 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 (R_S). 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:

$$I_o = -nE_i/R_S$$

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 con-
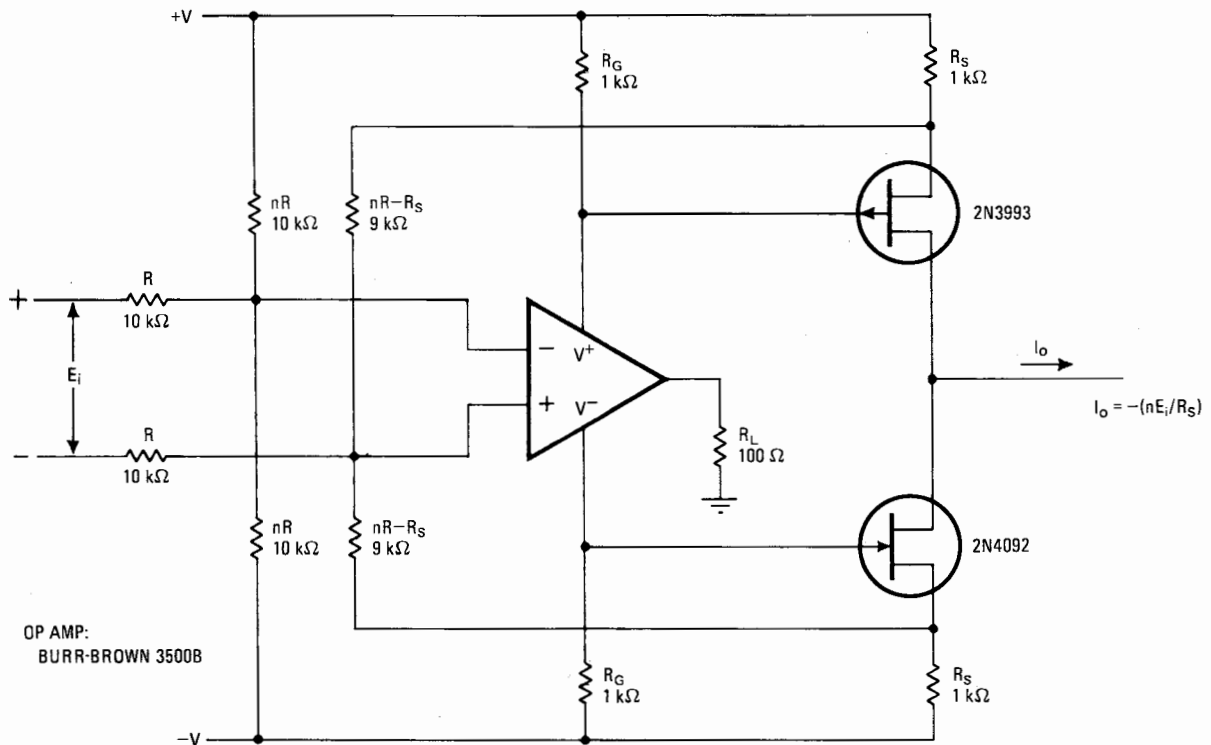
Current drive. Voltage-controlled current source can accept a single-ended or differential input, supply a unipolar or bipolar output, and handle a grounded or floating load or source. The difference current developed by the complementary FETs is sensed by resistors R_S and fed back to the amplifier 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 matched input and feedback networks connected to an op amp to form the common difference amplifier.[2]

To simplify biasing and improve large-signal bandwidth, 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 obtained from the quiescent current drains of the op amp, and no level-shifting bias must be set up from the amplifer to the FETs.

Large-signal bandwidth is also improved by the reduced output swing required from the amplifier. Only a 1-volt swing is needed across amplifier load resistor R_L 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 R_L small enough to limit output swing without excessively lowering amplifier gain. Large-signal bandwidth is then limited by the amplifier'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 limitations caused by the FETs are overcome by the feedback, except for the small contributions from gate-drain leakage currents.

Output current is limited to the I_{DSS} level of the FETs but can be boosted by using the transconductance multiplying technique sometimes employed for common FET controlled current sources.[1] Output impedance is multiplied, through the feedback, from that of the FETs to the practical limit imposed by stray and parasitic effects—it is around 10^{12} ohms shunted by 10 picofarads.

By virtue of the circuit's differential inputs, common-mode signals are eliminated by a common-mode rejection 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 (R_G).

The common-mode rejection can be adjusted by trimming the input resistors. Prior to this adjustment, any desired nulling of dc offset voltage should be performed by trimming the resistors denoted as nR. □
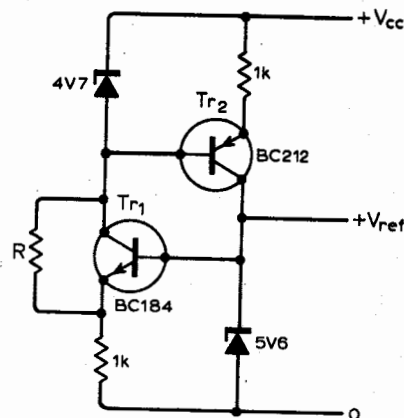
REFERENCES
1. J. Graeme, "Applications of Operational Amplifiers—Third Generation Techniques," McGraw-Hill, New York, 1973
2. G. Tobey, J. Graeme, and L. Huelsman, "Operational Amplifiers- Design and Applications," McGraw-Hill, New York, 1971.

Self-start 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 disadvantage that it reduces the stabilization ratio. The circuit shown here also has a single 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_1 and so there is no net effect on the normal operation of the circuit, provided of course that there is still a reasonable current through Tr_1. Even a value as low as 39kΩ produced no noticeable alteration of the performance of the circuit shown in the diagram, while a 1MΩ resistor between the bases reduced the stabilization from 5×10^4 to 2×10^4.

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Floating current source drives automatized test fixture

by Richard M. Fisher
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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
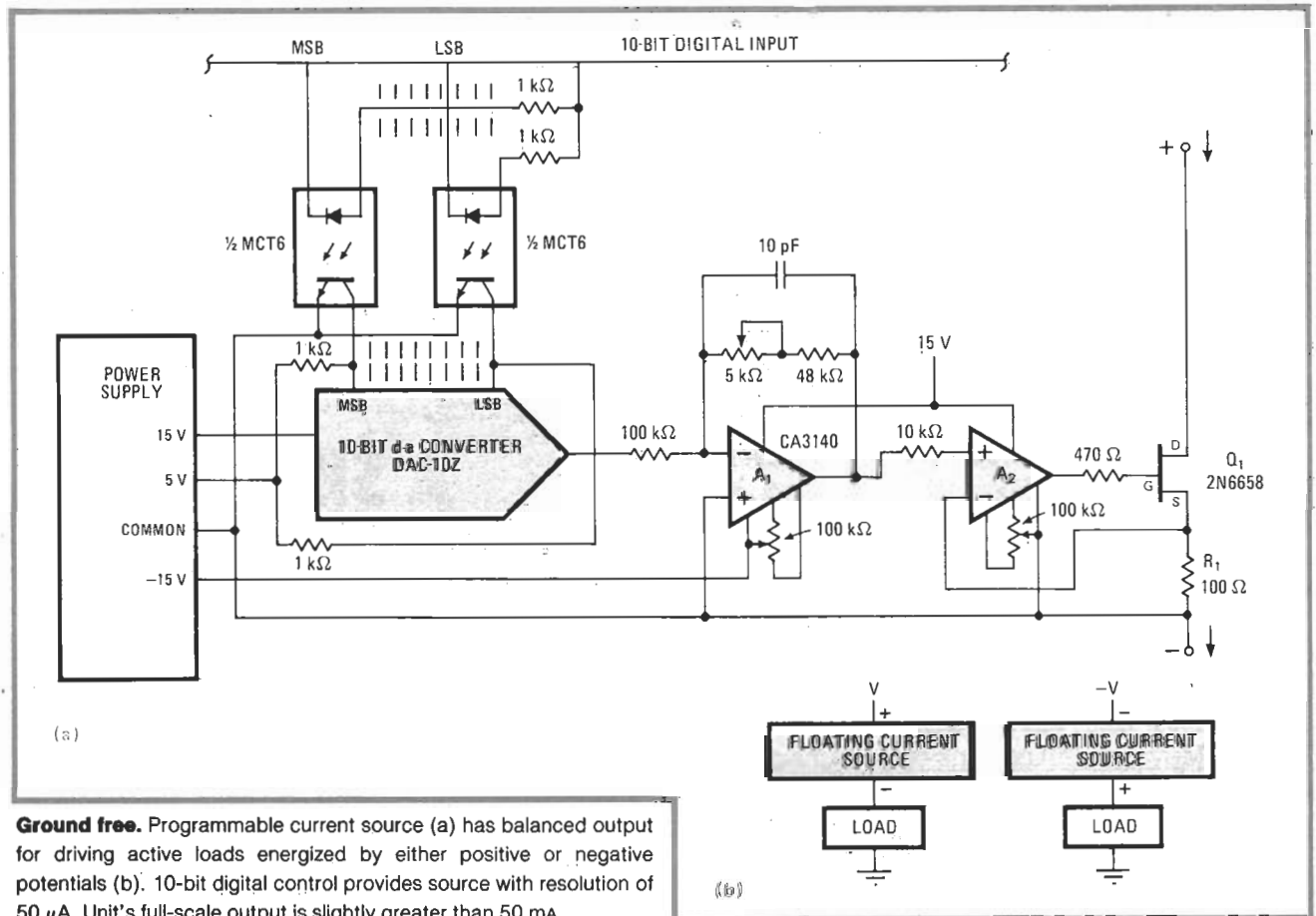
generator are obtained from circuitry associated with the isolated secondary winding of the transformer in the power supply.

Operational amplifier A_1 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 A_1. A_2, in conjunction with R_1 (= 100 ohms), thus provides a full-scale output current of 51.150 mA.

The V-groove MOS field-effect transistor, Q_1, serves as a voltage-to-current converter. Q_1 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.

## Back-to-back op amps stabilize constant-current source

Although 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 sensitivity 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 attain extremely high output impedance without closely matched resistors.**

At the input, 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 $I_{o\ (ma)} = V_{in}/A_2R$, where V_{in} is in volts, A_2 is the differential gain of op amp A_2, and R, the sensing resistor, is in kilohms. The output impedance is $Z_o = RAA_2$, 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 silicon transistors. Advantages of this method are less voltage lost across the source when compared with f.e.ts and similar sources, it is cheap, and the diode I_R increases with temperature in much the same manner as the h_{fe}. I_{cbo} in a transistor. The last point allows reliable micropower circuits to operate over a wide temperature range at
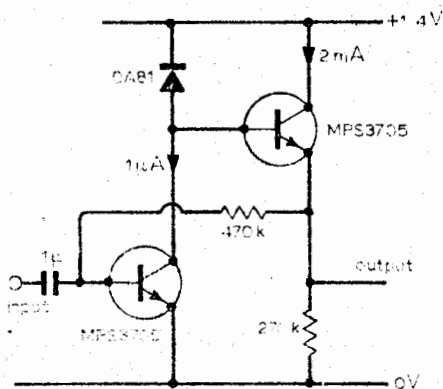
optimum current drain. This principle was applied in the amplifier circuit shown. The diode leakage current is arranged to be greater than the collector-emitter leakage of the transistor, permitting linear operation. Performance figures are: a voltage gain of 50, a −3dB bandwidth from 16Hz to 4kHz, a maximum output into 1MΩ of 500mV pk-pk (at 300Hz), an input impedance of 10kΩ (at 500Hz), and a consumption at 20°C of 4πW.

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 voltages.

M. G. Baker,

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.

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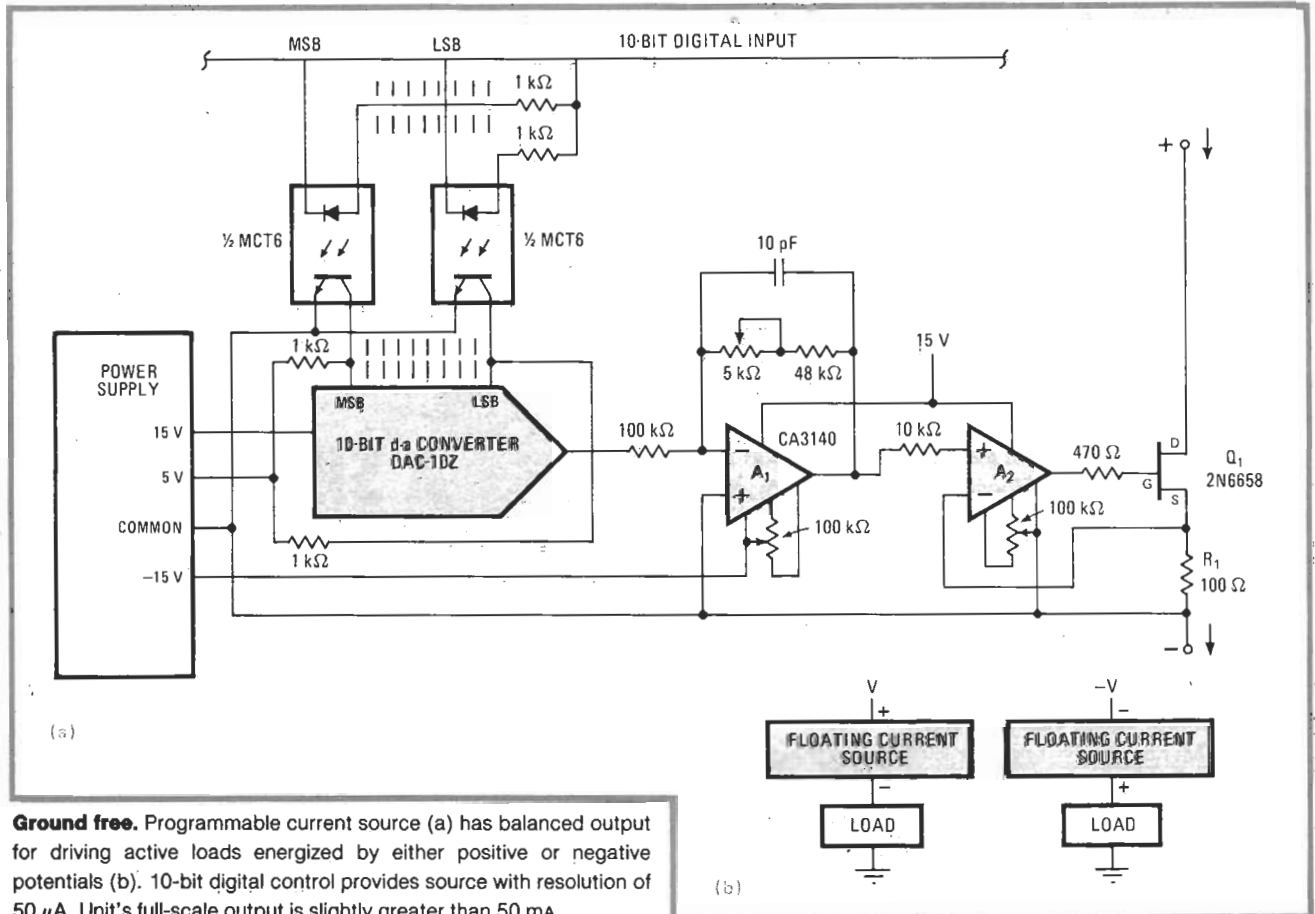
generator are obtained from circuitry associated with the isolated secondary winding of the transformer in the power supply.

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Split current source damps reactive load oscillations

by Yishay Netzer
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A standard bilateral current source of the type shown in the first part of the figure (a) will often generate oscillations in circuit loads that are grounded and have an impedance (Z_L) 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:

$$G(s) = K\frac{\omega_o{}^2}{s^2 + 2\zeta\omega_o s + w_o{}^2}$$

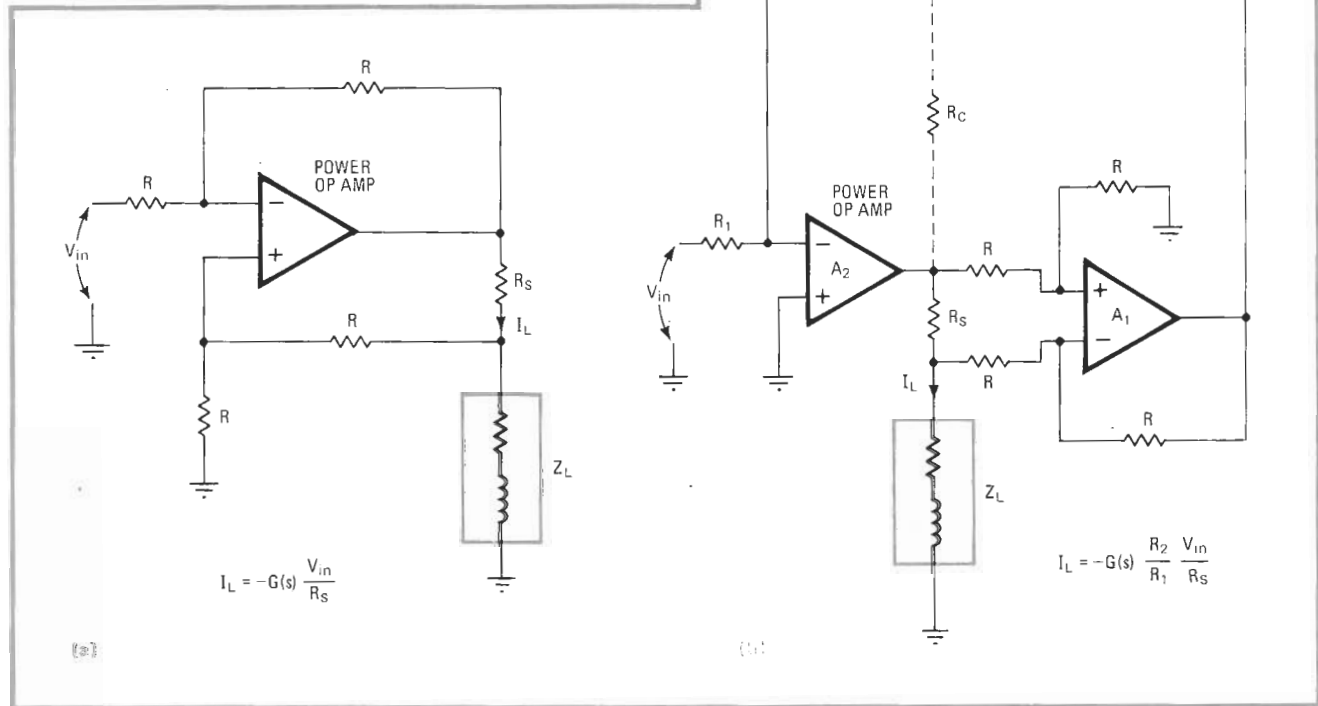where ω_o is the natural undamped frequency of the circuit, K is a constant, and ζ is the damping factor.

The various parameters are determined by circuit constants R, R_S, and Z_L. Of particular importance is the fact that once determined by the circuit configuration, ζ 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_1), which converts the load current into a single-ended voltage feedback signal.
- A power amplifier (A_2), which, aside from assuming its original function, reduces the effect of Z_L upon I_L by making use of the feedback voltage.

Note that by adding the feedback network, resistor R_C has been introduced to the circuit, and therein lies the major advantage of this circuit. R_C can vary (compensate) ζ right down to its optimum value ($2^{1/2}$ in this case), without disturbing the proportional relation of V_{in} to I_L throughout the useful range of the circuit; that is, below ω_o. The basic transfer function of the circuit is not

No oscillations. Standard current source (a) cannot drive inductive loads effectively because undamped circuit responses can occur and lead to oscillations. Adding operational amplifier A_1 and feedback network to circuit (b) enables R_C to adjust damping factor.

$$I_L = -G(s)\frac{V_{in}}{R_S}$$

$$I_L = -G(s)\frac{R_2}{R_1}\frac{V_{in}}{R_S}$$

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, in G(s) will be slightly smaller than its original value because of the feedback currents through R_C. $\square$

Bipolar current mirror scales, inverts signals

by Henry E. Santana
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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 A_1, which is biased by V_{ref}. If I_{in} is generated by a constant current source, V_{ref} 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 voltage-to-current converter at the output comprise the current mirror. As a consequence of the configuration, the voltage appearing at the output of A will thus be:

$$V_{A1} = V_{ref} + I_{in}R_1$$

for $R_1 >> R_2$ and R_L. The voltage applied to the output circuit is therefore:

$$V_2 - V_1 = I_{in}R_1$$

Writing the nodal equations for V_L, V_3, and V_4 yields these results:

$$I_L = -V_L(1/R_2 + 1/bR_2) + V_3(1/bR_2) + V_2(1/R_2)$$
$$V_3 = A_2(s)(V_L - V_4) = (GB/s)(V_L - V_4)$$
$$V_4 = V_1[a/(1+a)] + V_3[1/(1+a)]$$

where GB is A_2's gain-bandwidth product. Substituting V_3 and V_4 into the equation for I_L, it is seen that $I_L = (R_1/R_2)I_{in}$, given that a = b and s $<<$ GB/(1 + b).

The output impedance can be set, within limits, by selection of aR_2 and bR_2. The output impedance is:

$$Z_o(s) = \left[\left(\frac{a}{1+a}\right)\left(S + \frac{GB}{1+b}\right)R_2\right] \div$$
$$\left[S + \left(\frac{a-b}{1+a}\right)\left(\frac{GB}{1+b}\right)\right]$$

Since a must equal b for the circuit to work, this equation simplifies to $Z_o(s) = [1/(1+a)]\{1 + [1/1+a]GB/s\} R_2$, 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). □
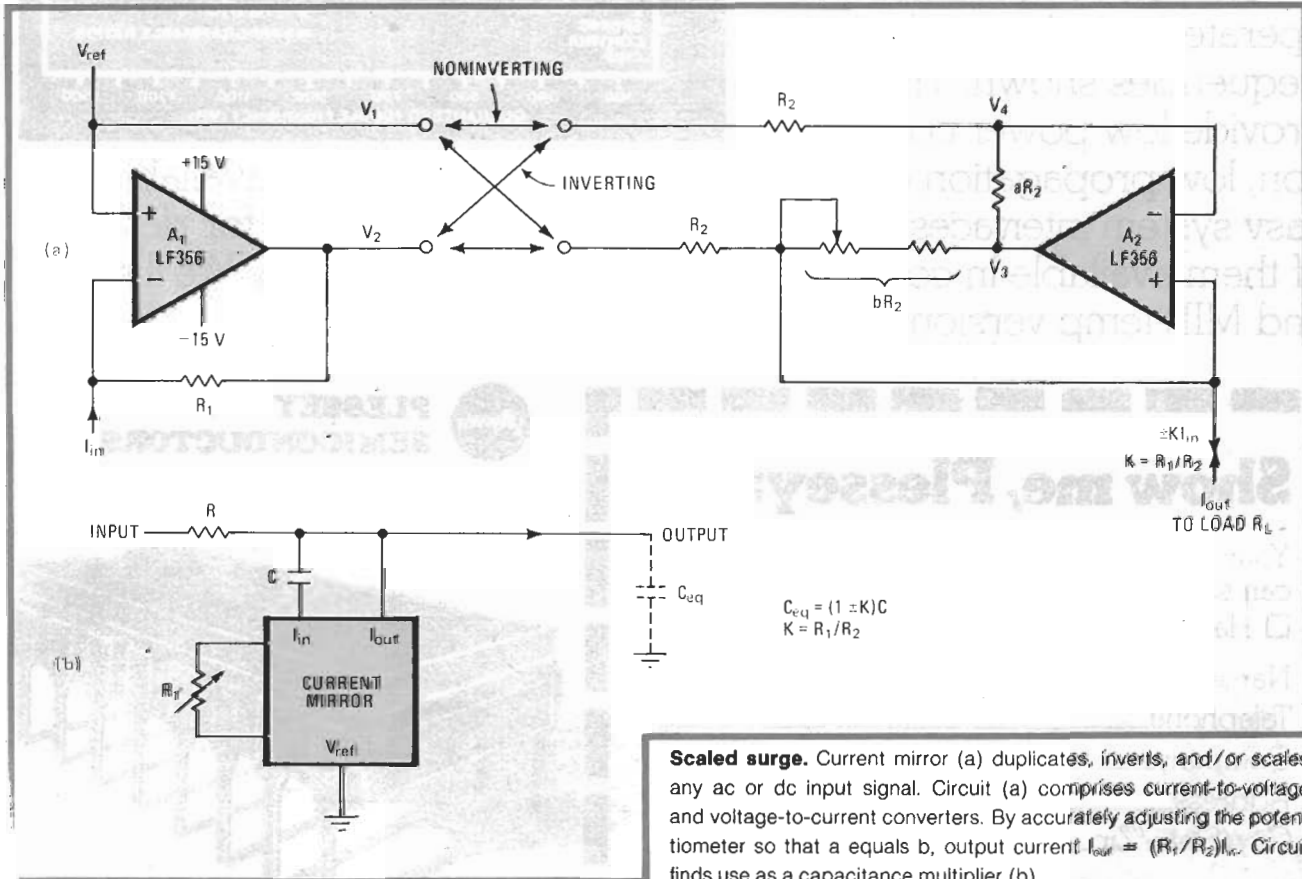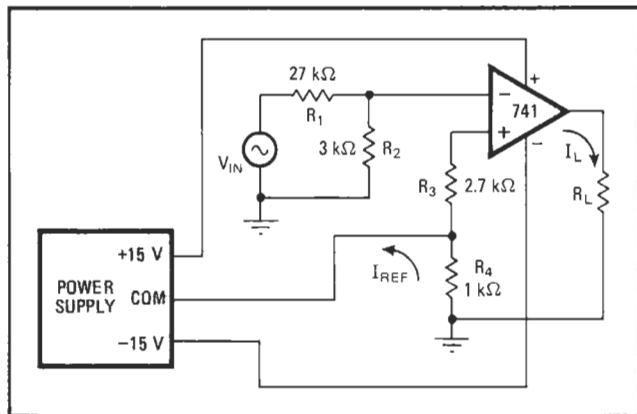

Scaled surge. Current mirror (a) duplicates, inverts, and/or scales any ac or dc input signal. Circuit (a) comprises current-to-voltage and voltage-to-current converters. By accurately adjusting the potentiometer so that a equals b, output current $I_{out} = (R_1/R_2)I_{in}$. Circuit finds use as a capacitance multiplier (b).

Controllable current source eliminates matched resistors

by James A. Stanko
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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 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_4. It is set to a suitably low value by input attenuator R_1 and R_2 to avoid thermally induced errors caused by power dissipated in the reference resistor. The values of R_1 and R_2 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

$$I_L = -I_{ref} = -\frac{V_{in}}{R_4}\frac{R_2}{R_1 + R_2}$$

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_L increases, the extra voltage drop through R_4 drives the noninverting input of the op amp lower and thus decreases the output.

Resistor R_3 is made equal to the parallel combination of R_1 and R_2 to minimize any error caused by input bias current. For the values shown in the figure, input voltages up to ±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. □

Uncritical. Load current produced by this circuit depends on input voltage, not load resistance. Circuit does not require matched resistors for accurate control of current, but power supply must float.

Designer's casebook

Milliampere current source is voltage-controlled

by William J. Mundl
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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 A_1 and then introduced to A_2, which with transistor Q_1 makes the current-monitoring feedback circuit. For a given input voltage, A_2 amplifies and inverts Q_1'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 V_{in} 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_1 need only be adjusted to null the output current for V_{in} = 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). Q_1 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. □
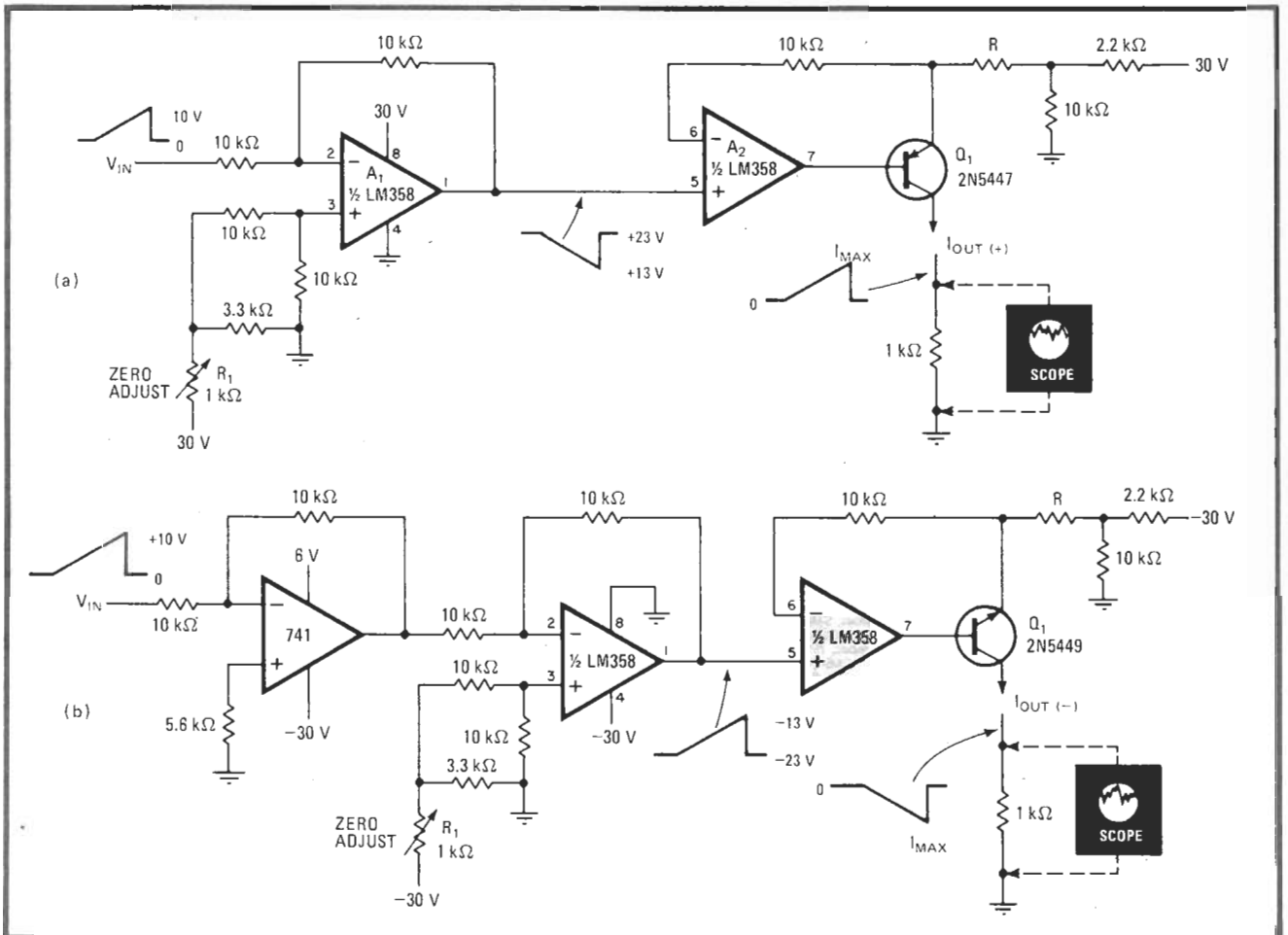
Milliampere magnitudes. The circuit's input voltage sets its constant output current to within 5% of the desired value, adjustable from 0 to 4 mA if R = 1.5 kΩ. Its linear response makes it attractive for microprocessor-based (automated) tests and measurements. The positive source in (a) or negative sink in (b) is simply calibrated by means of resistor R_1 and an oscilloscope monitor.

Bilateral current source is digitally programable

by Andrew Olesin
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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 programed for currents of ± 1 nanoampere to ± 1 milliampere 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 A_2 is a high-input-impedance voltage follower that drives the node where voltages V_{IN} and V_{OUT} are summed. The node voltages are

$$V_a = (V_{OUT} + V_{IN})/2$$
$$V_b = V_a[1 + (R_2/R_1)] = 2 V_a$$
$$= V_{OUT} + V_{IN}$$

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

$$I_{OUT} = V_{IN}/R_{OUT}$$

Maximum output current is limited by the current available from op amp A_1 at its maximum output volt-
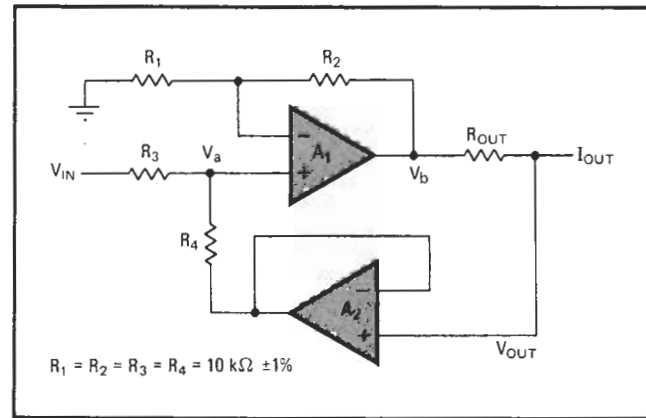
1. Current source. Basic circuit provides output current of V_{IN}/R_{OUT}. Direction of current is given by sign of V_{IN}. Resistance R_{OUT} can be made digitally adjustable, as shown in Fig. 2.
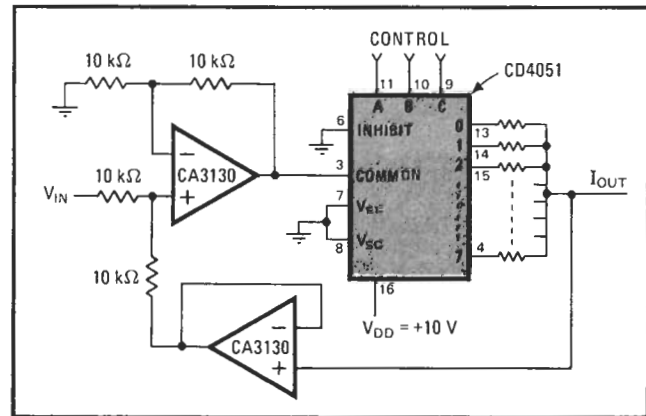
2. Programable. C-MOS multiplexer connects various resistors into circuit to serve as R_{OUT}. Thus current is adjusted by digital control.

Constant Current Source

J Macaulay

The circuit shown will provide 3 pre-set 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 Q2s 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.

Designer's casebook
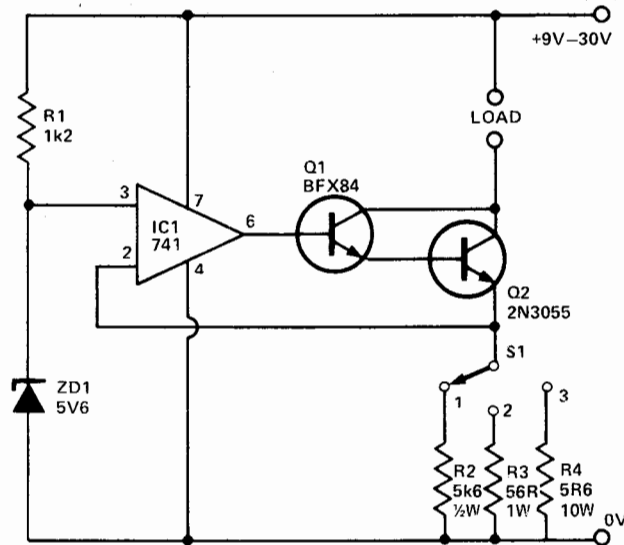
Voltage-to-current converter handles bilateral signals

by Kelvin Shih
*General Motors Proving Ground, Milford, Mich.*

Sending an analog voltage from one point to another via a slip ring and brush assembly often causes disaster 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_1 is applied to one branch of a summing-amplifier circuit consisting of A_1, R_1–R_3, and R_7. The other branch is driven by V_2, which is the transmitter's output voltage. As a consequence of this feedback arrangement, the voltage from inverting amplifier A_2 is $V_1 + V_2$.

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_o, with Q_1 becoming active for positive input voltages and Q_2 active for negative input voltages. Thus, $I_o = [(V_1 + V_2) - V_2]/R_6 = V_1/R_6$, and therefore the output current is a function of input voltage V_1 only.

At the receiver, A_4, Q_3, and Q_4 detect input current I_o and convert it to a voltage, $-V_1$. Note that the two-transistor arrangement similar to that employed in the transmitter is again required to process the bilateral input currents encountered. A_5 acts as an inverting amplifier so that the output signal, V_1, is recovered. □
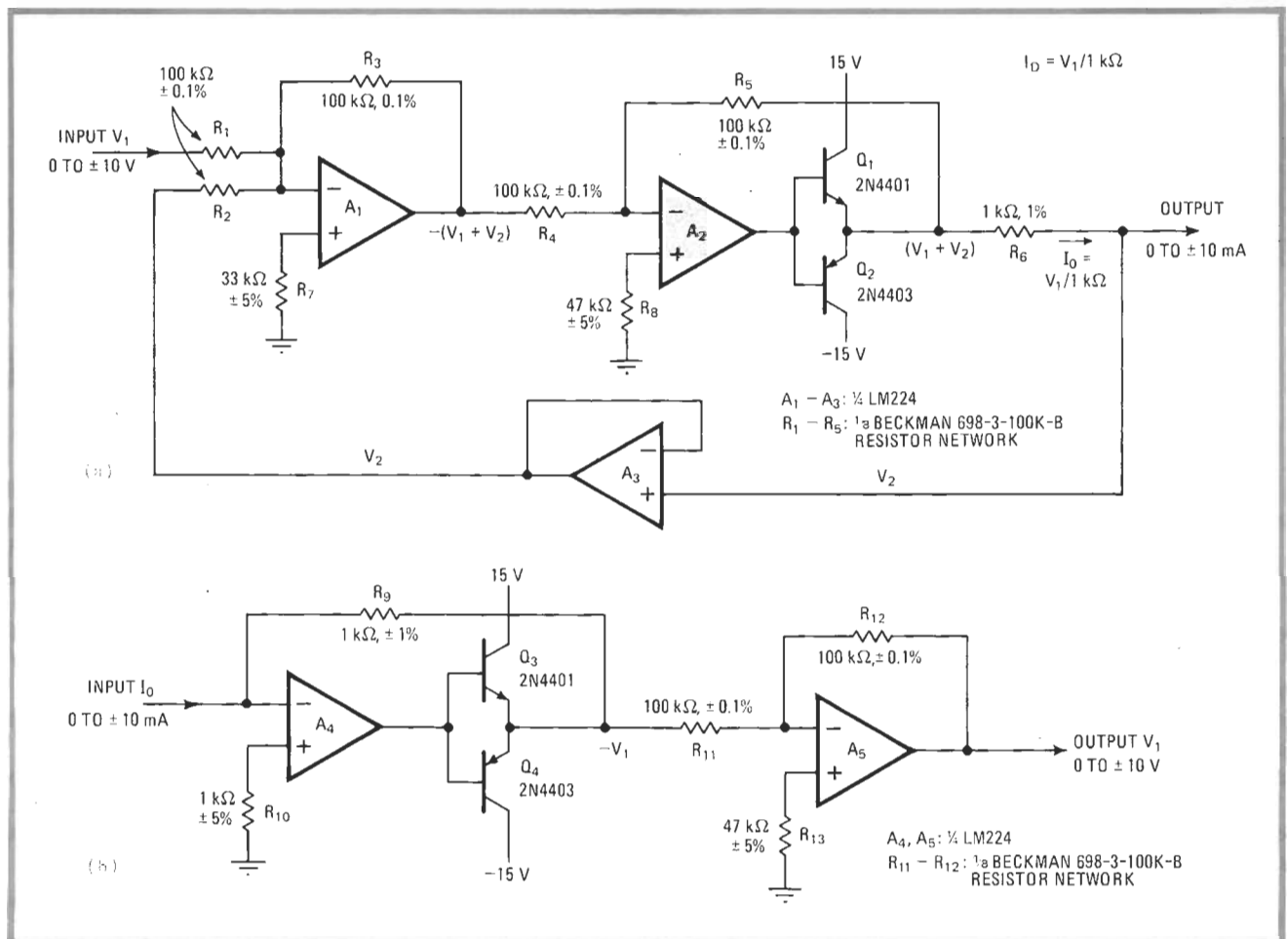
Communicating current. Converter (a) transforms bilateral analog voltages into corresponding currents for high-accuracy transmissions over high-resistance networks. Receiving converter (b) performs inverse operation to recover input voltage. Low-cost op-amps and transistors are used throughout. Beckman package in (a) and (b) provides low-cost source of matched resistors required for very precise conversions.

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 $Vin \frac{R2}{R1}$.

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.

$$Iout = \frac{R2}{R1} \frac{Vin}{R3}$$
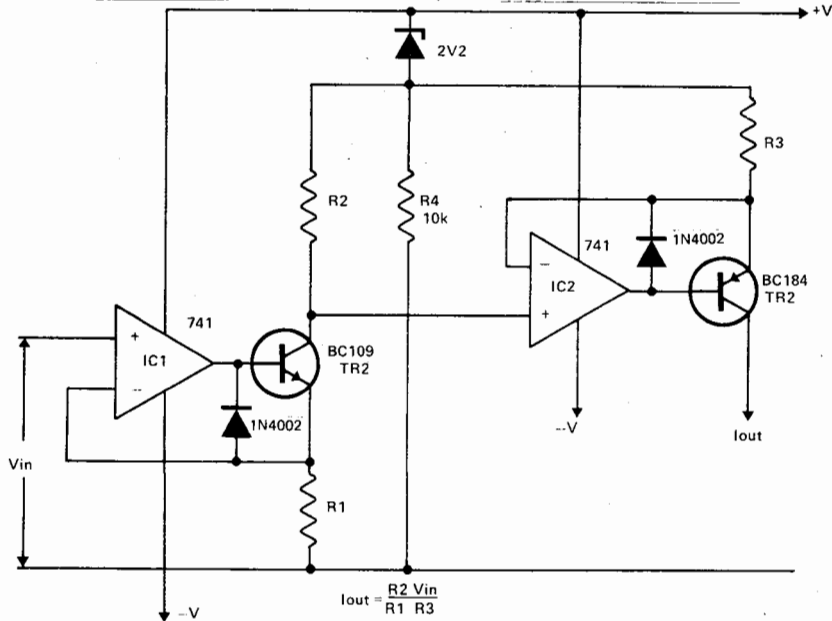
16
Exponential Current Source
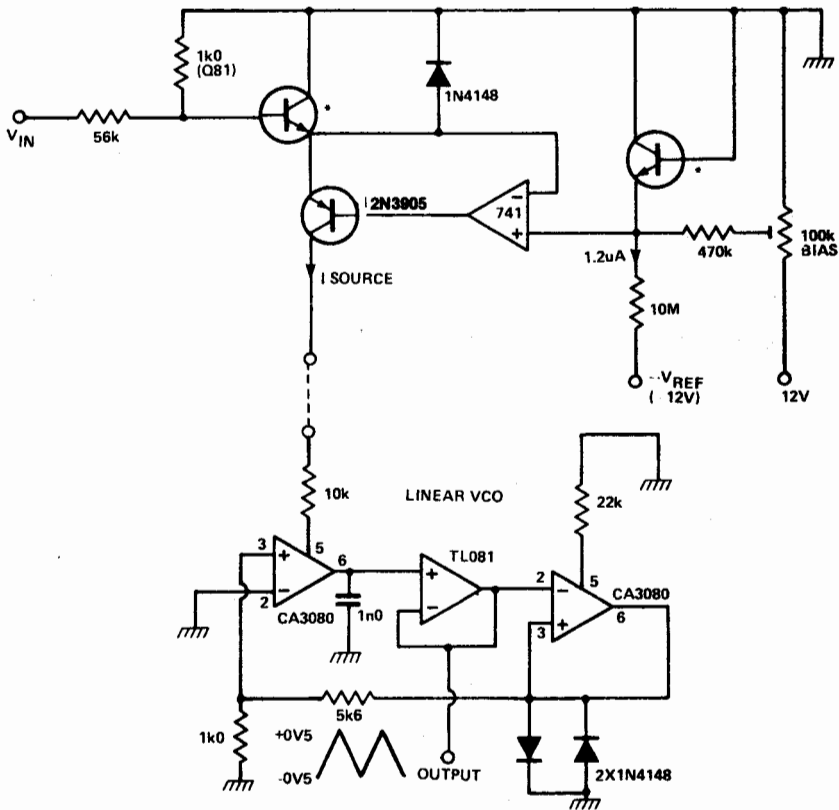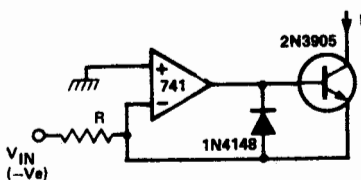

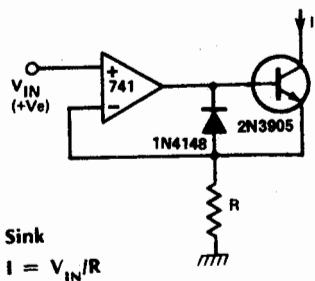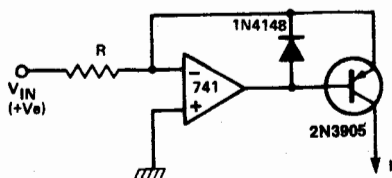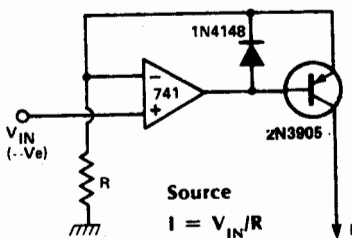An exponential current source can be used to drive a linear VCO.
The VCO then has a 1 V/octave response

Devices all powered from ± 12 V
*Matched transistors in thermal contact

17
Voltage-to-current Converters

V_{IN}
(-Ve)

1N4148

741

2N3905

R

Source

$I = V_{IN}/R$

I

1N4148

R

741

V_{IN}
(+Ve)

2N3905

I

V_{IN}
(+Ve)

741

I

2N3905

1N4148

R

Sink

$I = V_{IN}/R$

2N3905

I

741

V_{IN}
(-Ve)

R

1N4148

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 = Vin / 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 lineally 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 Vin. Second, the input bias current may well rob a lot of the current when Vin 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.
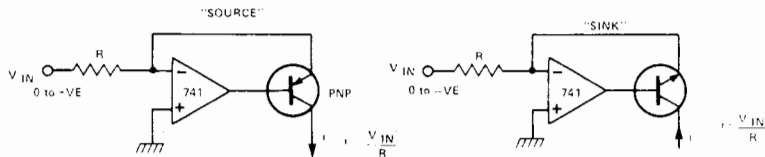
Fig. 14. Precision linear voltage to current converters.

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 Harbison, 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-variety npn and pnp 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*
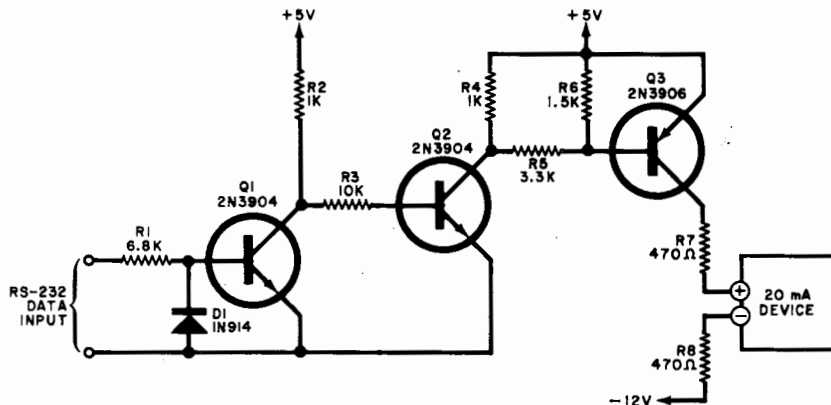
Twin regulators deliver constant voltage and current

by Ladislav Grýgera and Milena Králová
Tesla-Popov Research Institute, Prague, Czechoslovakia

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 A_1, 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 A_2, which acts to generate a signal at its V_{out} port.

The current-limit input of A_1 is then activated, and thus the current-limiting transistor internal to A_1, which acts as a shunt across the error amplifier, can control the amount of driving current supplied to pass transistor Q_1 at the set output voltage.

The output voltage is adjusted by R_1. The value of R_1 required is approximately 1 kilohm for each volt appearing at the load R_L. Because $R_2 = R_3$,

$$V_{out} = K_1 R_1 V_{ref1}$$

where $K_1 = 1/2R_4$.

Output current is adjusted by R_5, the value of which will increase 1 kilohm for every 100-milliampere increase in load current. Assuming $R_6 = R_7$, then it can be shown that:

$$I_{out} = K_2 R_5 V_{ref2}$$

where $K_2 = 1/2R_8 R_{sc}$.

Zener diode D_1 allows selection of the output current down to zero. Diodes D_2 and D_3 provide well-defined switching thresholds for A_1 and Q_1 to enhance the circuit's response time to a changing output current and/or voltage. ☐

Designer's casebook is a regular feature in *Electronics*. We invite readers to submit original and unpublished circuit ideas and solutions to design problems. Explain briefly but thoroughly the circuit's operating principle and purpose. We'll pay $50 for each item published.
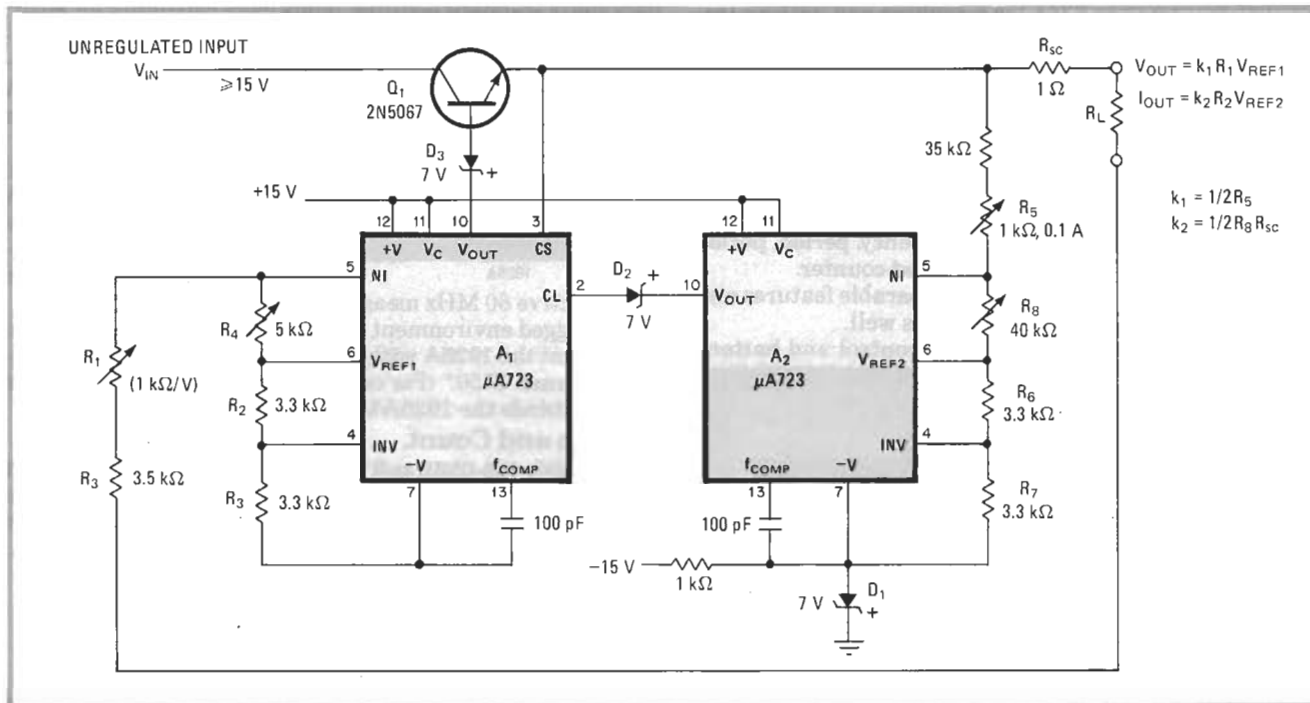
Steady. Cascaded regulators, one for monitoring load voltage, the other for current, form circuit that generates constant-voltage, constant-current output. Current and voltage are adjustable from zero. Maximum output voltage is 15 V; current limit depends on Q_1's rating.