design ideas

Edited by Brad Thompson

Quickly find pc-board shorts with low-cost tracer technique

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A predominant failure mechanism for production pc boards is shorted traces. Finding hidden shorts is often time-consuming and frustrating. Typical techniques of cutting traces, lifting pads, and "blowing" shorts are, at best, questionable because they may affect the reliability of the circuit, and the ever-decreasing geometries and lower voltage ICs make these practices tricky and risky. High-end, four-wire DMMs (digital multimeters) or ohmmeters, which can accurately measure the small resistance values, are expensive and sometimes not available on a designer's bench.

An inexpensive alternative approach for finding short circuits, using the concepts of four-wire DMMs and ohmmeters is simple and requires only the tools you already have on your bench and a basic understanding of Ohm's Law. This approach uses the principal that all conductors have resistance properties, and a distinct voltage drop exists between the various nodes in the shorted circuit. This approach systematically locates the nodes with lowest impendence between them and isolates the fault to two nodes.

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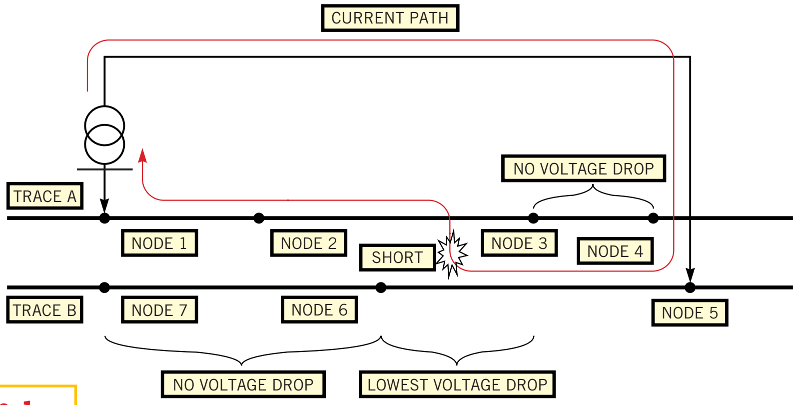


Figure 1

By applying a fixed current to various nodes and looking at the resultant voltage drops, you can home in on the likely location of a pc-board short circuit.

Most digital buses have at least 1Ω over the length of the run, but a trace impedance of only 200 mΩ still has a 2-mV drop with 10-mA current applied. Most lab-grade handheld DMMs can easily resolve to 1 mV. Because you are looking for relative values, the absolute accuracy of the instrument isn't critical. However, the current must be constant to achieve repeatable results, and you must isolate its current source from the ground of the circuit under test.

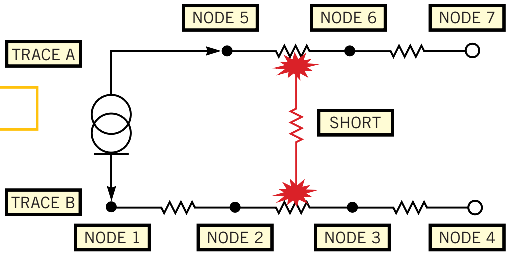
A 1.5V battery in series with a 1.5-kΩ resistor is an adequate current source for this purpose. The battery provides the isolation and relatively constant voltage; select the resistor to source around 10 mA. (For lower impedance traces, such as power-supply lines, or in situations in which the DMM lacks millivolt resolution, use a higher current.) An optional clamping diode, with a cathode connected to the battery's negative terminal and an anode connected to the resistor's free end, provides protection for low-voltage logic circuits. If you use the diode, you may also need to add a power switch to keep the battery from depleting when the circuit is not in use.

A node can be any accessible part of the circuit path under test, such as a via, a pad, or a test point (**Figure 1**). Note the current path: When current is flowing between two nodes, a minute voltage drop occurs across the two nodes. When the current doesn't flow between two nodes, there is no voltage drop across those nodes.

To find the short in this example, put one DMM probe on any node on Trace A and the other on any node on Trace B, and note the voltage drop. In this example, if you had started with the positive probe on Node 1 and the negative probe on Node 5 and moved the negative probe to Node 6, you would note a slight voltage drop. Next, you move the probe to Node 7 and note that the voltage drop is equivalent to the voltage drop at Node 6. From this test, you can deduce that the short must exist between nodes 5 and 6 because no current flows from Node 6 to Node 7. Then, move the positive probe to Node 2 and note a small voltage drop.

Continue down the line to Node 3 and note another small drop. Next, probe Node 4 and note there is no voltage drop. You can now deduce that the short must be between nodes 2 and 3 and nodes 5 and 6.

Figure 2



The equivalent circuit of the pc-board layout shows the principal of the source-and-probe technique.

Redrawing **Figure 1** with the equivalent circuit in **Figure 2** makes clear how this technique works. You are now looking at a simple series network of resistors and looking for voltage drops across any resistor that has current flowing through it. When a node is outside the current path, no voltage drop occurs. By understanding the relationship of each of the vias and their position in the current path, you can systematically isolate the short by looking for lower voltage (current flowing) or higher voltage (current not flowing). When current is flowing, the short is farther from the current source. If no current is flowing, then the short is closer to the current source. This two-valued logic makes it simple to isolate the problem. The beauty of this technique is that it doesn't matter to which two nodes the current source is connected, as long as one side of the current source is connected to any node on Trace A and the other side of the current source is connected to any node on Trace B.

In this example, the short is between two node pairs, and you can isolate the short only to those pairs. A little knowledge of the board layout and common sense now come into play. You need to know only where the two traces are adjacent between nodes 5 and 6 and nodes 2 and 3, and you have found the most likely place for the short. If it is underneath a component, you have to remove the component; removing the component often removes the short. If the short is on an internal layer, you may have to do some selective cutting and jumping to isolate the short from the traces, but at least you minimize the number of cuts on the board.□

Read isolated digital signals without power drain

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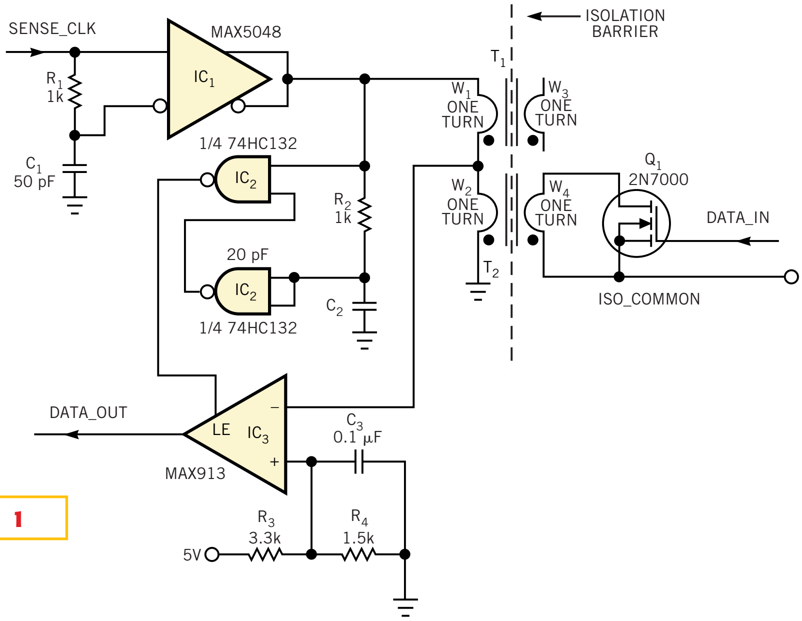
Although optocouplers offer designers a straightforward method of establishing galvanic isolation between circuits that operate at different ground potentials, they do not provide an ideal approach. An optocoupler draws power from the isolated circuit, switches relatively slowly, and loses current-transfer ratio as its light emitter ages.

The circuit in **Figure 1** overcomes these limitations by replicating a digital signal's state, drawing no power from the isolated input, and consuming only modest power on the nonisolated side. As **Figure 2** shows, the circuit imposes only a 20-nsec input-to-output delay from the positive edge of SENSE_CLK to DATA_OUT.

Figure 1



You can use a simple ferrite-bead transformer to isolate logic-level signals.

MOSFET transistor Q_1 operates in either of two states—high resistance between source and drain ($R_{DS(OFF)}$), or low resistance ($R_{DS(ON)}$) when a control signal drives Q_1 into conduction. When conducting, Q_1 imposes a low resistance across T_1's secondary winding, W_3. The remainder of the circuit senses the state of T_1's secondary resistance. Resistor R_1, capacitor C_1, and the complementary inputs of MOSFET-driver IC_1 differentiate the SENSE_CLK signal's positive-going input edge, producing a positive-going 5V pulse at IC_1's output and driving one end of winding W_1. **Figure 2** shows the relationship among the circuit's signals.

Connected in series-aiding mode, the two primary windings W_1 and W_2 of T_1

form a 2-to-1 inductive voltage divider whose center tap drives the inverting input of IC_3, a high-speed comparator. With Q_1 off and thus presenting an open circuit across the secondary of T_1, the junction of windings W_1 and W_2 applies a pulse of approximately 2.5V to comparator IC_3's inverting input and drives IC_3's internal state low. Meanwhile, IC_2's two gates, resistor R_2 and capacitor C_2 generate a short strobe pulse in the middle of IC_1's output pulse and applied to IC_3's LE (latch-enable) input.

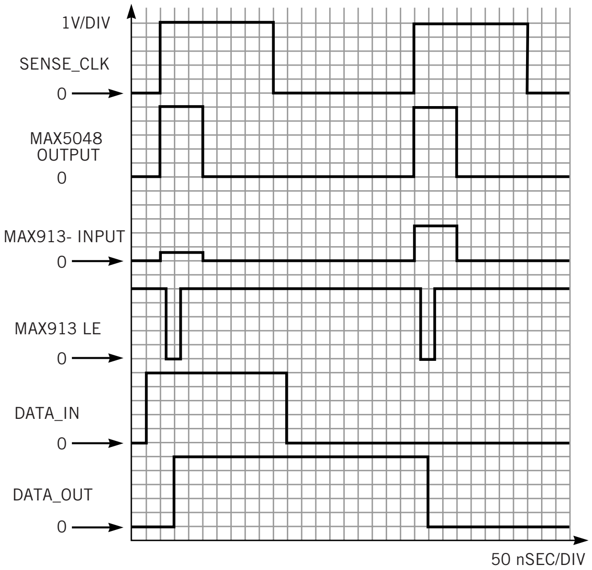


Figure 2 Each positive-going transition of SENSE_CLK transfers the state of the galvanically isolated digital signal at DATA_IN to DATA_OUT.

Latching IC_3's internal state to its external output (DATA_OUT) produces a logic-low output that follows DATA_IN. If DATA_IN goes sufficiently positive to bias Q_1 on, Q_1's low resistance across W_3 reflects a low impedance to windings W_1 and W_2 of T_1. The reduced pulse amplitude at the junction of W_1 and W_2 and IC_3's inverting input of approximately 0.5V is insufficient to trigger IC_3, and IC_3's internal state goes high. The latching pulse at LE forces IC_3's DATA_OUT high, again following the state of DATA_IN.

IC_1, IC_2, and IC_3 operate from a single 5V power supply. Separate bypass capacitors placed adjacent to each device's power pins minimize noise. Resistors R_3 and R_4 set IC_3's trigger-voltage threshold. Transformer T_1 provides a 1-to-1-to-1 turns ratio and comprises a single-hole ferrite bead (Fair-Rite part number 2673000101) with three identical single-turn windings. To minimize stray inductance, keep the connection to the junction of windings W_1, W_2, and IC_1 as short as possible. Also, the grounded end of W_2 should return to IC_1's ground connection.

The circuit's isolation capabilities depend on its pc-board layout and the properties of transformer T_1, whose type 73 ferrite core is moderately conductive. Thus, T_1's isolation properties depend on its windings' insulation. For example, Teflon or Kapton-insulated wire can withstand several kilovolts. If you carefully construct T_1 using the specified core and Teflon-insulated AWG #24 wire, the transformer can exhibit interwinding capacitances of 0.2 pF or less.□

MOSFET shunt regulator substitutes for series regulator

Stuart R Michaels, SRM Consulting

YOU WOULD NORMALLY use a series linear regulator or a dc/dc converter to obtain 3V dc from a higher supply. However, when breadboarding a concept, you may be able to use a shunt regulator, especially if a series regulator of the correct voltage is unavailable. The MOSFET in **Figure 1** can replace a zener diode in a shunt regulator and provide lower output impedance than a zener diode.

The MOSFET is self-biased by connecting its drain to its source. The difference between the input voltage and the gate-to-source threshold voltage, V_{GS}, sets the current. The IRF521 in this example has a threshold voltage of 2 to 4V at 250 μA. The upper curve of **Figure 2** shows that the IRF521 achieves a gate-to-source voltage of 3V at a current of about 200 μA. MOSFETs can vary from device to device, but the typical MOSFET has a threshold at approximately the mean between the maximum and the minimum limits.

The lower curve in **Figure 2** is the output impedance, which you obtain from the upper curve by differentiating the upper curve. Although the output impedance, R_{OUT}, is near 800Ω at a current of 100 μA, it rapidly drops to less than 6Ω at 50 mA. Because you operate the MOSFET at or near threshold, its on-resistance spec doesn't apply, and the output impedance of this circuit is far higher than you would expect from the on-resistance. However, in general, the lower the on-resistance, the lower the output impedance at a specific current near threshold.

This circuit may require that R_2 and C_1 stop the oscillation in the MOSFET. Add a filter capacitor to the output to minimize the effect of load transients. Connecting a large filter capacitor from the gate to the source with short leads eliminates the need for R_2. You can use other

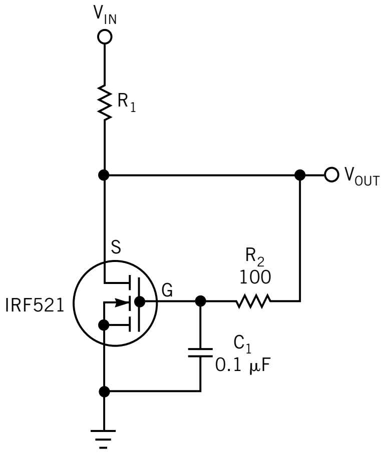


Figure 1 A MOSFET configured to replace a zener diode of a shunt regulator provides lower impedance than a diode-based implementation.

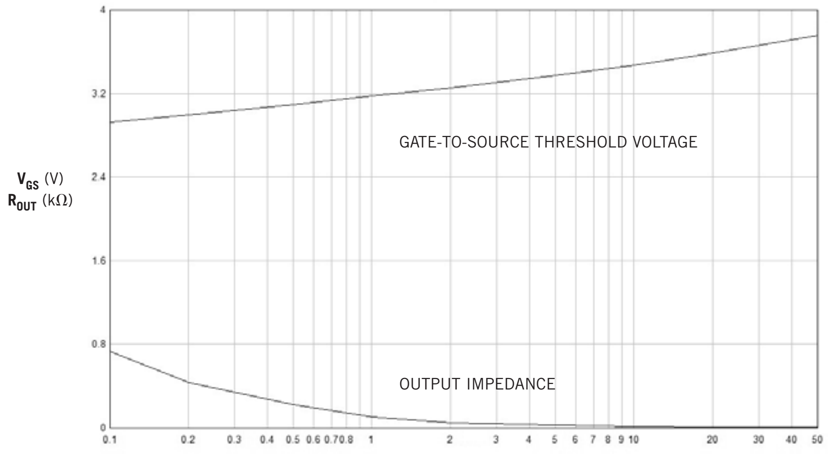


Figure 2 A plot of key parameters—gate-to-source voltage and output impedance—versus drain current shows smoothness of variation over two and one-half decades.

MOSFET families and other voltages if necessary.

Although you may be unable to get the exact output voltage you need at the current you prefer, many devices tolerate wide variations in operating voltage. For instance, many 3.3V-dc microcontrollers can operate as low as 2.5V dc and as high as 3.6V dc. Note that operating a MOSFET near its threshold causes a large negative-temperature coefficient of the gate-to-source voltage. This circuit has significant change in output voltage over a wide temperature range; it is suitable for only limited temperature ranges.□

Zener test circuit serves as dc source

John Jardine, JJ Designs, West Yorkshire, UK

This Design Idea describes a versatile test circuit for zener diodes after yet another misread zener diode had infiltrated the ranks of 1N4148 diodes assembled on a pc board. As a bonus, the circuit can serve as a moderate-voltage, power-limited adjustable dc source. Although conventional multimeters' resistance ranges typically apply enough voltage to forward-bias most diodes, few can drive a zener diode into reverse conduction. **Figure 1a** shows a simple variable-frequency dc/dc step-up converter whose output voltage depends on the device under test's breakdown voltage.

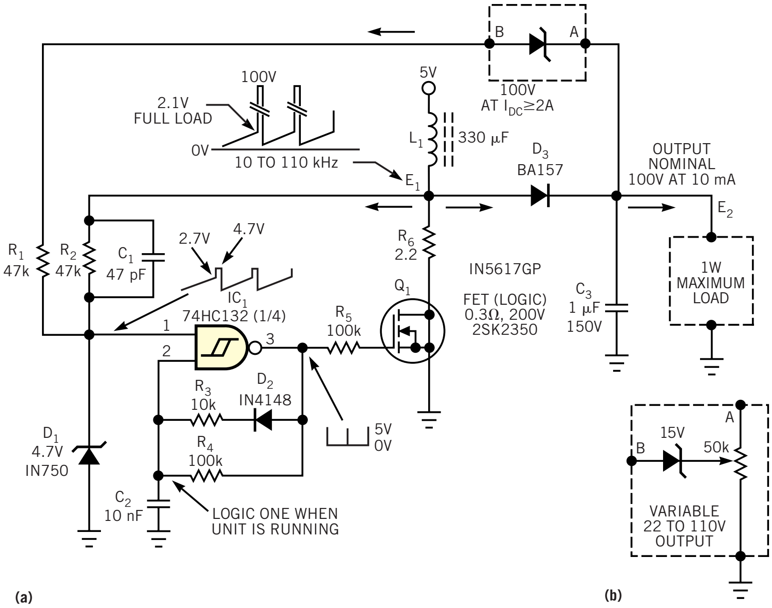


Figure 1 The output voltage of a simple variable-frequency dc/dc step-up converter depends on the device under test's breakdown voltage (a). To use the circuit as a variable medium-voltage power supply, replace the device under test with a network (b).

Upon power application, Pin 3 of IC_1 (one section of a 74HC132 quad dual-input Schmitt-trigger NAND gate) goes to logic one and switches on Q_1, an N-channel logic-level power MOSFET. Current flows through Q_1 and R_6 and stores energy in inductor L_1's magnetic field. Zener diode D_1 limits the voltage at IC_1's Pin 1 to 4.7V. Simultaneously, diode

D_2 and resistor R_3 charge C_2 and establish a logic one at IC_1's Pin 2. When the voltage at point E_1 reaches approximately 2.7V, IC_1's input-voltage threshold, IC_1's output goes to logic zero, switching off Q_1.

Energy stored in L_1's magnetic field discharges through fast-recovery diode D_3 and charges C_3. Capacitor C_1 helps remove diode D_1's stored charge and helps restart the charging cycle.

After several cycles, the voltage at E_2 reaches the device under test's reverse-breakdown voltage and feeds current via R_1 to IC_1's Pin 1. As a result, the voltage at E_2 stabilizes at the sum of the device under test's reverse-breakdown voltage and a constant offset voltage of 5.4V comprising the voltage across D_1—4.7V—plus the forward voltage across D_3—0.7V. Thus, for a 100V zener as the device under test, the voltage at E_2 measures approximately 105.4V.

At start-up and under fault conditions, resistor R_4, diode D_2, and resistor R_3 produce an asymmetrical oscillation at approximately 2 kHz, which reduces the average current through L_1 and Q_1 to a safe level.

To use the circuit as a variable medium-voltage power supply, replace the device under test with the network in **Figure 1b**. Adjusting the potentiometer varies the voltage at point E_2 from 22 to 120V. Maximum current available from the circuit depends on the dc resistance, L_1's magnetic-saturation characteristics, and Q_1's on-resistance. For a nominal 5V power supply and 430 mA of input current, the circuit delivers 10 mA at 100V for a 100V output, yielding an efficiency of approximately 50%. Feeding L_1 from a separate 12V power supply improves efficiency.

If you design your own inductor for L_1, aim for a nominal inductance of 330 μH at 2A and a dc winding resistance of less than 0.5Ω. For optimum operation, use a fast-recovery diode for D_3 and a logic-level N-channel MOSFET with a breakdown voltage of 200V or greater and an on-resistance of less than 0.3Ω for Q_1. Note that zener-diode manufacturers specify breakdown voltages at specific test currents. Also, when you subject them to high reverse voltages, signal diodes exhibit zener behavior.□

Gain-programmable circuit offers performance and flexibility

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You can use a standard precision instrumentation amplifier, such as the INA118 or AD623, as a gain-programmable amplifier with high accuracy and wide gain range. However, the gain range of such parts is fixed at certain values, limiting their flexibility. To solve the problem, a usual way is to use a gain-adjustable circuit controlled by a microcomputer (**Figure 1**).

IC_2 is a programmable 1-of-8 analogy multiplexer that connects to eight weighting resistors, R_1 to R_8, to improve the gain range of the circuit based on IC_2, a general-purpose precision amplifier. The overall gain of the circuit depends on the value of the selected weighting resistor, as follows:

$$V_{OUT} = -V_{IN}\left(\frac{R_X + R_{ON}}{R_0}\right),$$

where R_{ON} is the on-resistance of IC_2, and R_X is one of the selected weighting resistors, R_1 to R_8. You control the port-select pins Z_0 to Z_2 of IC_2 with a microcontroller to provide self-adjustable gain according to the selected weighting resistor. Unfortunately, the performance and quality of the circuit cannot provide good performance and high quality due to the on-resistance of IC_2, which you also cannot control, especially as the temperature changes.

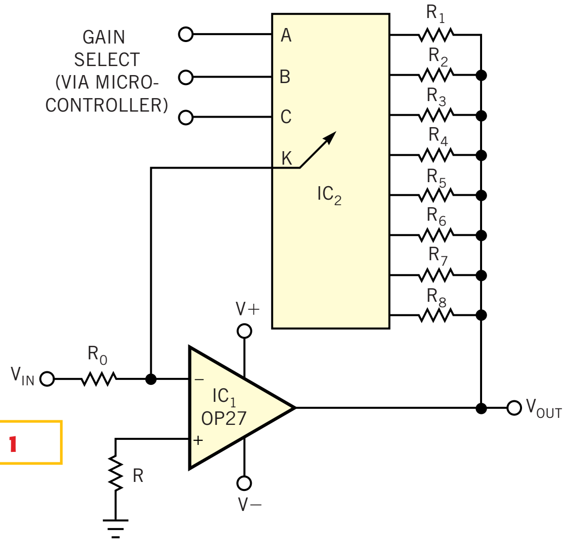

Figure 1

A basic gain-programmable amplifier circuit uses digital outputs from a microcontroller to set gain.

The modified gain-adjustable amplifier circuit in **Figure 2** uses the same IC_1 but changes IC_2 to a programmable 2-of-8 difference-input analog multiplexer, which connects to four balancing resistors, R_{01} to R_{04}, and eight weighting resistors, R_{G1} to R_{G8}, to improve the gain range of the circuit. By controlling the port-select pins Z_0 to Z_1 of IC_2 with a microcontroller, the circuit provides self-adjustable gain with high quality. The overall gain of the circuit is:

$$V_{OUT} = V_{IN}\left(1+\frac{R_{GB}}{R_{GA}}\right),$$

where R_{GA} is one of the selected weighting resistors, R_{G1} to R_{G4}, and R_{GB} is one of the selected weighting resistors, R_{G6} to R_{G8}.

Analog multiplexer IC_2 is on the input side of amplifier IC_1. Resistors R_{01} to R_{04} balance the signal-input channel to decrease the level-shifting because of the on-resistance of multiplexer IC_2 and minimize the effect of that resistance. Additionally, two operational amplifiers, IC_{01} and IC_{02}, act as followers to improve the overall driver performance and common-mode-rejection capacity of the circuit.□

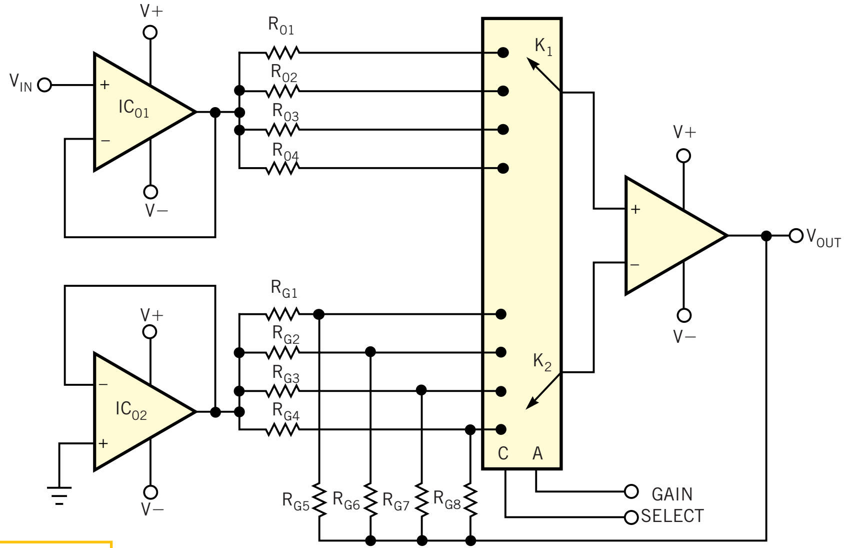

Figure 2

The modified circuit provides more flexibility, along with high performance.