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 impedance between them and isolates the fault to two nodes.

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.

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.
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.

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
Alfredo H Saab and Joseph Neubauer, Maxim Integrated Products Inc, Sunnyvale, CA

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.

MOSFET transistor Q1 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 Q1 into conduction. When conducting, Q1 imposes a low resistance across T1’s secondary winding, W3. The remainder of the circuit senses the state of T1’s secondary resistance. Resistor R3, capacitor C2, and the complementary inputs of MOSFET-driver IC3 differentiate the SENSE_CLK signal’s positive-going input edge, producing a positive-going 5V pulse at IC3’s output and driving one end of winding W1. Figure 2 shows the relationship among the circuit’s signals.

Connected in series-aiding mode, the two primary windings W1 and W2 of T1,
form a 2-to-1 inductive voltage divider whose center tap drives the inverting input of IC3, a high-speed comparator. With Q1 off and thus presenting an open circuit across the secondary of T1, the junction of windings W1 and W2 applies a pulse of approximately 2.5V to comparator IC3's inverting input and drives IC3's internal state low. Meanwhile, IC3’s two gates, resistor R2 and capacitor C2 generate a short strobe pulse in the middle of IC1’s output pulse and applied to IC3’s LE (latch-enable) input.

Latching IC3’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 Q1 on, Q1’s low resistance across W3 reflects a low impedance to windings W1 and W2 of T1. The reduced pulse amplitude at the junction of W1 and W2 and IC3’s inverting input of approximately 0.5V is insufficient to trigger IC3, and IC3’s internal state goes high. The latching pulse at LE forces IC3’s DATA_OUT high, again following the state of DATA_IN.

IC1, IC2, and IC3 operate from a single 5V power supply. Separate bypass capacitors placed adjacent to each device’s power pins minimize noise. Resistors R3 and R4 set IC3’s trigger-voltage threshold. Transformer T1 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 W1, W2, and IC3 as short as possible. Also, the grounded end of W1 should return to IC3’s ground connection.

The circuit’s isolation capabilities depend on its PCB layout and the properties of transformer T1, whose type 73 ferrite core is moderately conductive. Thus, T1’s isolation properties depend on its windings’ insulation. For example, Teflon or Kapton-insulated wire can withstand several kilovolts. If you carefully construct T1 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 \( \mu \)A. The upper curve of Figure 2 shows that the IRF521 achieves a gate-to-source voltage of 3V at a current of about 200 \( \mu \)A. 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 800\( \Omega \) at a current of 100 \( \mu \)A, it rapidly drops to less than 6\( \Omega \) at 50 mA. Because you operate the MOSFET at 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 R2 and C 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 R2. You can use other
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.

Upon power application, Pin 3 of IC₁ (one section of a 74HC132 quad dual-input Schmitt-trigger NAND gate) goes to logic one and switches on Q₁, an N-channel logic-level power MOSFET. Current flows through Q₁ and R₆ and stores energy in inductor L₁’s magnetic field. Zener diode D₁ limits the voltage at IC₁’s Pin 1 to 4.7V. Simultaneously, diode 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. □

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D2 and resistor R3 charge C2 and establish a logic one at IC1’s Pin 2. When the voltage at point E1 reaches approximately 2.7V, IC1’s input-voltage threshold, IC1’s output goes to logic zero, switching off Q1.

Energy stored in L1’s magnetic field discharges through fast-recovery diode D3 and charges C3. Capacitor C1 helps remove diode D1’s stored charge and helps restart the charging cycle.

After several cycles, the voltage at E2 reaches the device under test’s reverse-breakdown voltage and feeds current via R1 to IC1’s Pin 1. As a result, the voltage at E2 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 D1—4.7V—plus the forward voltage across D3—0.7V. Thus, for a 100V zener as the device under test, the voltage at E2 measures approximately 105.4V.

At start-up and under fault conditions, resistor R4, diode D2, and resistor R3 produce an asymmetrical oscillation at approximately 2 kHz, which reduces the average current through L1 and Q1 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 E2 from 22 to 120V. Maximum current available from the circuit depends on the dc resistance, L1’s magnetic-saturation characteristics, and Q1’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 L1 from a separate 12V power supply improves efficiency.

If you design your own inductor for L1, aim for a nominal inductance of 330 H and a dc winding resistance of less than 0.5 H. For optimum operation, use a fast-recovery diode for D3 and a logic-level N-channel MOSFET with a breakdown voltage of 200V or greater and an on-resistance of less than 0.3 H for Q1.

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.

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).

IC2 is a programmable 1-of-8 analogy multiplexer that connects to eight weighting resistors, R1 to R8, to improve the gain range of the circuit based on IC2, 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 IC2, 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 IC2 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 IC2, which you also cannot control, especially as the temperature changes.

The modified gain-adjustable amplifier circuit in Figure 2 uses the same IC1 but changes IC2 to a programmable 2-of-8 difference-input analog multiplexer, which connects to four balancing resistors, R1 to R4, and eight weighting resistors, R5 to R8, to improve the gain range of the circuit. By controlling the port-select pins \( Z_0 \) to \( Z_1 \) of IC2 with a microcontroller, the

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**Gain-programmable circuit offers performance and flexibility**

Luo Bencheng, Key Laboratory of Mental Health, Institute of Psychology, Chinese Academy of Sciences

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